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THE PRODUCTION, PROPERTIES AND CASTING POTENTIAL
OF A CLAY/OIL BONDED FOUNDRY MOULDING SAND

by

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A Doctoral Thesis
submitted in partial fulfilment of the requirements
for the award of
The Degree of Doctor of Philosophy
of the Loughborough University of Technology

January 1978

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Department of Engineering Production

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To my wife,

Suzanne,

without whose support and encouragement
this work would not have been possible.

ACKNOWLEDGEMENTS

The author is grateful to Dr. A.A. Das, research supervisor, for the advice given during the course of this research and to Mr. B.J. Goodman and the laboratory staff of the Department of Engineering Production for their valued support.

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CHAPTER 1

SYNOPSIS

1. SYNOPSIS

An investigation has been carried out into the use of an organo-clay as a bonding medium for foundry sand moulds.

The method and means of the modification of a naturally occurring Na bentonite to an oleophylic organo-clay, dimethyldioctadecylammonium bentonite, have been researched and the findings reported.

The physical properties of moulding sands bonded with the organo-clay and a light mineral oil have been investigated and the effects of varying the clay content, oil content, mulling temperature, mulling time, polar material additions and mould temperature have been reported. The effects upon the physical properties have also been studied when storing the mulled sand, using it over a number of casting cycles and making restorative additions of clay and oil after its use.

Finally, castings produced in moulds bonded with the organo-clay have been made in an aluminium-magnesium alloy, phosphor-bronze and in cast iron, and the surface finish, dimensional accuracy and casting soundness monitored.

CHAPTER 2

INTRODUCTION

2. INTRODUCTION

The majority of moulds used in the cast-metals industry are made from sand. In order that the mould may hold its shape, each sand grain must be bonded to its neighbour. The types of bond used must be carefully chosen for the properties which they impart to the moulding mixture, not only whilst the mould is being formed, but also during the pouring of the molten metal and the subsequent solidification of the casting.

Many types of bonding medium are now in common use in the foundry industry including resins, oils and silicates. The most widely used bond however, is a clay and water mixture. This is probably because it is also one of the oldest bonding mediums and most foundries have become well acquainted with its use, properties and problems. It has advantages over the more recently developed materials in that it is cheap, re-useable over many casting cycles and conveniently quarried from the ground complete with the sand in a ready mixed form.

It has, however, many disadvantages probably the principal one being the large volume of steam evolved when the water content of the mix is heated by the molten metal. This evolution tends to be sudden and almost explosive and, to prevent it from damaging the casting, must be allowed to disperse quickly through the mould and vent to the atmosphere. A fairly coarse sand must therefore be used to give the steam an unrestricted passage through the voids between each sand grain. This inevitably leads to poor casting surface finish and the possibility of metal penetration into the

mould walls. Further problems arise however, even if the mould has sufficient permeability to allow efficient dispersal of the steam. With certain "reactive" metals its presence in the mould wall, cavity and running system causes poor surface finish, dross inclusions, gas holes within the casting and a general reduction in the mechanical properties.

Some years ago it was discovered that clays could be modified so as to render them oleophilic, thus giving similar properties when mixed with oil as naturally occurring clays exhibited with water. This type of clay has been utilised with a mineral oil to form a bond for sand in foundry moulds, and thus the production of steam during casting was eliminated. The mixture was found to have many of the advantages of the clay/water-bonded system and since the rate of evolution of oil vapour was much lower than that of steam a finer grade of sand could be used and the casting surface finish thus improved.

Although a few testimonies of this material have been found, scant reference exists to any technical information on the physical properties of the moulding mixture. This research was therefore undertaken in an attempt to rectify the position and also to investigate the casting potential of the moulding mixture. Before starting this work, however, some considerable time was devoted to the production of a suitable chemically modified clay, since it was considered that insufficient information was available concerning the proprietary brand.

CHAPTER 3

LITERATURE SURVEY

3. LITERATURE SURVEY

3.1. Introduction

The literature survey was carried out under three main headings; the modification of clays, the properties of moulding mixtures bonded with organo-clay and the use of the moulding mixtures for casting purposes.

The literature available on the modification of clays was vast and it became apparent during a preliminary survey that, in order to narrow the field of reading slightly, an early decision would have to be made on the type of clay and reactants which would give a product suitable for a foundry sand mould bonding medium. Reading was then continued around the minerology of the chosen clay and the theory and method of its modification to an oleophilic form. The information gained from this work led to further studies of the types of equipment needed to carry out the chemical processes. Finally, procedures were sought for testing the clay both before and after the modification process.

The second field of investigation was concerned with the properties of the moulding mixtures based on the modified clay bond. Very little information was found to have been published on this subject but that which could be found was duly noted.

Finally information was sought on the use of organo-clay bonded moulding materials and a similar situation was found to that above, with little work of a technical nature having been reported.

3.2. Clay Modification

3.2.1. Preliminary Search of Literature and Choice of Materials.

The modification of clay by means of organic reactants was first noted in 1916 by Lloyd⁽¹⁾ who reported the adsorption of alkaloids by fuller's earth. Little was known, however, about the reaction until Smith⁽²⁾ reacted organic bases and their salts with bentonite and reported in 1934 that the process was one of base-exchange. The strong affinity of certain modified clays for organic liquids was not noted until 1946 when Hauser⁽³⁾ patented a process for modifying clays so as to give them the ability to swell and form gels in organic liquids. Since that time a great deal of research has been carried out on the modification of various types of clay with many more different types of organic compounds of widely varying molecular complexity.

During the preliminary literature survey special attention was paid to finding references on clay modification reactions producing organo-clays suitable for bonding sands. No such complete reference was found and it became clear that a decision as to the choice of clay and reactant would have to be made on a series of facts gleaned from various papers. One such reference⁽⁴⁾ stated that organo-clays for bonding sand moulding mixtures had been produced from montmorillonite and attapulgite. Although little information could be found on the modification of the latter clay, montmorillonite proved to be one of the most popular materials for the reported research into clay modification. The choice of this material for modification therefore had obvious advantages in that

a large and comprehensive volume of information would be available for reference during future research."

Montmorillonite is the main constituent of the clay deposit bentonite which is well known in the foundry industry as a good bonding medium for moulding sand when mixed with water. It is characterised by its ability to swell in polar liquids such as water, first forming pastes of good plasticity making it ideal for sand bonding, and on the addition of further water giving stable gels. Hauser⁽³⁾ showed that this characteristic was retained after suitable modification, the clays then exhibiting good gelling properties in organic liquids. Thus it might be assumed that this mineral group, when appropriately modified, would give suitable properties with an organic liquid for bonding sand moulds.

The modification of montmorillonite was found to be essentially the exchange of inorganic cations on the clay for the organic cations of the reactant⁽²⁾. Montmorillonites may exist with many different types of these exchangeable cations. Some contain a mixture such as Na^+ , Ca^{++} and Mg^{++} though more usually one of the ions predominates to the exclusion or almost exclusion of the others. McAtee⁽⁵⁾ showed that in an inorganic/organic cation exchange the Na^+ ion was replaced preferentially to the others and with greater ease and efficiency. Thus it would seem important that a montmorillonite containing predominantly Na^+ ions be chosen as the basic material for this research. McAtee⁽⁵⁾ further proved that the larger the organic cation in the reactant the faster the reaction took place. He cited as an example the quaternary ammonium salt dimethyldioctadecylammonium chloride and indeed this chemical

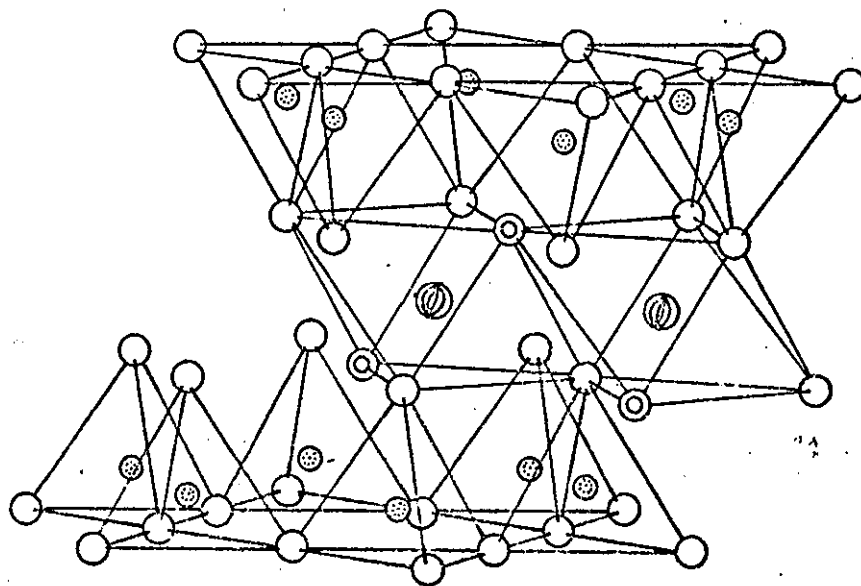
seemed to have been used regularly in the investigations into clay modification, thus providing considerable reference material. For these reasons, this reactant was chosen as being the most suitable for the modification process.

The materials used in this project therefore were Na bentonite, a commercially available clay deposit composed mainly of the mineral Na montmorillonite, and dimethyldioctadecylammonium chloride, a salt of the quaternary ammonium type.

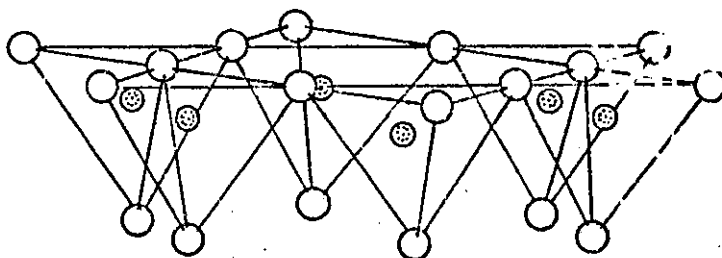
3.2.2. Basic Mineralogy of Montmorillonite.

In order to understand the modification of Na bentonite it was first necessary to study the basic mineralogy of montmorillonite, its chief constituent.

Na bentonite is now mined in many parts of the world though it was originally discovered near Fort Benton, Wyoming. After quarrying it is dried and crushed and sold in the form of fine particles or flakes of varying shapes which are made up of stacks of "unit layers" of montmorillonite each stack being randomly orientated within the flake. The accepted atomic structure for these unit layers is shown in Fig. 1. It can be seen that each layer is made up of three "sheets" which would normally continue both along and into the plane of the paper beyond the limits drawn in the figure. The top and bottom sheets in the layer are mirror images of themselves and are composed of silica tetrahedrals whilst the inner sheet is made up of alumina octahedrals. Some slight variations



exchangeable cations
 nH_2O



- oxygen
- ⊙ hydroxyl
- ⊗ aluminium, iron or magnesium
- ⊖ silicon, occasionally aluminium

Fig. 1 Diagrammatic sketch of the structure of montmorillonite according to Hofmann, Endell and Wilm (1933), Marshall (1935) and Hendricks (1942).

are always found in the type of ions at the centre of each sheet. For example, the Al^{+++} ion of the octahedral sheet may become substituted by Mg^{++} and the Si^{++++} ion of the tetrahedral sheet by Al^{+++} . This results in an imbalance of charges within a structure which would normally have an overall balanced charge.

The unit layers are stacked on top of each other with oxygen atoms of each unit being adjacent. This means that only a weak bond exists between the units thus affording excellent cleavage. The main characteristic of this structure is the ability of water and other polar molecules to enter between the unit layers causing the stack to expand upwards.

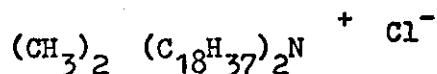
Also associated with the clay units are exchangeable cations. These are held on the clay by the overall negative charge caused by the lattice substitution previously mentioned and the exposed broken bonds on the edges of the unit layers. In montmorillonite it is thought that 80 per cent of the exchangeable cations are attracted as a result of the lattice substitutions and lie between the unit layers whilst 20 per cent of the ions occur at the edges of the unit layers.

The type of these exchangeable cations lying between the unit layers in some way affects the thickness of the inter-layer water. At a given water vapour pressure it has been found that Na^+ ions are the most active in attracting water. Indeed, a Na montmorillonite in sufficient water will swell and eventually dissociate completely forming a suspension of unit layers. As their name suggests, these cations also have the ability to be exchanged

under favourable conditions. Thus, for example, a Ca montmorillonite may be treated with a solution of a sodium salt to produce a Na montmorillonite and, perhaps of greater significance to this project, a Na montmorillonite may be converted to an organo-montmorillonite by reaction with a suitable organic compound.

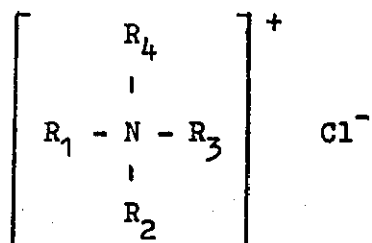
3.2.3. The Organic Reactant

The reactant chosen for the modification process was dimethyldioctadecylammonium chloride hereinafter referred to as DDAC, of the formula:



The large cation hereinafter referred to as DDA^+ , replaces the Na^+ exchangeable cation of the clay which goes into solution with the Cl^- anions.

Its basic structure of four radicals attached to a nitrogen atom characterises it as a chemical of the quaternary ammonium type as illustrated.



To produce a chemical of such purity that it is entirely composed of DDAC would be prohibitively expensive. As supplied, therefore,

the two large radicals are often of slightly varying carbon chain length and atomic structure. The nominal percentage of long chain radicals in the material obtained were:

- 24 per cent hexadecyl (16 carbon atoms)
- 75 per cent octadecyl (18 carbon atoms)
- 1 per cent octadecenyl (18 carbon atoms)

The material is produced as a soft paste containing 75 per cent of active ingredient plus, approximately, 0.5 per cent sodium chloride 18.0 per cent propan-2-ol, and 6.5 per cent water. It is insoluble in water but can produce a stable dispersion at a concentration of approximately 7.5 per cent (by weight). It is, however, soluble in certain organic solvents such as benzene, chloroform, methanol and isopropanol.

3.2.4. The Modification Process

The methods adopted for carrying out the modification process were found to be substantially the same for all investigators, though specific reasons for many of the procedures were never stated, being taken as standard. Explanations given here are derived in the main from information supplied by Grim⁽⁶⁾ who has in turn based much of his dialogue on the observations of many other investigators.

As previously mentioned, the process is one of exchange of the Na^+ ion on the clay for the organic cation of the reactant, 80 per cent of these ions being held between the unit layers of the clay. Since the exchange is largely achieved through diffusion this

would suggest a relatively slow rate of reaction. Na-montmorillonite, however, has the ability to dissociate completely in water, given suitable mechanical agitation, thus exposing the cation sites to the suspending medium and allowing a faster and more complete reaction to take place. Thus the starting point in nearly all the reported modification processes was the dispersal of the montmorillonite in water. Whilst most investigators made little or no mention of their methods, Street and White⁽⁷⁾ reported briefly that they subjected the clay and water mixture to a high rate of shear for thirty minutes by surrounding a high speed stirrer with a series of baffles.

McAtee⁽⁵⁾ showed that in the inorganic/organic cation exchange sodium was replaced preferentially to other exchangeable ions and at a much greater rate. Thus many investigators ensured that their supply of montmorillonite contained Na^+ ions to the exclusion of others by first carrying out an inorganic/inorganic cation exchange on the clay dispersion either by passing it through an exchange column containing proprietary sodium-containing resins or, more simply, by adding a solution of a sodium salt directly to the dispersion.

Further pretreatment was often given by allowing the suspension to stand or treating it in a centrifuge to remove all non-clay particles that would not take a part in the cation exchange reaction. This procedure was usually carried out when detailed examination such as X-ray analysis of the final structure might be hindered by the presence of the impurities.

It is generally agreed by all investigators that the dispersion should be heated prior to the addition of the reactant. Grim⁽⁶⁾ noted that the rate of cation exchange was increased slightly by the application of moderate heat whilst excessive heat had been shown to reduce the capacity of Na montmorillonite to exchange its ions. In most cases the cation exchange experiments were carried out at a temperature of 60 - 70°C.

Little mention was made by the investigators of their methods of mixing the organic reactant and the clay suspension. In most of the research, however, the reactions were carried out on a test-tube scale where simple shaking was employed for varying periods of a few minutes to, in some cases, several hours. Street and White⁽⁷⁾, who conducted larger-scale modifications, reported that they added a two per cent dispersion of organic base to the clay suspension at a rate of 100ml per min whilst stirring the contents of the vessel. The stirring was continued for a further thirty minutes after adding all the reactant to ensure completion of the reaction. McAtee⁽⁸⁾ was also of the opinion that the mix should be agitated and the reactants added slowly to the hot clay suspension.

One of the main reasons for the mixing action was undoubtedly to achieve rapid and thorough dispersion of the organic reactant around the mixing vessel. However, it was probably also important to prevent premature precipitation of the flocculating clay. This flocculation was noted by Jordan⁽⁹⁾ who studied the increase in viscosity of the clay suspension during the addition of the reactant. He reported that it reached a maximum at the end of the reaction corresponding to the maximum flocculation of the

particles. The clay, now being in a hydrophobic condition, precipitated and was recovered by filtration. Jordan also noted that the filtration characteristics of the modified clay were best at the completion of the reaction.

The final stages of treatment of the modified clay were basically the same for all investigators. The filtrate was washed to remove the reaction products, dried, crushed and in some instances graded for particle size. The temperatures employed for the drying processes varied from room-temperature to 110°C . McAtee and Concillio⁽¹⁰⁾ showed that little damage was done to the organo-clay up to a temperature of 170°C . However, at higher temperatures a sudden decomposition of the organic cations occurred. It would therefore seem that a drying temperature of 110°C would not only be faster than those below 100°C but also be quite safe.

The crushing of the clay was carried out in many different types of apparatus and to widely varying limits of particle size. In the main, the clay samples were small and often the desired results could be obtained with a mortar and pestle. For larger batches of clay a hammer mill or other suitable piece of apparatus was employed.

The grading was carried out either by an optical technique in which, for example, the majority of particles were seen to be below two microns in size, or by carrying out a sieve analysis when only that portion of the clay passing a certain mesh size, often the 200 mesh, was used for subsequent research.

3.2.5. The Cation Exchange Capacity of the Clay.

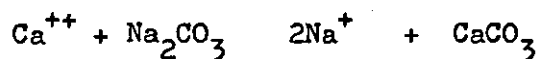
Since the work of Smith⁽²⁾ it has been known that organic compounds enter into a cation exchange reaction with clays. It was also known from the extensive work on inorganic/inorganic cation exchange that a clay exhibited a limit to the number of ions available for exchange. This was termed the base exchange capacity or cation exchange capacity of the clay.

In 1945, however, both Bradley⁽¹¹⁾ and MacEwan⁽¹²⁾ found that some organic compounds could be adsorbed by clay minerals other than by entering into a cation exchange reaction. Hendricks⁽¹³⁾ also indicated that organic cations could be held on the clay by both coulombic forces as a result of cation exchange and Van der Waals forces, the larger the organic molecule, the stronger the Van der Waals forces. Further, Grim, Allaway and Cuthbert⁽¹⁴⁾ showed that whilst small organic ions were adsorbed only up to the cation exchange of the clay, when large organic ions were added in excess of the cation exchange capacity, the clay carried on adsorbing the organic compound. They found that initially only the large ions were adsorbed onto the clay but on exceeding the cation exchange capacity the complete organic molecule was adsorbed and held in position probably by Van der Waals forces.

This phenomenon proved of great significance when the clay was to be used later in an organic liquid. Jordan, Hook and Findlayson⁽¹⁵⁾ showed that maximum compatability of an organo-clay with an organic liquid was achieved when complete cation exchange had taken place. Above and below this, the gel strength in organic liquids was found to decrease.

No single cation exchange capacity value can be given to a specific clay mineral. It not only varies from clay to clay but also from sample to sample of one type of clay. Thus the cation exchange capacity of a clay must be determined before modification processes can be correctly carried out.

In theory, the cation exchange reaction takes place stoichiometrically. Thus, for example, if the Ca^{++} ions of a Ca montmorillonite was to be replaced by Na^+ using say sodium carbonate the following reaction will take place:



and one equivalent of Na^+ would be replaced by one equivalent of Ca^{++} . The fact that this balance of equivalents occurs leads to the cation exchange capacity of a clay being conveniently expressed in milliequivalents per 100g of clay. Thus to replace 1 equivalent of Ca^{++} by 1 equivalent of Na^+ , 1 equivalent of Na_2CO_3 must be used ie. 53. 1 meq per 100g of clay would therefore require 0.053 per cent addition of Na_2CO_3 . The cation exchange capacity of a clay is reached when all the available exchangeable cations have been replaced. Therefore, for example, if a clay was found to have a cation exchange capacity of 100meq per 100g 5.3g of Na_2CO_3 would be needed to replace all the Ca^{++} ions in a 100g sample of clay.

Many methods of determining the cation exchange capacity were found to be available but most involved careful chemical analysis. Differences in results were noted, not only with variations in the competence of the operator but also between each type of

method employed. It was therefore important that qualified analysts were employed to carry out these experiments and in stating the final cation exchange capacity to refer to the method used.

One method was, however, found to have been developed by Robertson and Ward⁽¹⁶⁾ which did away with the necessity for sophisticated chemical analysis. It was based on the fact that clay, under the correct conditions, adsorbs the organic dye methylene blue up to the cation exchange capacity thus effecting a change in the shade of the dye solution. This could be optically compared with the colour of standard solutions of methylene blue and thus the adsorption of dye estimated. It was claimed that this method could be carried out quite rapidly with relatively unsophisticated apparatus. If their recommendations were followed carefully quite accurate results could be obtained which were comparable to those obtained by the more complex methods such as the barium method.

3.2.6. The Testing of Organo-clay

Having carried out the modification processes on the clay it was necessary to ascertain whether the correct amount of organic cations had in fact been adsorbed. A simple but effective method, suitable for both small scale and large batch production, of clay, was suggested by McAtee⁽⁵⁾ who carried out loss-on ignition tests on dried samples of the modified clay. By subtracting the ignition weight losses of unmodified clay and knowing the molecular weight of the reactant, the amount of adsorbed organic material could be deduced relatively accurately.

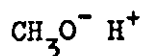
3.2.7. The Dispersion of Organo-clay in Organic Liquids

The organic liquid chosen for this work was a light mineral oil principally because of its low volatility, high boiling point, ready availability and comparative cheapness over other suitable organic media.

No information was available, however, on the production of clay and oil pastes such as those produced on the surface of sand grains during mulling, but considerable investigation was found to have been carried out on the swelling of organo-clay in relatively large volumes of organic liquids to produce gels or greases. It was from this information, therefore, that criteria had to be established for producing the best possible methods for creating a bonding medium with the organo-clay.

In early work, Jordan⁽¹⁵⁾ and ⁽¹⁷⁾ showed that the first essential for producing good compatibility with organic liquids was that the cation exchange capacity of the clay should be satisfied but not exceeded. It was also noted that in non-polar liquids such as mineral oil, the clay could not be adequately dispersed to form a gel unless a polar additive were used. It was postulated that this polar additive became attached to those parts of the clay unit layers not covered by organic cations and assisted in parting the clay layers thus giving access to the dispersing medium. The polar additive was found to have most success in small quantities, whereas large quantities served only to reduce the gel strength. Of the polar additives tested, low molecular weight alcohols were found to give the strongest gels and with minimum additions. Thus methanol was found to be a most efficient polar additive.

In later work, Granquist and McAtee⁽¹⁸⁾ theorised that the mechanism of the polar additive was essentially one of producing a double diffuse layer in a similar fashion as water on a naturally occurring clay. The polar additive described was methanol, which, it was suggested, formed the dipole:



This entered between the clay unit layers and became fixed electrostatically to the coated surface of the clay by the H^+ end of the molecule while the other end stood vertically out from the surface of the clay. If the same occurred on the adjacent unit layer the particles would be prised apart at least to the length of two molecules of methanol, about 7 Å. Further additions of methanol increase the separation of the plates by increasing the depth of the double diffuse layer allowing access for the organic dispersing liquid to solvate onto the organic cations of the clay plate thus causing the clay to swell. Further additions of methanol diffused the double layer even more and allowed complete dispersion of the clay in the organic liquid.

All the investigators researching the gelling of clay in organic liquid recognised the importance of applying some form of mechanical force. Indeed, information on Bentones⁽¹⁹⁾, a series of proprietary organo-clays, stated that in order to develop the full properties of a modified clay in organic liquids, some form of energy must be supplied. This may take the form of mechanical shear, the application of moderate heat or by the introduction of a polar additive either individually or in combination.

The shear action breaks down the clay agglomerates and disperses the already wetted clay to expose that which has remained protected from the dispersing liquid. The thermal energy lowers the viscosity of the organic liquid and reduces the strong cohesive force holding the dry clay flakes together. Temperatures ranging from 66-80°C were recommended. The polar additive is usually necessary to fully disperse the clay, the amount of addition varying according to the dispersing medium.

Thus it would seem that to obtain the optimum properties from the modified clay in a light mineral oil the clay should be modified to its cation exchange capacity. Energy must be supplied to the clay/oil mixture either by mechanical shear, the application of moderate heat or by the introduction of a polar additive.

3.3. The Properties of Moulding Mixtures Bonded with Organo-clay

On the relatively small amount of literature found on this subject, the majority was concerned with casual observations of the moulding mixtures during use rather than controlled research. The only exception found to this was an investigation carried out by Komarov et al.⁽²⁰⁾. Unfortunately, most of the basic materials were impossible to identify being referred to in code only and so could not be directly related to other results. However, the reported trends are of interest. The mixing was carried out in an edge runner mill, allowing two minutes dry mixing of the sand and clay before adding the oil and continuing for a further two minutes. Finally the polar additive was poured into the mill and the mulling

continued for a further seven minutes. It was stressed that this latter period of mixing was of great importance in developing the full properties of the bond.

A brief test was carried out into the effectiveness of the polar additive, in this instance being acetone. Using a basic mix of six per cent organo-clay and 2.5 per cent spindle oil, an increase in the range of green compression strengths was achieved on the addition of acetone from 0.05 - 0.06 to 0.5 - 0.6 kg per cm^2 (4.9 - 5.9 to 49 - 59 kN per m^2).

The effect of varying oil additions was also investigated on a mix containing six per cent organo-clay dispersed with acetone. Both the green compression strength and green tensile strength increased with increasing oil additions up to a maximum of about three to four per cent of a low viscosity oil, subsequent additions causing a slight drop in these properties. It was noted that the best flowability and green compression strength were obtained using 2.5 - 3.0 per cent spindle oil and 0.2 - 0.3 per cent polar additive.

These investigators also studied the effect of recycling a moulding sand containing 5.0 per cent organo-clay and 2.5 per cent mineral oil dispersed with 0.3 per cent of polar additive. The sand was tested both before use and after being subjected to seven casting cycles. The moulds were formed under a pressure of 13.0 kg per cm^2 (1275 kN per m^2) having a mould cavity of 235cm^3 and utilised 15 kg of sand. Cast iron was poured into them at 1370 - 1400°C and the casting knocked out 1 hour later. A standard new sand addition was made after each new casting cycle.

At the end of seven such casting cycles it was found that the green compression strength ^{6.107}11 - 15 per cent lower, permeability ninety per cent higher, flowability thirty per cent higher and friability doubled. However, the mould hardness was found to have remained constant at 80 - 87 units probably, it was suggested, because of the increased flowability.

Observations by Johnson⁽²¹⁾ suggested that when a sand bonded with organo-clay is subjected to continuous recycling the addition of further bonding material was necessary when the green compression strength fell from 8 to 3 lb per in² (55-21 kN per m²). At this point it was recommended that an oil addition should be made corresponding to fifteen per cent of the original oil addition. Further falls in strength were remedied by the addition of more oil and clay at the rate of twenty per cent of the original addition and the application of more polar additive.

Megaw and Miericke⁽²²⁾ also studied the recycling of this type of moulding sand and commented that the mere observation of green compression strength might not be sufficient to determine the rebonding point since the mould hardness was found to act independently of this property. It was also noted that rebonding was required more frequently the hotter the pouring temperature of the casting and the quicker the casting was knocked out.

In other, more general observations, it was noted⁽²³⁾ that when preparing a five per cent organo-clay, two per cent oil mix based on a sand of grain fineness number 140, the green compression strength increased with mulling time. Without the addition of a

polar additive the green compression strength was found to be still increasing after one hour's mulling. However, using a suitable polar medium eighty per cent of the ultimate strength was achieved after only five minutes mulling.

Further observations⁽²⁴⁾ and ⁽²⁵⁾ were concerned with the strengths that could be obtained with moulding mixtures based on organo-clay and oil. Using a bond of 4.0 - 5.0 per cent organo-clay and 2.0 per cent motor oil SAE No. 40 on a sand of grain fineness number 150, green compression strengths of 7.0 - 11.0 lb per in² (48 - 76 kN per m²) were obtained. Another mixture based on sands of grain fineness numbers 100 - 180 bonded with 5.0 per cent organo-clay and 2.0 per cent SAE No. 40 oil was found to have a green compression strength of 12 lb per in² (83 kN per m²) and a hot compression strength of 100 lb per in² (690 kN per m²):

It has also been noted that with continual use, the sand gradually becomes hotter and difficulties were experienced in attempts at cooling. The sand was found to become weak at elevated temperatures and 'further problems developed'.

Mention has been found of the use of iron oxide additions. In one instance it was reported to increase the hot compression strength whilst its addition has also been advised as a method of soaking up excess oil additions.

3.4. The Casting Potential of the Moulding Mixture.

In the few papers concerning themselves with this aspect of the moulding material most reported a superior casting surface finish.

Johnson⁽²¹⁾ noted that the use of this type of moulding materials gave consistently good surface finish in a foundry producing brass and bronze castings. It also gave close dimensional tolerances, left the casting cleanly at the knock-out, required less new sand additions than conventional clay and water bonded sand and permitted better filling of the intricate parts of the mould cavity because of the reduced chilling tendency.

Komarov et al⁽²⁰⁾ went to some lengths to evaluate the surface finish of cast iron castings produced in a specially designed mould bonded with organo-clay and oil. Each mould contained inserts which had been prepared under carefully controlled conditions. The surfaces produced by these inserts and by the mould walls were inspected visually and by a sensitive measuring probe. The surface finish of the castings was reported to be extremely clean and smooth, resembling that produced by the lost wax process. No surface defects, either internal or external, were found.

Deviations in the dimensional accuracy and weights of the castings produced were found to be quite random despite using various grades of sand and different proportions of the bonding medium and were within a range of ± 1.5 per cent.

Other authors have noted both good casting surface finish and dimensional accuracy with aluminium and copper based alloys and some improvements have been noted in the surface finish of thin section magnesium castings when using a facing sand bonded with organo-clay and oil and in thicker sections if mould-metal reaction inhibitors were employed.

CHAPTER 4

MATERIALS USED

4. MATERIALS USED

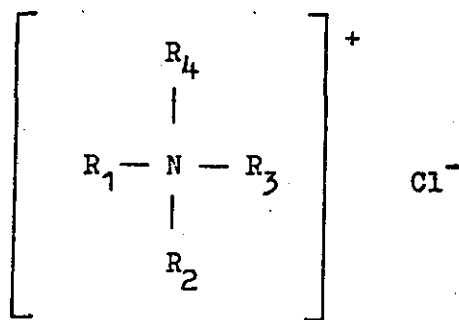
4.1. The Clay

The clay obtained for the modification process was a Wyoming bentonite from the Black Hills region of the U.S.A., having a total cation exchange capacity of approximately 100meq per 100g of clay, the predominant exchangeable cation being Na^+ . It was obtained under the trade name of Volclay by the American Colloid Company in the form of a fine powder, 75 - 90 per cent passing through a 200 mesh sieve.

4.2. The Quaternary Ammonium Compound

The quaternary ammonium compound was obtained from Armour Hess Chemicals Limited under the name of Arquad 2HT 75. As produced it contained seventy five per cent active ingredient, 0.5 per cent NaCl , 6.5 per cent water and 18.0 per cent propan-2-ol.

The active ingredient was of the form:



R_1 and R_2 being methyl radicals and R_3 and R_4 being seventy five per cent octadecyl, twenty four per cent hexadecyl and one per cent octadecenyl radicals.

4.3. The Polar Additive

The polar additive was methanol SLR having the following specification:

Molecular weight:	32.04
Acidity (CH_3COOH):	less than 0.004 per cent
Boiling range (95 per cent):	64.5 - 65.5°C
Residue after evaporation:	less than 0.002 per cent
Weight per ml at 20°C:	0.790 - 0.793 g

4.4. The Iron Oxide

This was precipitated red oxide powder containing approximately 85 per cent Fe_2O_3 .

4.5. The Sand

The base sand used for all the moulding mixtures was Redhill 110 from British Industrial Sand Limited having the following specification:

Grain shape:	angular/low sphericity
Average AFS fineness:	111
Mean partical size:	0.110mm
Loose bulk density:	85 lb per ft ³ (1.36g per cm ³)
Base permeability:	(3.5 per cent moisture): 50
Specific surface:	272 cm ² per g
Coefficient of angularity:	1.425.

Analysis:

L.O.I.	0.16 (per cent)
SiO ₂	99.30
Fe ₂ O ₃	0.063
Al ₂ O ₃	0.25
K ₂ O	0.02
Na ₂ O	trace
CaO	nil
TiO ₂	0.23 (per cent)
Cr ₂ O ₃	35 (ppm)

Sieve Grading:

BS sieve	per cent retained
60	1
72	2
100	20
150	49
200	17
200 ⁺	11

4.6. The Oil

This was a straight mineral oil or spindle oil sold by BP under the trade name of Energol EM 50. Typical characteristics are given below:

Specific gravity at 60°F (15.5°C): 0.87

Viscosity Redwood No. 1 (s):

70°F (21.1°C)	198.0
100°F (37.8°C)	94.0
140°F (60.0°C)	53.5
200°F (93.3°C)	37.5
210°F (98.9°C)	36.5

Closed flash point: 375°F (190.6°C)

Pour point: 10°F (-12.2°C)

4.7. Casting Alloys

4.7.1. Phosphor-bronze

This alloy was melted from ingot of the following composition:

Cu	Sn	Pb	Fe	Ni	Zn	P
Bal.	10.6	0.09	0.05	0.04	0.05	0.83

4.7.2. Aluminium-magnesium

This was obtained as ingots of the LM 10 alloy having the following nominal composition:

Al	Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn
Bal.	0.10	9.5-11.0	0.25	0.35	0.10	0.10	0.10	0.05	0.05
Ti									
0.20									

4.7.3. Cast Iron

The melt was produced from pig of the following nominal

range of composition:

TC	Si	Mn	P	S	Fe
3.70 - 4.50	1.50-2.00	0.70-1.20	0.04-0.12	0.05	Bal.

CHAPTER 5

EQUIPMENT USED

5. EQUIPMENT USED

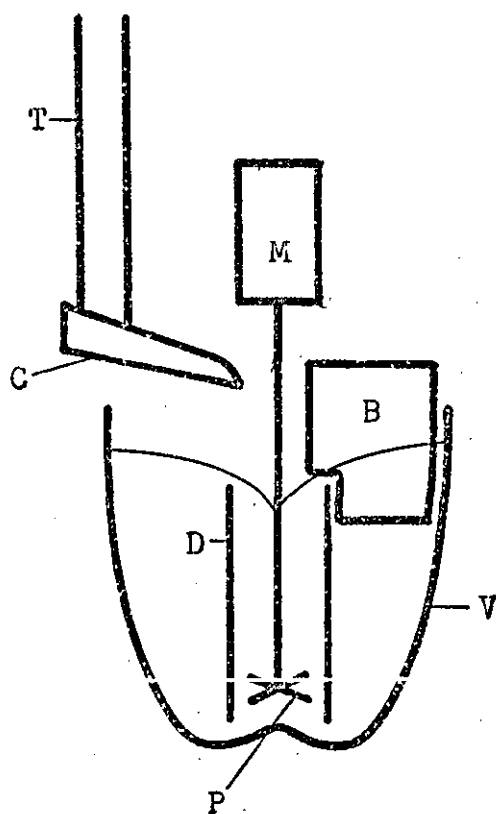
5.1. The High Speed Mixer - Development and Design

In order to carry out an efficient cation exchange reaction it was first necessary to disperse the Na bentonite clay as unit layers in a large volume of water. Na bentonite powder, however, cannot easily be dispersed in water because of the initial formation of a gel at the clay/water interface which inhibits further penetration of water to the remaining clay powder. It was found that mechanical agitation of the water and clay was necessary to continually break up the protective gel and allow water to reach all the clay particles.

Many types of mixing machines were tested and it was discovered that the best results were obtained by adding the clay powder slowly to a small, deep vessel of about 1 litre capacity in which was placed a high speed disc impeller. In order to reproduce the same mixing action in a larger vessel of more suitable capacity it was found necessary to restrict the mixing area within the vessel and circulate the dispersion from the vessel past the impeller.

A mixing machine was then designed utilising these findings and detailed drawings are given in the appendix. (DRG. 1, 1/1, 1/2, 1/3, 1/4). A simplified diagram of the machine is given in Fig. 2. illustrating the basic components.

Clay powder was fed into chute C which was vibrated by the high speed motor M to which it was attached. When dispensing



- | | | | |
|---|------------------|---|---------------|
| C | vibrating chute | V | mixing vessel |
| M | high speed motor | D | draft tube |
| T | storage tube | B | baffle plate |
| P | propeller | | |

Fig. 2 Diagrammatic sketch of the high speed mixer showing the basic component parts.

large amounts of clay, a feed tube T was positioned above the chute from which the clay flowed automatically. The vibration from the motor was sufficient to feed the clay slowly and evenly into the vortex within the draft tube D and thus was subjected to an immediate high shear mixing action in a confined area. The mixing was produced by a small, four bladed propeller P which also served to pump the dispersing medium round the vessel V and through the draft tube. On being ejected at the base of the tube, the dispersion impinged on the walls of the vessel which were smoothly curved to eliminate any "dead spots" and assist the movement of liquid to the surface where it was drawn back into the draft tube for further mixing and clay addition.

Since the flow of liquid from the base of the draft tube was not completely radial a swirling action was soon set up in the mixing vessel. When the liquid level was low, prior to the possible addition of reactant, the vortex created was sufficient to expose the top of the draft tube giving rise to unstable mixing conditions. A baffle plate B was therefore incorporated to hinder the tangential flow when necessary. A wind guard was attached to the motor to deflect its cooling air from the clay feed area.

The complete motor, shaft, propeller and chute assembly were designed to be easily withdrawn from the vessel which was clamped to the base of the mixer. The draft tube was purposely left free-standing in the vessel since it was found that any restraining arms projecting through the surface of the dispersion collected unmixed clay gel particles which could not easily be

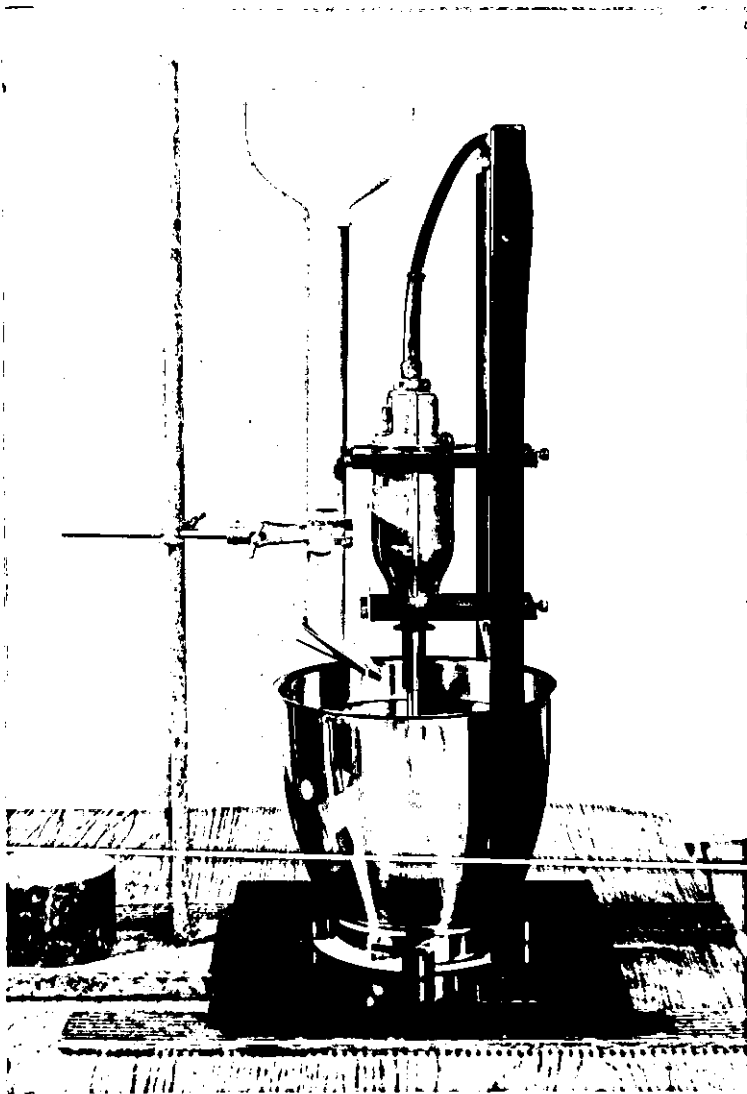


Fig. 3 The high speed mixer.

reintroduced to the mix.

All those components in contact with the dispersion were made from stainless steel in order to prevent corrosion. This was particularly important when using the mixer for small scale clay modification as the products of the reaction were of a corrosive nature.

Fig. 3 shows a general view of the completed high speed mixer together with the clay feeder tube referred to in 6.4.1.

5.2. The Large Batch Mixer - Development and Design

Having designed and built a mixing machine suitable for producing the clay dispersions and small, experimental batches of modified clay, it was necessary to design a much larger mixer in which to modify batches of clay of sufficient size for use in the sand testing programme and mould production.

Tests in the laboratory showed that a high speed mixing action was not necessary for the conversion process but that a strong pumping action was vital to distribute the added reactant quickly and break up the clay as it flocculated during the reaction. To obtain the optimum mixing action, the design of the vessel and propeller was calculated from data given by Sterbacek and Tausk⁽²⁶⁾ Based on fig. 4. the following range of dimensions were recommended.

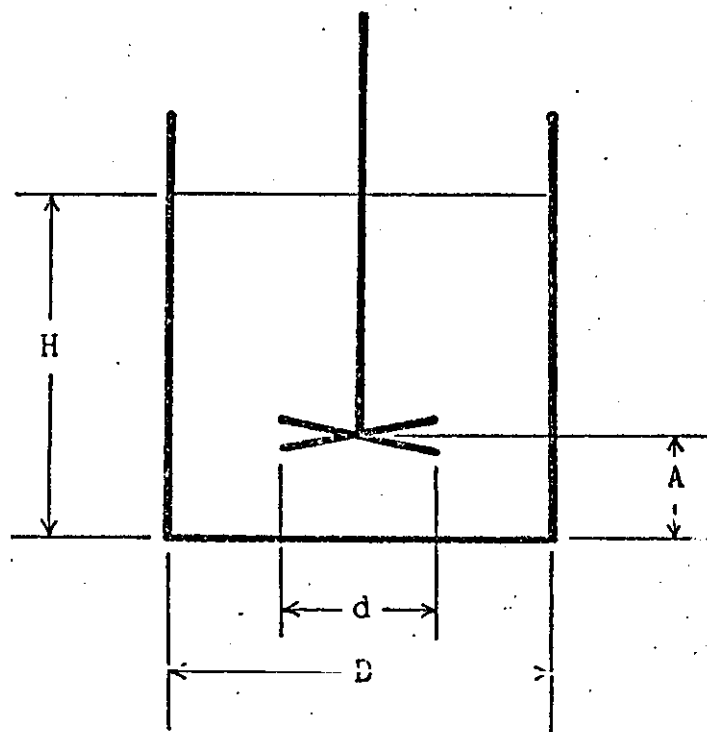


Fig. 4 Diagram of simple mixer showing basic critical dimensions.

Diameter of impeller:	$d = 0.5D - 0.2D$
Height of impeller from base:	$A = 0.5d - 1.0d$ $= 0.1D - 0.5D$
Depth of stirred liquid:	$H = 0.8D - 1.2D$
Propeller pitch:	$s = 1.0d - 3.0d$
Depth of submersion of propeller:	$= 2.0d - 4.0d$
Rotational speed:	$= 440 - 2400 \text{ rpm}$

The critical dimensions of the final mixer design are given below, together with their relationship to other relevant measurements.

Average diameter of vessel:	$D = 24.0 \text{ in}$
Diameter of impeller:	$d = 6.8 \text{ in} = 0.28D$
Height of impeller from base:	$A = 4.5 \text{ in} = 0.19D = 0.66d$
Depth of stirred liquid:	$H = 18.0 - 20.0 \text{ in} = 0.75D - 0.84D$
Propeller pitch:	$s = 3.0 \text{ in} = 0.44d$
Depth of submersion of propeller:	$= 13.5 - 15.5 \text{ in} = 1.99d - 2.28d$
Rotational speed:	$= 1420 \text{ rpm}$

It can be seen that the height of liquid is outside the lower end of the range. This dimension was, however, dictated by the size of available vessel and the discrepancy was considered to be small enough to be neglected. The pitch of the propeller was also outside the required limits. This derived from the fact that a true propeller of marine design could not be obtained and one was consequently fabricated from sheet metal. It was found that a 3in pitch in this material was the maximum possible if it was not to distort in use. Further, it was considered that since the level of

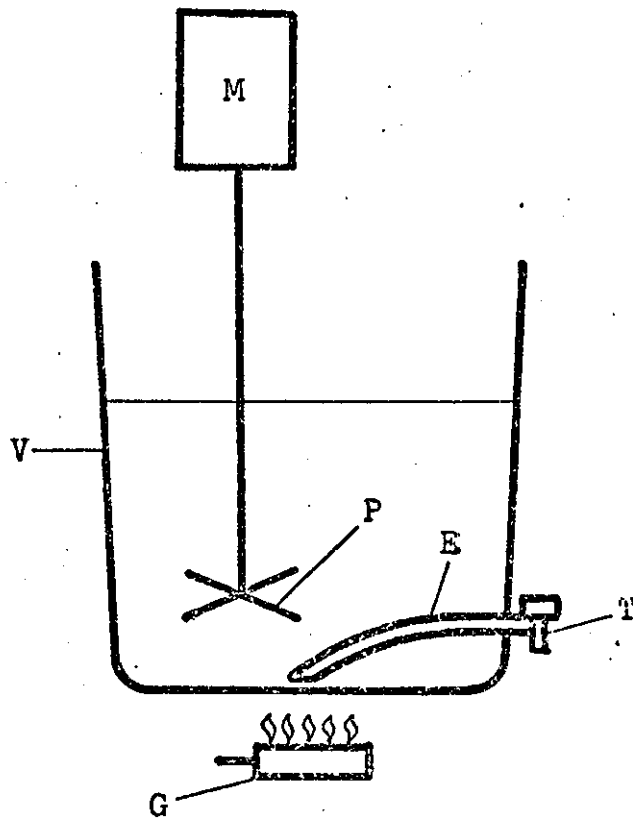
the liquid was at the low end of the range the efficiency requirements of the propeller could be reduced slightly.

Detailed drawings of the final design of the batch mixer are given in the appendix, (Drg. 2, 2/1, 2/2, 2/A, 2/A/1, 2/A/2, 2/A/3), whilst a simplified sketch is shown in Fig. 5.

The vessel V had a maximum working capacity of approximately 150 l. It was constructed of stainless steel and thus was resistant to the attack of the corrosive bi-products of the modification process. The motor M of $1/3$ HP turned a six bladed propeller P via a stainless steel shaft. This was placed off-centre within the vessel to prevent the formation of an excessively large vortex. A tap T was fitted near the base of the vessel. An extension pipe E protruding from the back of the tap was directed to the bottom of the vessel to allow the maximum removal of reaction bi-products and water. The whole mixer assembly was mounted on a steel frame which was raised from the ground to accommodate the gas ring G. The complete mixer is shown in Fig. 6 just prior to starting a modification. The vessel to the right of the motor contained the reactant which could be added in controlled amounts by using the tap.

5.3. The Filter Press.

A filter press was used to extract the water from the modified clay after treatment. This apparatus comprised a pump which passed the clay suspension into six filter cells under a maximum pressure of approximately 80 lb/in^2 . The walls of each cell



- | | | | |
|---|---------------|---|----------------|
| V | mixing vessel | T | drainage tap |
| M | motor | E | extension pipe |
| P | propeller | G | gas ring |

Fig. 5 Diagrammatic sketch of the large batch mixer showing the basic component parts.

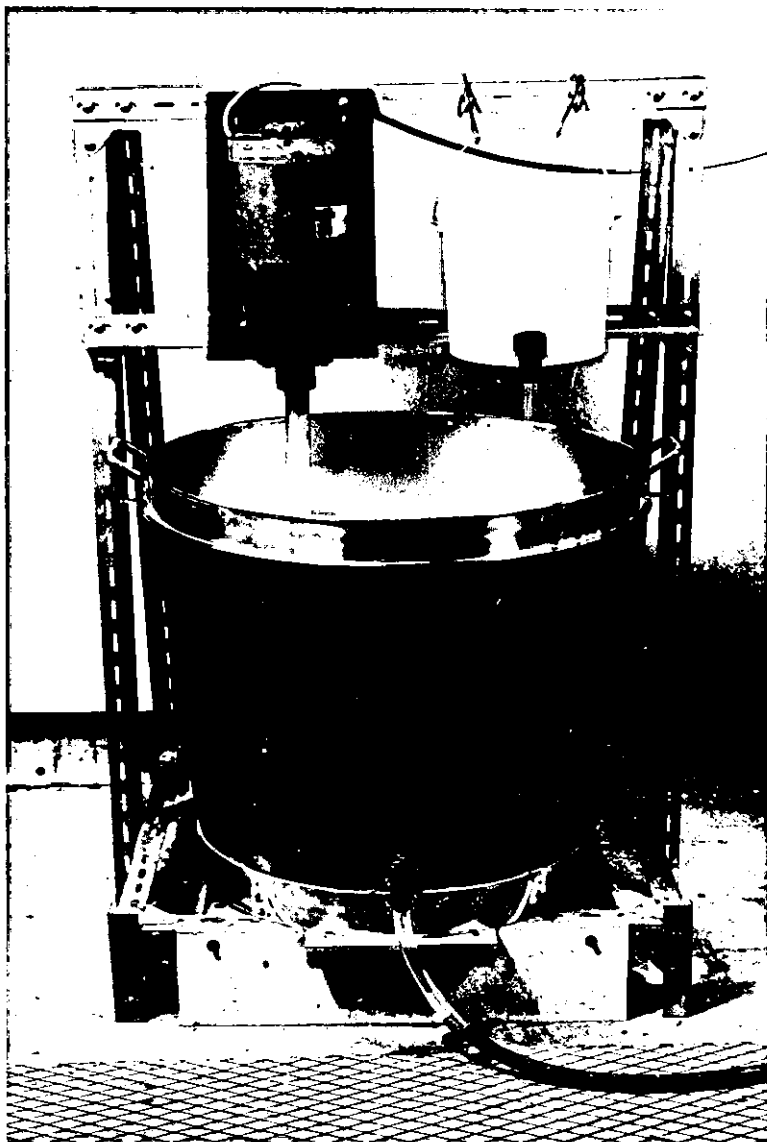


Fig. 6 The large batch mixer.

were composed of strong, closely woven material which, whilst retaining the clay, allowed the water to pass through. By dismantling the bank of cells the clay could be removed in the form of a compacted paste.

5.4. The Grinder

The grinder was composed of a stainless steel tube split into three chambers by perforated partitions. Each chamber contained hardened steel balls of varying sizes, and the whole was vibrated by an eccentric motor. The clay was fed via a funnel into the first chamber from which, after pre-grinding, it passed through the perforations into the main grinding chamber and finally the exit chamber where it flowed into a storage bin.

5.5. The Sand Muller

The moulding sand mixes were prepared in a Ridsdale laboratory muller of 3.5 kg maximum capacity. This apparatus was made up of a stationary pan in the centre of which revolved a pillar at 30 revs/min driven by a $\frac{3}{4}$ hp motor. Attached to the pillar were two heavy steel rollers, which turned freely on horizontal axes, and two carefully aligned ploughs. The purpose of the rollers was to knead the clay and oil and spread the mixture onto the surface of the sand grains, thus developing the bond. The ploughs were so arranged as to turn the mix and feed it into the path of the rollers. The prepared moulding sand was discharged through a sliding door in the base of the muller.

It was found most important with this type of clay-bonded mix to maintain both the base of the muller and the surface of the rollers in a rough condition otherwise the rollers ceased to turn, merely pushing the mix round the pan without kneading or mixing it. To achieve a rough surface on these components they were removed and shot blasted for about half-an-hour. With continued use of the muller, however, the surfaces again became polished and a more permanent method was found in the grinding of shallow, radial grooves in the base of the muller whilst the surfaces of the rollers were peened using a centre punch and hammer.

5.6. The Sand Testing Equipment

The testing of the physical properties of the sand mixes was carried out on apparatus normally used for the more conventional clay/water-bonded sand. Since these pieces of equipment are standard in any sand laboratory, their description has been omitted from this section but is referred to in the appendix.

5.7. The Sand Temperature Controller

Since the temperature of the moulding sand was found to be a variable affecting the physical properties a simple piece of apparatus was designed to heat and cool the test batches of sand and to maintain the desired temperature to within at least $\pm 1^{\circ}\text{C}$. It consisted of a water-jacketed box linked to a temperature controlled water-bath as shown in section in Fig. 7. Detailed dimensions of the box are given in the appendix. (Drg. 4).

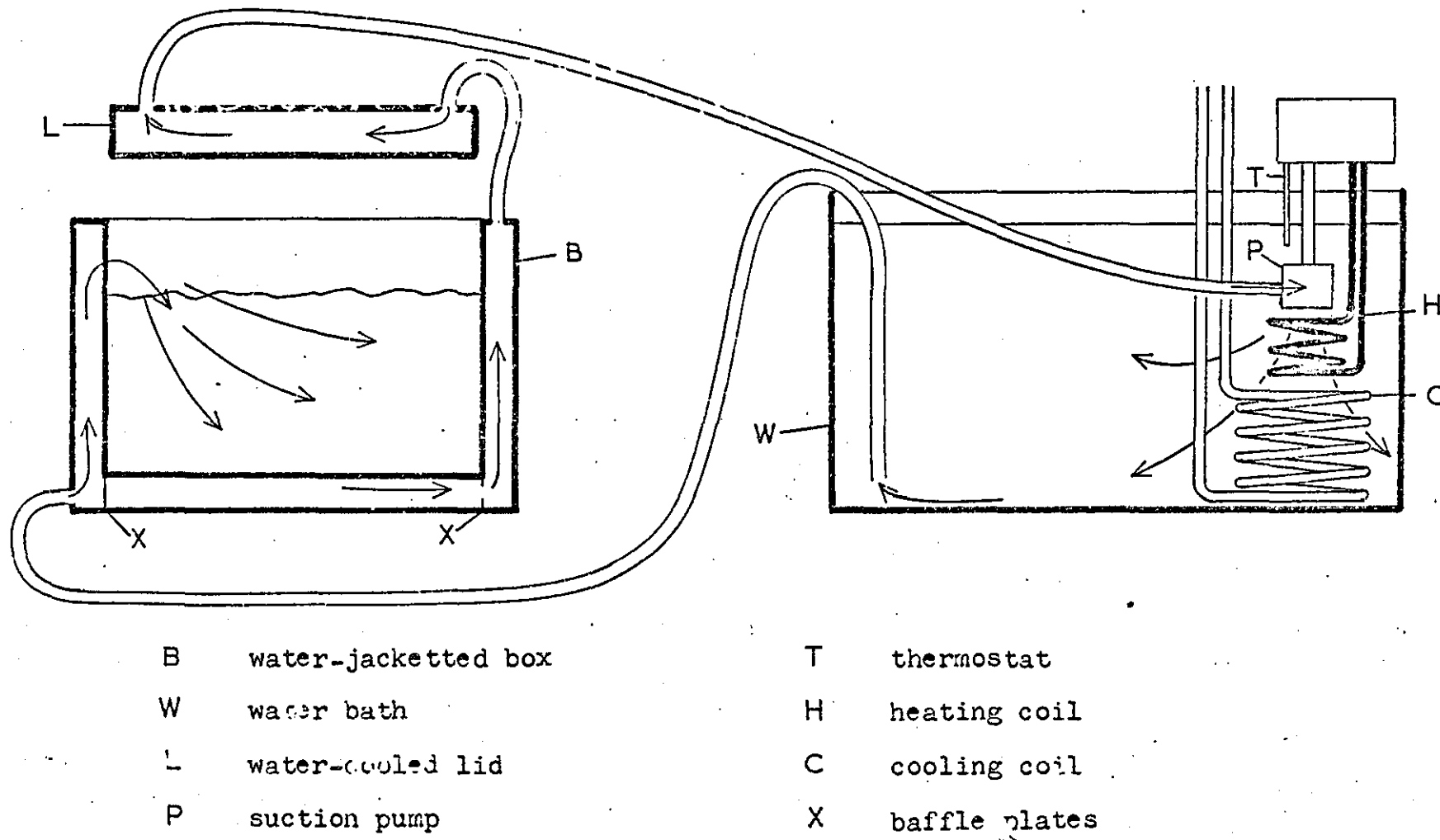


Fig. 7 Diagrammatical sectional view of the sand temperature controller.

The box B was designed to be deep and narrow whilst still allowing adequate access for removal of sand samples. This shape ensured that only a small area of sand was left exposed to room temperature and that the thickness of sand through which heat had to be conducted was kept to a minimum. A lid L was designed so that it could be laid directly onto the top surface of the sand during the heating or cooling period. The water was drawn as indicated by the arrows, via flexible tubing from the water-bath, W through the jacket and the lid and back into the water-bath by means of a small suction pump P. Two baffles X, extended from the top to the bottom of the water jacket and incorporating strategically placed orifices which directed the water through as much of the jacket as possible. Their design is shown in greater detail in the appendix. (Drg. 4). The temperature of the bath was controlled by a thermostat T operating a heating coil H. When temperatures below ambient were required cooling was achieved by circulating mains water through a copper coil C immersed in the water-bath.

5.8. The Test Casting and Pattern Equipment

The test casting was designed to monitor surface finish and dimensional accuracy and is shown in fig. 8 together with the running system. It was semi-hexagonal in cross-section, the straight sides and definite angles facilitating the checking of dimensional accuracy. The semi-cylindrical cavity was formed by two 2 x 2in. laboratory test pieces the ends of which were slightly modified by a special end piece in the specimen tube, details of which have been shown in the appendix (Drg. 3). The position of this cavity

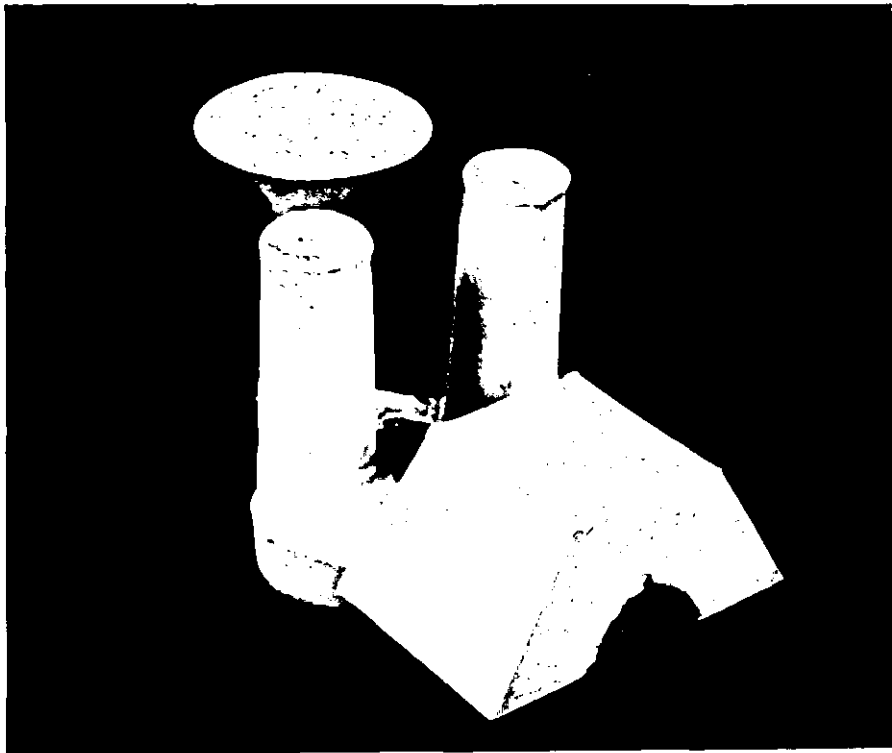


Fig. 8 General view of the test casting
and running system.

was designed to be close to the heat centre of the casting whilst allowing easy access for later inspection of the surface.

The pattern equipment is shown mounted on pattern boards in Fig. 9, detailed drawings being shown in the appendix (Drg. 3). The mould cavity formed is sketched in Fig. 10. A hand-cut pouring basin P accepted the molten metal into the sprue S. From the sump of the sprue the metal flow divided and entered the sumps of two risers R at a tangent to induce a spinning action. These then acted as whirl gates, collecting any dross in the centre where, with continued pouring, it was channelled up the risers. The clean metal to the outer edges of the sumps passed into the mould cavity C by way of two in-gates G. The cross-sectional area of these gates was made larger than the rest of the running system to avoid excessive flow rates and consequential turbulence of the metal as it entered the mould cavity. Further, being large, they remained molten long enough to allow feed metal to be drawn from the risers during the solidification of the casting.

The cope and drag halves of the mould can be seen in Figs. 11 and 12 the former showing the empty core print, the latter showing the same mould after the insertion of the two 2 x 2in test pieces.

5.9. The Moulding Equipment

The moulds were produced on a British Moulding Machine consecutive jolt/squeeze moulder type BT1 having a jolt capacity of 205kg and squeeze load of 3 880kg at the working pressure of 6.3kg per cm² (620 kN per m²).

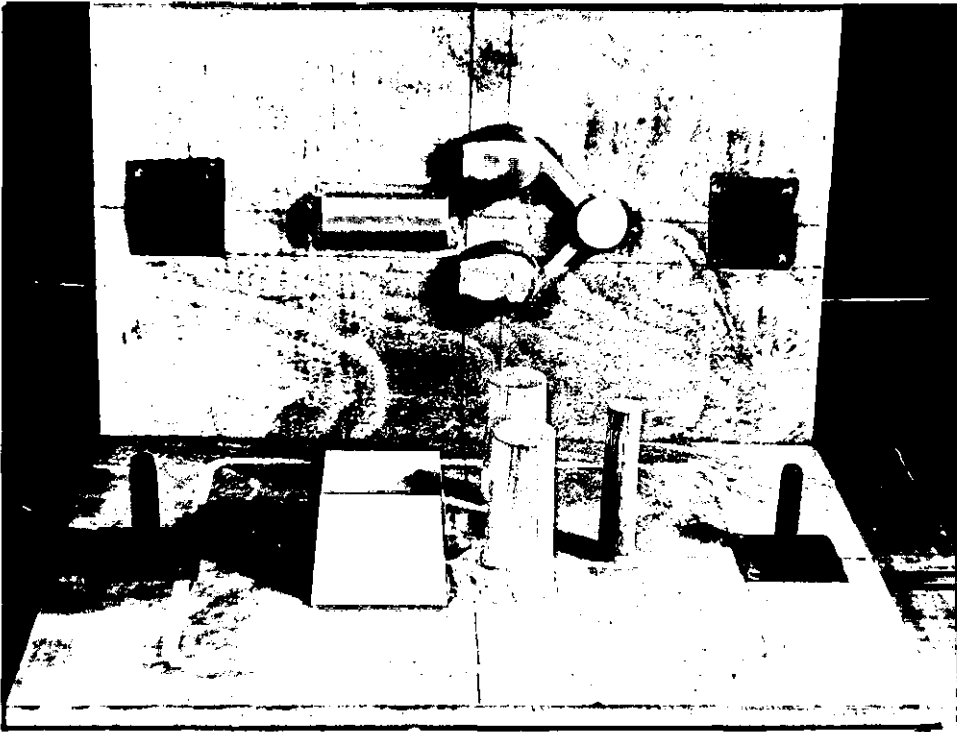
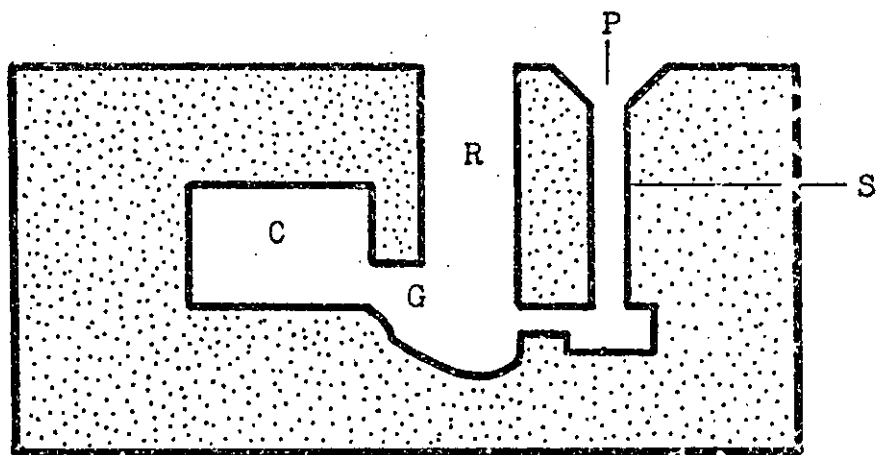


Fig. 9 General view of the cope and drag
patterns (cope in foreground).



- | | | | |
|---|---------------|---|--------------|
| P | pouring basin | C | mould cavity |
| S | sprue | G | in-gates |
| R | risers | | |

Fig. 10 Diagrammatic sketch of the mould cavity for the surface finish and dimensional accuracy casting.



Fig. 11 Test casting mould showing core print.

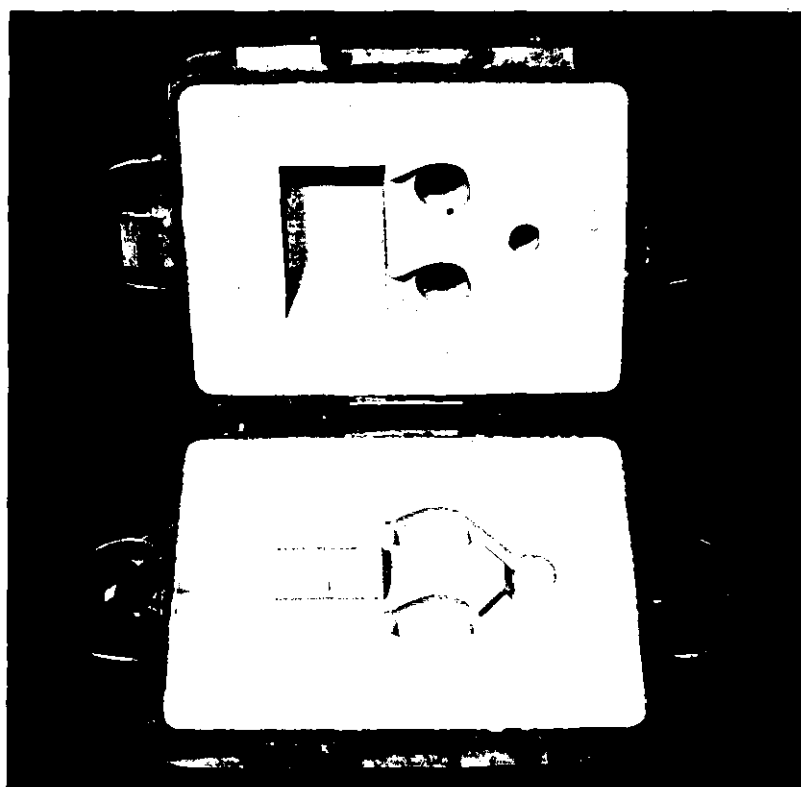


Fig. 12 Test casting mould with cores in place.

5.10. The Furnaces

The non-ferrous alloys were melted in a simple gas-fired crucible furnace having a maximum capacity of approximately 4.5 kg of aluminium and 13.5 kg of bronze.

The cast iron was melted in a medium frequency coreless induction furnace of approximately 27.0 kg maximum capacity.

5.11. The Sand Mixer

The recycled moulding sand was mixed in a Fordath laboratory core sand mixer comprising a stationary pan in which revolved two ploughs so designed as to thoroughly turn and mix the contents.

CHAPTER 6

EXPERIMENTAL PROCEDURES

6. EXPERIMENTAL PROCEDURES

6.1. The Purity of the Clay

Two main impurities were known to be contained by the clay which took no part in the cation exchange process. These were non-clay particles, such as quartz, and 'free water' lying between the unit layers of the clay. The former was found difficult to quantify with any accuracy and was assumed to be constant for the batch of clay reserved for the research. The latter, however, was known to vary according to the ambient water vapour pressure and had to be determined before each modification session.

The free water was easily determined by taking samples of known weight and drying them in an oven at 110°C to constant weight. Such was the affinity of Na bentonite for water that the samples were found to be rapidly gaining weight during the cooling period and weighing operation. Therefore all samples were cooled in a desiccator and weighed as quickly as possible.

6.2. The Cation Exchange Capacity of the Clay

This value was usually quoted for pure, dry clay, but since the non-clay solids proved difficult to quantify they were taken as being constant and thus all results for cation exchange capacity referred to are for the non-pure, dry clay. This was found to be acceptable since the clay to be used in the modification process also contained the non-clay solids and was taken from the same batch of reserved clay tested.

The method chosen for determining the cation exchange capacity of the clay was the methylene blue test. In order that solutions of known concentration could be made up, it was important to quantify the main impurity in the solid, that of water of crystallisation. This was determined in a similar manner to the free water in the clay, by heating to constant weight in an oven at 110°C . A standard solution was then made up to a concentration of 0.3 per cent.

The clay was prepared in a 250ml capacity glass bottle provided with a close fitting glass stopper. This ensured that no part of the bottle was of a material which could adsorb the dye. A weighed sample of clay was added to the bottle and since the amount was small, approximately 0.25g, care was taken to weigh the measuring scoop both before and after the weighing process so that the exact addition to the bottle was recorded. 5.0 ml of demineralised water was added to the clay using a small pipette and the clay allowed to stand for 24hr to become fully swollen.

Exactly 25ml of the standard 0.3 per cent methylene blue solution was then pipetted into the bottle which was tightly stoppered and shaken vigorously for 20 min. The contents of the bottle were then poured into a filter funnel containing a Whatman's No. 1 filter paper. The first light coloured filtrate, having had some of the dye removed by the paper, was discarded whilst the remainder was collected in a conical flask. Precisely 2.0ml of the filtrate was withdrawn and placed in a 100ml measuring cylinder. To a further measuring cylinder was added 100ml of a 0.002 per cent

solution of methylene blue made up from 3.34ml of the standard 0.3 per cent solution in 500ml of water. Demineralised water was then progressively added to the cylinder containing the sample of filtrate until the contents of the two cylinders appeared to be the same shade of blue. The end point was checked by placing the two cylinders on a sheet of brightly illuminated white paper and placing one eye to the top of each vessel simultaneously. After a little practice, it was found that the end point could be determined easily and consistently.

The cation exchange capacity of the clay expressed in meq per 100g of dry clay could be calculated using the following formula:

$$\frac{(I-F) \times P}{\frac{E}{1000} \times \frac{100}{V} \times W} \quad (6.2)$$

where I = the percentage of dye initially
 F = the percentage of dye in the filtrate
 P = the percentage purity of the dye
 E = the equivalent weight of the dye
 V = the volume of dye used
 W = the dry weight of the clay

(according to Robertson and Ward⁽¹⁶⁾.)

This formula is shown derived in the appendix C(i).

6.3. The Purity of the Quaternary Ammonium Compound

This material was supplied with three main impurities that would take no part in the modification process. They were water, iso-propanol and sodium chloride, their concentrations being reported to be nominally 6.5, 18.0 and 0.5 per cent respectively. However, since the first two were of a volatile nature it was decided to evaluate their exact concentration before carrying out the modification. The sodium chloride, being non-volatile and present in only a small quantity, was assumed to be still at the concentration reported.

To obtain an accurate value of the active ingredient in the manufactured quaternary ammonium salt involved sophisticated analytical techniques for which neither equipment nor time were available. It was therefore decided to simply evaporate the water and alcohol to constant sample weight and thus find the weight of active ingredient by subtraction. Several evaporation techniques were explored but the most consistent and reproducible results were obtained using the following method.

To avoid the evaporation losses of the alcohol and, to a lesser extent, water during the initial weighing procedure, samples of the quaternary ammonium salt were packed into a syringe and approximately 1.0 - 1.5g injected quickly into weighed vessels. These were sealed and reweighed before being warmed to 50°C when the material liquified. The lids were removed and the vessels placed in a vacuum desiccator for approximately 24hr before being reweighed under seal. The evaporation under vacuum was then

continued until a constant weight was achieved. The loss in weight was taken to be the water and iso-propanol and after adding the 0.5 per cent sodium chloride the weight of active DDAC was found by subtraction.

6.4. The Clay Modification Process

6.4.1. The Clay Dispersion

This process was carried out in the high speed mixer. The vessel was filled with 5.0 l of water, the draft tube placed in the base and the motor and shaft assembly lowered into position. The motor was switched on and the clay placed into the vibrating chute from which it was slowly fed into the vortex as can be seen in Fig. 13. After the last of the clay had been added to the liquid, mixing was continued for a further 5 min. 100g of clay was normally treated in this manner, but when larger volumes of dispersion were required for batch production mixes were made to higher concentrations and subsequently diluted in the large mixing vessel.

It was found that a maximum of approximately 400g of clay could be processed in 5.0 l of water before the viscosity of the mix reduced the efficiency of the stirring action. To facilitate the addition of this amount of clay a vertical tube of 2.5cm diameter was clamped with its base about 1.0cm above the bottom of the vibrating chute. A funnel was inserted into the top of the tube and the complete batch of clay to be processed fed into it. As the clay was vibrated into the water at the base, the level in the chute was maintained from the reservoir in the tube. As for the small scale dispersion, the mixing was continued for 5min

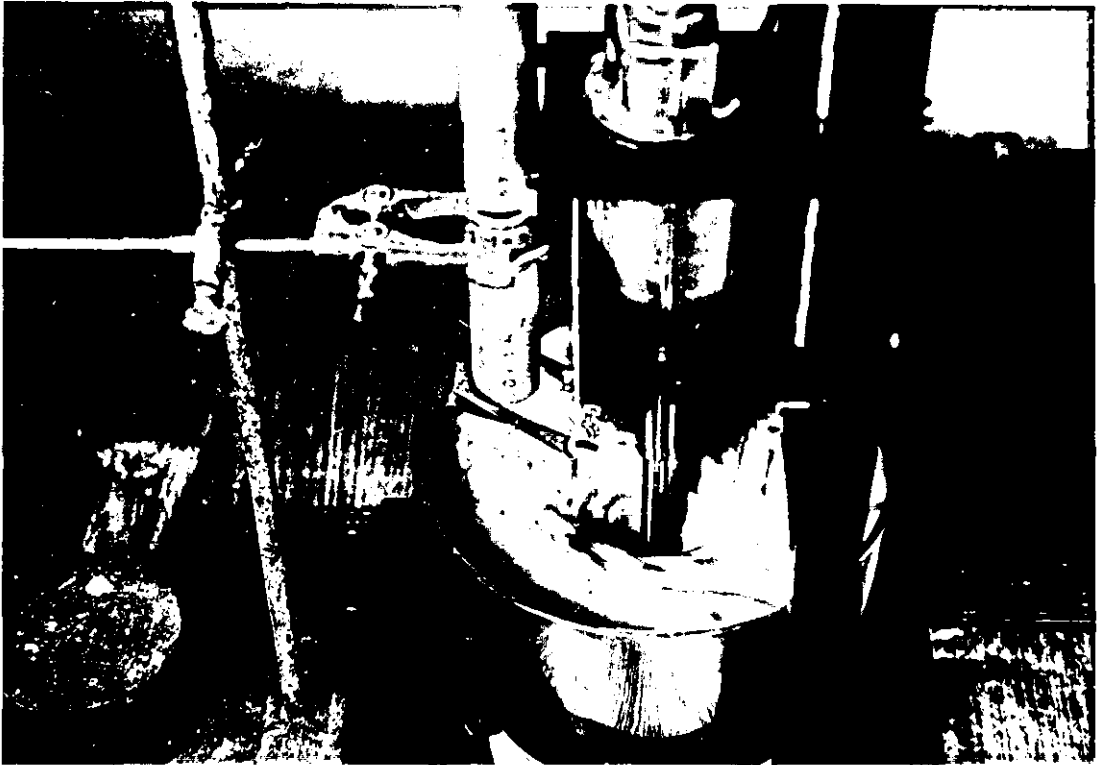


Fig. 13 The high speed mixer showing the introduction of Na bentonite during the preparation of a clay dispersion.

after the completion of the additions after which the dispersion was poured into the larger mixer which already contained 50 l. of water. The stirring action in large vessel was maintained whilst further similar dispersions were made up in the high speed mixer to bring the final amount of clay in the large vessel to 3.0kg in 100 l. of water.

6.4.2. The Clay Treatment

In initial small scale experiments the clay dispersion was pre-treated with a solution of sodium carbonate to ensure that all exchangeable cations were of the sodium form. However, tests showed that this made no appreciable difference to the final cation exchange reaction and the practice was discontinued. Similarly, the preparation of the quaternary ammonium salt as a dispersion in water was abandoned early in the work since its limit of dispersion was low and necessitated the addition of large volumes of liquid to the clay dispersion. This overloaded the small high speed mixer in which the preliminary modifications were carried out whilst in the large batch production it would have required a vessel of impractical capacity. It was found, however, that the quaternary ammonium salt could be prepared in a liquid form of more convenient volume by dissolving it in iso-propanol. This was produced by adding the alcohol to the salt in the ratio of approximately 2.0kg salt to 1 litre of alcohol, in a vessel equipped with a tightly fitting lid and placing the whole into a water-bath at 40°C.

Prior to the addition of the quaternary ammonium salt solution the clay dispersion was heated to 60°C to assist the rate of reaction. The rate of additions was carefully controlled to avoid both excessive clay flocculation and the production of a heavy foam. The additions for the large scale production were made from a vessel equipped with a tap suspended over the reaction vessel and took a period of about 30min to complete. This process is shown in Fig.14. Mixing was then continued for a further 20 min to ensure complete reaction after which the contents of the vessel were allowed to stand undisturbed overnight.

The small pilot scale tests on clay modification were designed to study the reaction between the organic reagent and the clay dispersion. To this end additions of the reagent were added varying from amounts well below the cation exchange capacity of the clay to amounts greatly in excess. The physical characteristics of the dispersion were noted during the mixing, settling and filtering to gain knowledge for future work and the retention of the organic reagent were tested for each addition. Additions to the large batch mixes were calculated to just satisfy the cation exchange capacity of the clay.

The additions of organic reagent were calculated according to the following equation, the derivation of which is given in appendix C(ii):



Fig. 14 The large batch mixer showing the introduction of DDAC to a clay dispersion during the modification process.

$$B = \frac{F \times C(100 - D) \times G}{A \times 100\,000} \quad (6.4.2)$$

where A = purity of organic reagent (per cent)

B = weight of addition of organic reagent (g)

C = weight of clay as supplied (g)

D = clay moisture content (per cent)

F = meq of DDAC to be added per 100g of dry clay

G = molecular weight of DDAC

6.4.3. Washing the Modified Clay

The method of washing the modified clay was developed around an unexpected phenomenon of the modification process. As the cation exchange capacity of the clay was satisfied by the organic ions, the modified clay was found to float rather than precipitate and, now being in a hydrophobic condition, left clear water below. By opening a tap at the base of the reaction vessel, this water together with the bi-products of the reaction could be easily drawn off until the first signs of the floating clay were observed to be entering the exit pipe. This water constituted about half of the total volume of the contents of the vessel. By replacing this with fresh water and stirring for a further 20 minutes the washing procedure was easily accomplished. After approximately 4 hr during which period the clay was allowed to float to the surface again, the tapping and washing procedure was repeated. A total of four washings were completed before passing on to the filtration procedure.

6.4.4. Filtering the Modified Clay

The clay was kept in suspension by constantly circulating it through a pump. By adjusting a throttle in the return pipe to the vessel a part of the suspension was diverted into a bank of high pressure filter cells in a filter press. The throttle was gradually closed until the pressure within the cells reached 80 lb per in² (550kN per m²). This was maintained until the flow of clear water from the outlet of the press ceased. The press was then dismantled, the cakes of clay removed from the cells and the procedure repeated until all clay had been processed.

In the smaller laboratory tests a less involved method of filtration could be used. The clay suspension was poured onto a Whatman's No. 3 filter paper in a Buchner funnel. The filtrate was collected in a large conical flask to which a vacuum pump was attached in order to hasten the rate of filtration.

6.4.5. Drying the Modified Clay

The filter cakes were crumbled into metal trays and placed in an air-circulating oven at 110°C for 24 hr.

6.4.6. Grinding the Modified Clay

The dried clay lumps were fed into the vibrating grinder in small amounts to prevent over-loading. After processing the complete batch it was passed through the grinder for a second time to ensure that no small lumps remained. Samples of the final product were found to pass through a 200mesh sieve and this was taken as the criterion for the adequacy of grinding in further batches.

6.5. Testing the degree of Modification of the Clay

Samples of the dried clay weighing approximately 4g were placed in a desiccator for 24 hours and then added to pre-weighed fireclay boats and weighed again. During exposure to the atmosphere of the laboratory the samples were found to gain weight rapidly and thus the speed of weighing proved critical to the final accuracy of the results.

The boats were then placed in a muffle furnace which was gradually heated to 250°C thus causing a slow decomposition of the organic constituents of the clay which were able to volatilize with the minimum of disturbance to the clay sample. After approximately 30 minutes the temperature of the furnace was raised to 900°C and maintained at this level for two hours. The furnace was then allowed to cool slowly until the boats were just cool enough to handle and be transferred to a desiccator for final cooling to room temperature. The boats were reweighed taking care once more to expose the samples as little as possible to the atmosphere of the laboratory.

Samples of unmodified clay were also tested in this manner so that a distinction could be made between the loss in weight of the clay due to the ignition of the organic component and the hydroxyl ion loss of the basic clay structure.

The exchange of organic ions that had occurred during the modification process could then be determined by the following formula and expressed in meq per 100g of dry clay:

$$\frac{(I - C) \times 100\ 000}{(100 - I) W} \quad (6.5)$$

where I = the percentage ignition loss of organo-clay
 C = the percentage ignition loss of unmodified clay
 W = the molecular weight of the quaternary ammonium cation
 (after McAtee⁽⁵⁾).

The derivation of this formula is shown in appendix C(iii).

6.6. The Sand Mulling

In initial experimental work it became evident that the efficiency of the mulling process was affected by the temperature of the mix. To control the mulling temperature would have required elaborate modification of the muller to provide heat when the mix temperature was to be above ambient and cooling to remove the heat produced by the mulling procedure. It would also have been necessary to design a method of continuously monitoring the temperature of the sand during mixing. In view of the practical difficulties envisaged in attaining these ends and of the limited time available it was decided to use the muller in its existing form but for each variable under test prepare four mixes at differing mulling temperatures. The temperature of the sand mix was recorded both before and after the mulling operation and the results charted to ascertain the trends.

A range of temperatures was sought which most closely corresponded to those found in industry, the higher end of the range relating to the temperature attained over a long period of continuous

recycling of the sand from the casting bay to the sand plant and the lowest to the type of temperature experienced on starting up a sand muller in a cold foundry. In practice, this range was limited by the high rate of cooling at the top end of the range making temperature recording inaccurate, and at the lower end of the range by the relatively high ambient temperatures experienced during the experimental work.

This range of temperatures was found to be best achieved using the following procedure. The first mix was carried out using both sand and the muller at room temperature. 3.0kg of Redhill 110 sand was added to the muller and mixed for 2min to ensure that a stable temperature was reached. The clay was then added and the mixing continued for a further minute to thoroughly distribute it around the sand grains. The muller was stopped and the sand spread evenly over the pan and two thermometers inserted, one on each side of the drive pillar. Whilst the thermometers reached equilibrium the oil was sprinkled over the surface of the mix and turned in to prevent it sticking to the rollers in later mulling. When a polar additive was to be used it was placed in a flask equipped with a tap which was clamped to the outer plough arm so that it could be discharged evenly around the mix. The thermometer readings generally agreed but where a slight discrepancy occurred the difference was halved. The thermometers were removed, the polar additive flow commenced at a fast drip and the muller started. After a timed period the muller was stopped and a thermometer inserted into a pile of the mix. The average of the starting and finishing temperature was taken to be the mulling

temperature for the purposes of charting the results.

The second mix was carried out in the muller after it had been preheated by mulling 5.0kg of dry sand at 200°C. After 5min the sand was quickly discharged, the muller cleaned out and the 3.0kg of sand to be mixed added at a pre-heated temperature of 200°C. In this manner it was found that a mulling temperature approaching 60°C could be attained. The same basic procedure was then followed as for the room temperature mix.

Two further mixes were made in the muller as it was cooling using 3.0kg of sand at room temperature. With this procedure initial mulling temperatures of approximately 45.0 and 30.0°C respectively could be achieved. The four mixes prepared as described above were all stored in sealed containers until tested which, in most instances, was within 3 hours of mulling.

6.7. Testing the Physical Properties of the Mulled Sand

In most instances each experimental batch of sand was subjected to seven physical tests:

- (i) Green Compression Strength
- (ii) Green Shear Strength
- (iii) Hot Compression Strength
- (iv) Permeability
- (v) Mould Hardness
- (vi) Shatter Index
- (vii) Flowability.

These were all tests of a standard nature normally carried out on the clay and water-bonded moulding sands and the method of procedure has therefore been omitted from this section of the thesis. It can, however be found in Appendix A.

6.7.1. Temperature Control of the Mulled Sand

During the initial experimental work on the physical properties of the moulding sand it was evident that the results obtained were not as reproducible as those normally obtained when testing a clay/water-bonded moulding sand. It was also noted that the appearance of a sand mix changed from being dry and powdery to wet and sticky when warmed slightly and thus it was assumed that variations in the ambient temperature could be a primary cause of the problem.

A water-jacketted box was therefore constructed as a holding vessel for each batch of sand to be tested and in the majority of cases a temperature of 20°C was maintained by this means. The preparation and testing of each sand test piece was carried out as quickly as possible to ensure minimum subsequent temperature variation. In most instances this procedure was carried out within 15 seconds of the sand being removed from the water-jacketted box.

6.7.2. Determination of the Effect of Sand Temperature

In order to determine how critical the testing temperature was upon the physical properties of the moulding sand a batch of sand mulled at an average temperature of 30°C was

divided into four parts, each of which was heated or cooled to differing degrees in the water-jacketted box before being tested. The four temperatures selected for testing were 15°C, 25°C, 35°C and 45°C. In each case care was taken to ensure that all equipment coming into contact with the sand during the preparation and testing of the test piece was as close to the temperature of the sand as possible.

6.7.3. Determination of the Effect of Mulling Time

A series of tests was carried out to establish the effect of mulling time upon the physical properties of the resulting moulding sand. From the results of these tests it was hoped to find an optimum period which would develop the bond to its fullest potential for a particular mix. To this end a number of sand mixes containing 5 per cent organo-clay and 3 per cent oil were mulled for 2.5, 10 and 20 minutes at varying mulling temperatures both with and without 0.5 per cent methanol addition. Each mix was then subjected to a full physical analysis.

6.7.4. Determination of the Effect of a Polar Additive

Since it had been shown that the introduction of a polar material improved the development of the clay/oil bond, tests were carried out to determine the effect of adding such a material in varying amounts to the sand mix during the mulling cycle. Methanol, the polar additive chosen for this work, was added to a series of sand mixes containing 5 per cent clay and 3 per cent oil in varying amounts of 0.5, 1 and 2 per cent. Each level of addition

was tested at four mulling temperatures using a standard mulling time of 10 minutes and the physical properties of all the sand mixes so produced were subsequently investigated in the usual manner.

6.7.5. Determination of the Effect of Clay

Batches of sand containing 3, 5 and 7 per cent clay were mulled at four different temperatures for 10 minutes with a standard addition of 3 per cent oil. In order to carry out a comprehensive study of the effect of these additions the first tests were made on mixes to which no polar additive had been introduced. However, since under production conditions a polar material would most probably be added, all tests were repeated using a 5 per cent addition of methanol. The physical properties of all the mixes were investigated.

6.7.6. Determination of the Effect of Oil.

This investigation was carried out in a similar manner to that used for the effect of clay addition. However, in this instance the clay content of the mix was standardised at 0.5 per cent and the oil additions tested at 2, 3 and 4 per cent. These mixes were mulled for 10 minutes both with and without a 0.5 per cent addition of methanol using four different mulling temperatures. The physical properties of each mix were ascertained in the usual manner.

6.7.7. Determination of the Effect of Mould Temperature Variation.

In a previous experiment the effect of varying the testing temperature of a moulding sand was investigated, the test pieces having been rammed at the temperature of the test. This work was carried out to see how a mould would behave when temperature variations occurred after the sand had been compacted. It was considered that this information would be important in a production environment where cold sand could be rammed into a hot moulding box or hot, recycled sand might be rammed and allowed to cool before the mould was poured. The temperature variations selected for this investigation were considered to be not unlikely in a high production foundry.

Samples of the same batch of sand as was used in 6.7.2. were held at 15°C in the water-jacketted box before being formed into standard test pieces. Care was taken to ensure that all the equipment used in the preparation of the test pieces was as close to that of the sand as possible. The sand compacts were then placed in an air-circulating oven at 45°C. After sufficient time had elapsed to ensure thorough heating of the test pieces, as indicated by thermometers placed both within and on the surface of one of the pieces, they were removed individually and subjected to one of the five physical tests to be carried out. These were green compression and shear strengths, permeability, mould hardness and shatter index, the hot compression strength and flowability test both being irrelevant to this investigation.

A second experiment was carried out in a similar manner to that above to determine the effect of cooling conditions on a mould. In this instance the sand was rammed at 45°C and cooled before testing its physical properties at 15°C.

6.7.8. Determination of the Effect of Storage

In order to determine whether the properties of the mulled sand were effected by storage, some selected batches of sand were stored in a sealed container after their initial test to be retested after periods of 3 and 14 days. The mixes used for this test contained 5 per cent clay and 3per cent oil and had been mulled for varying periods of 2.5, 10 and 20 minutes, the effect of each mulling time having been examined at four different mulling temperatures. The effect of a 0.5 per cent methanol addition was also investigated on a mix which had been mulled for 10 minutes and stored under identical conditions.

6.8. Mould Production

6.8.1. Moulding Sand Preparation

The basic method described in section 6.6 was used to prepare the sand mixes for mould production. The main constituents of each mix were:

- 3.0 kg Redhill 110 sand
- 150g Organo-clay (5. per cent)
- 90g Energol EM 50 oil (3 per cent)

The mulling time was 5 minutes during the first part of which 15g

(0.5 per cent) of methanol was dripped in from the pear shaped flask attached to the plough. By preheating the muller and replacing a small proportion of the cold sand addition with sand at 200°C an average mulling temperature of approximately 30°C was maintained for each mix.

6.8.2. Moulding Machine Jolting Time

It was known that the mould hardness at the joint face increased with jolting time up to a certain value after which the mould hardness remained approximately constant. Since it was desirable for all moulds produced to have a standard mould hardness a series of experiments were conducted to find the minimum jolting time to give maximum and consistent mould hardness.

Using the basic procedure for mould production given below a series of cope moulds were produced using different jolting times and the mould hardness tested at specific points on the joint face. Since the hardness was found to increase with increasing jolting time up to about 30 seconds and remained relatively constant during subsequent jolting up to 60 seconds a period of 35 seconds was chosen as standard.

6.8.3. Moulding Practice

The cope pattern was bolted to the table of the moulding machine as shown in Fig. 15 and a 12 x 18 x 5in deep (30.5x45.7x12.7cm) box located on it with box pins. The moulding sand was warmed in an air circulating oven to approximately 30°C to ensure good strip and added loosely to the moulding box until level with the top of its

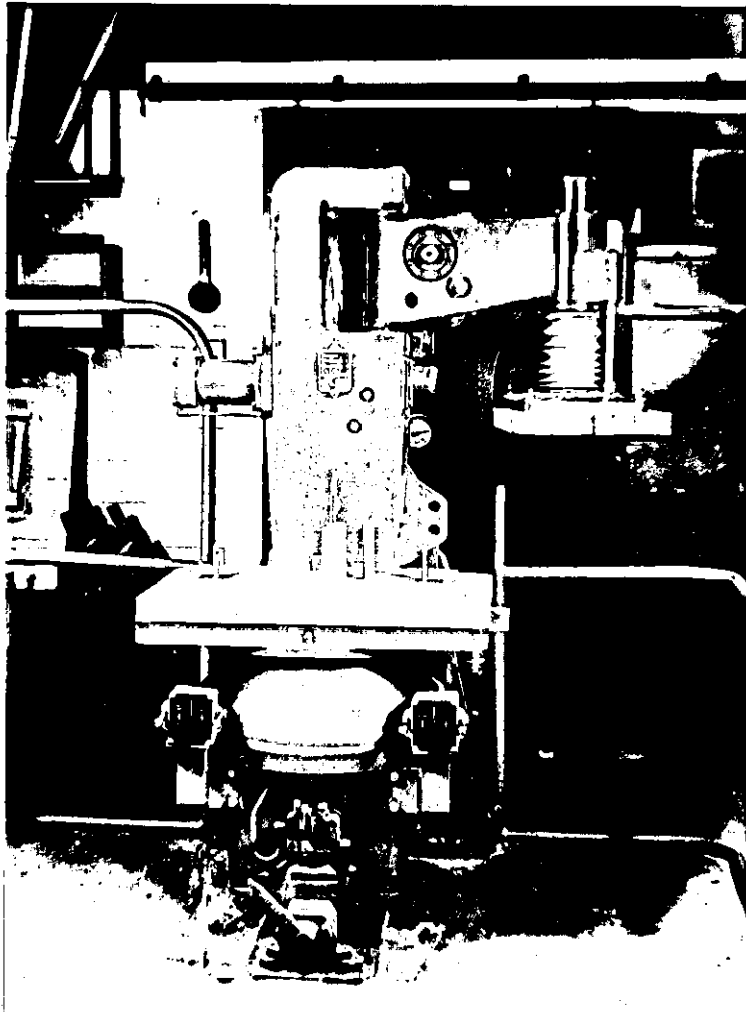


Fig. 15 The moulding machine with the cope pattern mounted prior to making the mould.

walls. The box and pattern were then jolted for 35 seconds. A frame, 3cm in height was placed on top of the box and further sand loosely packed in to a height of approximately 10 cm above the top of the frame. The squeeze action was then operated until no further compact on was noted, the frame removed and the mould strickled off. The box was rolled over, the pattern vibrated and the mould drawn. A pouring basin was hand cut in the top of the mould, its sides tapering smoothly into the sprue to prevent turbulence during the filling of the mould and the tops of the risers trimmed to prevent loose sand from falling into the mould cavity.

The drag half of the mould was produced in a 12 x 18 x 3in deep (30.5x45.7x7.6cm) box in the same manner as the cope.

6.9. Melting Practice.

6.9.1. Phosphor-bronze

The basic theory behind the two methods of melting practice for phosphor-bronze is given in the appendix.

6.9.1.1. Melting Under Oxidising conditions

About 500g of an oxidising flux based on one part of fused borax, one part of cupric oxide and one part of dry silica sand was placed in the bottom of the crucible. A total of 14kg of phosphor-bronze ingot was charged and the furnace lit, its gas to air ratio being adjusted to give an oxidising atmosphere characterised by a short green flame. Melting was continued until a

pouring temperature of 1000°C was attained at which point additional dry silica sand was added to the slag layer to thicken it, thus facilitating its removal. The crucible was lifted from the furnace, placed into a hand shank and poured into the mould as quickly as possible. This method was used to produce casting No. 1.

6.9.1.2. Melting Under Reducing Conditions

Approximately 200g of powdered charcoal was placed in the crucible to reduce the oxygen content of the furnace atmosphere at the molten metal surface. After chagging 14kg of phosphor-bronze ingot, the furnace was lit using a high gas to air ratio. During melting the charcoal cover was constantly replenished. Approximately 100°C above the intended pouring temperature the furnace was shut down and dry nitrogen bubbled through the melt using a graphite lance. After 10 minutes of this treatment the temperature was again checked and the metal cast on reaching the desired pouring temperature. Using this method two castings were poured, one at 1000°C (casting No. 2) and the other at 1100°C (casting No. 3).

6.9.2. Aluminium-magnesium

The basic theory associated with the melting practice for this alloy is given in the appendix.

The crucible was prewarmed and 100g of a proprietary flux based on magnesium chloride was added. A total of 10kg of aluminium-10 per cent magnesium alloy ingot (LM 10) was charged and melting continued using a neutral furnace flame. When the alloy reached

a plastic condition a further 300g of flux was added. On reaching a temperature of 720°C the furnace was shut down and dry nitrogen bubbled into the melt using a graphite lance. Samples of the melt were taken at approximately 3minute intervals for solidification under partial vacuum. The degassing was continued until a sample was seen to solidify with a concave top surface showing no signs of dissolved hydrogen coming out of solution during solidification. The temperature of the melt was then taken again, the flux skimmed off and the casting poured quickly.

Three castings were produced in this manner; castings No. 4, 5 and 6.

6.9.3. Cast Iron

25kg of pig iron was melted in an induction furnace to a temperature of 1450°C. The slag was skimmed off, the melt poured into a preheated ladle and immediately cast.

Castings No. 7, 8 and 9 were produced in this manner.

6.10. Recycling of the Moulding Mixture

6.10.1. Treatment of the Used Sand

After knocking out one of the phosphor-bronze castings the moulding sand was collected and fed into a Fordath core sand mixer. As the sand was mixed a small continuous flow was allowed through the discharge door which had been held slightly ajar. When the complete batch had been passed through the mixer in this manner

the process was repeated a further three times to ensure a homogenous mix free from any lumps. A 3kg sample of this sand was taken and its physical properties investigated as described in section 6.7

6.10.2. Remoulding

The mixed sand, without any further treatment, was then used to make another test mould in the same manner as described in section 6.8.3. Any shortage of sand encountered when completing the back of the drag half of the mould was made up with new sand. A further amount of new sand was added to the bin intended for collecting the knock-out sand to make a total new sand addition of 5 per cent.

6.10.3. Casting

The moulds were weighted, cast with iron at 1400°C and left to cool overnight before knocking out and recycling. A total of three castings were produced in cast iron, which together with the original phosphor-bronze casting, made a total of four casting cycles.

6.10.4. Restoration of the Used Moulding Sand Properties

Several 3kg batches of the sand collected from the mould of the fourth casting and treated in the core mixer were remulled for 5 minutes. To some of the batches 0.5 per cent additions of oil, clay and alcohol were made either singly or in combination. After studying the physical properties of these mixes and comparing the results with those of the sand before remulling, further batches were treated with carefully selected amounts of oil, clay and alcohol

in an endeavour to attain physical properties most closely approaching those of the original unused sand mix.

6.11. Casting Evaluation

6.11.1. Visual Examination

After knocking out, loose sand was removed from the surface of the castings with a soft brush, the running system removed and the casting inspected for defects particularly on the cored surface. Records were kept by means of photography.

For comparison with commercially finished castings, one of the phosphor-bronze castings was sand blasted and one in cast iron shot blasted.

6.11.2. Measurement

The castings were set up on a surface table using three adjustable jacks to place the castings in the required positions for measurement. A vernier height gauge was used to measure the vertical distances between critical points on the casting and the top of the surface table. Using this method the dimensions of the castings could be found to the nearest 0.1mm.

In addition, each casting was weighed to the nearest gramme.

6.11.3. Internal Inspection

To investigate the internal soundness of the castings one each of the alloys was sawn in half at right angles to the axis

of the 2 x 2 in cored cavity. The cut surfaces were rubbed down, inspected and photographed.

CHAPTER 7

EXPERIMENTAL RESULTS AND OBSERVATIONS

7. EXPERIMENTAL RESULTS AND OBSERVATIONS.

7.1. Clay Purity

The free water impurities of the Na bentonite clay were tested twice during the period of research and the results are given in Table 1.

The results of the first test, headed batches 1234, were obtained just prior to the first series of large scale modifications of the clay and just after the small scale experimental clay modifications. The 11.80 per cent average of the three results obtained during this test were therefore applied to both the small and the first of the large scale modification calculations.

The second test was made towards the end of the research period, just before the final series of modifications. The results of this test, given under the heading of batches 56789, yielded an average free water content of 12.33 per cent. The difference in the two average results was probably due to the change in humidity conditions prevailing in the clay storage area during the period of research.

7.2. The Cation Exchange Capacity of the Clay

The detailed results of the three Methylene Blue tests carried out to determine the cation exchange capacity of the clay are given in the appendix (Table (i)). Using the formula 6.2 these results were used to calculate the cation exchange capacities of the Na bentonite which are shown, together with their average, in Table 2. It was considered that, whilst the results of each test differed

Table 1

Na BENTONITE MOISTURE CONTENT _____ (PER CENT)

BATCH No.s	1,2,3,4	5,6,7,8,9
SAMPLE No. 1	11.77	12.25
2	11.75	12.41
3	11.88	12.32
AVERAGE	11.80	12.33

Table 2

CATION EXCHANGE CAPACITY OF Na BENTONITE — (Meq/100 g CLAY)
 RESULTS ACCORDING TO THE METHYLENE BLUE METHOD

SAMPLE No. 1	99.38
2	98.46
3	98.16
AVERAGE	98.67

slightly, their reproducibility was as good as the experimental procedure permitted and that the average result obtained was sufficiently accurate to be used in the necessary calculations for the modification process.

7.3. Quaternary Ammonium Compound Purity

Because of the highly volatile nature of the propan-2-ol impurity in the quaternary ammonium compound a series of four tests to determine the impurities was carried out immediately before each period of use. The results of those tests carried out prior to the small scale experimental work are given in Table 3 whilst those made before the production of batches 1-4 and 5-9 of organo-clay are given in Table 4.

The four results from each test made to find the combined water and propan-2-ol content have been averaged. The percentage of NaCl impurity, as obtained from the suppliers of the quaternary ammonium compound, was taken as being constant throughout its period of use and was added on to the average result to give the total percentage of impurities in the compound.

7.4. The Effect of Modification Conditions

The effects of using a low speed and high speed stirrer in the modification process and the necessity of using a Na_2CO_3 treatment on the clay dispersion prior to modification were tested by carrying out a loss-on-ignition on the organo-clay produced. These results are given in the appendix (Table (ii)) and have been converted to units of Meq/100g of clay using the formula 6.5 for use in Table 5.

Table 3

QUATERNARY AMMONIUM COMPOUND IMPURITIES _____ (PER CENT)

SMALL SCALE EXPERIMENTAL WORK

PROPAN-2-OL AND WATER		
SAMPLE No.	1	20.65
	2	20.74
	3	20.67
	4	20.40
AVERAGE		20.62
SODIUM CHLORIDE		0.50
TOTAL IMPURITIES		21.12

Table 4

QUATERNARY AMMONIUM COMPOUND IMPURITIES _____ (PER CENT)

BATCH No.s	1,2,3,4	5,6,7,8,9
PROPAN-2-OL AND WATER		
SAMPLE No. 1	18.14	16.19
2	18.15	16.15
3	17.89	15.68
4	18.05	16.10
AVERAGE	18.06	16.03
SODIUM CHLORIDE	0.50	0.50
TOTAL IMPURITIES	18.56	16.53

Table 5

RETENTION OF DDA⁺ BY Na BENTONITE _____ (Meq/100 g CLAY)
EFFECT OF REACTION CONDITIONS

DDAC ADDITION: 89.42 Meq/100 g CLAY

SAMPLE No.	1	2	AVERAGE
USING LOW SPEED STIRRER	90.00	90.06	90.03
USING HIGH SPEED STIRRER	91.13	90.92	91.03
WITHOUT Na ₂ CO ₃ PRE-TREATMENT	91.28	91.41	91.35

Table 6

RETENTION OF DDA⁺ BY Na BENTONITE _____ (Meq/100 g CLAY)
EFFECT OF VARYING DDAC ADDITIONS

SAMPLE No.	1	2	AVERAGE
DDAC ADDITION 22.35	23.78	23.81	23.80
44.71	45.55	45.58	45.57
67.06	67.18	67.21	67.20
89.42	90.00	90.06	90.03
134.13	135.21	135.16	135.19
178.84	158.32	159.02	158.67
(Meq/100 g CLAY) 223.54	158.59	158.46	158.53

From this table it can be seen that slightly more organic cations were retained than were added. This can most probably be attributed to the limitations in accuracy in determining the purity of the Na bentonite, the purity of the quaternary ammonium compound and the loss-on-ignition of the modified clay.

The results would suggest that little advantage was to be gained by using a high shear mixing action for the modification process and indeed, since considerable difficulty was experienced with excessive foam production under these conditions this method held distinct disadvantages. Further modification was therefore undertaken using a relatively low speed stirring action.

The use of a sodium carbonate pre-treatment upon the clay was also found to be of no advantage and the procedure was therefore abandoned.

7.5. The Modification Characteristics of the Clay

The degree of modification of a clay was ascertained by carrying out loss-on-ignition tests on the modified clay and the results are given in the appendix (Table (iii)). By using the formula 6.5 however, these results have been converted into the more useful units of Meq/100g of clay and appear in Table 6. This shows the retention of the organic cation and/or molecule by the Na bentonite as successively larger amounts of the organic compound were used in the modification process.

It would appear from the results that slightly more organic cation was retained than supplied. This same phenomenon was also reported in 7.4 and its cause may be attributed to the same limitations of accuracy stated in that section.

A graphical representation of the results obtained is shown in Fig. 16. The point at which the organic compound ceased to be adsorbed is represented by the point of intersection of the extrapolated lines on the graph; approximately 158 Meq/100g of clay. From the limited number of results obtained, however, it is impossible to state whether this sharp cessation of adsorption takes place as the amount of organic reagent is increased. For this reason the graph around the area of non-stoichiometric character is represented by a dotted line.

The results of this work served two useful functions with regard to subsequent bulk modification processes. The first was to confirm that the reaction between Na bentonite and DDAC proceeded in a stoichiometric manner, 1 Meq of DDAC giving up exactly 1 Meq of DDA^+ to the clay. The amount of reagent necessary to achieve complete cation exchange could thus be calculated accordingly.

The second function of this experiment was to see if the reaction ceased completely at the cation exchange capacity, thus permitting the use of slight excesses of the reagent to ensure complete modification. This proved not to be the case and confirmed the findings of Grim et al⁽¹⁴⁾. Further it was found that the use

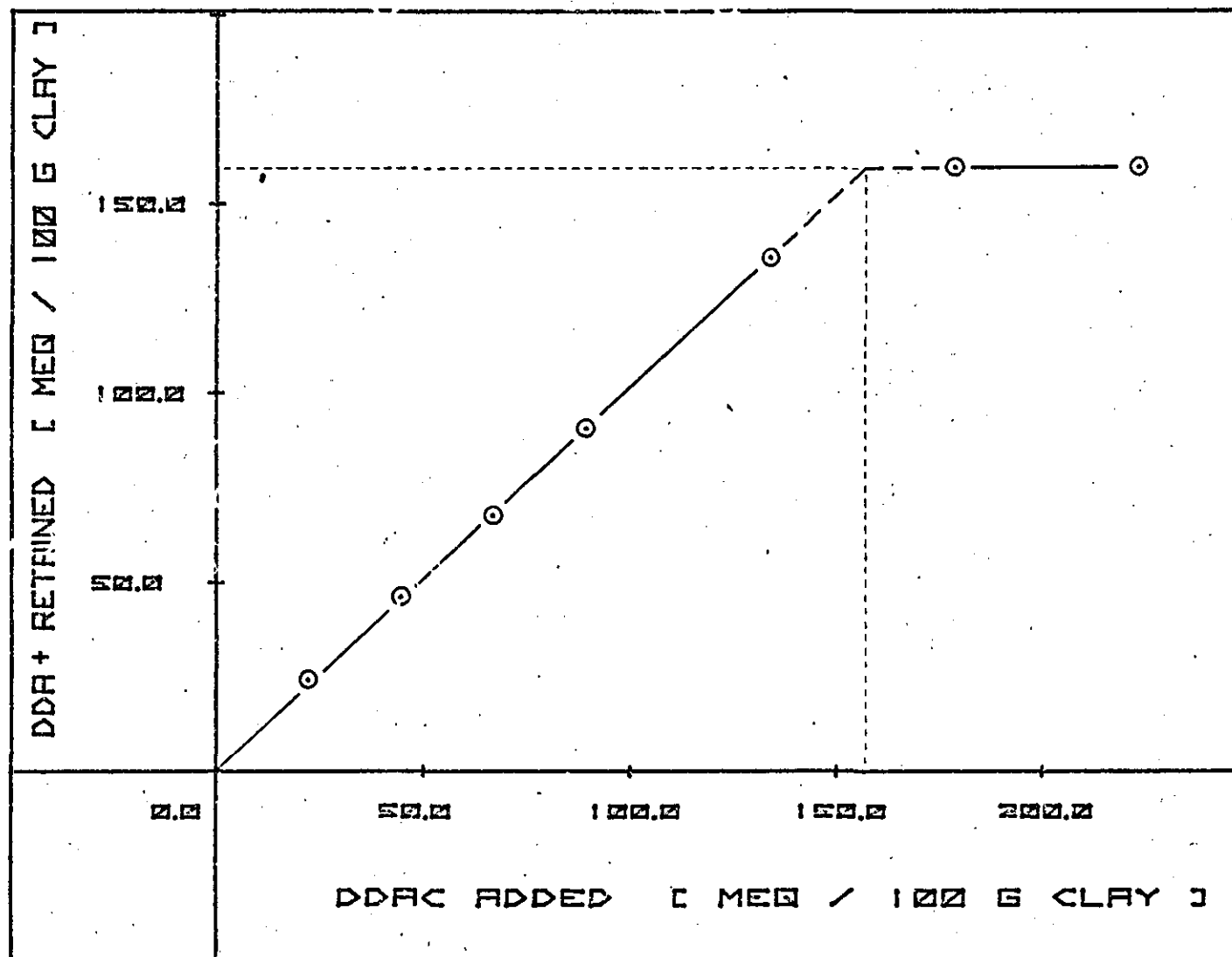


Fig. 16 Graph of the retention of organic cations and molecules by Na bentonite.

of excess reagent severely impaired the filtering process as was suggested by Jordan⁽⁹⁾. Thus, it was proved essential to add the exact amount of reagent as dictated by the cation exchange capacity.

7.6. Degree of Modification of Batch Produced Organo-clay.

The degree to which the batch produced clay had been modified was, as in previous cases, determined by the loss-on-ignition technique and the results are given in the appendix (Table(iv)). Table 7 shows these results expressed in units of Meq/100g of clay using formula 6.5. The average number of Meq/100g of clay retained by each batch varied slightly. Since, however, the batches were subsequently mixed together for grinding purposes to form two large lots of clay comprising batch numbers 1 - 4 and 5 - 9, the combined averages of these lots has also been shown on this table. It was considered that these figures were close enough to the desired retention of 98.67 Meq/100g of clay as to make little difference to the subsequent properties of the clay when used as a bonding medium for the moulding sand.

7.7. Physical Properties of the Moulding Mixtures

7.7.1. The Units

In general, seven physical properties have been quoted for each sand mixture tested. Of these, the permeability, mould hardness and flowability have been recorded directly from the apparatus on which they were obtained whilst the shatter index was calculated as described in appendix A(vii). The green compression strength, green shear strength and hot compression strength have

Table 7

RETENTION OF DDA⁺ BY Na BENTONITE _____ (Meq/100 g CLAY)
 LARGE SCALE PRODUCTION

SAMPLE No.	1	2	3	4	AVERAGE
BATCH No. 1	97.72	98.06	97.11	97.05	97.49
2	98.55	98.32	98.60	98.57	98.51
3	94.80	95.02	94.59	94.71	94.78
4	95.80	95.79	95.82	95.68	95.76
AVERAGE					96.64
5	98.73	100.63	100.67	100.01	100.01
6	98.59	99.05	99.16	99.11	98.98
7	97.23	96.29	97.16	97.25	96.98
8	95.32	95.57	95.46	95.53	95.47
9	95.19	94.78	94.78	95.21	94.99
AVERAGE					97.29

all been recorded in SI units having first been converted from, in the first two cases, lb/in² and in the latter case kg/cm².

It should be noted that all these tests have been based on the 2in x 2in test piece and that the results, despite being quoted in metric form, cannot be directly compared to results obtained using 50mm x 50mm test pieces formed on metrically designed equipment.

7.7.2. Effect of Mulling Temperature

Because of the temperature sensitivity of the sand mixes the effect of mulling temperature was recorded for all the variables of clay, oil, mulling time and polar additive. The results are given in Tables (v)-(xx) inclusive, each table showing the physical properties of one particular mix mulled at four different mulling temperatures. Using these results sets of graphs have been drawn, each set illustrating the effect of mulling temperature upon one of the physical properties at various clay, oil and polar additive contents and after different mulling times. These graphs are shown in the appendix in Figs (i)-(vii). From these the following effects of mulling temperature have been noted:

Green Compression Strength:

For a standard mulling time the green compression strength of a sand mix was increased by employing increasing mulling temperatures. A maximum strength for any mix not containing polar additives was generally achieved when using temperatures of approximately

40 - 45°C whereas, by using 0.5 per cent methanol maximum strengths were obtained at temperatures in the range 30-35°C.

When working below these temperatures considerable reductions in strength were experienced whilst it was found that little was gained by using mulling temperatures above these ranges.

Green Shear Strength:

This property exhibited a similar relationship with mulling temperature to that described above for green compression strength and reached maximum values within the same temperature ranges. However, mixes with a high clay content containing 0.5 per cent methanol had a tendency toward increased green shear strength as mulling temperatures above 35°C were employed.

Hot Compression Strength:

Despite this test being carried out at high temperature, the results still show a dependence upon the mulling temperature, increasing mulling temperatures tending to give increased hot compression strength. The temperature ranges giving maximum values are not as clearly defined as with green compression and shear strengths, low clay/oil ratio mixes exhibiting maximum strengths at much lower temperatures than the high clay/oil ratio mixes. In general however, the use of

0.5 per cent methanol reduced the mulling temperature required to achieve maximum hot compression strength. There would appear to be a definite tendency, particularly in the absence of a polar additive, for high mulling temperatures to yield sand mixes of strengths below the maximum possible.

Permeability:

The variations in permeability took place over a very limited range and thus no great significance can be placed upon the trends found. The greatest effect of mulling temperature was found with sand mixes having a high clay/oil ratio, the higher the mulling temperature, the greater the permeability.

Mould Hardness:

The results of this test were, as might have been expected, closely analogous to those obtained for green compression and shear strength. The mould hardness of a sand mix was increased by the use of higher mulling temperatures. Maximum values were recorded in the 40-45°C temperature range in the absence of a polar additive whilst the use of 0.5 per cent methanol substantially decreased the temperature required to obtain similar results to about 30°C. These trends were noted for all mulling periods tested.

Shatter Index:

This property was also increased by the use of higher mulling temperatures. It would appear however, that maximum values were not closely related to any specific mulling temperature range. The effect of mulling temperature was noted at all the mulling times tested.

Flowability:

Flowability was generally decreased by the use of increasing mulling temperatures especially in mixes of high clay content. Mixes having a low clay content were relatively unaffected by temperature.

It would appear from these results that in order to fully develop the clay-oil bond to its maximum strength as tested at both high and low temperatures, mulling temperatures in the range of 40-50°C must be employed. The use of 0.5 per cent methanol, however, reduced the necessary heat energy, optimum properties being developed in the 30-35°C range. Under these conditions values of shatter index could be achieved close to the maximum thus ensuring a reasonably tough sand mix. As would be expected, as the strength of the mix was increased, the flowability decreased. However, since even the minimum values obtained represented moulding mixtures of relatively high flowability this effect would be of little detriment.

7.7.3. Effect of Mulling Time

In order to study the effect of mulling time upon the physical properties of the sand mixes, variations due to mulling temperature had to be taken into account. Since the mulling temperature could not be controlled sufficiently accurately to allow each mix to be mulled at a specific temperature results have had to be derived from the curves in Figs (i)-(vii) e and f showing the variation of properties over a range of temperatures.

Three temperatures were selected; 25, 35 and 45°C and the effects of mulling time upon the physical properties are shown together with other variables in Tables 8 - 14. From these results graphs have been drawn as shown in Figs. 17-23, each figure showing the effect of mulling time on one particular physical property at three different mulling temperatures both in the absence of a polar additive and when using an addition of 0.5 per cent methanol.

Green Compression Strength:

The rate of increase of green compression strength with mulling time was found to be dependent upon the mulling temperature and the presence of methanol in the mix. Relatively slow rates of increase were evident when mixes without polar additive were mulled at low temperatures. By increasing the temperature of this type of mix higher rates of strength development were recorded, a maximum value being obtained after about 8 minutes mulling. The use of 0.5 per cent

GREEN COMPRESSION STRENGTH _____ (N/m² x 10³)

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)	25.0	35.0	45.0
POLAR ADDITIVE			
CONTENT			
0.0	37.5	57.0	67.0
0.5	63.5	70.0	69.0
1.0	67.0	74.0	72.0
(PER CENT)	2.0	70.5	75.0
		72.0	

MIXES WITHOUT POLAR ADDITIVE

MULLING TIME	2.5	22.5	50.5	58.0
	10.0	37.5	57.0	67.0
(MIN)	20.0	36.0	58.0	67.0
CLAY CONTENT	3.0	17.0	25.5	33.0
	5.0	37.5	57.0	67.0
(PER CENT)	7.0	61.5	85.0	90.0
OIL CONTENT	2.0	40.0	60.0	65.5
	3.0	37.5	57.0	67.0
(PER CENT)	4.0	36.0	55.5	65.0

MIXES WITH 0.5 PER CENT POLAR ADDITIVE

MULLING TIME	2.5	64.0	70.5	68.5
	10.0	63.5	70.0	69.0
(MIN)	20.0	59.5	68.0	70.5
CLAY CONTENT	3.0	30.0	35.0	34.5
	5.0	63.5	70.0	69.0
(PER CENT)	7.0	93.0	97.0	98.0
OIL CONTENT	2.0	60.5	67.0	67.5
	3.0	63.5	70.0	69.0
(PER CENT)	4.0	56.5	65.5	65.0

GREEN SHEAR STRENGTH _____ (N/m² x 10³)

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)		25.0	35.0	45.0
POLAR ADDITIVE CONTENT	0.0	8.6	13.8	16.1
	0.5	14.5	15.1	16.2
	1.0	13.4	15.9	16.0
	(PER CENT) 2.0	15.6	16.2	16.0

MIXES WITHOUT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	4.7	11.6	13.5
	10.0	8.6	13.8	16.1
	20.0	9.8	14.2	16.2
CLAY CONTENT (PER CENT)	3.0	3.7	6.4	8.0
	5.0	8.6	13.8	16.1
	7.0	14.2	20.3	21.3
OIL CONTENT (PER CENT)	2.0	7.9	12.0	14.7
	3.0	8.6	13.8	16.1
	4.0	7.8	13.7	16.8

MIXES WITH 0.5 PER CENT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	15.3	17.8	15.3
	10.0	14.5	15.1	16.2
	20.0	15.9	15.4	17.3
CLAY CONTENT (PER CENT)	3.0	7.7	8.9	8.5
	5.0	14.5	15.1	16.2
	7.0	19.2	21.4	22.9
OIL CONTENT (PER CENT)	2.0	13.9	14.2	14.7
	3.0	14.5	15.1	16.2
	4.0	15.6	17.8	17.6

HOT COMPRESSION STRENGTH _____ (N/m² x 10³)

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT) 5.0
 OIL CONTENT (PER CENT) 3.0
 MULLING TIME (MIN) 10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)		25.0	35.0	45.0
POLAR ADDITIVE CONTENT	0.0	242.0	285.0	300.0
	0.5	270.0	297.0	268.0
	1.0	219.0	261.0	266.0
	(PER CENT) 2.0	254.0	295.0	318.0

MIXES WITHOUT POLAR ADDITIVE

MULLING TIME	2.5	244.0	250.0	259.0
	10.0	242.0	285.0	300.0
	(MIN) 20.0	243.0	255.0	322.0
CLAY CONTENT	3.0	167.0	203.0	182.0
	5.0	242.0	285.0	300.0
	(PER CENT) 7.0	365.0	428.0	445.0
OIL CONTENT	2.0	252.0	354.0	384.0
	3.0	242.0	285.0	300.0
	(PER CENT) 4.0	296.0	311.0	304.0

MIXES WITH 0.5 PER CENT POLAR ADDITIVE

MULLING TIME	2.5	242.0	292.0	267.0
	10.0	270.0	297.0	268.0
	(MIN) 20.0	332.0	340.0	333.0
CLAY CONTENT	3.0	186.0	188.0	192.0
	5.0	270.0	297.0	268.0
	(PER CENT) 7.0	368.0	402.0	414.0
OIL CONTENT	2.0	275.0	313.0	320.0
	3.0	270.0	297.0	268.0
	(PER CENT) 4.0	282.0	307.0	304.0

Table 11

PERMEABILITY _____ (SMALL ORIFICE)

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)		25.0	35.0	45.0
POLAR ADDITIVE CONTENT	0.0	18.6	19.2	20.1
	0.5	18.8	18.8	20.1
	1.0	18.8	19.5	20.2
	(PER CENT) 2.0	19.7	20.6	20.8

MIXES WITHOUT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	19.5	17.9	18.3
	10.0	18.6	19.2	20.1
	20.0	21.3	20.4	18.2
CLAY CONTENT (PER CENT)	3.0	21.2	20.5	20.3
	5.0	18.6	19.2	20.1
	7.0	19.3	22.1	20.0
OIL CONTENT (PER CENT)	2.0	19.8	22.2	22.4
	3.0	18.6	19.2	20.1
	4.0	17.6	17.5	18.4

MIXES WITH 0.5 PER CENT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	23.7	24.0	25.0
	10.0	18.8	18.8	20.1
	20.0	20.0	20.2	20.5
CLAY CONTENT (PER CENT)	3.0	21.1	21.1	21.4
	5.0	18.8	18.8	20.1
	7.0	20.6	20.9	21.0
OIL CONTENT (PER CENT)	2.0	20.4	23.6	24.1
	3.0	18.8	18.8	20.1
	4.0	17.2	17.3	17.2

Table 12

MOULD HARDNESS _____ (C SCALE)

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)		25.0	35.0	45.0
POLAR ADDITIVE CONTENT	0.0	21.5	26.0	27.5
	0.5	27.5	28.5	28.0
	1.0	28.0	29.0	29.0
	(PER CENT) 2.0	28.5	28.5	27.5

MIXES WITHOUT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	12.0	26.0	28.0
	10.0	21.5	26.0	27.5
	20.0	15.0	25.0	27.0
CLAY CONTENT (PER CENT)	3.0	8.5	13.5	16.0
	5.0	21.5	26.0	27.5
	7.0	27.5	32.0	31.5
OIL CONTENT (PER CENT)	2.0	20.0	25.0	27.0
	3.0	21.5	26.0	27.5
	4.0	17.5	25.5	28.0

MIXES WITH 0.5 PER CENT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	28.0	29.0	27.5
	10.0	27.5	28.5	28.0
	20.0	26.5	28.0	26.5
CLAY CONTENT (PER CENT)	3.0	15.0	17.5	17.0
	5.0	27.5	28.5	28.0
	7.0	33.5	32.5	32.0
OIL CONTENT (PER CENT)	2.0	25.5	26.0	26.0
	3.0	27.5	28.5	28.0
	4.0	25.5	28.0	27.0

Table 13

SHATTER INDEX

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)		25.0	35.0	45.0
POLAR ADDITIVE CONTENT (PER CENT)	0.0	58.5	65.0	66.5
	0.5	67.0	73.5	59.0
	1.0	66.0	67.0	64.0
	2.0	69.0	71.0	67.0
MIXES WITHOUT POLAR ADDITIVE				
MULLING TIME (MIN)	2.5	40.0	49.0	50.5
	10.0	58.5	65.0	66.5
	20.0	67.0	76.5	67.0
CLAY CONTENT (PER CENT)	3.0	51.0	62.5	68.0
	5.0	58.5	65.0	65.5
	7.0	58.0	66.0	65.0
OIL CONTENT (PER CENT)	2.0	36.0	39.5	42.0
	3.0	58.5	65.0	66.5
	4.0	74.0	88.0	86.5
MIXES WITH 0.5 PER CENT POLAR ADDITIVE				
MULLING TIME (MIN)	2.5	69.0	70.0	68.5
	10.0	67.5	74.0	69.5
	20.0	76.0	72.5	68.5
CLAY CONTENT (PER CENT)	3.0	68.0	70.0	68.5
	5.0	67.5	74.0	69.5
	7.0	66.0	65.0	62.0
OIL CONTENT (PER CENT)	2.0	44.0	40.5	40.0
	3.0	67.5	74.0	69.5
	4.0	86.5	95.5	89.5

Table 14

FLOWABILITY _____ (PER CENT)

EFFECT OF POLAR ADDITIVE, MULLING TIME, CLAY AND OIL CONTENT

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0

EXCEPT WHERE OTHERWISE STATED IN THE TABLE

MULLING TEMPERATURE (°C)		25.0	35.0	45.0
POLAR ADDITIVE CONTENT	0.0	84.0	80.5	78.5
	0.5	82.0	79.0	80.5
	1.0	82.0	79.5	79.0
	(PER CENT) 2.0	61.5	79.0	79.0

MIXES WITHOUT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	83.0	80.5	80.0
	10.0	84.0	80.5	78.5
	20.0	87.0	84.0	79.5
CLAY CONTENT (PER CENT)	3.0	86.5	87.0	85.5
	5.0	84.0	80.5	78.5
	7.0	81.5	75.5	72.0
OIL CONTENT (PER CENT)	2.0	84.5	81.5	80.5
	3.0	84.0	80.5	78.5
	4.0	84.5	82.0	80.5

MIXES WITH 0.5 PER CENT POLAR ADDITIVE

MULLING TIME (MIN)	2.5	81.0	79.0	78.0
	10.0	82.0	79.0	80.5
	20.0	81.5	80.0	81.0
CLAY CONTENT (PER CENT)	3.0	86.0	86.0	86.0
	5.0	82.0	79.0	80.5
	7.0	79.5	73.5	73.0
OIL CONTENT (PER CENT)	2.0	82.5	80.0	79.0
	3.0	82.0	79.0	80.5
	4.0	82.5	79.5	81.0

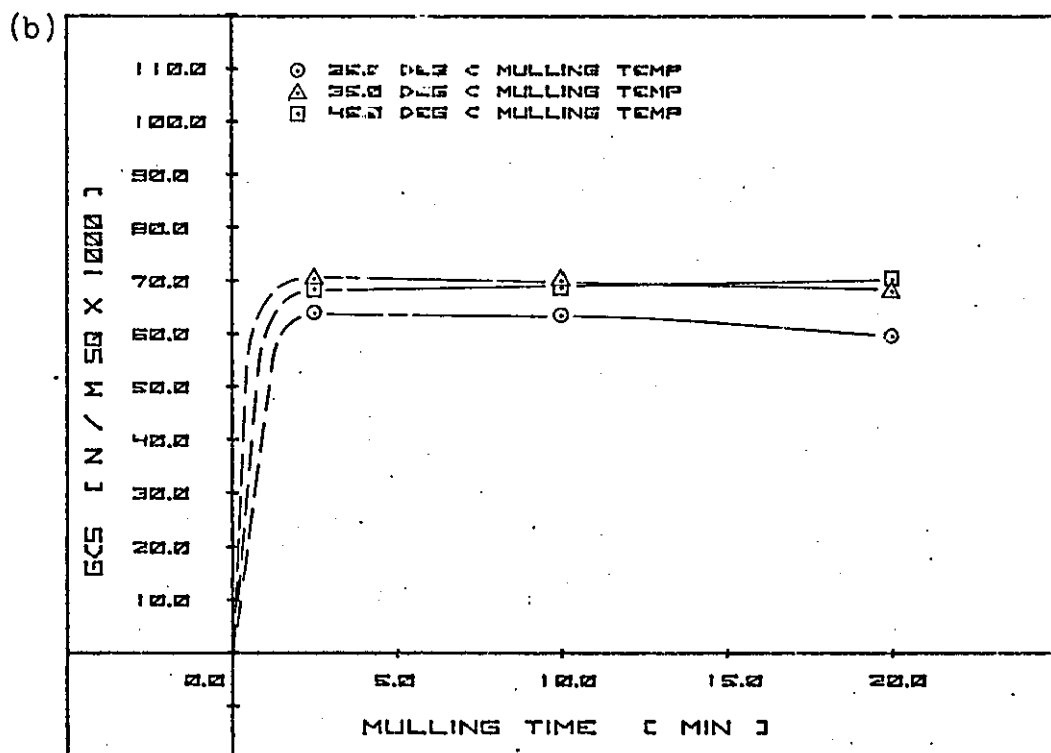
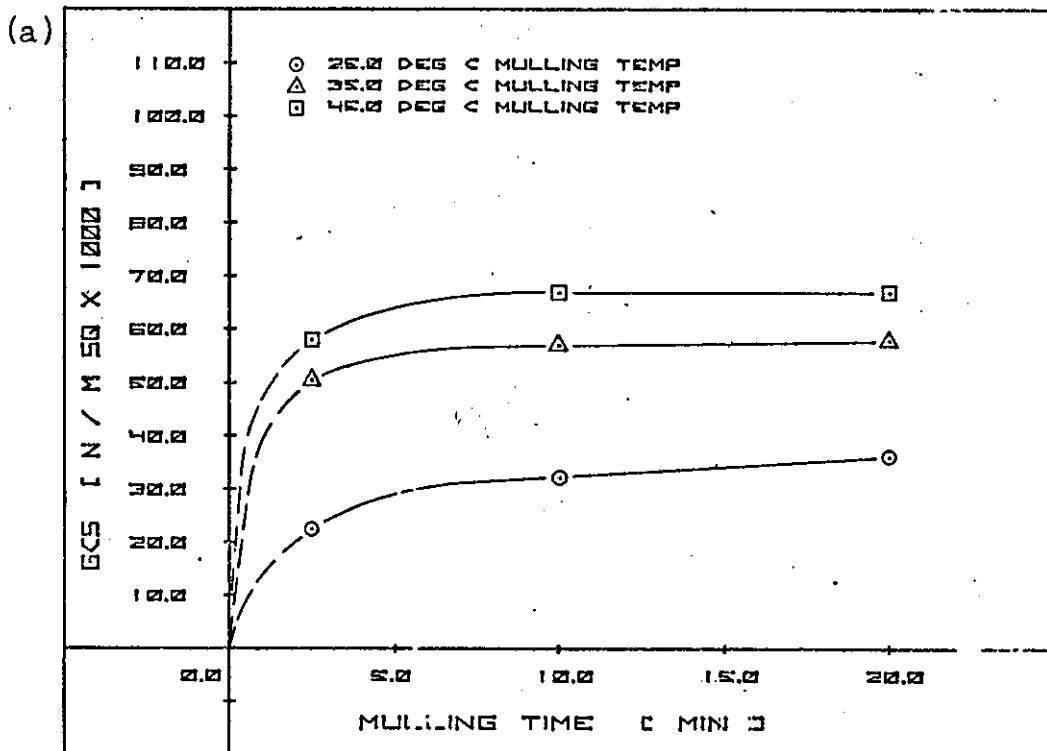


Fig. 17 Effect of mulling time on green compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

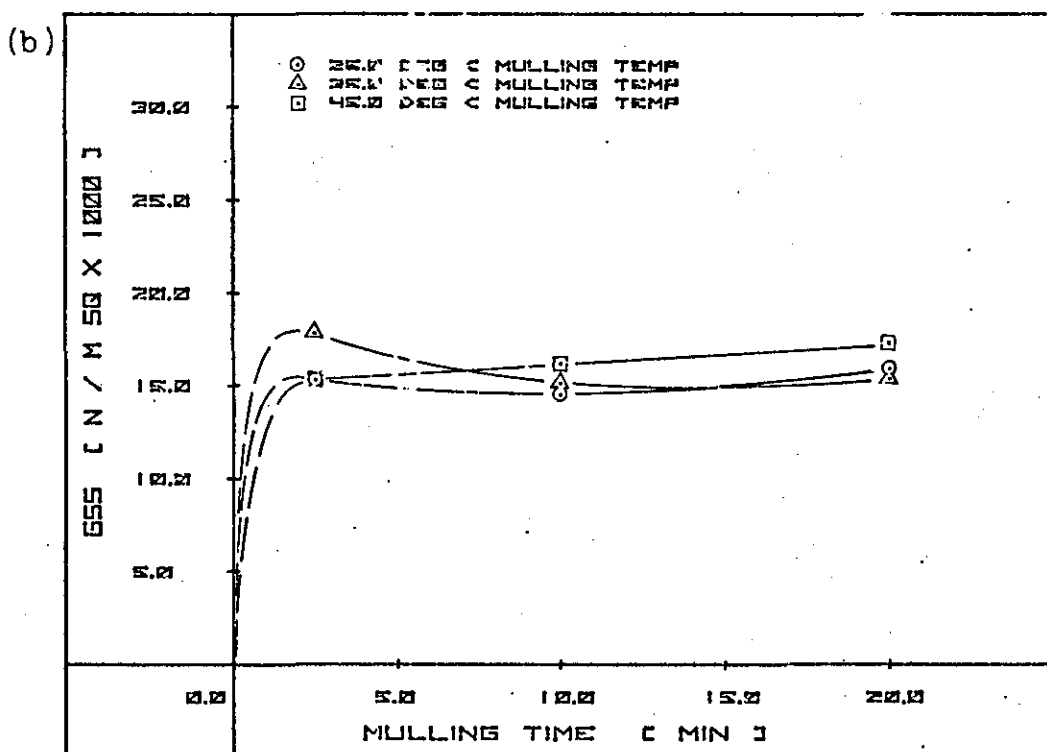
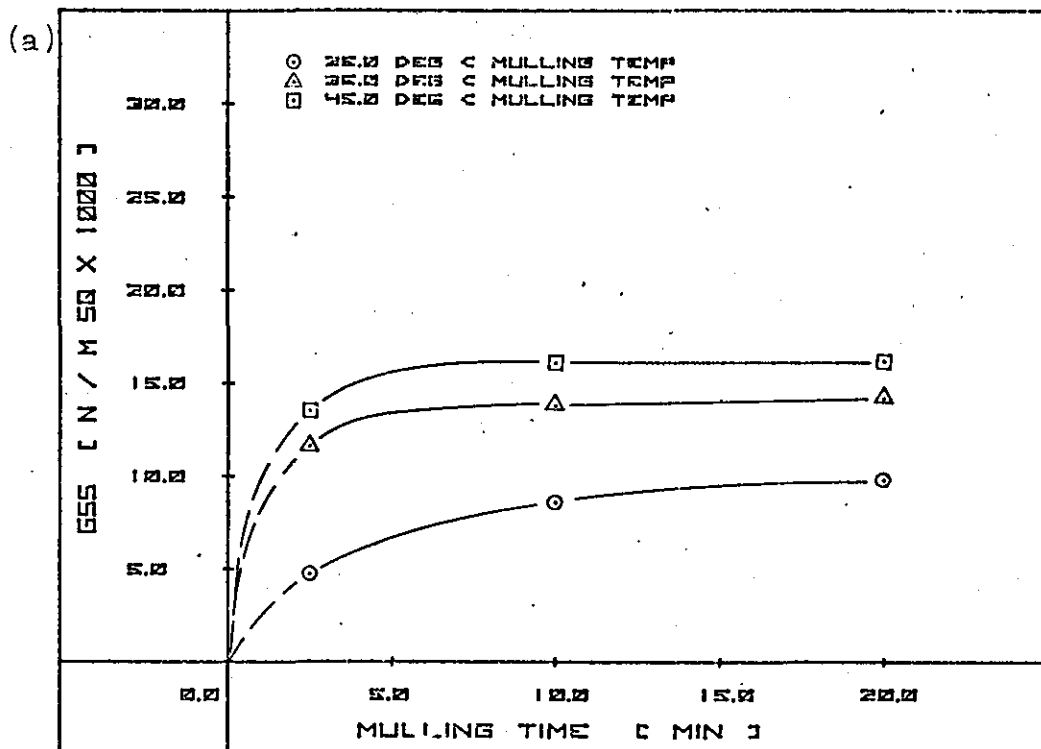
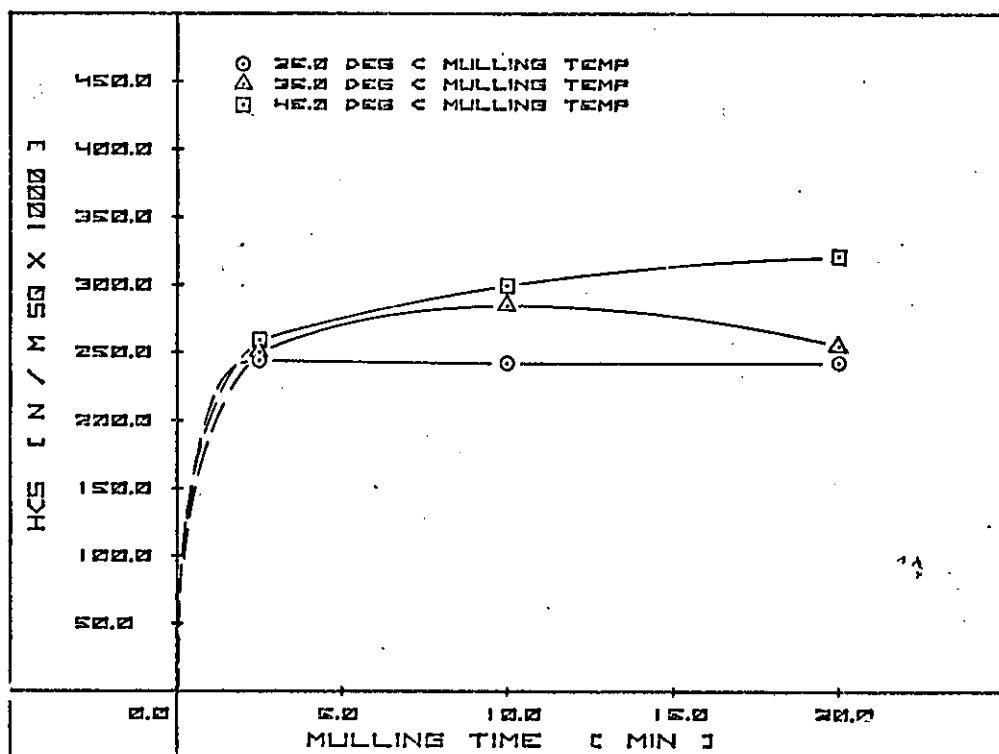


Fig. 18 Effect of mulling time on green shear strength, (a) without polar additive, (b) with 0.5 per cent methanol.

(a)



(b)

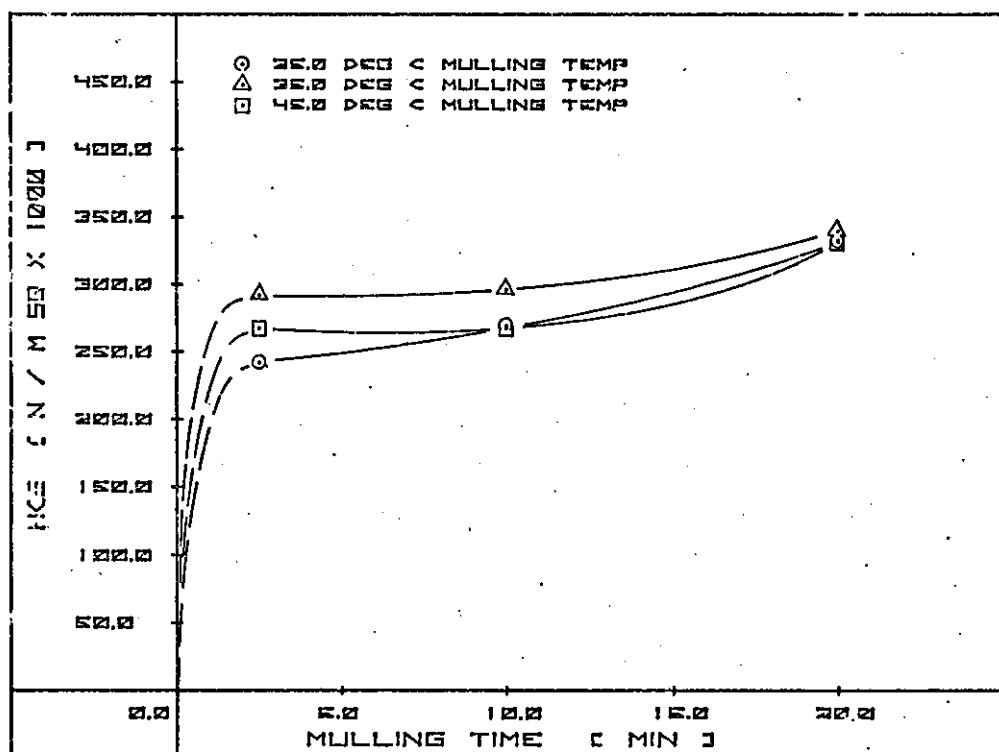
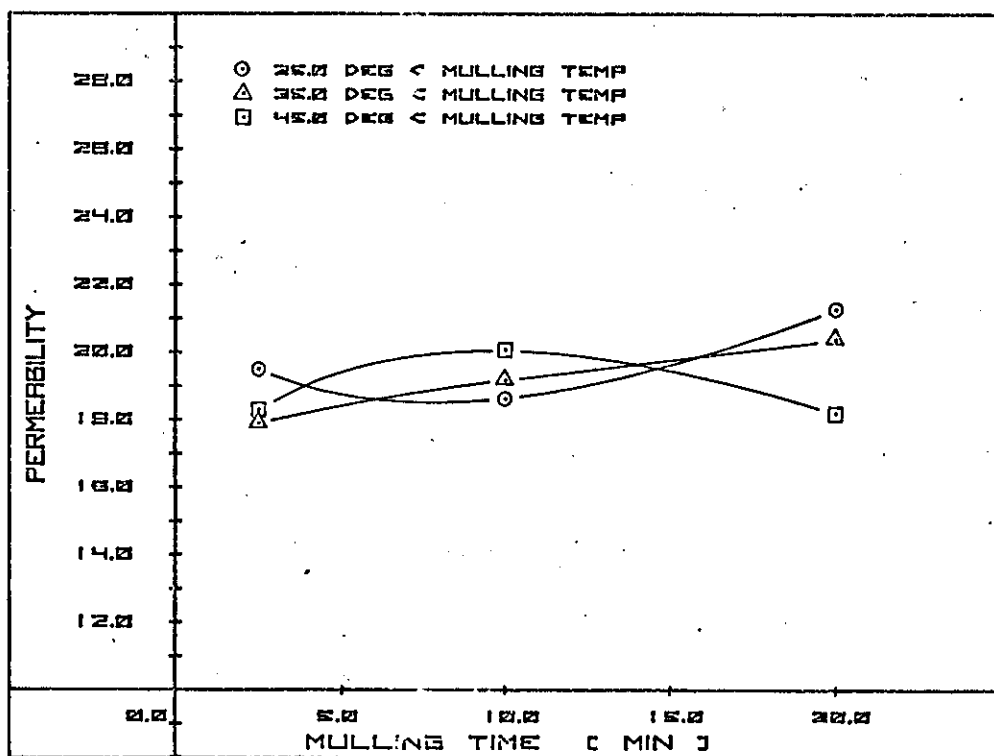


Fig. 19 Effect of mulling time on hot compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

(a)



(b)

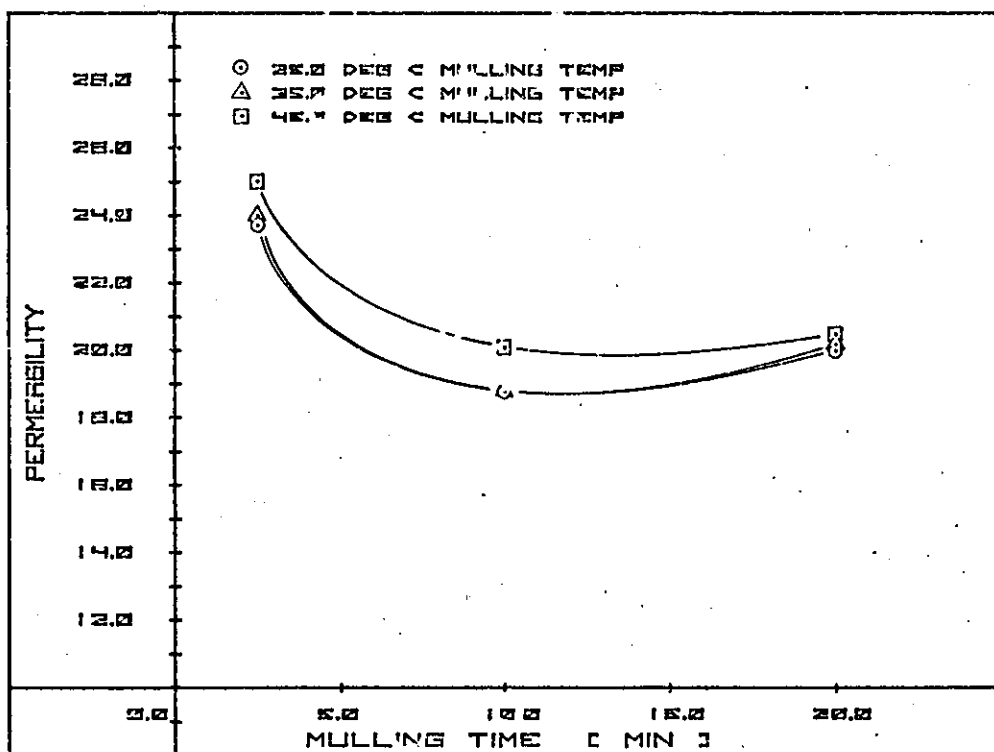
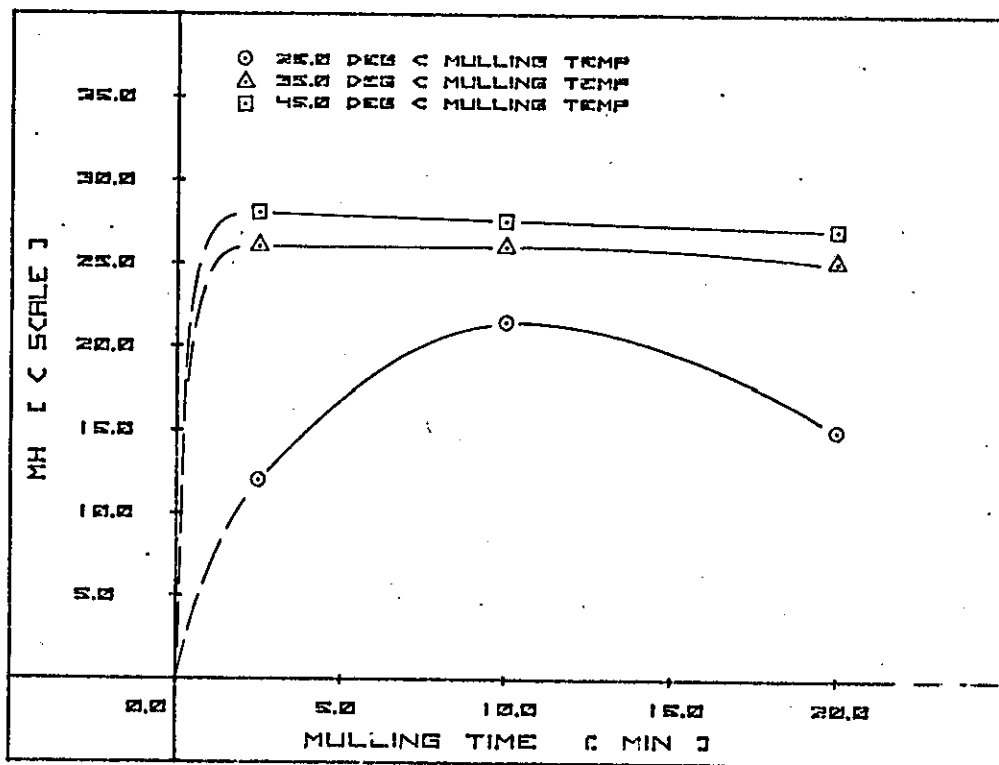


Fig. 20 Effect of mulling time on permeability, (a) without polar additive, (b) with 0.5 per cent methanol.

(a)



(b)

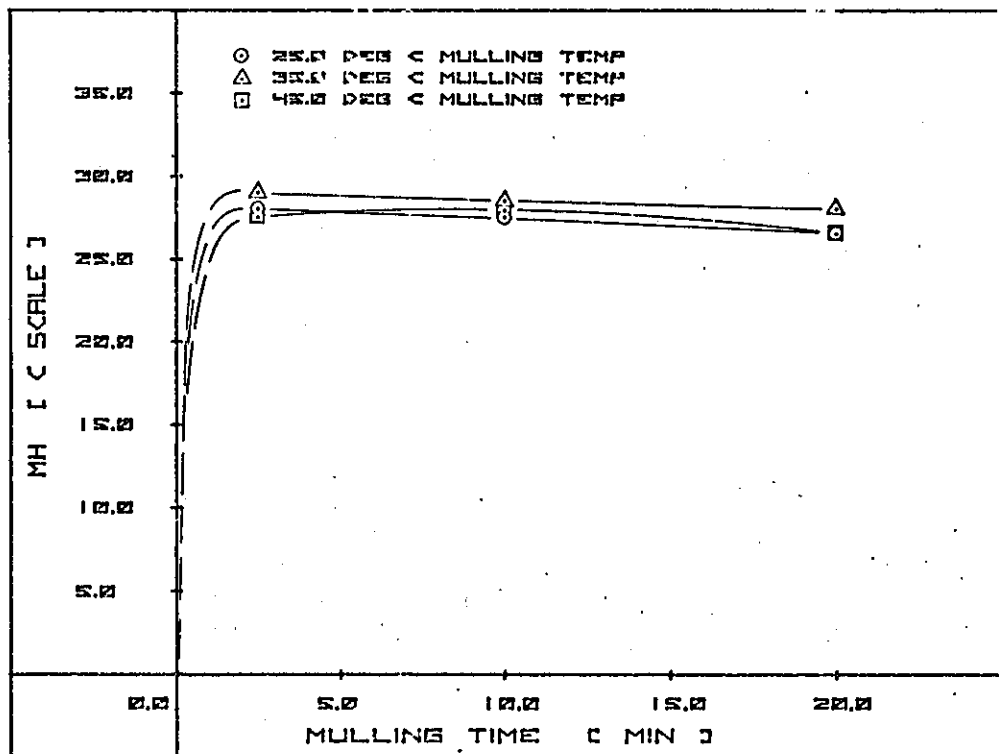
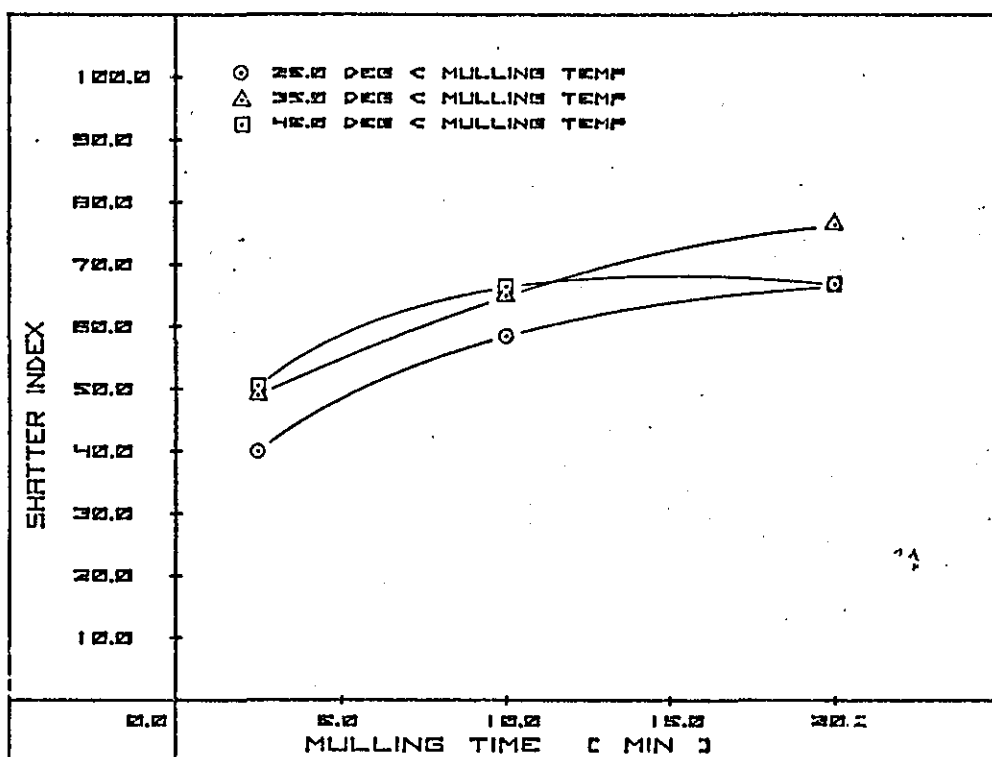


Fig. 21 Effect of mulling time on mould hardness, (a) without polar additive, (b) with 0.5 per cent methanol.

(a)



(b)

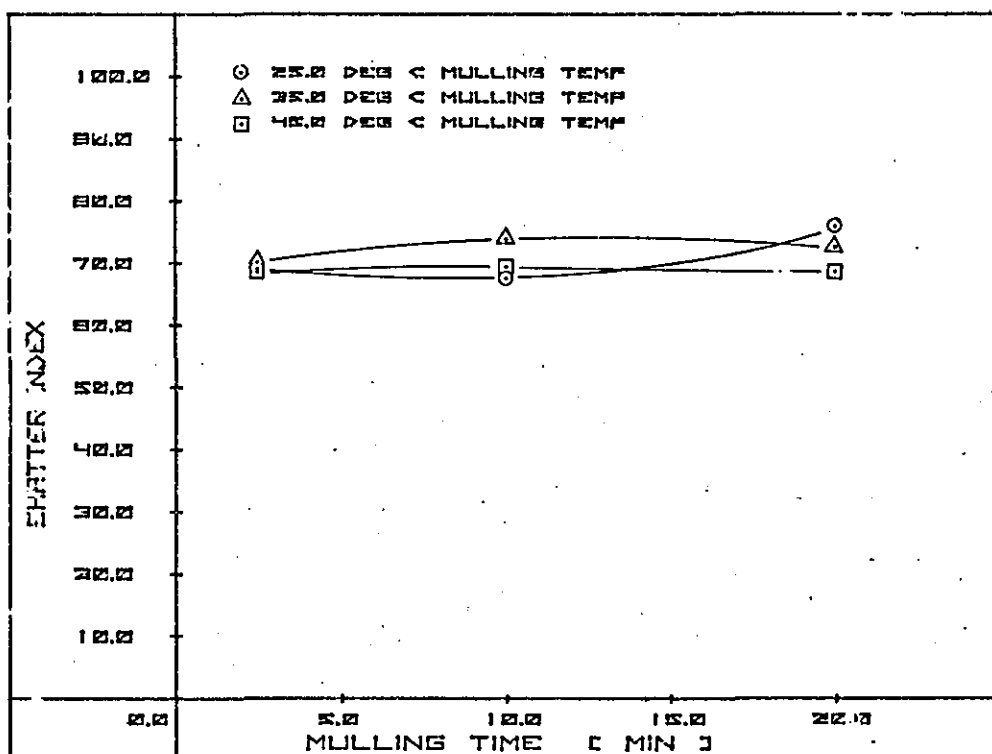


Fig. 22 Effect of mulling time on shatter index, (a) without polar additive, (b) with 0.5 per cent methanol.

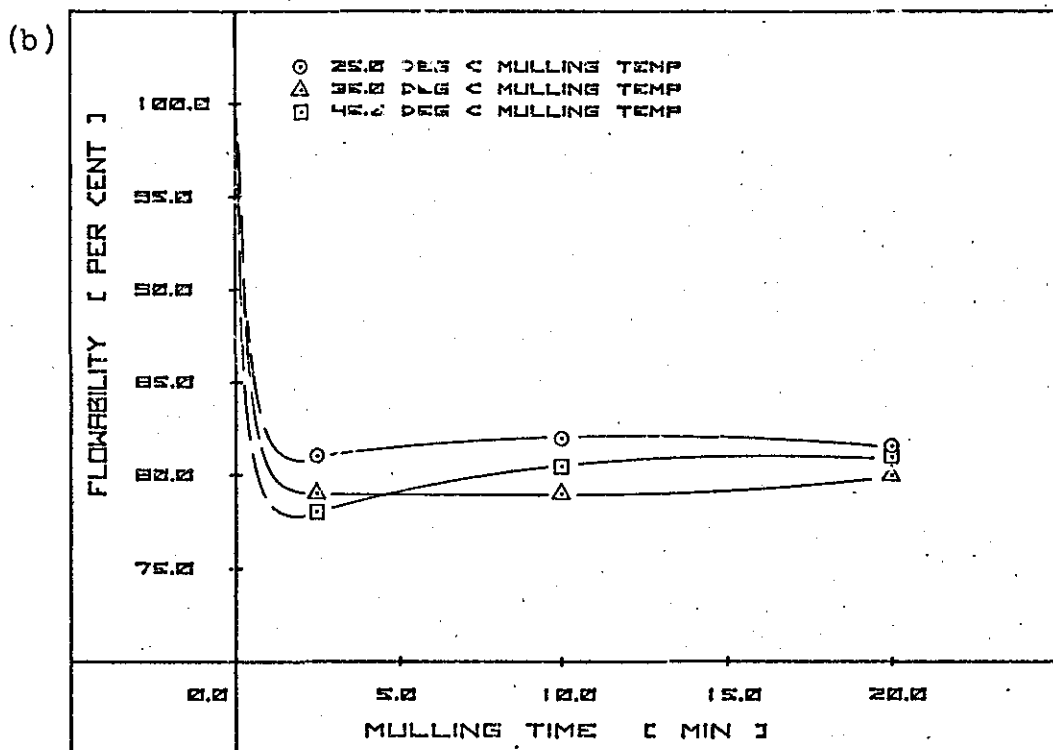
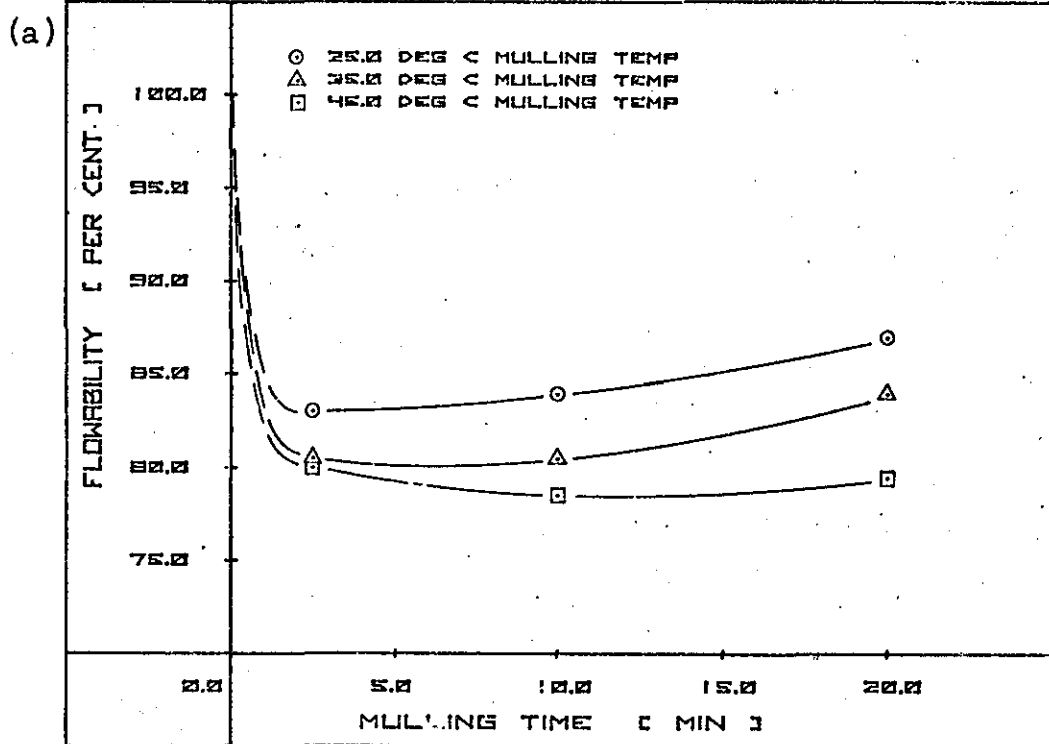


Fig. 23 Effect of mulling time on flowability
 (a) without polar additive, (b) with
 0.5 per cent methanol.

methanol greatly increased the rate of strength development, maximum strengths at all temperatures being achieved after about $2\frac{1}{2}$ minutes mulling. It was interesting to note that the greatest rate of increase in strength was recorded with the mix mulled at 35°C . This was probably the result of the high rate of evaporation of the methanol at 45°C effectively reducing its potential. After 20 minutes mulling, however, this high temperature mix proved to give a slightly stronger mix than the other two mulled at the lower temperatures.

Green Shear Strength:

The results of these tests produced graphs of similar character to those for green compression strength.

Here again, the mix containing the 0.5 per cent addition and mulled at 35°C produced the greatest rate of strength development though on subsequent mulling the strength appeared to decrease whilst that of the mix mulled at 45°C increased, eventually giving the strongest mix.

Hot Compression Strength:

The hot compression strength of a sand mix was generally increased by employing increasing mulling times. Two exceptions were noted. At 25°C a mix without methanol remained relatively unaffected by continued mulling after the initial $2\frac{1}{2}$ minutes. There also appeared to be

a tendency for mixes mulled at 35°C without a polar additive to suffer a loss in hot compression strength on mulling for times greater than 10 minutes.

Mixes mulled with 0.5 per cent methanol exhibited the same phenomenon as both green compression and shear strength in that the hot strength of the mix mulled at 35°C exceeded that of the mix mulled at 45°C. On further mulling, however, mixes at all temperatures increased in hot strength until, after 20 minutes, very similar results were achieved.

Permeability:

Mixes mulled without a polar additive showed a minimal change over the mulling times tested and the differences in character of the curves for each temperature are probably not of great significance when considering the small range over which they occur. However, those mixes mulled with 0.5 per cent methanol all showed a relatively high permeability after the first 2½ minutes mulling, subsequent mulling causing a rapid reduction to levels of similar value to those in mixes mulled without polar additive.

Mould Hardness:

In all but the low temperature mix without methanol, mould hardness was found to be at its maximum after only 2½ minutes mulling. Thereafter, a gradual decline in value was noted as mulling proceeded. When mulling at

25°C without a methanol addition, however, mould hardness was slow to develop reaching its maximum value after about 10 minutes mulling, longer periods proving to be detrimental. Again it was noted that the effect of the methanol addition was diminished slightly by mulling at 45°C.

Shatter Index:

In mixes without a polar additive shatter index was increased by increasing mulling times. At 45°C it was found that no additional benefit was to be gained by mulling for longer than 10 minutes. When using a 0.5 per cent methanol addition the sand attained most of its toughness in the first 2½ minutes subsequent mulling giving no great advantage.

Flowability:

This property remained relatively constant for all sand mixes mulled for the varying times tested. However, the weaker sands resulting from low temperature mulling without polar additive showed some slight improvement in flowability as mulling time was increased.

It would appear from these results that if a 0.5 per cent methanol addition was made to the sand during mulling most physical properties had attained an optimum or nearly optimum level after only 2½ minutes mulling. There was evidence to show, however, that the hot compression strength could be improved by extending the mulling period.

In the absence of a polar additive the mulling temperature became an important factor in determining the length of mulling time required to reach optimum properties, particularly in the case of green compression strength, green shear strength and mould hardness. It was found that the lower the temperature the longer the period of mulling required. Even at the higher temperatures at least 8 minutes was required to develop maximum green compression and shear strength and the values obtained were still less than those found to be possible when using a polar additive. The development of shatter index was found to be much slower at all temperatures when methanol was omitted from the mix.

7.7.4. Effect of Moulding Sand Testing Temperature

The results of the physical property tests carried out upon batches of moulding sand at 15, 25, 35 and 45°C are given in Table 15 and shown in graphical form in Figs. 24-29.

It can be seen that whilst nearly all the properties tested showed a slight variation with increased temperature of the sand; green compression strength and permeability decreasing whilst green shear strength and flowability increased, the property to be most affected by temperature was the toughness of the sand as indicated by the shatter index. In all routine sand testing reported in this work therefore, a standard testing temperature of 20°C was adopted, this being achieved by storing the mulled sand in a water-jacketted box as described in 5.6.

Table 15

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	5.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	Tested at various temperatures Milled at an average of 30.0°C

SAND MIX No.	303	304	307	308
TESTING TEMPERATURE (°C)	15.0	25.0	35.0	45.0
SPECIMEN WEIGHT (g)	156	158	158	159
GREEN COMPRESSION STRENGTH	65.5 67.6 67.6 67.6 67.6	66.9 67.6 66.9	66.2 66.9 66.9	65.5 65.5 64.8
(N/m ² x 10 ³)				
Average	67.2	67.1	66.7	65.3
GREEN SHEAR STRENGTH	14.8 14.8 14.8	16.5 15.5 16.5 16.9 15.5	16.9 17.2 18.3 17.9 17.6	17.6 17.6 17.6
(N/m ² x 10 ³)				
Average	14.8	16.2	17.6	17.6
PERMEABILITY	21.1 21.1 21.1 21.1	18.8 19.0 18.9 19.0	18.2 18.1 18.1	16.8 17.0 17.2 17.0
(small orifice)				
Average	21.1	18.9	18.1	17.0
MOULD HARDNESS	29 29 28 29	29 30 30 29	29 28 29 30	28 30 28 29 29
('C' scale)				
Average	29	30	29	29
SHATTER INDEX	58 58 63 55	75 73 75 75	91 92 87 91 89	91 91 91
Average	58	75	90	91
FLOWABILITY	80 80 79	80 81 81 81	81 81 81 81	82 82 81 82
(per cent)				
Average	80	81	81	82

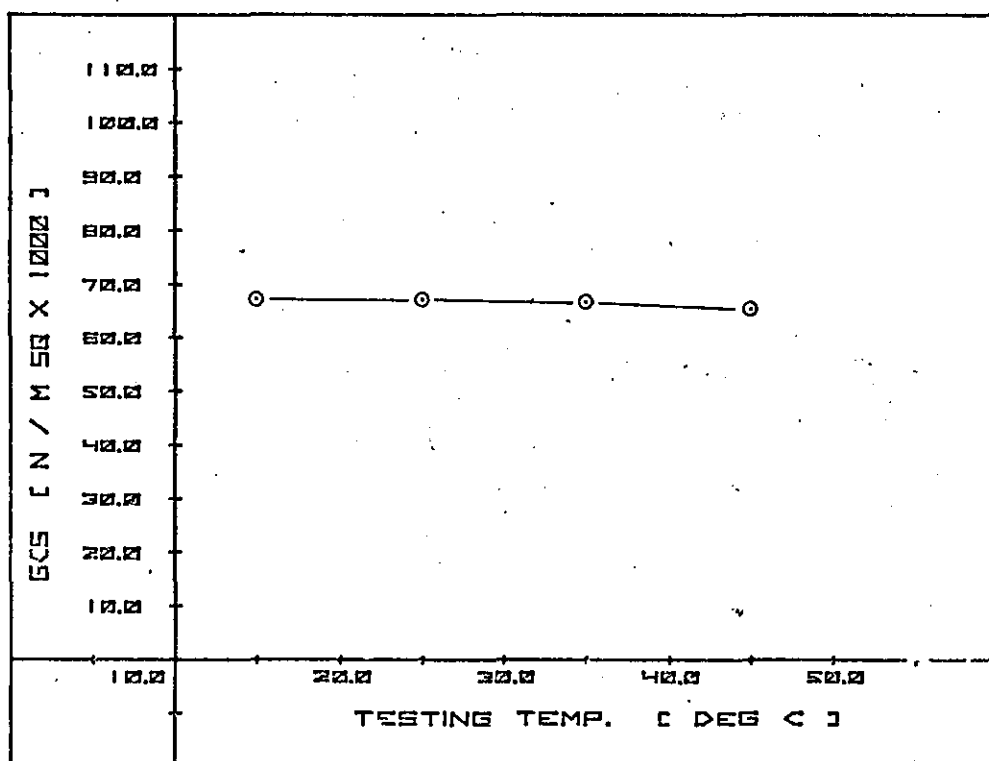


Fig. 24 Effect of testing temperature on green compression strength.

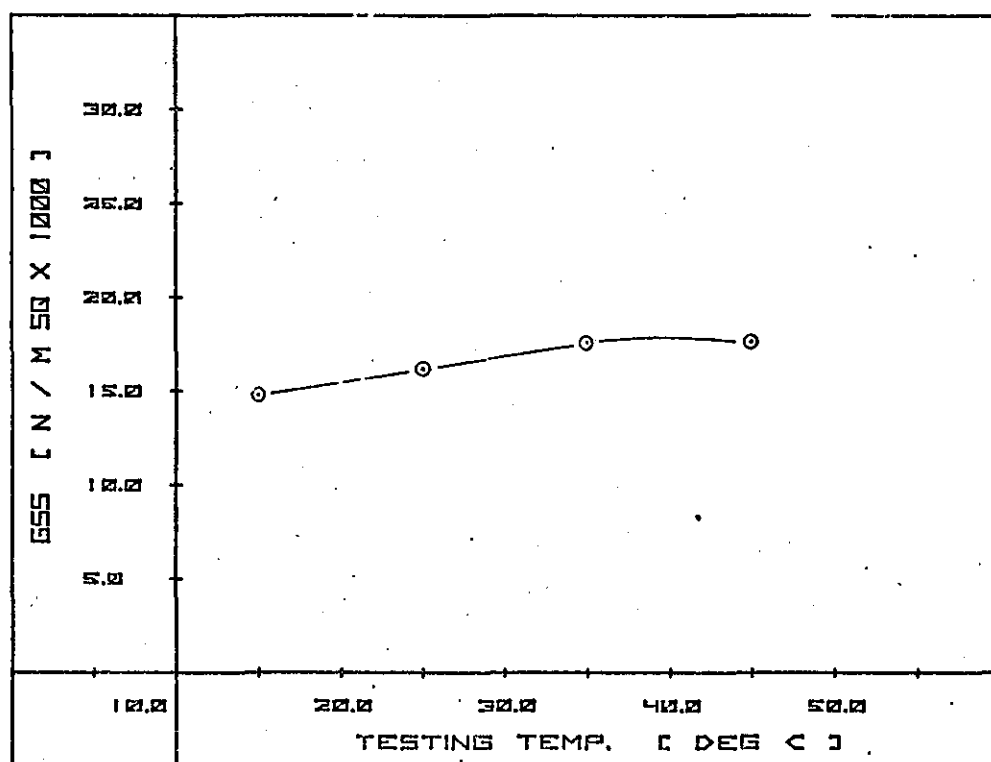


Fig. 25 Effect of testing temperature on green shear strength.

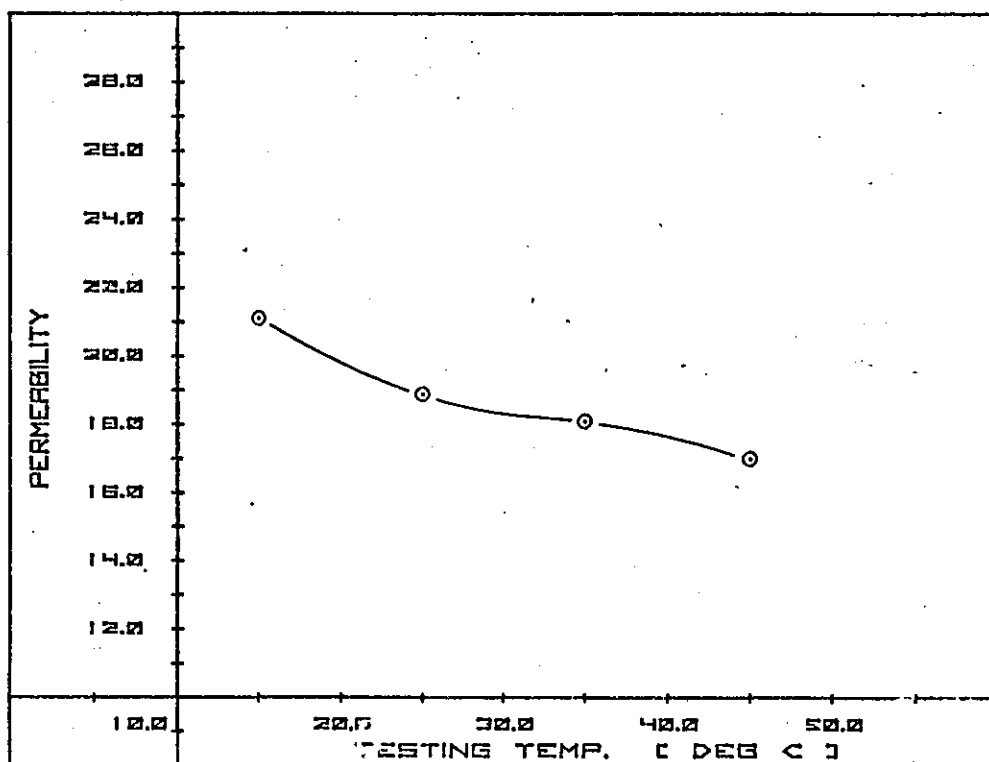


Fig. 26 Effect of testing temperature on permeability.

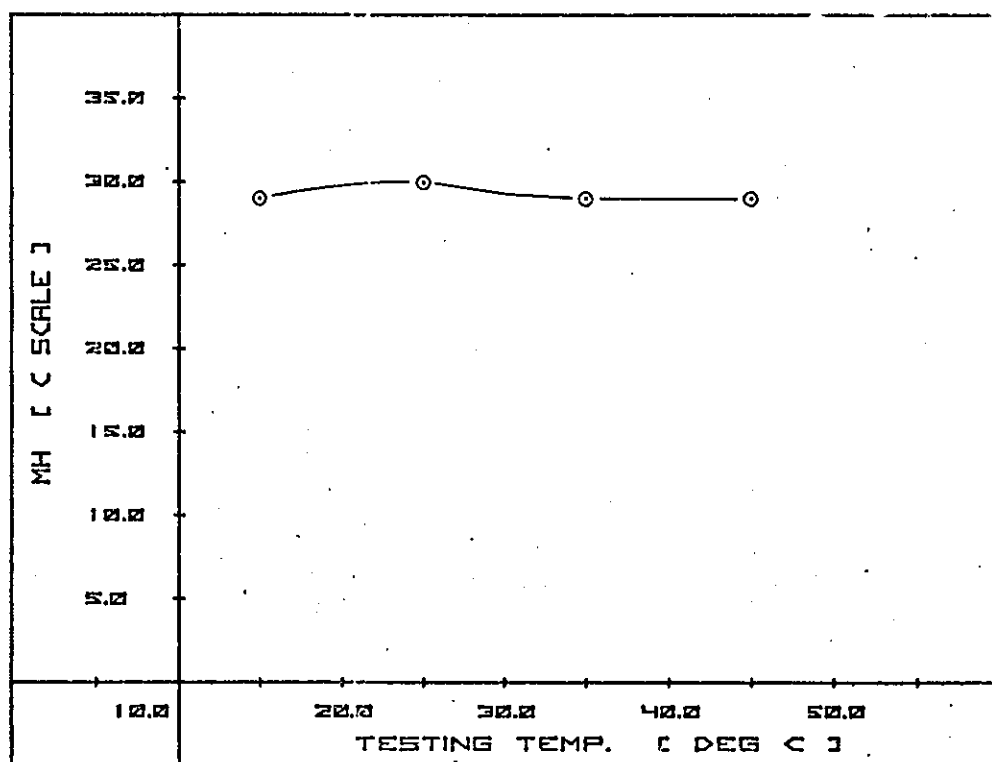


Fig. 27 Effect of testing temperature on mould hardness.

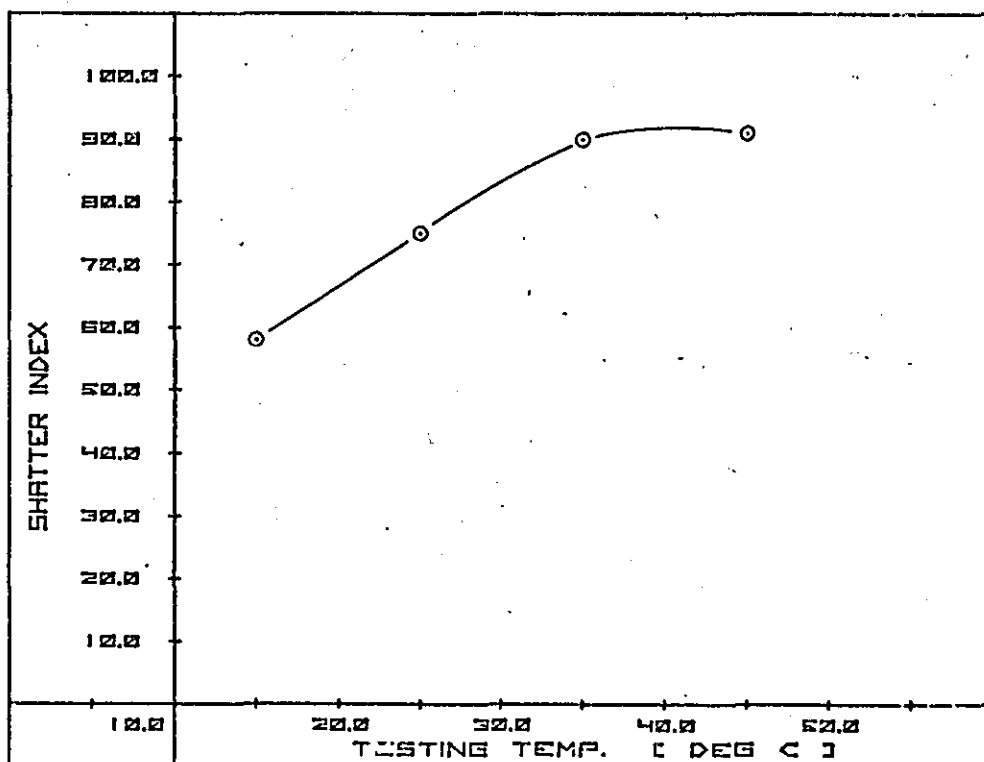


Fig. 28 Effect of testing temperature on shatter index.

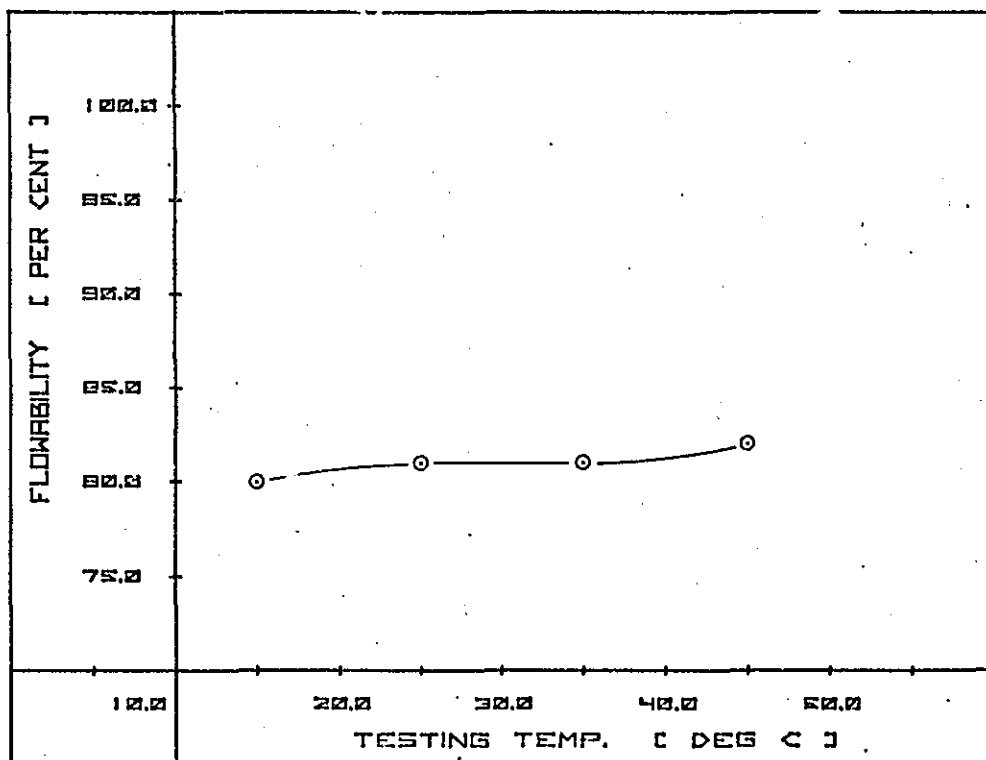


Fig. 29 Effect of testing temperature on flowability.

7.7.5. Effect of the Polar Additive

The effect of varying amounts of methanol on the physical properties of a sand mix containing 5 per cent clay and 3 per cent oil mulled for 10 minutes are recorded in Tables 8-14. The values of each of the properties were, as were those for mulling time, derived from Figs.(i) - (vii)g in the appendix for mulling temperatures of 25, 35 and 45°C giving rise to the three curves on each graph in Figs. 30-36.

Green Compression Strength:

The use of increasing additions of methanol increased the green compression strength, the effect being most marked on the weaker, low temperature mixes. The greater part of the increase was achieved with only 0.5 per cent methanol, greater additions giving little further benefit. The best results were obtained when using methanol in a mix mulled at 35°C, higher mulling temperatures probably causing excessive evaporation of the polar additive and thereby reducing its potential.

Green Shear Strength:

Increasing amounts of methanol produced similar effects on the green shear strength as on the green compression strength. However, at the lower mulling temperatures there appeared to be a tendency for a 1 per cent addition to yield strengths below those obtainable with 0.5 and 2 per cent. Unlike the green compression strength, this property would appear to gain more from the use of high mulling temperatures

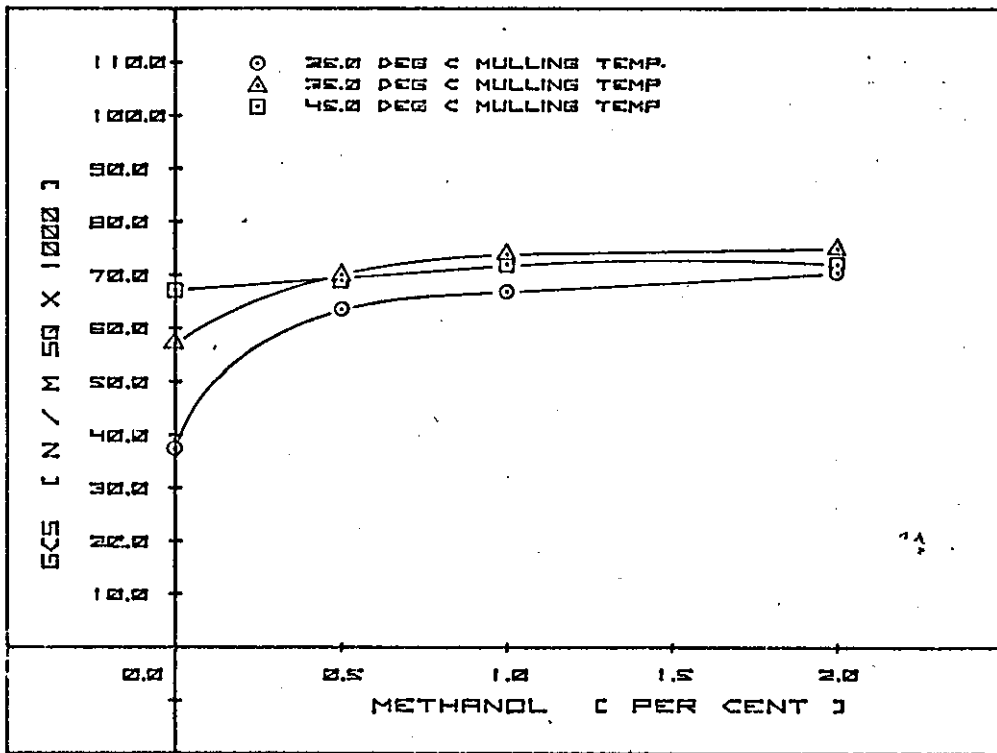


Fig. 30 Effect of methanol on green compression strength.

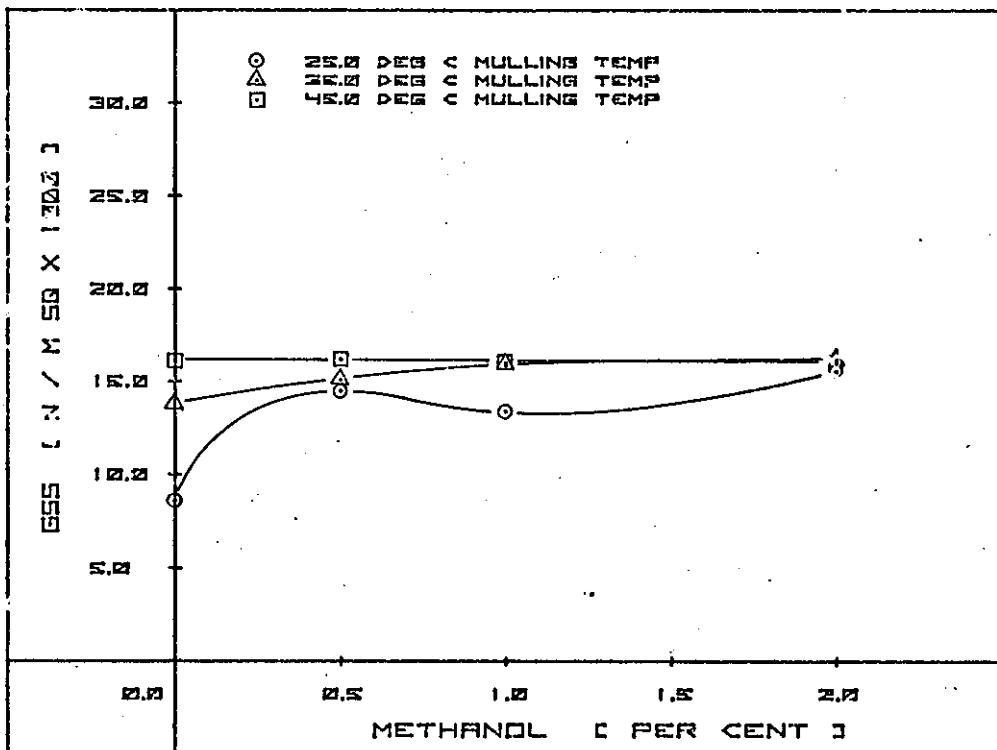


Fig. 31 Effect of methanol on green shear strength.

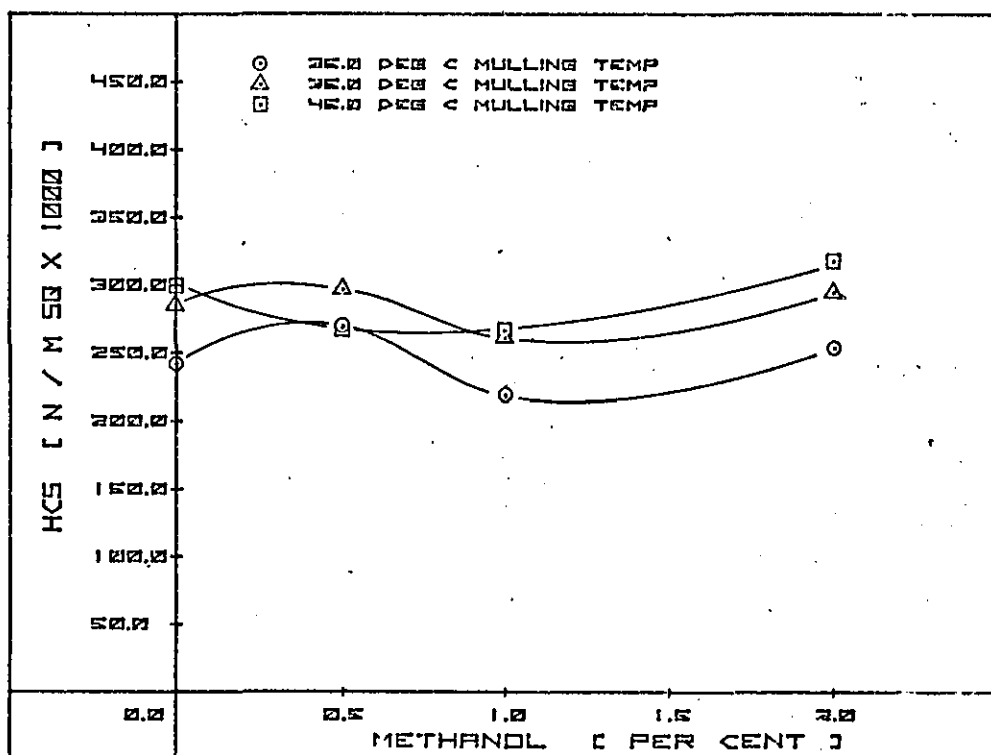


Fig. 32 Effect of methanol on hot compression strength.

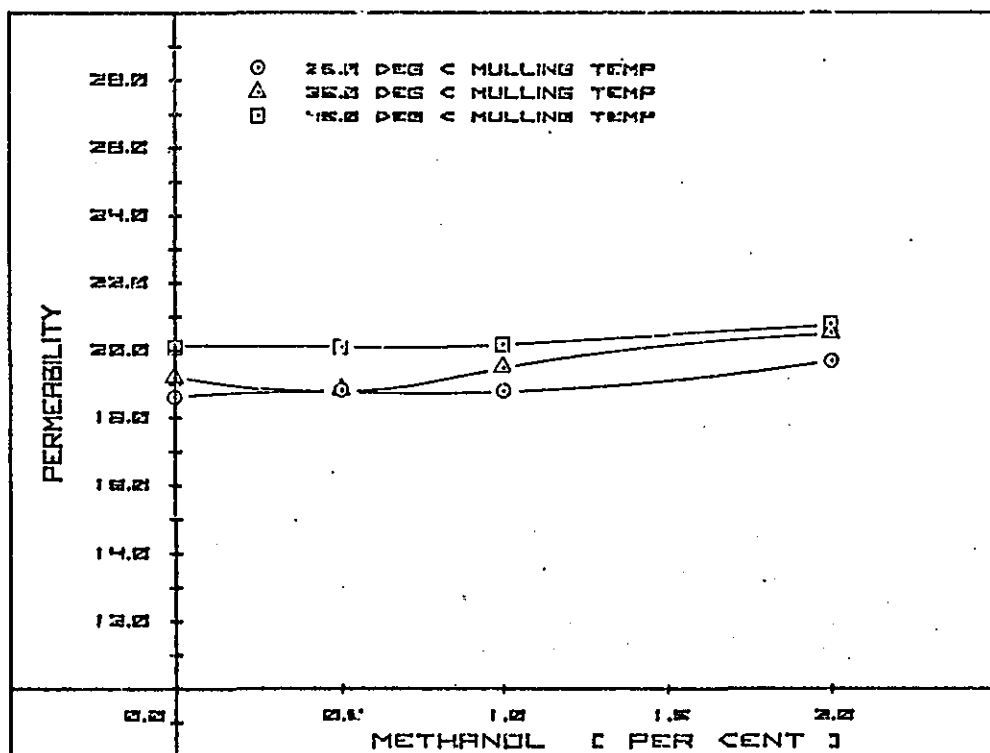


Fig. 33 Effect of methanol on permeability.

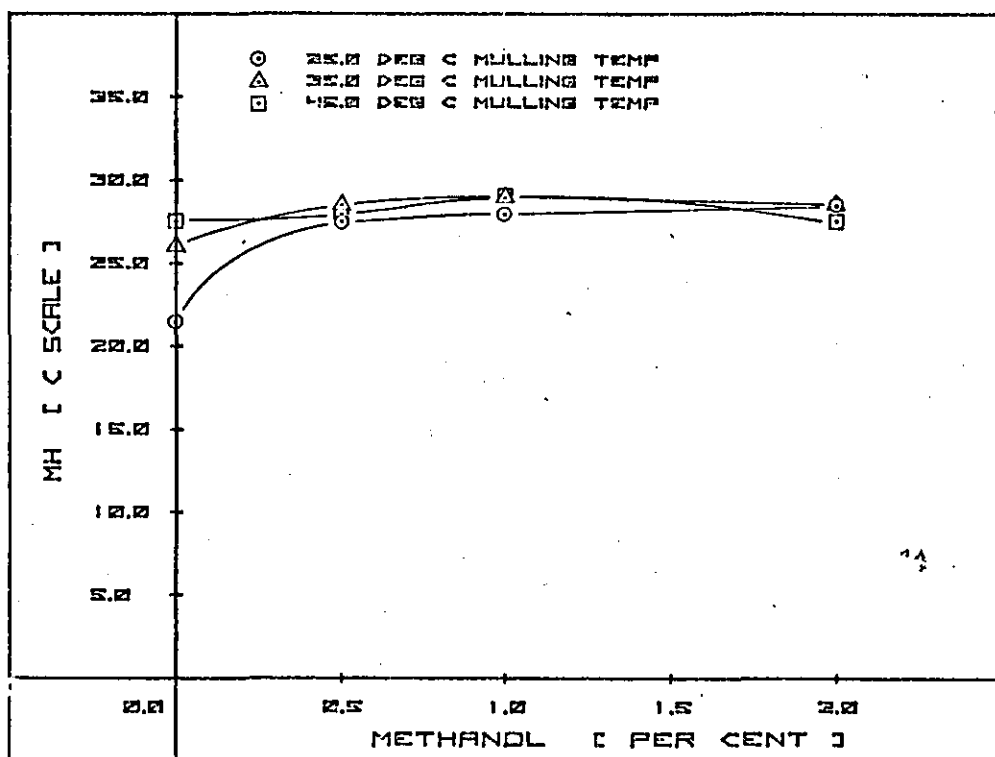


Fig. 34 Effect of methanol on mould hardness.

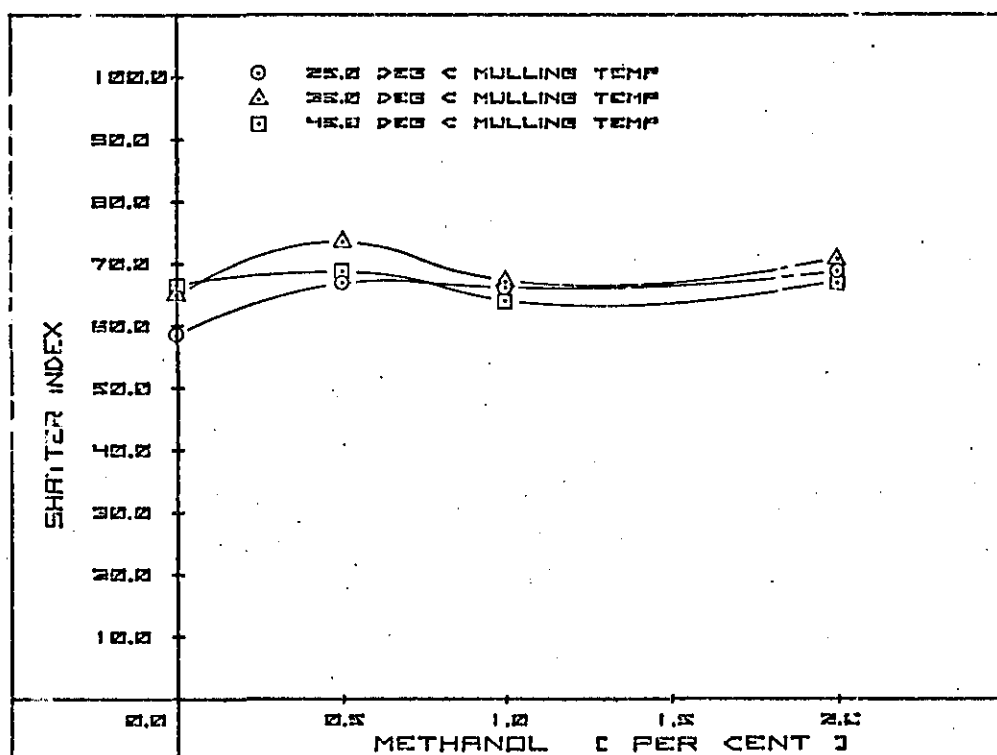


Fig. 35 Effect of methanol on shatter index.

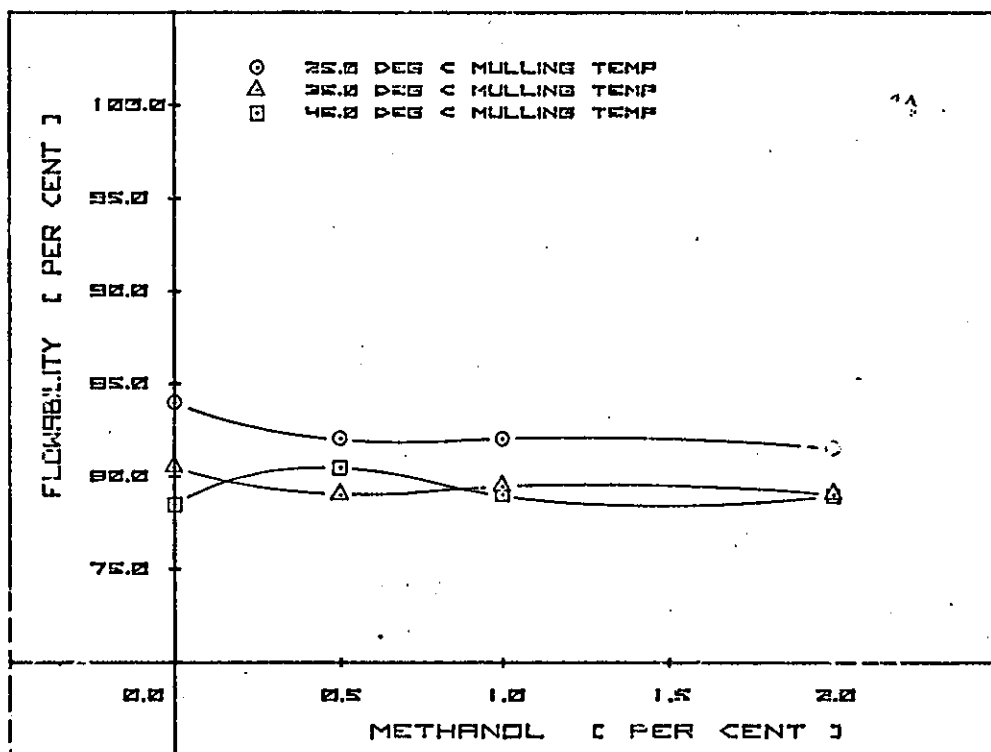


Fig. 36 Effect of methanol on flowability.

than from using low additions of Methanol as can be seen from comparing the strength of the mix mulled at 45°C without polar additive to that obtained at 35°C with a 0.5 per cent addition of methanol.

Hot Compression Strength:

This property would appear to have benefitted slightly from the use of 0.5 per cent methanol at mulling temperatures of 25 and 35°C. A 1 per cent addition at these temperatures however, seemed to cause a fall in hot strength, whilst a 2 per cent addition had little effect at all. When using a 45°C mulling temperature additions of 0.5 and 1 per cent methanol had a reducing effect upon the strength whilst a 2 per cent addition was slightly beneficial.

Permeability:

The use of methanol in amounts up to 2 per cent had very little effect on the final permeability of a mix mulled for 10 minutes.

Mould Hardness:

As would be expected, the results obtained for mould hardness reflect almost exactly those for green compression strength. The use of 0.5 per cent methanol increased the potential mould hardness of both the mix mulled at 25°C and that mulled at 35°C, further additions

producing no great benefit. The use of methanol on the mix mulled at 45°C had little effect.

Shatter Index:

The addition of 0.5 per cent methanol to the sand mix improved the shatter index. This improvement was less marked in the mix mulled at 45°C, again perhaps as a result of the high evaporation rate of the methanol at these temperatures. Additions higher than 0.5 per cent were useful for the low temperature mix, slightly less so for the mix mulled at 35°C and made little difference to that at the higher temperature of 45°C.

Flowability:

This property was reduced by the addition of methanol to mixes mulled at 25 and 35°C whilst at 45°C it was increased by the addition of 0.5 per cent methanol, further additions giving little or no effect.

It has already been shown that the addition of 0.5 per cent methanol to a sand mix increased the rate at which the optimum physical properties were developed during the mulling operation. It was also seen to reduce the mulling temperature required to develop the optimum properties.

In this work the effect of methanol has been studied on mixes mulled for 10 minutes when the greater part of the ultimate value for each property had been attained. Thus for each particular

mulling temperature these experiments show the effect of the polar additive on the final mix as would have been produced for moulding purposes.

It can be seen that in properties which relate to the strength of the bond, i.e., green compression strength, green shear strength, hot compression strength, mould hardness, shatter index and flowability, the use of 0.5 per cent methanol in mixes mulled at 25 and 35°C was beneficial. Larger additions were either of no great value or in some instances detrimental. Mixes mulled at 45°C derived little or no benefit from the use of methanol, partly because the mulling temperature alone was sufficient to give very good results and partly, perhaps, because at these high temperatures much of the methanol evaporated.

7.7.6. Effect of Clay Content

The physical properties of sand mixes mulled with 3 per cent oil for 10 minutes and containing varying amounts of 3, 5 and 7 per cent clay are given in Tables (v) (vii) (ix) in the appendix. The results of similar experiments carried out with a 0.5 per cent addition of methanol quoted in Tables (vi)(viii)(x). From these results values for each of these properties have been deduced for mulling temperatures of 25, 35 and 45°C using Figs (i)-(vii)a&b, and shown in Tables 8-14. Figs.37-43 reproduce these in graphical form.

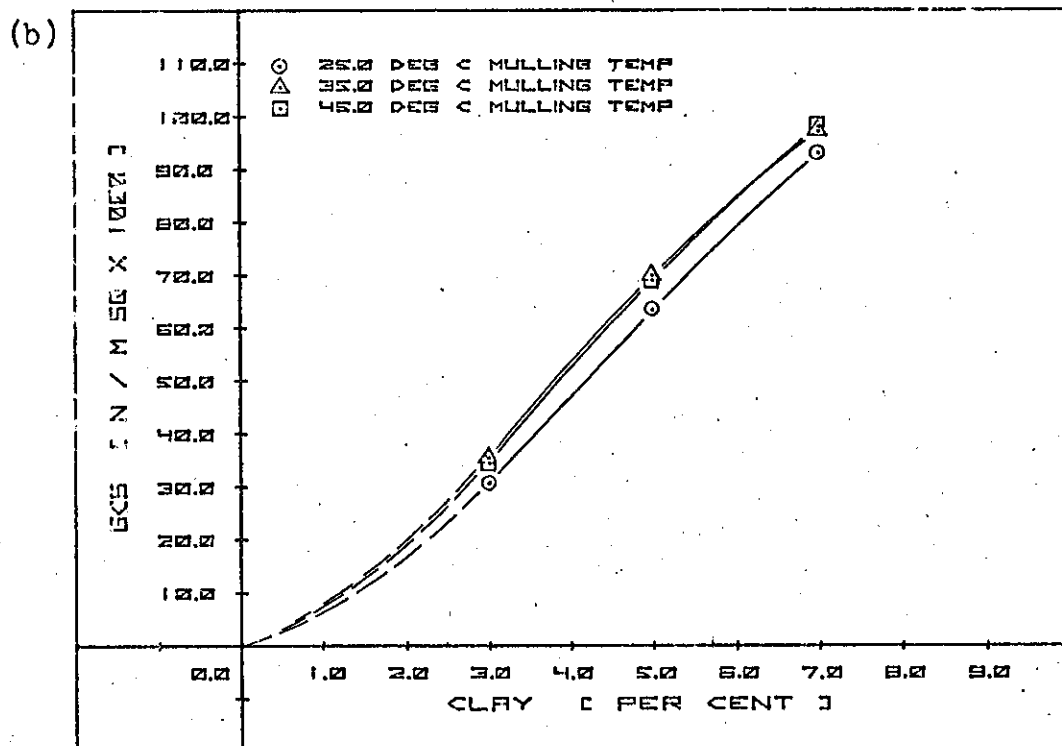
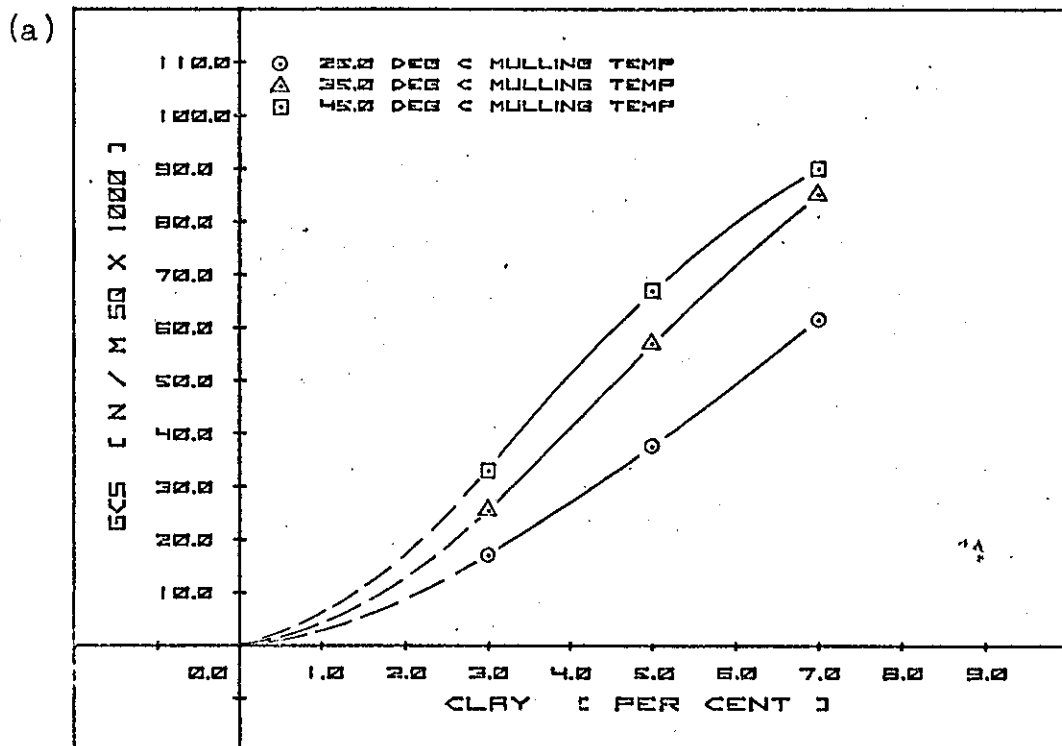


Fig. 37 Effect of clay on green compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

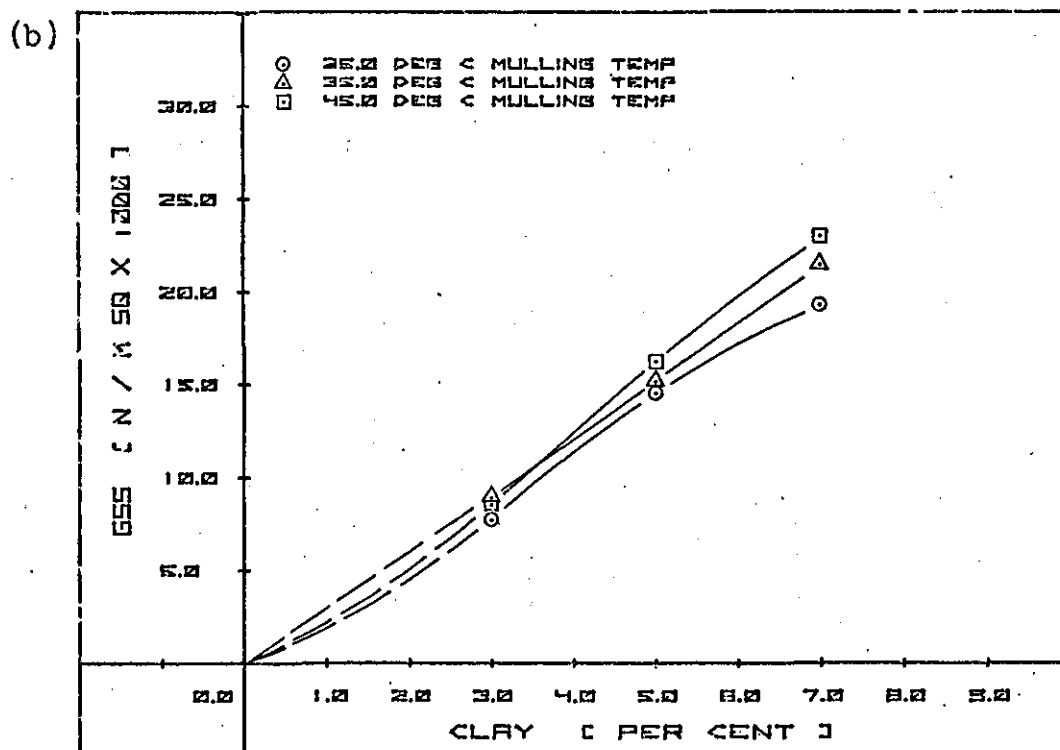
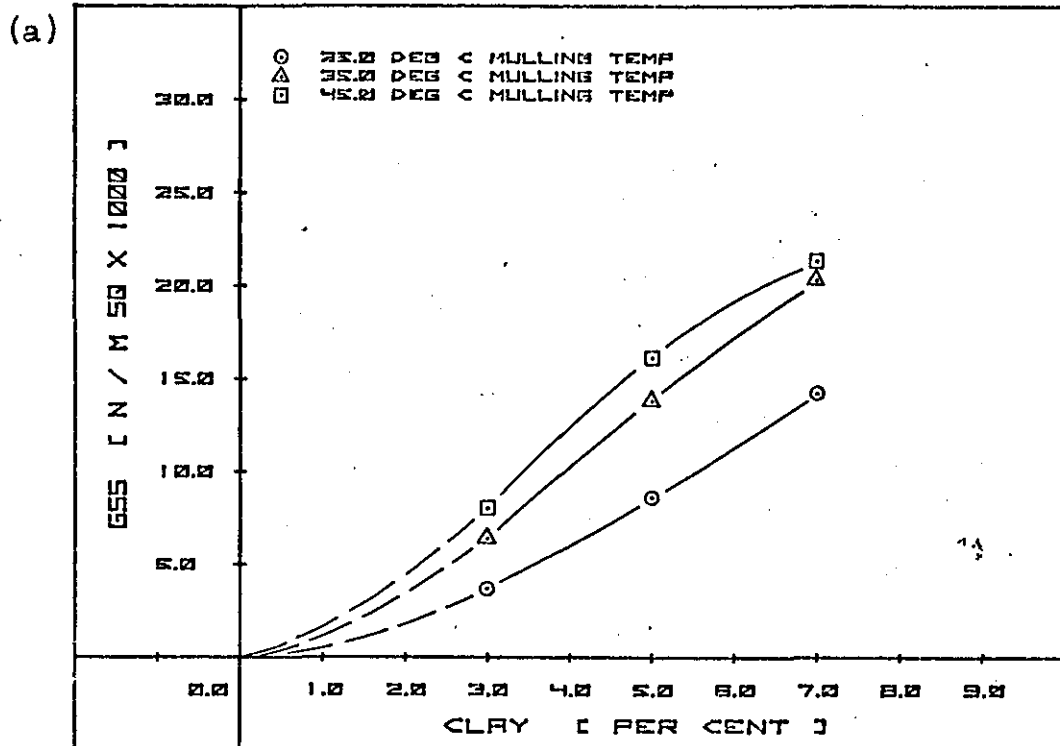


Fig. 38 Effect of clay on green shear strength, (a) without polar additive, (b) with 0.5 per cent methanol.

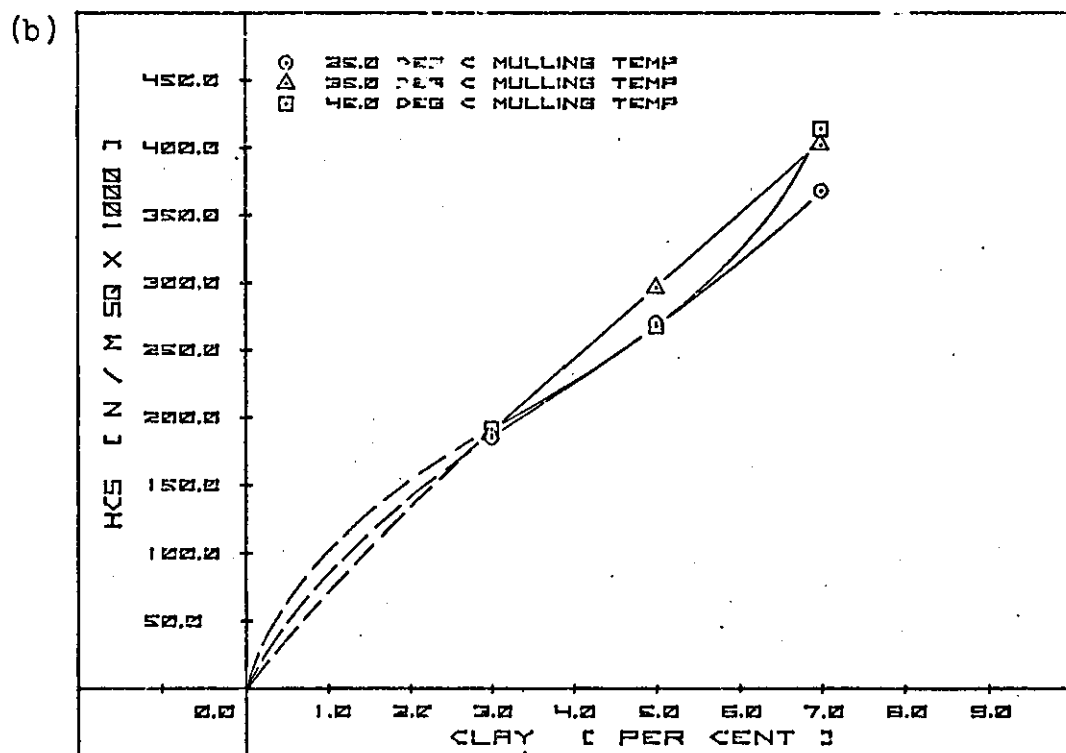
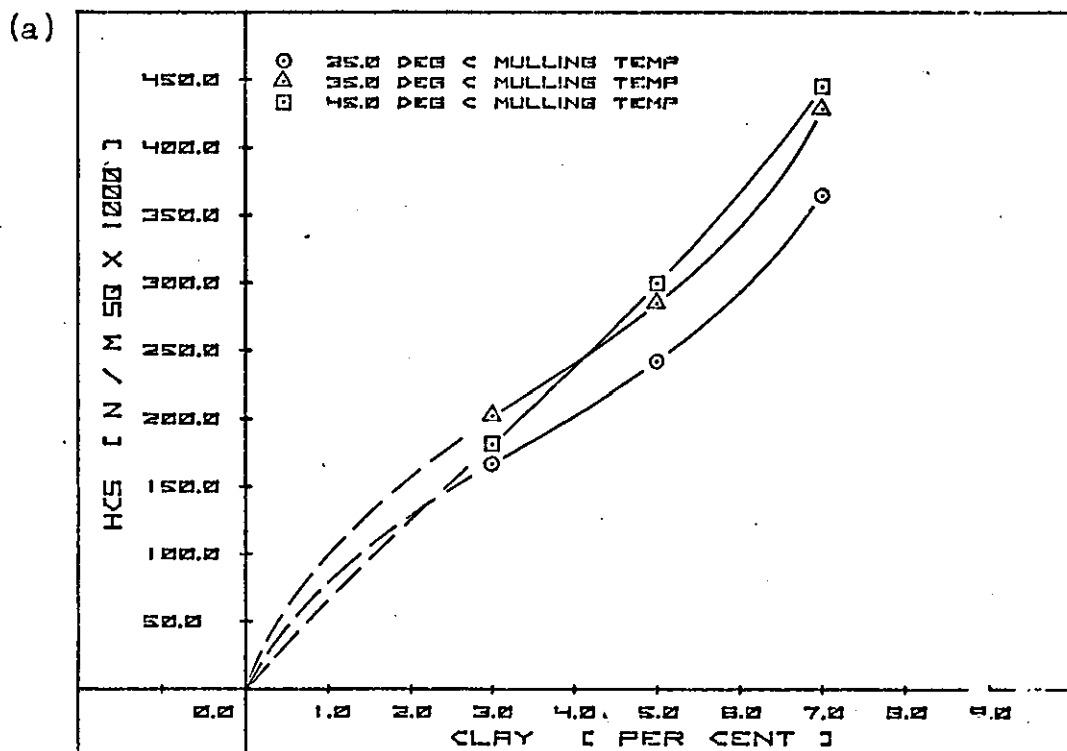


Fig. 39 Effect of clay on hot compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

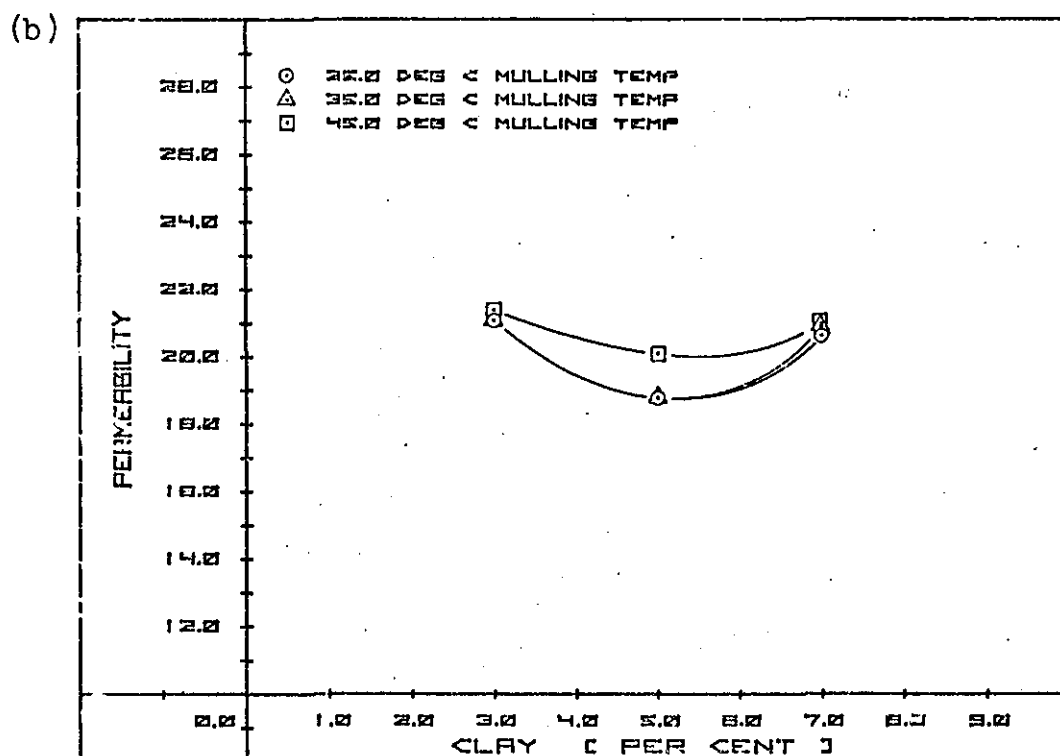
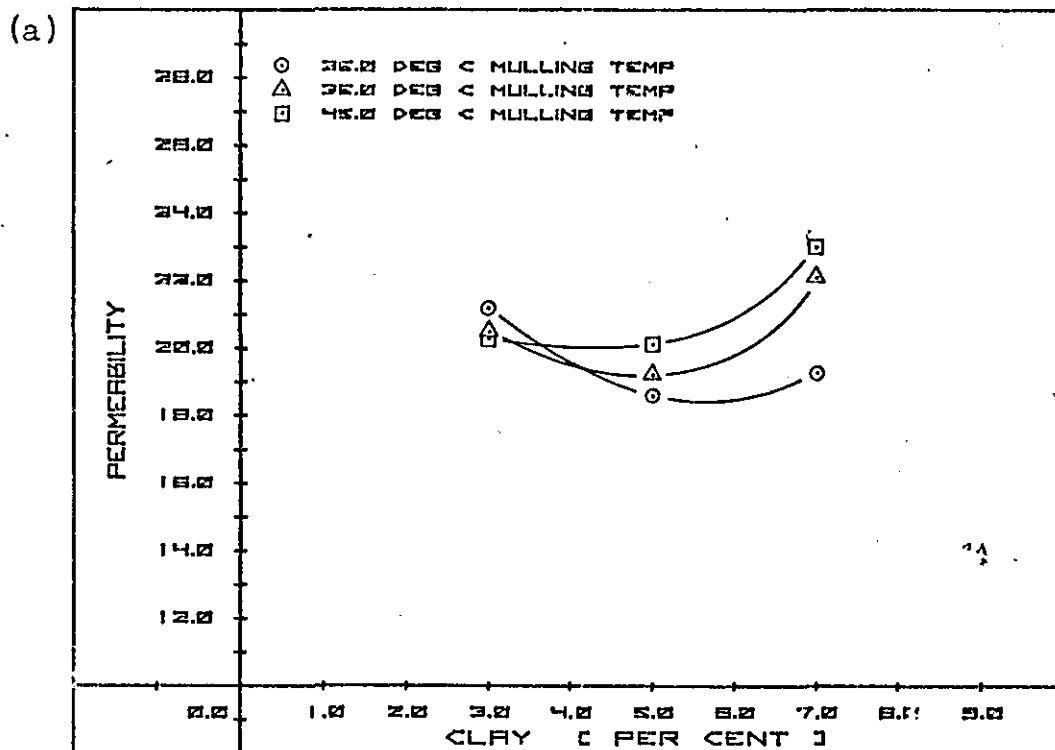


Fig. 40 Effect of clay on permeability, (a) without polar additive, (b) with 0.5 per cent methanol.

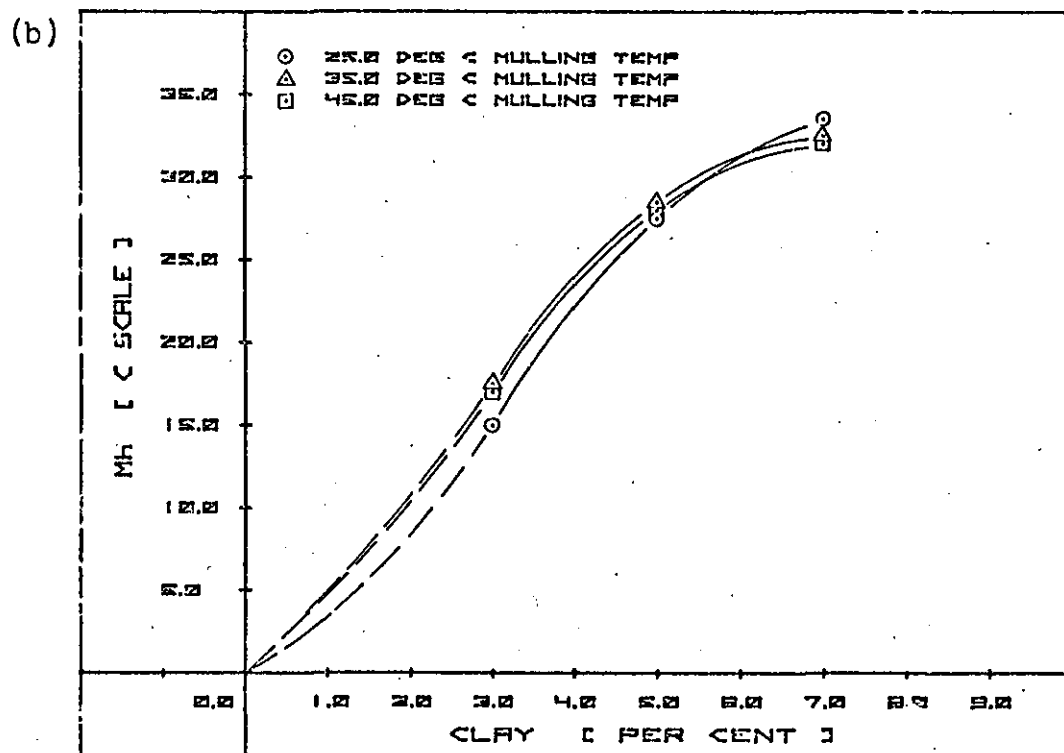
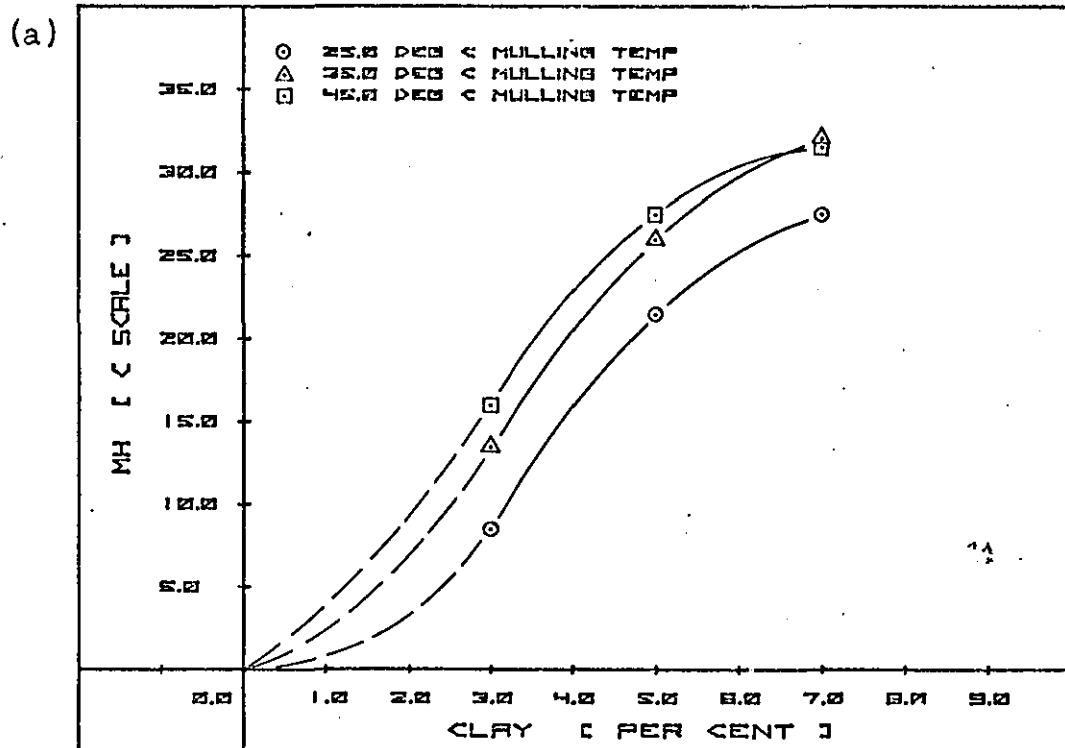
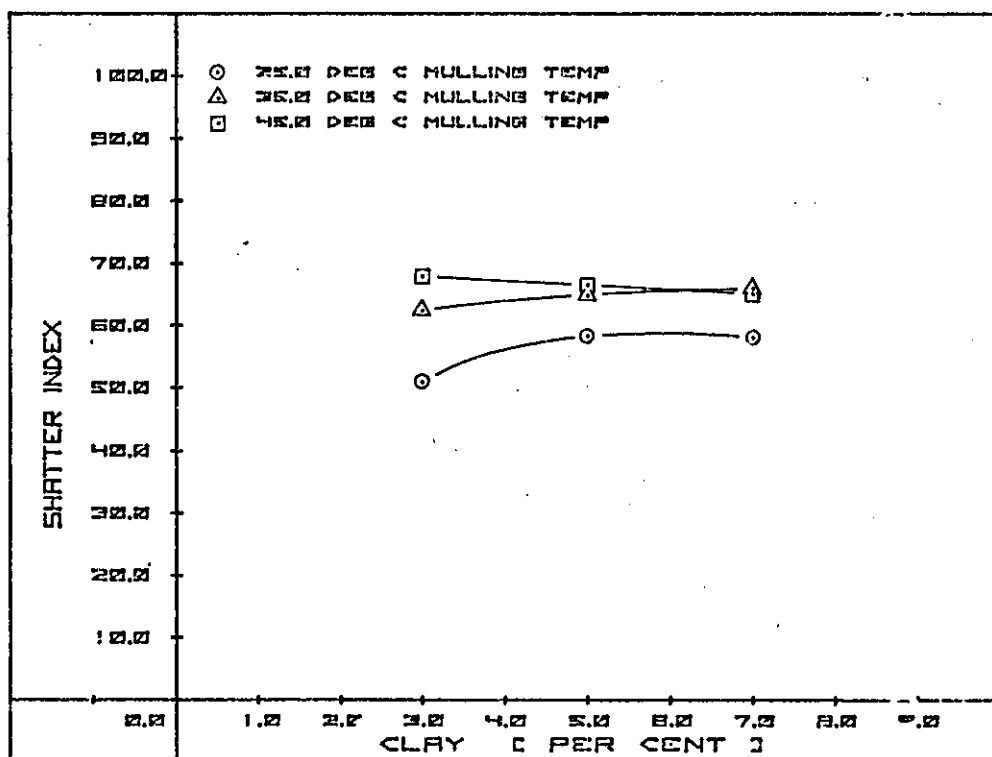


Fig. 41 Effect of clay on mould hardness,
(a) without polar additive, (b) with
0.5 per cent methanol.

(a)



(b)

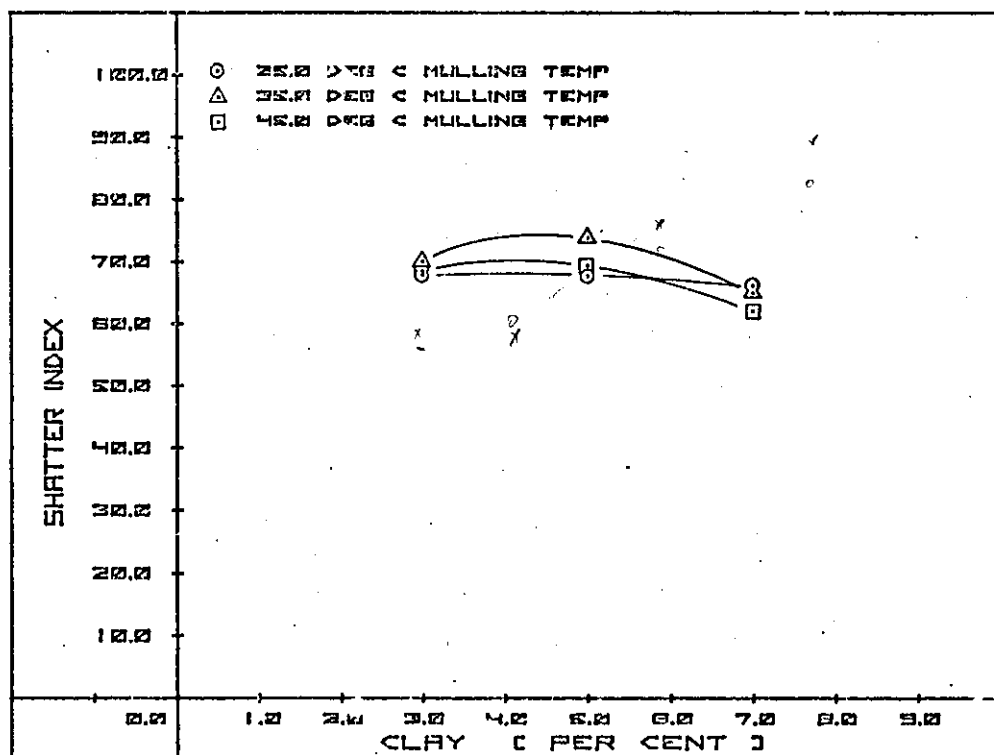


Fig. 42 Effect of clay on shatter index,
(a) without polar additive, (b) with
0.5 per cent methanol.

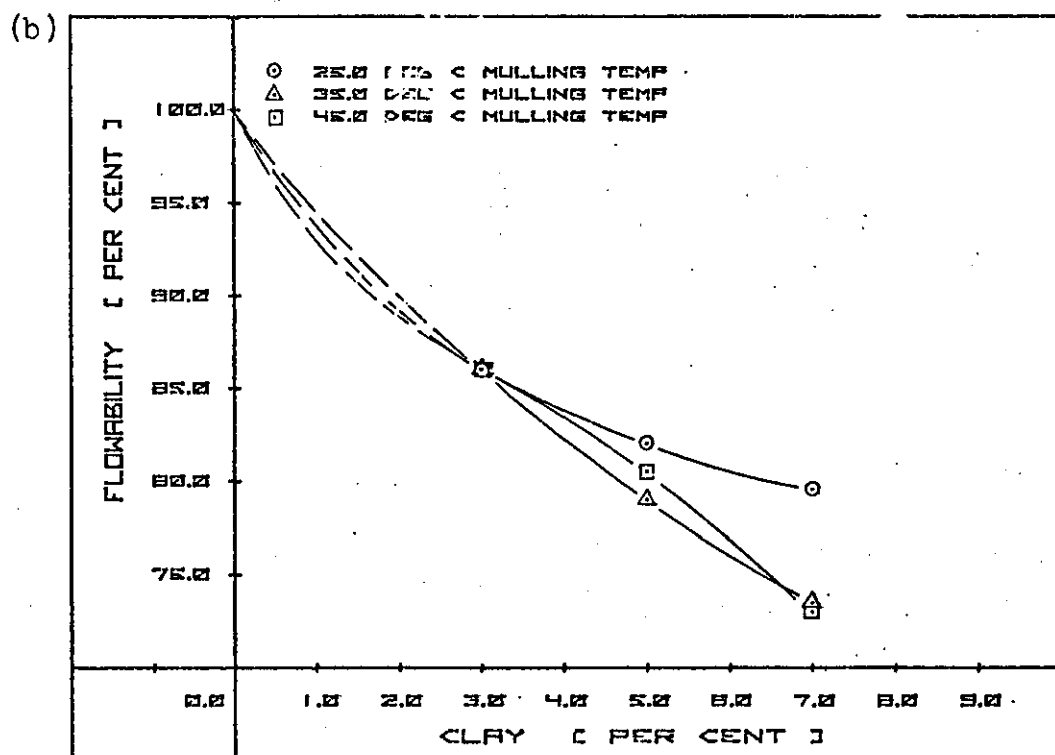
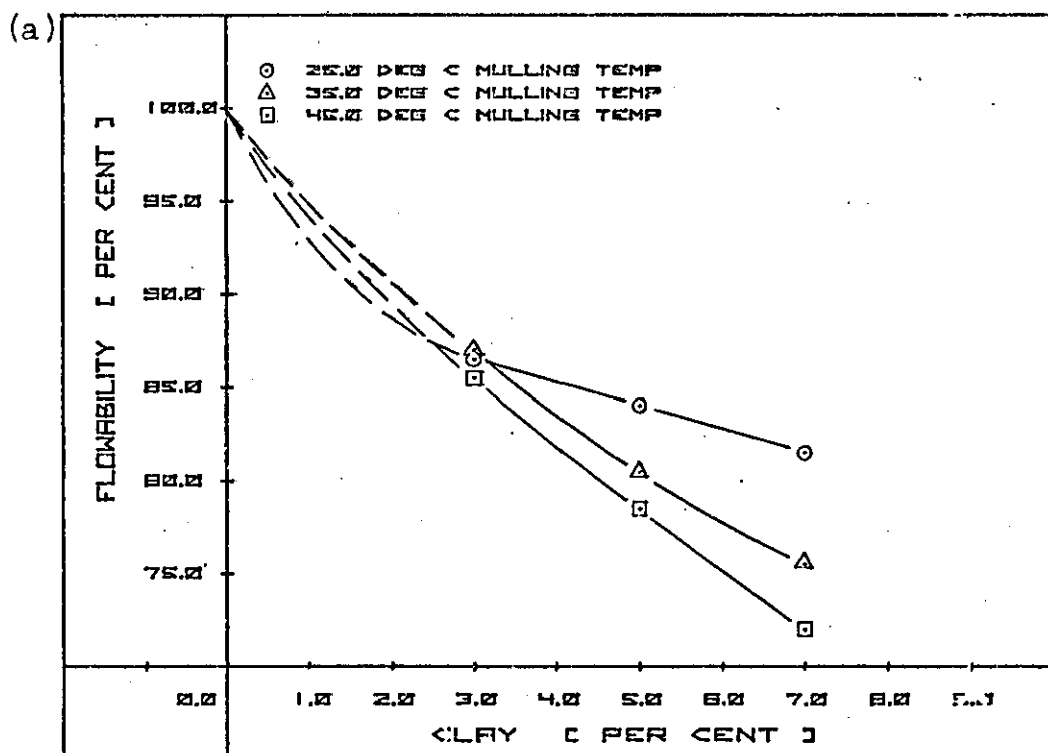


Fig. 43 Effect of clay on flowability, (a) without polar additive, (b) with 0.5 per cent methanol.

Green Compression Strength:

The addition of increasing amounts of clay to a sand mix containing 3 per cent oil increased the green compression strength in an almost linear fashion. This effect is similar to that found when the clay content of a conventional clay/water bonded sand is increased. The effectiveness of the clay addition was dependent upon the mulling temperature and the use of methanol additions. The lower the mulling temperature the less effective was the clay addition at imparting strength to the sand mix. The use of 0.5 per cent methanol improved the effectiveness of the clay and reduced the detrimental effects of using a lower mulling temperature.

Green Shear Strength:

This property behaved in a very similar manner to that of green compression strength as the clay addition was increased.

Hot Compression Strength:

This property also reflected many of the characteristics of the green compression strength. At high clay contents, however, the potential of the clay to increase the hot compressive strength seemed to be generally increasing.

Permeability:

As the clay content of the mix was increased there was a very slight reduction in permeability,

minimum values being experienced at about 5 per cent clay. Further additions, however, caused a slight increase. These variations took place over a very narrow band of permeability values and would probably not be noticed in the use of the mixes as a moulding material.

Mould Hardness:

Values of this property were greatly increased by increasing the clay content, following a similar pattern to those of green compression strength. The effectiveness of the clay to increase mould hardness was apparently diminished at the higher clay levels. This may be attributed to the characteristics of the test itself, it being known that as green compression strength increases mould hardness values tend toward a maximum.

Shatter Index:

The shatter index remained relatively constant as the clay content was varied between 3 and 7 per cent. It is interesting to note that in the clay/water bonded system similar variations in clay content give pronounced increases in shatter index.

Flowability:

Flowability was markedly decreased as the clay content of the mixes was increased, the effect being most noticeable in mixes mulled at the higher temperatures.

This work has shown that the clay content of the sand mix has a definite effect upon its strength, both when cold and at temperatures of 1000°C. In this respect its behaviour is closely related to that of a sand mix bonded with Na bentonite and water.

The shatter index was seen to remain relatively constant as the clay content was increased. Shatter index is a test which reflects not only the ability of a mould to deform but also the strength of the bond thus combining to give a measure of the toughness. Thus, it can be said that if the strength rises as the clay content of the mix is increased and the shatter index remains relatively constant, the ability of the mould to deform under load is reduced. In all probability, therefore, a mix of high clay content will be susceptible to damage by stress encountered in sudden jolting of moulding boxes or pattern stripping.

As the strength of the sand increased with the clay content and its ability to deform decreased it would be expected that the compaction of the sand would become more difficult, and this fact was reflected in the flowability curves. Indeed as the mulling temperature of the mixes without polar additive was decreased the effect of increasing clay upon the strength was reduced and the flowability was consequently seen to increase.

As the clay content of the mix was increased it would be expected that the volume of the voids between the sand grains would become smaller thus reducing the permeability of the test piece.

However, at high clay content the compaction of the sand became more difficult producing a less dense specimen of slightly higher permeability.

7.7.7. The Effect of Oil Content

The results of physical properties tested on sand mixtures mulled at varying temperatures for 10 minutes and containing 5 per cent clay are given in the appendix in Tables (xi)(vii)(xiii). These show the effect of using oil in amounts of 2, 3 and 4 per cent. The effect of using a 0.5 per cent addition of methanol in each mix was also evaluated and these results appear in the tables (xii)(viii)(xiv). From graphs of these results Figs.(i)-(vii)_c & d, Tables 8-14 have been made up showing the effects of varying the oil content at standard mulling temperatures of 25, 35 and 45°C and these results have been used to form the graphs shown in Figs. 44-50.

Green Compression Strength:

Over the range of oil additions tested the green compression strength remained relatively constant, most of the strength being developed with oil additions of less than 2 per cent as suggested in the dotted portion of the graph. The same variations of water content in the clay/water bonded sand system would tend to cause a decrease in green compression strength. The most efficient mulling conditions, those of high mulling temperature with a 0.5 per cent methanol addition produced a maximum strength with about 3 per cent oil, further additions causing a slight reduction

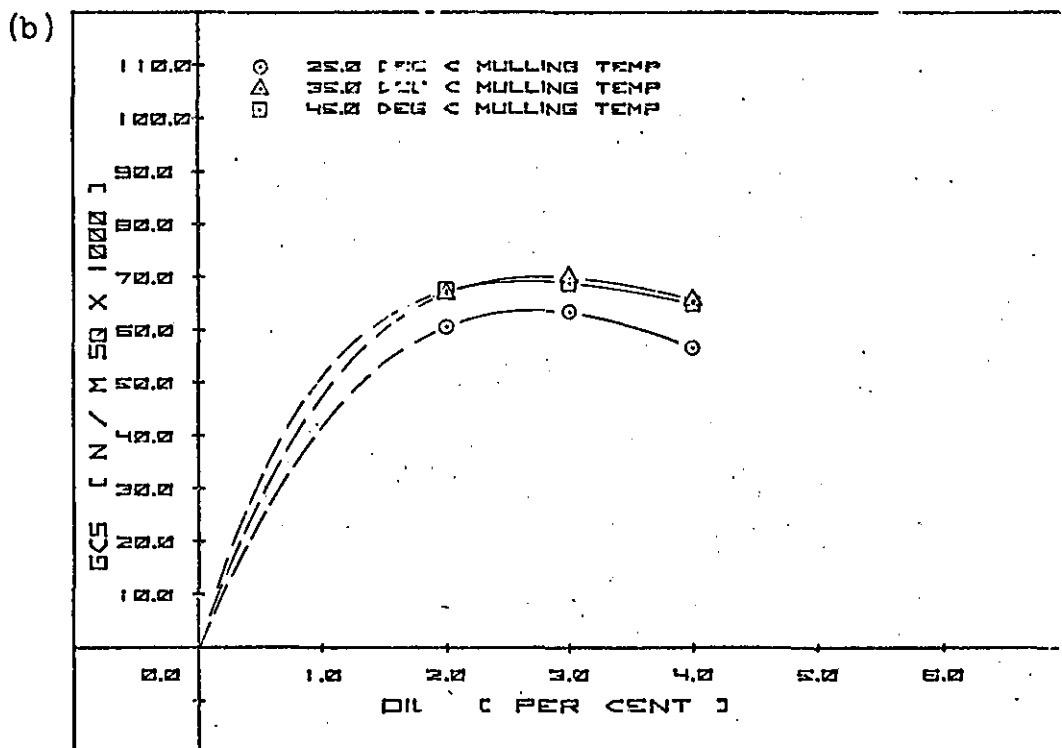
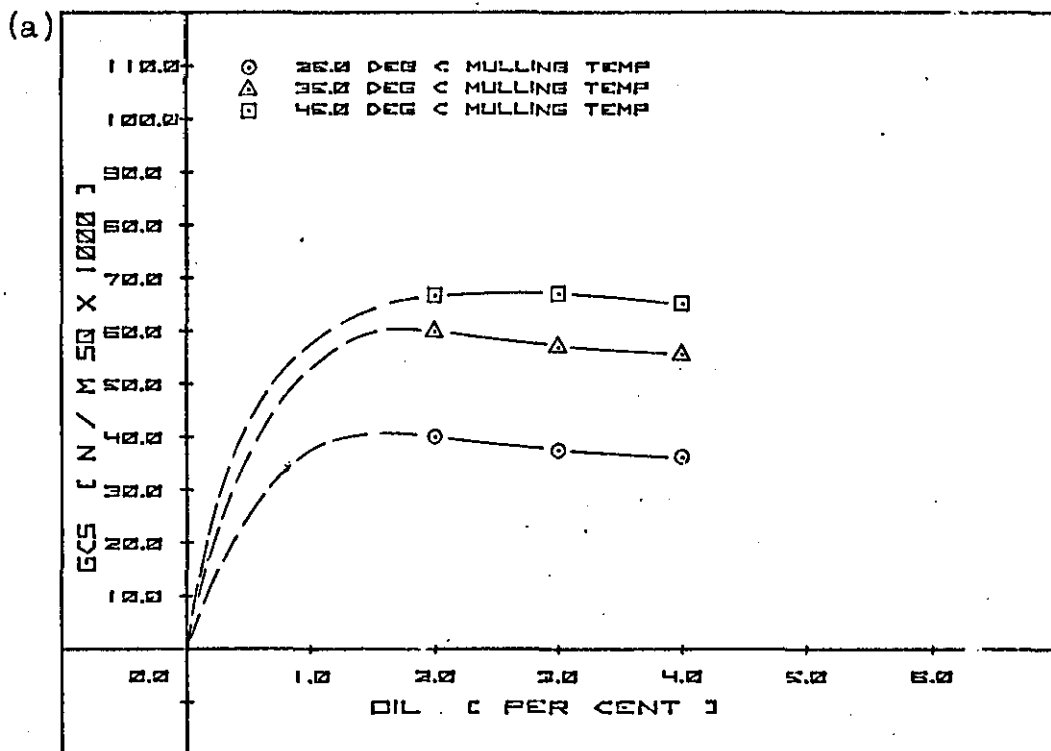


Fig. 44 Effect of oil on green compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

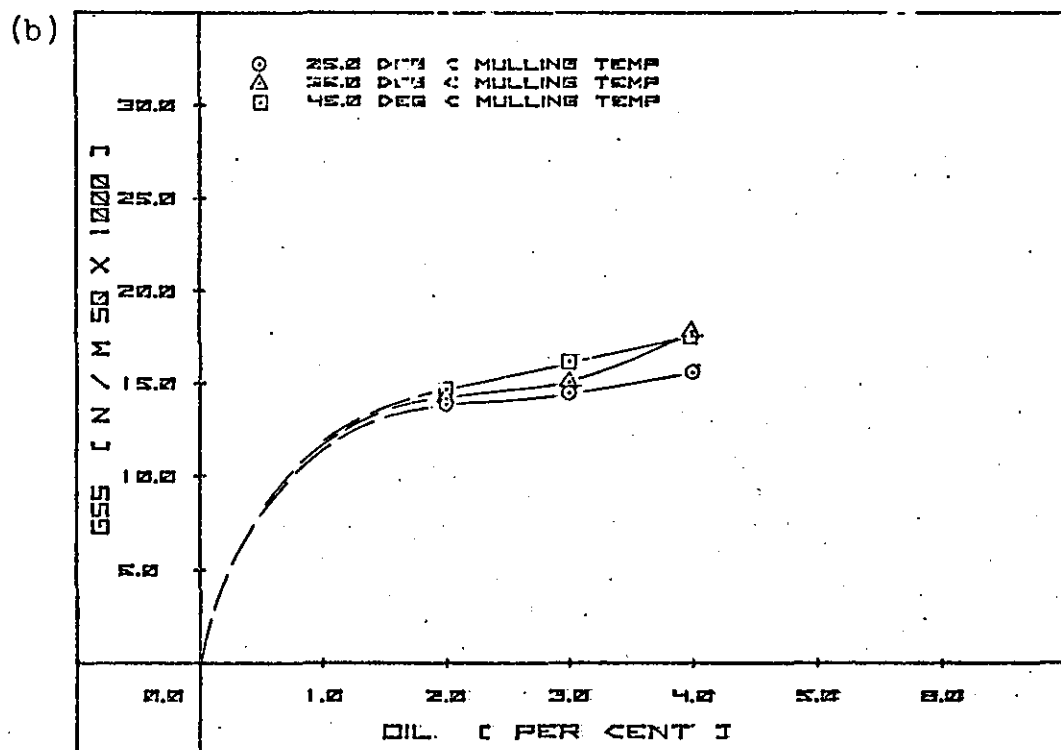
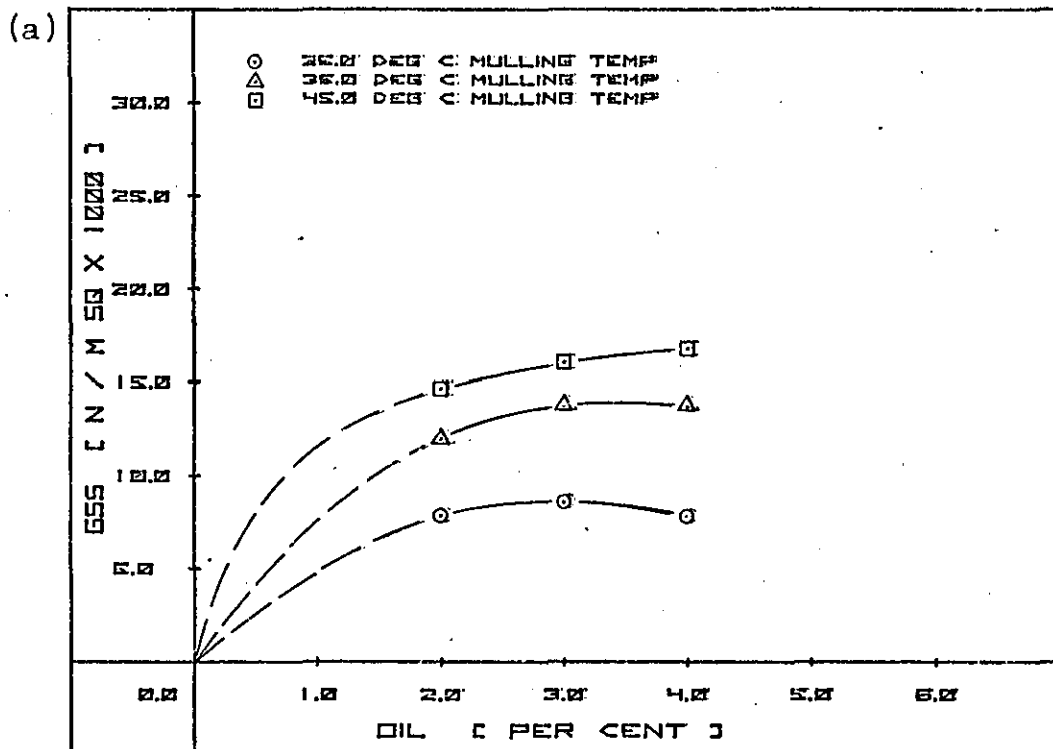


Fig. 45 Effect of oil on green shear strength, (a) without polar additive, (b) with 0.5 per cent methanol.

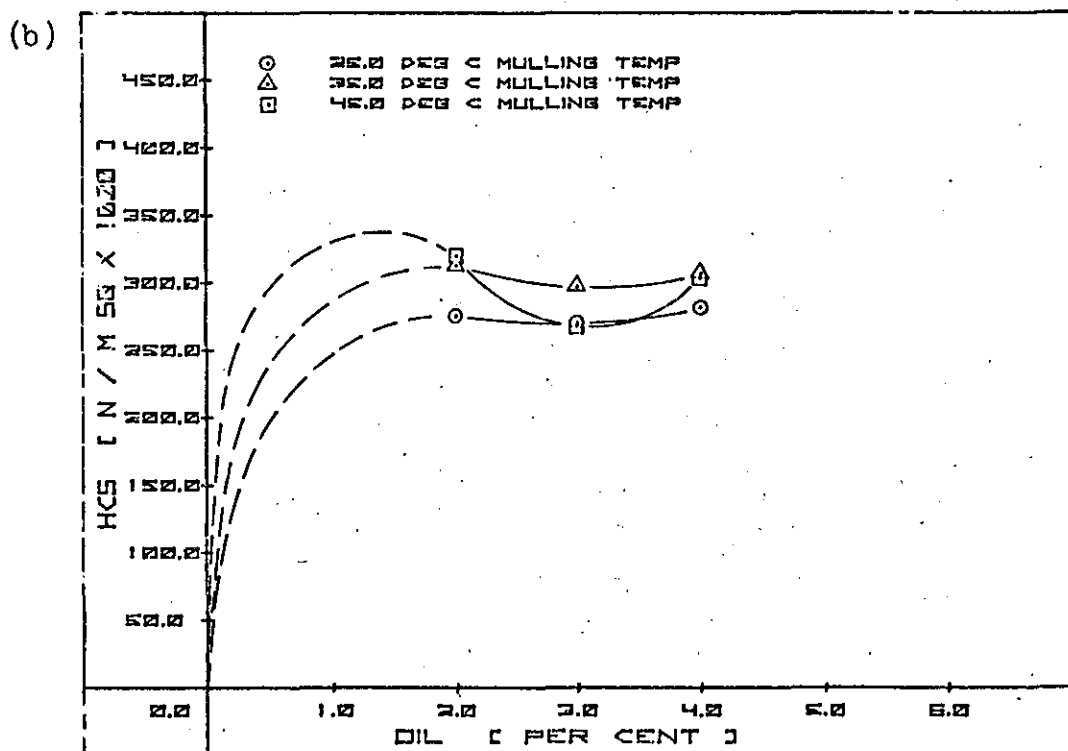
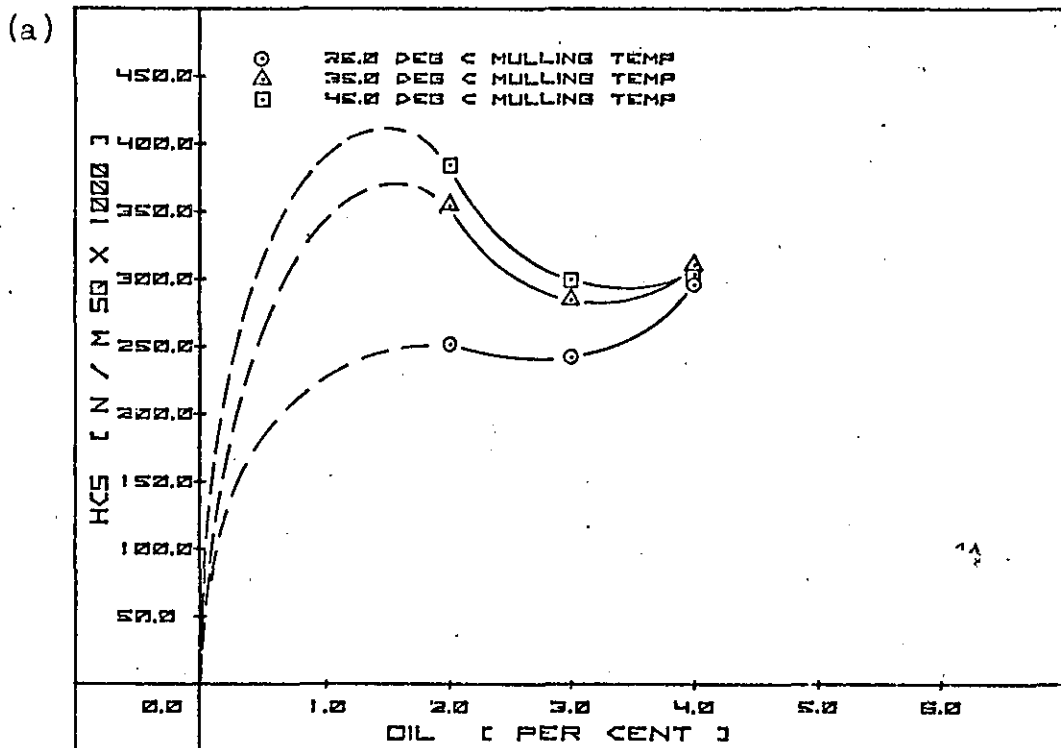


Fig. 46 Effect of oil on hot compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

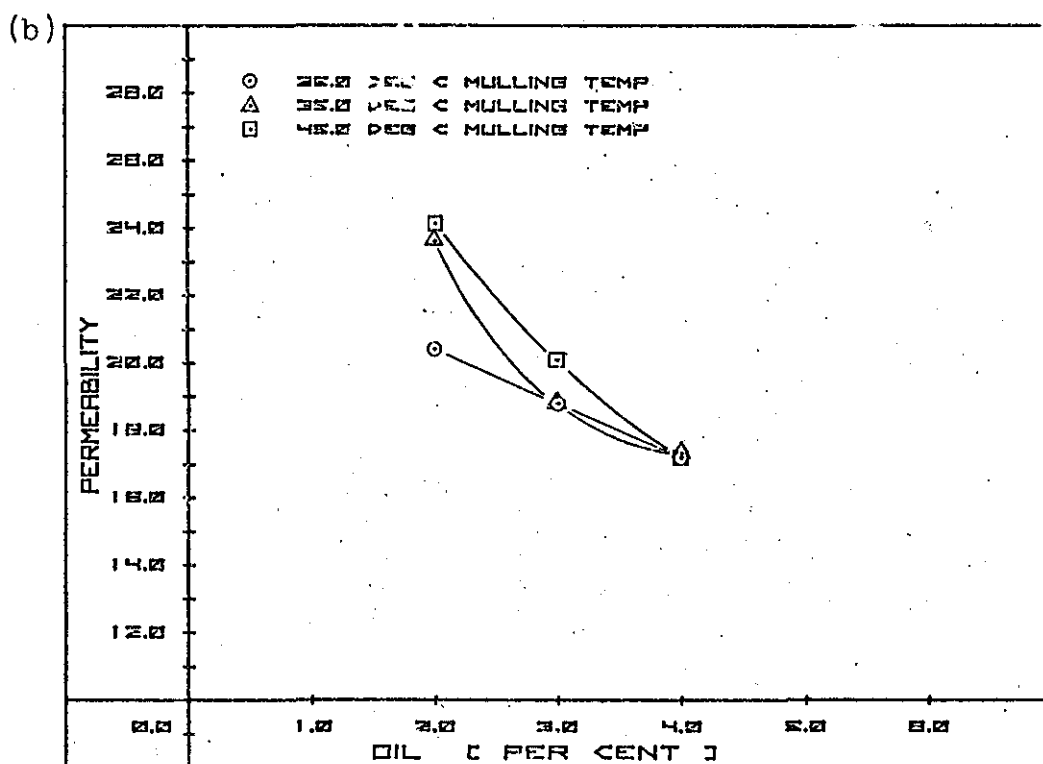
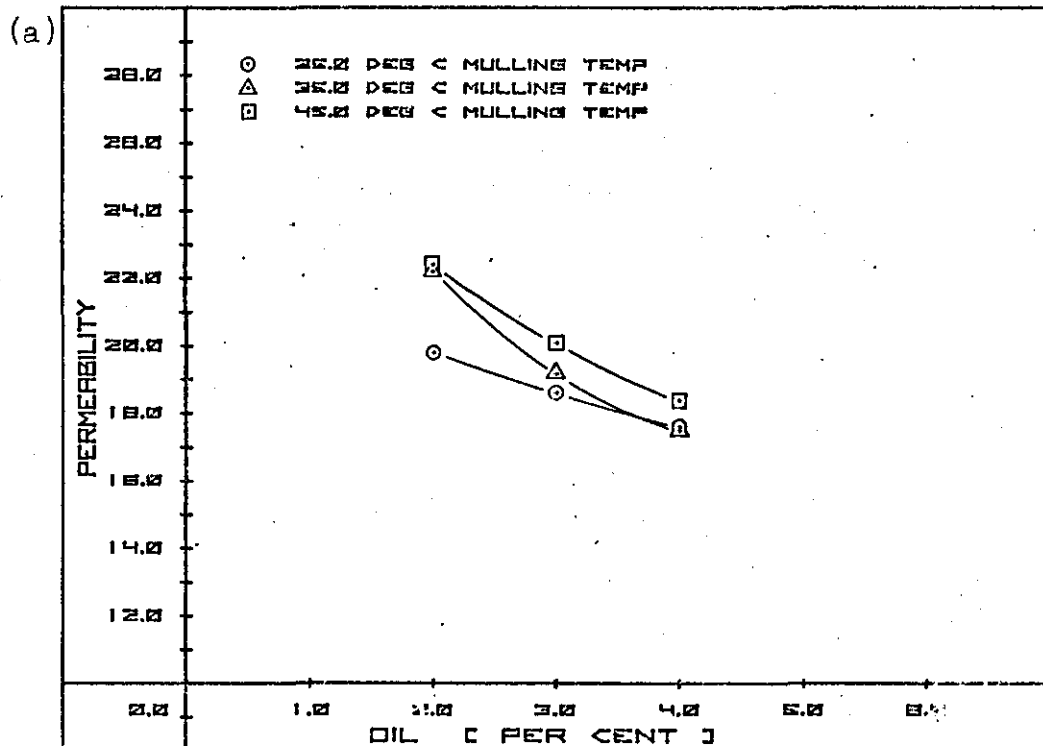


Fig. 47 Effect of oil on permeability, (a) without polar additive, (b) with 0.5 per cent methanol.

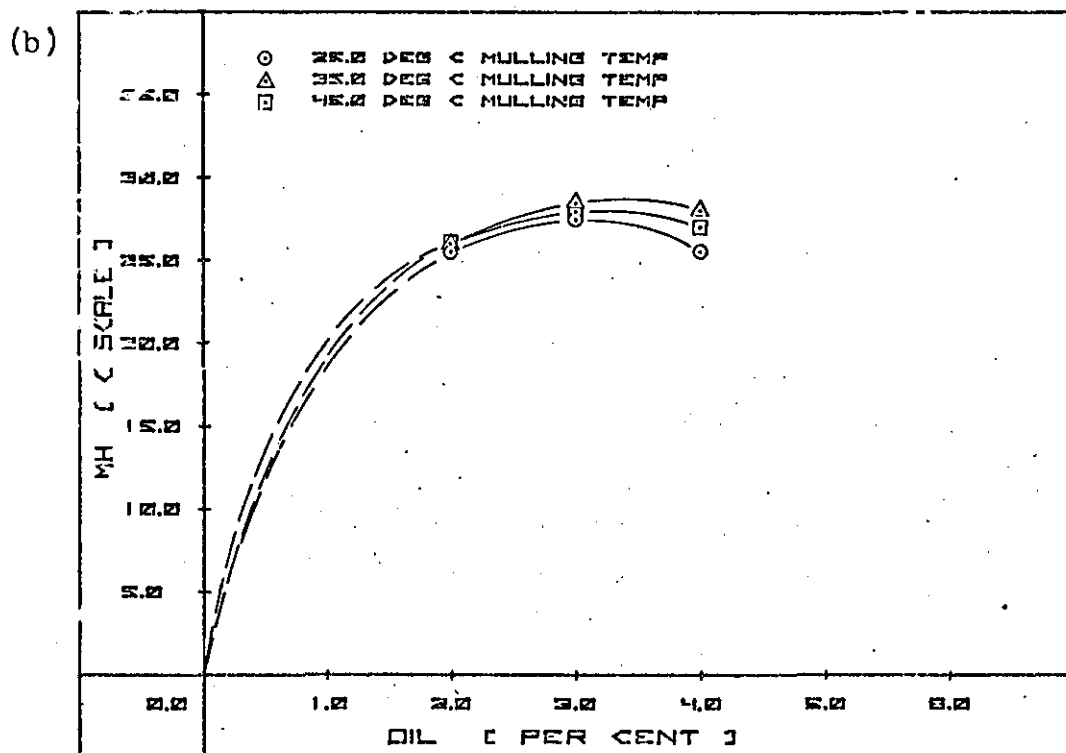
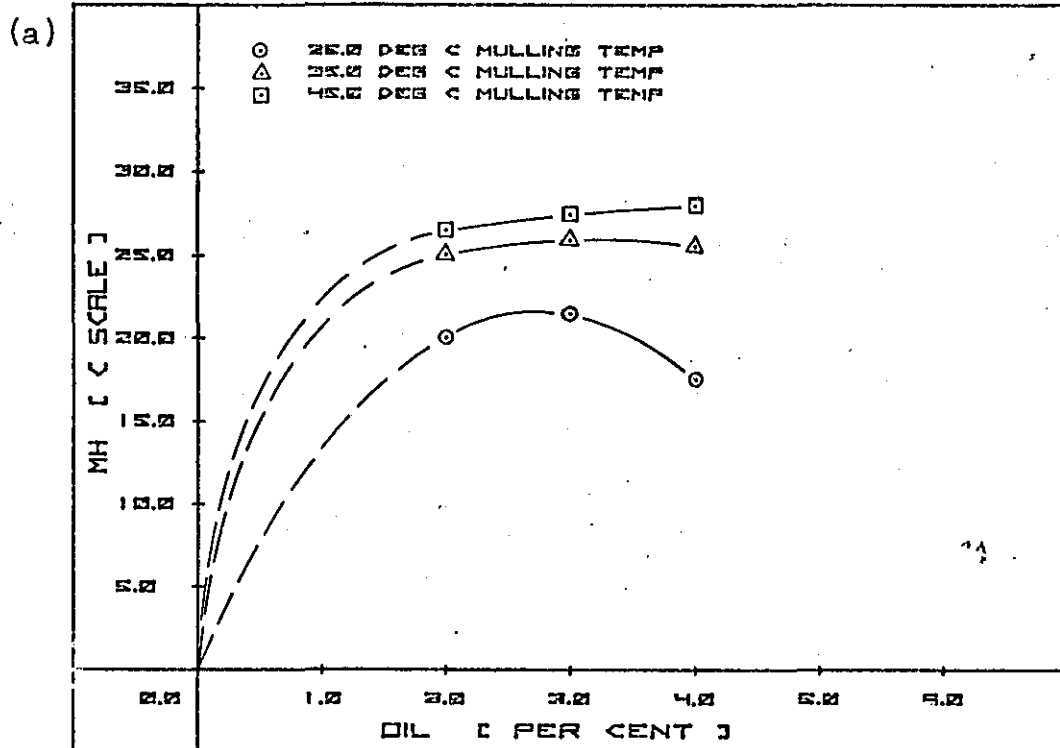


Fig. 48 Effect of oil on mould hardness,
 (a) without polar additive, (b) with
 0.5 per cent methanol.

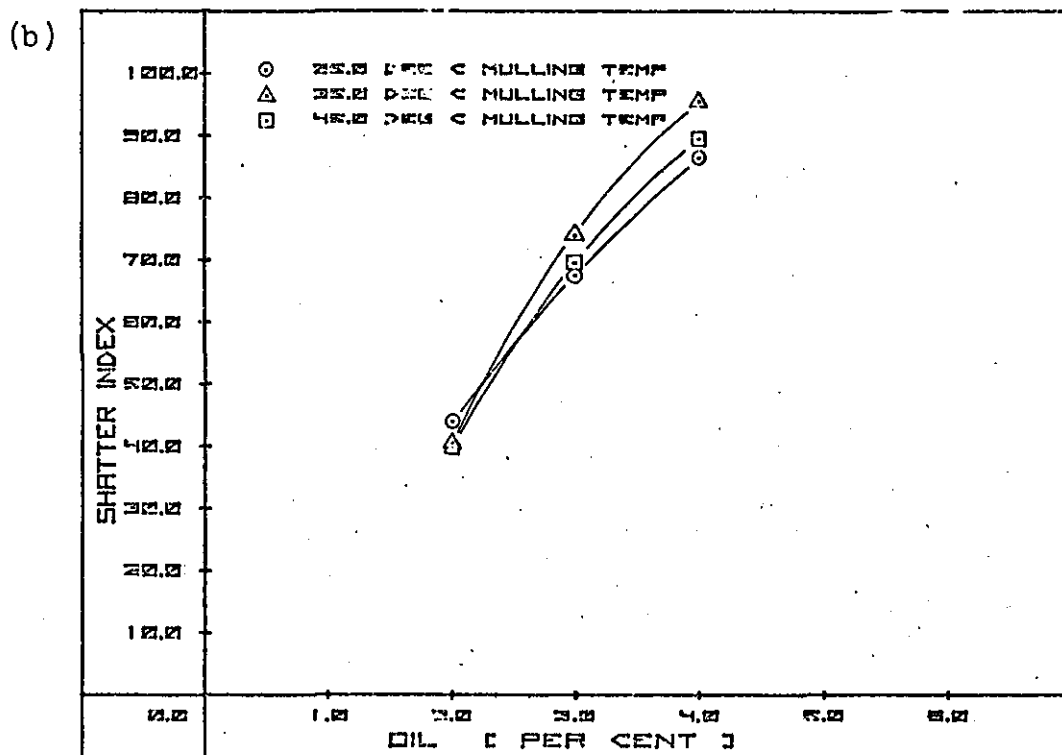
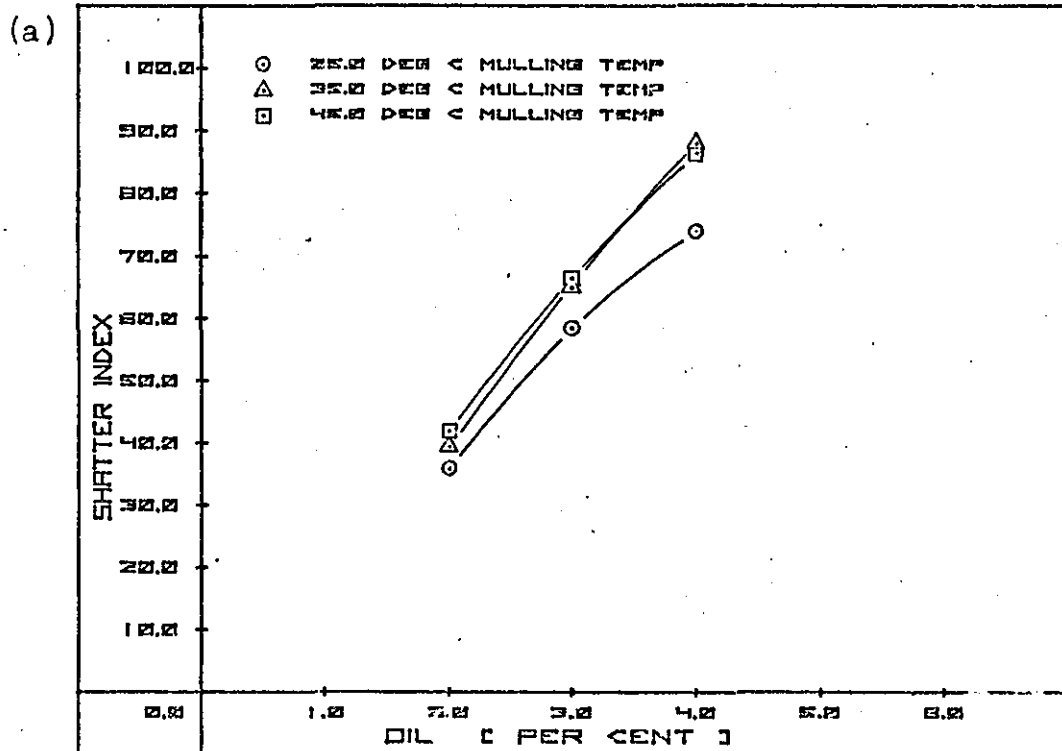


Fig. 49 Effect of oil on shatter index, (a) without polar additive, (b) with 0.5 per cent methanol.

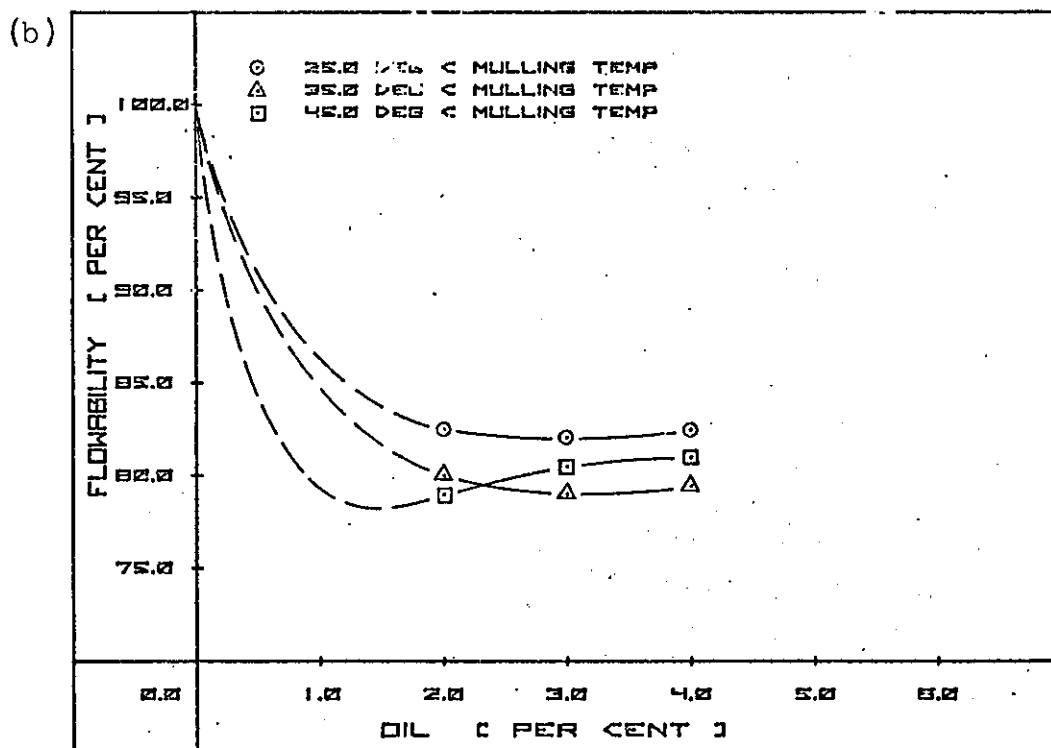
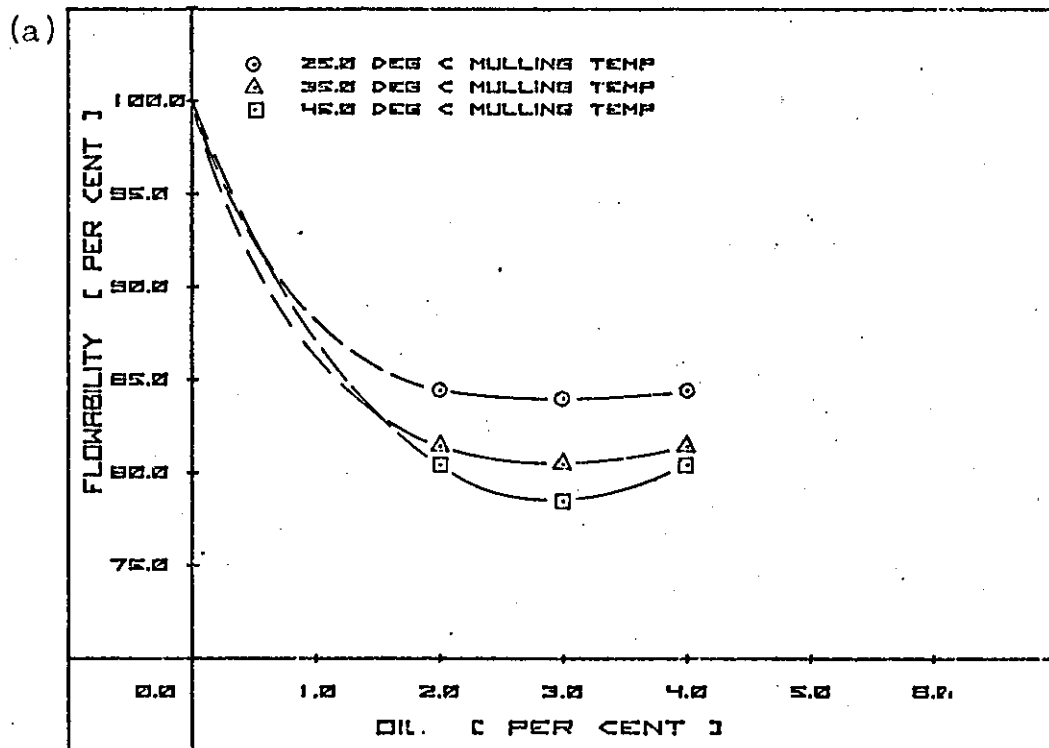


Fig. 50 Effect of oil on flowability, (a) without polar additive, (b) with 0.5 per cent methanol.

in strength. The use of lower mulling temperatures and the absence of methanol resulted generally in low overall strengths with peaks occurring at oil contents of less than 2 per cent, greater amounts of oil causing slight decreases in strength.

Green Shear Strength:

In all but the sand mixes mulled under poor conditions, i.e., at low temperature, without a polar additive, the green shear strength was found to increase very slightly as the oil content of the mix was increased from 2 to 4 per cent. Those mulled at low temperature without methanol reached a maximum and thereafter decreased slightly in strength.

Hot Compression Strength:

An increase in the oil content of a mix from 2 to 3 per cent caused a decrease in the hot compression strength. Subsequent additions up to 4 per cent effecting an increase. The highest strengths were obtained in mixes mulled at high temperature without a polar additive and containing 2 per cent or less of oil. Under these conditions, however, an increase in oil content caused a most marked decrease in hot compression strength and ultimately with a 4 per cent addition, the sand mixes, no matter what the mulling temperature, produced test pieces of very similar strength.

When using a 0.5 per cent methanol addition the effect of increasing oil additions was less marked and, with the exception of the 45°C mulling temperature, gave relatively constant strengths irrespective of oil content. The reason for the aforementioned exception is not clear and may be the result of experimental error. All mixes containing 4 per cent oil, no matter what the condition of mulling exhibited similar hot compression strength.

Permeability:

This property decreased as the oil content of the mix was increased. This effect was most noticeable on the efficiently mulled mixes i.e., those containing 0.5 per cent methanol mulled at high temperature. It was noted that all mixes containing 4 per cent oil were of similar permeability whatever the mulling conditions.

Mould Hardness:

In all mixes mulled with 0.5 per cent methanol the mould hardness was found to increase with increasing oil content, thereafter there was a slight reduction.

In the absence of a polar additive mould hardness values were not so great. At high mulling temperatures a gradual increase in hardness values was obtained as the oil content was increased, however, at the mulling temperature of 25°C the maximum was reached at an oil

content of about 2.7 per cent further additions decreasing the hardness value.

Shatter Index:

Increasing oil contents markedly increased the shatter index in an almost linear fashion. This effect was at its greatest with mixes containing 0.5 per cent methanol, muller at 35°C. Presumably at the higher temperature of 45°C some effectiveness of the polar additive was lost due to evaporation. The smallest rate of increase was obtained at the lowest mulling temperature in the absence of a polar additive.

It was interesting to note that variations of 2 to 4 per cent water in a clay/water bonded sand system would only give very slight increases in the shatter index.

Flowability:

This property remained relatively constant over the range of oil contents tested, though at mulling temperatures of 45°C a slight increase of flowability was evident, this being most noticeable in the presence of 0.5 per cent methanol.

It was obvious from this work that the oil contents of the sand mixes were not greatly affecting the strengths, but by increasing the ability of the test piece to deform without breaking

increased the toughness as illustrated by the values of the shatter index.

Since it was found in the previous section that variations in clay increased the strengths of the test pieces whilst leaving the shatter index relatively unchanged, it would appear that these two properties can be controlled independently simply by adjusting the clay and oil contents of the mixes. This theory is dealt with in greater detail in 7.10. As can be deduced from previous remarks comparing the effect of varying the clay and water content of the conventionally bonded green sand system, this independent control of green strengths and shatter index would not be possible.

As the oil content of the sand mix was increased the clay would be subjected to a swelling action, thus decreasing the volume of the voids between the sand grains. Since the strength and the flowability of the mix remained relatively constant it would be assumed that the specimens were rammed to approximately the same density regardless of oil content and thus the permeability would, by virtue of the swelling of the clay, be reduced with increasing oil additions. This is borne out in the results.

7.7.8. Effect of Mould Temperature Variation

The results of this investigation are shown in Table 16. By comparing the physical properties of the sand rammed at 15°C and tested at 45°C with those of sand rammed and tested at 15°C and shown in Table 15 it can be seen that by allowing a mould to

Table 16

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	5.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	Rammed and tested at varying temperatures Mulled at an average of 30.0°C

SAND MIX No.	310	311
RAMMING TEMPERATURE (°C)	15.0	45.0
TESTING TEMPERATURE (°C)	45.0	15.0
SPECIMEN WEIGHT (g)	156	159
GREEN COMPRESSION STRENGTH	34.5 35.2 35.2	135.8 135.8 135.1 140.7
(N/m ² x 10 ³)		
Average	34.9	136.9
GREEN SHEAR STRENGTH	9.7 10.0 9.3 10.3	35.9 35.9 37.9 38.6 34.8
(N/m ² x 10 ³)		
Average	9.8	36.6
PERMEABILITY	18.5 17.8 18.6	19.8 19.8 19.5
(small orifice)		
Average	18.3	19.7
MOULD HARDNESS	15. 17 16	39 42 42
('C' scale)		
Average	16	41
SHATTER INDEX	74 74 76	90 91 91
Average	75	90

Table 16

warm up the green compression strength, green shear strength and mould hardness were all considerably decreased in value. In addition, permeability suffered a slight decrease whilst shatter index was found to have increased.

A similar comparison between the properties of sand rammed at 45°C and cooled to 15°C before testing with those results obtained from a sand which had been both rammed and tested at 45°C shown in Table 15 shows that green compression strength, green shear strength and mould hardness were greatly increased, whilst permeability was found to increase only slightly. The shatter index, however, showed little variation with the temperature change.

It was not possible within the scope of this research to investigate the physical properties of the clay and oil mixture alone and so, in trying to explain some of the above phenomenon the system can only be discussed on a macro scale and even in this some suppositions have had to be made.

Morgan⁽²⁷⁾ put forward a theory for the bonding of sand grains with a clay and water mixture, pointing out that after mulling the clay does not lie as a smooth film around the grain but in the form of a series of peaks and ridges formed by the continual drawing out and breaking of the bonds during the mulling operation. The physical appearance of these ridges was found to be dependent on the clay/water mix. At low water content the bonds or bridges between the sand grains fractured with little necking down leaving a sharp ridges round the breaking plane. At higher

water contents the clay film was less viscous and the bridges necked down before breaking leaving peaks of clay which subsequently slumped to give a smoother undulating film around the sand grain. These results were supported with scanning electron micrographs.

It was noted that the viscosity of the organo-clay/oil bond used in this work not only varied with the ratio of oil to clay, but also with the temperature of the mix. It can be seen that the viscosity of the oil (section 4.6) varies greatly with the temperature and this is undoubtedly the major reason for this effect. A cold sand mix was found to be dry and powdery whilst the same mix became progressively wetter in appearance and stickier to the touch as the temperature was raised.

This theory of bonding put forward by Morgan explained well the variations in many of the physical properties of sand mixes rammed at one temperature and tested at another.

The clay ridges and peaks formed during mulling will have a high viscosity and rigidity when cooled. Thus on ramming in the standard manner relatively little deformation will take place and the contact area will be small. On warming the rammed specimen the viscosity will decrease and will easily deform and break under load. Thus the strength as reflected in the green compression strength, green shear strength and mould hardness would be reduced. This can be seen by comparing these results with those obtained with specimens both rammed and tested at 15°C which should have had the same contact area. It was interesting to note that the strengths at

45°C were also less than those obtained from the specimen not only tested but rammed at this temperature. In this instance since the viscosity of the bond would be the same the effect of the small contact area of the bond can be seen. Despite the reduction in the strength the shatter index was found to be increased by heating the test piece and this can no doubt be attributed to the greater ability of the bond to deform because of its reduced viscosity. However, when comparing the results with those of the test piece both rammed and tested at 45°C it was found that because of the smaller contact areas within the heated test piece the shatter index was lower.

At the high ramming temperature, the peaks around each sand grain would be weaker and easily deformed giving large areas of contact. On cooling the viscosity and strength of the bond would increase and this is clearly shown when comparing the strength results obtained with those of the test pieces both rammed and tested at 45°C which should have the same contact area between each sand grain. The effect of the greater contact area can be seen by comparing the results with those obtained from test pieces both rammed and tested at 15°C which should have the same bond viscosity at test.

Since on cooling, the resistance to deformation was decreased, it might be expected that the shatter index would also decrease. However, since the strength of a test piece also has a bearing on this value its large increase was the probable cause of it being almost unaffected by the reduction in temperature. Certainly, on impact during the test the base of the test piece was

seen to crumble but the remainder was left completely intact with none of the deformation seen with the high temperature tests, its strength being sufficient to cope with that part of the shock loading not adsorbed by the contact face. The variations in permeability were slight but may be explained by an expansion or contraction of the clay and oil bond during the heating or cooling of the test piece respectively. It was indeed noted that those specimens rammed at 45°C and left in the specimen tube during cooling had been reduced in size slightly and slid easily from the tube at 15°C.

7.7.9. Effect of Storing the Moulding Sand

The variations found in the physical properties of the moulding sand during the period of storage tested were generally not very great and therefore the plotting of graphs was found to be of little value. The results obtained have, however, been listed and appear in the appendix in tables (xxi)-(xxviii) those results found immediately after mulling being shown in tables (vii)(viii) (xv) and (xvii).

Trends, where found, were generally slight and associated with the efficiency of the mulling procedure used when the mix was originally made. Green compression strength, green shear strength and mould hardness were seen to increase if the mulling conditions had been poor, i.e., low mulling temperatures, short mulling times and absence of a polar additive. Conversely, when mulling conditions were good the values of these three properties tended to fall slightly.

The hot compression strength showed no definite trends though a few significant variations in values were noted which can only be attributed to experimental error.

The shatter index showed a general slight decrease in value with storage particularly if the mulling conditions had been good. Flowability, on the other hand, exhibited a slight increase during storage when similar mulling conditions had been used.

It would appear, therefore, that although some slight change had occurred in the bond during storage, it was not significant enough to be of any detriment to the moulding material nor would it suggest that any longer periods of storage would render the material of no use.

7.7.10. Effect of the Surface Conditions of the Muller

Some difficulty was experienced in maintaining the pan and roller surfaces of the muller in a suitably rough condition for an efficient mulling action. Two different methods of roughening the mulling surfaces were used during the experimental work which were both effective for a limited period of use. However, since it was not known how the efficiency of mulling varied with the degree of roughness three control tests were carried out. The first, series A, was made at the start of mulling with a shot blasted surface, the second, series B, after some use of the muller and the surface was showing signs of becoming smooth, the third, series C, after remedial action had been taken by grinding radial groove in the pan and peening the surfaces of the rollers. Similar tests

were carried out at corresponding intervals using the same sand mix and mulling time but including an addition of methanol, these being referred to as series D, E and F. The results are given in the appendix as tables (vii)(viii)(xxix)(xxx)(xxxi)&(xxxii) each series being made up of the following sand mix Nos:

Series A	Sand mix Nos. 147, 153, 151, 149, Table(xxix)
Series B	Sand mix Nos. 261, 264, 263, 262, Table(vii)
Series C	Sand mix Nos. 276, 279, 278, 277, Table(xxx)
Series D	Sand mix Nos. 167, 166, 168, 169, Table(vii)
Series E	Sand mix Nos. 265, 268, 267, 266, Table(xxxi)
Series F	Sand mix Nos. 280, 283, 282, 281, Table(xxxii)

These results have been used to form the graphs shown in Figs. 51 to 57.

Those results for green compression strength, green shear strength, hot compression strength and mould hardness showed only slight variations the largest of which usually occurred in the low mulling temperature region and none of which were significant enough to greatly affect the trends in the graphs derived from these or any other physical property results.

Permeability results do show some apparent wide variations which, whilst not significant as regards the performance of the moulding sand in practice, because of the very small range of the permeability scale in which they occur, they could affect the graphical trends as shown throughout this work. This fact has, however, already been pointed out, all but the strongest trends in the results being treated with caution.

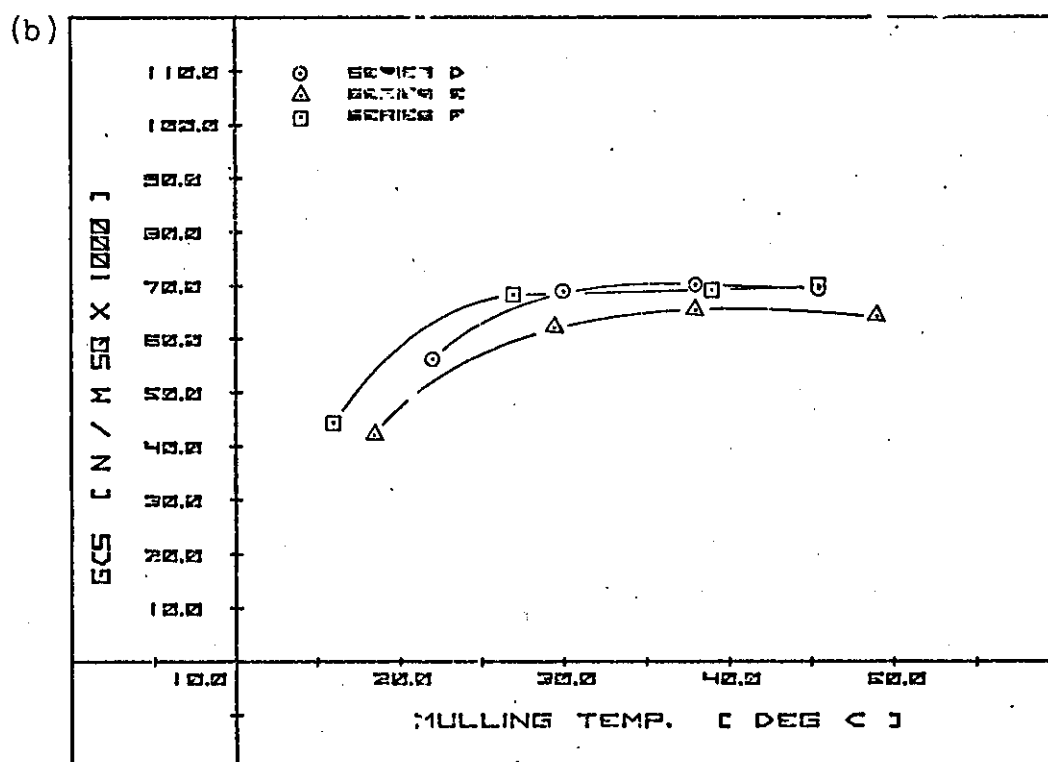
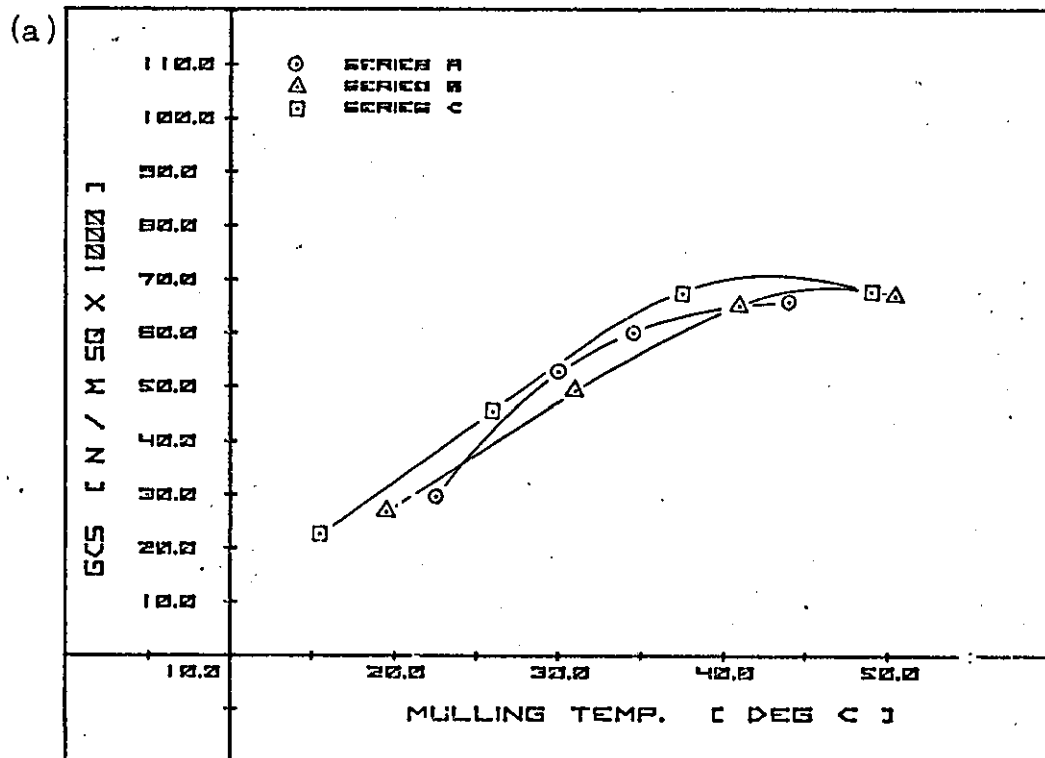


Fig. 51. Effect of mulling temperature on green compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

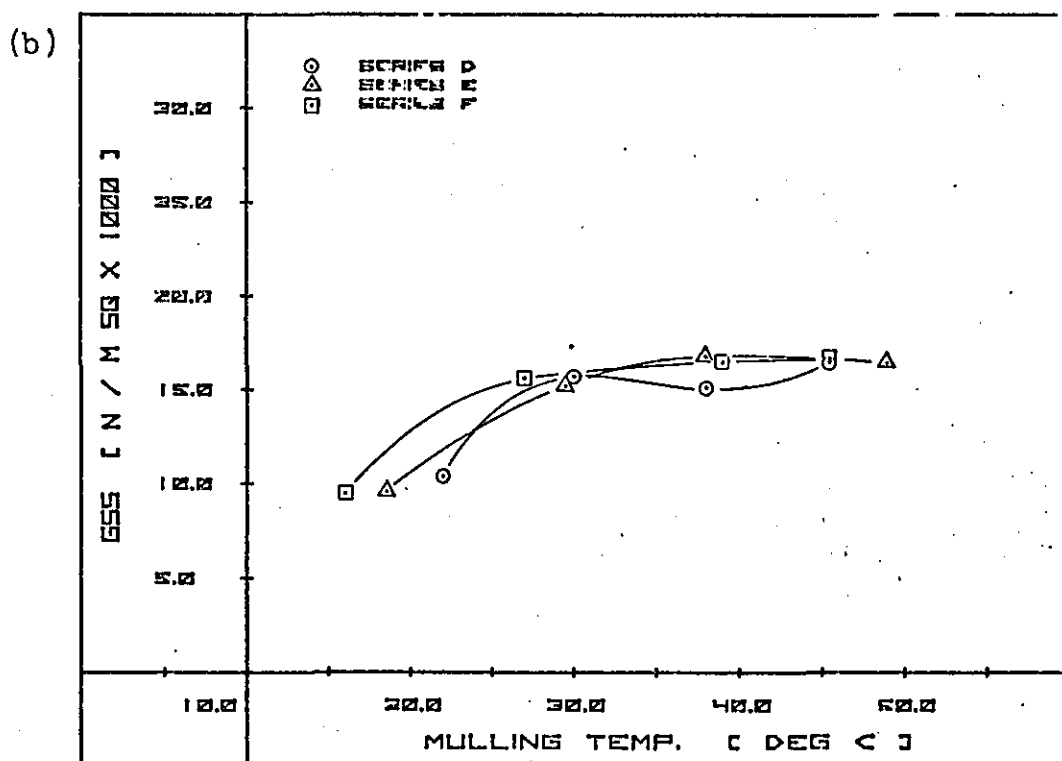
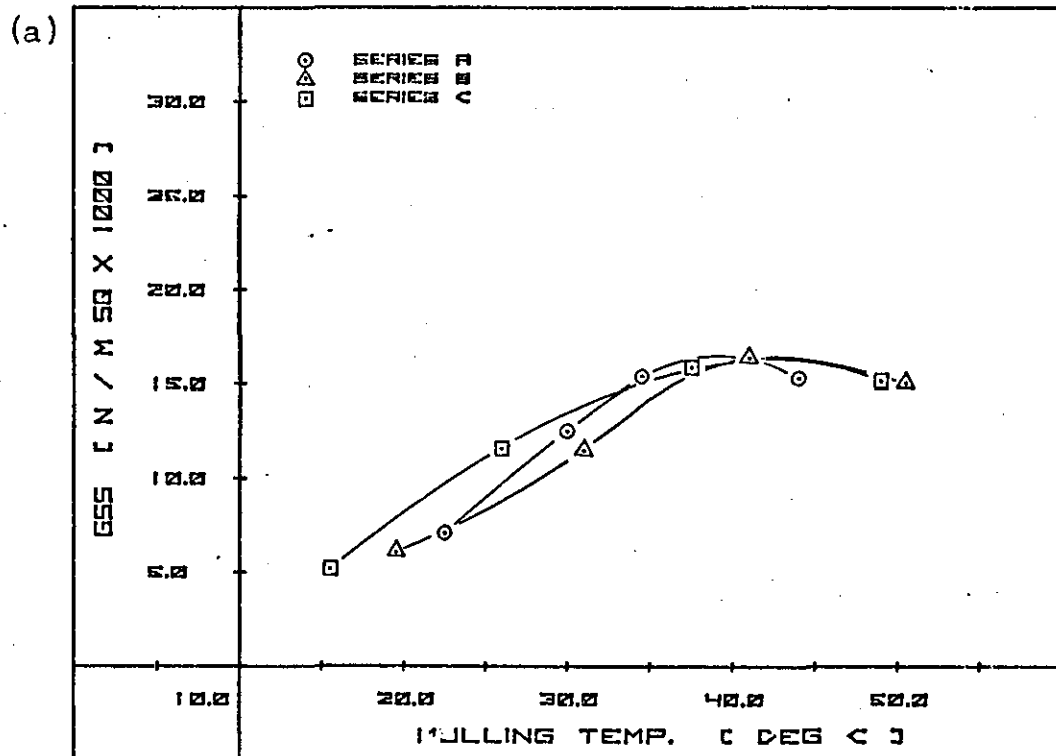
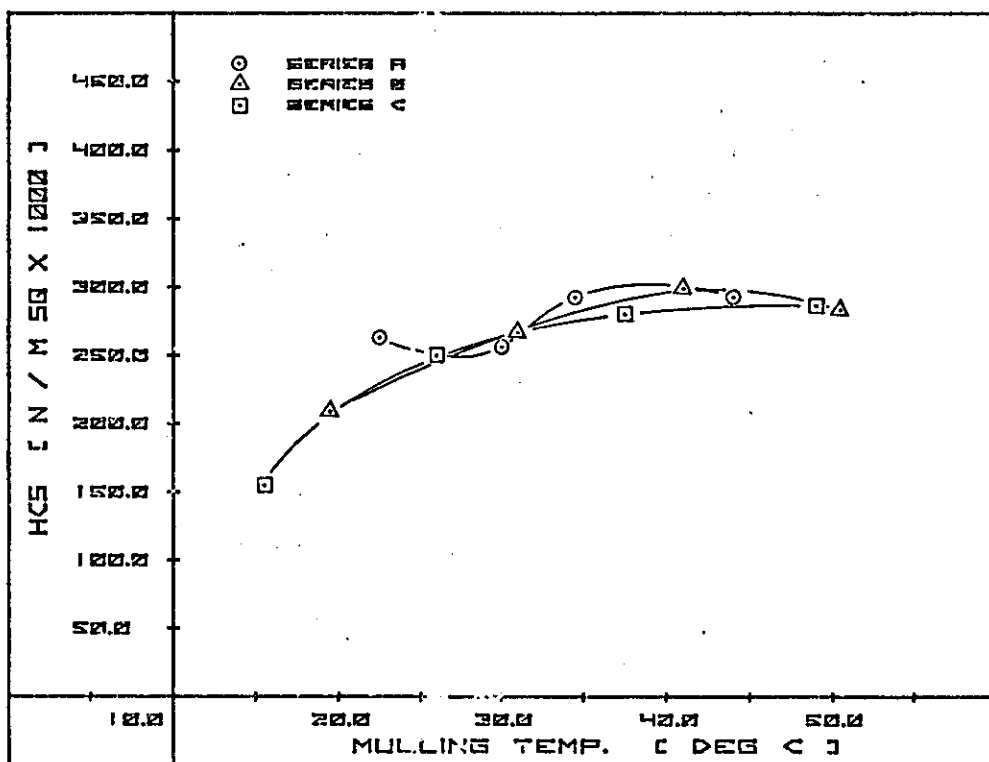


Fig. 52 Effect of mulling temperature on green shear strength, (a) without polar additive, (b) with 0.5 per cent methanol.

(a)



(b)

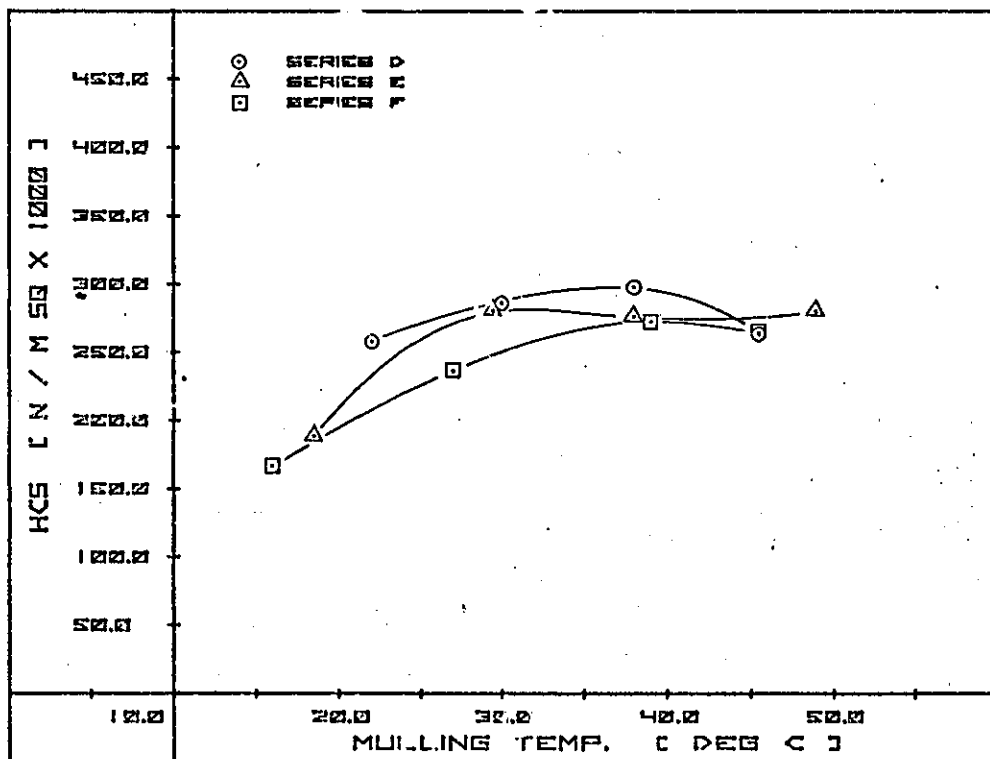


Fig. 53 Effect of mulling temperature on hot compression strength, (a) without polar additive, (b) with 0.5 per cent methanol.

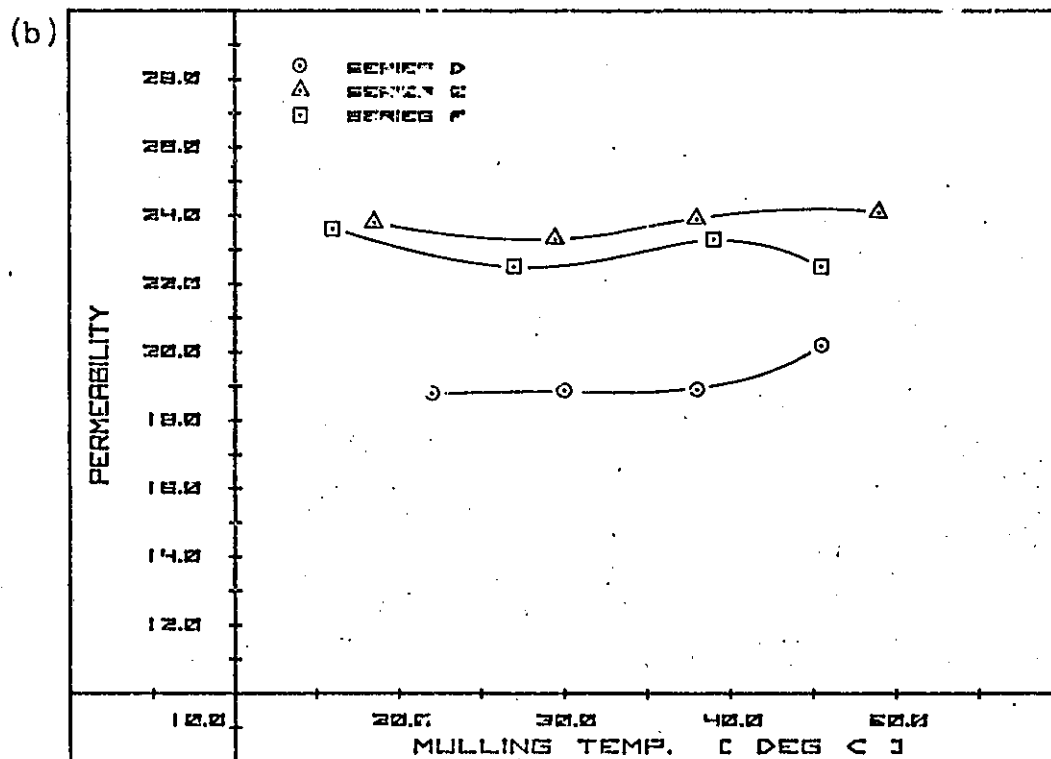
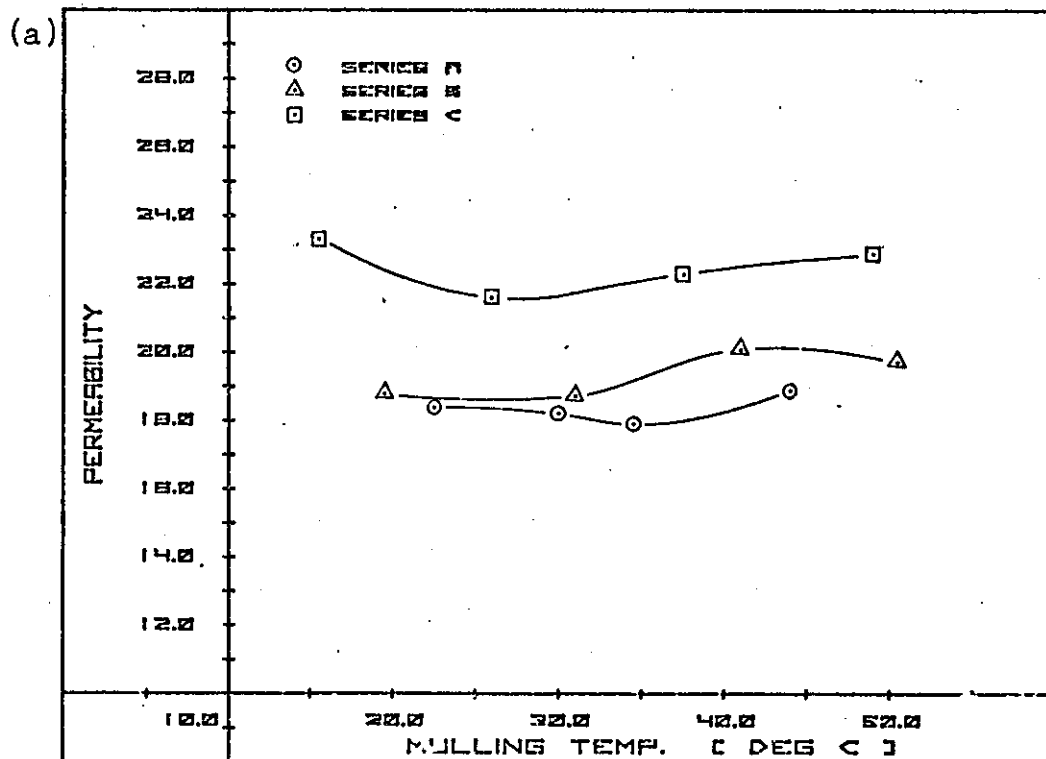


Fig. 54 Effect of mulling temperature on permeability, (a) without polar additive, (b) with 0.5 per cent methanol.

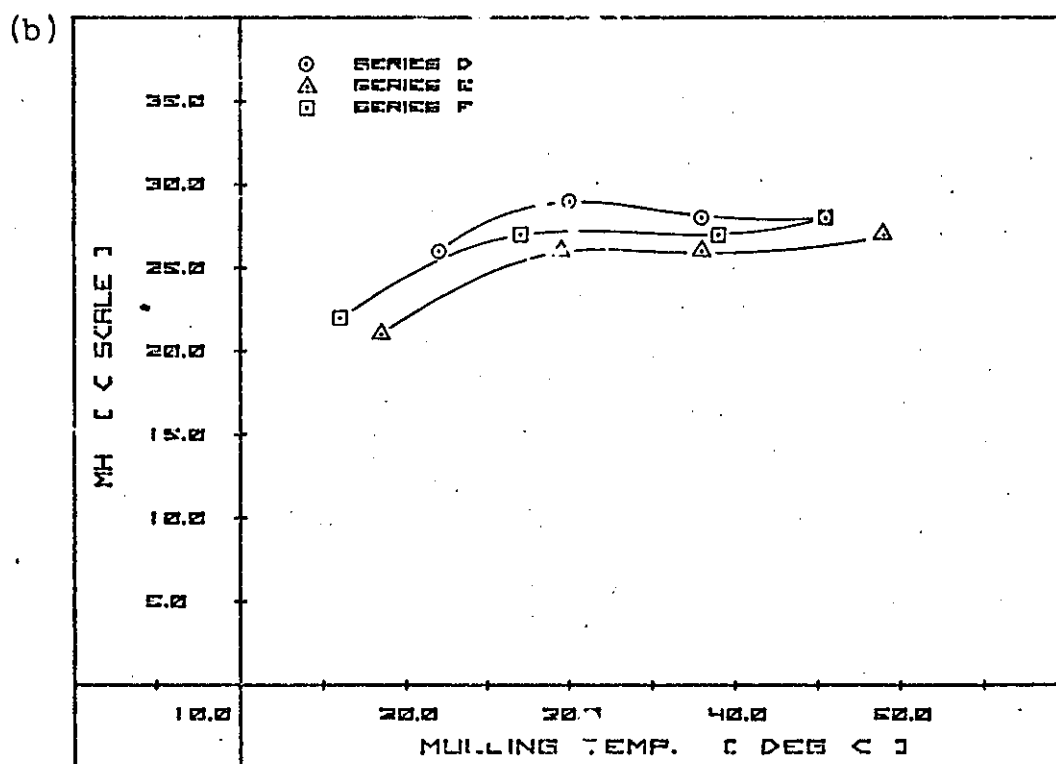
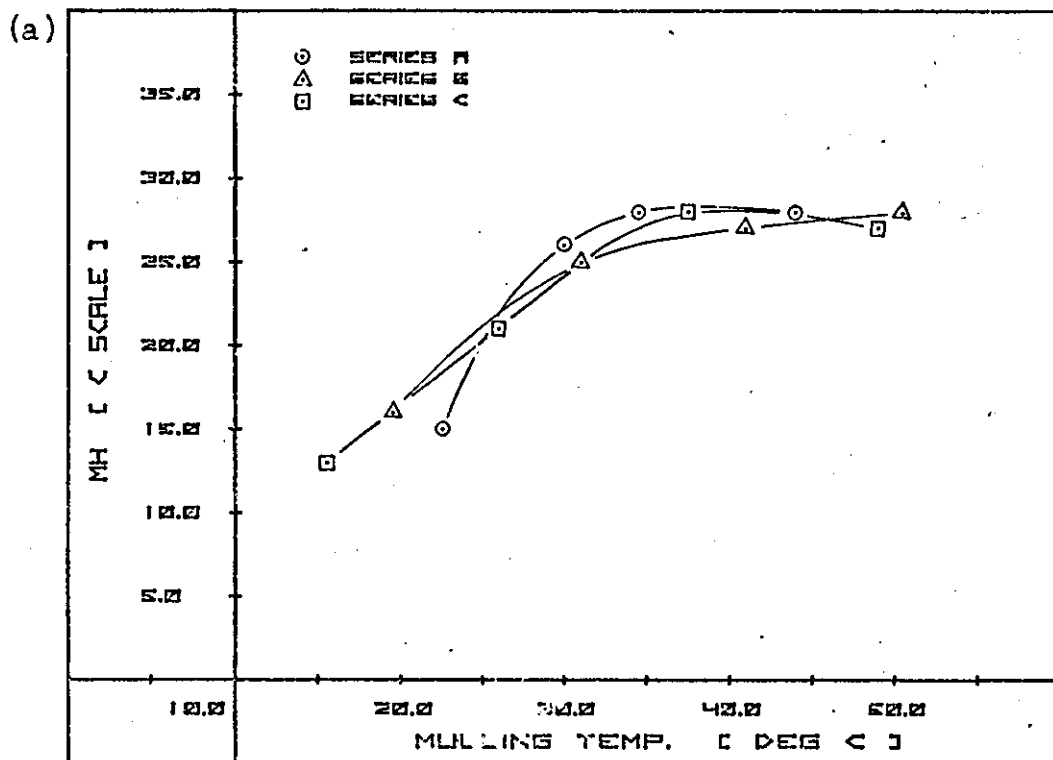


Fig. 55 Effect of mulling temperature on mould hardness, (a) without polar additive, (b) with 0.5 per cent methanol.

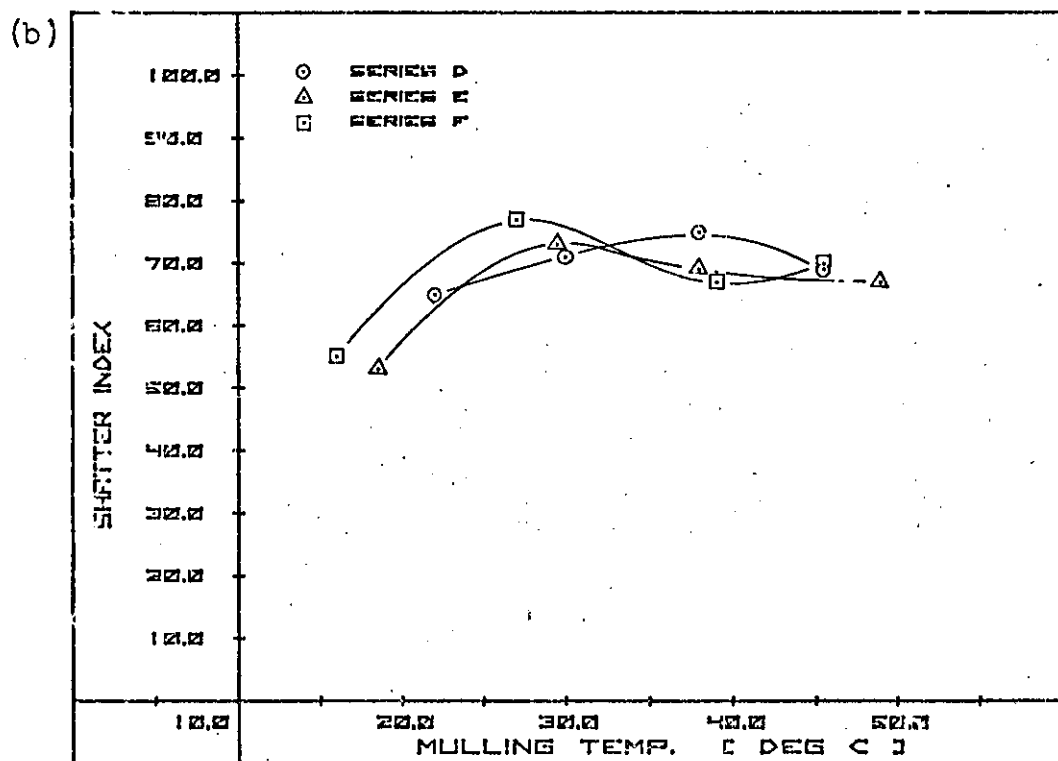
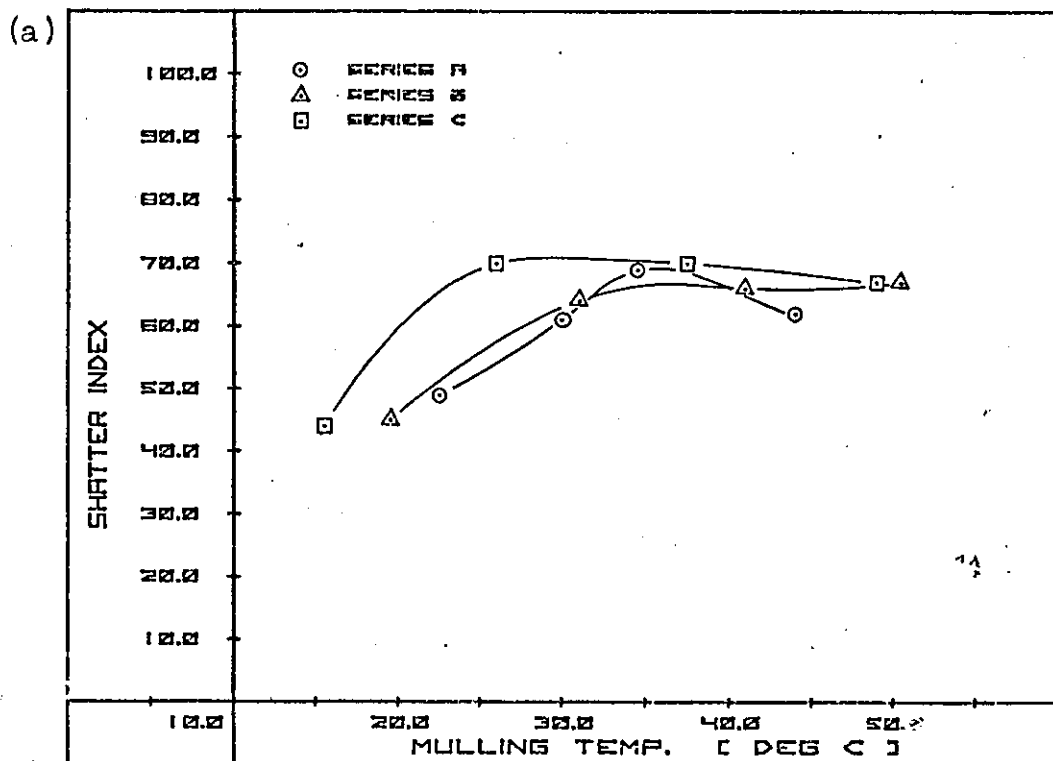


Fig. 56 Effect of mulling temperature on shatter index, (a) without polar additive, (b) with 0.5 per cent methanol.

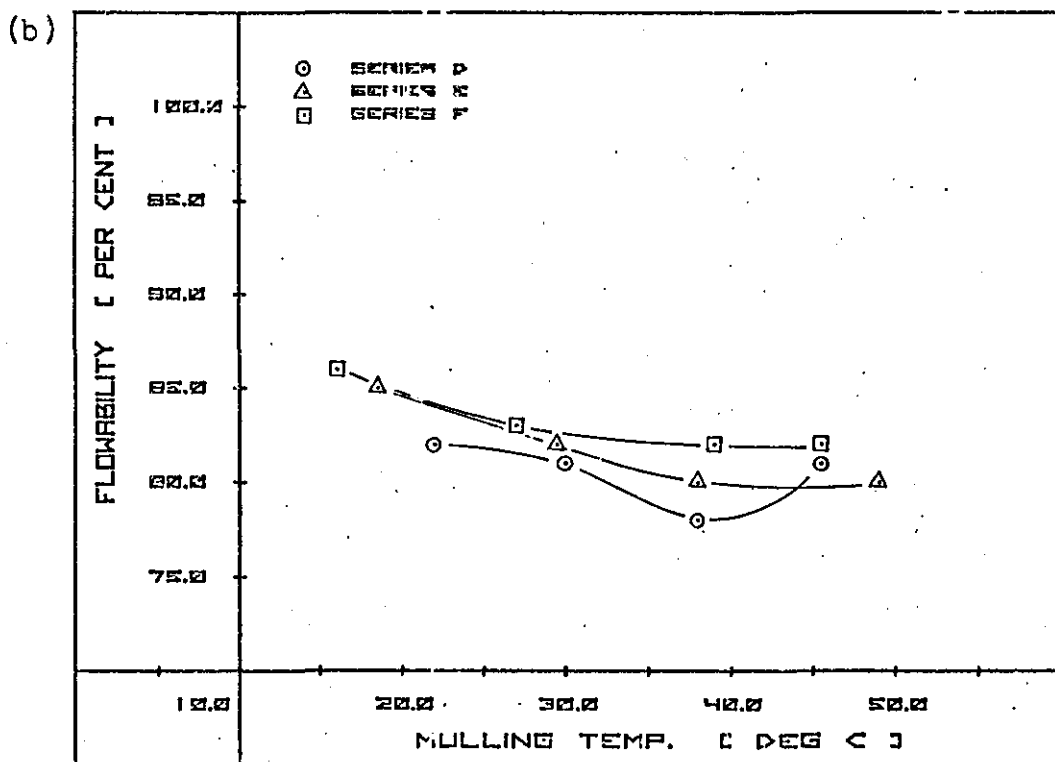
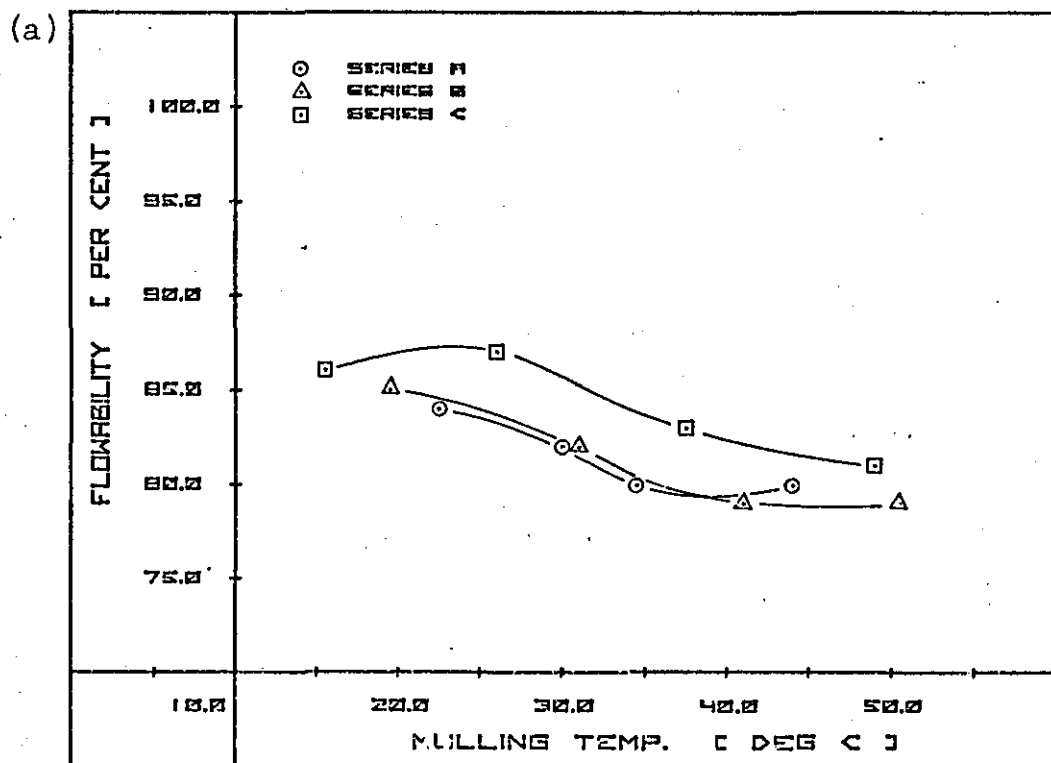


Fig. 57 Effect of mulling temperature on flowability, (a) without polar additive, (b) with 0.5 per cent methanol.

The shatter index was, in most cases, relatively reproducible the main variations occurring as with the strength tests in the low mulling temperature regions of the graphs where the property was still being developed.

Flowability showed some variations and therefore it must be noted, as with the permeability results, that all but the strongest trends noted in flowability should be treated with caution.

There is some evidence to show when studying green compression strength, green shear strength and shatter index that the radial grooving of the pan and the peening of the rollers as shown in series C and F improved the efficiency of the mulling action. This is particularly evident at the low mulling temperatures whilst at the higher temperatures all the properties tended towards the same value.

There is little evidence to show, however, that when the muller was worn smooth almost to the point of the mulling action ceasing, as shown in series B and E, it was any less efficient in developing the bond than when the muller had just been shot-blasted, the results of which are illustrated by series A and D.

It is thus apparent from this work that if the surface of the muller is sufficiently rough to give a mulling action rather than simply push the mix around the pan in front of the rollers, the quality of the resulting moulding sand should not vary significantly. This fact is particularly true if other mulling conditions are efficient, i.e., by using a temperature of about 30-35°C, a polar additive and a mulling time of approximately ten minutes.

7.8. Effect of Molten Metal on the Mould

The results of casting phosphor-bronze into a mould made of freshly mixed sand can be seen in Fig. 58. This shows a view of the joint face of the cope half of the mould after careful removal of the drag. Six distinct layers of differing colouration could be distinguished surrounding the casting. These may be described as follows in order of increasing distance from the casting:

- (i) Layers of lustrous carbon and sand grains coated in same,
- (ii) sand grains surrounded by sooty carbon,
- (iii) sand grains surrounded by light grey carbonaceous material,
- (iv) layer of dark brown sand,
- (v) layer of light brown sand,
- (vi) unaffected moulding sand.

Loss-on ignition tests were carried out on dry samples of each layer to ascertain how much of the sand might contain re-useable bonding material and also whether any oil vapour had migrated to condense in cooler regions of the mould in the same manner that water migrates in the more conventional clay and water-bonded moulds.

The results of these tests are given in Table 17. Because of the difficulty in collecting samples composed solely of material from one layer only a moderate degree of reproducibility was attained for each of the three tests making up the average loss-on-ignition figure. However, it was considered that the average obtained were accurate enough to be able to draw the conclusions sought.

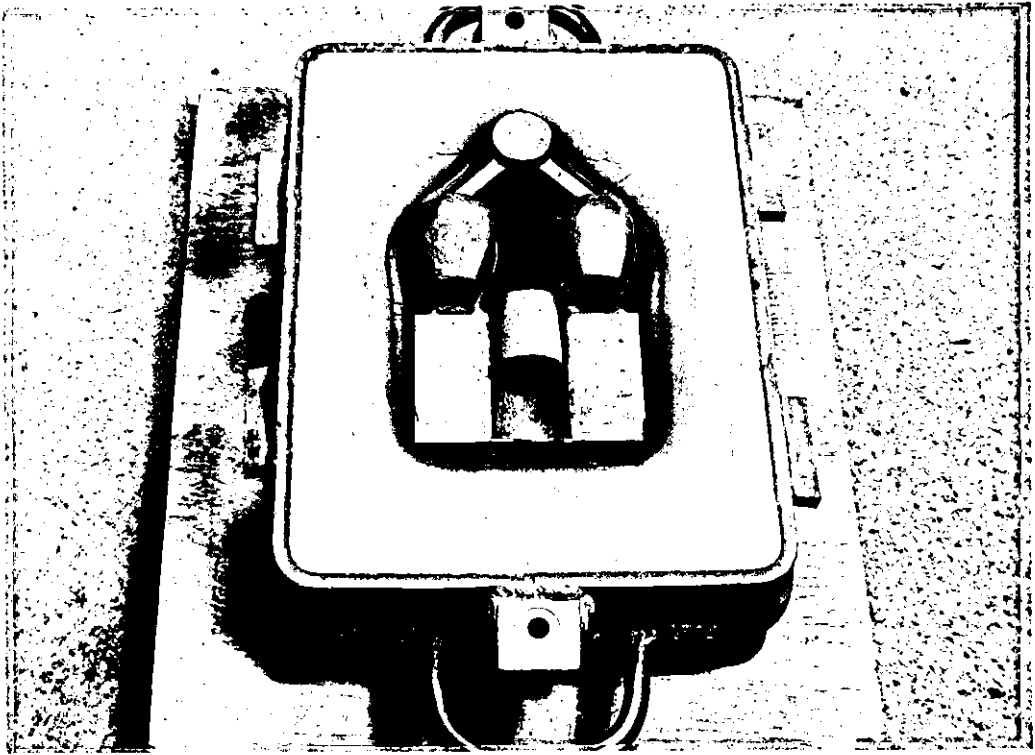


Fig. 58 The cope face of a mould after casting
 showing the phosphor-bronze casting and
 the effect of its heat on the moulding
 sand.

Table 17

LOSS ON IGNITION _____ (PER CENT)
TESTING OF SAND LAYERS SURROUNDING A PHOSPHOR BRONZE CASTING

SAMPLE No.	1	2	3	AVERAGE
LAYER No. 1	1.11	1.17	1.06	1.11
2	0.89	0.85	0.81	0.85
3	1.87	1.53	1.61	1.67
4	6.10	6.10	5.98	6.06
5	6.53	6.77	6.78	6.69
6	4.85	4.93	5.06	4.95

The first three layers exhibited a very low loss-on-ignition figure suggesting that the bond in this region was probably totally burned out. In the first layer a high proportion of the sample was in the form of lustrous carbon with relatively little sand adhering. The loss-on-ignition figure was therefore slightly higher than that of the second layer which contained a higher amount of sand surrounded by a sooty carbon deposit. Layer three showed a slightly higher loss-on-ignition figure suggesting that the oil and/or organic cations in the clay had not been quite completely carbonised. Layers four and five exhibited a much larger loss-on-ignition figure, higher in fact than that of layer six, suggesting that some condensation of oil had indeed taken place in this region of the mould. Layer six gave a loss-on-ignition value very similar to that of the virgin sand mixture and quoted in Table 19, under mix 289, and was therefore taken to be such.

Since layers 4, 5 and 6 were considered to be composed of material of a reuseable nature and were located not more than 0.5in from the surface of the casting, it would seem probable that the bulk of the moulding sand within the mould could be recycled with little further preparation.

7.9. Recycling of the Moulding Sand.

The results of the physical properties of the moulding sands ascertained after each casting cycle are given in Table 18, and graphed in Figs. 59-65.

Table 18

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	5.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	Tested after each of four casting cycles

SAND MIX No.	289	305	312	316	324
TEMPERATURE BEFORE AND AFTER MULLING (°C)	31.5 28.0	- -	- -	- -	- -
Average	30.0	-	-	-	-
CASTING CYCLE No.	0	1	2	3	4
SPECIMEN WEIGHT (g)	159	158	156	156	156
GREEN COMPRESSION STRENGTH	70.3 71.0 69.6 68.9	61.4 61.4 60.7	42.7 42.1 42.1	31.7 31.7 32.4	25.5 25.5 25.5
(N/m ² x 10 ³)					
Average	70.0	61.1	42.3	31.9	25.5
GREEN SHEAR STRENGTH	17.2 15.9 15.9	15.2 14.8 14.8	10.7 10.7 10.3	7.6 7.2 7.9 7.9	5.9 5.9 5.9
(N/m ² x 10 ³)					
Average	16.3	14.9	10.6	7.8	5.9
HOT COMPRESSION STRENGTH	313.2 294.6 281.8 303.4	266.1 261.2 271.0	267.1 275.0 231.8 273.0 283.8	218.1 246.5 232.8 224.0	200.4 224.9 195.5 217.1 208.3
(N/m ² x 10 ³)					
Average	298.2	266.1	266.1	230.3	209.3
PERMEABILITY	19.6 19.6 19.6	21.2 21.1 20.9 21.0	24.3 24.9 25.2 25.0	27.5 27.9 28.0	27.3 27.8 27.2
(small orifice)					
Average	19.6	21.1	24.9	27.8	27.4
MOULD HARDNESS	28 29 28 28 28	27 28 28 27	21 23 21 23 22	18 18 16 17 17	15 15 14 15
('C' scale)					
Average	28	28	22	17	15
SHATTER INDEX	73 75 74 75	68 67 68	53 50 51 53	45 46 46	43 42 42
Average	74	68	52	46	42
FLOWABILITY	81 81 81 82 81	83 82 83 82	82 83 84 83 82	85 85 85 85	86 86 86 86
(per cent)					
Average	81	83	83	85	86

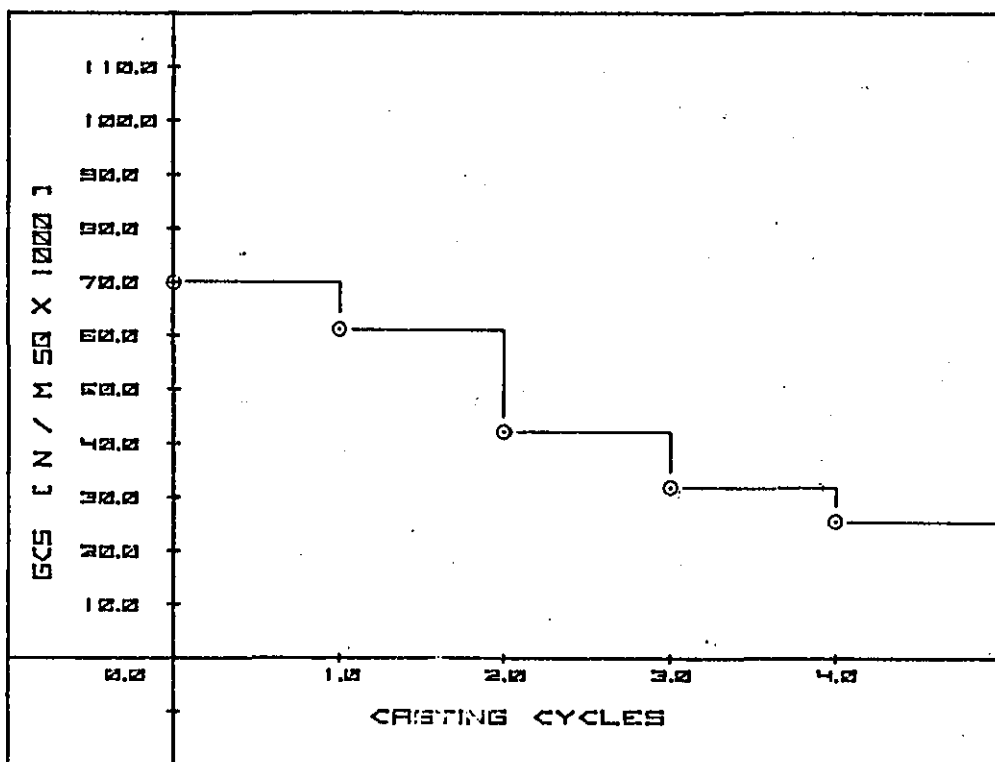


Fig. 59 Effect of moulding sand re-use on green compression strength.

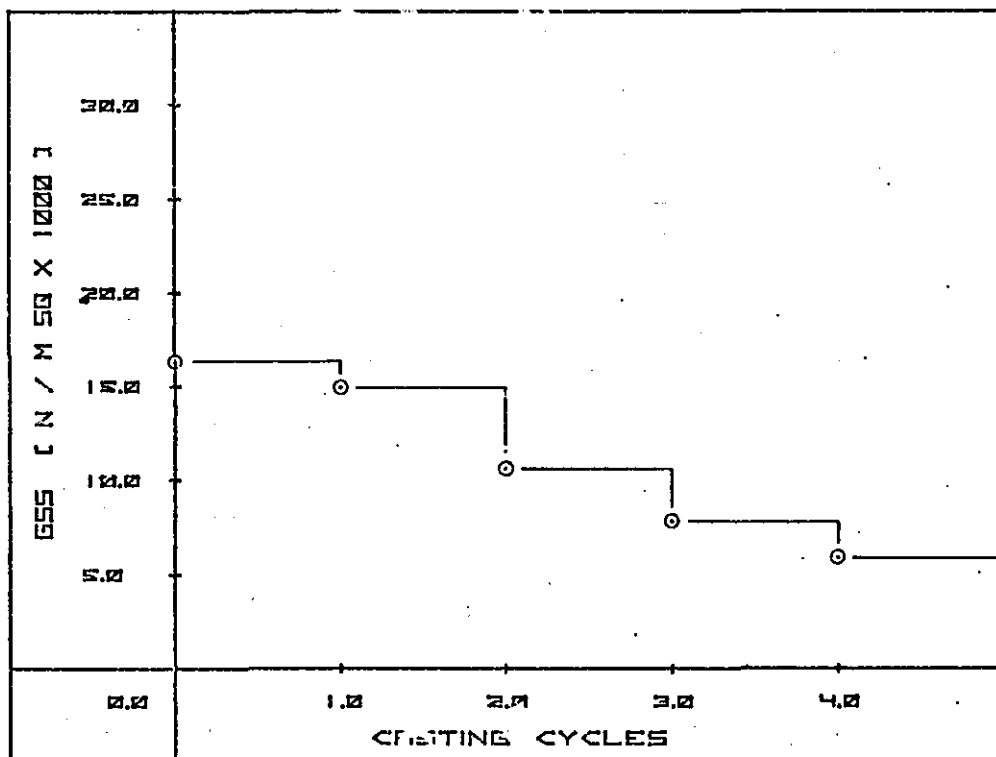


Fig. 60 Effect of moulding sand re-use on green shear strength.

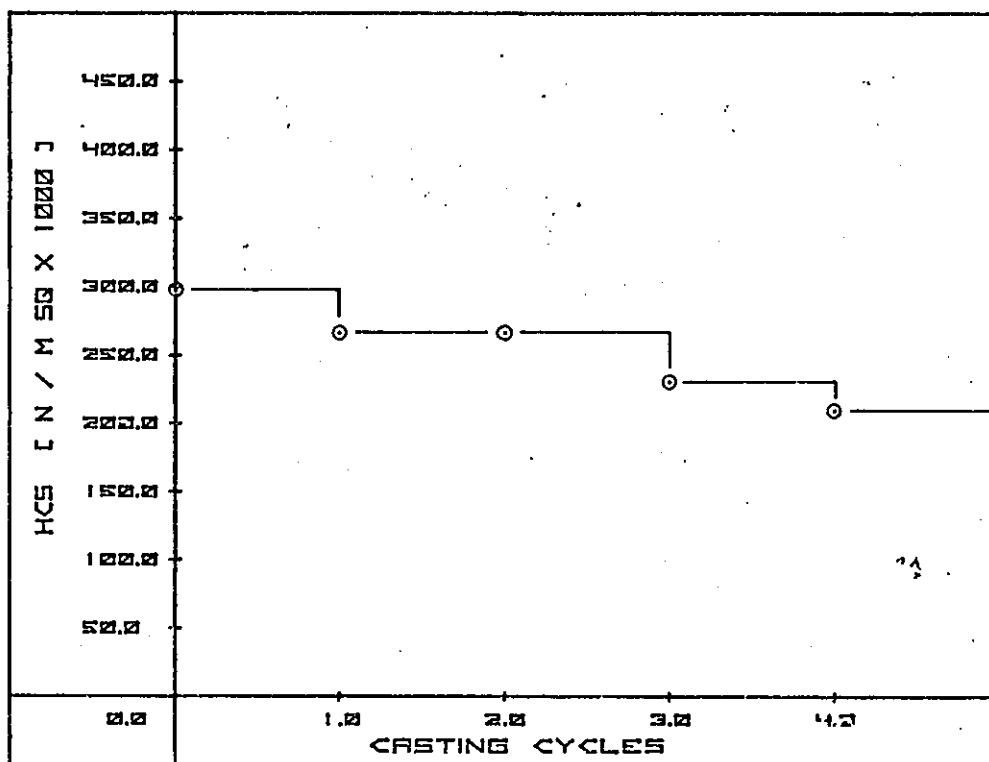


Fig. 61 Effect of moulding sand re-use on hot compression strength.

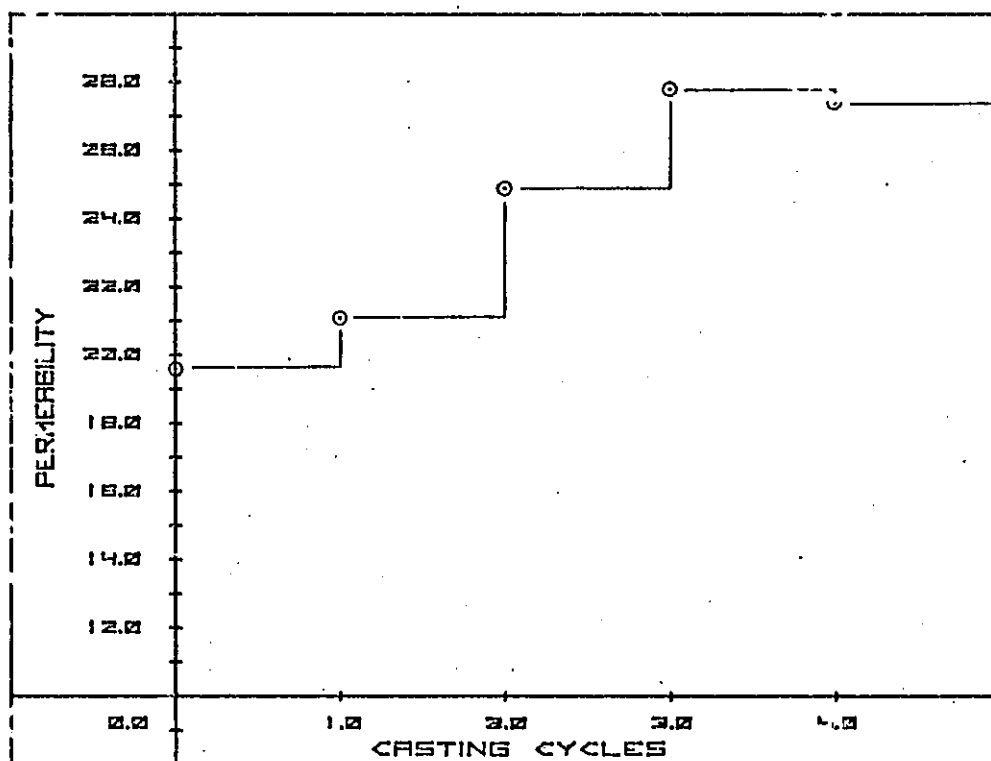


Fig. 62 Effect of moulding sand re-use on permeability.

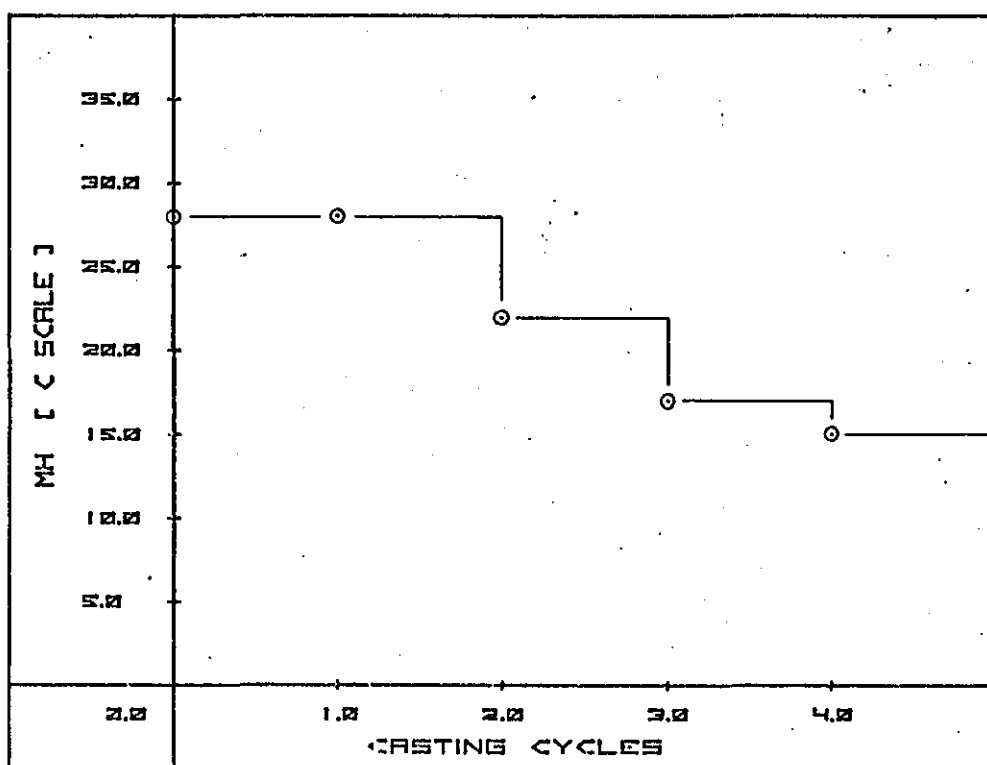


Fig. 63 Effect of moulding sand re-use on mould hardness.

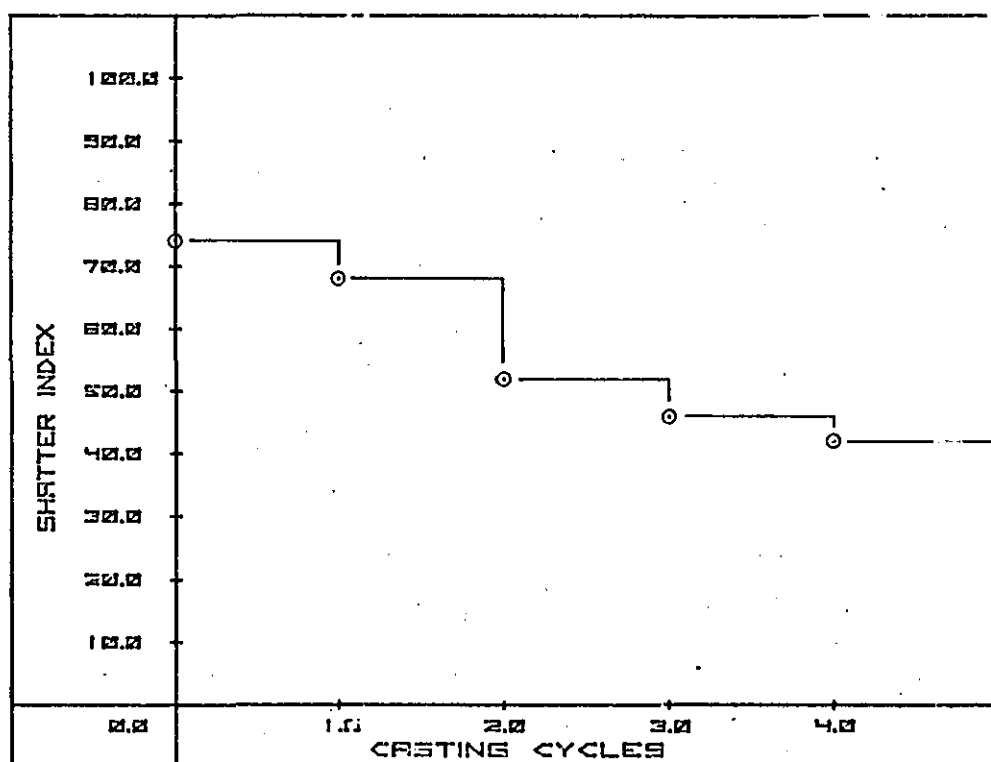


Fig. 64 Effect of moulding sand re-use on shatter index.

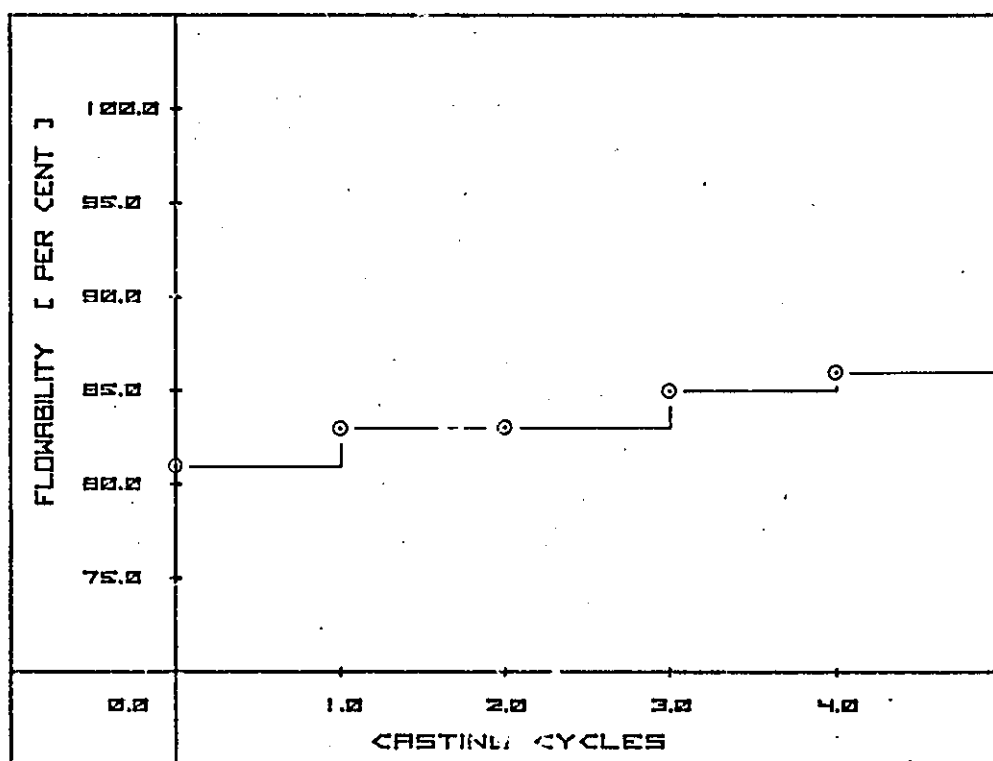


Fig. 65 Effect of moulding sand re-use on flowability.

X

With the exception of the hot compression strength and flowability of the sand the changes in properties after the first casting cycle were less than those found after the second. This was probably caused by the fact that the first cast was made in phosphor-bronze poured at 1100°C whilst the second and subsequent castings were made in cast iron at the higher pouring temperature of 1400°C . This is borne out by the loss-on-ignition results given in Table 19, the combustibles being lost in the first casting cycle being much less than in the second.

Green compression strength, green shear strength, mould hardness and shatter index all decreased in value during the use of the sand, the rate of decrease diminishing with each casting cycle carried out using cast iron. The permeability and flowability showed an increase in value over the casting cycles, the former reaching an apparent limit after the third cast. The hot compression strength exhibited an overall decrease in value though the rate per casting was found to be more erratic than in other strengths. The first cast caused a relatively large decrease in strength to a level which was maintained after the second use. Subsequent castings, however caused further decreases in strength.

The practical limitation to the use of the sand was found in attempting to produce the fifth mould when the toughness of the mould, as indicated by the shatter index, had been reduced to a level such that a clean strip from the pattern was extremely difficult to obtain. It was also noted from the final casting produced that the mould had lacked sufficient strength to withstand

Table 19

LOSS ON IGNITION _____ (PER CENT)

EFFECT OF RECYCLING THE MOULDING SAND

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	5.0
AVERAGE MULLING TEMPERATURE (°C)	30.0
POLAR ADDITIVE (PER CENT)	0.5

SAND MIX No.	289	305	312	316	324
CASTING CYCLE No.	0	1	2	3	4
SAMPLE No. 1	4.90	4.74	3.81	3.69	3.40
2	4.90	4.76	4.09	3.75	3.34
3	4.89	4.71	3.97	3.65	3.55
Average	4.90	4.74	3.96	3.70	3.43

the ferro-static pressure and eutectic expansion forces resulting in a distorted casting.

It is clear from this work that it was not necessary to remull the sand between useage in order to obtain a mouldable sand, though a mixing action should be used to produce a homogeneous mix. However, in order to prevent excessive deterioration in properties during continuous use of the sand fresh clay and oil should be added periodically and these would require to be mulled in for maximum benefit.

7.10. Restoration of the Properties of the Used Moulding Sand

During the use of the moulding mixtures the oil and organic part of the clay would undergo thermal decomposition and in so doing lose some or all of their ability to contribute towards the bond. Initial tests were carried out to determine the effect of replacing these components in amounts of 0.5 per cent. To achieve the full effect from these additions it was necessary to remull the sand with 0.5 per cent methanol. Therefore, to identify the effect of the additions alone, tests were first carried out to discover the effect of the mulling action. The results of these tests, carried out on 3.0kg samples of the used sand, are shown in Table 20. For comparison, the initial physical properties of the used sand are shown in Table 21 (mix No. 324).

The effects of mulling this sand for 5 minutes are shown under sand mix No. 325 in Table 20. Apart from a slight increase in all strengths, very little was achieved by this action. This

Table 20

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)
OIL CONTENT (PER CENT)
MULLING TIME (MIN)
POLAR ADDITIVE (PER CENT)
OTHER VARIABLES

5.0 (Originally)
3.0 { " }
5.0 { " }
0.5 (Methanol)
Tested after 4 casting cycles
and after subsequent treatments

SAND MIX No.	325	326	327	328	329
SAND TREATMENT	Mulled	Mulled	Mulled	Mulled	Mulled
POLAR ADDITIVE (PER CENT)	-	0.5	0.5	0.5	0.5
OIL ADDITION (PER CENT)	-	-	0.5	-	0.5
CLAY ADDITION (PER CENT)	-	-	-	0.5	0.5
TEMPERATURE BEFORE AND AFTER MULLING (°C)	32.0 30.0	30.0 29.0	32.0 28.0	32.0 28.0	32.0 28.0
Average	31.0	29.5	30.0	30.0	30.0
SPECIMEN WEIGHT (g)	157	157	158	158	158
GREEN COMPRESSION STRENGTH	26.2 26.9 26.2	27.6 27.6 27.6	26.2 26.2 26.2	35.9 37.2 35.9 37.2 35.9	37.2 36.5 35.9 36.5
(N/m ² x 10 ³)					
Average	26.4	27.6	26.2	36.4	36.5
GREEN SHEAR STRENGTH	6.2 6.2 5.9	6.2 6.2 6.6	6.9 6.6 6.6	9.0 8.6 9.3	9.0 9.3 9.3
(N/m ² x 10 ³)					
Average	6.1	6.3	6.7	9.0	9.2
HOT COMPRESSION STRENGTH	220.0 225.9 242.6 200.4	218.1 230.8 205.3 230.8	278.9 274.0 293.6 311.2 306.3	259.3 229.8 195.5 224.9 205.3	245.5 291.6 295.5 285.7
(N/m ² x 10 ³)					
Average	222.2	221.3	292.8	223.0	279.6
PERMEABILITY	26.2 26.1 26.3	26.0 26.3 26.1	25.8 26.2 26.2 26.1 26.0	24.2 24.7 24.0 24.3	25.1 24.8 25.0 24.5 25.0
(small orifice)					
Average	26.2	26.1	26.1	24.3	24.9
MOULD HARDNESS	14 14 14	15 14 15 16	13 15 14 14 15	18 19 18 19	19 19 18 21 18
('C' scale)					
Average	14	15	14	19	19
SHATTER INDEX	42 40 41	39 41 40	46 47 49 50 47	43 40 41 40	52 54 56 53 53
Average	41	40	48	41	53
FLOWABILITY	86 86 86	86 86 86 85	85 84 85 85 84	85 85 85 84	83 83 82 84 83
(per cent)					
Average	86	86	85	85	83

Table 21

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0 (Originally)
OIL CONTENT (PER CENT)	3.0 (")
MULLING TIME (MIN)	5.0 (")
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	Tested after 4 casting cycles and after subsequent treatments

SAND MIX No.	324	330	332	333
SAND TREATMENT	-	Mulled	Mulled	Mulled
POLAR ADDITIVE (PER CENT)	-	0.5	0.5	0.5
OIL ADDITION (PER CENT)	-	0.85	0.85	0.99
CLAY ADDITION (PER CENT)	-	2.60	1.85	2.09
TEMPERATURE BEFORE AND AFTER MULLING (°C)	-	33.0 33.0	30.0 30.0	36.0 36.0
Average	-	33.0	30.0	36.0
SPECIMEN WEIGHT (g)	156	157	157	158
GREEN COMPRESSION STRENGTH	25.5 25.5 25.5	80.7 80.7 80.7	66.2 66.9 64.1 65.5 66.2	73.1 71.0 69.6 72.4 71.0
(N/m ² x 10 ³)				
Average	25.5	80.7	65.8	71.4
GREEN SHEAR STRENGTH	5.9 5.9 5.9	20.3 19.3 20.3 21.0	14.5 16.5 15.9 15.5 16.2	16.5 16.9 17.2 17.9 17.9
(N/m ² x 10 ³)				
Average	5.9	20.3	15.7	17.3
HOT COMPRESSION STRENGTH	200.4 224.9 195.5 217.1 208.3	389.7 371.1 432.8	345.6 324.0 283.8	351.4 406.4 394.6 383.8 357.3
(N/m ² x 10 ³)				
Average	209.3	397.9	317.8	378.7
PERMEABILITY	27.3 27.8 27.2	22.2 22.0 21.8 22.7 22.0	22.0 22.1 22.2 22.1	21.0 21.7 21.2 21.7 21.3
(small orifice)				
Average	27.4	22.1	22.1	21.4
MOULD HARDNESS	15 15 14 15	30 30 31 31	28 29 29	29 28 29
('C' scale)				
Average	15	31	29	29
SHATTER INDEX	43 42 42	63 67 64 66 66	68 66 65 69 69	72 69 74 69 69
Average	42	65	68	71
FLOWABILITY	86 86 86 86	78 78 78 78	80 80 80	80 80 80
(per cent)				
Average	86	78	80	80

would suggest that not only was it unnecessary to mull the sand between each casting cycle as discussed in 7.9 but to do so would give little benefit. The use of 0.5 per cent methanol during the mulling action was also found to have little effect (mix 326).

The addition of 0.5 per cent oil to the used sand followed by a five minute mulling period with 0.5 per cent polar additive (mix 327) had the effect of increasing the hot compression strength and shatter index whilst leaving the remaining properties relatively unaffected. On substituting the oil addition with 0.5 per cent clay (mix 328) the green compression strength, green shear strength and mould hardness were greatly increased whilst the permeability was decreased. However, the hot compression strength and shatter index were almost unaffected. A combined treatment of 5 minutes mulling with 0.5 per cent methanol and 0.5 per cent additions of both oil and clay (mix 329) increased the green compression strength, green shear strength, hot compression strength, mould hardness and shatter index whilst reducing the values for permeability and flowability.

Most of the trends observed as a result of the oil and clay additions were in agreement with those observed in earlier work when these additions were varied independently in virgin sand mixes. The most notable exception was that of hot compression strength which would have been expected to decrease on increasing the oil content and to increase with increasing clay. The fact that this was not the case may have been the result of a reduction in clay and oil content below the range of those tested in the virgin sand mixes. Further, since the sand had already been subject to intense

heat during use, that applied during the hot compression strength test would be additional giving a different degree of thermal decomposition at the moment of applying the load and consequently different hot strength characteristics to those of a virgin sand. Permeability changes with increasing oil were also unexpected, previous tests having suggested a decrease in value.

It can be seen that the remulling of the used sand with 0.5 per cent oil and 0.5 per cent clay had not restored the physical properties to those of the sand before use. Clearly the making of arbitrary additions in the hope of reproducing the original properties would be extremely time consuming and thus a method of ascertaining the residual oil and active organo-clay was sought to form the basis of further additions. Complex chemical analysis might have revealed the required information but this was beyond the scope of this research and would probably prove impractical as a routine test in the foundry. It has, however, been shown that at a constant clay content of 5.0 per cent, oil additions in the range of 2 to 4 per cent influence the shatter index whilst leaving the green compression strength relatively unaffected. Also, at a constant oil content of 3 per cent, clay additions in the range 3 to 7 per cent effect the green compression strength whilst exerting little effect upon the shatter index. Since these trends have also been observed when making the clay and oil additions to the used sand it was hoped that by monitoring these two specific physical properties the residual oil and clay contents of the used moulding material could be estimated and suitable additions made to restore most of the physical properties to their original, unused values.

The value of the green compression strength of the used sand after remulling with 0.5 per cent methanol was $27.6 \text{ N/n}^2 \times 10^3$ which from the graph of green compression strength against clay content mulled at 35°C with 0.5 per cent methanol would suggest a residual live organo-clay content of approximately 2.4 per cent and thus a restorative addition of 2.6 per cent. A similar exercise comparing the shatter index of 40 of the used sand with the shatter index against oil content graph at constant clay content mulled at 35°C with 0.5 per cent methanol suggested a residual oil content of 2 per cent. Since the shatter index is somewhat increased by increasing clay and in view of the proposed clay addition the full 1 per cent oil addition was reduced slightly to 0.85 per cent. The results of these additions are given in Table 21 under mix No. 330 and it can be seen that the clay addition was giving a higher green compression strength than was expected whilst the oil addition was insufficient to raise the shatter index to the original value of the moulding sand. The final value of the green compression strength would suggest a total clay content of approximately 5.75 per cent and thus in the next test, mix No. 332, the addition was reduced to 1.85 per cent. From the graph of shatter index against clay content, such a reduction would be expected to increase the shatter index slightly and so the oil addition was kept constant at 0.85 per cent. From the results of this test the green compression strength was found to be lower than that required whilst the shatter index, as expected, was raised slightly but not sufficiently to reach the original value.

In the third and final test the original method of attempting to estimate the residual clay content from the green compression strength was abandoned as it had become obvious that the

clay additions were having a greater effect upon this property than was anticipated. Instead, assuming a linear increase in strength between the 1.85 and 2.6 per cent clay additions an addition of 2.09 per cent was made to achieve the final required strength. In a similar manner, the oil addition was fixed at 0.99 per cent. The final results for green compression strength and shatter index as shown under mix No. 333 were found to be reasonably close to those of the original unused sand. The only property found to be greatly different to the original was that of hot compression strength and this was an improvement.

These tests show that it was feasible to restore the used sand by the use of clay and oil additions. The required amount of clay could be roughly estimated from the value of the green compression strength though it was noted that the effectiveness of the clay was slightly greater than would be suggested by the trends observed in the graphs of green compression strength against clay content for virgin sand mixes. The amount of oil can be similarly roughly estimated from the values of the shatter index of the used sand.

It was found that the relatively large additions required in this work could not be accurately calculated from the properties of the sand after use. However, a circulating sand system in a foundry would be tested more frequently and probably have a larger ratio of available moulding sand to casting weight. Thus the condition of the sand would not be allowed to deteriorate to the

extent of that used in this research and the additions required would be much smaller. Under these conditions, therefore, particularly after acquiring some experience, it should be possible to use the green compression strength and shatter index properties to calculate the restorative amounts of clay and oil respectively with a reasonable degree of accuracy.

7.11. Casting Evaluation

7.11.1. Visual Examination

On removing the castings from the moulds it was found that each was covered in a shiny black, brittle film of lustrous carbon which was easily removed with a soft brush. The thickness of this film was found to be greater on those alloys having a higher pouring temperature, the cast iron having the strongest and thickest film whilst that on the aluminium-magnesium alloy was extremely friable. These films assisted greatly in the removal of sand from the surface of the casting. Fig. 66 shows one of the aluminium-magnesium castings still in position within the cope half of the mould, the drag half having been carefully lifted off and placed to one side. Much of the carbon layer remained adhering to the mould leaving the surface of the casting almost clean. The phosphor-bronze casting pictured in Fig. 58 shows the shiny layer of lustrous carbon still adhering to the surface of the casting.

Figs. 67, 68 and 69 show general views of the cored surfaces of castings made in phosphor-bronze, aluminium-magnesium and cast iron respectively. In each case, though the surface finish

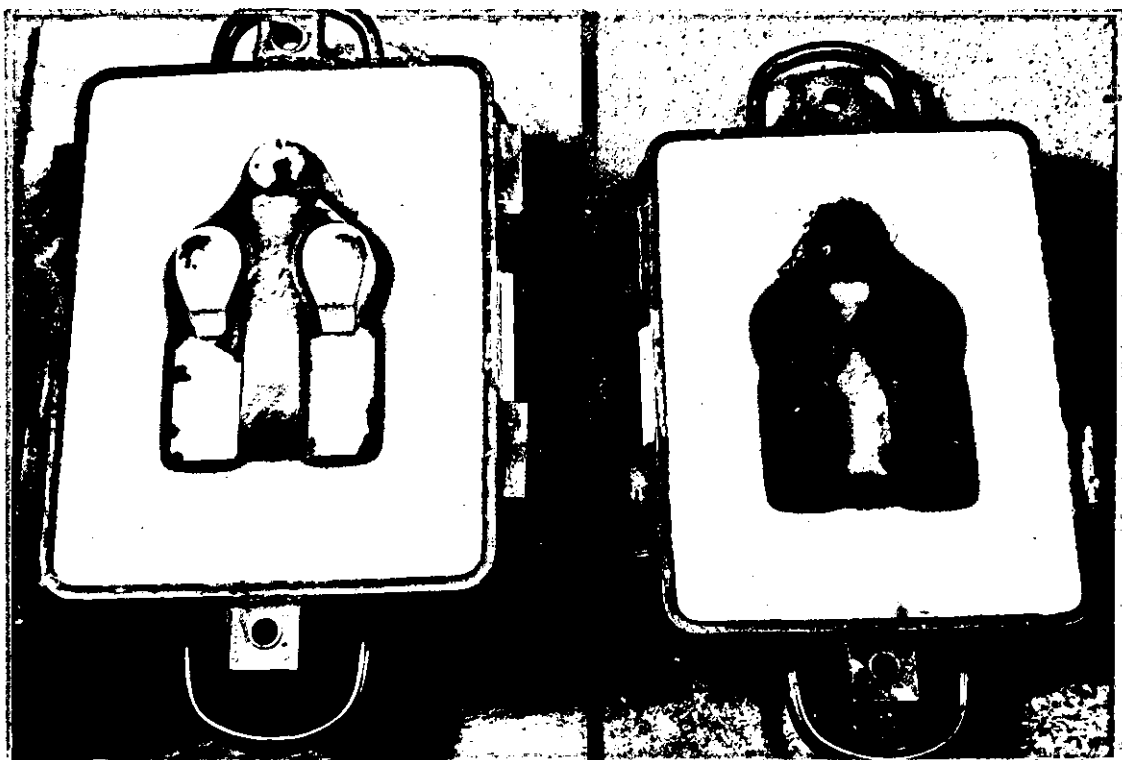


Fig. 66 The cope and drag faces of a mould after casting in the aluminium-magnesium alloy showing a clean strip.

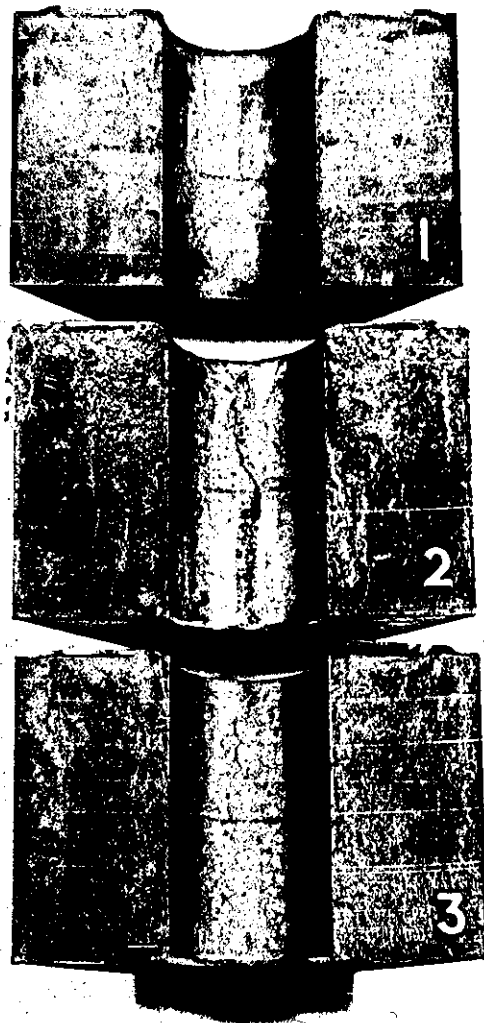


Fig. 67 View of the cored surfaces
of the three phosphor-bronze
castings.

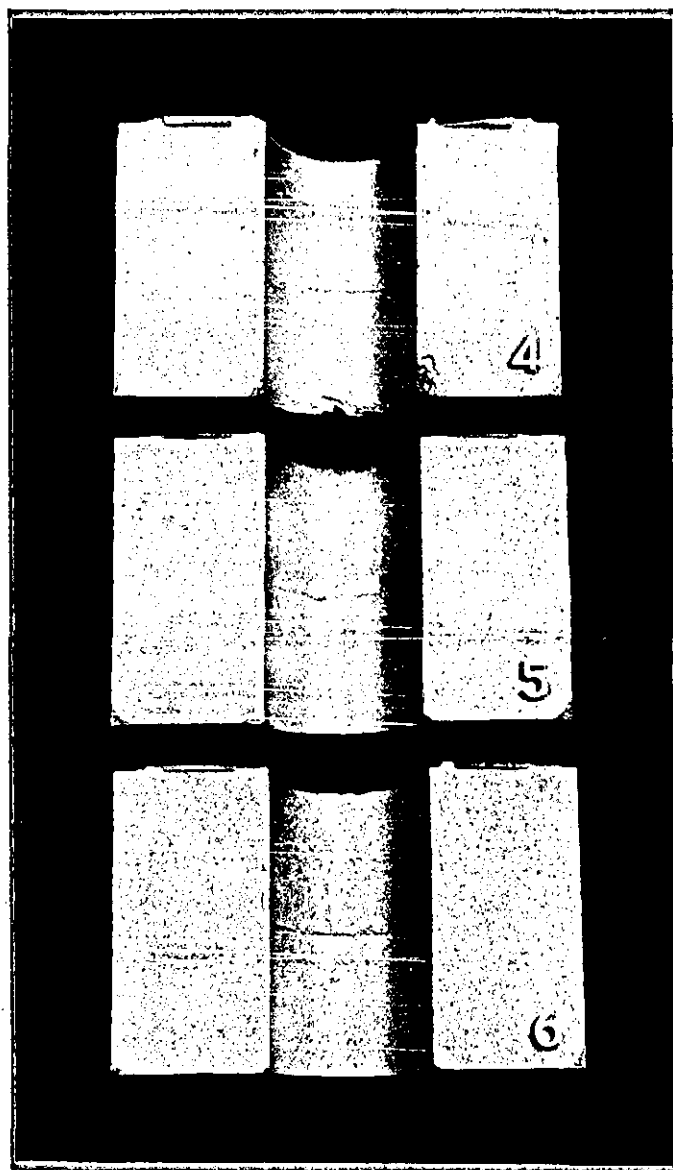


Fig. 68 View of the cored surfaces
of the three aluminium-
magnesium castings.

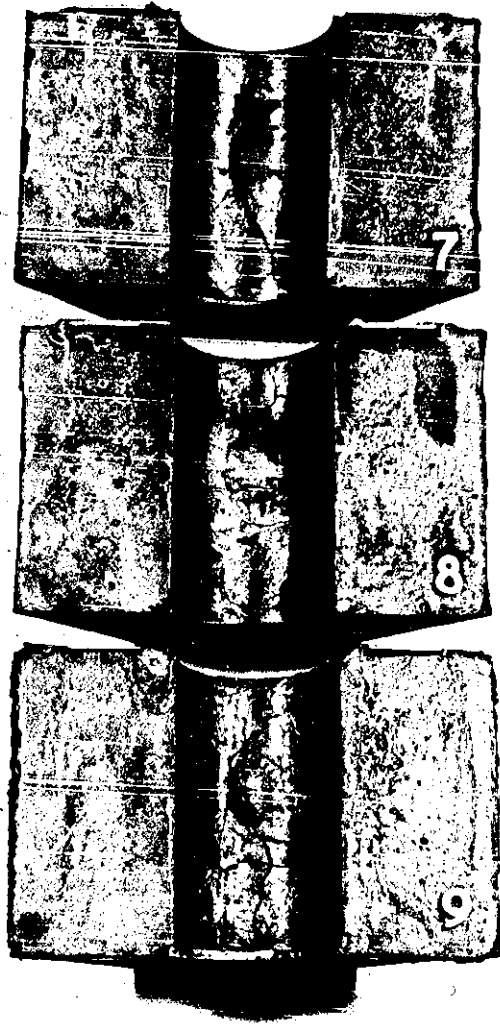


Fig. 69 View of the cored surfaces
of the three cast iron
castings.

was generally good, veining and finning were to be found on many of the cored surfaces, the severity of this defect being much greater when alloys of higher pouring temperature were used. Previous work²⁸ has also shown this veining effect on a casting of similar design. The moulding sand contained a proportion of polystyrene emulsion producing, on casting, a thick layer of lustrous carbon as did the organo-clay bonded sand. It was postulated that the veining was caused by the cracking of the thick layer of lustrous carbon and it is the most probable cause of the defect encountered in this work. In later work²⁹ into similar excess carbon production by polyurethane cores iron oxide additions were made to the sand as oxidising agents to reduce the degree of carbon deposition with some success. It is therefore probable that such an addition to this sand may have similar beneficial effects (See appendix D for the effect of iron oxide on the physical properties of organo-clay bonded sand). A typical example of this defect is shown in detail in Fig. 70, a view of the cored as-cast surface of casting No. 7 in cast iron. Fig. 71 shows the same casting after shot blasting and it can be seen that much of the veining had been removed to leave an apparently serviceable casting. However, a view of the casting in Fig. 72 shows the surface finish of the casting to be severely impaired by what would appear to be gas blow holes. At the other extreme of pouring temperature, the aluminium-magnesium casting pictured in Fig. 73. shows a virtually flawless as cast cored surface composed of a fine, well-defined grain structure whilst the top surface as illustrated in Fig. 74 was composed of a much larger grain structure of rough texture as though some inter-dendritic shrinkage had taken place. Fig. 75 shows the as-cast surface of one of the phosphor-bronze castings and Fig. 76 the cored surface of the same casting after a

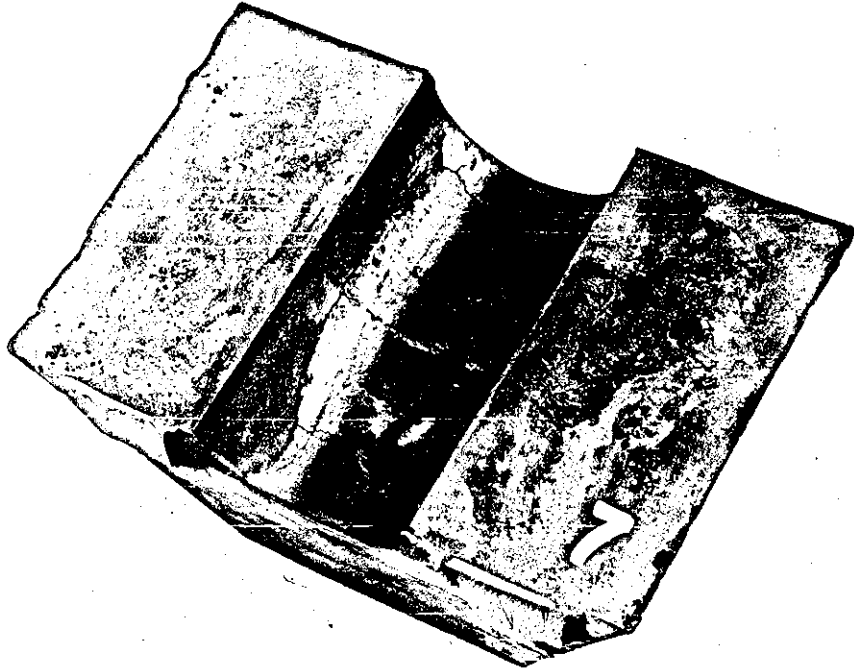


Fig. 70 View of the as-cast surface finish of a cast iron casting showing the finning defect.

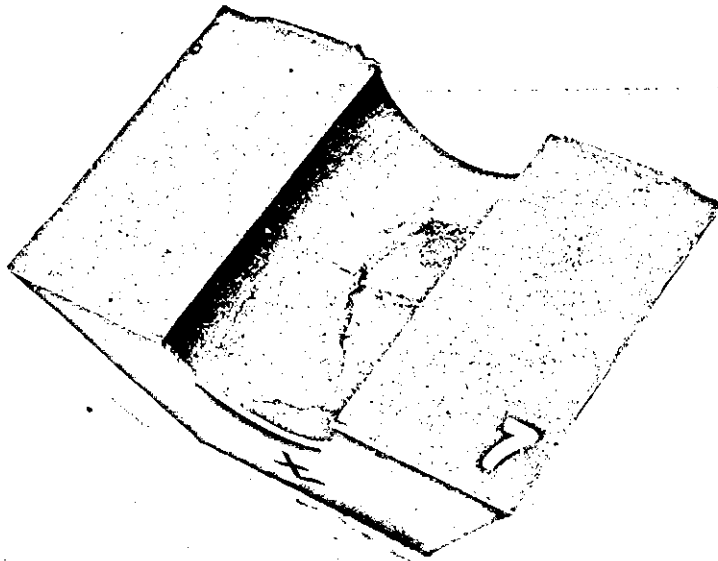


Fig. 71 View of the shot-blasted surface finish of the cast iron casting shown above.

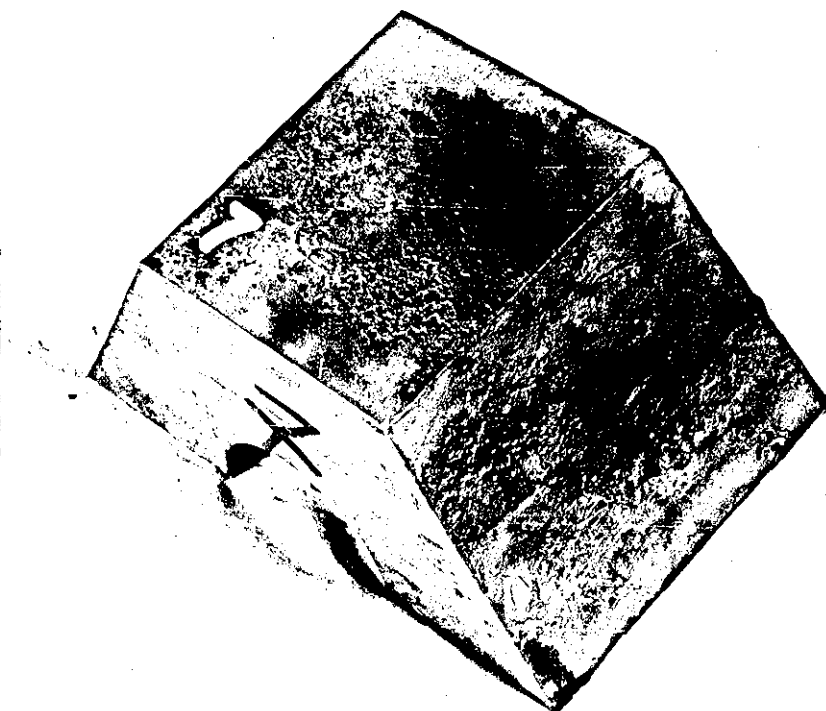


Fig. 72 View of the back of a cast iron
test casting showing gas-hole
defect.

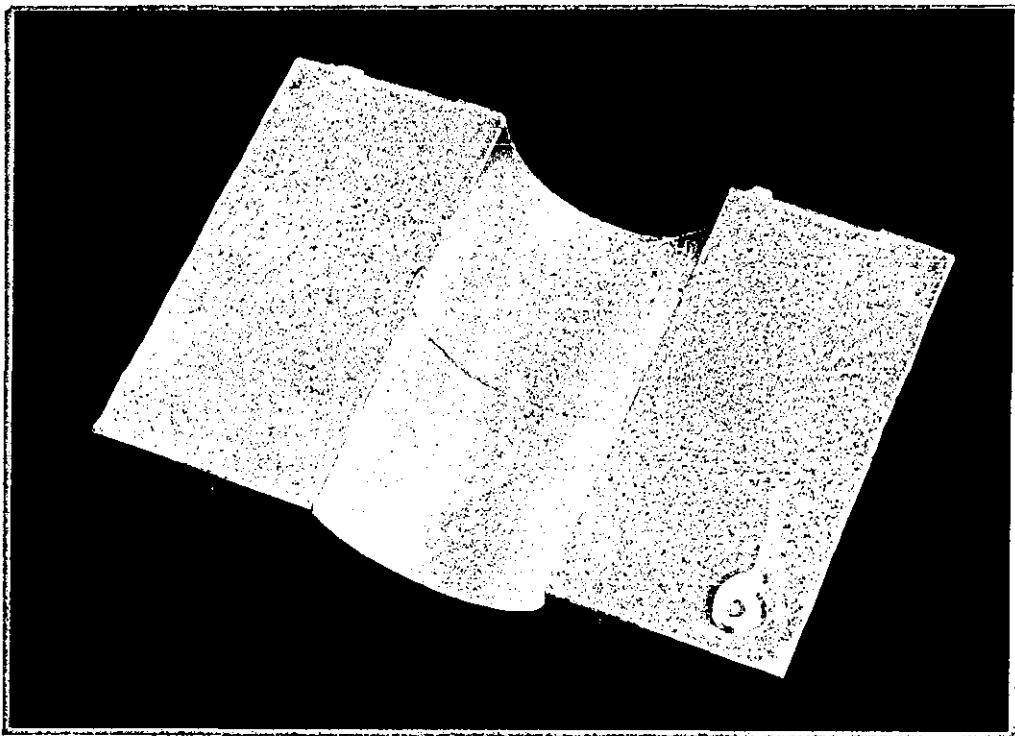


Fig. 73 View of the as-cast cored surface of an aluminium-magnesium alloy casting.

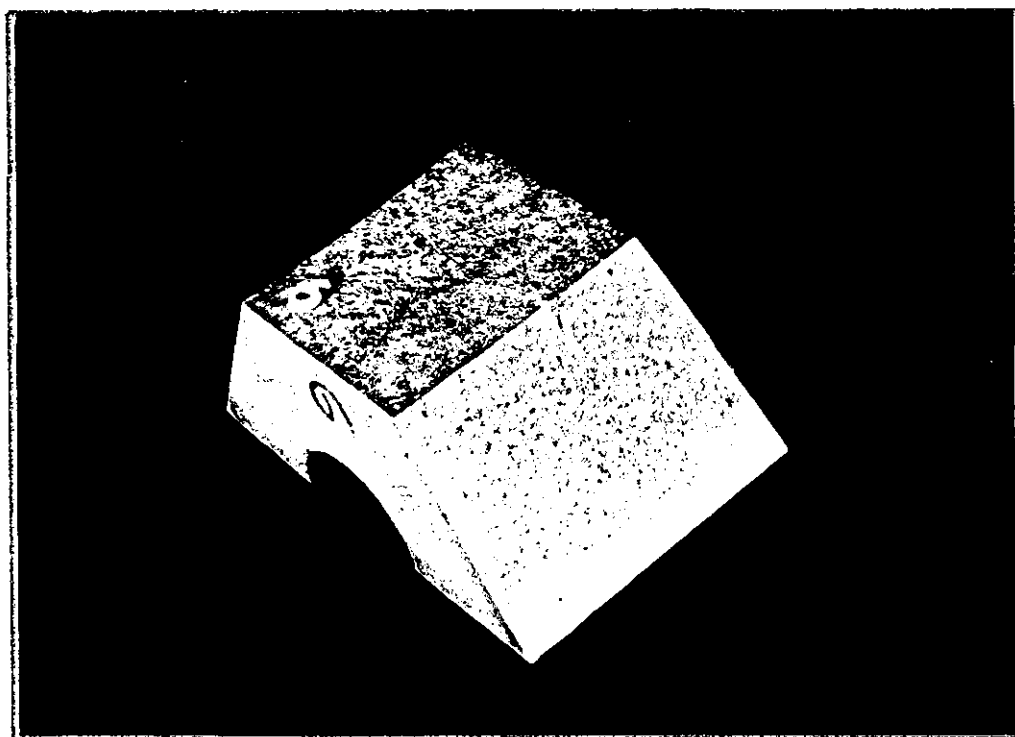


Fig. 74 View of the as-cast back surface of the casting above showing the inter-dendritic shrinkage defect.

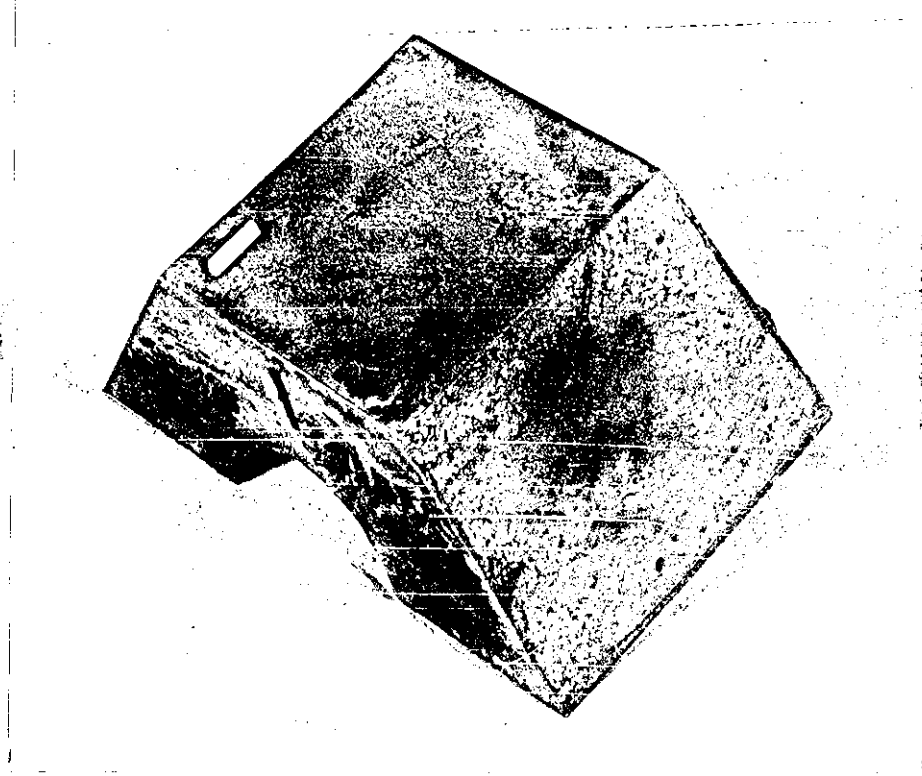


Fig. 75 View of the as-cast back surface
 of a phosphor-bronze casting.

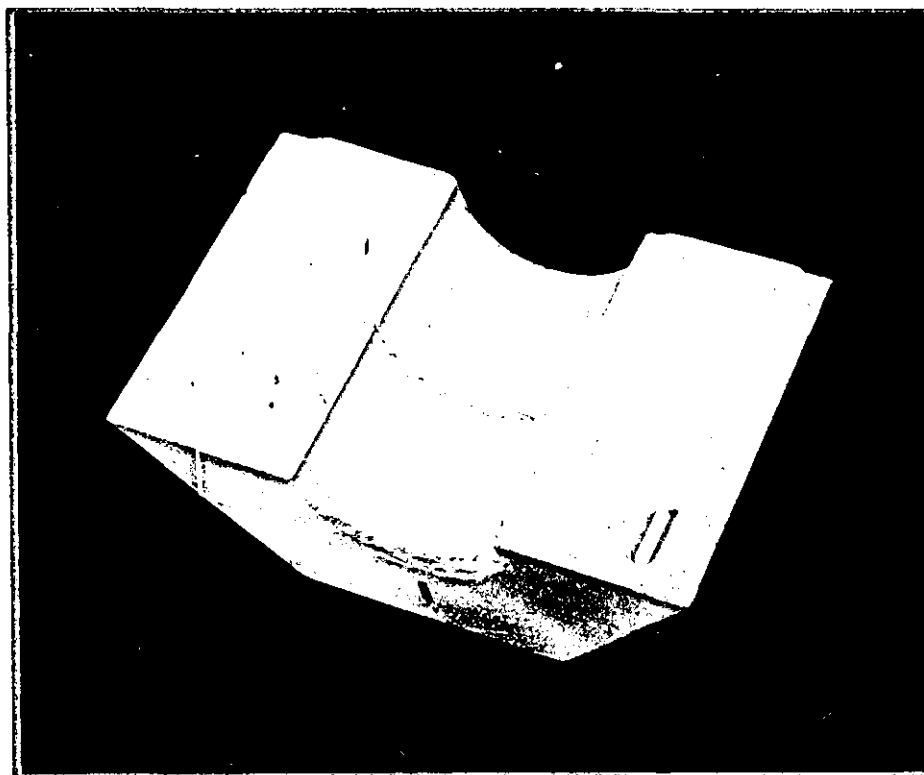


Fig. 76 View of the sand-blasted cored surface
 of the phosphor-bronze casting above.

short period of sand blasting to remove the lustrous carbon dust, It can be seen that the finish of these castings were generally very good, marred only by some slight veining of the cored surface.

The effect of reuse of the moulding sand is well demonstrated by studying Figs. 77 and 78, the fourth casting in the cycle. It can be seen that a bevelled bottom surface was produced in the casting as a result of mould wall movement during the solidification of the casting. A view of the top surface of the casting shows a further consequence of the lack of mould rigidity; a shrinkage cavity, into which, at a later period in the solidification some eutectic exudation has taken place. Fig. 79 shows the same casting before fettling and it can be seen that the weakness of the mould has also resulted in the production of excessive flash.

7.11.2. Casting Dimensions

A diagram of the test casting is shown in Fig. 80. Each dimension has been allocated a letter and in Tables 22, 23 and 24 the actual dimensions are given against each of these letters for castings made in phosphor-bronze (casting Nos. 1, 2 and 3), aluminium-magnesium (castings Nos. 4,5 and 6) and cast iron (casting Nos. 7,8 and 9) respectively. These may be compared with the corresponding pattern dimensions excepting letters M to T inclusive which are based on the position of the test piece within the mould cavity and varied slightly according to the degree of cross-jointing when the mould was assembled. A nominal figure for these dimensions is given in brackets.

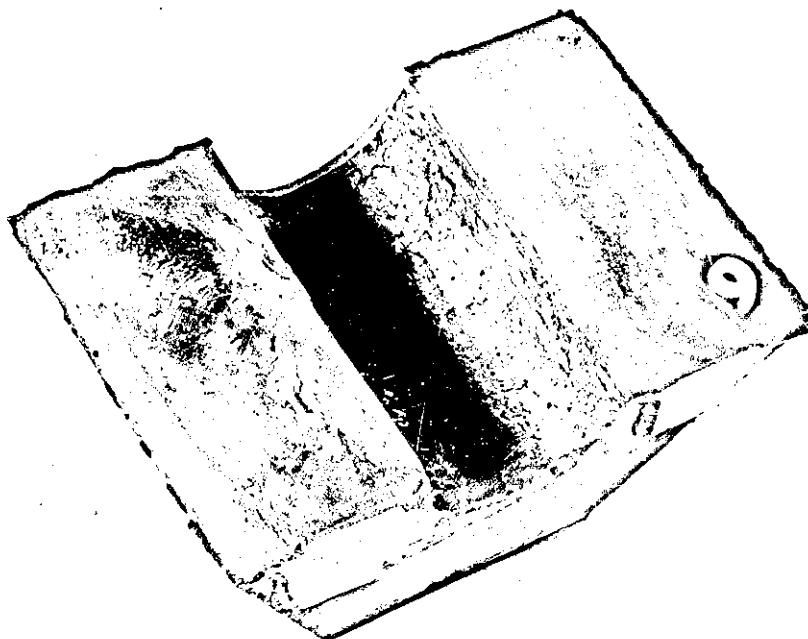


Fig. 77 View of the as-cast surface of a cast iron casting showing the effect of mould wall movement.

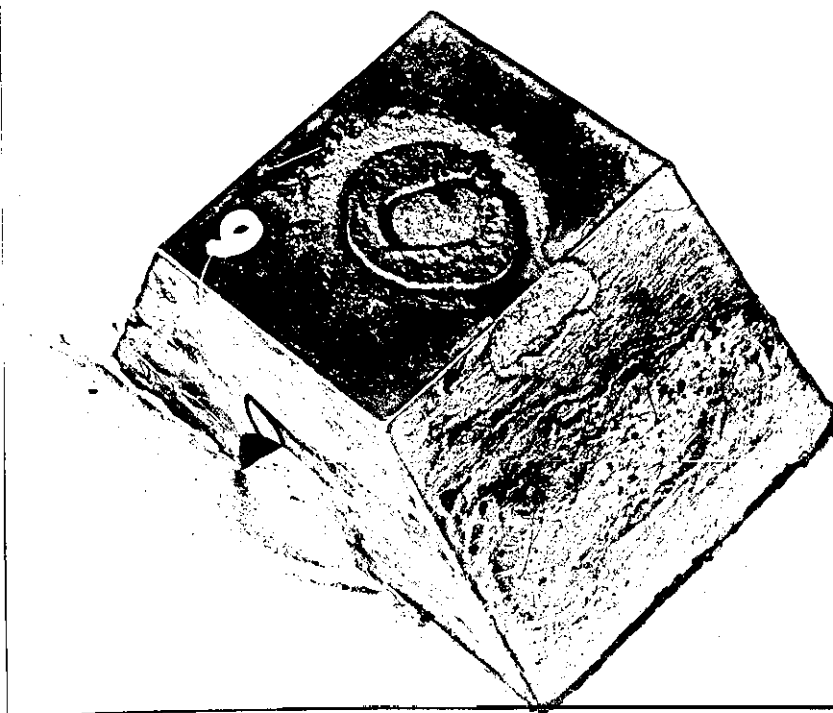


Fig. 78 View of the as-cast back surface of a cast iron casting showing shrinkage cavity and eutectic exudation.

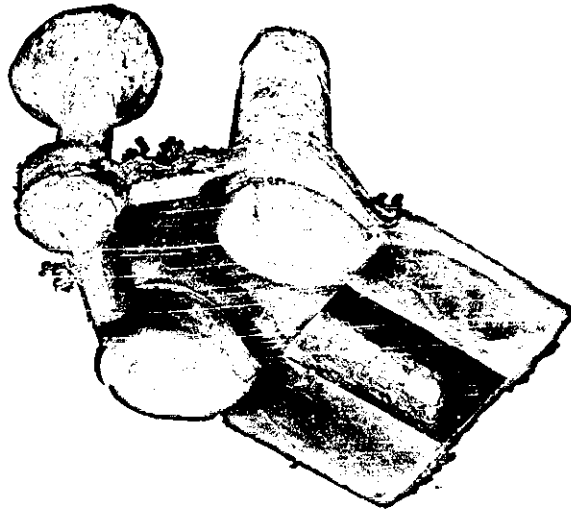


Fig. 79 View of the cast iron casting made in recycled sand showing the results of mould dilation.

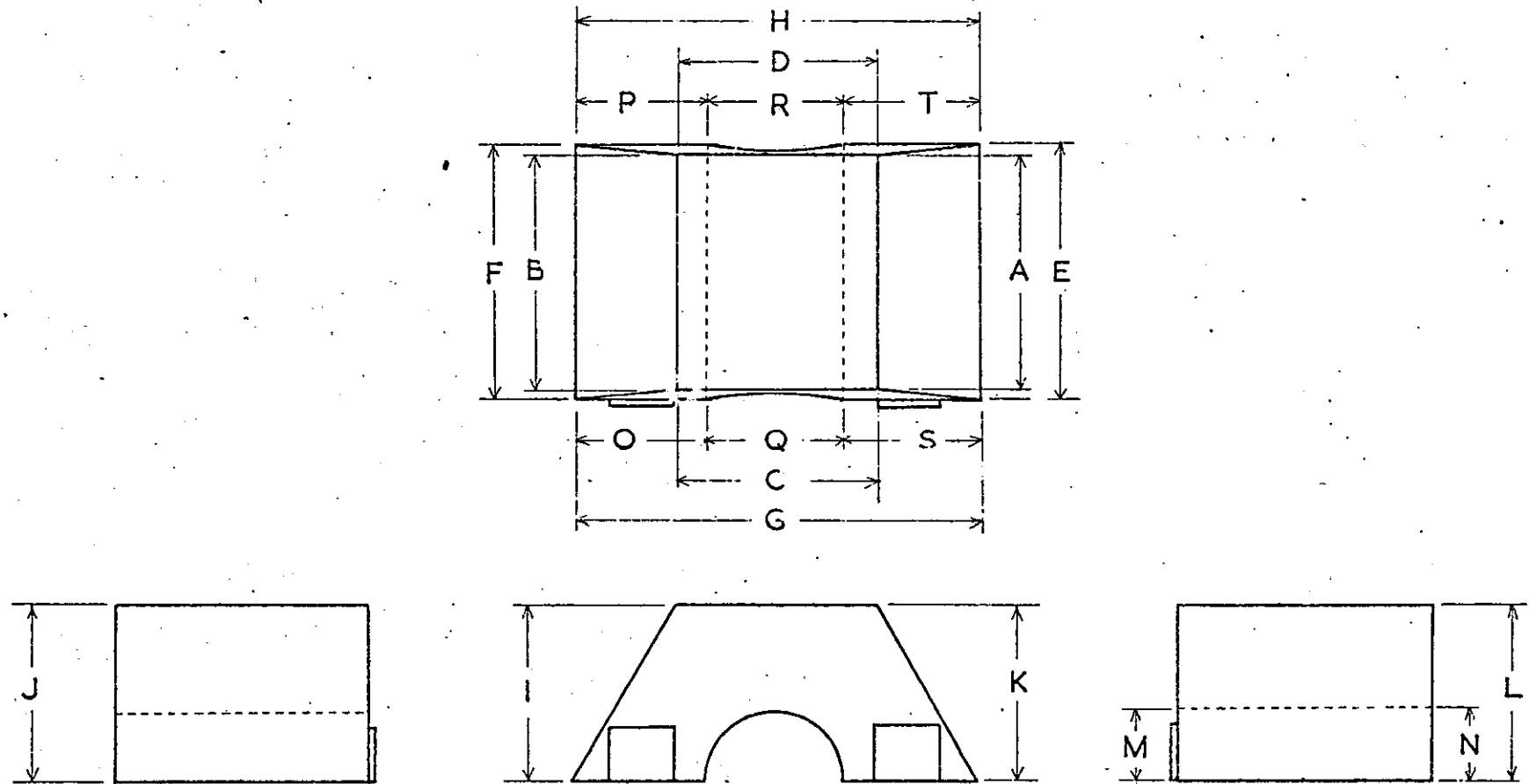


Fig. 80 Diagram of test casting identifying the dimensions measured.

Table 22

CASTING DIMENSIONS _____ (cm)
 PHOSPHOR-BRONZE

CASTING No.	1	2	3	PATTERN
DIMENSION A	8.43	8.38	8.40	8.60
B	8.43	8.36	8.37	8.65
C	7.17	7.25	7.17	7.37
D	7.12	7.16	7.19	7.35
E	9.59	9.58	9.59	9.65
F	9.59	9.59	9.57	9.65
G	14.87	14.84	14.83	15.00
H	14.87	14.84	14.83	15.00
I	6.53	6.57	6.54	6.64
J	6.61	6.57	6.61	6.64
K	6.51	6.56	6.58	6.64
L	6.60	6.58	6.57	6.63
M	2.51	2.52	2.58	(2.54)
N	2.57	2.54	2.57	(2.54)
O	5.03	5.01	4.96	(4.96)
P	5.01	5.02	4.91	(4.96)
Q	5.01	5.03	4.98	(5.02)
R	5.05	5.03	5.03	(5.08)
S	4.80	4.80	4.89	(4.96)
T	4.81	4.79	4.89	(4.96)

Table 23

CASTING DIMENSIONS _____ (cm)

ALUMINIUM-MAGNESIUM

CASTING No.		4	5	6	PATTERN
DIMENSION	A	8.41	8.38	8.38	8.60
	B	8.35	8.37	8.35	8.65
	C	7.16	7.13	7.17	7.37
	D	7.16	7.17	7.16	7.35
	E	9.60	9.59	9.61	9.65
	F	9.59	9.62	9.61	9.65
	G	14.80	14.83	14.82	15.00
	H	14.81	14.82	14.81	15.00
	I	6.57	6.57	6.56	6.64
	J	6.58	6.58	6.56	6.64
	K	6.55	6.56	6.57	6.64
	L	6.57	6.57	6.56	6.63
	M	2.48	2.55	2.47	(2.54)
	N	2.55	2.57	2.45	(2.54)
	O	4.96	4.95	4.98	(4.96)
	P	4.94	4.89	4.94	(4.96)
	Q	5.03	5.03	5.03	(5.08)
	R	5.03	5.05	5.02	(5.08)
	S	4.81	4.85	4.81	(4.96)
	T	4.84	4.88	4.85	(4.96)

Table 24

CASTING DIMENSIONS _____ (cm)

CAST IRON

CASTING No.	7	8	9	PATTERN
DIMENSION A	8.58	8.56	8.49	8.60
B	8.56	8.58	8.49	8.65
C	7.30	7.29	7.27	7.37
D	7.27	7.34	7.23	7.35
E	9.56	9.48	9.56	9.65
F	9.64	9.51	9.47	9.65
G	14.90	14.85	14.88	15.00
H	14.89	14.86	14.73	15.00
I	6.72	6.64	6.75	6.64
J	6.63	6.62	6.69	6.64
K	6.68	6.65	6.67	6.64
L	6.61	6.57	6.67	6.63
M	2.54	2.61	2.45	(2.54)
N	2.47	2.52	2.40	(2.54)
O	5.00	4.92	5.03	(4.96)
P	4.93	5.00	4.89	(4.96)
Q	5.06	5.08	5.03	(5.08)
R	5.03	5.00	5.00	(5.08)
S	4.84	4.85	4.82	(4.96)
T	4.93	4.86	4.84	(4.96)

The phosphor-bronze and aluminium-magnesium casting dimensions were less than those of the pattern as would be expected as a result of the contraction of the alloys on cooling. The reproducibility of the casting dimensions was found to be good, particularly in the aluminium-magnesium alloy where the maximum variation in any one dimension between the three castings was only 0.03cm and the average of all the variations was approximately 0.02cm. The phosphor-bronze showed maximum dimensional variations of 0.08cm though the average was about 0.04cm.

The iron castings exhibited dimensions closer to those of the pattern, again a predictable result since the contraction allowance for cast iron is less than that for the two non-ferrous alloys. Dimensions I and K were actually found to be generally greater than those of the pattern, this probably being due to a combination of factors. The effects of the eutectic expansion would be most pronounced at this, the hot, gated end of the casting where the iron would remain molten for the longest period. Furthermore, these dimensions lie along the line of least mould rigidity, there being only the strength of the mould material and the force exerted by the weights placed on top of the mould to restrain any mould-wall movement.

Since the iron castings were produced consecutively in the same batch of recycling moulding sand which, as was shown in section 7.9, became weaker with use, it was expected that increasing

mould wall movement would be experienced on each casting cycle, thus giving progressively larger castings. Dimensions A to H inclusive, the lengths and widths of the castings at their edges, showed, however, a general slight reduction in value whilst the dimensions indicating the casting heights, I, J, K and L, showed a reduction on the second iron casting in the series but an increase on the third casting. The fact that there are one or two anomalies to this generalisation and that it would have been expected to observe a general increase in dimensions as the moulding sand was reused may be explained by several factors.

Firstly, in order to achieve a good pattern strip it was necessary to increase the shatter index, and this was done by heating the moulding sand in an air circulating oven. It has already been demonstrated that when the moulding material is rammed in a hot condition and allowed to cool the physical properties can be very different from those of a mould rammed and used at the same temperature. Since it was found impractical to control the temperature of the moulding sand either before or after ramming the physical properties of the moulding sand found under laboratory conditions may bear little resemblance to those of the mould just prior to pouring.

Secondly, on pouring the first (No. 7) of the castings no weights were applied to the top surface of the mould. Consequently the mould cope sand lifted slightly allowing mould wall movement to occur unhindered in this direction. Later castings (Nos. 8 and 9) were weighted to avoid this problem thus giving a degree of restraint. This is the most likely reason for the decrease in dimensions I, J, K and L in the casting No. 8. The collapse of the weakening sand in

the drag of casting No. 9 caused an increase in these dimensions.

Thirdly, the overall dimensions of the castings at their edges did not totally describe its true volume. Mould wall movement, if occurring, would be most likely on the faces of the castings where completion of the solidification would have been much slower than on the corners of the casting and thus would have reflected to a greater extent the effects of the eutectic expansion. The profiles of the casting faces proved difficult to measure accurately due to their irregular nature. To gain a better idea of the volume of the castings they were weighed in the fettled condition. Casting No. 7 weighed 2097 g as against the 2 077g of casting No. 8. This slight reduction may have been the result of the application of weights to casting No. 8. The No. 9 casting, however, weighed 2 244g a large increase particularly considering the fact that this casting had a top surface shrinkage cavity. This increase reflected the collapse of the lower surface of the mould, probably under ferro-static pressure, as illustrated in Fig. 77. The subsequent eutectic expansion was accommodated to a large extent in the shrinkage cavity and thus may explain why the other dimensions of the casting show a reduction when compared with those of castings 7 and 8. It would therefore appear that the moulding sand had reached the limit of its usefulness at this point and could be defined by the physical properties as quoted under laboratory conditions.

7.11.3. Internal Inspection

Cross sectional views of the castings in the three different alloys are shown in Fig. 81 and it can be seen that no

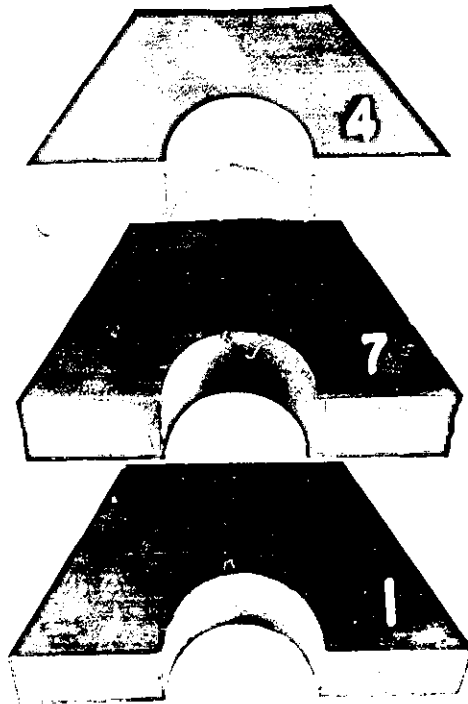


Fig. 81 . View of the cross-sections of
(from top to bottom) an aluminium-
magnesium, a phosphor-bronze and
a cast iron casting showing
internal soundness.

gross internal shrinkage cavities were evident. Indeed, further examination under the microscope revealed that microporosity was also absent, even beneath the surface of the casting where its presence would have suggested mould-metal reaction.

CHAPTER 8

DISCUSSION OF RESULTS

8. DISCUSSION OF RESULTS

The organo-clay produced by the cation exchange reaction between Na bentonite and dimethyldioctadecylammonium chloride proved to be most successful as a bonding medium with oil for foundry sand moulds. There was no way, however, that it could be assessed as the best possible organo-clay for this purpose. The quest for a more suitable type, types or even blend of types for any particular use or combination of physical properties could well be the subject of a great deal of further research.

The methods of organo-clay production developed for this project also proved most successful even though some of the control techniques and equipment were, of necessity, not the best available. During the course of the research into the clay production it was found that a high speed, high shear mixer was necessary to disperse the Na bentonite sufficiently for optimum modification conditions whilst a relatively low speed, strong stirring action mixer was desirable for the modification process itself.

The cation exchange capacity of the clay had to be completely satisfied though not exceeded during the modification reaction to obtain a product of optimum oleophilic properties. In order to ensure this condition it was necessary to establish the purity of the clay and the organic reagent and to assess with reasonable accuracy the cation exchange capacity of the Na bentonite. For the latter property the methylene blue method proved to be both relatively simple and yet give results of adequate accuracy.

From the outset of the research into the physical properties of the organo-clay/oil bonded sand mixtures it became apparent that temperature was an important variable. The temperature of mulling, ramming and testing all had an effect upon the final physical property results of the sand, a phenomenon not noted in the conventional clay/water bonded sand system. This complicated the experimental methods which had to be employed to obtain accurate and reproducible results but offered advantages in that, by using the effect carefully, properties could be varied to give optimum results.

The literature survey produced no evidence of temperature control at any stage of the preparation, testing and use of organo-clay bonded moulding sands and it is doubted that unless such control is exercised, any quantitative results are of much relevance.

The temperature of the sand mix during mulling affected both the rate at which strength was developed and the final value of the physical properties. In the absence of a polar additive, high mulling temperatures in the order of 40-45°C produced the best results and gave good sand compacts of high strength and toughness. The use of 0.5 per cent methanol reduced the temperature required to attain these properties to about 30-35°C whilst allowing even lower temperatures to be used to give acceptable results.

The effects of the temperature of the sand at the time of moulding were, in most of the properties tested, less marked. However, the shatter index was found to vary greatly, being high at

elevated temperatures and diminishing as the temperature was reduced. This could prove to be a very valuable property if the lack of toughness of a sand is causing, for example, poor pattern strip for the mixture need only be warmed slightly to remedy the situation. However, where sand temperature control is not possible, problems may be encountered when the ambient temperature of the foundry is low.

Investigations into the effects of mould temperature variation after ramming show further benefits of ramming the mould with warm sand. On allowing the mould to cool to ambient temperature, the strength of the sand would be considerably increased whilst the shatter index would remain relatively constant. If the reverse situation were to occur the mould would become weak. This would point to the fact that a mould rammed in cold conditions would lose rigidity on casting as the heat permeated through the mould giving rise to mould wall movement and dimensional inaccuracies.

During the course of this research several factors were established as being necessary if maximum strength and toughness were to be developed during the mulling operation. Firstly, the surface condition of the muller had to be rough. No steady reduction in mulling efficiency was experienced as the surface became worn smooth with use, but a point was reached at which the mulling action ceased abruptly and the rollers simply pushed the mixture around the pan. It is probable that a muller in continuous use would have to be modified to present a totally different type of surface to the sand such as hard rubber rollers and pan.

Secondly, it was found, as previously mentioned, that some application of heat was beneficial, the best temperature varying between about 45°C if no polar additive were used to approximately 30°C when using a polar additive. It would not be uncommon to develop at least the lower of these temperatures purely by mechanical heat during extended mulling and certainly would be attained in a constantly recirculating sand system where hot sand would be returned from the knock-out station. Where neither of these methods can be employed it would be desirable to make some provision on the muller to heat the contents but care would be required in its control so as not to reduce the effect of polar additives by attaining excessive temperatures.

Thirdly, the use of a polar additive was found to increase the strength and toughness of the mulled sand and the rate at which these properties could be attained. In this work only methanol was tested, but there should be no reason why other polar organic liquids could not be used to similar or even better advantage. Nothing was found to be gained by using methanol in amounts greater than 0.5 per cent and it is possible that even smaller additions may prove quite as effective.

Finally, the period of mulling required to obtain optimum properties of the sand were found to vary according to the temperature and the use of a polar additive. When using 0.5 per cent methanol at approximately 35°C a 5 min mulling period was found to be more than adequate.

In studying the effects of varying the clay and oil contents of the sand mixtures the most notable feature was that, for the range of additions tested, i.e., 3.0-7.0 per cent clay and 2.0-4.0 per cent oil, the clay dictated the strength and hardness of the mould whilst the oil controlled the toughness. By increasing the clay content the strength was increased in an almost linear fashion, leaving the shatter index of the sand relatively constant. Increasing the oil content had little effect upon the strength but increased the shatter index almost linearly. These effects should offer a unique opportunity to control the basic physical properties of sand mix very closely and indeed, in this research, formed the basis for the determination for the amount of clay and oil required to restore a used sand to its original properties. In this instance, the green compression strength was used as an indication of the required restorative clay addition and the shatter index for the oil addition. Whilst it was found that the amounts could not be calculated accurately for a sand which had been used to the end of its useful life, it was thought that sufficiently good estimations could be made using this method where the physical properties of a sand are carefully monitored during the more gradual decline in values that would be experienced in foundry conditions.

In studying the overall properties of the virgin sand mixes it may be said that a mix containing 5 per cent clay and 3 per cent oil, mulled for 5 minutes at 30°C with 0.5 per cent methanol produced a good mouldable sand. However, later moulding trials with such a sand showed that the strip on deep draws was a problem indicating that the shatter index was not as high as would be desired. This would be overcome by increasing the oil content of

the sand. Alternatively, a slight warming of the sand was also found to increase the shatter index and in a circulating sand system the oil addition might prove to be unnecessary. Furthermore, as has been discussed earlier, there were further advantages in using a warm sand that could be allowed to cool slightly after moulding, these being the marked increase in mould hardness and strength.

The storage of such a sand albeit under sealed conditions, had little effect upon the physical properties. Sand used in the production of the moulds was left with little attempt at sealing for periods in excess of a week, and no detrimental effects were noted. This makes the organo-clay sand mixes an ideal medium for the jobbing foundry where relatively large batches can be mulled and simply stored in a heap until required.

From this work on the physical properties of the organo-clay moulding sand it would appear that only two basic features of the mix need be monitored to describe the condition of the moulding sand. These are the green compression strength and the shatter index. As an alternative to the former, the green shear strength or mould hardness may be used for they both follow closely the variation in green compression strength. The green shear strength test is, however, a test in which it is difficult to obtain consistently reproducible results. The mould hardness may, on the other hand, prove to be a simpler and quicker test to perform. The shatter index has, within the range of tests carried out in this work, no substitute and is considered of great importance in describing the condition of the sand. The hot compression strength

is considered to be a rather specialised test and also one in which reproducible results are difficult to obtain. It is not necessary as a routine test but might be investigated from time to time particularly if unusual additions are made to the mix such as iron oxide which were found to have a devastating effect (see appendix). Flowability was found to be excellent in all the mixes tested and is not therefore a particularly significant routine test. Permeability was, with this fine sand, very low, but apparently quite sufficient for this type of moulding material. Variations in the clay and oil additions and in the usage of the sand varied this property over a very small range of values and, unless trouble is experienced or the base sand altered, it is not considered to be a test of great importance in this oil based sand.

The castings produced in moulds made from this sand mix showed that there were limitations to its use. The phosphor-bronze and aluminium-magnesium castings were basically good, most of those defects present being considered to be a function of the casting design and its associated running and feeding system rather than a fault of the moulding material. The finning in the phosphor-bronze castings however may indicate a necessity for a little further research. It is possible that some change in the base sand is required or an investigation into the thick lustrous carbon coating around the casting which, on cracking, could well have been the cause of the fins. These defects were, however, not considered to be detrimental to the serviceability of these castings. At the higher casting temperatures used for the iron castings the finning defect was most pronounced as was a crazing of the otherwise smooth surface.

These defects are known to occur in green sand with a high carbon content particularly when the carbonaceous material contains the benzene ring structure. This leads to the excessive formation of lustrous carbon deposits as a crust around the casting and it is most likely that the cracking and distortion of this layer plays a significant part in the formation of the finning and crazing. Further, the surface finish of the iron castings appeared to be impaired by gas blow holes which would suggest that at these high temperatures the permeability of the sand was insufficient for the high rate of gas evolution.

Overall, this moulding material, if used wisely, is capable of producing sound castings of reproducible dimensional accuracy and good surface finish.

CHAPTER 9

CONCLUSIONS

9. CONCLUSIONS

- (i) Organo-clays can be produced by carefully reacting Na bentonite with dimethyldioctadecylammonium chloride under controlled conditions.
- (ii) Dimethyldioctadecylammonium bentonite, when mulled with a light mineral oil provides an effective bonding medium for foundry sand moulds.
- (iii) The temperature at which the mulling operation is carried out effects the physical properties of the final mix. Generally temperatures in the range 40-45°C give the most efficient mulling conditions and development of the optimum physical properties. The addition of 0.5 per cent methanol to the muller as a polar additive reduces the temperature requirement to a range of 30-35°C.
- (iv) The rate at which the sand mix develops its optimum properties during mulling depends upon the temperature of the mix, the higher the temperature, the greater the rate. The use of a polar additive greatly increases the rate at which the optimum properties are developed.
- (v) The toughness of an organo-clay bonded sand, as indicated by the shatter index, is greatly affected by the temperature of the moulding sand, the greater the temperature, the tougher the sand.
- (vi) The strength of a moulding sand mix is improved by the addition of 0.5 per cent methanol to the mix during the mulling operation particularly when temperatures of

approximately 35°C are employed. At higher temperatures no particular benefit is to be gained from its use.

- (vii) The strength of a moulding sand is largely dictated by the clay content of the mix, the greater the clay content, the stronger the bond.
- (viii) The oil content of a sand mix has a pronounced effect upon the shatter index of the mould, the greater the addition of oil, the higher the shatter index.
- (ix) The variation of mould temperature after ramming affects the physical properties of the compacted sand. Heating tends to reduce the strength of the mould whilst increasing the shatter index. Cooling considerably increases the strength whilst leaving the shatter index relatively unaffected.
- (x) The mulled moulding sand can be stored for at least 14 days with little or no change in its physical properties.
- (xi) Used moulding sand can be recycled after a simple stirring operation to mix the burnt and unburnt sand and reused without further treatment over a limited number of cycles. Slight deterioration in all physical properties is encountered but not of sufficient magnitude to prevent further excellent castings being produced. There is no need nor is anything to be gained by passing the sand through a muller.

- (xii) The used moulding sand can be reconstituted by selective additions of oil and clay and remulling. A rough guide to the amount of additions required can be made by studying the green compression strength which is controlled almost exclusively by the clay content, and the shatter index which is largely controlled by the oil addition.
- (xiii) The general surface finish of castings made in the organo-clay bonded sand mould was excellent. However, a surface veining defect was apparent on both the phosphor-bronze castings and cast iron castings which, whilst not rendering the castings unserviceable, would necessitate extra fettling and thus obviate the advantage of having an otherwise very good surface finish.
- (xiv) Castings of close dimensional tolerance can be produced using this moulding sand.

CHAPTER 10

SUGGESTIONS FOR FURTHER WORK

10. SUGGESTIONS FOR FURTHER WORK

1. Modification of clay with different organic reagents to establish their effects upon the physical properties of the moulding sands.
2. The use of other types of oil with reference to their effect upon the physical properties.
3. The use of various types of polar additive to find a cheap, more efficient and less hazardous material than methanol.
4. Further investigation into the use of iron oxide to overcome the excess lustrous carbon problems without adversely affecting the physical properties of the sand.
5. The design of a more suitable mulling machine which does not require its surfaces to be roughened on a regular basis to ensure efficient mulling conditions.
6. Investigation into other moulding techniques for this material such as a high pressure squeeze, boxless system.
7. Investigation into a cheaper method of producing the moulding sand, perhaps by carrying out the cation exchange reaction in the sand muller of an existing clay/water bonded sand system, thereby allowing the replacement of some or all of the water by oil with consequent reduction in steam and the possible elimination of coal dust in sand used for iron castings. .
8. Further work into the hot ramming of the moulding sand followed by cooling as a possible method of producing an easily recyclable hard sand mould.

APPENDICES

APPENDIX (A)

A. SAND TESTING

A(i) The Sand Test Piece

A standard cylindrical sand test piece, 2in. in diameter and 2in. in height, was used in all but the hot compression strength test. Its dimensions and method of preparation were based upon the recommendations of the American Foundrymen's Society.

A predetermined weight of mulled sand was dropped into a steel specimen tube having a height of 5in. and an internal diameter of 2in., the lower end of which was located in a flat bottomed cup. The assembly was then placed in the ramming device and a plunger of flat profile and 2in. diameter was lowered gently down the tube to rest on the surface of the sand. This was then compacted by applying three standard blows to the ramming head, each blow being caused by the impact of a 14 lb. weight falling from a height of 2in. The height of the test piece could be read directly from the rammer, the weight of the sand used being predetermined by trial and error to give a value of 2in.⁺ 1/32in.

Most of the experiments required that the test piece remain within the tube for all or part of the test. However, for the green compression strength and green shear strength tests the test piece had to be ejected from the tube by inverting it over a 2in. diameter stripping post, removing the cup and gently sliding the tube downward to leave the sand compact on the top of the post.

A(ii) The Green Compression Strength

A standard test piece was located so that its ends were held between the two flat plates of the George Fischer Universal Strength Testing Machine as shown in Fig. (viii) Plate A was held rigidly to the apparatus whilst plate B was attached to a hydraulic piston. The pressure on the piston was gradually increased by turning a handle at a steady rate until the test piece collapsed. The breaking load was recorded by means of a pointer on the pressure gauge and read in lb per in².

A(iii) The Green Shear Strength

This test was carried out in essentially the same manner as for the green compression strength. The end plates between which the test piece was held were, however, of a stepped profile as shown in Fig. (ix) thus creating a shear plane along the axis of the cylindrical test piece. The load was applied more slowly than in the previous test because of the relatively low strength. The load at which the test piece sheared was recorded in lb. per in².

A(iv) The Hot Compression Strength

In this experiment the 2in. x 2in. test piece was too large to be heated uniformly and quickly to the test temperature of 1000°C. A smaller test piece was therefore used, 11mm. in diameter and 20mm high, and was formed in a steel tube with a removable base plug using a hand operated plunger. This was forced down the tube until arrested by a stop exactly 20mm above the base plug. The weight of sand used for the test piece was 2 per cent of that

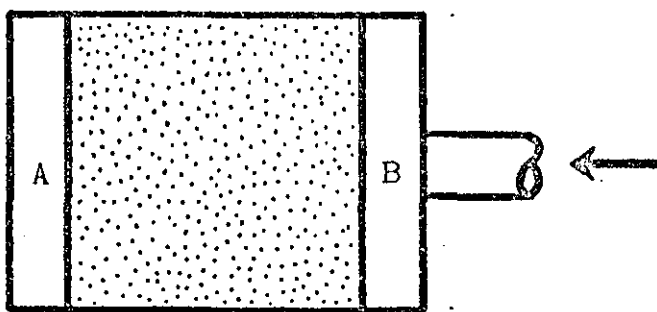


Fig. (viii)
Arrangement of the
test piece for the
green compression
test.

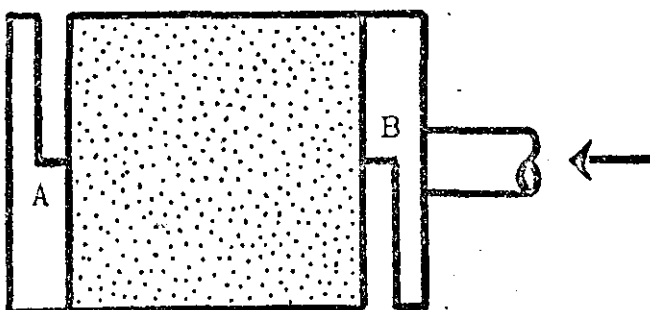


Fig. (ix)
Arrangement of the
test piece for the
green shear test.

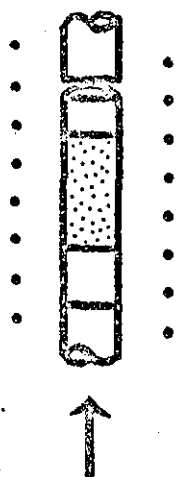


Fig. (x)
Arrangement of the
test piece for the
hot compression
test.

required for the standard 2in. x 2in test piece.

The specimen was ejected from the tube using a stripping post on top of which had been placed a small cylindrical silica disc, 11mm in diameter and 9mm in height. The silica disc and test piece were carefully lifted off the post and placed on the bottom silica press rod of the George Fischer Hot Compression Strength Testing Apparatus and a further silica disc, 11mm in diameter, and 10mm in overall height and having a domed upper surface was placed on top as shown in Fig. (x). A load was applied to the bottom press rod via a hydraulic system attached to the Universal Strength Testing Machine sufficient to float the bottom push rod assembly and locating the test piece just below the fixed upper push rod. The furnace was then lowered over the test piece and a heating period of exactly 60s allowed to elapse. The bottom push rod was then raised by steadily increasing the pressure in the hydraulic system until the test piece collapsed. The breaking load was recorded in kg per cm² and the true load to which the test piece had been subjected was found by subtracting the load necessary to float the bottom silica push rod and specimen assembly.

A(v) The Permeability

A standard 2in x 2in test piece as formed in its specimen tube was placed over the centre post of a Ridsdale Dietert Electric Permmeter and sealed by means of an expanding collar. With the operating lever in the 'check' position the pressure was adjusted to give a permeability reading of zero. By switching the position of the lever to 'test' the permeability of the test piece was read directly from the pressure gauge.

A(vi) The Mould Hardness

A specimen tube with test piece was inverted over a stripping post and held lightly in position whilst a Ridsdale Dietert Hardness Tester 'C' scale was pressed firmly onto the exposed surface of the test piece. The mould hardness was then read directly from the scale of the dial gauge.

A(vii) The Shatter Index

A specimen tube was placed in the holder of a Ridsdale Shatter Index Tester, the test piece being accommodated at the lower end of the tube. A piston was pushed down the inside of the tube, very slowly ejecting the test piece until, released from the tube, it fell a distance of exactly 6ft (182.8cm) onto a circular steel anvil. All those parts of the shattered test piece, if any, which passed through the 13.2mm mesh sieve were collected in a pan and weighed. The shatter index was then given by the following formula:

$$\text{Shatter index} = \frac{SW - PW}{SW} \times 100$$

where SW = specimen height

PW = weight of sand in the pan

A(viii) The Flowability

A test piece was formed on the rammer using four instead of the standard three blows. A dial gauge attached to the rammer was then moved into position so that its probe touched the top of the plunger attached to the ramming head and was adjusted so as to read zero. After giving the test piece a fifth blow the movement of the plunger was recorded by the gauge and the percentage flowability read directly from the dial.

APPENDIX (B)

B. MELTING THEORY

B(i) Basic Theory of Melting Phosphor-bronze

Tin-bronze dissolves both oxygen and hydrogen from the furnace atmosphere. On solidification these gases, if not removed, combine to form steam and give rise to 'reaction unsoundness' in the resulting castings.

As Fig.(xi) shows, an excess of oxygen in the metal tends to restrict the absorption of hydrogen and vice versa. In phosphor-bronze, however, the phosphorus combines preferentially with the oxygen in the furnace atmosphere and limits that available for absorption in the bronze. This results in the unrestricted absorption of any hydrogen present into the metal, a situation which is further aggravated by the production of a very fluid phosphate slag which offers little resistance to the passage of the hydrogen from the furnace atmosphere into the melt.

The oxygen in the furnace can be the result of excess air or the thermal decomposition of steam produced by the combustion of the gas. Hydrogen is also produced by the thermal decomposition of steam and as a biproduct of the oxidation of the melt by steam. By increasing the volume of air to the furnace over that required for complete combustion of the gas, the partial pressure of hydrogen above the melt can be reduced whilst that of oxygen is increased to give oxidising conditions. By decreasing the air supply oxidising conditions are reduced to a minimum whilst the partial pressure of hydrogen remains high giving reducing conditions. Thus the

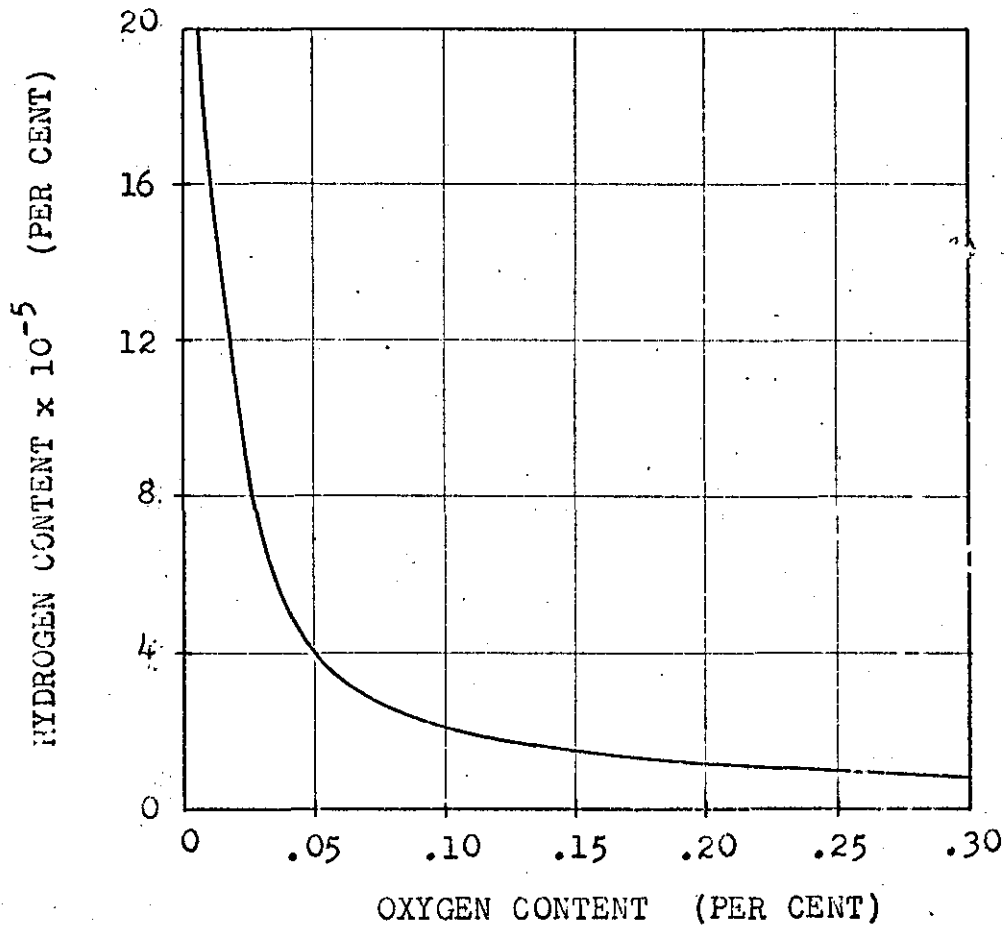


Fig.(xi) Graph showing the relationship between the dissolved oxygen and hydrogen content of bronze.

solubility of oxygen and hydrogen can be controlled to some extent by varying the gas to air ratio of the furnace. Since the temperature of the metal also influences the rate of gas absorption, further control can be achieved by keeping melt temperatures to a minimum. This also results in reduced losses in phosphorous by oxidation.

Two different methods of melting phosphor-bronze are therefore possible. The first is to melt under oxidizing conditions thus limiting the partial pressure of hydrogen in the furnace atmosphere. Using this method, however, phosphorus losses of up to 40 per cent can be expected due to oxidation. The second method is to use a reducing atmosphere, accepting the consequently high absorption of hydrogen which would later have to be purged from the melt by reducing the partial pressure of the gas at the liquid metal surface. This would be carried out by bubbling dry nitrogen through the molten bronze. This, however, in turn creates a great deal of turbulence and promotes an increased rate of oxidation of the phosphorus with the atmosphere.

B(ii) Basic Theory of Melting Aluminium-Magnesium Alloys

Aluminium-magnesium alloys present certain melting problems associated with its magnesium content. This oxidises preferentially to the aluminium forming a dross which, unlike the normal aluminium oxide skin, is non-protective resulting in its continuous formation during the melting process and consequent loss of magnesium. The oxidation of the magnesium by water vapour in the furnace atmosphere produces hydrogen which, together with that already in the furnace dissolves into the melt. If this gas is not removed it comes out of solution during subsequent solidification

to give rise to porosity in the final casting. It is therefore important to keep the partial pressure of both oxygen and hydrogen above the melt to a minimum by providing just sufficient air to the furnace to burn the gas supplied completely.

To minimise the oxidation of the magnesium and the absorption of hydrogen it is important to protect the surface of the melt from the furnace atmosphere with a suitable flux. Since the oxidation and gas absorption increase with temperature it is also important not to overheat the melt. In fact, excessive heating can result in the magnesium catching fire with disastrous consequences.

APPENDIX C

C. FORMULA DERIVATION

C(i) Derivation of formula 6.2

Required: The cation exchange capacity of the clay.

This may be found by ascertaining the number of meq of pure dye adsorbed by 100g of dry clay.

Utilising the following symbols for brevity:

I = the percentage of dye initially

F = the percentage of dye in the filtrate

P = the percentage purity of the dye

E = the equivalent weight of the dye

V = the volume of the dye used

W = the dry weight of the clay

it can be said that the weight of pure dye adsorbed by the clay sample =

$$\frac{(I - F)}{100} \times V \times \frac{P}{100} \text{ g}$$

The weight of pure dye adsorbed by 100g dry clay =

$$\frac{(I - F)}{100} \times V \times \frac{P}{100} \times \frac{100}{W} \text{ g}$$

The number of meq of pure dye adsorbed by 100g of dry clay =

$$\frac{(I - F)}{100} \times V \times \frac{P}{100} \times \frac{100}{W} \times \frac{1000}{E}$$

Rearranging, this gives:

$$\frac{(I - F) \times P}{\frac{E}{1000} \times \frac{100}{V} \times W}$$

which is formula 6.2

C(ii) Derivation of formula 6.4.2.

Required: The weight of organic reagent to be added to a clay suspension to achieve a known addition of meq DDAC per 100g of dry clay.

Utilising the following symbols for brevity:

A = purity of organic reagent (per cent)

B = weight of addition of organic reagent (g)

C = weight of clay as supplied (g)

D = clay moisture content (per cent)

F = meq of DDAC to be added per 100g of dry clay

G = molecular weight of DDAC

$$F \text{ meq of DDAC} = F \times \frac{G}{1000} \text{ g of DDAC}$$

$$\text{Now } F \times \frac{G}{1000} \text{ g DDAC} = F \times \frac{G}{1000} \times \frac{100}{A} \text{ g of organic reagent}$$

$$\text{and } 100 \text{ g dry clay} = \frac{100}{100 - D} \times 100 \text{ g clay as supplied}$$

therefore, to add F meq DDAC per 100g dry clay

$$F \times \frac{G}{1000} \times \frac{100}{A} \text{ g organic reagent must be added to}$$

$$\frac{100}{100 - D} \times 100 \text{ g of clay as supplied.}$$

If the suspension is to contain C g of clay as supplied, the addition of organic reagent, B g, becomes:

$$F \times \frac{G}{1000} \times \frac{100}{A} \times \frac{100 - D}{100} \times \frac{1}{100} \times C \text{ g}$$

Rearranging this gives:

$$\frac{F \times C(100 - D) \times G}{A \times 100\,000}$$

which is formula 6.4.2.

C(iii) Derivation of formula 6.5

Required: The amount of organic material (DDA^+) present in a modified clay.

Using the following symbols for brevity:

I = the percentage ignition loss of the organo-clay

C = the percentage ignition loss of unmodified clay

W = the molecular weight of the quaternary ammonium cation

In 100g of organo-clay there will be $(100 - \text{DDA}^+)$ g of base clay.

Associated with this base clay will be

$\frac{C}{100} \times (100 - \text{DDA}^+)$ g of chemically combined water which is lost during ignition.

$$\text{Therefore } I = \frac{C}{100} \times (100 - \text{DDA}^+) + \text{DDA}^+$$

$$= C - \frac{C}{100} \times \text{DDA}^+ + \text{DDA}^+$$

$$= C + \text{DDA}^+ \left(1 - \frac{C}{100}\right)$$

$$= C + \frac{\text{DDA}^+(100 - C)}{100}$$

$$\text{Therefore } \text{DDA}^+ = \frac{(I - C)100}{100 - C}$$

This DDA^+ is associated with $(100 - \text{DDA}^+)$ g of base clay, therefore, associated with 100g of base clay there is

$$\frac{(I - C)100}{100 - C} \times \frac{100}{100 - \text{DDA}^+} \text{ g of } \text{DDA}^+$$

$$= \frac{(I - C)100}{100 - C} \times \frac{100}{100 - \frac{(I - C)100}{100 - C}}$$

$$= \frac{(I - C)100}{100 - C} \times \frac{100(100 - C)}{100(100 - C) - (I - C)100}$$

$$= \frac{(I - C)100}{(100 - C) - (I - C)}$$

$$= \frac{(I - C)100}{(100 - I)}$$

Expressed in meq per 100g of base clay this becomes

$$\frac{(I - C)100}{(100 - I)} \times \frac{1000}{W}$$

Rearranging, this gives:

$$\frac{(I - C) \times 100\ 000}{(100 - I)W}$$

which is formula 6.5

APPENDIX D

D. Determination of the Effect of Iron Oxide

Because brief mention was made in the literature concerning the use of iron oxide in the moulding sand⁽²⁴⁾ tests were carried out with 2 per cent additions of Fe_2O_3 to study the effects upon the physical properties of the sand. The basic mix was 5 per cent clay and 3 per cent oil mulled for ten minutes. Four mixes at different mulling temperatures were carried out using 0.5 per cent methanol as polar additive and a further four made without the use of a polar additive.

Although time would not permit a full investigation into the use of the material, the physical property results obtained were of interest and have been quoted in this appendix, tables (xxxiii) and (xxxiv).

A comparison of these results with those of the same mix without iron oxide, shown in Tables (vii) and (viii) would suggest that the iron oxide slightly increases the strength of the sand, decreases the flowability and has a devastating effect upon the hot compression strength. This latter effect is probably due to the rapid oxidation of the products of combustion which would normally have formed the bond at this elevated temperature. For this reason the use of this material should be treated with caution particularly in large moulds where heat penetration of the mould would be great and possibly lead to sand erosion and surface cracking.

APPENDIX TABLES

Table (i)

CATION EXCHANGE CAPACITY OF Na BENTONITE

EXPERIMENTAL RESULTS USING THE METHYLENE BLUE METHOD

SAMPLE No.		1	2	3
WEIGHT OF CLAY	(g)	0.1650	0.1615	0.1500
WATER ADDITION TO CLAY	(ml)	5.0606	5.0000	5.0000
WATER ADDITION TO FILTRATE	(ml)	53.0	59.0	73.0

Table (ii)

LOSS ON IGNITION OF ORGANO CLAY _____ (PER CENT)

EFFECT OF REACTION CONDITIONS

ARQUAD ADDITION: 46.84 g/30 g CLAY

SAMPLE No.	1	2
USING LOW SPEED STIRRER	37.7177	37.7308
USING HIGH SPEED STIRRER	37.9745	37.9262
WITHOUT Na ₂ CO ₃ PRE-TREATMENT	38.0088	38.0371

Table (iii)

LOSS ON IGNITION OF ORGANO-CLAY _____ (PER CENT)

EFFECT OF VARYING QUATERNARY AMMONIUM COMPOUND ADDITIONS

SAMPLE No.		1	2
ARQUAD ADDITION	0.00	6.9711	6.8015
	11.71	17.6547	17.6670
	23.42	25.5397	25.5508
	35.18	32.0075	32.0174
	46.84	37.7177	37.7308
	70.26	46.5978	46.5906
	93.68	50.2158	50.3288
(g/80 g CLAY)	117.10	50.2669	50.2479

Table (iv)

LOSS ON IGNITION OF ORGANO-CLAY _____ (PER CENT)

LARGE SCALE PRODUCTION

SAMPLE No.		1	2	3	4
BATCH No.	1	39.4375	39.5102	39.3041	39.2921
	2	39.6150	39.5663	39.6263	39.6192
	3	38.7969	38.8450	38.7513	38.7772
	4	39.0171	39.0161	39.0228	38.9920
	5	39.6541	40.0607	40.0700	39.9290
	6	39.6240	39.7245	39.7464	39.7369
	7	39.3303	39.1248	39.3145	39.3348
	8	38.9127	38.9677	38.9424	38.9576
	9	38.8845	38.7930	38.7940	38.8889

Table (v)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	3.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	192	195	194	193
TEMPERATURE BEFORE AND AFTER MULLING (°C)	20.5 22.0	31.5 32.5	43.0 43.0	52.0 45.0
Average	21.5	32.0	43.0	48.5
SPECIMEN WEIGHT (g)	161	161	160	159
GREEN COMPRESSION STRENGTH	14.5 13.8 13.8 13.8	22.8 23.4 23.4	33.1 32.4 32.4	31.7 31.0 31.7
(N/m ² x 10 ³)				
Average	14.0	23.2	32.6	31.5
GREEN SHEAR STRENGTH	3.1 2.4 2.8	5.5 5.5 5.9	7.6 8.3 8.3	7.6 8.3 7.9
(N/m ² x 10 ³)				
Average	2.8	5.6	8.0	7.9
HOT COMPRESSION STRENGTH	138.6 148.4 149.4 138.6	203.4 195.5 195.5 185.7 208.3	191.6 192.6 183.7 195.5 188.7	161.2 151.4 158.3
(N/m ² x 10 ³)				
Average	143.8	197.7	190.4	156.9
PERMEABILITY	21.3 21.7 21.3	20.8 20.7 20.7	20.3 20.2 20.0	20.8 20.9 20.6 21.0 20.9
(small orifice)				
Average	21.4	20.7	20.2	20.8
MOULD HARDNESS	5 6 6 6	11 12 13 12 13	16 16 16	15 16 16
('C' scale)				
Average	6	12	16	16
SHATTER INDEX	47 48 47	61 59 57 60	69 67 70	63 60 65 60 62
Average	47	59	69	62
FLOWABILITY	86 86 87 86	86 88 87 86	86 85 86	84 85 84
(per cent)				
Average	86	87	86	84

Table (vi)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	3.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	196	199	198	197
TEMPERATURE BEFORE AND AFTER MULLING (°C)	19.5 20.5	30.0 31.0	44.0 41.5	53.0 45.0
Average	20.0	30.5	43.0	49.0
SPECIMEN WEIGHT (g)	160	159	159	160
GREEN COMPRESSION STRENGTH	23.4 22.8 24.1 22.8	33.8 33.8 33.8	35.2 35.2 35.2	33.1 33.1 33.1
(N/m ² x 10 ³)				
Average	23.8	33.8	35.2	33.1
GREEN SHEAR STRENGTH	5.5 5.5 5.5	7.9 9.0 9.3 8.3 9.3	8.6 7.9 9.3 8.6 8.6	7.6 9.0 7.6 8.6 8.6
(N/m ² x 10 ³)				
Average	5.5	8.8	8.6	8.3
HOT COMPRESSION STRENGTH	173.9 171.0 183.7 171.0	190.6 187.7 191.6	187.7 198.5 182.8 187.7	197.5 185.7 195.5 203.4
(N/m ² x 10 ³)				
Average	174.9	190.0	189.1	195.5
PERMEABILITY	21.7 21.6 21.7	20.9 20.9 20.9	21.6 21.3 21.4	21.2 21.2 21.2
(small orifice)				
Average	21.7	20.9	21.4	21.2
MOULD HARDNESS	11 11 13 12 12	17 16 17 18 18	18 17 17 17 18	16 16 17 17 17
('C' scale)				
Average	12	17	17	17
SHATTER INDEX	57 56 57	71 72 70	67 71 69 70	69 68 68
Average	56	71	69	68
FLOWABILITY	86 85 86 87 87	86 86 87 85 85	85 87 86 87 85	86 86 86 85 86
(per cent)				
Average	86	86	86	86

Table (vii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	261	264	263	262
TEMPERATURE BEFORE AND AFTER MULLING (°C)	19.0 20.0	30.5 31.0	41.0 41.0	57.0 44.0
Average	19.5	31.0	41.0	50.5
SPECIMEN WEIGHT (g)	161	159	157	158
GREEN COMPRESSION STRENGTH	26.9 26.2 26.9 26.9	48.3 49.0 49.0 49.6	64.1 64.8 65.5 64.8	66.9 66.9 66.2 66.9
(N/m ² x 10 ³)			65.5	
Average	26.7	49.0	64.9	66.7
GREEN SHEAR STRENGTH	5.9 6.2 6.2	11.4 10.7 11.4 12.1 12.1	17.2 15.9 15.5 16.9	14.1 14.8 15.5 14.8 15.9
(N/m ² x 10 ³)				
Average	6.1	11.5	16.4	15.0
HOT COMPRESSION STRENGTH	206.3 210.2 210.2	272.0 281.8 267.1 247.5	311.2 294.6 293.6 298.5	278.9 292.6 285.7 276.9
(N/m ² x 10 ³)				
Average	208.9	267.1	299.5	283.5
PERMEABILITY	18.8 18.7 18.7 18.8	18.8 18.7 18.5 18.7	20.1 20.2 20.0	19.8 19.6 19.7
(small orifice)				
Average	18.8	18.7	20.1	19.7
MOULD HARDNESS	16 16 15 15	24 24 25 26	27 26 28 28	27 27 27 29
('C' scale)				
Average	16	25	27	28
SHATTER INDEX	42 45 47 43 45	65 64 64	66 66 67	66 67 68
Average	45	64	66	67
FLOWABILITY	83 85 85 85	82 82 82 82	79 78 78 79	79 79 79 78
(per cent)				
Average	85	82	79	79

Table (viii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	167	166	168	169
TEMPERATURE BEFORE AND AFTER MULLING (°C)	21.0 23.0	30.0 30.0	40.0 36.0	49.0 42.0
Average	22.0	30.0	38.0	45.5
SPECIMEN WEIGHT (g)	159	159	158	157
GREEN COMPRESSION STRENGTH	56.5 55.8 56.5	68.9 68.9 68.9	69.6 70.3 71.0 70.3	68.9 69.6 68.9
(N/m ² x 10 ³)				
Average	56.3	68.9	70.3	69.2
GREEN SHEAR STRENGTH	10.0 10.3 10.3 11.0	15.5 16.2 15.5	15.5 14.5 15.5 14.8	15.9 17.2 17.2 15.2 17.2
(N/m ² x 10 ³)				
Average	10.4	15.7	15.1	16.5
HOT COMPRESSION STRENGTH	254.4 264.2 255.3	274.0 284.8 303.4 283.8	312.2 293.6 292.6 293.6	271.0 254.4 263.2 264.2
(N/m ² x 10 ³)				
Average	258.0	286.5	298.0	263.2
PERMEABILITY	18.9 18.8 18.7	19.0 19.0 18.8	18.8 18.8 19.0	20.3 20.0 20.2
(small orifice)				
Average	18.8	18.9	18.9	20.2
MOULD HARDNESS	27 26 26 26	28 29 28 30	28 29 28 28	28 28 29 28
('C' scale)				
Average	26	29	28	28
SHATTER INDEX	67 64 64 65	69 70 74 72 69	77 73 75 75	69 68 69
Average	65	71	75	69
FLOWABILITY	82 81 82 83 83	80 81 81 81 80	78 78 78 78 78	82 81 80 81 80
(per cent)				
Average	82	81	78	81

Table (ix)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	7.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	200	203	202	201
TEMPERATURE BEFORE AND AFTER MULLING (°C)	19.0 20.5	32.0 33.5	43.0 42.0	54.0 44.0
Average	20.0	33.0	42.5	49.0
SPECIMEN WEIGHT (g)	160	156	153	154
GREEN COMPRESSION STRENGTH (N/m ² x 10 ³)	42.7 41.4 42.1 42.7	81.4 82.0 82.0	91.0 89.6 90.3 89.6 90.3	89.6 90.3 89.6 89.6
Average	42.2	81.8	90.2	89.8
GREEN SHEAR STRENGTH (N/m ² x 10 ³)	9.3 9.3 9.7	19.3 19.7 19.7	21.4 21.0 21.4	20.7 20.3 20.7
Average	9.4	19.5	21.3	20.6
HOT COMPRESSION STRENGTH (N/m ² x 10 ³)	329.9 317.1 318.1 324.0	431.9 412.2 419.1 401.5	452.5 448.5 452.5 453.4	410.3 414.2 401.5 412.2
Average	322.3	416.2	451.7	409.5
PERMEABILITY (small orifice)	17.4 17.2 17.3	21.9 21.5 21.8 21.6	23.5 23.0 23.2 23.2	21.6 21.2 21.6
Average	17.3	21.7	23.2	21.5
MOULD HARDNESS (°C scale)	23 23 22 22 23	32 31 32 33 32	32 31 32 31 32	30 32 32 30 32
Average	23	32	32	31
SHATTER INDEX	41 43 43	65 67 65 65	63 65 64 66	64 67 67
Average	42	66	65	66
FLOWABILITY (per cent)	82 83 82 83 83	78 77 78 77 77	72 72 72 72 72	73 73 72 73 73
Average	83	77	72	73

Table (x)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	7.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	230	233	235	231
TEMPERATURE BEFORE AND AFTER MULLING (°C)	17.0 19.0	27.0 29.0	39.0 36.0	58.0 45.5
Average	18.0	28.0	37.5	52.0
SPECIMEN WEIGHT (g)	159	156	155	155
GREEN COMPRESSION STRENGTH	71.7 71.0 70.3 71.7 71.0	94.5 95.8 95.1 95.8	97.2 96.5 97.2	97.9 99.3 98.6 98.6
(N/m ² x 10 ³)				
Average	71.2	95.3	97.0	98.6
GREEN SHEAR STRENGTH	14.5 15.5 14.1	20.0 20.3 20.7 20.7	21.7 20.7 21.7 21.7	25.5 24.5 23.8 24.5 25.9
(N/m ² x 10 ³)				
Average	14.7	20.4	21.5	24.8
HOT COMPRESSION STRENGTH	324.0 334.8 324.0 332.8	396.6 391.6 365.2 378.9 374.0	411.3 403.4 423.0 391.7	409.3 426.0 412.2 409.3
(N/m ² x 10 ³)				
Average	328.9	381.3	407.3	414.2
PERMEABILITY	17.9 18.2 18.3 18.0	20.9 21.0 20.7 20.8	20.8 20.9 20.9 21.0	21.2 21.0 21.1 21.2
(small orifice)				
Average	18.1	20.9	20.9	21.1
MOULD HARDNESS	28 29 29 30 28	33 34 34 34 33	33 31 33	32 32 33 33
('C' scale)				
Average	29	34	32	33
SHATTER INDEX	53 52 52	69 69 67 67	65 64 63	63 59 61 63
Average	52	68	64	61
FLOWABILITY	81 82 83 82 83	78 80 77 78 78	73 73 73	74 75 74 75
(per cent)				
Average	82	78	73	75

Table (xi)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	2.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	221	224	223	222
TEMPERATURE BEFORE AND AFTER MULLING (°C)	20.0 21.0	30.0 31.0	37.0 39.0	54.0 45.0
Average	20.5	30.5	38.0	49.5
SPECIMEN WEIGHT (g)	160	158	157	157
GREEN COMPRESSION STRENGTH	29.6 29.6 28.3 29.0	51.0 50.3 51.7 51.7	62.7 62.1 65.5 65.5 64.8	63.4 64.1 64.8 64.8 62.7
(N/m ² x 10 ³)				
Average	29.1	51.2	64.1	64.0
GREEN SHEAR STRENGTH	6.6 6.6 5.9 6.2	10.3 11.0 10.0 10.3	14.5 12.8 12.4 13.8 12.4	14.1 14.1 14.1
(N/m ² x 10 ³)				
Average	6.3	10.4	13.2	14.1
HOT COMPRESSION STRENGTH	193.6 182.8 189.6 176.9	323.0 303.4 313.2 315.2	383.8 366.2 367.1 373.0	365.2 354.4 374.0 357.3
(N/m ² x 10 ³)				
Average	185.7	313.7	372.5	362.7
PERMEABILITY	19.0 19.2 19.2	20.9 20.9 20.9	22.7 22.3 22.6	21.6 22.0 22.0 22.0
(small orifice)				
Average	19.1	20.9	22.5	21.9
MOULD HARDNESS	17 17 17	24 23 23	26 26 26 25	27 26 26
(‘C’ scale)				
Average	17	23	26	26
SHATTER INDEX	36 37 37	39 37 38	41 41 41	43 40 43 43
Average	36	38	41	42
FLOWABILITY	86 86 86	83 83 83	81 82 80 81	81 81 81
(per cent)				
Average	86	83	81	81

Table (xii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	2.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	225	228	227	226
TEMPERATURE BEFORE AND AFTER MULLING (°C)	19.5 20.0	27.0 27.0	35.5 36.5	58.0 41.0
Average	20.0	27.0	36.0	49.5
SPECIMEN WEIGHT (g)	159	157	155	155
GREEN COMPRESSION STRENGTH	48.3 50.3 50.0 50.0	64.1 63.4 63.4 63.4	66.9 66.9 66.9	67.6 65.5 66.2 66.2
(N/m ² x 10 ³)				
Average	49.1	63.6	66.9	66.4
GREEN SHEAR STRENGTH	10.3 10.7 10.3	14.8 13.8 14.8 13.1 14.5	14.5 15.5 12.8 14.8 12.8	15.9 14.8 15.2 15.9
(N/m ² x 10 ³)				
Average	10.5	14.2	14.1	15.4
HOT COMPRESSION STRENGTH	256.3 288.7 278.8 269.1 266.1	275.9 279.9 281.9 277.9	304.4 323.0 312.2 322.0	323.0 323.0 313.2 318.1
(N/m ² x 10 ³)				
Average	271.8	278.9	315.4	319.3
PERMEABILITY	19.7 19.8 19.8	20.5 20.8 20.7 20.8	23.3 23.7 23.8 23.9	24.0 23.9 24.3 24.0
(small orifice)				
Average	19.8	20.7	23.7	24.1
MOULD HARDNESS	22 23 24 22	26 26 25 27	26 26 26	25 26 26 27
(°C scale)				
Average	23	26	26	26
SHATTER INDEX	36 38 39	43 46 43 48 45	41 40 43 39	45 40 41 43
Average	38	45	40	42
FLOWABILITY	85 85 85 85	83 82 81 83	80 80 80	79 80 79 79
(per cent)				
Average	85	82	80	79

Table (xiii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	4.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	237	240	239	238
TEMPERATURE BEFORE AND AFTER MULLING (°C)	19.0 20.0	31.0 33.0	41.5 40.5	54.0 43.0
Average	19.5	32.0	41.0	48.5
SPECIMEN WEIGHT (g)	163	162	160	160
GREEN COMPRESSION STRENGTH	22.8 22.8 22.8	50.3 49.6 49.6	62.7 62.7 62.7	64.1 64.8 64.8
(N/m ² x 10 ³)				
Average	22.8	49.9	62.7	64.6
GREEN SHEAR STRENGTH	4.8 4.8 4.8	12.1 11.4 12.1 12.4	16.5 17.2 16.5 16.5	15.5 16.5 16.2 15.9
(N/m ² x 10 ³)				
Average	4.8	12.0	16.7	16.0
HOT COMPRESSION STRENGTH	268.1 264.2 274.0 266.1	314.2 294.6 315.1 311.2	314.2 312.2 303.4 302.4	306.3 293.6 292.6
(N/m ² x 10 ³)				
Average	268.1	308.8	308.0	297.5
PERMEABILITY	18.2 18.4 18.0	17.6 17.3 17.3 17.4	18.4 18.4 18.3	18.2 18.2 18.2
(small orifice)				
Average	18.2	17.4	18.4	18.2
MOULD HARDNESS	11 11 13 12	23 23 24 23 23	27 28 27 28	27 28 28
('C' scale)				
Average	12	23	28	28
SHATTER INDEX	52 50 52	88 86 90 85	87 89 88	84 87 84 86
Average	51	87	88	85
FLOWABILITY	85 85 85 85	83 83 83 81 84	79 80 80	80 81 81
(per cent)				
Average	85	83	80	81

Table (xiv)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	4.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	241	244	243	242
TEMPERATURE BEFORE AND AFTER MULLING (°C)	21.0 22.0	32.0 33.0	42.0 43.0	55.0 48.0
Average	21.5	32.5	42.5	51.5
SPECIMEN WEIGHT (g)	162	160	160	161
GREEN COMPRESSION STRENGTH	48.3 48.3 48.3	64.8 65.5 64.8	65.5 64.8 64.8	66.2 66.2 66.9
(N/m ² x 10 ³)				
Average	48.3	65.0	65.0	66.4
GREEN SHEAR STRENGTH	11.0 11.7 10.3 11.4	17.6 16.9 18.6 17.9 17.6	17.6 17.9 17.6	17.6 17.9 16.9 16.9
(N/m ² x 10 ³)				
Average	11.1	17.7	17.7	17.3
HOT COMPRESSION STRENGTH	259.3 263.2 251.4 260.2	293.6 274.0 340.6 293.6 317.1	293.6 320.1 296.5 324.0 290.6	315.1 298.5 285.7 305.3
(N/m ² x 10 ³)				
Average	258.5	303.8	305.0	301.2
PERMEABILITY	17.2 17.2 17.3	17.3 17.3 17.2 17.2	17.2 17.3 17.2	17.2 17.0 17.0 17.1
(small orifice)				
Average	17.2	17.3	17.2	17.1
MOULD HARDNESS	24 24 23 22	28 27 29 27	27 26 28 26	28 28 28 27 28
('C' scale)				
Average	23	28	27	28
SHATTER INDEX	77 77 81 80 77	95 93 97 96	92 91 92	87 88 85 89
Average	78	95	91	87
FLOWABILITY	84 83 83 84	80 80 81 80	81 80 80 81	81 82 81 82 81
(per cent)				
Average	84	80	81	81

Table (xv)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	2.5
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	160	156	158	154
TEMPERATURE BEFORE AND AFTER MULLING (°C)	16.5 20.5	25.0 25.5	38.0 37.5	51.0 48.0
Average	18.5	25.5	38.0	49.5
SPECIMEN WEIGHT (g)	159	159	157	157
GREEN COMPRESSION STRENGTH	18.6 19.3 19.3	22.8 22.8 23.4	54.5 54.5 54.5	57.9 57.9 58.6
(N/m ² x 10 ³)				
Average	19.1	23.0	54.5	58.1
GREEN SHEAR STRENGTH	4.1 4.1 4.1	5.2 4.5 4.8	12.4 12.8 13.1 12.8	12.8 13.8 13.1 13.1
(N/m ² x 10 ³)				
Average	4.1	4.8	12.8	13.2
HOT COMPRESSION STRENGTH	181.8 192.6 193.6 184.7	239.6 248.5 251.4	252.4 247.5 256.3 251.4	276.9 262.2 257.3 269.1
(N/m ² x 10 ³)				
Average	188.2	246.5	251.9	266.4
PERMEABILITY	19.3 19.5 19.2	19.5 19.5 19.5	17.8 17.8 17.9	19.2 19.2 19.3
(small orifice)				
Average	19.3	19.5	17.8	19.2
MOULD HARDNESS	10 12 11 12	12 11 12 11	26 28 26 26	28 28 27
('C' scale)				
Average	11	12	27	28
SHATTER INDEX	40 40 40	39 41 40	52 50 52	48 49 48
Average	40	40	51	48
FLOWABILITY	82 80 81 81 82	83 83 84 83	80 81 80 80	79 80 81 79
(per cent)				
Average	81	83	80	80

Table (xvi)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	2.5
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	284	287	286	285
TEMPERATURE BEFORE AND AFTER MULLING (°C)	15.5 14.5	25.0 23.5	37.0 34.5	52.0 42.0
Average	15.0	24.5	36.0	47.0
SPECIMEN WEIGHT (g)	156	155	154	153
GREEN COMPRESSION STRENGTH	45.5 45.5 45.5	64.1 63.4 62.7 63.4	71.0 71.0 70.3	65.5 66.2 66.9 65.5
(N/m ² x 10 ³)				
Average	45.5	63.4	70.8	66.0
GREEN SHEAR STRENGTH	10.3 10.0 11.0 10.7 10.7	15.9 15.5 14.8 14.8 14.8	17.9 17.9 17.9	14.1 13.1 13.1
(N/m ² x 10 ³)				
Average	10.5	15.2	17.9	13.4
HOT COMPRESSION STRENGTH	183.8 173.9 156.3 169.0 183.8	252.4 238.7 221.0 264.2 218.1	294.6 295.6 295.6	278.9 224.9 244.6 254.4 223.0
(N/m ² x 10 ³)				
Average	173.4	238.9	295.2	245.1
PERMEABILITY	23.2 23.2 23.1	23.5 23.9 23.8 23.3 23.8	24.1 24.2 24.1	24.9 25.3 25.7 24.9
(small orifice)				
Average	23.2	23.7	24.1	25.2
MOULD HARDNESS	23 24 24 24 25	28 28 28 28	29 29 30 28	26 27 27 27 27
(°C scale)				
Average	24	28	29	27
SHATTER INDEX	58 58 56	70 69 68 67 69	69 71 72 70	70 68 67 69
Average	57	69	70	68
FLOWABILITY	82 82 82 82	81 81 82 81 81	79 79 79 79	78 78 79 79 78
(per cent)				
Average	82	81	79	78

Table (xvii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	20.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	133	134	136	137
TEMPERATURE BEFORE AND AFTER MULLING (°C)	15.0 19.0	24.0 24.5	33.0 30.5	50.0 41.0
Average	17.0	24.5	32.0	45.5
SPECIMEN WEIGHT (g)	160	160	158	158
GREEN COMPRESSION STRENGTH	26.2 26.9 26.9	33.8 33.8 33.8	53.1 53.8 53.8	66.9 66.9 67.6
(N/m ² × 10 ³)				
Average	26.7	33.8	53.6	67.1
GREEN SHEAR STRENGTH	6.9 6.9 7.2	9.3 9.7 9.7	13.4 11.7 13.4 13.8	16.5 16.5 15.9
(N/m ² × 10 ³)				
Average	7.0	9.5	13.1	16.3
HOT COMPRESSION STRENGTH	248.5 254.4 238.7 235.7	246.5 242.6 244.5	267.1 240.6 252.4 242.6	304.4 316.1 325.0 355.4 333.8
(N/m ² × 10 ³)				
Average	244.3	244.5	250.7	326.9
PERMEABILITY	21.7 22.2 21.8	21.8 21.1 21.1	21.0 20.8 20.9	18.2 18.1 18.0
(small orifice)				
Average	21.9	21.3	20.9	18.1
MOULD HARDNESS	12 14 14	14 15 15	24 22 24	28 26 28
('C' scale)				
Average	13	15	23	27
SHATTER INDEX	56 59 57	66 64 66	75 77 77	65 66 65
Average	58	66	76	66
FLOWABILITY	88 87 89	87 87 87	84 84 86 85	80 79 79
(per cent)				
Average	88	87	85	79

Table (xviii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	20.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	217	220	219	218
TEMPERATURE BEFORE AND AFTER MULLING (°C)	14.5 20.5	25.5 27.5	38.0 36.0	50.0 38.0
Average	17.5	26.5	37.0	44.0
SPECIMEN WEIGHT (g)	160	159	158	158
GREEN COMPRESSION STRENGTH	52.4 53.1 51.7 52.4	60.7 60.0 61.4 61.4	69.6 68.9 68.9	70.3 70.3 71.0
(N/m ² × 10 ³)				
Average	52.4	60.8	69.2	70.6
GREEN SHEAR STRENGTH	11.7 10.7 11.0 11.7	16.2 16.5 16.5 15.2 16.2	15.2 15.5 15.9	17.2 16.5 16.9
(N/m ² × 10 ³)				
Average	11.3	16.1	15.5	16.9
HOT COMPRESSION STRENGTH	232.8 246.5 246.5 244.5	337.7 341.6 330.8	331.8 352.4 337.7 337.7	330.8 340.7 339.7 326.9
(N/m ² × 10 ³)				
Average	242.6	336.7	339.9	334.5
PERMEABILITY	19.2 19.4 19.0	20.0 20.1 20.1	20.3 20.4 20.0 20.0	20.3 20.7 20.4
(small orifice)				
Average	19.2	20.1	20.2	20.5
MOULD HARDNESS	25 27 25 26	27 26 27	28 28 27	28 27 27 27
('C' scale)				
Average	26	27	28	27
SHATTER INDEX	68 69 68	77 77 76	69 72 72 72 72	68 70 67
Average	68	77	71	68
FLOWABILITY	83 84 84 84	81 81 81	80 81 80	79 80 80 80
(per cent)				
Average	84	81	80	80

Table (xix)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	1.0 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	183	182	184	185
TEMPERATURE BEFORE AND AFTER MULLING (°C)	20.5 20.5	30.0 28.0	41.0 35.0	51.0 45.0
Average	20.5	29.0	38.0	48.0
SPECIMEN WEIGHT (g)	160	158	157	157
GREEN COMPRESSION STRENGTH	54.5 53.8 55.2 54.5	71.7 71.7 71.0	73.8 73.1 74.5 74.5	71.0 71.0 69.6 71.0
(N/m ² x 10 ³)				
Average	54.5	71.5	73.9	70.7
GREEN SHEAR STRENGTH	11.7 10.7 12.1 11.4	15.9 14.5 14.1 14.5	16.2 15.2 16.2 17.9 16.9	14.8 14.5 15.9 15.9 15.9
(N/m ² x 10 ³)				
Average	11.5	14.7	16.5	15.4
HOT COMPRESSION STRENGTH	210.2 197.5 216.1 206.3	244.6 232.8 232.8 224.0	274.0 262.2 266.1 267.1	255.3 254.4 262.2 266.1
(N/m ² x 10 ³)				
Average	207.5	233.5	267.4	259.5
PERMEABILITY	18.6 18.7 18.8	19.0 19.0 19.0	19.7 19.8 19.9 19.7	20.2 20.4 20.2 20.2
(small orifice)				
Average	18.7	19.0	19.8	20.3
MOULD HARDNESS	26 27 25 26	30 29 28 29 30	29 28 30 30	28 29 29 29 28
('C' scale)				
Average	26	29	29	29
SHATTER INDEX	58 58 59	67 67 68	68 66 64 68	61 65 62 64 62
Average	58	68	66	63
FLOWABILITY	84 84 84	79 81 80 82	79 79 78 79	79 80 78 79
(per cent)				
Average	84	81	79	79

Table (xx)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	2.0 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	186	191	189	190
TEMPERATURE BEFORE AND AFTER MULLING (°C)	20.0 20.0	30.0 31.0	42.0 36.0	52.0 46.0
Average	20.0	30.5	39.0	49.0
SPECIMEN WEIGHT (g)	160	158	157	157
GREEN COMPRESSION STRENGTH	61.4 60.7 61.4	74.5 74.5 75.2	73.1 74.5 73.8	70.3 69.6 68.9
(N/m ² x 10 ³)				
Average	61.1	74.7	73.8	69.6
GREEN SHEAR STRENGTH	14.1 15.2 13.4 14.5 13.1	16.5 15.5 16.5 16.2	16.5 15.9 15.2 16.5	16.2 15.5 16.2
(N/m ² x 10 ³)				
Average	14.1	16.2	16.0	16.0
HOT COMPRESSION STRENGTH	225.9 223.0 215.1	306.3 280.8 282.8 264.2 264.2	311.2 300.4 306.3 305.4	321.0 315.2 340.7 308.8 332.8
(N/m ² x 10 ³)				
Average	221.3	279.7	305.8	323.6
PERMEABILITY	19.0 19.0 18.8	20.3 20.2 20.3	20.8 20.7 21.0	20.5 20.5 20.7 20.7
(small orifice)				
Average	18.9	20.3	20.8	20.6
MOULD HARDNESS	26 28 27 27 27	29 29 29 28 29	28 29 28 28 29	28 28 27 27 27
('C' scale)				
Average	27	29	28	27
SHATTER INDEX	63 63 61	73 72 72	68 68 70	65 65 68 68
Average	62	72	69	66
FLOWABILITY	83 83 84	80 79 81 80 79	79 79 79 79 79	78 79 78 79 79
(per cent)				
Average	83	80	79	79

Table (xxi)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	Tested after 3 days storage

SAND MIX No.	152/147	157/153	155/151	152/2/149
TEMPERATURE BEFORE AND AFTER MULLING (°C)	22.0 23.0	29.0 30.5	36.0 33.0	49.0 39.0
Average	22.5	30.0	34.5	44.0
SPECIMEN WEIGHT (g)	161	161	160	160
GREEN COMPRESSION STRENGTH	31.0 31.0 30.3	51.0 50.3 51.0	60.0 60.0 59.3	59.3 60.0 60.7 60.7 60.7
(N/m ² x 10 ³)				
Average	30.8	50.8	59.8	60.3
GREEN SHEAR STRENGTH	7.6 7.6 7.2	11.7 11.7 12.4 12.1	16.2 13.1 14.5 14.1 14.1	14.5 14.8 15.9 13.8
(N/m ² x 10 ³)				
Average	7.5	12.0	14.4	14.7
HOT COMPRESSION STRENGTH	257.3 251.4 276.9 260.2	322.0 288.7 274.9 303.4 278.9	293.6 276.9 280.8 276.9	252.4 258.3 269.1 265.1
(N/m ² x 10 ³)				
Average	261.5	293.6	282.1	261.2
PERMEABILITY	18.1 18.0 18.0	17.8 18.0 17.7	17.7 17.7 17.7	18.0 18.0 18.0
(small orifice)				
Average	18.0	17.8	17.7	18.0
MOULD HARDNESS	17 18 18	26 26 24 25	27 26 26	27 29 28
('C' scale)				
Average	18	25	26	28
SHATTER INDEX	46 48 46	61 63 59	66 65 64	61 62 61
Average	47	61	65	61
FLOWABILITY	85 85 85	83 82 83 84	82 82 83	81 80 82
(per cent)				
Average	85	83	82	81

Table (xxii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	Tested after 14 days storage

SAND MIX No.	165/147	172/2/153	171/151	165/2/149
TEMPERATURE BEFORE AND AFTER MULLING (°C)	22.0 23.0	29.0 30.5	36.0 33.0	49.0 39.0
Average	22.5	30.0	34.5	44.0
SPECIMEN WEIGHT (g)	162	161	160	161
GREEN COMPRESSION STRENGTH	30.3 31.7 31.0 31.0	51.7 51.7 51.0	57.9 57.9 57.9	60.7 60.7 61.4
(N/m ² × 10 ³)				
Average	31.0	51.5	57.9	60.9
GREEN SHEAR STRENGTH	6.2 7.2 8.3 6.9	11.7 12.1 11.0	13.4 11.7 14.5 13.4	13.4 14.5 14.5 12.8
(N/m ² × 10 ³)	7.2		14.1	12.8
Average	7.2	11.6	13.4	13.6
HOT COMPRESSION STRENGTH	254.3 249.4 254.3	274.0 270.0 276.9	269.1 264.2 253.4	270.0 277.9 275.9 290.6
(N/m ² × 10 ³)				
Average	252.7	273.6	262.2	278.6
PERMEABILITY	18.0 18.1 18.0	17.7 17.7 17.8	17.6 17.7 17.7	17.5 17.5 17.7
(small orifice)				
Average	18.0	17.7	17.7	17.6
MOULD HARDNESS	16 16 17 17	25 24 23 23	25 26 26 25	27 28 28 26 26
('C' scale)				
Average	17	24	26	27
SHATTER INDEX	51 46 44 46 49	58 60 61 59	64 62 64	58 58 58
Average	47	60	63	58
FLOWABILITY	86 86 84 85 84	84 83 83 83 82	82 82 83 83 83	83 83 84 84 83
(per cent)				
Average	85	83	83	83

Table (xxiii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	Tested after 3 days storage

SAND MIX No.	174/167	172/166	174/2/168	175/169
TEMPERATURE BEFORE AND AFTER MULLING (°C)	21.0 23.0	30.0 30.0	40.0 35.0	49.0 42.0
Average	22.0	30.0	38.0	45.5
SPECIMEN WEIGHT (g)	160	160	160	160
GREEN COMPRESSION STRENGTH	53.8 53.8 54.5	65.5 66.9 66.9	68.3 68.3 68.9	67.6 68.3 68.3
(N/m ² x 10 ³)				
Average	54.0	66.5	68.5	68.0
GREEN SHEAR STRENGTH	12.8 12.4 13.4	14.5 15.2 14.1	16.2 14.8 16.2 15.5	14.8 15.2 14.8
(N/m ² x 10 ³)				
Average	12.9	14.6	15.7	14.9
HOT COMPRESSION STRENGTH	244.5 227.9 239.6 231.8	257.3 245.5 293.6 287.7 274.0	315.2 318.1 317.1	276.9 283.8 281.8
(N/m ² x 10 ³)				
Average	236.0	271.6	316.8	280.8
PERMEABILITY	18.0 18.1 18.2	17.9 18.2 18.3	17.0 16.9 16.9	17.9 18.2 18.0
(small orifice)				
Average	18.1	18.1	16.9	18.0
MOULD HARDNESS	25 26 26 25	27 27 28 27	29 29 29	28 29 27 28
('C' scale)				
Average	26	27	29	28
SHATTER INDEX	66 67 68	69 68 69	67 66 67	64 65 63 64
Average	67	69	66	64
FLOWABILITY	83 82 83 82 83	83 82 82 82 81	81 81 81 82 81	82 82 82 81 81
(per cent)				
Average	83	82	81	82

Table (xxiv)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	Tested after 14 days storage

SAND MIX No.	179/167	178/2/166	179/2/168	181/169
TEMPERATURE BEFORE AND AFTER MULLING (°C)	21.0 23.0	30.0 30.0	40.0 36.0	49.0 42.0
Average	22.0	30.0	38.0	45.5
SPECIMEN WEIGHT (g)	160	160	160	160
GREEN COMPRESSION STRENGTH	53.1 53.1 53.1	64.1 62.7 64.1 63.4	66.9 66.2 66.9	67.6 66.9 66.9
(N/m ² x 10 ³)				
Average	53.1	63.6	66.7	67.1
GREEN SHEAR STRENGTH	11.4 12.1 12.8 12.1	16.2 15.5 15.2 14.8	14.5 14.5 13.8	14.1 14.5 14.8
(N/m ² x 10 ³)	12.1	15.2		
Average	12.1	15.4	14.2	14.5
HOT COMPRESSION STRENGTH	248.5 232.8 243.6 231.8	283.8 267.1 264.2 245.5 245.5	290.6 298.5 297.5 299.5	286.7 281.8 278.9 274.0
(N/m ² x 10 ³)				
Average	239.2	261.2	296.5	280.3
PERMEABILITY	17.9 17.8 18.0	17.8 17.7 17.8	16.5 16.6 16.7 16.7	18.0 18.0 17.9
(small orifice)				
Average	17.9	17.8	16.6	18.0
MOULD HARDNESS	25 26 25 26	27 28 28 28	28 28 28	28 27 27 28 29
('C' scale)				
Average	26	28	28	28
SHATTER INDEX	62 62 61	63 64 61	63 60 63	58 61 59
Average	61	63	62	59
FLOWABILITY	82 82 82 83	83 82 83	83 82 82	82 83 83 82 83
(per cent)				
Average	82	83	82	83

Table (xxv)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	2.5
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	Tested after 3 days storage

SAND MIX No.	164/160	161/156	163/158	157/2/154
TEMPERATURE BEFORE AND AFTER MULLING (°C)	16.5 20.5	25.0 25.5	38.0 37.5	51.0 48.0
Average	18.5	25.5	38.0	49.5
SPECIMEN WEIGHT (g)	159	160	158	157
GREEN COMPRESSION STRENGTH	21.4 21.4 22.1	24.8 24.8 24.1	53.1 53.8 53.8	56.5 55.8 56.5
(N/m ² x 10 ³)				
Average	21.6	24.6	53.6	56.3
GREEN SHEAR STRENGTH	4.1 4.5 4.5	5.9 5.5 5.9	11.7 12.4 13.1 12.1	12.8 12.4 12.4 13.1
(N/m ² x 10 ³)				
Average	4.4	5.7	12.3	12.7
HOT COMPRESSION STRENGTH	180.8 196.5 187.7 195.5 182.8	211.2 208.3 207.3	303.4 303.4 301.4	265.1 234.7 251.4 227.9 244.6
(N/m ² x 10 ³)				
Average	188.7	208.9	302.7	244.7
PERMEABILITY	18.8 18.9 18.9	19.0 19.1 19.1	17.7 17.5 17.7	18.7 18.3 18.9 18.7
(small orifice)				
Average	18.9	19.1	17.6	18.7
MOULD HARDNESS	11 12 12 12	14 14 14	25 27 28 25 26	26 25 27
('C' scale)				
Average	12	14	26	26
SHATTER INDEX	38 38 39	39 41 41	52 49 52	52 49 48 46 49
Average	39	40	51	49
FLOWABILITY	82 84 83 83 83	84 84 83 83 84	81 82 81 81 82	81 81 81
(per cent)				
Average	83	84	81	81

Table (xxvi)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	2.5
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	Tested after 14 days storage

SAND MIX No.	178/160	176/156	176/2/158	173/154
TEMPERATURE BEFORE AND AFTER MULLING (°C)	16.5 20.5	25.0 25.5	38.0 37.5	51.0 48.0
Average	18.5	25.5	38.0	49.5
SPECIMEN WEIGHT (g)	159	160	159	158
GREEN COMPRESSION STRENGTH	22.8 21.4 22.1	26.2 24.8 25.5	52.4 53.1 52.4	57.9 57.2 56.5 57.2
(N/m ² × 10 ³)				
Average	22.1	25.5	52.6	57.2
GREEN SHEAR STRENGTH	4.5 4.8 4.8	5.9 5.9 5.9	12.4 12.4 12.1	12.8 11.7 12.4
(N/m ² × 10 ³)				
Average	4.7	5.9	12.3	12.3
HOT COMPRESSION STRENGTH	147.5 162.2 148.4 162.2	200.4 194.5 192.6	256.3 255.3 234.7 248.5 250.4	276.9 268.1 281.8
(N/m ² × 10 ³)				
Average	155.1	195.8	249.1	275.6
PERMEABILITY	18.5 18.8 18.8	19.0 19.0 18.8	16.9 17.2 17.3 17.2	18.0 18.0 18.1 18.1
(small orifice)				
Average	18.7	18.9	17.2	18.1
MOULD HARDNESS	12 13 12 13	15 15 15 15	26 26 27 27	27 28 27 28
('C' scale)				
Average	13	15	27	28
SHATTER INDEX	39 38 39	40 38 39	52 47 48 50	46 47 49
Average	39	39	49	47
FLOWABILITY	82 83 83 83 84	83 83 82 82 82	83 82 83 82 83	82 81 82 81 82
(per cent)				
Average	83	82	83	82

Table (xxvii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	20.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	Tested after 3 days storage

SAND MIX No.	135/133	135/2/134	138/136	142/137
TEMPERATURE BEFORE AND AFTER MULLING (°C)	15.0 19.0	24.0 24.5	33.0 30.5	50.0 41.0
Average	17.0	24.5	32.0	45.5
SPECIMEN WEIGHT (g)	160	160	158	159
GREEN COMPRESSION STRENGTH	28.3 28.3 28.3	35.9 35.9 35.2	53.8 54.5 55.2 54.5	63.4 64.8 62.7 63.4
(N/m ² x 10 ³)				
Average	28.3	35.6	54.5	63.6
GREEN SHEAR STRENGTH	7.9 7.6 7.6	9.7 9.3 9.3	13.1 13.4 13.8	12.8 13.8 13.8 13.1
(N/m ² x 10 ³)				
Average	7.7	9.4	13.4	13.4
HOT COMPRESSION STRENGTH	233.8 217.1 213.2 225.9	244.5 251.4 248.5	203.4 206.3 206.3	300.4 297.5 264.2 275.9 293.6
(N/m ² x 10 ³)				
Average	222.5	248.1	205.3	286.3
PERMEABILITY	21.8 21.8 21.8	20.0 20.0 20.0	20.9 20.7 20.8	16.8 16.8 16.7
(small orifice)				
Average	21.8	20.0	20.8	16.8
MOULD HARDNESS	14 14 14	21 17 21	22 24 22	28 28 26
('C' scale)				
Average	14	20	23	27
SHATTER INDEX	53 52 54	64 63 62	70 71 65 65	62 63 64
Average	53	63	68	63
FLOWABILITY	87 86 87	87 87 87	84 85 86	83 81 82
(per cent)				
Average	87	87	85	82

Table (xxviii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	20.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	Tested after 14 days storage

SAND MIX No.	146/133	146/2/134	148/136	150/137
TEMPERATURE BEFORE AND AFTER MULLING (°C)	15.0 19.0	24.0 24.5	33.0 30.5	50.0 41.0
Average	17.0	24.5	32.0	45.5
SPECIMEN WEIGHT (g)	159	160	158	162
GREEN COMPRESSION STRENGTH	36.5 36.5 35.9	37.2 36.5 35.2 36.5	53.1 52.4 53.1 53.8	60.0 58.6 57.9 60.0 59.3
(N/m ² x 10 ³)				
Average	36.3	36.4	53.1	59.2
GREEN SHEAR STRENGTH	7.9 7.9 9.0 7.6	9.3 9.7 9.3	12.8 12.1 13.4 12.4	14.5 15.2 14.5
(N/m ² x 10 ³)				
Average	8.1	9.4	12.7	14.7
HOT COMPRESSION STRENGTH	185.7 209.2 183.7 183.7	244.5 256.3 232.8 227.9 254.4	242.6 254.4 229.8 232.8	281.8 278.9 278.9
(N/m ² x 10 ³)				
Average	190.6	243.2	239.9	279.8
PERMEABILITY	22.3 22.3 22.3	21.0 20.7 20.5	20.9 20.9 21.1	17.1 17.2 17.0
(small orifice)				
Average	22.3	20.7	21.0	17.1
MOULD HARDNESS	19 21 21 19	19 17 17 17	24 24 24	26 29 28
('C' scale)				
Average	20	18	24	28
SHATTER INDEX	48 47 46	62 63 61	65 66 66	59 60 60
Average	47	62	66	60
FLOWABILITY	87 86 87	86 87 85 87	83 84 85	84 83 83
(per cent)				
Average	87	86	84	83

Table (xxix)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	147	153	151	149
TEMPERATURE BEFORE AND AFTER MULLING (°C)	22.0 23.0	29.0 30.5	36.0 33.0	49.0 39.0
Average	22.5	30.0	34.5	44.0
SPECIMEN WEIGHT (g)	161	160	159	159
GREEN COMPRESSION STRENGTH	29.6 29.6 29.6	53.1 52.4 52.4	60.7 59.3 59.3 60.0	66.2 65.5 65.5
(N/m ² x 10 ³)				
Average	29.6	52.6	59.8	65.7
GREEN SHEAR STRENGTH	6.9 7.2 7.2	12.4 12.8 12.4	15.9 14.8 15.5 15.5	15.9 15.9 14.8 14.8
(N/m ² x 10 ³)				
Average	7.1	12.5	15.4	15.3
HOT COMPRESSION STRENGTH	256.3 271.0 258.3 266.1	255.3 247.5 264.2 256.3	303.4 293.6 289.7 283.8	294.6 283.8 293.6 300.4
(N/m ² x 10 ³)				
Average	262.9	255.8	292.6	293.1
PERMEABILITY	18.4 18.4 18.3	17.8 18.5 18.2 18.1	17.8 17.8 18.2 17.9	19.0 19.0 18.8
(small orifice)				
Average	18.4	18.2	17.9	18.9
MOULD HARDNESS	15 15 15	26 26 27	28 28 27	28 28 28
('C' scale)				
Average	15	26	28	28
SHATTER INDEX	53 50 47 48 48	63 60 62	70 68 69	60 64 63
Average	49	61	69	62
FLOWABILITY	84 83 84	82 82 82	80 80 80 80	81 80 80
(per cent)				
Average	84	82	80	80

Table (xxx)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	None

SAND MIX No.	276	279	278	277
TEMPERATURE BEFORE AND AFTER MULLING (°C)	14.5 16.0	26.0 26.0	37.5 37.5	55.0 43.0
Average	15.5	26.0	37.5	49.0
SPECIMEN WEIGHT (g)	159	158	156	156
GREEN COMPRESSION STRENGTH	22.8 22.8 22.1	45.5 45.5 44.8	66.9 67.6 66.9	66.9 68.3 67.6 67.6
(N/m ² x 10 ³)				
Average	22.5	45.3	67.1	67.6
GREEN SHEAR STRENGTH	5.5 5.2 4.8	11.4 11.4 12.1 11.7	16.5 15.5 16.2 15.5	15.2 15.5 14.8 14.8
(N/m ² x 10 ³)				
Average	5.2	11.6	15.9	15.1
HOT COMPRESSION STRENGTH	148.4 157.3 167.1 146.5	258.3 242.6 264.2 235.7	280.8 293.6 267.1	285.7 283.8 291.6
(N/m ² x 10 ³)				
Average	154.8	250.2	280.5	287.0
PERMEABILITY	23.4 23.3 23.3 23.2	21.8 21.6 21.6 21.3 21.7	22.3 22.3 22.3	22.9 22.9 22.9
(small orifice)				
Average	23.3	21.6	22.3	22.9
MOULD HARDNESS	13 13 13 12	22 21 21 21	27 27 28 28	27 28 28 27 26
('C' scale)				
Average	13	21	28	27
SHATTER INDEX	42 45 46 46 43	72 68 71 66 72	69 72 68 71 69	65 69 67 65 67
Average	44	70	70	67
FLOWABILITY	86 85 86 87	86 87 86 87	83 83 81 83	81 80 81 82
(per cent)				
Average	86	87	83	81

Table (xxxi)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	265	268	267	266
TEMPERATURE BEFORE AND AFTER MULLING (°C)	18.0 18.5	29.0 30.0	37.5 38.0	55.0 43.0
Average	18.5	29.5	38.0	49.0
SPECIMEN WEIGHT (g)	157	156	155	155
GREEN COMPRESSION STRENGTH (N/m ² x 10 ³)	42.1 42.7 42.1 41.4	61.4 62.7 61.4 62.7	65.5 65.5 65.5	63.4 64.1 64.8 63.4 64.1
Average	42.1	62.2	65.5	64.0
GREEN SHEAR STRENGTH (N/m ² x 10 ³)	9.7 9.3 9.7 9.7	15.2 15.2 14.5 15.9	17.6 17.2 16.2 15.9 17.2	16.5 15.9 16.9 17.2 15.5
Average	9.6	15.2	16.8	16.4
HOT COMPRESSION STRENGTH (N/m ² x 10 ³)	183.8 183.8 196.5 192.6	283.8 285.7 264.2 288.7	280.8 272.0 275.0	284.8 277.9 302.4 262.2 275.0
Average	189.1	280.6	275.9	280.4
PERMEABILITY (small orifice)	23.9 23.6 23.8 23.8	23.4 23.3 23.0 23.3	24.0 23.9 23.6 24.0	24.3 24.0 23.9 24.3
Average	23.8	23.3	23.9	24.1
MOULD HARDNESS (°C scale)	20 21 20 22 21	25 26 26 26	25 26 26 27	28 27 28 26 27
Average	21	26	26	27
SHATTER INDEX	53 54 53	76 72 72 73	69 69 69	65 67 68 67
Average	53	73	69	67
FLOWABILITY (per cent)	85 84 85 85 85	82 81 82 82	80 80 79 80	80 80 79 79 80
Average	85	82	80	80

Table (xxxii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	None

SAND MIX No.	280	283	282	281
TEMPERATURE BEFORE AND AFTER MULLING (°C)	15.5 16.5	27.0 27.0	40.0 38.0	51.0 39.5
Average	16.0	27.0	39.0	45.5
SPECIMEN WEIGHT (g)	158	157	156	156
GREEN COMPRESSION STRENGTH	44.1 44.8 44.1	67.6 68.3 68.9 68.3	69.6 68.9 68.9	69.6 71.0 70.3 69.6
(N/m ² x 10 ³)				
Average	44.4	68.3	69.2	70.2
GREEN SHEAR STRENGTH	9.3 10.0 9.3	15.5 15.9 15.5	16.9 16.2 16.9 15.9 16.9	16.9 16.5 16.5
(N/m ² x 10 ³)				
Average	9.5	15.6	16.5	16.7
HOT COMPRESSION STRENGTH	171.0 164.1 173.9 159.2	234.7 245.5 233.8 231.8	266.1 290.6 287.7 254.4 266.1	247.5 282.8 258.3 267.1
(N/m ² x 10 ³)				
Average	167.1	236.5	273.0	263.9
PERMEABILITY	23.8 23.5 23.4 23.7	22.7 22.1 22.5 22.9 22.3	23.3 23.3 23.3	22.8 22.3 22.0 22.8 22.5
(small orifice)				
Average	23.6	22.5	23.3	22.5
MOULD HARDNESS	23 21 21 22	27 27 28 28 27	29 27 27 27 27	27 28 27 28 28
(°C scale)				
Average	22	27	27	28
SHATTER INDEX	55 54 58 55	78 78 77	68 67 67	71 71 70
Average	55	77	67	70
FLOWABILITY	86 86 86 87	84 82 83 84 82	81 81 81 83 82	81 82 81 83 81
(per cent)				
Average	86	83	82	82

Table (xxxiii)

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	None
OTHER VARIABLES	2.0 per cent addition of Fe_2O_3

SAND MIX No.	245	248	247	246
TEMPERATURE BEFORE AND AFTER MULLING ($^{\circ}\text{C}$)	22.0 20.0	31.5 32.5	40.5 43.0	55.0 47.0
Average	21.0	32.0	42.0	51.0
SPECIMEN WEIGHT (g)	160	158	156	156
GREEN COMPRESSION STRENGTH	40.7 41.4 41.4	67.6 67.6 68.9 68.3	78.6 78.6 78.6	75.1 75.1 75.8
($\text{N/m}^2 \times 10^3$)				
Average	41.1	68.1	78.6	75.4
GREEN SHEAR STRENGTH	9.0 8.6 8.6	17.2 17.2 17.2	17.6 17.6 18.6 18.6	17.6 17.6 17.6
($\text{N/m}^2 \times 10^3$)				
Average	8.7	17.2	18.1	17.6
HOT COMPRESSION STRENGTH	68.0 79.8 75.9 87.6 73.9	89.6 79.8 69.0 84.7	52.4 61.2 51.4 59.2	56.3 51.4 45.5 45.5
($\text{N/m}^2 \times 10^3$)				
Average	77.1	80.8	56.0	49.7
PERMEABILITY	21.0 21.0 21.1 21.0	20.9 21.2 20.9 21.1	22.7 22.8 22.6 22.4	22.8 22.3 22.3
(small orifice)				
Average	21.0	21.0	22.6	22.5
MOULD HARDNESS	23 23 22 22	28 28 29 29	30 30 31 29	30 30 30
('C' scale)				
Average	23	29	30	30
SHATTER INDEX	46 43 43 46	71 66 67 73 66	74 67 74 69 71	68 66 68
Average	44	69	71	67
FLOWABILITY	82 82 82 82	76 76 78 77	73 75 73 75	73 73 74
(per cent)				
Average	82	77	74	73

Table 1 (xxxiv).

PHYSICAL PROPERTIES OF SAND MIXES

CLAY CONTENT (PER CENT)	5.0
OIL CONTENT (PER CENT)	3.0
MULLING TIME (MIN)	10.0
POLAR ADDITIVE (PER CENT)	0.5 (Methanol)
OTHER VARIABLES	2.0 per cent addition of Fe_2O_3

SAND MIX No.	249	252	251	250
TEMPERATURE BEFORE AND AFTER MULLING ($^{\circ}\text{C}$)	17.0 18.0	30.5 31.5	42.0 41.0	56.0 44.0
Average	17.5	31.0	41.5	50.0
SPECIMEN WEIGHT (g)	160	157	156	156
GREEN COMPRESSION STRENGTH	60.0 60.0 60.0	80.0 80.0 79.3	77.9 79.3 78.6 79.3	81.4 82.7 82.0 82.0
($\text{N/m}^2 \times 10^3$)				
Average	60.0	79.8	78.8	82.0
GREEN SHEAR STRENGTH	14.1 13.4 12.4 13.1 13.4	17.2 19.3 18.6 19.7 18.3	17.2 18.6 18.3 17.9 .	18.3 18.3 18.6
($\text{N/m}^2 \times 10^3$)				
Average	13.3	18.6	18.0	18.4
HOT COMPRESSION STRENGTH	47.4 46.5 36.7 40.6	39.6 32.7 37.6 34.7	41.6 35.7 32.7 38.6	40.6 36.7 35.7
($\text{N/m}^2 \times 10^3$)				
Average	42.8	36.2	37.2	37.6
PERMEABILITY	19.1 19.2 19.2 19.0	21.8 21.8 21.8	22.6 22.4 22.4	22.4 22.2 22.3
(small orifice)				
Average	19.1	21.8	22.5	22.3
MOULD HARDNESS	28 27 27 26	33 32 32 32	31 32 31 32	31 32 31 31
($^{\circ}\text{C}$ scale)				
Average	27	32	32	31
SHATTER INDEX	51 51 54 49	73 75 71 70 71	69 67 68	67 65 68
Average	51	72	68	67
FLOWABILITY	82 82 81 81	77 76 76	75 74 76 75	75 75 74 75
(per cent)				
Average	82	76	75	75

APPENDIX FIGURES

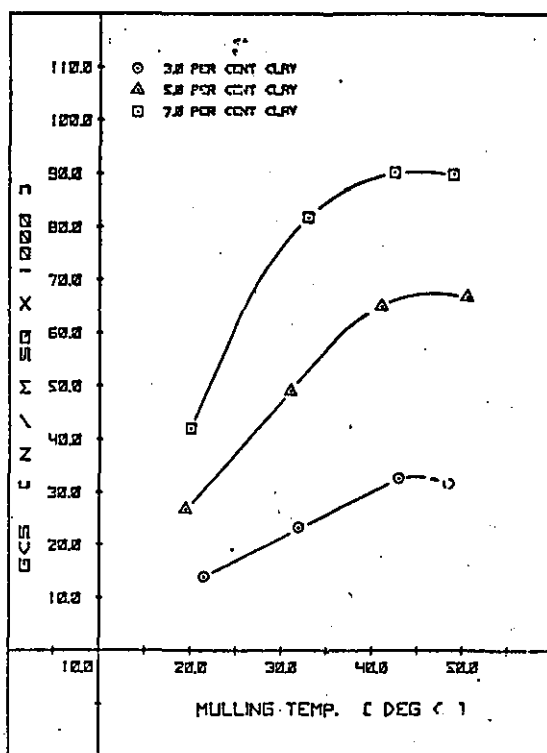


Fig. (i)a Varying clay.
No polar additive.

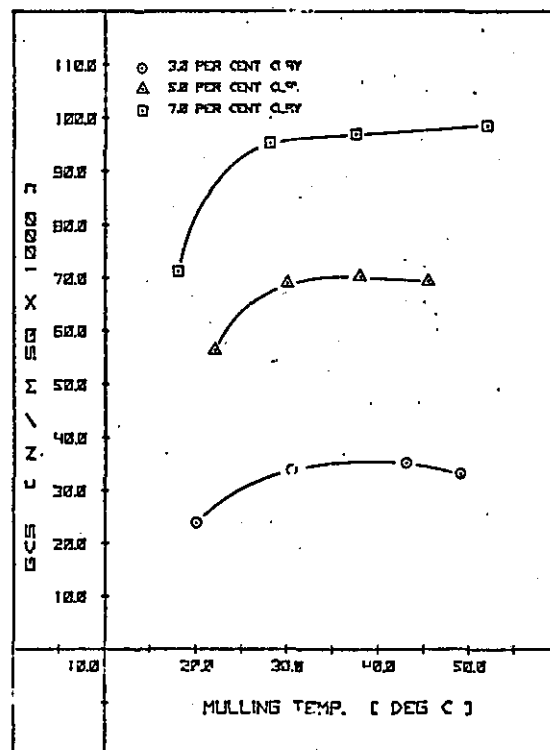


Fig. (i)b Varying clay.
0.5 per cent methanol.

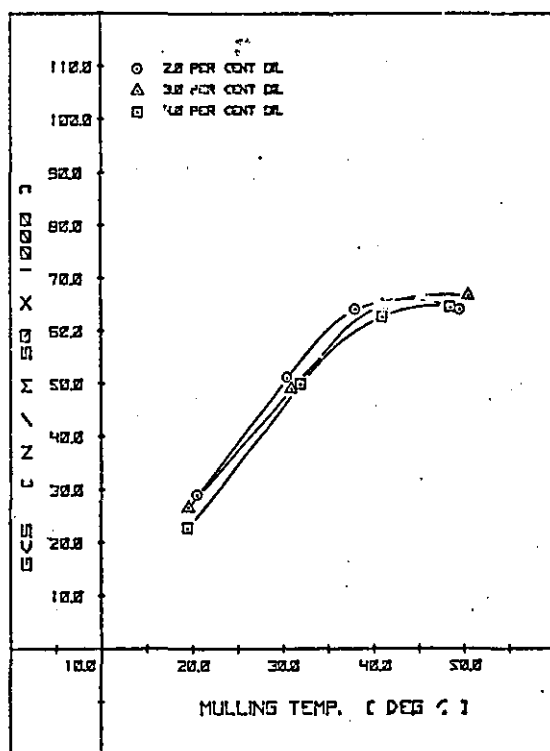


Fig. (i)c Varying oil.
No polar additive.

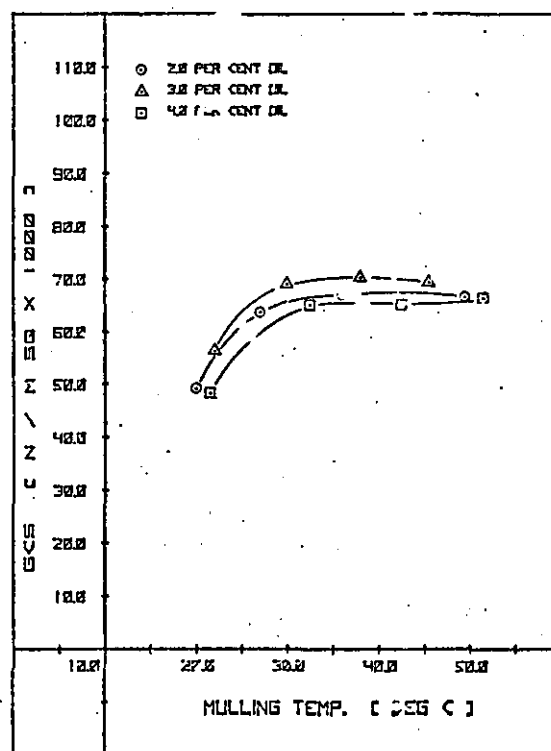


Fig. (i)d Varying oil.
0.5 per cent methanol.

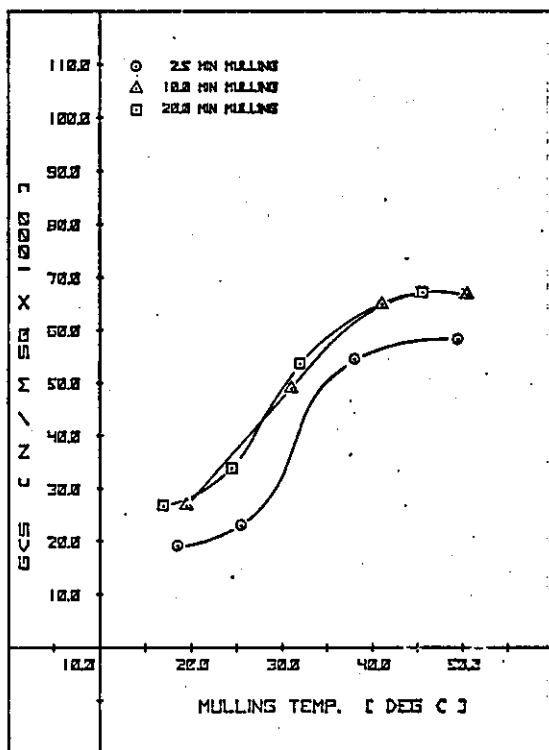


Fig. (i)e Varying mulling time.
No polar additive.

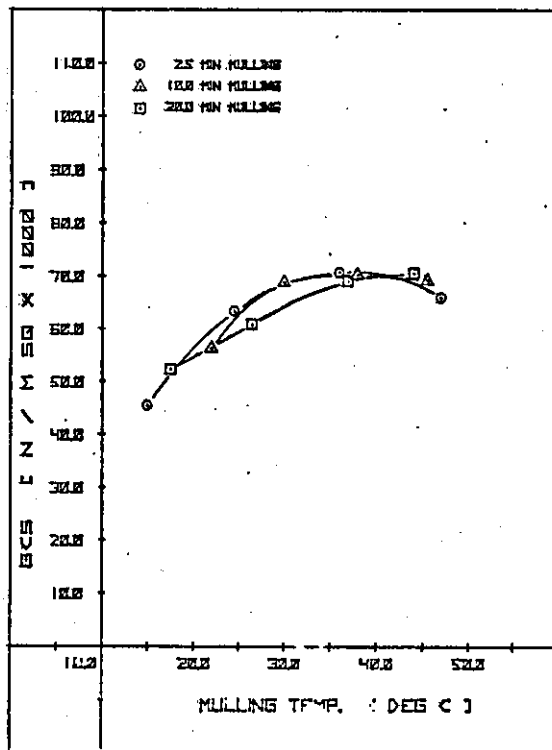


Fig. (i)f Varying mulling time.
0.5 per cent methanol.

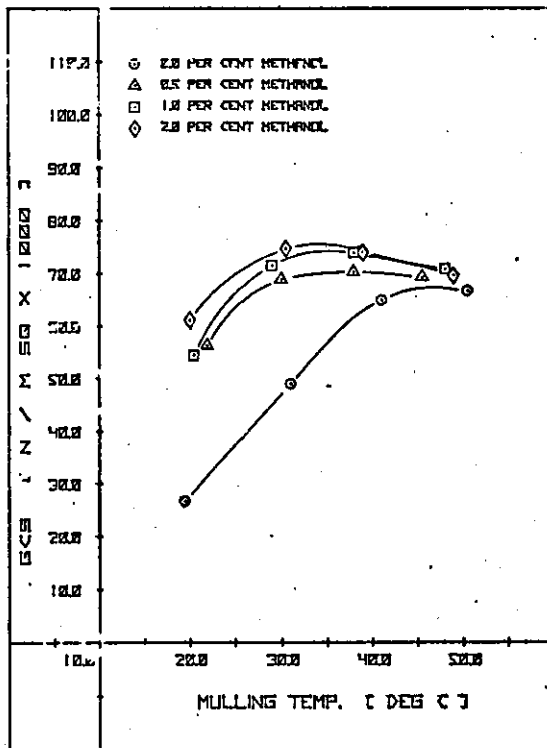


Fig. (i)g Varying methanol.

Fig. (i) Effect of mulling temperature upon green compression strength at varying clay and oil contents, mulling times and methanol additions.

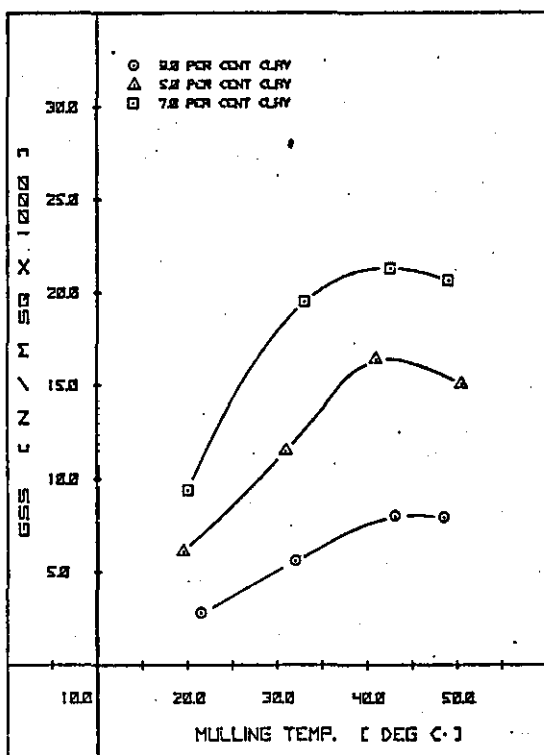


Fig. (ii)a Varying clay.
No polar additive.

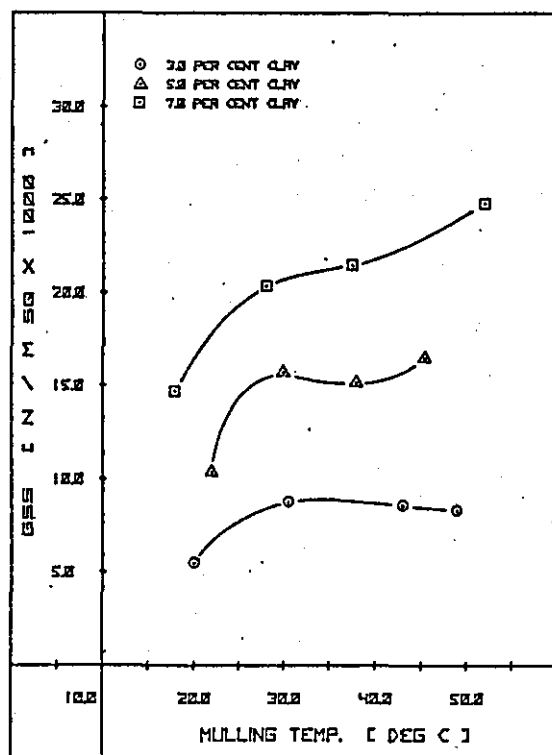


Fig. (ii)b Varying clay.
0.5 per cent methanol.

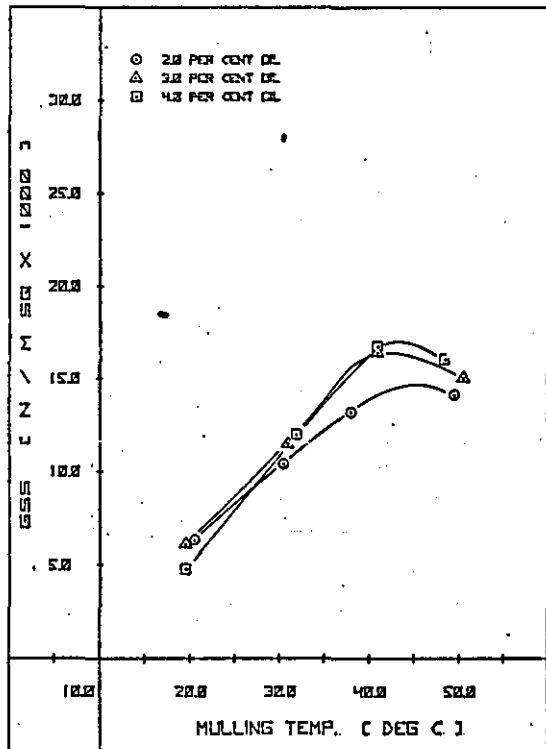


Fig. (ii)c Varying oil.
No polar additive.

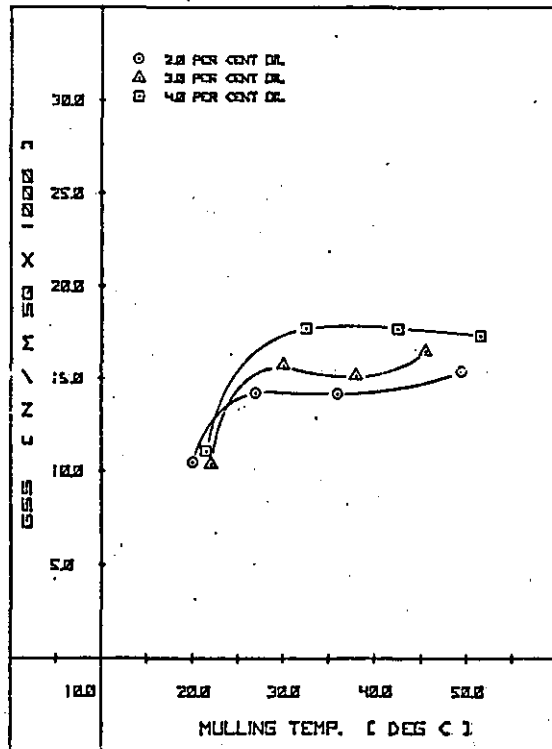


Fig. (ii)d Varying oil.
0.5 per cent methanol.

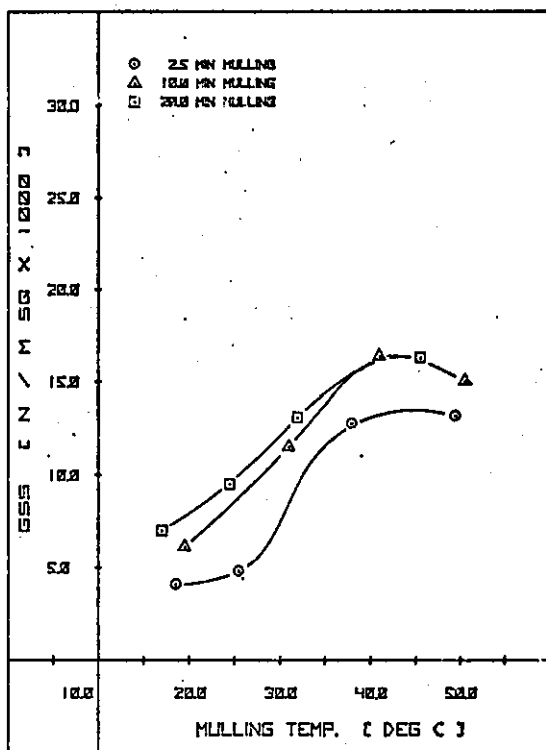


Fig. (ii)e Varying mulling time.
No polar additive.

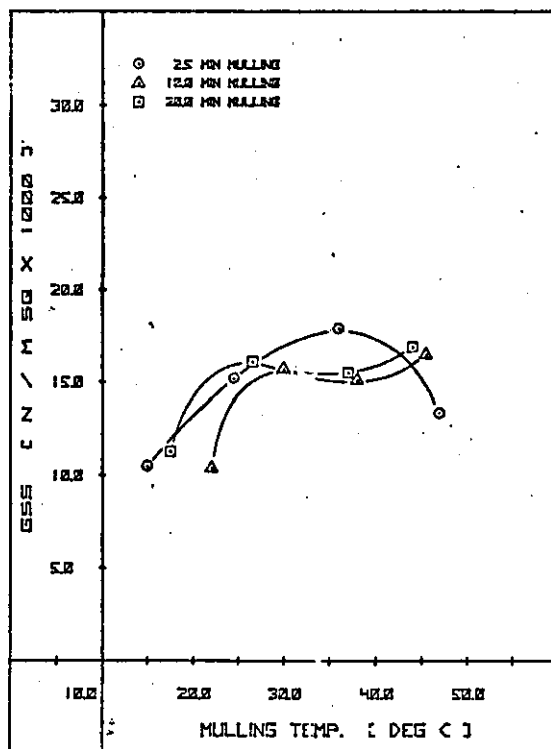


Fig. (ii)f Varying mulling time.
0.5 per cent methanol.

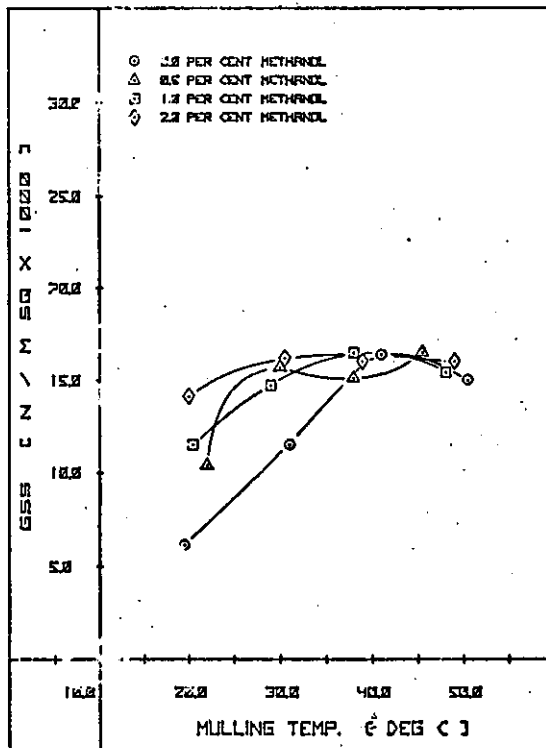


Fig. (ii)g Varying methanol.

Fig. (ii) Effect of mulling temperature upon green shear strength at varying clay and oil contents, mulling times and methanol additions.

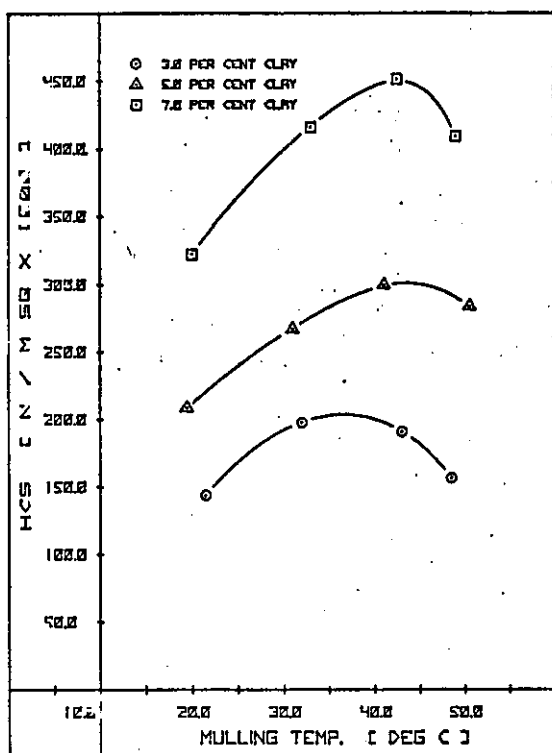


Fig. (iii)a Varying clay.
No polar additive.

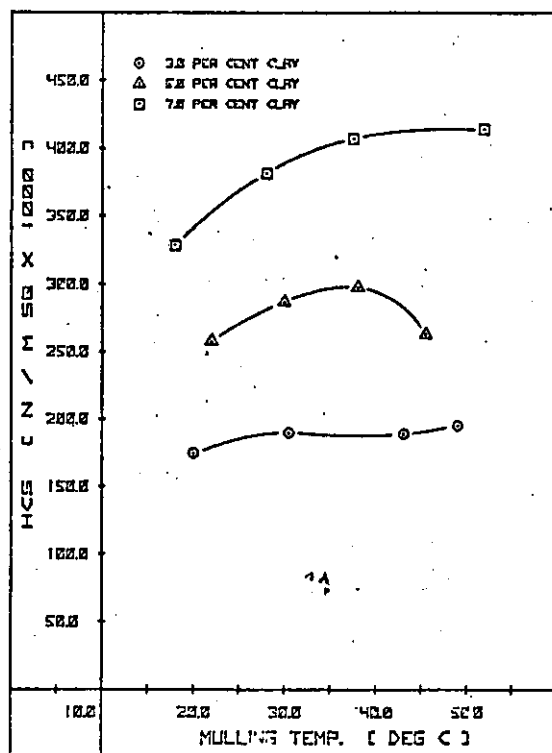


Fig. (iii)b Varying clay.
0.5 per cent methanol.

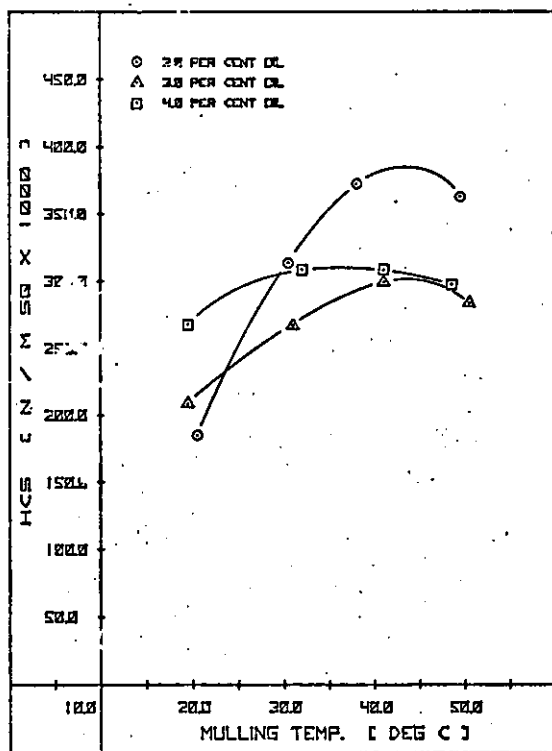


Fig. (iii)c Varying oil.
No polar additive.

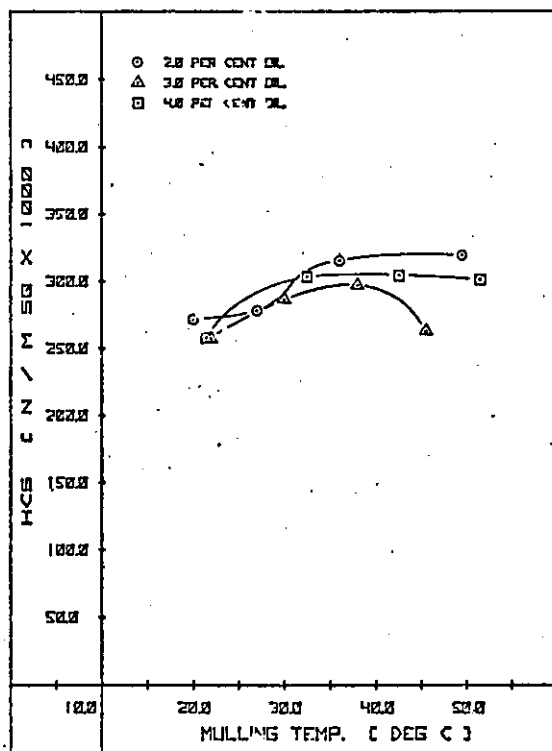


Fig. (iii)d Varying oil.
0.5 per cent methanol.

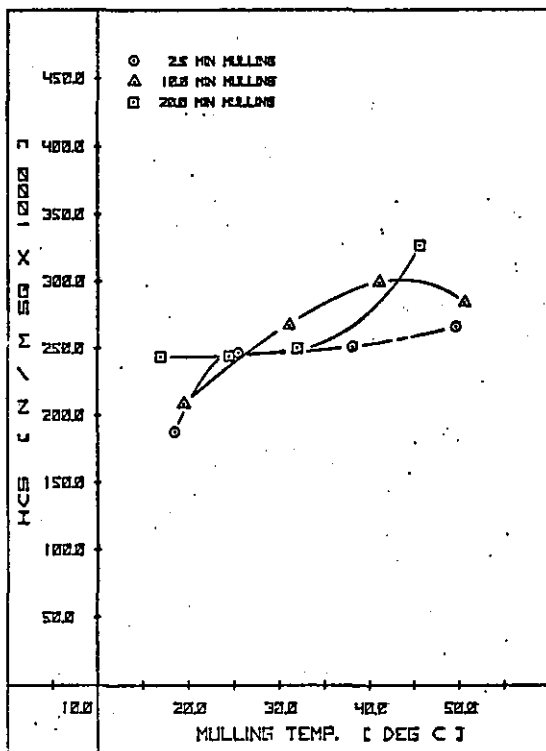


Fig. (iii)e Varying mulling time.
No polar additive.

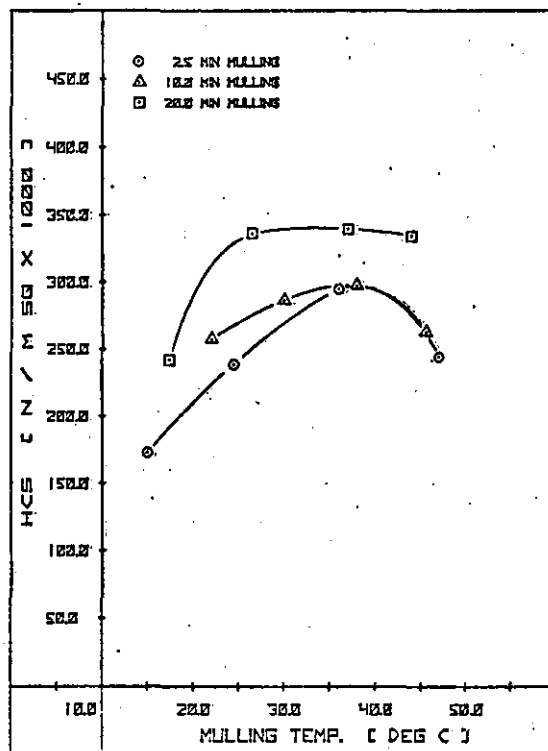


Fig. (iii)f Varying mulling time.
0.5 per cent methanol.

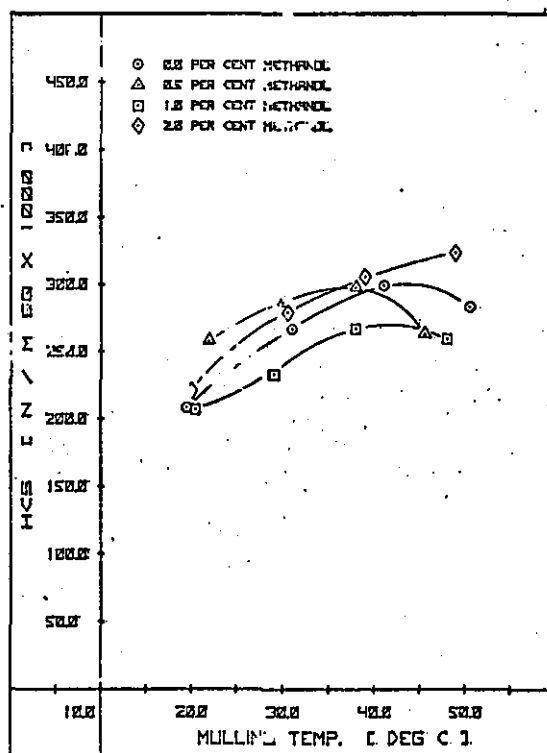


Fig. (iii)g Varying methanol.

Fig. (iii) Effect of mulling temperature upon hot compression strength at varying clay and oil contents, mulling times and methanol additions.

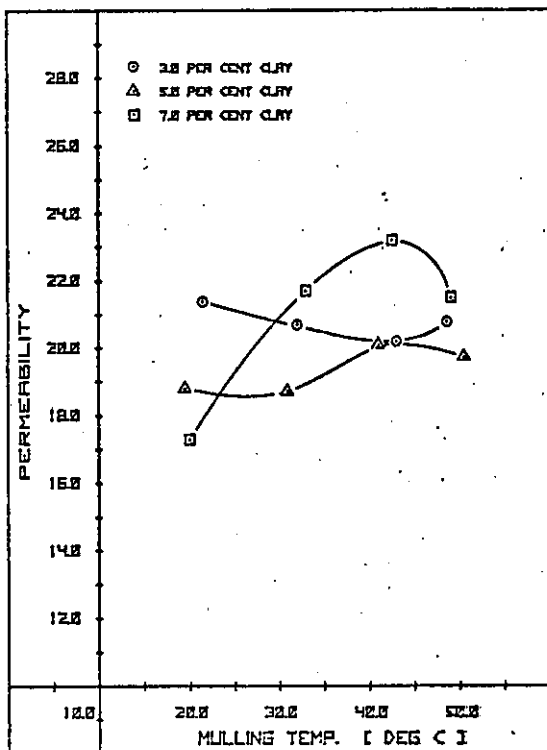


Fig. (iv)a Varying clay.
No polar additive.

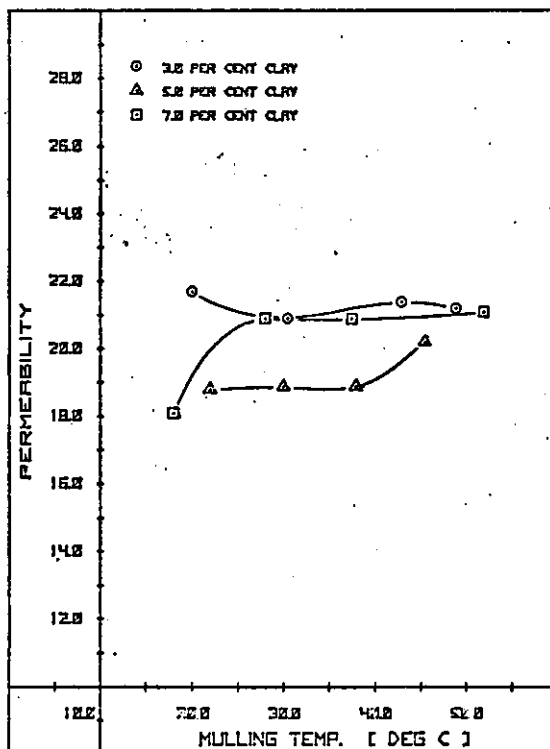


Fig. (iv)b Varying clay.
0.5 per cent methanol.

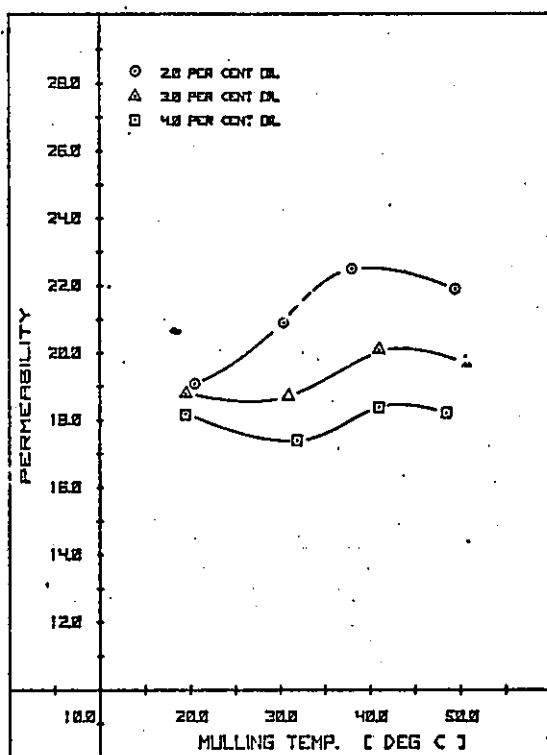


Fig. (iv)c Varying oil.
No polar additive.

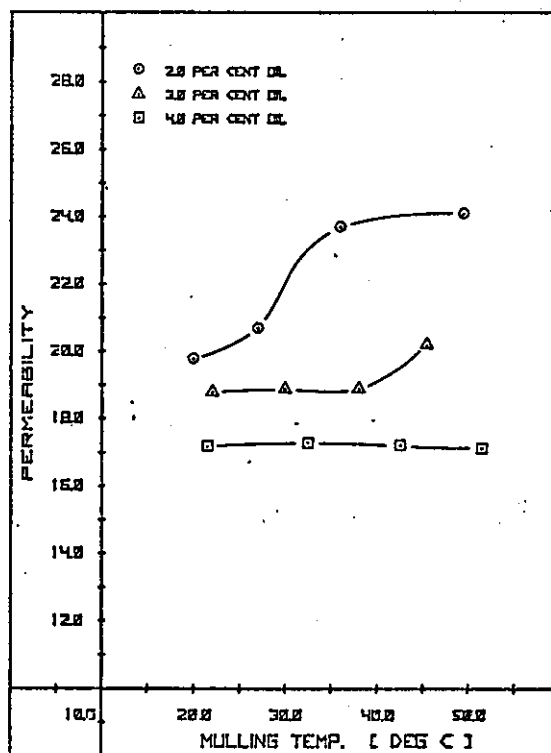


Fig. (iv)d Varying oil.
0.5 per cent methanol.

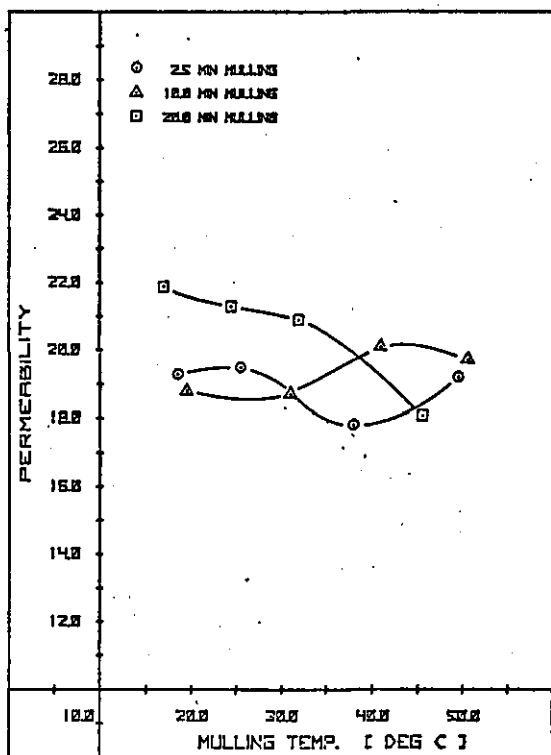


Fig. (iv)e Varying mulling time.
No polar additive.

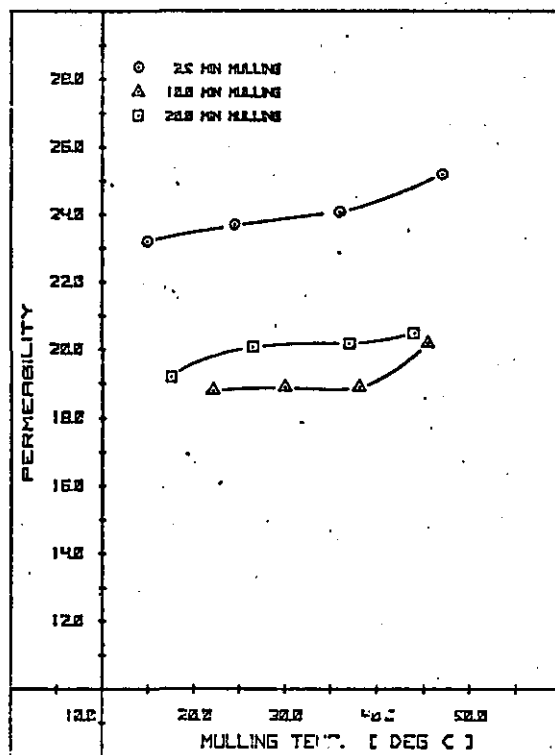


Fig. (iv)f Varying mulling time.
0.5 per cent methanol.

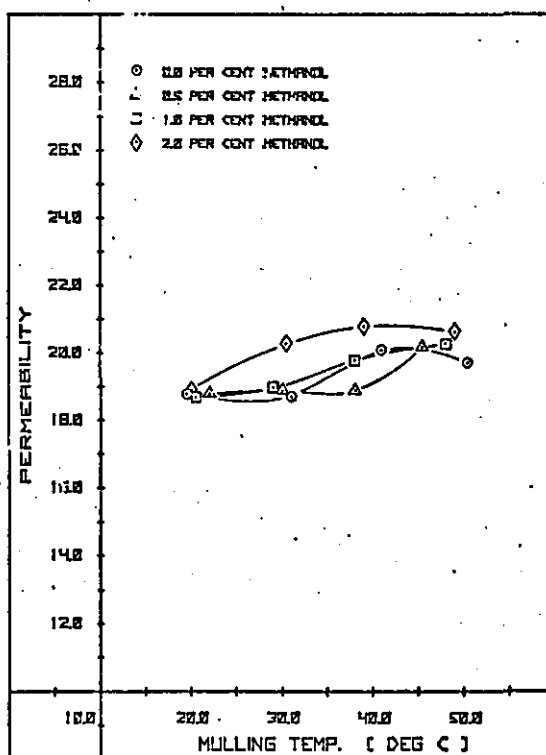


Fig. (iv)g Varying methanol.

Fig. (iv) Effect of mulling temperature upon permeability at varying clay and oil contents, mulling times and methanol additions.

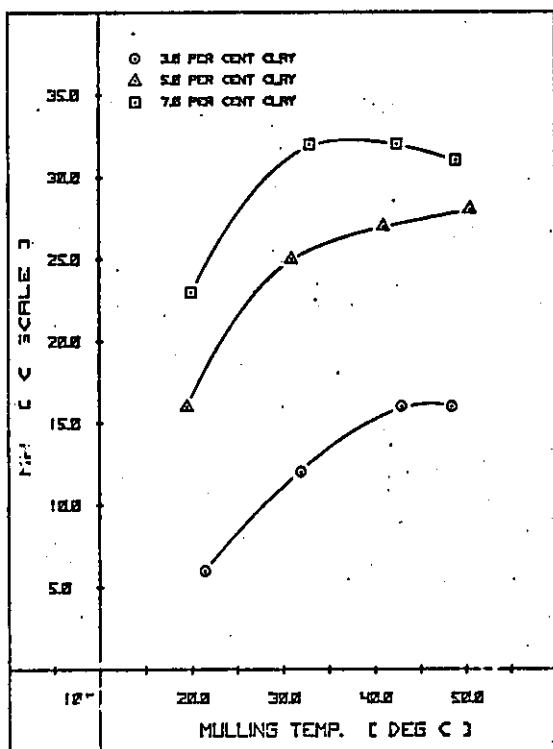


Fig. (v)a Varying clay.
No polar additive.

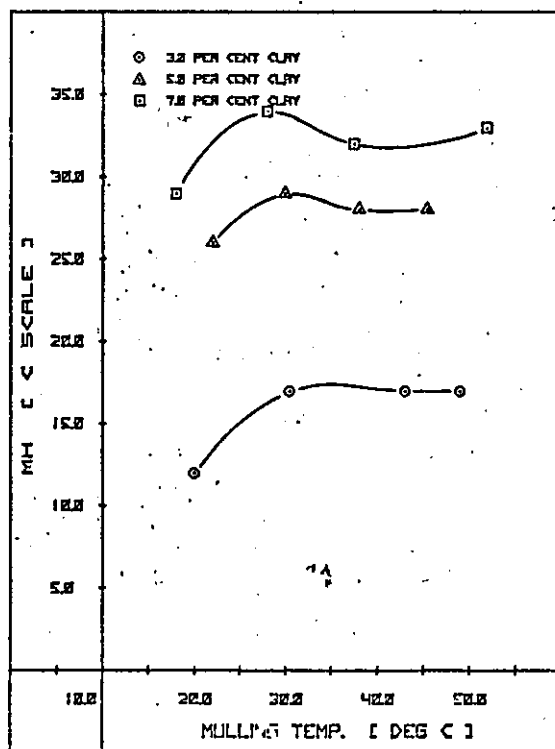


Fig. (v)b Varying clay.
0.5 per cent methanol.

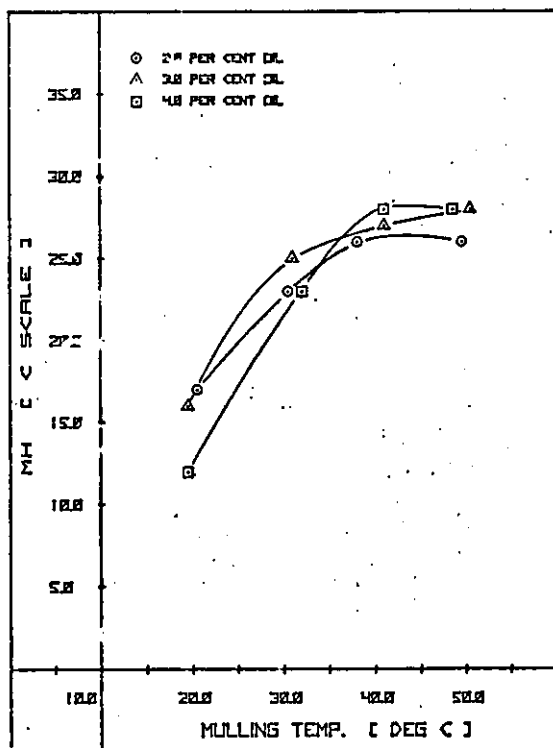


Fig. (v)c Varying oil.
No polar additive.

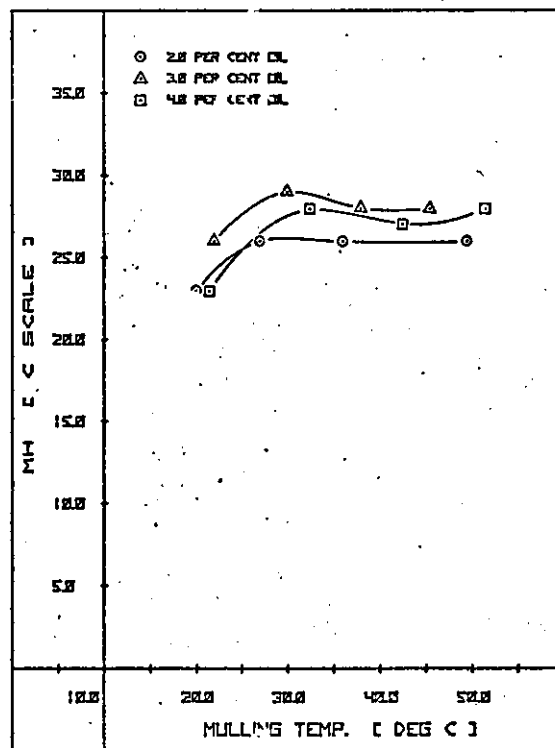


Fig. (v)d Varying oil.
0.5 per cent methanol.

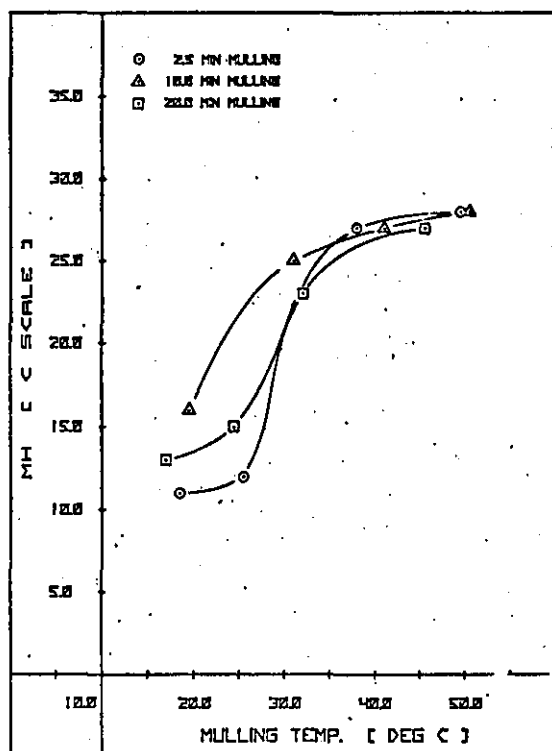


Fig. (v)e Varying mulling time.
No polar additive.

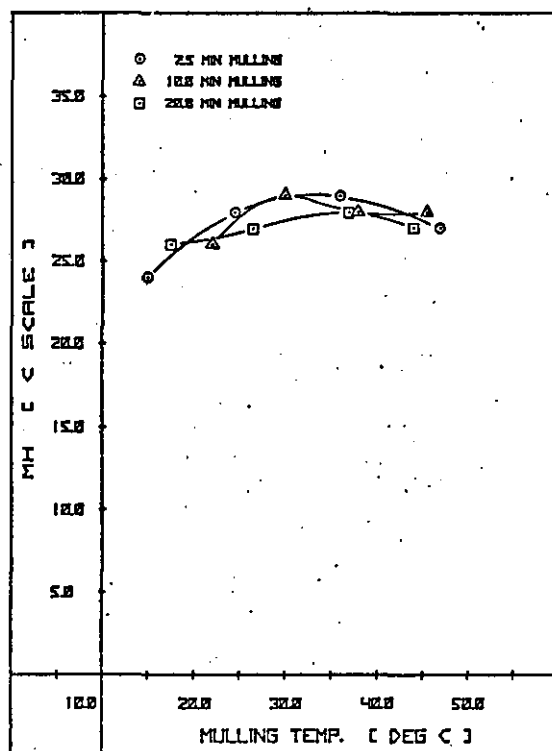


Fig. (v)f Varying mulling time.
0.5 per cent methanol.

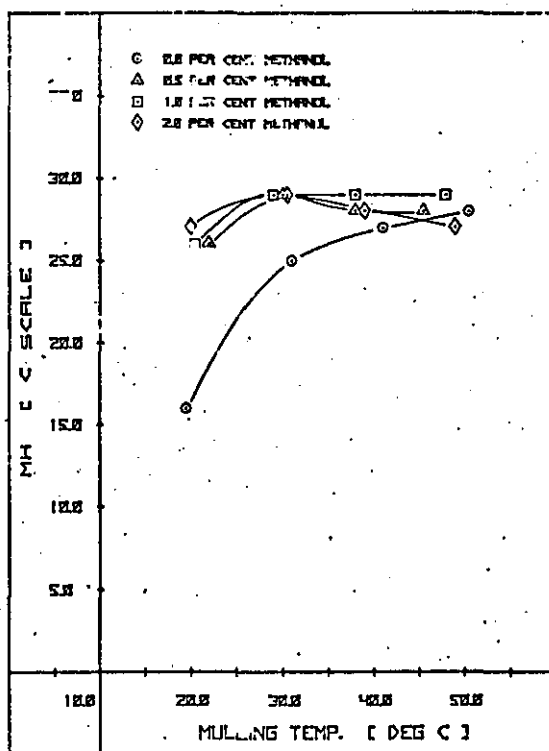


Fig. (v)g Varying methanol.

Fig. (v) Effect of mulling temperature upon mould hardness at varying clay and oil contents, mulling times and methanol additions.

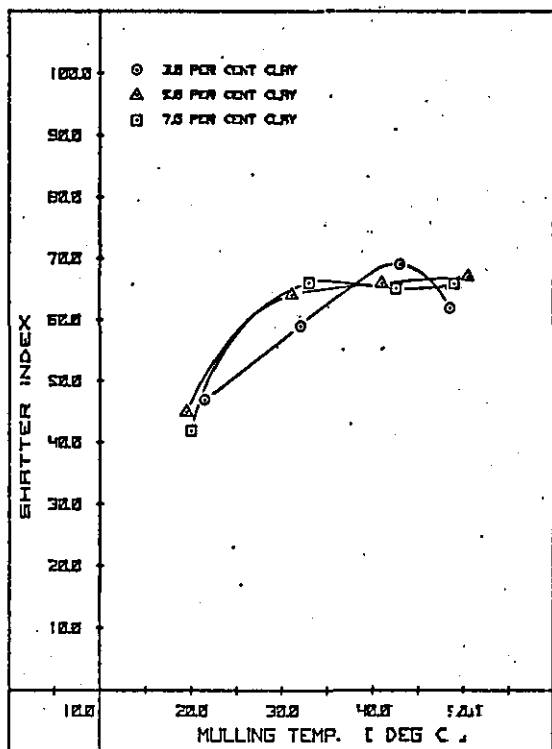


Fig. (vi)a Varying clay.
No polar additive.

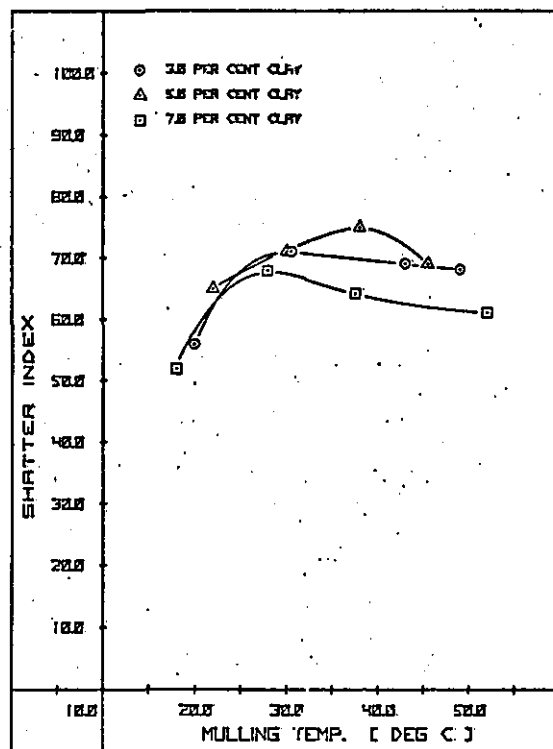


Fig. (vi)b Varying clay.
0.5 per cent methanol.

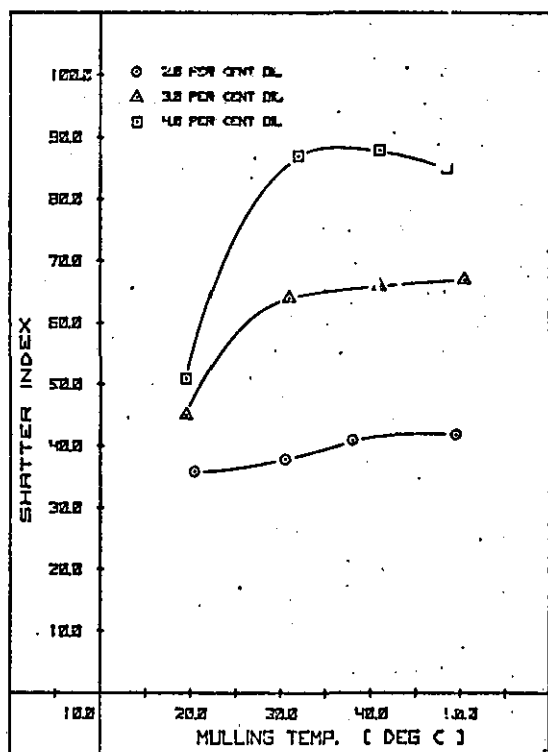


Fig. (vi)c Varying oil.
No polar additive.

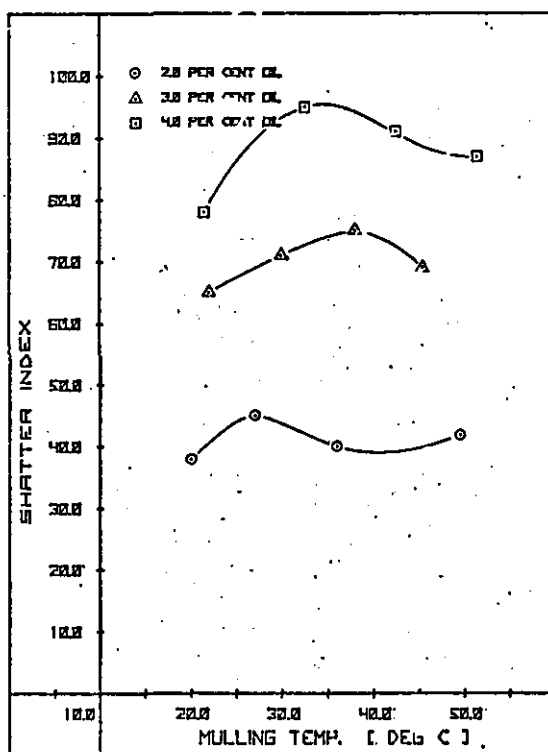


Fig. (vi)d Varying oil.
0.5 per cent methanol.

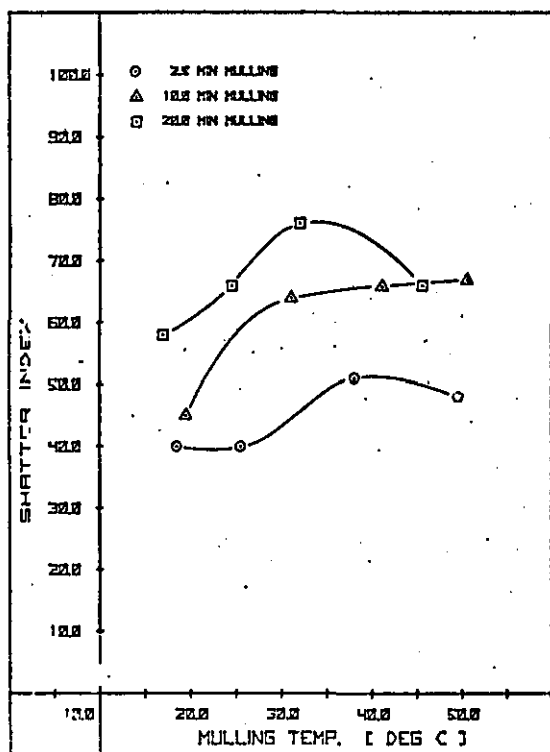


Fig. (vi)e Varying mulling time.
No polar additive.

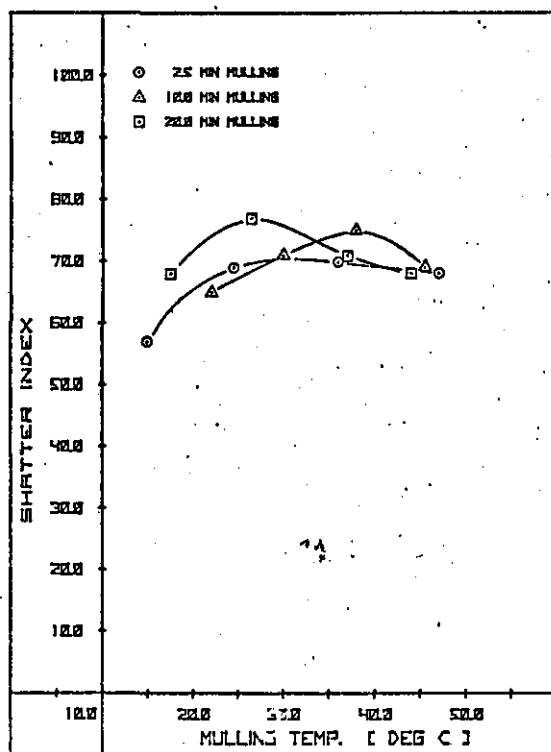


Fig. (vi)f Varying mulling time.
0.5 per cent methanol.

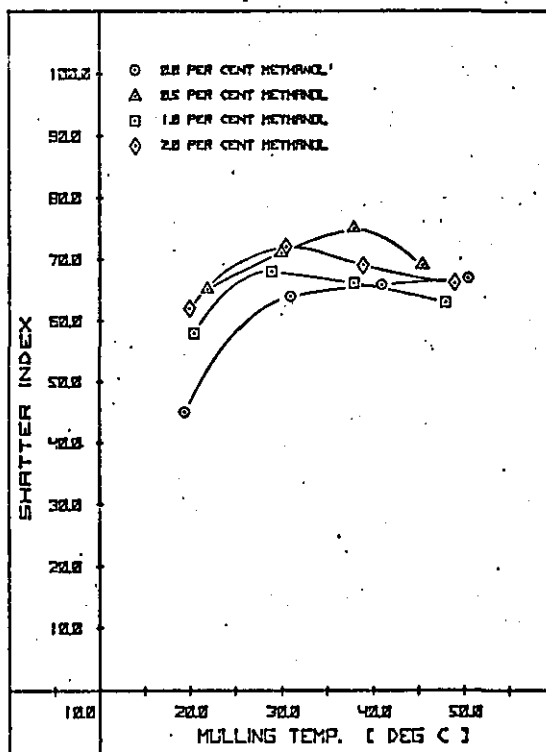


Fig. (vi)g Varying methanol.

Fig. (vi) Effect of mulling temperature upon shatter index at varying clay and oil contents, mulling times and methanol additions.

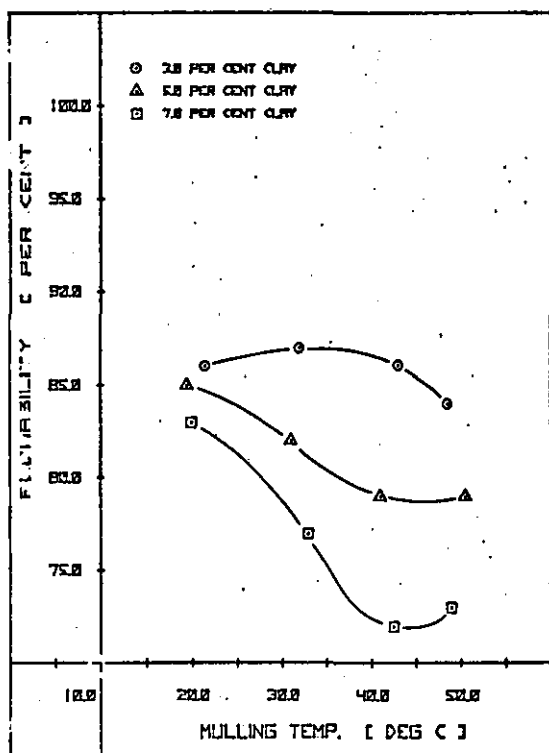


Fig. (vii)a Varying clay.
No polar additive.

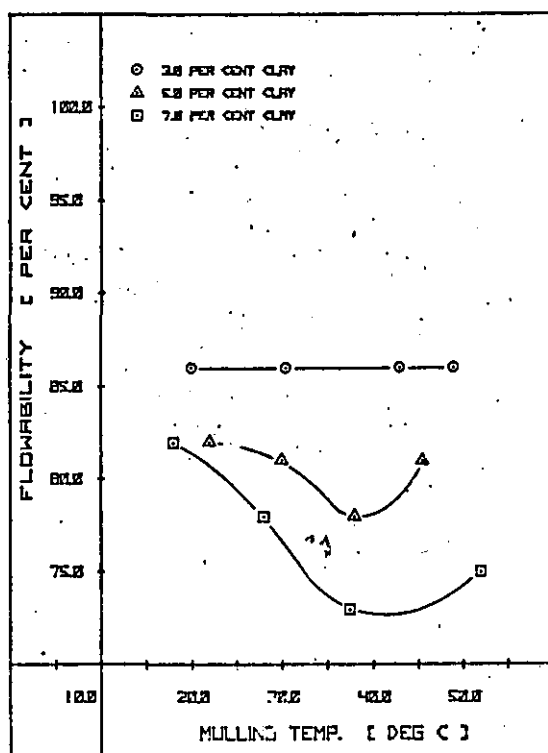


Fig. (vii)b Varying clay.
0.5 per cent methanol.

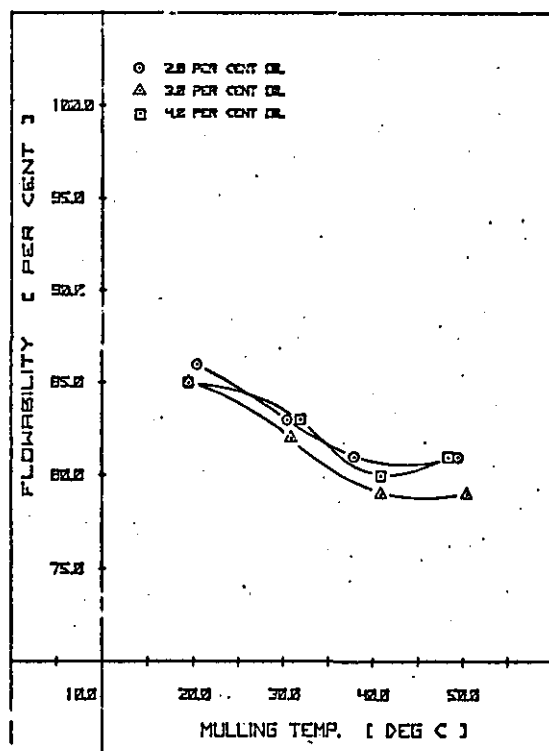


Fig. (vii)c Varying oil.
No polar additive.

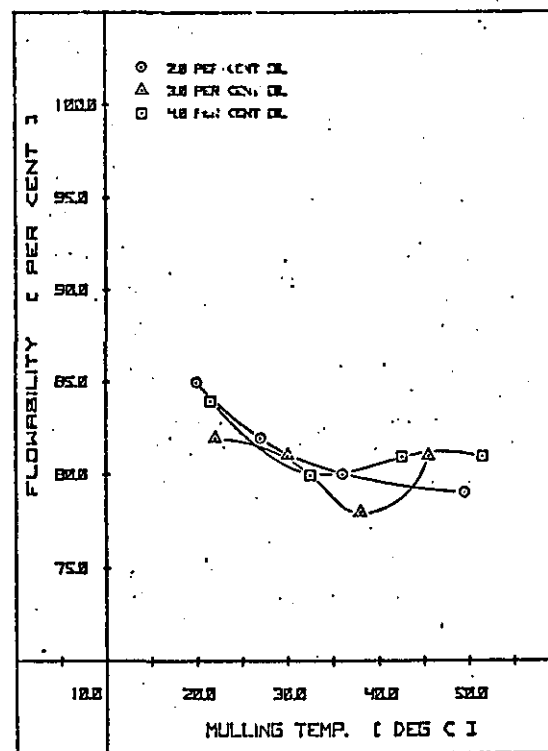


Fig. (vii)d Varying oil.
0.5 per cent methanol.

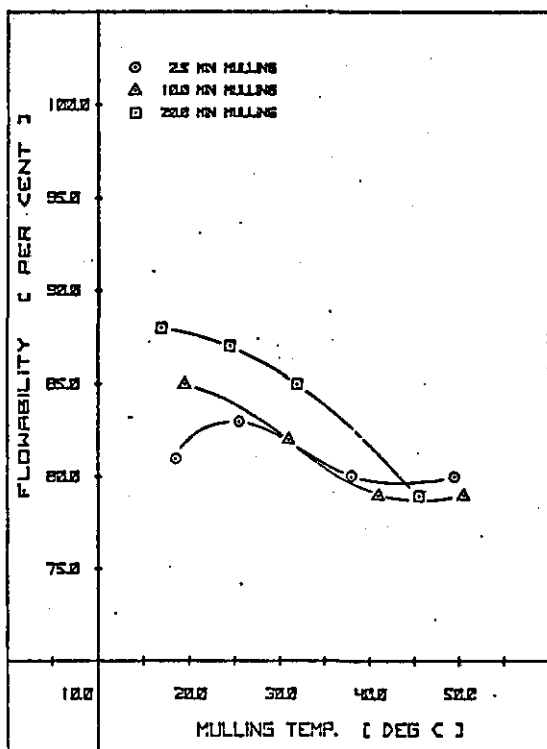


Fig. (vii)e Varying mulling time.
No polar additive.

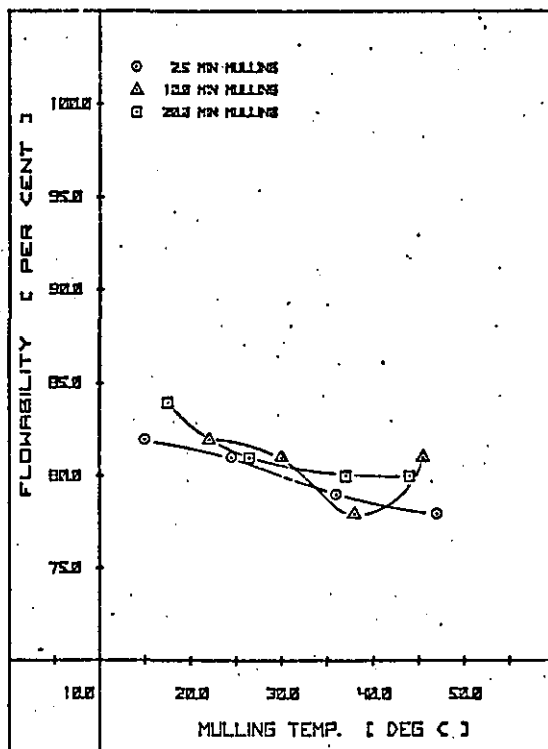


Fig. (vii)f Varying mulling time.
0.5 per cent methanol.

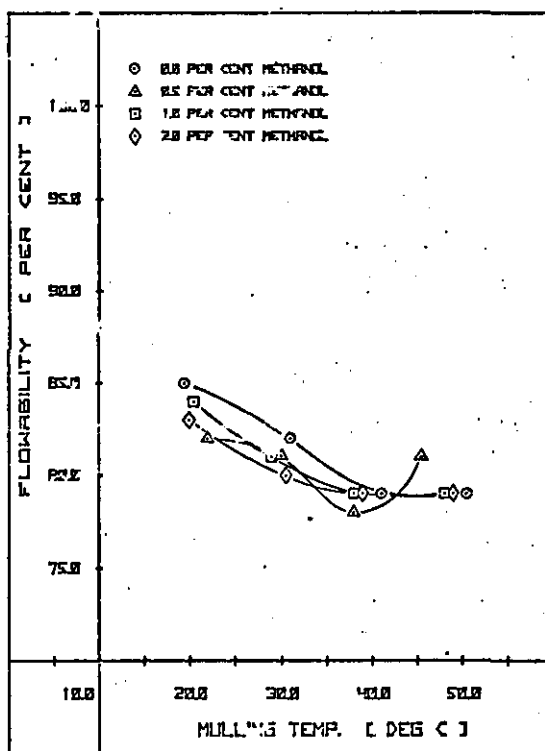
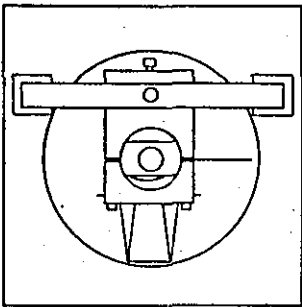


Fig. (vii)g Varying methanol.

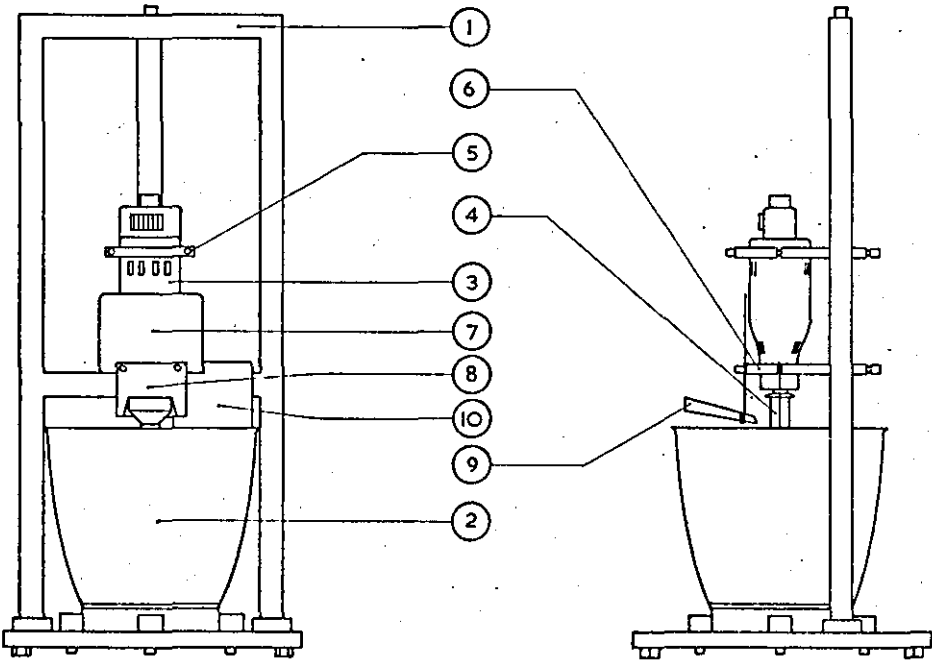
Fig. (vii) Effect of mulling temperature upon flowability at varying clay and oil contents, mulling times and methanol additions.

APPENDIX DRAWINGS

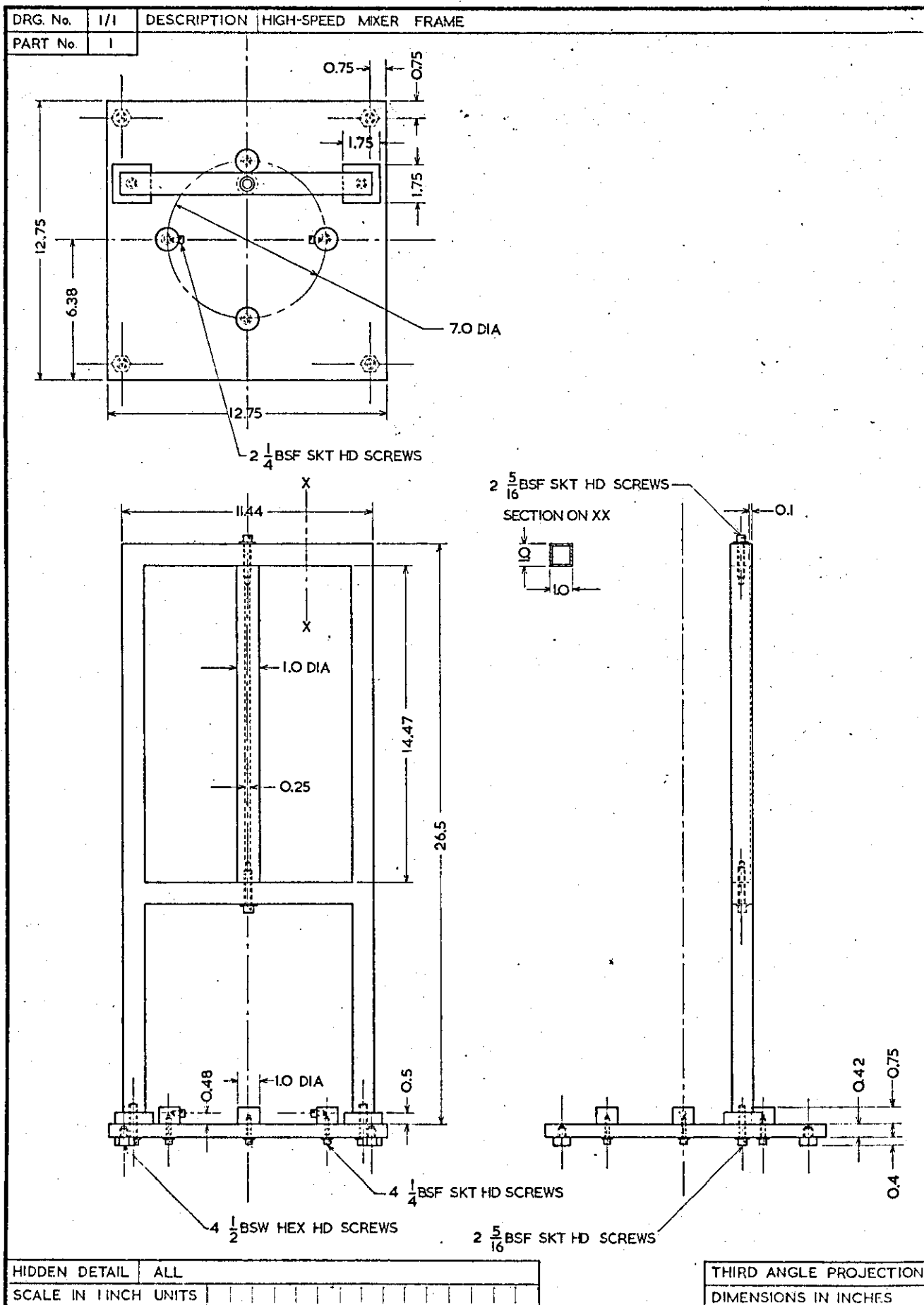
DRG. No.	I	DESCRIPTION	HIGH-SPEED MIXER ASSEMBLY
PART No.			

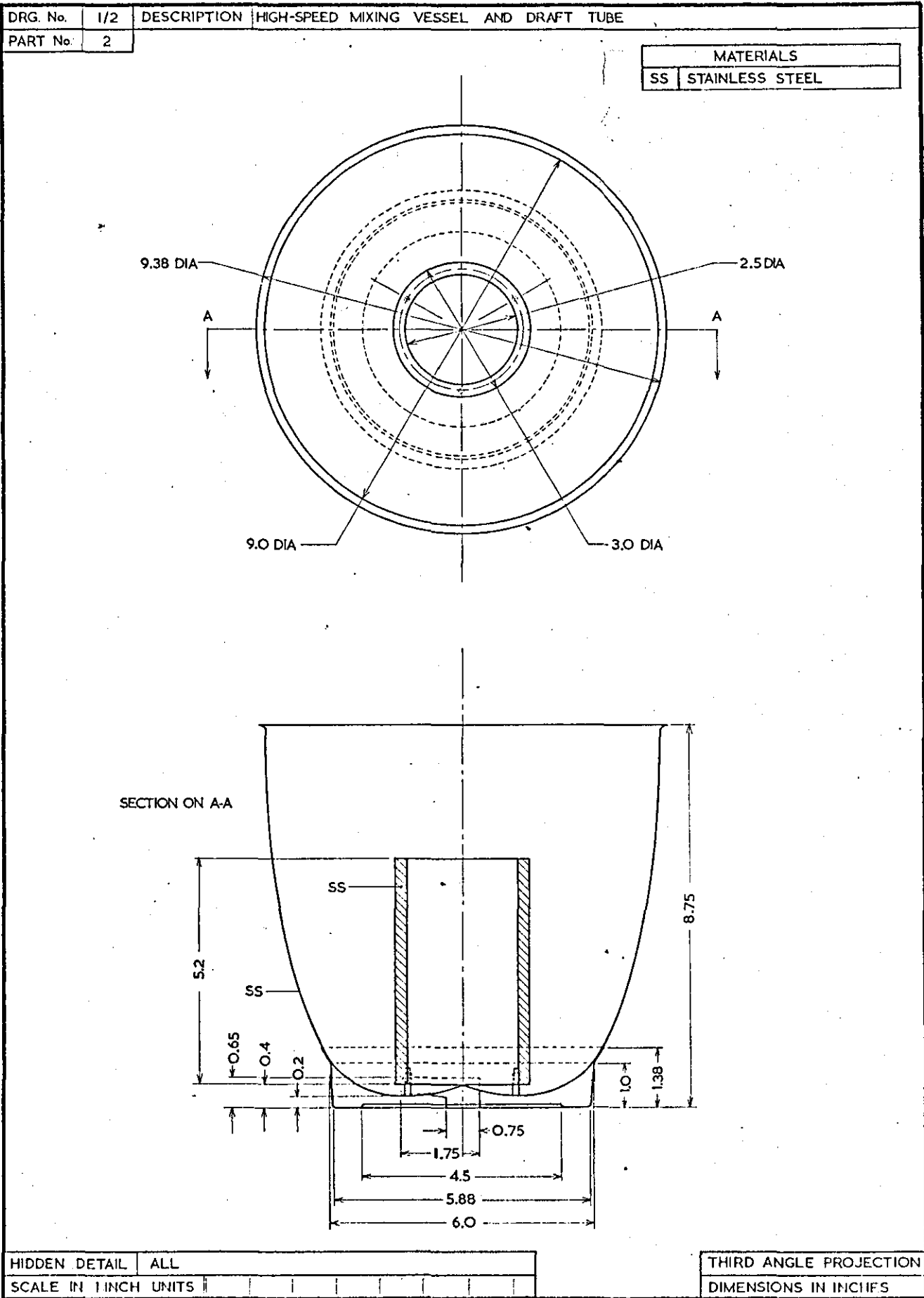


PARTS AND SUB-ASSEMBLIES	
1	MIXER FRAME
2	MIXING VESSEL AND DRAFT TUBE
3	MOTOR
4	PROPELLER AND SHAFT
5	MOTOR BRACKET
6	MOTOR BRACKET
7	WIND GUARD
8	CHUTE HOLDER
9	CHUTE
10	BAFFLE PLATE

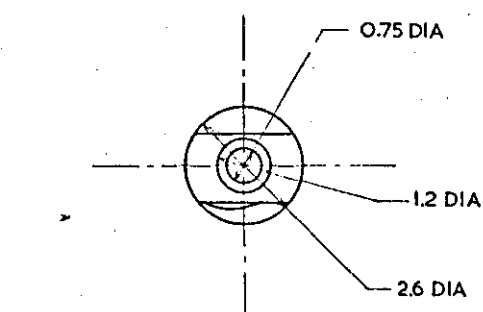


HIDDEN DETAIL	NONE	THIRD ANGLE PROJECTION
SCALE IN INCH UNITS		DIMENSIONS IN INCHES

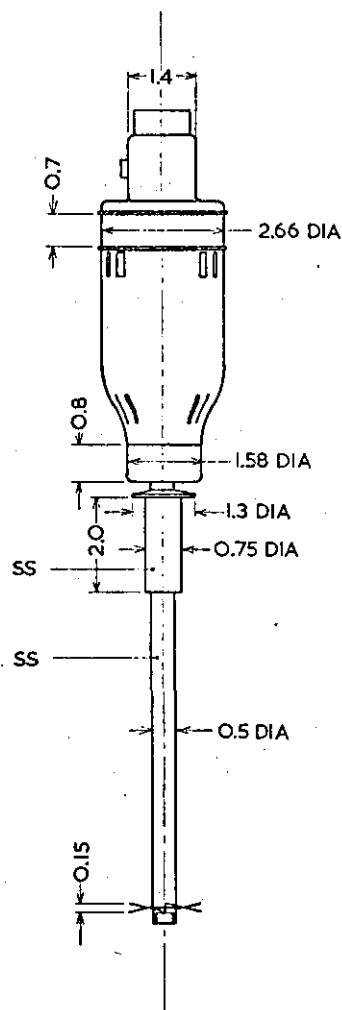
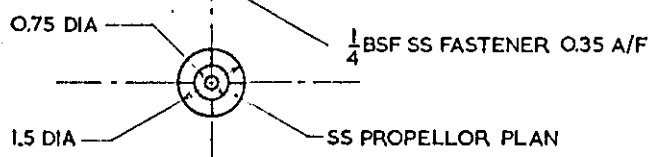
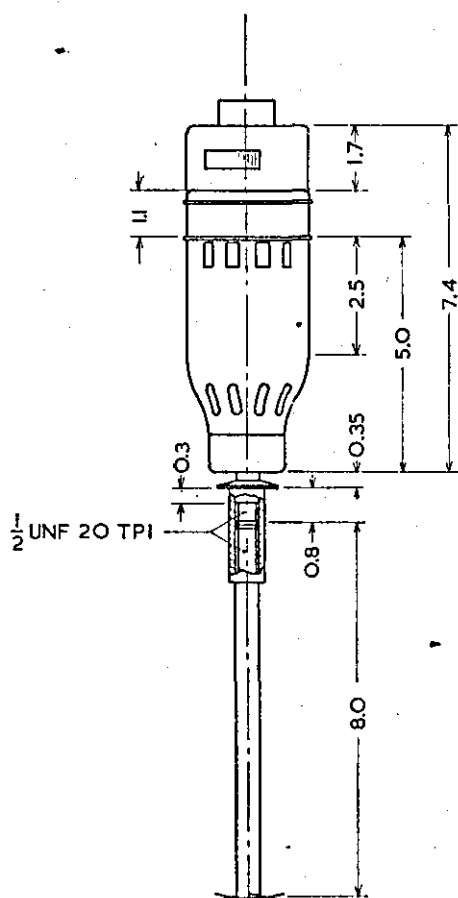




DRG. No.	1/3	DESCRIPTION	MOTOR AND PROPELLER SHAFT ASSEMBLY
PART No.	3&4		



MATERIALS	
SS	STAINLESS STEEL



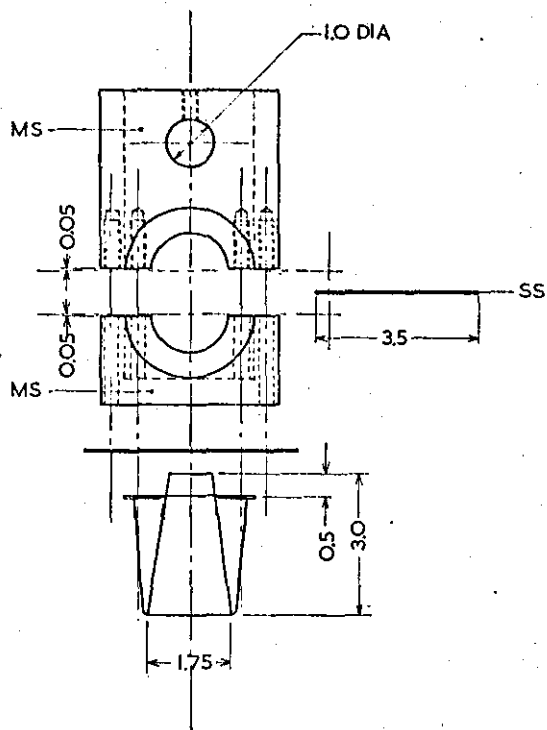
HIDDEN DETAIL NONE

SCALE IN INCH UNITS

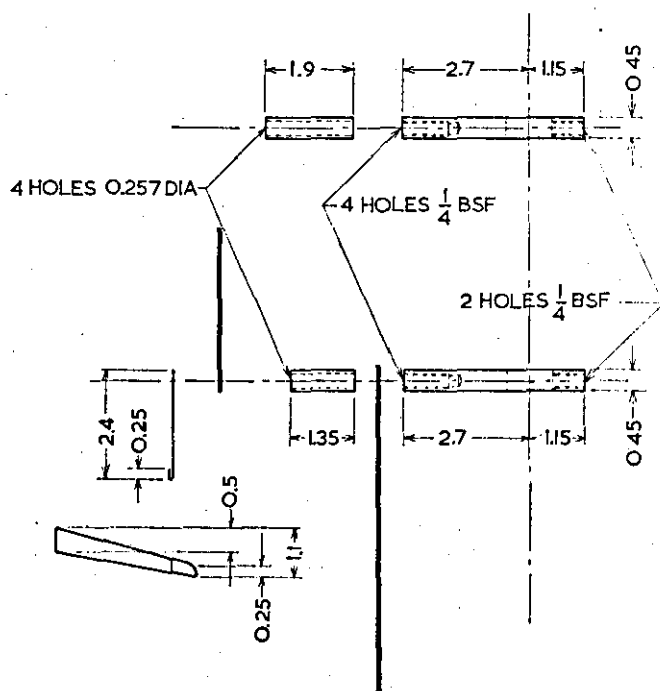
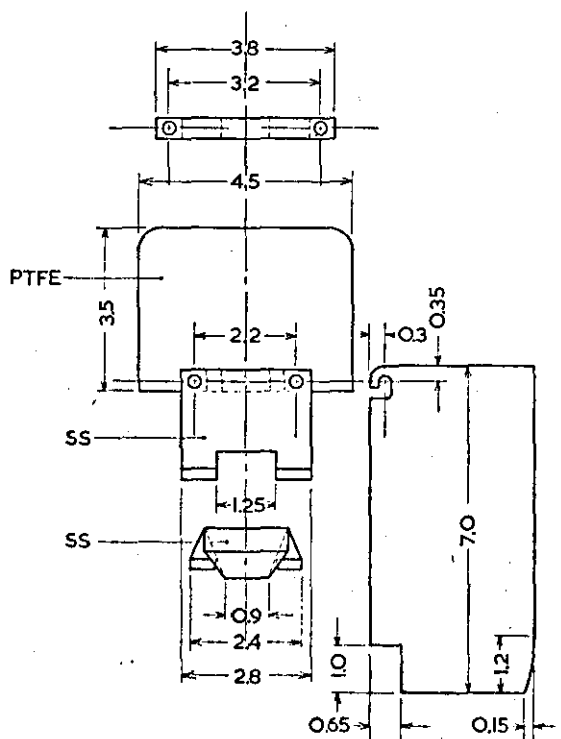
THIRD ANGLE PROJECTION

DIMENSIONS IN INCHES

DRG No.	1/4	DESCRIPTION	MOTOR BRACKETS AND HIGH-SPEED MIXER ACCESSORIES
PART No.	5-10		

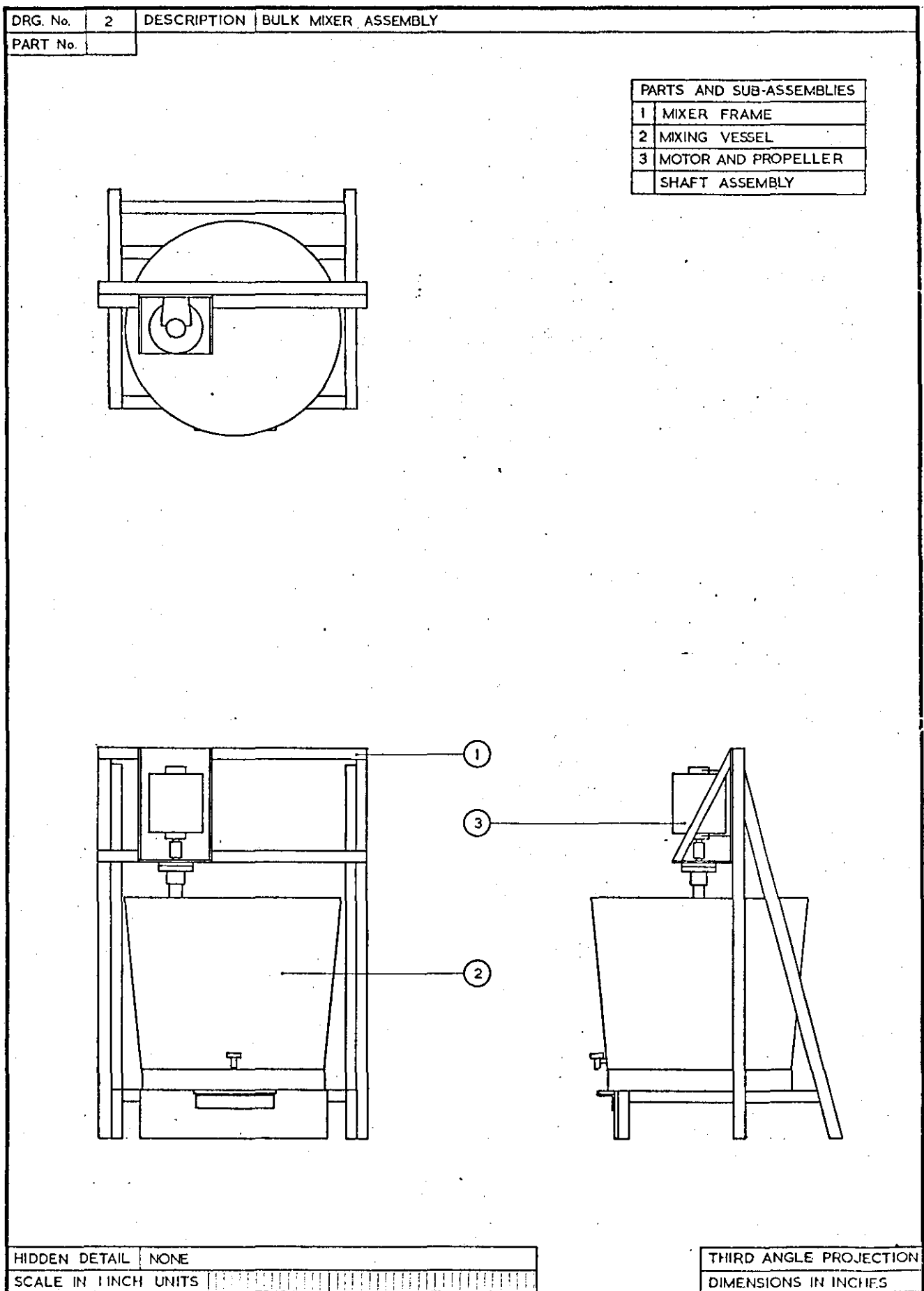


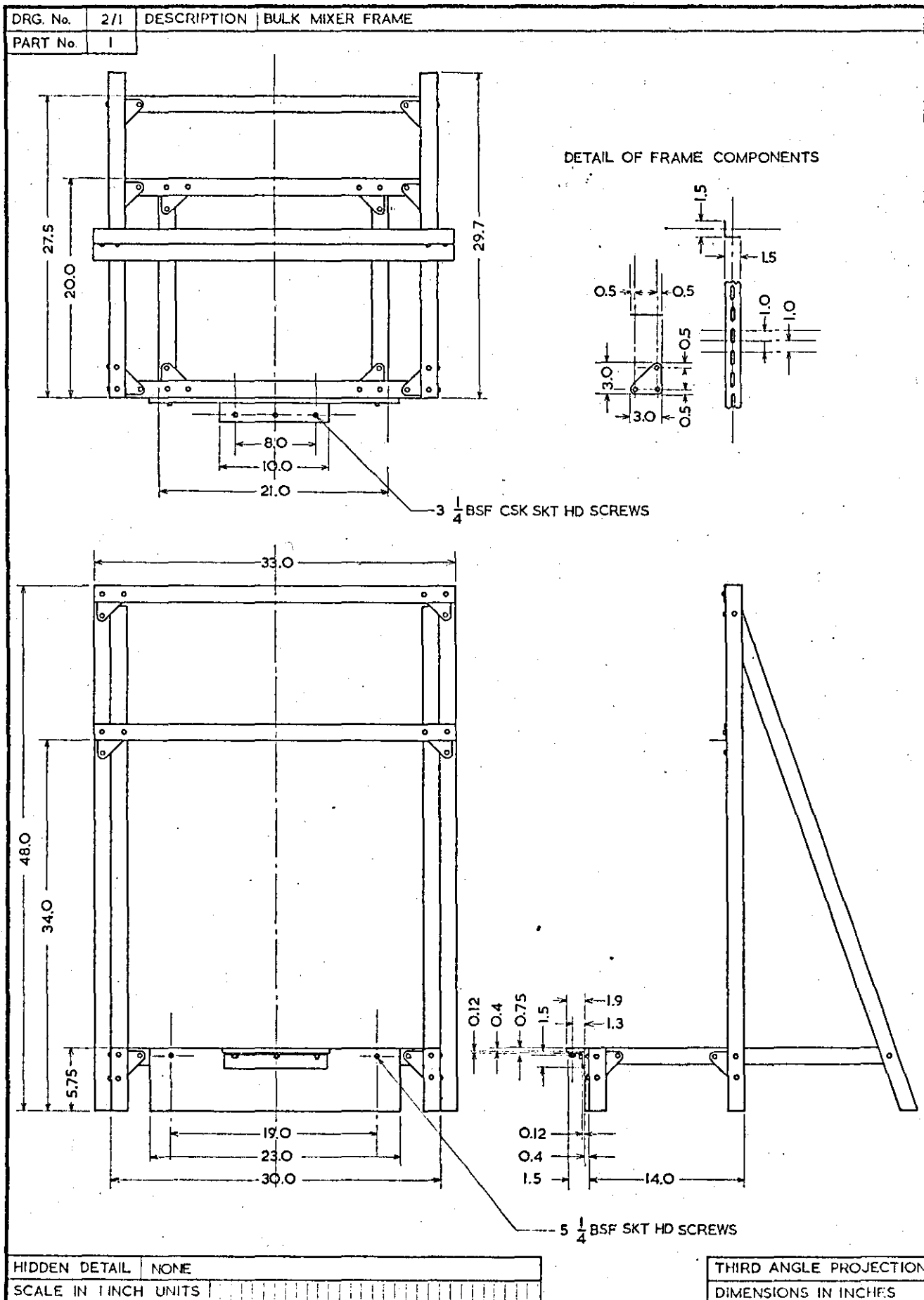
MATERIALS	
SS	STAINLESS STEEL
MS	MILD STEEL
PTFE	POLYTETRAFLUOROETHYLENE



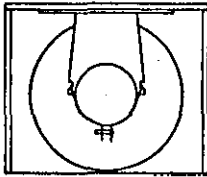
HIDDEN DETAIL	ALL
SCALE IN INCH UNITS	

THIRD ANGLE PROJECTION
DIMENSIONS IN INCHES

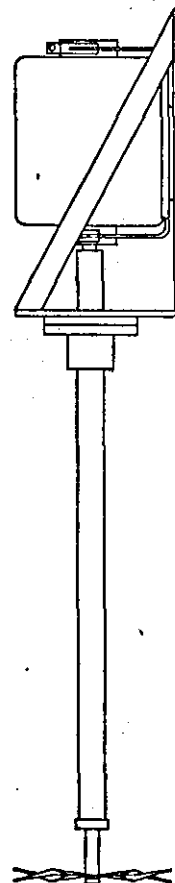
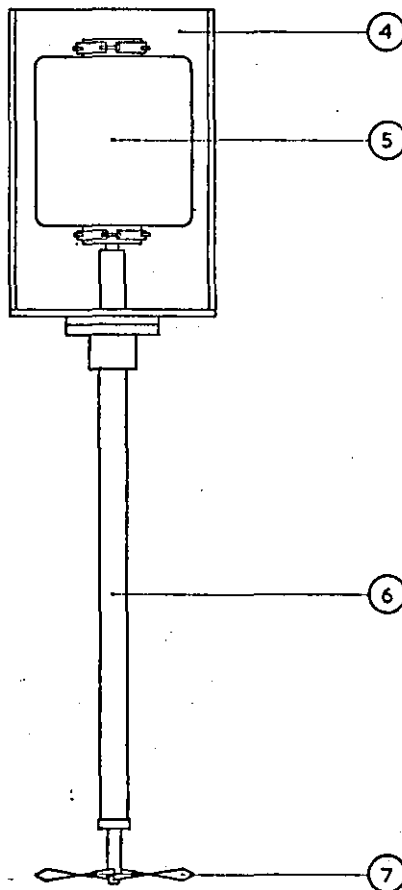




DRG. No.	2/A	DESCRIPTION	MOTOR AND PROPELLER SHAFT ASSEMBLY
PART No.			



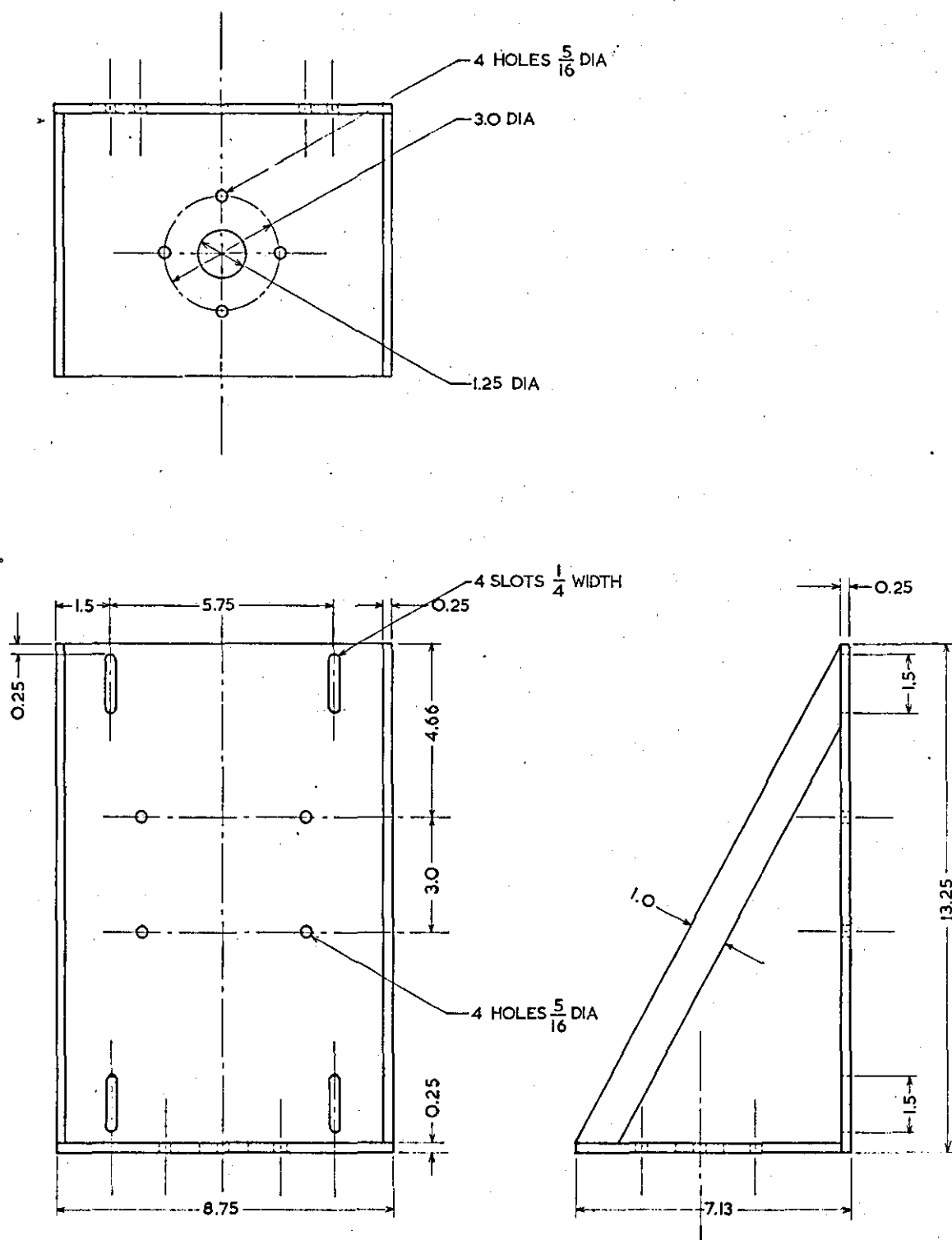
PARTS AND SUB-ASSEMBLIES	
4	MOTOR BRACKET
5	MOTOR
6	SHAFT ASSEMBLY
7	PROPELLER



HIDDEN DETAIL	NONE
SCALE IN INCH UNITS	

THIRD ANGLE PROJECTION
DIMENSIONS IN INCHES

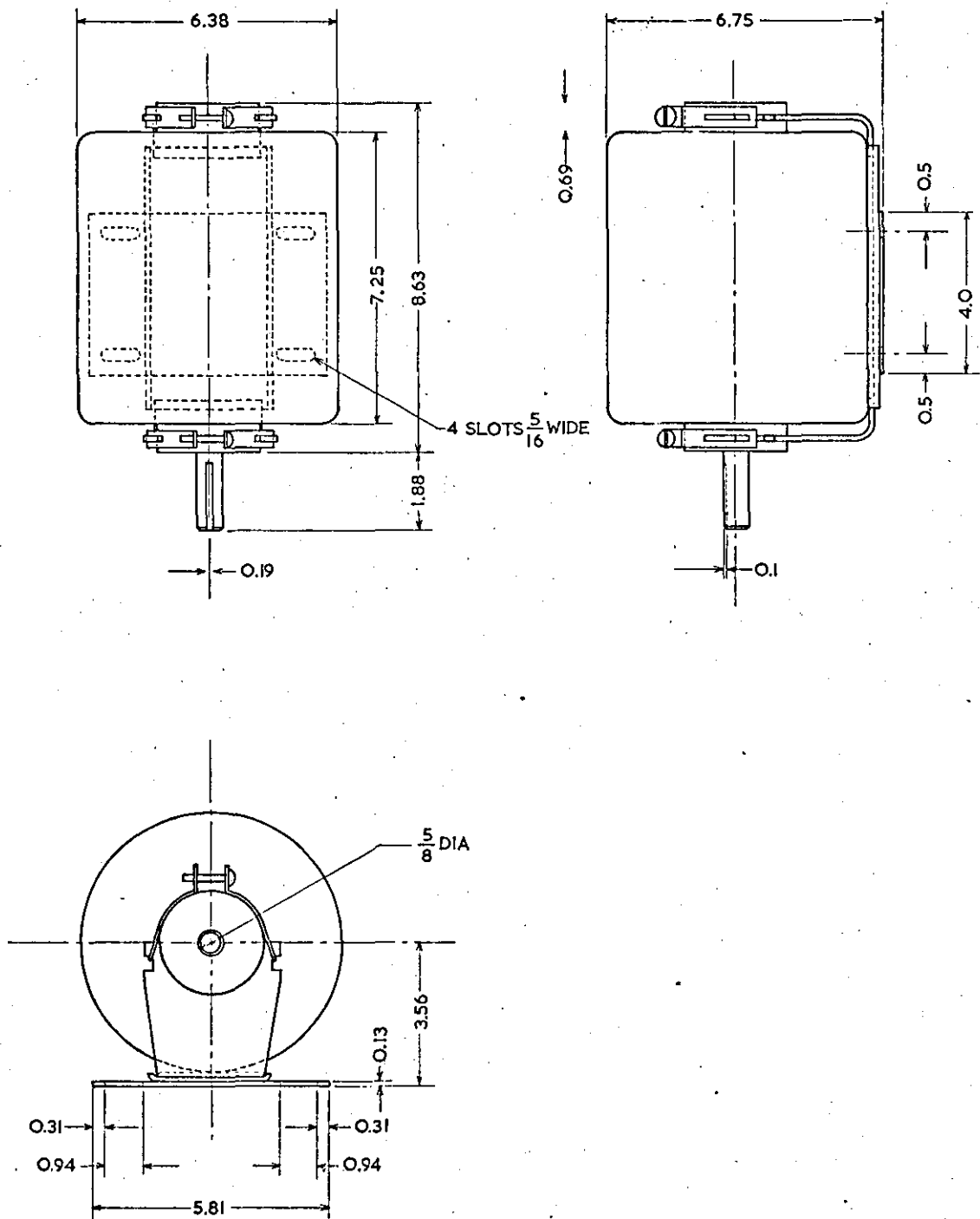
DRG. No.	2/A/1	DESCRIPTION	MOTOR BRACKET
PART No.	4		



HIDDEN DETAIL	ALL
SCALE IN INCH UNITS	

THIRD ANGLE PROJECTION
DIMENSIONS IN INCHES

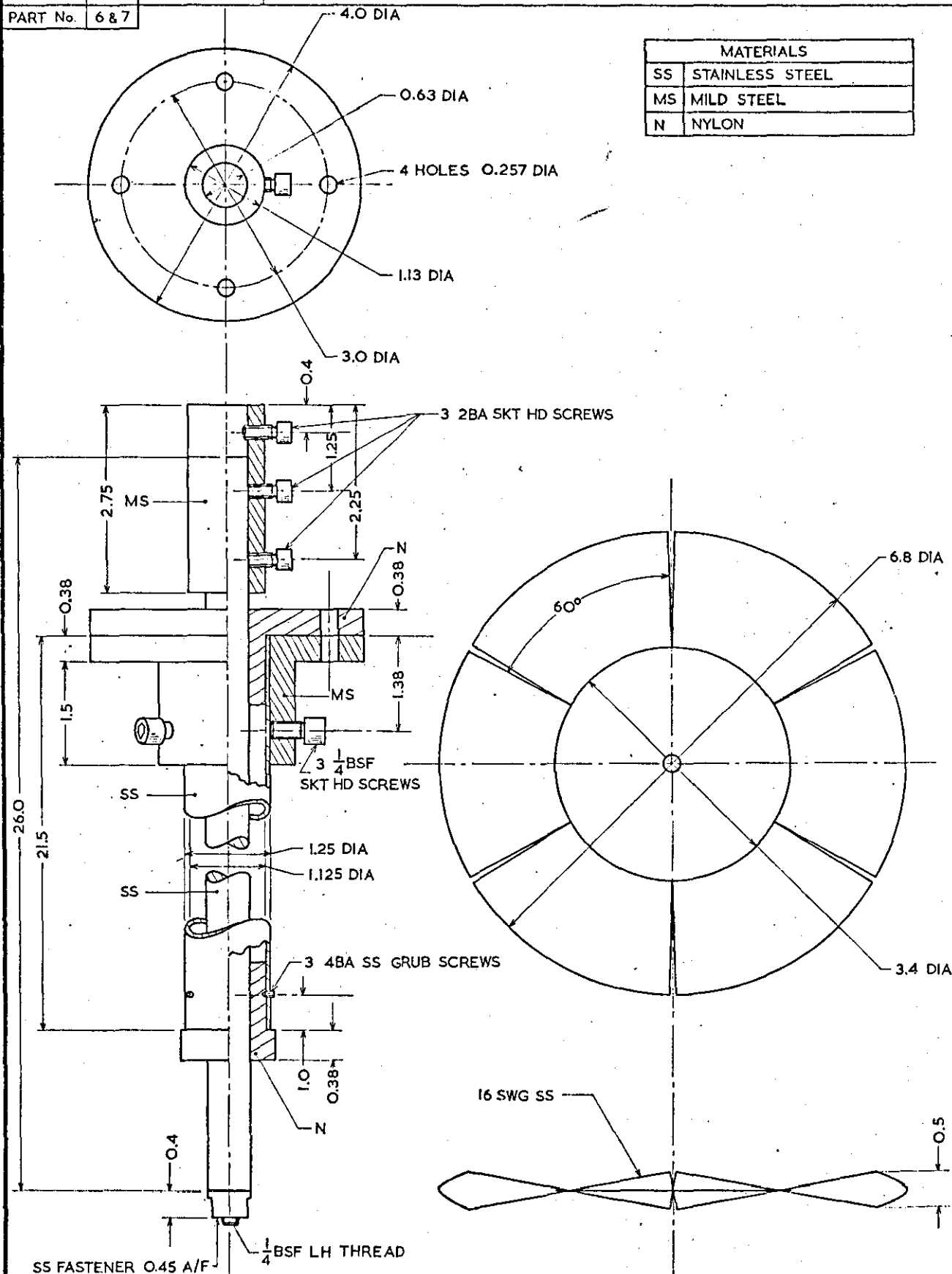
DRG. No.	2/A/2	DESCRIPTION	MOTOR
PART No.	5		



HIDDEN DETAIL	ESSENTIAL ONLY	THIRD ANGLE PROJECTION
SCALE IN INCH UNITS		DIMENSIONS IN INCHES

DRG. No.	2/A/3	DESCRIPTION	PROPELLER SHAFT ASSEMBLY AND PROPELLER
PART No.	6 & 7		

MATERIALS	
SS	STAINLESS STEEL
MS	MILD STEEL
N	NYLON

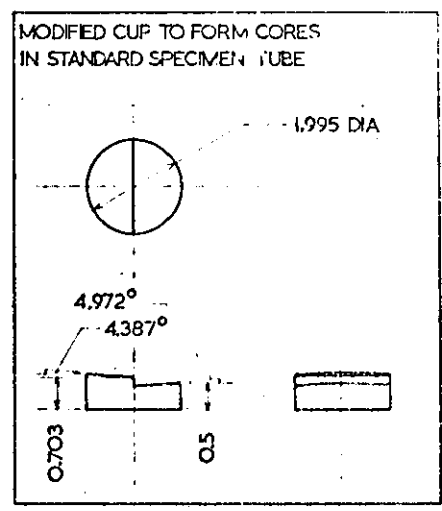
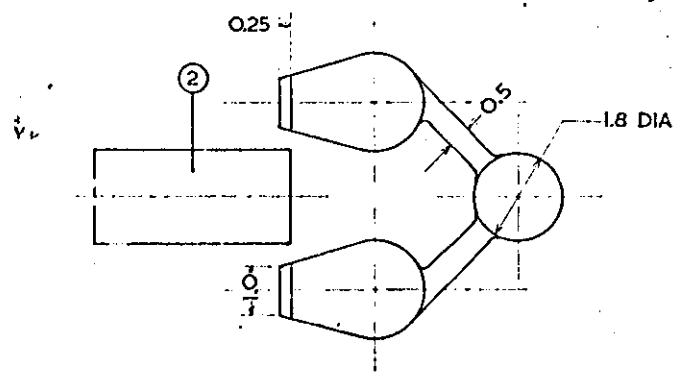
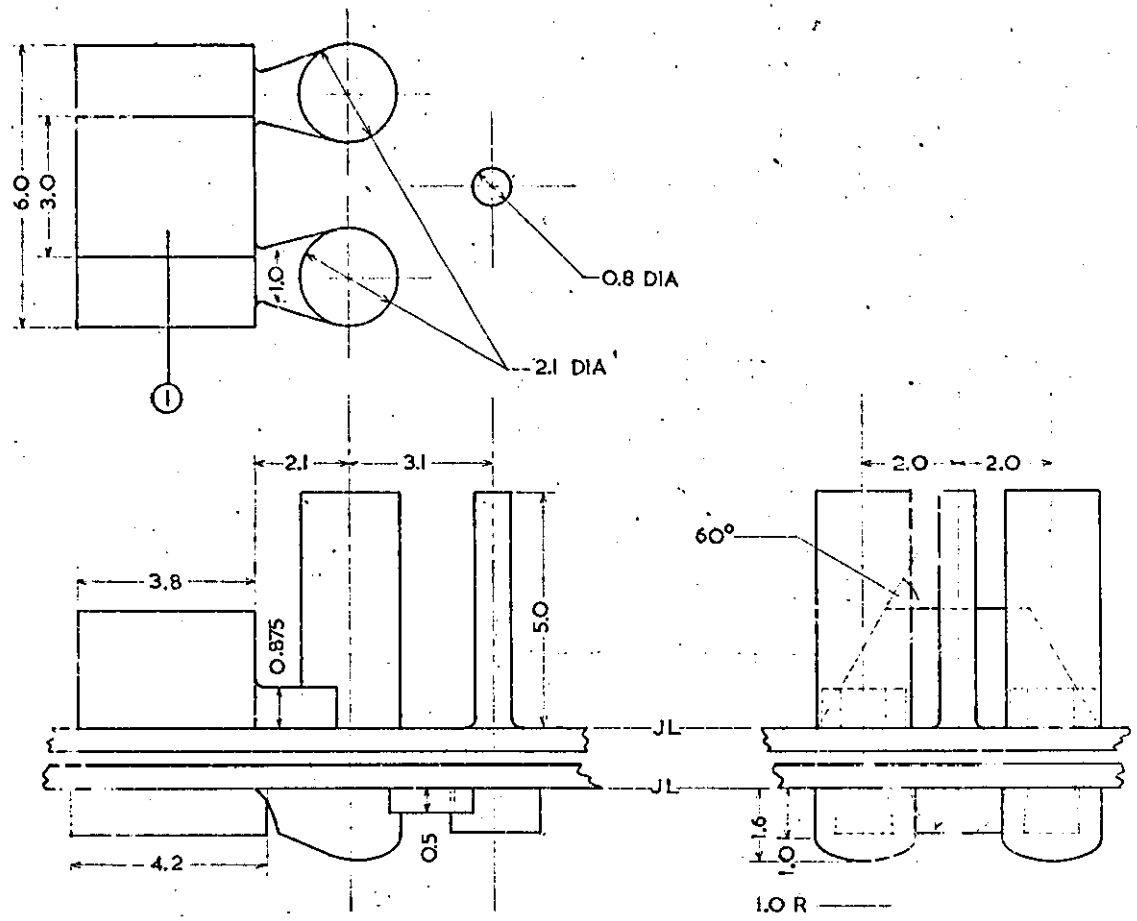


HIDDEN DETAIL NONE

SCALE IN INCH UNITS

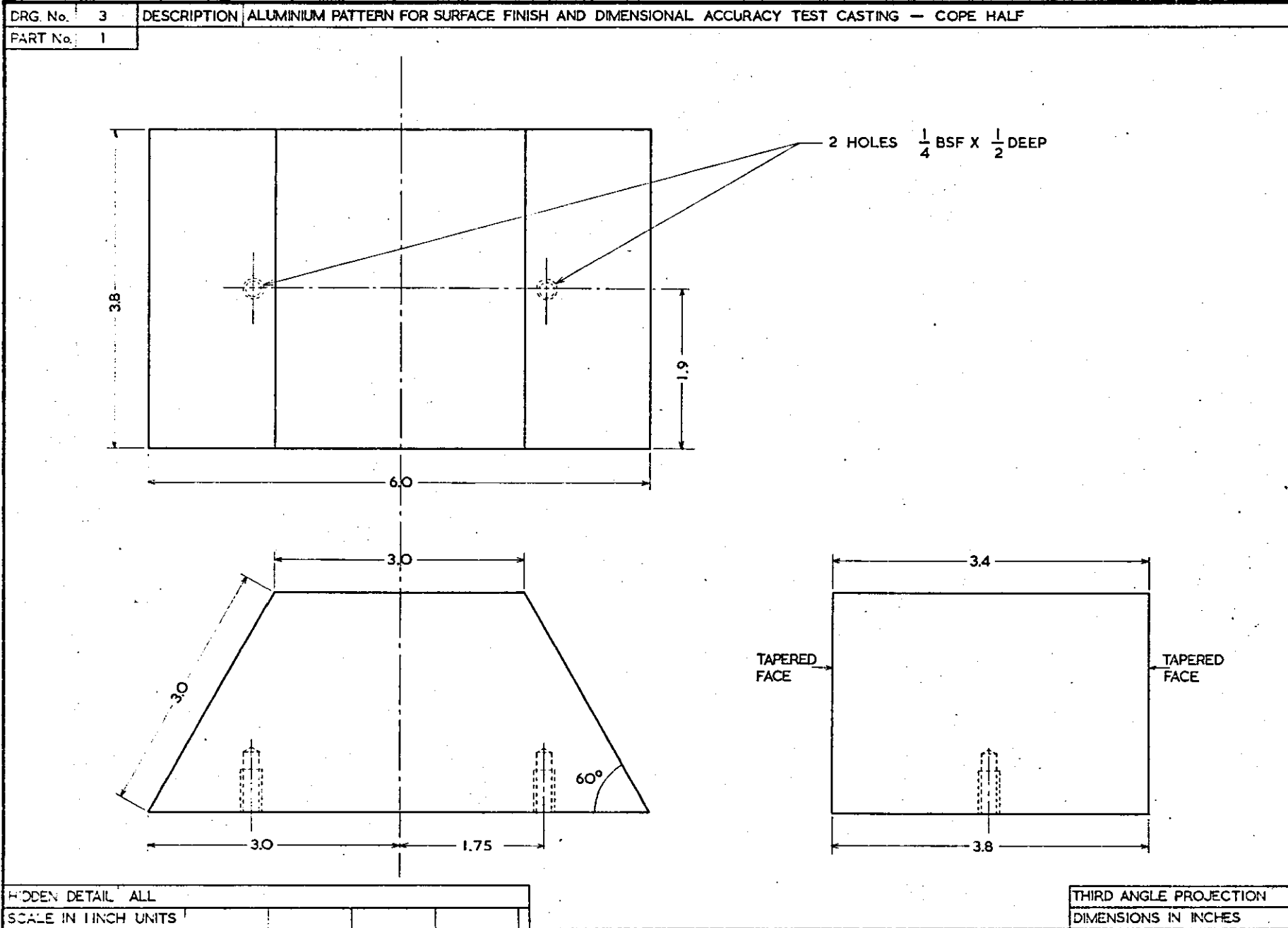
THIRD ANGLE PROJECTION
DIMENSIONS IN INCHES

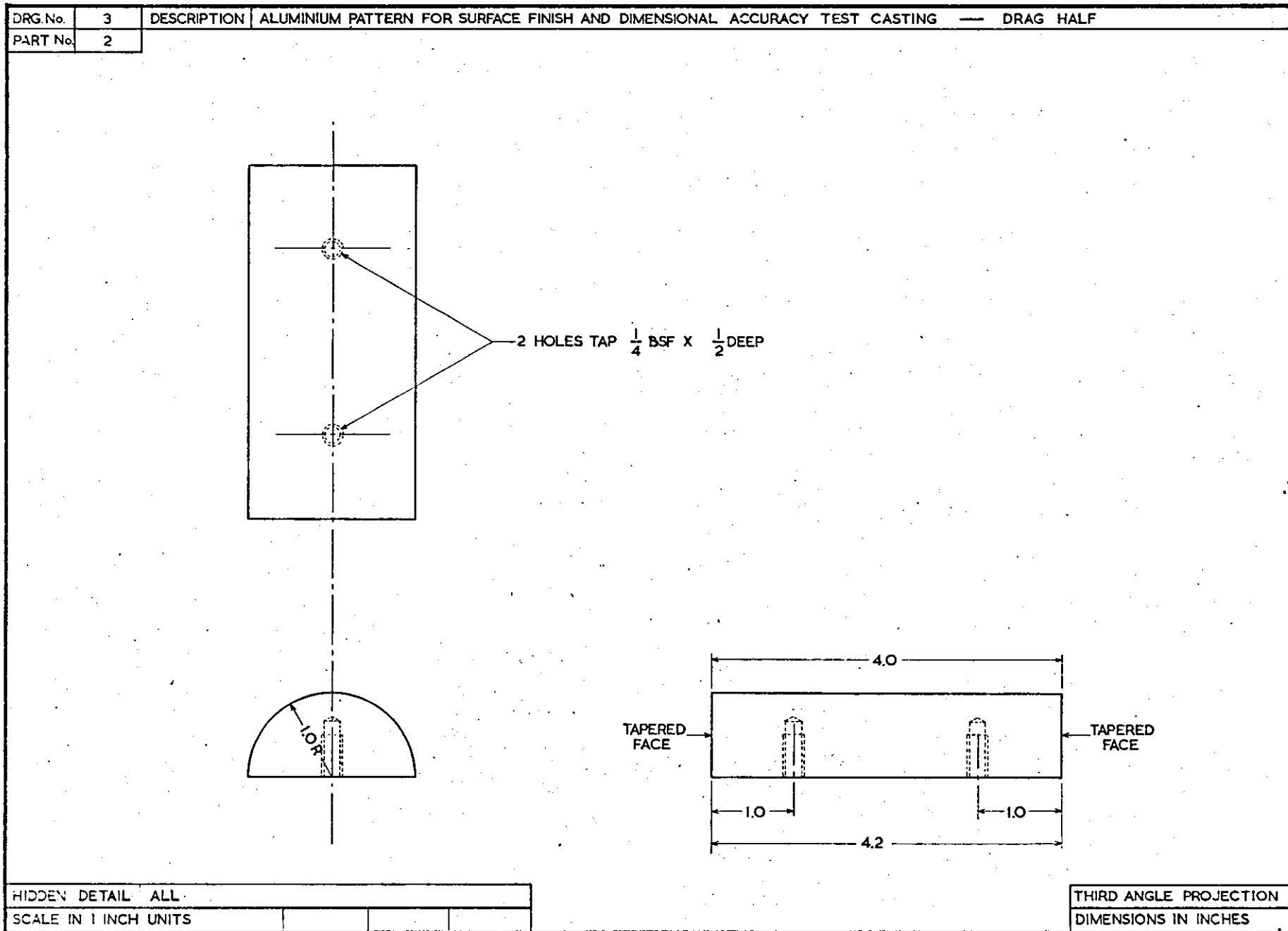
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PART No.			

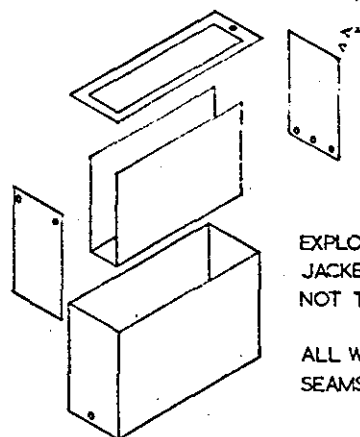


HIDDEN DETAIL ESSENTIAL ONLY
 SCALE IN INCH UNITS

THIRD ANGLE PROJECTION
 DIMENSIONS IN INCHES

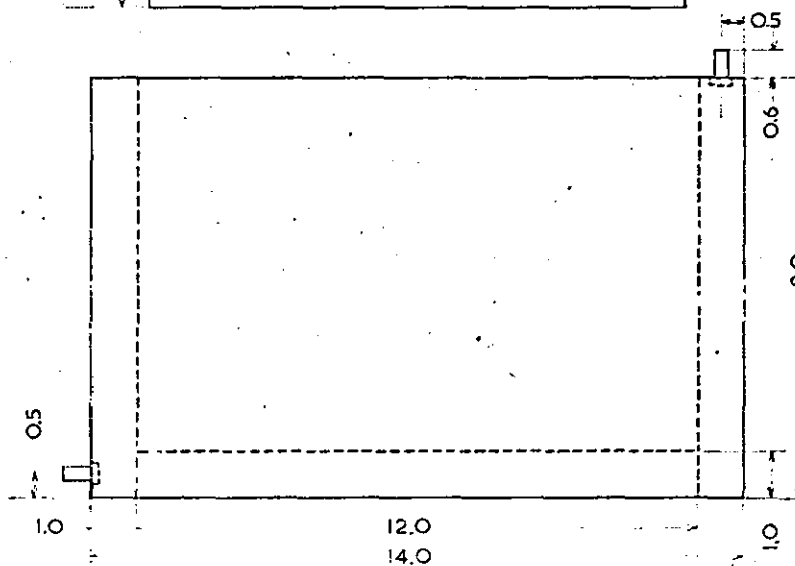
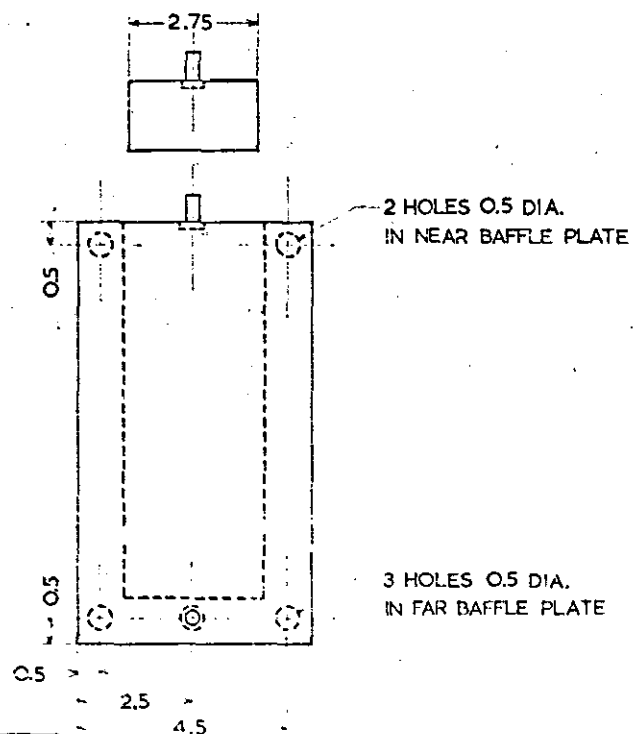
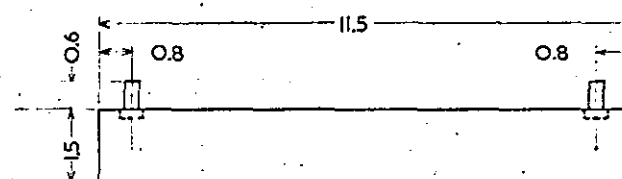
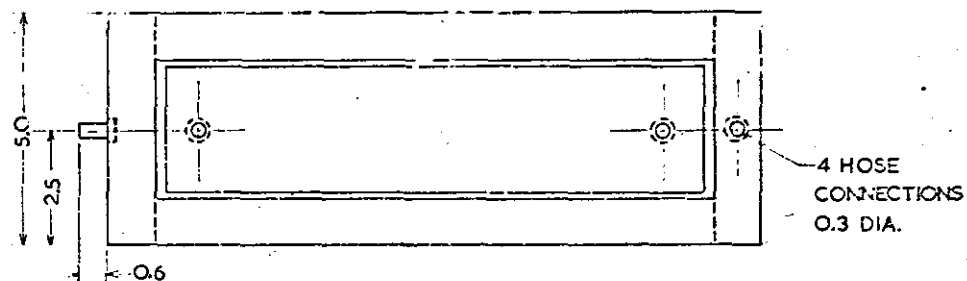






EXPLODED VIEW OF
JACKET COMPONENTS.
NOT TO SCALE.

ALL WATER-TIGHT
SEAMS BRAZED.



THIRD ANGLE PROJECTION
DIMENSIONS IN INCHES

HIDDEN DETAIL	ALL
SCALE IN 1 INCH UNITS	

REFERENCES

REFERENCES

1. Lloyd(J.U) 'Discovery of the Affinities of Hydrocarbons of Hydrous Aluminium Silicate'. J.Amer.Pharm.Assn. v.5 1916 pp.381-390, pp.490-495.
2. SMITH(C.R.) 'Base Exchange Reactions of Bentonite and Salts of Organic Bases'. J.Amer.Chem.Soc. v.56, 1934, pp.1561-1563.
3. HAUSER(E.A.) 'Modified Gel-forming Clay and Process of Producing Same'. U.S. Patent 2 531 427, 3 May 1946.
4. GRIM(R.E.) 'Applied Clay Minerology'. McGraw-Hill Book Co. Inc. New York (1962), p.202.
5. McATEE(J.L) (Inorganic-organic Cation Exchange on Montmorillonite' Am.Mineralogist. v.44, 1959, p.1230.
6. GRIM(R.E.) 'Applied Clay Minerology'. 2nd Edition. McGraw-Hill Book Co.Inc., New York (1968).
7. STREET (G.B.) and WHITE(D.), 'Adsorption of Phenol by Organo-clay Derivatives'. J.App.Chem., v.13 May, 1963 pp.203-206.
8. McATEE(J.L) 'Random Interstratification in Organo-Bentonite'. Clays and Clay Min.Proc. of the 5th Nat.Conf.(Nat.Acad.Sci-Nat. Res.Council. Pub.566) 1958, pp. 308-317.
9. JORDAN (J.W.) 'Alteration of the Properties of Bentonite by Reaction with Amine'. Mineralog.Mag., v.28, 1949, pp.598-605
10. McATEE(J.L) and CONCILIO(C.B) 'Effect of Heat on Organo-montmorillonite Complex'. Am.Min., v.44, 1959, p.1219.
11. BRADLEY(W.F.) 'Molecular Association between Montmorillonites and some Polyfunctional Organic Liquids'. J.Am.Chem.Soc., v.67, 1945, pp. 975-981.
12. MacEWAN(D.M.C.) 'Identification of the Montmorillonite Group of Materials by X-rays'. Nature, v.154, pp.577-588.
13. HENDRICKS(S.B.) 'Base Exchange of Clay Mineral Montmorillonite for Organic Cations.' J.Phys.Chem. v.45 1941 pp.65-81.
14. GRIM(R.E.), ALLAWAY(W.H.) and CUTHBERT(F.L.) 'Reaction of Different Clay Minerals with some Organic Cations' J.Am.Cer.Soc., v.30, May, 1947, pp.137-145.

15. JORDAN(J.W), HOOK(B.J) and FINLAYSON(C.M.)
'Organophyllic Bentonites, II Organic Liquid Gels'.
J.Phys. and Coll.Chem., v.54, 1950, pp. 1196-1208.
16. ROBERTSON(R.H.S) and WARD(R.M.) 'Assay of Pharmaceutical Clays'
J.Pharm.Pharmacol., v.3, 1951, pp.27-35.
17. JORDAN(J.W.) 'Organophyllic Bentonites, I Swelling in Organic Liquids'. J.Phys.Coll.Chem., v.53, 1949, pp.294-306.
18. GRANQUIST(W.T) and McATEE(J.L) 'Gelation of Hydrocarbons by Montmorillonite-organic Complexes; Role of the Dispersant'.
J.Coll.Sci., v.18, June, 1963, pp. 409-420.
19. ABBEY CHEMICALS LIMITED 'Bentone Gelants'
20. KOMAROV (L.E.) et al, 'Synthetic, Non-Aqueous Moulding Sands'
Russian Castings Production v.5, May, 1966, pp.193-195.
21. JOHNSON(O.E) 'The Use of Oil-Bentone Sand for Higher Quality Finish in Brass and Bronze Castings'. Modern Castings, v.34, Aug., 1958, pp.415-417.
22. MEGAW(R.G.) and MIERICKE(K.A.) 'Oil Bonded Moulding Sand'.
Trans.Amer.Found.Soc., v.65, 1957, pp. 513-516.
23. BAROID CHEMICALS, INC. 'Petro Bond'
24. 'Oil Bonded Green Moulding Sand'. Modern Castings, Dec.1962, pp.72-74.
25. 'Copper-base Alloys Foundry Practice'. 3rd Edition. Published by Amer.Found.Soc. 1965.
26. STERBACEK(Z.) and TAUSK(P.) 'Mixing in the Chemical Industry'. Pergamon 1965.
27. MORGAN(A.D.) 'Bonding of Sand Grains in Common Moulding Processes'. B.C.I.R.A. Journal, v.22, Sept.1974, pp.480-486.
28. HILL(P.A.E.) 'Investigation into the Use of Polystyrene as a Possible Substitute for Coal Dust in Clay-Bonded Moulding Sands'. B.C.I.R.A. Journal. v.20, Sept. 1972, pp.437-443.
29. HILL(P.A.E.) 'Investigation into the Prevention of Carbon Scale Defect in Castings Produced with a Polyurethane-Bonded Cores'. B.C.I.R.A. Journal. v.21, Sept. 1973, pp.320-326.

