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Foundry Sand. (pgs. 1-18)
June 1976. (No Plans)

LARRETT, M.J.W. and (Dr) W.G. SPENCER. 1976

Service report 1/16/15/0
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18 June 1976

The Director
S.A. Department of Mines
P.O. Box 151
EASTWOOD SA 5063

PROGRESS REPORT NO. 1

SUBJECT: Foundry Sand.

Investigation and Report by: Dr Graham L.F. Powell.

Officer in Charge, Materials Technology Section: Dr Graham L.F. Powell.

[signature]

for F. R. Hartley
Director

## 1. INTRODUCTION

In a letter dated 15 October 1974 (your ref. DM 1055/72 RLW:JS) Amdel was requested to commence a project entitled 'Foundry Sands in South Australia'. The first part of the project was to be '(i) a literature survey to determine the latest advances in sand technology'. While this progress report (No. 1) does not set out to be an exhaustive literature survey, it is considered that it achieves the following objectives:

1. It summarises the various binder systems for moulding sands and
2. It attempts to anticipate future moulding sands trends. For the latter, reference has been made particularly to :

IRVING, R., (1976). A comparative view of synthetic bonding materials Part 1 Inorganic Binders. Castings 39-41.

JOHNSON, W.A., (1976). A comparative view of synthetic bonding materials Part 2 Organic Binders. Castings 41-43.

PALMER, S.W., (1974). Future technology in the foundry industry. Proceedings of Australian Foundry Institute National Seminar, Adelaide.

ROBERTS, W.R., (1974). Moulding materials - current developments and trends. Proceedings of Australian Foundry Institute National Seminar, Adelaide.

## 2. MOULDS FOR CASTINGS

The major production of castings is in sand moulds. In most instances, more sand than metal is required to produce a casting. Consequently, the amount of sand which must be handled in a sand-casting foundry is large. Therefore a great deal of attention should be given to the details and operations of preparing, controlling, handling and properly using the sand. A foundry sand is a composite material consisting of a discontinuous refractory component, usually silica, bonded together with a continuous matrix constituent of which a mixture of clay and water is the most common. However, replacements for the clay-water binder are resin and sodium silicate.

In addition to the use of sand-binder mix to form the mould, cores are commonly produced from sand-binder mixes. A core usually functions to form an internal cavity surrounded by metal and as such must disintegrate following initial solidification to minimise stresses on the casting and to make its removal from the casting easy during subsequent shaking out. Because of its differing function, the properties of a sand-binder mix for cores are different to those required for moulds.

# 2. CLAY BONDED MOULDING SANDS

## 2.1 General Properties

Since the sand mould is the 'tool' which forms the casting, a poor moulding sand usually produces poor castings and hence certain specific properties have been identified and testing procedures adapted for their quantitative description. The American Foundryman's Society (AFS) 'Foundry Sand Handbook' sets forth the standard conditions of testing the sand properties. Those properties of most obvious importance include the following :

1. Green strength. The green sand, after water has been mixed into it, must have adequate strength and toughness for making and handling of the mould. The sand must develop this strength during the moulding process when it is forced into the shape of the mould.

2. Dry strength. As a casting is poured, sand adjacent to the hot metal quickly loses its water as steam. The dry sand must have strength to resist erosion and also the metallostatic pressure of the molten metal or else the mould may enlarge.

3. Hot strength. After the moisture has evaporated, the sand may be required to possess strength at some elevated temperature, above 100$^{o}$C. Metallostatic pressure of the liquid metal bearing against the mould walls may cause mould enlargement, or if the metal is still flowing, erosion, cracks, or breakage may occur unless the sand possesses adequate hot strength.

4. Permeability. Heat from the casting causes a green-sand mould to evolve a great deal of steam and other gases. The mould must be permeable to permit the gases to pass off or else the casting will contain gas holes.

5. Thermal stability. Heat from the casting causes rapid expansion of the sand surface at the mould-metal interface. The mould surface may then crack, buckle, or flake off (scab) unless the moulding sand is relatively stable dimensionally under rapid heating.

6. Refractoriness. The absence of melting, softening, or adherence of the sand to the casting makes for better casting surface and easier cleaning of the casting. Higher pouring temperature, such as those for ferrous alloys at 1320$^{o}$C to 1760$^{o}$C, require greater refractoriness of the sand. Low-temperature metals, for example, aluminium, poured at 700$^{o}$C, do not require a high degree of refractoriness from the sand.

7. Flowability. The sand should pack well under jolting, squeezing, or slinging types of moulding, i.e., should flow under load. Moulds of nonuniform hardness and soft moulds obtained from sands of low flowability may result in enlargement of the casting or roughness of the casting surfaces, especially side walls.

8. Produce good casting finish. Finer sands generally produce a smoother casting surface, other factors being equivalent.

9. Collapsibility. Heated sand which becomes hard and rocklike is difficult to remove from the casting and may cause the contracting metal to tear or crack.

10. The sand should be reusable.

11. Ease of sand preparation and control.

The above items by no means include all the properties which might be desirable. Obviously, the most important characteristic of a moulding sand is that it facilitates the economic production of good castings. To that end, a multitude of moulding-sand mixtures and properties have been found useful in different foundries.

## 2.2 Components of Moulding Sands

Moulding sands are actually mixtures of three or more ingredients. A green sand always contains clay and water as well as the principal sand constituent, $SiO_2$. These three constituents provide the bulk and plasticity required of the moulding sand. A number of other materials may be present or may be added to the sand to enhance certain of the properties, but first consideration must be given to the three basic ingredients.

Sand.

Granular particles of sand, i.e. $SiO_2$ principally, comprise 50 to 95 percent of the total material in a moulding sand. In different moulding sands, these sand particles may differ in the following ways :

1. Average grain size, grain size distribution, and grain shape.
2. Chemical composition.
3. Refractoriness and thermal stability.

Generally the purest silica sand, 99.8+ per cent $SiO_2$, is considered the most refractory and thermally stable. The presence of excessive amounts of iron oxide, alkali oxides, and lime can cause objectionable lowering of the fusion point in some sands. Average fineness of the sand grains establishes the fineness of the moulding sand as a whole, while the grain size distribution affects many of the sand properties. The shape of sand grains may be rounded, angular, or subangular depending on their geologic history. Compounded grains are agglomerated particles of angular or subangular sands. In moulding sands as they are used in foundries, the sand grains are of mixed origin. Some come initially from new moulding sand, others as additions of new silica sand, still others as sand from disintegrated cores, and in some cases as used sand which has been reclaimed. Agglomerated grains of sand and clay may also be found because of the action of heat and moisture in the mould.

Clay.

Moulding sands may contain about 2 to 50 percent of clay. With a suitable water content, it is the principal source of the strength and plasticity of the moulding sand. Clay is thus the "bond" or "binder" of moulding sands. In some mineral deposits, clay and sand occur mixed in proper proportions so that the sand can be mined and used directly for moulding. It is then referred to as a "natural moulding sand". In other sands, clay bond must be added to develop the proper strength and plasticity. Several types of clay are used for this purpose. In general these clays are defined as essentially aggregates of extremely minute crystalline, usually flake-shaped particles that can be classified on the basis of their structure and composition into a few groups which are known as clay minerals. Some clays are composed of particles of a single clay mineral, whereas others are mixtures of clay minerals. Some clays are composed entirely of clay minerals whereas others contain admixtures of quartz, pyrite, organic matter,etc.

Clay minerals used as bonding additions to sands include the following types :

1. Western and southern (USA) bentonites (montmorillonites)
2. Australian bentonites
3. Fire clays (kaolinites)
4. Special clays (halloysite, illite)

Types 1 and 3 are the most commonly used.Australian bentonites are not favoured for foundry purposes. A clay coating of the sand grains confers many of the clay properties to the moulding-sand aggregate.

Water.

Water, present in amounts of about 1.5 to 8 percent, activates the clay in the sand, causing the aggregate to develop plasticity and strength. Water in moulding sands is often referred to as "tempering" water. The water is absorbed and held rigidly by the clay up to a limiting amount. Water in excess of that which can be adsorbed by the clay exists as free water. Only that water rigidly held (adsorbed) by the clay appears to be effective in developing strength. The rigid clay coatings of the sand grains may be forced together, causing a wedging action and thus developing strength. Free water, however, can act as a lubricant and makes the sand more plastic and more mouldable, though the strength may be lowered. Thus control of the water percentage in the sand(clay) is very important. Clean water, least variant in tendency to cause variation in base exchanges with the clay, is favoured.

Special Additives.

In addition to the three basic ingredients, other materials may be present in moulding sands. They are usually added to enhance some certain property or combination of properties and are often referred to as "additives".

## 2.3 Properties of Naturally Bonded Sands

Naturally bonded fine-grained sands are used in nonferrous foundries as well as in gray-iron foundries casting enamelware, hardware, sanitary ware, ornamental fittings, and gray-iron stove plate. It has been conceded that these "velvet feeling" sands give excellent finish.

The bond in naturally bonded sands is due to the thin pellicles, enveloping each of the siliceous grains. This condition is difficult to effect artifically. Most naturally bonded sands seem to possess these qualities.

Naturally bonded sands have ability to retain moisture for a longer period of time. The water-holding capacity is at a maximum in naturally bonded sands, as the bond is well distributed.

Each envelope of water and hydrated iron oxide (if present) tends to hold a skin or envelope of water, and the surface tension knits the sand in a firm yet elastic mass. Resilience is thus obtained, allowing the mould to bend upon use without cracking and yielding with the metal under expansion and contraction. Naturally bonded sands are less sensitive than either fireclay or bentonite-bonded sands.

The distinguishing feature of these sands is the ability to absorb and adsorb (on surface) water without really becoming wet.

The range of this property differs with various sands, yet the range is quite wide. The disadvantage is offset by the fact that moulds are more easily patched, tooled, and finished because of this characteristic.

Since they are of sedimentary deposition, it is difficult to maintain standards for naturally bonded sands when shipped at different periods from different sections of the pit. They are liable to variation in the field, and to differences in composition and grain size.

Some natural moulding sands are high in impurities such as organic matter, feldspar, unweathered mica and, if near lime deposits, will be contaminated with calcium carbonate. These impurities usually are ground into the silt content, which interlocks with the clay grain. However, most natural-sand producers blend sands and segregate the sand bed. Sands are now closely ordered by clay content and are more uniform.

Naturally bonded sand may be used without extensive mechanical preparation. This is not true of synthetic sands.

The clay content of the average naturally bonded sand has a fusion point of approximately 1320-1370$^{o}$C, and many have tested as low as 1220$^{o}$C. The clay is of a type that exerts low initial bond strength and dehydrates readily, losing its plasticity rapidly. Because of this behaviour, the natural sands must have from three to four times as much clay substance as the average synthetic sand. The silica portion also has a lower refractoriness than a high quality silica sand used in synthetic practice.

Because of their low durability, naturally bonded sands are difficult to reclaim. Much new sand must be added to bring back strength, and yet the calcined portion remains in the heap as fines. As the heap closes, more new sand is added to "open" it, which is expensive. Natural sand with low pan material rebonds better without balling than that of high pan material.

## 2.4 Properties of Synthetic Moulding Sands

The most important advantage of synthetic sands is that of economy. Uniformity of grain size and grain distribution are easily controlled.

Because of the higher permeability and venting value of synthetic sands, moulds may be rammed harder, thus eliminating swells, cuts, washes, and other defects associated with soft ramming. Castings are held within closer tolerances, and pattern dimensions are maintained.

Higher refractoriness of synthetic sands results in cleaner castings, but the sands are more friable and brittle than naturally bonded sands, making patching and repairing of the mould more difficult. Moulds left standing are more easily damaged.

The average natural moulding sand requires from 100 to 220 percent more temper water than synthetic sands bonded with strong clay bonds. It has been pointed out that synthetic sands dry out faster than naturally bonded sands because the sharp silica grains are more permeable. It is not a case of synthetic sands drying out faster than naturally bonded sands, but rather a case of each losing the same amount of moisture in the same period of time.

While the naturally bonded sand contains from six to eight percent working moisture, many synthetic sands contain only three percent. Therefore, if one percent is subtracted from each of the two sands it can be readily seen that the effect is greater on the synthetic sands than on the naturally bonded sands.

The moisture range of synthetic sand is quite narrow, but this may be given as an advantage as well as a disadvnatage. Since sands turn over so rapidly in the foundry, synthetic sands maintain their moisture for the required period of time. Low moisture means less oxidizing atmosphere in the mould cavity during casting.

Synthetic sands can be easily varied by blending various grades, and lend themselves to a variety of physical changes. By employing one coarse and one fine silica sand, less storage space is required. Desired physical properties are easily obtained. Castings clean easier because the silt, fine sand, and superfine material is controlled.

Synthetic sands are more durable because little new bond is required to rejuvenate the system and a closer control is possible, resulting in a decrease in scrap losses.

## 2.5 Moulding of Clay Bonded Sands

Hand ramming is the oldest and slowest method of making a mould. It is usually necessary for loose-pattern moulding, and it is used also on mounted patterns when sample castings are being produced.

### 2.5.1 Squeeze Moulding Machines

Squeeze moulding machines utilise pressure as a means of packing the mould. Pressure, applied pneumatically or manually through a squeeze head or plate pushes the sand against the pattern. The squeeze is limited to light work which can be made in shallow flasks, preferably 2 to 4 in depth.

### 2.5.2 Jolt-type Moulding Machines

These operate with the pattern mounted on a pattern plate, which in turn is fastened to the machine table. The table is fastened to the top of the operating air piston. A flask is placed on the table or on the pattern plate, and is located by pins so that the pattern is centered in the flask cavity. The flask is filled with sand, and the jolt valve to the air supply is opened. This allows compressed air to about 90 psi to enter under the piston and lift it a few inches, at which point a port is uncovered and all of the air is released. The piston, together with the table, pattern, sand and flask, falls by gravity until the bottom of the piston strikes on the bottom of its cylinder with a sharp jolt. Air re-enters and the action repeats, at several times a second, until the air supply is turned off. The number of jolts can be preset to suit the pattern, sand, and mould hardness required. Because the sand is compacted only by its own weight, it is harder near the pattern plate, and a tall pattern thus can have appreciable decreases in mould hardness vertically.

When ramming is complete, push-off pins, bearing against the bottom edges of the flask and operated by a separate air cylinder, lift or strip the flask and contained sand off the pattern. Various mechanisms are used to accomplish stripping and then also to rotate the flask $180^{\circ}$ so that the mould cavity will be upward.

Ramming of the sand on the pattern by jolting eliminates much of the manual ramming labor. It also increases production rate and provides more uniformly rammed moulds.

Jolt-type moulding machines are made in several sizes. On intermediate-size work, one man operates the machine for making drag moulds and another the machine for making cope moulds. On larger jobs, two men operate each machine. Machines of this type are available for ramming moulds in flasks up to approximately 20 by 28 by 12 in.

### 2.5.3 Jolt-squeeze Moulding Machines

Jolt-squeeze moulding machines use the same pattern equipment as jolt machines, but after the jolting operation, the sand is squeezed by air pressure, producing a more uniform and harder rammed mould. Such equipment takes flasks up to approximately 30 by 40 by 15 in., and is widely used because of its simplicity and low capital cost.

A high-pressure jolt-squeeze machine uses a hydraulic system for the squeeze operation. The compensating head equalizes the pressure applied to each floating peen block as the sand-filled flask is hydraulically raised against the peen blocks. This develops a uniformly dense packing of moulding sand against the entire surface of the pattern. The mould may or may not be jolted, depending on requirements. The machine is capable of producing moulds of maximum hardness, rammed uniformly throughout the flask at production rates up to 300 moulds per hour. A high-pressure moulding machine can be automated when high-production rates are required. Because of the high pressures used (up to 300 psi), pattern equipment must be more accurately designed and constructed, and flasks must be made stiff enough to withstand the pressures exerted against the sidewalls. The flask must not distort or spring during the squeeze operation; this would affect the casting dimensions and accuracy of the flask alignment on the pattern plate.

## 2.6 High Density Moulding

With the objectives of producing higher quality castings at faster production rates, the application of high density green sand moulding has become widespread and is becoming the accepted method of producing repetition ferrous castings in the small and medium size range.

### 2.6.1 General Factors

High density green sand moulds are normally produced either by a squeeze action or by a combined jolt and squeeze action. To put the process into perspective, it should be remembered that with a conventional jolt squeeze moulding machine, the squeeze pressure exerted on the mould is rarely in excess of 30 $lb/in^2$ of mould area, whereas in high density moulding the squeeze pressure normally used ranges between 100-250 $lbs/in^2$ of mould area.

The way in which the clay bonded moulding sand reacts to the application of squeeze pressure has greatly influenced, and has in certain cases retarded, the development of the high density moulding process. Several workers have shown that the behaviour of a clay bonded moulding sand is intermediate between than of a liquid and a solid, since when vertical pressure is applied to a clay bonded moulding sand aggregate only a proportion of the applied pressure is transmitted in a horizontal direction.

This characteristic introduces problems when moulds are compacted by squeezing. For example, when a simple pattern and a flat squeeze head are used to produce a mould, it is found that the sand between the squeeze head and that part of the pattern closest to the squeeze head is readily compacted to a high density, but that the sand adjacent to the pattern plate is compacted to a lesser degree, and a non-uniform and inadequately compacted mould results. The reason for this is that squeezing of a flat squeeze head produces a uniform reduction in the height of the moulding sand in the moulding box, and so the greatest reduction in height and therefore the greatest compaction occurs on that part of the pattern adjacent to the squeeze head. Increasing the squeeze pressure will not cause the sand to flow freely in the mould, and so the movement of the squeeze head is limited by the high density sand column that forms between the squeeze head and that part of the pattern adjacent to the squeeze head.

American workers have used squeeze pressure as high as 40,000 $lb/in^2$ in an attempt to destroy these high density sand columns and produce uniformly compacted moulds. However, such high pressures did not produce uniform compaction but only resulted in the fragmentation of the sand grains in the high density column.

One answer to this problem is to use a shaped squeeze head. The purpose of the head is to produce a uniform reduction in the height of the sand above each section of the pattern, thereby preventing the formation of the high density columns. This type of squeeze head can be very successful, but suffers from the considerable disadvantage that generally a different squeeze head is required for each pattern, and it is thus only really applicable when relatively long runs are required.

High pressure moulding machines can be either pneumatically or hydraulically powered and if a shallow pattern is being used, such that there are only small variations in sand depth in the moulding box, uniformly compacted moulds can be obtained using a flat squeeze head and a squeeze pressure of 100-200 $lbs/in^2$ of mould area. On the other hand, if the geometry of the pattern is such that high density columns build up between the pattern and the flat squeeze head, it is necessary to use some form of shaped squeeze head if uniformly compacted moulds are to be produced. This can be either a shaped squeeze head as already described, or a self-contouring squeeze head which will automatically adjust itself to pattern contours. Such squeeze heads are available on machines produced by a number of manufacturers.

With certain applications, particularly those in which deep moulding boxes are used, a jolt as well as a squeeze action is required to produce acceptable moulds. This jolt action can be either a pre-jolt or may be simultaneously applied with the squeeze action.

# 3. CHEMICALLY BONDED MOULDING

## 3.1 Shell Moulding

Shell moulding as a moulding process for making sand castings was invented by Croning of Germany during World War II.

The sand used for shell moulding consists of a mixture of the following ingredients :

1. Dry-sand grains, AFS fineness 90 to 140, distributed over 4 to 5 screens.

2. Synthetic-resin binder, 3 to 10 percent by weight. Resins which may be used are the phenoformaldhydes, urea formaldehydes, alkyds, and polyesters. The resin must be a thermosetting plastic since the strength developed by the mould depends entirely on the strength of the plastic binder after the mould has been heated.

The shell is cured in two stages. When the sand mixture drops onto a pattern heated to about 170 to 370$^{o}$C, the plastic partially thermosets and builds up a coherent sand shell next to the pattern. The thickness of this shell is related to pattern temperature, dwell time on the pattern, and the sand mixture. The shell, still on the pattern, can then be cured by heating it to 290 to 345$^{o}$C for 1 to 3 min. Stripping the shell from the mould presents a problem since the shell is very strong and grips the mould tightly. A mould release agent or parting agent is necessary so that the ejector pins can push the shell off the patterns. Silicone parting solutions sprayed on the pattern have been found satisfactory . The shell halves may then be assembled and poured.

### 3.1.1 Sand Characteristics

Sands suitable for the shell process vary over a comparatively narrow range of purity, grain size, grain structure and grain distribution. In addition, chemical analysis, sintering point, thermal expansion and retained moisture vitally affect their performance. All of these properties are determined by the geological history of the deposit and subsequent preparation by the sand producer. Generally speaking, shell sands are much finer than those used in conventional foundry practice, but in recent years, due to improved resin systems and buffers, coarser sands are now being utilized. Sand producers have improved their methods for classifying sands so that shell sands of utmost uniformity are readily available.

Common shell process foundry problems which can and do arise from improper selection and handling of bulk sand may be defined as :

1. Generally rough as-cast surface finish due to poor packing characteristics of segregated natural sands.

2. Rough as-cast surface finish in deep pockets due to low sintering point of a sand.

3. Veining and run outs due to poor thermal shock resistance of the moulds and cores.

4. Dimensional variance on castings due to excessive thermal expansion of a sand.

5. Excessive resin binder consumption due to sand grain surface contaminants.

3.1.1.1 Grain Shape Effect

For foundry purposes, sand grain shape is referred to as rounded, subangular or angular.

Greatest permeability is conferred by rounded grain sands, because they have minimum contact area between grains when bonded with a fully cured synthetic resin. They also require the least amount of resin binder for high cold strength, but do not produce high hot strengths in moulds or cores.

Sharply angular sands confer the least permeability when bonded with a fully cured synthetic resin, and, generally speaking, result in the lowest cold strength moulds and cores but considerably higher hot strengths without a proportionate increase in resin binder.

On the other hand, subangular sand grains exhibit the best compromise between low resin binder content, medium cold strength and high hot strength, all these properties being relative. Shell moulds and cores made with subangular sands show the least tendency to washing and metal penetration, but sand grain shape is not the sole factor in correcting these faults in the foundry. The mineralogical composition of a sand will determine the presence or absence of cleavage planes within the individual grains.

Sand grains which contain cleavage planes break down readily under heat shock and mechanical handling. Also, these sands generally require more binders.

Minerals such as calcium and magnesium may be present as weak, brittle silicates instead of the more desirable carbonates. Pure quartz or silica is tough and not easily fractured by thermal shock which occurs when the sand grains are subjected to violent changes of temperature.

A simple method for comparing thermal shock resistance of graded silica shell sands is to carry out the standard check test on grain distribution over selected screens, make a simple hollow drained pin core, one in. diameter outside, 1/8 in. wall thick and 6 in. long. The pin core is supported horizontally over a shallow vessel of cold water. The pin core is then disintegrated by firing an oxyacetylene torch up the hollow center of the core so that the white hot sand grains fall in a shower to be quenched in the cold water. The sand grains and residue are filtered out of the water, air dried and the standard screen analysis repeated. Any marked increase in the percentage of fines is an indication of the number of grain fractures at the planes of cleavage.

If a silica sand is being considered for use in a shell sand reclamation system, the comparative thermal shock resistance check test should be repeated the same number of times as is proposed, to cycle the sand through the reclamation system before discarding it.

3.1.1.2. Grain Size Effect

Sand grain size has a direct bearing on the refractory property of a sand mass. In general, the finer the grains the less refractory the mass, but in the case of shell moulds and cores the carbonaceous residue of burned out synthetic resin binder improves the refractory property of the mass so that much finer silica sands can be used without reaching the point of insipient fusion. In the case of zircon sands, grain fineness need not be considered in relation to insipient fusion due to ~~his~~ its higher sintering temperature.

Sand grain size also has a direct bearing on the amount of high cost resin binder necessary to maintain required cold and hot strength properties in shell moulds and cores. Surface area of the individual grains increase rapidly with a decrease in fineness. Not only does the grain surface area vary inversely as the cube of the diameter. In practice this means that in a given volume vary inversely as the cube of the diameter. In practice this means that in a given volume of sand there would be eight times as many 270 mesh grains as 140 mesh grains. For resin binder, this means an increase from 3.5 percent by weight of sand for 140 mesh to 12 percent for 180 mesh sand.

The fixed relationship between sand grain shape, size, surface area, number of grains in a given volume and resin binder content have been developed and proved in practice by both large and small foundries.

3.1.2 Advantages

Based on experience, there appear to be several advantages in shell moulding over conventional moulding methods :

1. Tolerances can be held closer than conventional methods but not as close as the small investment castings. In some cases, dimensions have been held to 0.002 in. per in. In other cases, it has been difficult to hold any closer than 0.007 to 0.010 in. per in. The degree of precision appears to depend on the shape, contours of the mould, and the type of metal being poured.

2. Less draft is required than for sand moulding. In many cases, parts of the pattern will draw with no draft at all.

3. Castings can be poured with thinner wall sections and with metal at lower temperatures than would be possible in green sand. This appears to be due to the fact that the shell moulds cool the metal more slowly because of the insulating effect of the shell. Also, the higher permeability of the shell promotes free venting of gases.

4. Small cored holes, intricate pockets and sharp contours which would be impractical in other methods are frequently possible in shell moulding. Holes 1/4 in. in diameter and ½ in. deep have been quite accurately cast.

5. Much smoother surfaces can be obtained, because it is possible to use a very fine sand. A marked improvement is noticeable with the higher melting temperature metals.

3.1.3 Costs

Shell castings as a rule are more expensive per pound than their counterpart in green sand. Therefore, to justify making a casting in this manner the end-product cost should be used as the basis for evaluation. Reduction of casting weights, minimizing or eliminating machining operations, elimination of cores or special time-consuming moulding operations by reason of being able to draw more intricate and difficult designs are the main advantages of shell moulding. Cleaning and grinding operations are about on a par with those done on green-sand castings. Yield is not increased to any great extent since the method of feeding a shrinking head of metal is not changed.

3.1.3.1 Pattern

Here perhaps is the most important factor in the switch to shell moulding. Pattern costs are several times greater than for the ordinary matchplate. Patterns must be made of a heat-resistant material; machined to extreme accuracy; and have additional components such as ejectors, springs and sand strips.

For a production shell pattern some foundrymen prefer a chrome-nickel cast-iron alloy, although meehanite, ductile iron and steel are used extensively. Brass and aluminium patterns can be used for short-run jobs or experimental work but are not recommended for long-run, high production castings.

The cost of these patterns can be reduced somewhat by adhering closely to those dimensions only which are critical and allowing more tolerance on the others.

On multiple-cavity patterns, one cavity should be finished and from it castings made and checked for accuracy before completing the entire pattern, since any attempt at close tolerances with the standard shrink rule is purely an estimate which can prove to be costly.

From the customers viewpoint, a standardization of basic pattern designs and sizes should be adopted so that patterns can be moved from one shell foundry to another, for reasons of cost, quality, or shut downs, without adding modification expenses to already high initial pattern cost.

3.1.3.2 Materials

Resin, sand and additives (when used) represent a considerable portion of the shell-casting cost. The phenol formaldehyde resins are expensive and so long as the raw materials which go into their manufacture remain at the present price level there appears to be little hope for any major change. A great deal of experimentation is being carried out in an attempt to find a less costly material which will do the job. This, together with attempts to reduce the percentage of resin used, appears to be the main hope for a cost reduction.

There are many sands available which will work equally well in producing shell castings and their cost varies depending on the quality demanded and the location of the sand source in relation to the foundry. Even when the sand is reclaimed it is still a greater cost factor per casting than that involved in green-sand moulding.

3.1.3.3 Equipment

Initially there were practically no adequate moulding machines available for constant high production of shell moulds and foundrymen became machine builders out of necessity. As a result of these efforts, and those of recognized equipment manufacturers, there are several automatic machines on the market doing an excellent job. This equipment, however, is expensive and represents a considerable investment for the foundry owner. It should be purchased only after a great deal of consideration of a particular operation.

Several shell-core machines are commercially available and the same evaluation of suitability should be used as with moulding equipment. Mixers for blending the resin and sand are for the most part standard foundry devices and are available from the regular suppliers. Pouring units are still being constructed by the individual foundry to suit individual needs and methods, although there are several being manufactured.

## 3.2 Cold Setting Chemically Bonded Moulding Sands

### 3.2.1 Cold Setting Resin Binders

The most important and successful of these are based on furfuryl resins which are acid catalyzed and harden without need of stoving or baking. Sands bonded with furfuryl resins have excellent flowability which enables moulds to be compacted with little effort. By adjustment of the amount of catalyst, the hardening rate, i.e. setting off time, is controlled as required, thus making the process suitable for any size of mould. The important advantages of "no-bake" furfuryl resin binder systems include high strength moulding material with good breakdown properties, and dimensionally accurate sound castings obtained from relatively unskilled labour. In view of the relatively high cost of the furane sand mixture, techniques are being applied to reduce the size of mould compact to a minimum.

### 3.2.1 Sodium Silicate Binders

Sand bonded with sodium silicate, cold hardened by $CO_2$ gas have also progressively replaced clay bonded sands for semi-repetition and jobbing work, the versatility of this process enabling it to be used for small or large castings production. Compared with green sand, it gives stronger and more rigid moulds and better dimensional accuracy, particularly on larger castings. It is suitable for relatively high rates of production in mechanized systems. Sodium silicate binders are also used in the castable or fluid sand process which has evidently been developed extensively in Russia for the production of steel works ingot moulds, bottom plates and slag ladle castings.For this process it is claimed that mechanized production can be readily applied, that labour requirements are low and that capital costs need only cover simple mixing plant and sand reclamation. Because of the difficulty of reclaiming from the sodium silicate binder the clean silica sand necessary for this process, it has not been adopted very widely elsewhere.

In recent years, cold self-setting silicate binders have become available for medium and large sized mould production using organic esters such as glycerol di-acetate as hardeners. This process provides a less costly alternative to self-setting resin bonded sands, being suitable also for use with low grade sands.

Accompanying the increased use of these binder systems was the need to get the mixed sand into the moulding or corebox in the shortest possible time. This resulted in the development of continuous mixers. These are now an accepted part of the foundry scene and units are available with outputs of mixed sand in excess of 50 tons per hour.

In a unit of this type, mixing is normally carried out in a single horizontal trough, sand, binder and catalyst being charged at one end, mixed sand being discharged at the other end of the trough. On certain machines this trough can be articulated. Difficulties arise when mixers of this type are being used with rapid setting resin or sodium silicate binder systems since there is the possibility of sand hardening in the mixer. This has resulted in the introduction of "high speed" mixers typical of which are those with two separate primary troughs, sand and binder being mixed in one, sand and catalyst in the other. The outputs of the primary troughs are discharged into a vertical mixer prior to the sands being discharged into a moulding box or corebox. Several manufacturers produce machines of this type, some of which deliver sand continuously, others delivering sand on a batch basis. With machines of this type, stripping times as low as 2 minutes can be obtained with resin bonded sands, and as low as 4 minutes with sodium silicate bonded sands. The output of machines available at present range up to 15 tons per hour.

Conventional continuous mixers and resin or sodium silicate binders have combined to largely replace dry sand moulding in jobbing foundries. The introduction of the new "high speed"mixers not only enables this work to be produced at higher production rates, but also, probably for the first time, makes it possible for resin or sodium silicate bonded sands to compete with green sand moulding for the production of small/medium castings.

A comparison of chemically bonded sands with current Australian costs is given in Appendix 1.

## 4. CONCLUSIONS

It is not the intention of this progress report to anticipate or prempt the analysis of a survey presently in preparation. However, it seems appropriate to highlight certain features of current and future foundry sand practice.

1. Although zircon, olivine and chromite are being used increasingly for steel founding, silica remains and is expected to remain the moulding material for repetition foundries.

2. Clay is expected to remain the principal binding agent for moulding sands with a swing to high density moulding.

3. Chemically bonded (as distinct from clay) moulds are expected to become more widely used in iron and steel foundries since the major metallurgical problems have been overcome.

4. The cleanness of the silica is far more important for chemically bonded sands as small amounts of clay moulding increase the amount of chemical binder and hence the cost.

5. The choice of a particular chemical binder may depend on such divergent factors as environmental hazard to escalating cost in the case of oil derivatives.

Appendix 1

## COMPARISON OF CHEMICALLY BONDED MOULDING SANDS

| Cost $ Per Tonne Bonded Sand | Furan 22-25.70 | Alkyd 19-25.30 | Ester Silicate 11.70-14.80 | $CO_2$ Silicat 7.75-9.00 |
|---|---|---|---|---|
| Environment | Questionable | Objectionable | No Problem | No Problem |
| SENSITIVITY TO SAND VARIABLES | | | | |
| Moisture | V. sensitive | Low | Sensitive | Sensitive |
| Clay | V. sensitive | Low | Sensitive | Low |
| Alkalinity | V. sensitive | Nil | Sensitive | Low |
| Temperature | Medium | Low | Sensitive | Low |
| Max. Prod. Rate Moulds/Pattern/Shift | 100 | 30 | 100 | 400 |
| Cured Strength | High | High | High | Medium |
| Metal Mould Reaction | Low | Medium | V. low | V. low |
| Hot Strength | High | Low | Medium | Medium |
| Shake out Strength | Low | Medium | High** | High** |
| (Reclaimability) Re-use Rate | 90 | 80-90 | 40-50** | 40-50** |

** Can be improved.

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6.8.76

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In reply quote:

1/1/167

5 August 1976

The Director,
S.A. Department of Mines,
P.O. Box 151,
EASTWOOD. 5063

A62/76

~~PROGRESS~~ SERVICE REPORT ~~3/1976~~ 1/16/15/0

| | |
|---|---|
| YOUR REFERENCE: | Application dated 29 June 1976 |
| SUBJECT: | Foundry sands |
| MATERIAL: | A223/76 |
| DATE RECEIVED: | 30 June 1976 |
| INFORMATION REQUIRED: | Size Analysis, Chemical Analysis, Microscopy |

Investigation and Report by: M. J. W. Larrett and Dr. W. G. Spencer

Officer in Charge, Materials Technology Section: Dr. Graham L. F. Powell

for F. R. Hartley
Director

DJL

amdel

## 1 INTRODUCTION

A sample of sand, applicant's mark FS15, Mines Department sample No. A223/76, from Hundred of Barossa, Section 3070, was submitted for size grading, chemical analysis and microscopic examination.

## 2 PROCEDURES AND RESULTS

A riffled portion of sand was analysed chemically with results shown in Table 1.

Results of the microscopical examination are shown in Table 2. Sizing data are shown in Table 3 and Graph No. 1 and were obtained following AFS procedures.

## 3 DISCUSSION

The sand is a high grade silica sand with 0.57% clay. Its iron content is too high for glass-making for which less than 0.03 or 0.05% $Fe_2O_3$ is required. For foundry use it is a three-screen sand of A.F.S. No. 63 moderately well-sorted and subangular, containing some organic matter and clay.

TABLE 1 : CHEMICAL ANALYSIS OF A223/76

| Element | % |
|---|---|
| $SiO_2$ | 98.46 |
| $TiO_2$ | 0.21 |
| $Al_2O_3$ | 0.44 |
| $Fe_2O_3$ | 0.12 |
| FeO | 0.05 |
| MnO | <0.01 |
| MgO | 0.05 |
| CaO | 0.04 |
| $Na_2O$ | 0.03 |
| $K_2O$ | 0.06 |
| $P_2O_5$ | <0.05 |
| $H_2O+$ | 0.22 |
| $H_2O^-$ | 0.05 |
| $CO_2$ | 0.05 |
| Organic carbon | 0.05 |
| Total | 99.77 |

TABLE 2 : MICROSCOPY

| Sample | Colour | Shape | Constituent Minerals etc. | Est. % H.F. | H.M. Pres |
|---|---|---|---|---|---|
| A223/76 | Fawn | Subangular | Moderately well sorted unconsolidated quartz sand with slight to moderate iron-staining. Some grains, ∿10% sugary and more heavily iron-stained. Minor organic matter (mostly root fibres) present. Non calcareous. | Nil | Nil |

# FOUNDRY SAND

## TABLE 3 : SCREEN SIZE ANALYSIS

SAMPLE IDENTIFICATION: Amdel No.: –

Mines Dept. No.: A223/76

Series No.: FS15

SIZE OF SAMPLE: 61.51gm

AFS CLAY (AVERAGE): 0.57% (Class B)

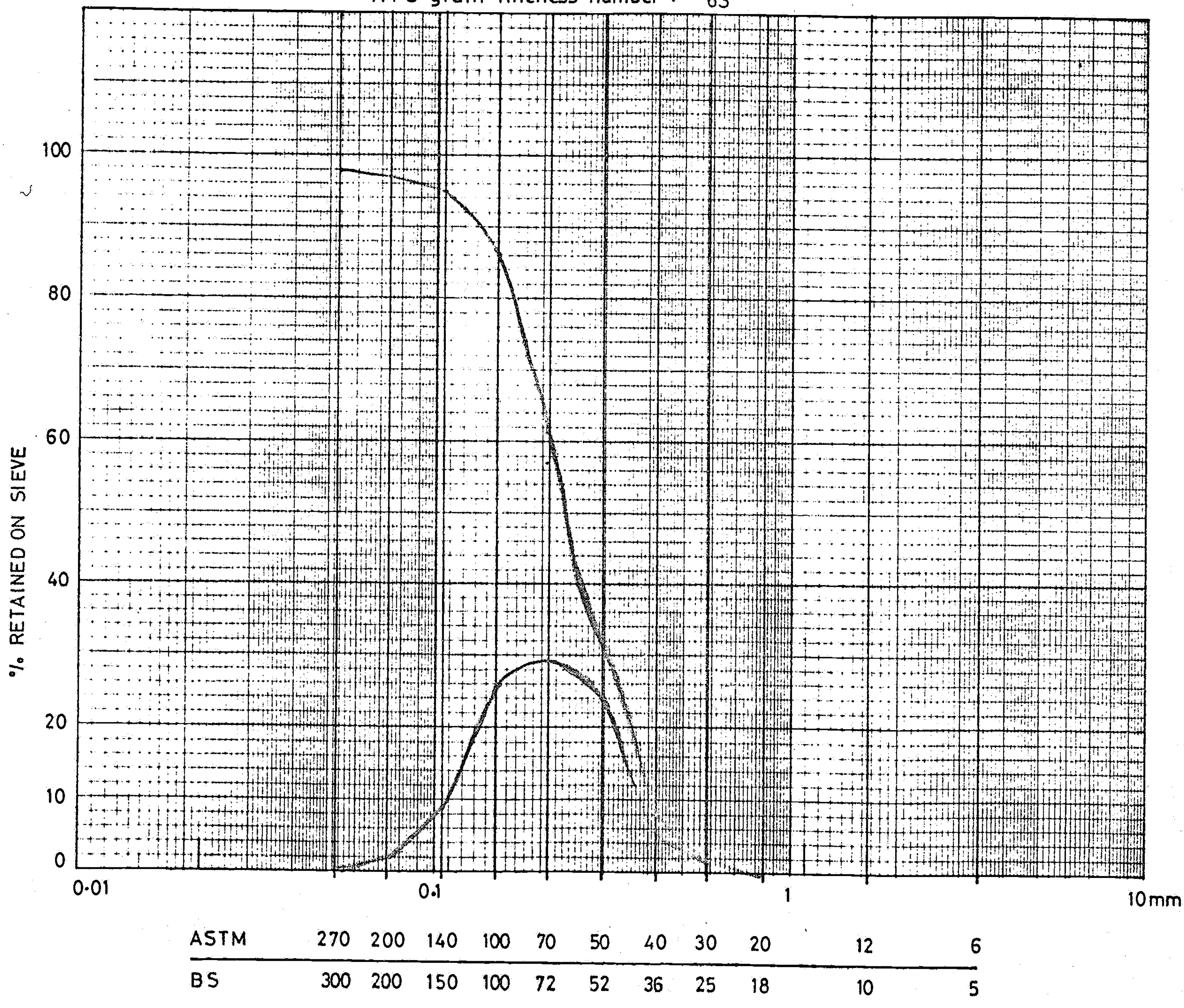
AFS GRAIN FINENESS NO: 63 (Class 5)

| U.S. SERIES NO. (ASTM) | EQUIVALENT MESH BSS | WEIGHT RETAINED | % RETAINED | % CUMULATIVE |
|---|---|---|---|---|
| 6 | 5 | – | – | |
| 12 | 10 | – | – | |
| 20 | 18 | 0.10 | 0.2 | 0.2 |
| 30 | 25 | 0.82 | 1.3 | 1.5 |
| 40 | 36 | 3.42 | 5.6 | 7.1 |
| 50 | 52 | 15.21 | 24.7 | 31.8 |
| 70 | 72 | 17.76 | 28.9 | 60.7 |
| 100 | 100 | 15.60 | 25.4 | 86.1 |
| 140 | 150 | 5.42 | 8.8 | 94.9 |
| 200 | 200 | 1.40 | 2.3 | 97.2 |
| 270 | 300 | 0.51 | 0.8 | 98.0 |
| | -300 | 0.92 | 1.5 | 99.5 |

Total % sand grade 99.5

GRAPH Nº:
FOUNDRY SAND

Sample FS15 : A223/76
AFS clay : 0.57
AFS grain fineness number : 63

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D.M.—C 33

DEPARTMENT OF MINES—SOUTH AUSTRALIA

# APPLICATION FOR EXAMINATION OF SPECIMENS OR SAMPLES

| Applicant's Mark | Dept. Sample No. | Location: Hundred | Location: Sects. | Location: * Other Locality Information | Information Required |
|---|---|---|---|---|---|
| F15. | A223/76 | Barossa | 3070 | | Foundry Sand Project<br>1. Size grading, AFS no, AFS clay<br>2. Chem analysis<br>3. Microscopic examination<br><br>This sample was collected by the Dept of Environment and is representative of a deposit for which consent to work has been applied for. |

* Locality information includes distance, direction and name of nearest town or well known point; claim or lease number (if any); pastoral lease (if out of hundreds)—photo and run number or military sheet reference.

Disposal of Specimens Return to Sender.

**Method of Collection**—Selected Specimens or Representative Sample—taken from surface, open working, prospecting shaft, underground working, bore hole, etc. surface

**Estimated Size of Deposit** ——

**Costs Chargeable to:—**

**Department/~~Client~~**

**Name of Applicant** [signature]

**Address**— Head Office

Please forward to—
The Director,
Department of Mines,
Box 38, Rundle Street P.O.,
Adelaide, S.A. 5000.

Signed [signature]

Date 29.6.1976

OFFICE USE ONLY

Submitted to the Australian Mineral Development Laboratories for—
Analysis,
Petrological Laboratory Examination, as above.
Other.

Charge against Mines Department Project No. 1/1/167

Approved for submissions to A.M.D.L.

*Director of Mines*

Copy 1—A.M.D.L. Copy (via head office).
Copy 2—Mines Department, Rundle Street, (T.I. Section).
Copy 3—Originator (Mines Department only).
Copy 4—Thebarton

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