THE CLAY BONDED PROCESSES

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The first paper on ‘sand properties’ and the ‘hot curing’ processes was published in the April 1993 issue of “The Foundryman”.

This second paper deals with the subject of the “clay bonded” processes, which are ‘dry sand’ and ‘green sand’ and has been written to provide the basic data on the processes and properties but does not claim to be completely comprehensive.

GREEN SAND

1. Base Sand Selection:

This topic is more important than the technical staff of foundries often realise, and is essential to ensure that the basics are correct, otherwise leading to casting problems.

The selection of a sand to be used in a green sand is dependent upon such factors as casting design, metal to be cast, pouring temperature and the cosmetic finish required.

Sands are categorized by grain shape, (i.e. - rounded, sub-angular or angular - see Fig. 1), sieve distribution and sizing.

A round grained sand gives higher green strengths, better flowability and good permeability, due to more regular and even distribution of the bonding agents.

A sub-angular, semi-rounded sand grain is more common, angular and compounded grains are more difficult to control and are often only used for cost savings.

In the UK the silica sands available are generally of the sub-angular type, and give reasonable results in iron and steel foundry practice. However, in specific cases it may be necessary to use a very round grained fine sand such as zircon, in order to give an excellent finish plus chilling characteristics. Larger castings could use chromite sand particularly for its chilling properties rather than the cosmetic finish obtained. Olivine sand is used specifically for manganese steel production.

The grain shape and size of all these sands must be taken into consideration, along with their thermal expansion and thermal conductivity characteristics. These factors will determine the correct additions to be made to the green sand to produce good results.

To obtain these criteria, most UK
foundry sand suppliers wash, screen and dry the silica sand in order to deliver it to foundries with an acceptable sieve grading, generally AFS Fineness No. 40-90, which gives the foundries a good starting point.

In some iron foundry production and more specifically in non-ferrous castings, natural sands are sometimes used. Generally these sands contain a percentage of indigenous clay, and are normally delivered in the damp condition. They generally hold moisture well, give good casting finish, but care must be taken to avoid expansion defects. Naturally bonded sands exhibit greater variability in their properties than synthetic sands. If a washed and screened silica sand is used in non-ferrous production, it is generally of a finer nature to give as good a casting finish as possible, whilst having sufficient permeability to permit escape of gases during the pouring cycle.

For green sand production a good base sand with a four sieve spread, gives far better results than one which has a widely dispersed grading, or peaks on one or two sieves.

A major priority, often overlooked in many foundries, is that new sand must be added on a continuous basis to the return sand in the ratio of 10 to 15% of the weight of metal poured, or 2 to 3% of sand mixed. Far too often foundries consider that the sand returned via cores is sufficient, and experience has proved that this can create extensive problems. Core sands of a specific grain size and shape can alter the green sand grading substantially over a period of time, leading to a close packed hexagonal structure, which can result in expansion defects.

2. Clay Binders:

There are various clays available worldwide, many having been tried for foundry application, but the three basic types generally in use are Kaolinites (fire clay), Montmorillonites (bentonites) and Illite.

Montmorillonite is the major clay mineral of bentonite, a three layer sheet structure composed of two layers of silicon-oxygen tetrahedrons and one central dioctahedral or trioctahedral aluminium-hydroxylayer (Gibbsite). This central aluminium layer is made up of octahedrons having an aluminium atom surrounded by 6 hydroxyl units (Al(OH). See Figs. 2 & 3

Sodium clays, calcium clays and “ion exchange” bentonites fall into this category and are the ones used most extensively in the Industry.

Kaolinite, a two layer structure with one aluminium octahedral layer and one silica tetrahedral layer. The silica layer is composed of 1 silicon and 4 oxygen atoms. The second layer (Gibbsite) is composed of 1 aluminium atom and 6 hydroxyl atoms. See Fig. 4.

Fire clays, china clays, kaolins and ball clays fall into this category. These are used very little in modern foundry practice, the main application remaining in dry sand practice for steel casting.

Illite is a low refractory clay. It is the predominant constituent clay found in most naturally bonded sands, but is never isolated and used as a basic clay material addition.

Montmorillonite, having the central aluminium hydroxyl sheet in the sandwich between the two silicon oxygen layers is never totally pure aluminium hydroxide. Part of the aluminium is always replaced by divalent magnesium, creating an ionic imbalance which requires balancing. Balancing may be achieved with sodium/calcium or magnesium, known as an “exchange ion”.

In modern foundry practice many clays used in foundries are of the “ion exchange” variety.

The two major Montmorillonites used in foundry applications are (a) sodium bentonite, characterized by high swelling properties and (b) calcium bentonite, which is non-swelling and absorbs less water.

“Ion exchange” bentonites are calcium bentonites treated with sodium salts, i.e sodium carbonate (soda ash), to improve the characteristics of the clay. This activation increases wet tensile and liquid limit figures to give improved durability and anti-expansion defect properties.
without the particular disadvantage of high dry strength. This activation can be ‘dry’ or ‘wet’, but results indicate that wet activation is superior.

Sodium bentonites, calcium bentonites and ‘ion-exchange’ clays each exhibit unique properties. Choosing the correct clay or blend will be dependent on process requirements and economic justification on a foundry to foundry basis.

It will generally be found in green sand foundries that sodium bentonite (Wyoming), is used for steel casting production, calcium or ‘ion exchange’ bentonite or a blend of sodium/calcium clay is used in iron and non-ferrous application.

Each foundry should know its own requirements and select its clays accordingly. A clay or blend can be developed to suit most requirements. This is particularly important with the advent of high pressure moulding and the demands placed upon the performance of green sand additives.

3. Other Additives:
Over the years, many alternative additives have been tried to improve the performance of green sand, but the major ones currently in use are listed below.

a) Coal Dust
b) Coal Dust Replacements
c) Starches, Cereals, Dextrines
d) Wood Flour
e) Iron Oxide

a) Coal Dust:
This is primarily used in iron casting production with some application to non-ferrous work. Coal dust improves casting strip and to some degree casting finish. It helps control expansion defects due to its burn out characteristics, particularly on the mould face. Volatiles given off during casting produce lustrous carbon which improves casting strip.

On casting, coal dust burns, and oxygen to support combustion is drawn from the mould cavity, producing a reducing atmosphere within the mould cavity.

As the temperature increases, the coal dust ‘cookes’, producing uncondensable reducing gases, such as hydrogen and methane. The tars and oils burn producing a carbon film. This ‘sooting’ helps prevent metal penetration into the sand grains and forms a cushion which allows the metal to lie quietly on the mould surface. The burnt out coal dust at the mould/metal interface increases permeability assisting the escape of gases and helps to compensate for surface sand expansion preventing rat tails, scabbing etc.

b) Coal Dust Replacements:
These have been developed over the last 20 years, and normally consist of a blend of high volatile/high lustrous carbon producing base material, blended with coal dust and clay.

Originally, coal dust was not used, but it was found that control limits required were very restrictive, and in most cases coal dust was introduced to provide greater flexibility, particularly with regard to moisture control and the requirement for an extended reducing atmosphere for SG iron.

Coal dust replacements have been accepted in UK foundries as a match for coal dust; they are generally more economical and particularly more environmentally acceptable, due to less fume evolution on casting. They can be tailored to suit particular applications particularly with regard to high pressure moulding, and also for the production of SG iron, where the sulphur content is reduced substantially, helping to prevent the edge flake defect.

c) Starches, Cereals and Dextrines:
These are used mainly in steel casting production, but occasionally in iron for specific applications.

Cereals tend to increase green strength, dry strength and sand toughness, but can reduce flowability. More water may be required to be added to the sand mix, with the attendant potential for moisture related defects.

Dextrines promote better flowability and plasticity.

They help with moisture retention and are particularly useful in preventing moulds drying out and edges becoming friable.

Starches produce a reducing atmosphere similar to coal dust in iron casting. Due to it being a volatile carbohydrate it uses oxygen from the mould cavity.

As the temperature increases, starches burn out to accommodate sand expansion, helping the prevention of expansion defects. This is the area where foundries feel they are obtaining the greatest benefit.

d) Woodflour:
A very fine soft wood flour used predominantly in iron casting production, as steel foundries tend to use a starch based additive, but it is claimed that woodflour is similar to the starches in that it produces a reducing atmosphere although to a lesser extent, and on burn out gives good resistance to expansion defects. However, woodflour tends to lower dry strength and if care is not taken friability of moulds can occur. Too high a moisture level makes the sand spongy, difficult to ram and susceptible to moisture related defects.

In malleable iron production, it is particularly useful, giving good collapsibility with lower hot strength, thereby helping to prevent expansion defects. On moulding, it decreases density, improves flowability and accepts water readily giving a much more flexible moisture band. It does not feel 'sticky' as the starches tend to.

It is often used with naturally bonded sand, to overcome expansion defects, particularly on flat surfaces and also helps to improve casting strip. In some instances it can be substituted for a percentage of the ceramic or starch addition.

Environmentally undesirable, due to the amount of smoke generated on casting.

e) Iron Oxide:
Used primarily to overcome finning and veining. It improves hot plastic deformation and increases hot strength. Although it is sometimes used in green sand in small amounts, its predominant use is with Hot Box Resins, Shell, Dry Sand and Phenolic Urethanes.

4 Water:
Although water quality may seem of little importance, due to the increase in the recent past of chemically bonded sands, which break down and enter the return sand system, it has been proved that some of the chlorides and sulphates produced from return material, plus those contained in mains supply water at certain levels of concentration, can have a detrimental effect on the clay binder, causing lack of bond development, friability and premature break down of the sand and a demand for increased clay additions.

A number of foundries are already using de-ionised water additions to overcome this problem. Breakdown products from some modern core binder materials contaminate return moulding sand and may increase water requirements for control of the system.
5 Mixing/Mulling:
The requirement is to develop correct properties to produce good sand moulds and good castings.

Sand mulling must be thorough. Too many foundries do not mull long enough, often due to production requirements and thereby lose consistency.

Hot return sand requires more mulling and higher moisture additions to compensate for evaporation cooling.

Short mulling time produces brittle sand, with low green strength, undermixed additives and, most importantly, variable moulding properties and lack of control.

Therefore, optimum mulling cycles must be established and adhered to in all foundries and particular attention must be given to manufacturers' instructions and maintenance.

The use of aerators immediately prior to the moulding machine hopper or the moulding machine itself, produces improved flowability and mouldability (equivalent to 'riddling' the sand) and often helps to partially overcome shortcomings in the mulling operation.

6 Moulding:
Recent improvements in moulding machines, the introduction of automatic moulding and the demands for higher productivity have greatly increased the requirements for green sand to be able to cope with these demands. The quality and formulations have been progressively improved to meet the more stringent requirements of today.

Foundries must place great emphasis on maintaining their equipment to obtain optimum sand properties and mould quality.

a) Ramming:
Hand ramming and pneumatic wind ramming are still used in jobbing work in green sand foundries, particularly on larger type jobs and the 'one-offs'. However, although many excellent castings are produced by these methods, results can be somewhat inconsistent due to variation in operators.

b) Jolt-squeeze:
The predominant moulding method in green sand for many years, where the sand filled mould box is jolted for several seconds to ensure initial compaction of sand and then a squeeze pressure is applied for final compaction.

Jolt and squeeze are often used together for compaction. Even distribution of the sand into the moulding box is important in this process and generally a box frame is used to ensure sufficient sand is available. The more flowable the sand, the better the operation.

A pin lift or roller lift system is employed to lift the box from the pattern and must be properly aligned to ensure good mould quality.

Modern technology has improved this system to automatic operation, where the squeeze pressure can be applied by individual multi-piston squeeze heads over the box area, either pneumatically or hydraulically controlled, with varying squeeze pressures for outer and inner feet. This allows for pattern depth etc., and helps to ensure a mould of reasonably uniform hardness. Again, sand distribution in the box is very important.

c) Shoot squeeze:
This method is being used extensively in green sand automatic moulding, to produce flaskless moulds on the male/female matchplate principle, where the sand is blown into the chamber between male and female pattern plates, which then either both squeeze inward, or more generally the rear plate squeezes under pressure to the static rigid front plate. Variations on this may be vertical squeeze, squeeze or standard one plate squeeze.

Sand for this operation is usually far stronger than normal, with green strength strengths in excess of 20 psi. However, as good shake out is required, high hot strength with low dry strength must be a characteristic of the sand to ensure almost total reclamation.

d) Strickling:
This is used very little nowadays, other than for specific types of castings.

A loam sand is normally employed, backed up by various mechanical means and utilizing straw, rope, ashes etc., as fillers.

A skilled moulder is required to ensure good quality and although much of this work has been replaced by modern cold setting processes, pattern costs can be a deterrent and therefore strickling is still used.

e) Impact moulding:
A fairly recent process, where the sand is compacted into the box by means of pressure generated by explosion or by air. This can be backed up by squeeze pressure if required.

Variations on this are the air flow, air stream, vacuum assisted etc., type of moulding machine, where air under pressure assists sand compaction initially and when squeeze head pressure is applied, the air is evacuated by vents in the pattern plate.

Both these methods produce hard uniform moulds and again the sand must be tailored to suit this application.

7 Reproducibility:
With the advent of BS5750, ISO9000 series, Ford Q1 and ever more stringent customer quality demands, it is most important that casting quality remains consistent and to this end the performance of the green sand is of paramount importance. Consistency is the key word, with every batch of green sand being delivered to the moulding machine with similar properties throughout the production run.

Green sand additives must similarly be consistent, reliable and effective.

8 Process control
Most UK foundries operate SPC systems, and many have obtained BS5750 accreditation, as required by their customers.

With the aid of Computerised Sand Control Systems, visual wall charts and control graphs etc., variability in greensand properties can be greatly reduced leading to consistency in results and improved control.

9 Reclamation:
Green sand, under normal conditions, should give high levels of reclamation, with sufficient new sand addition to maintain properties.

The process is fairly simple and if contaminants such as scrap metal etc., are removed there is generally little problem other than temperature variation, which can hinder consistency. Whenever possible, foundries must endeavour to utilize methods of cooling return sand, in order to present it to the mill at consistent temperature levels.

Care must be taken with selection of core binders, in order to prevent a build up of unwanted contaminants. Again, it is essential that new sand be added on a consistent basis.
DRY SAND

The use of dry sand has been reduced drastically in recent times, due to the advent of cold setting processes, which have eliminated the need for expensive drying operations and have decreased production times dramatically.

Basic Principle:

A mixture of sand, clay and water, plus other additives as required, are correctly mulled, moulded and thoroughly dried to produce a mould suitable for casting.

Major Criteria:

The major criteria of dry sand are the same as for green sand with variations in the addition rates for the specific requirements of the process.

Intricate large moulds were difficult to cast to accurate dimensions in green sand and dry sand was introduced to overcome this.

Dry sand is generally used in steel casting production, particularly with stainless where the results have been good and the higher cost factor is of less importance. Generally, moisture and clay levels are higher in a dry sand mix with the clay 10% or more. Occasionally, fireclay is used as part of the clay addition to complement a Wyoming Bentonite. The higher clay levels also help prevent expansion defects.

When the sand has been mixed and moulded, the moulds are baked in an oven or stove at temperatures of 300°C to 600°C with particular care being taken in the drying time, otherwise the moisture will not be dissipated. Drying time is determined by the size, weight and section thickness of the moulds being made.

It is more expensive than green sand due to the extra additive costs, the need to use stoves or ovens to dry thoroughly and far slower production times.

Its advantages are stronger moulds, which are easier to handle; far less moisture to give steam related defects such as expansion scabs; more dimensional accuracy and, as coatings are generally used, a very good casting finish is often obtained.

CASTING DEFECTS

The aim of foundries is to produce consistent, good quality, saleable castings. The vast majority of castings produced worldwide are manufactured in green sand and the quality of the castings is determined by the control of the process.

The various defects have been examined in depth by many learned foundrymen and papers are available on all types of casting defects.

It is most important that the defect is correctly diagnosed, in order that the appropriate remedial action may be taken.

NB: The IBF Manual of Defects has been up-dated from the 1962 edition and is to be published in 1993.

These can be categorized under five separate headings:

1. Inclusions
2. Penetration
3. Expansion
4. Shrinkage
5. Porosity

1 Inclusions:

These can be a major cause of scrap in the foundry and consist of sand, slag or other materials present in the casting.

Causes:
- Poor quality mould or core, which is friable and allows loose sand to be carried into the mould by erosion.
- Loose sand can arise from mishandling on assembly or detached by movement on transfer prior to top pouring.
- Poor housekeeping - dirty moulds or patterns that have not been completely cleaned.
- Gas explosions, which can damage the surface of the mould and allow free sand into the cavity.
- Poor running systems, which can create turbulence in the mould thereby eroding sand from the mould face.

2 Penetration:

Penetration can be categorized as follows:
- Mechanical penetration
- Burn on/chemical reaction
- Vapour state penetration
- Eutectic exudation

a) Mechanical Penetration:

occurs when liquid metal enters the pore spaces at the mould face, due to pressure or capillary forces, producing a rough casting finish, often described as 'burn in'. This usually occurs in hot spout areas, or areas of high ferrostatic pressure.

b) Burn On:

is a chemical reaction whereby the metal is oxidized by the atmosphere present at the mould/metal interface and the oxide formed reacts with the mould media.

This produces a rough surface finish and burn on caused by:
- Oxidising conditions in the mould cavity.
- High moisture.
- Too high pouring temperature.
- Poor refractoriness of sand.

c) Vapour State Penetration:

is said to occur when metal, particularly steel, is vapourised due to extreme pressures and temperatures. The vapour is said to diffuse into the sand and recondense, producing a fused mass of sand and metal.

Caused by:
- Highly oxidizing mould conditions
- Insufficient venting of the mould and cores
- High internal mould or core pressure during and after pouring.
- High ferrostatic pressure.
- Excessive pouring temperatures combined with pouring shock.

d) Explosion Penetration:

is defined as: 1) explosive evaporation of the moisture at the mould surface when molten metal collides under pressure with the mould wall, or 2) explosive ignition of trapped mould gases. This forces metal into the mould face cavities, often producing extensive metal penetration on the casting surface.

Causes:
- High moisture levels.
- Hot moulding sand.
- Excessive use of organic additives.
- Inadequate permeability, creating excessive mould pressure.
- Poor venting practice.
- Very hard moulds with low permeability.
e) Eutectic Exudation: a form of mechanical penetration, which occurs during eutectic solidification of cast iron, when the pressure from graphitisation forces the metal into the sand face usually at hot spot areas.

Causes:
- If the carbon equivalent approaches that of the maximum eutectic composition, then eutectic exudation is possible. Expansion pressure due to the formation of graphite flakes cannot be accommodated by sand composition or moulding sand compaction.
- High levels of phosphorus, molybdenum additions and type of inoculant all have an influence on this condition.
- Exceptionally hard moulds that suppress shrinkage due to mould dilution often increase the possibility of exudation penetration by countering the metal expansion pressure.

3 Expansion:
These defects take the form of scabs, buckles, rat tails, finning and veining.

Scabbing (expansion scab):
this occurs where the sand is subjected to intense heat prior to metal reaching the mould surface, producing the formation of a wet condensation layer behind a crust of dry sand.

Sand expansion restrictions cause the crust to crack or break loose, allowing metal to penetrate behind the mould face, thus forming the scab.

Buckles and rat tails
are lesser forms of expansion scabbing.

Erosion Scab:
caused by a low strength wet condensation layer, which allows the mould face to crack due to expansion restrictions. The metal stream picks up these pieces of sand-crust and carries them up through the mould cavity to lodge at the cope surface, whilst leaving a rough casting surface finish where the sand has been removed.

Can be aggravated by an expansion scab, or by metal turbulence due to mould gases.

Boil Scab:
produces a fused mass of metal and sand, caused by the metal being agitated by excess gases in the mould cavity and with expansion stresses weakening the mould or core surface.

Finning and Veining:
caused by excessive thermal movement of the sand which can lead to a crack in the mould or core surface allowing metal entry to form a fin or vein. Iron oxide can be used to improve the hot plastic deformation properties of the sand.

Causes:
- Weak sand due to insufficient clay bond.
- Low wet tensile strength.
- High moisture content.
- Inappropriate sand grading - poor distribution.
- Low carbonaceous content.
- Hard moulds.
- Slow pouring rate with poor gating system.
- High pouring temperature.

4 Shrinkage:
A shrinkage cavity is an irregular or spongelike area, often displaying a dendritic structure.

A shrinkage depression on the surface of a casting, is a recession from the true plane of the mould surface. If gases are involved in shrinkage, any subsequent expansion pressure can squeeze the gases to such a degree during solidification as to produce a round or elliptical cavity with no dendrites present.

A shrinkage cavity and a gas blow are often confused. Gas can follow the solidification pattern of a casting and lodge in a heavy section or isothermic area. These gas holes may appear in a random fashion internally, or break through the casting surface. This is Pinhole Porosity.

Types of Shrinkage:
Draw or Sink:
a depression from the true plane, and of a smooth, uniform nature. Sometimes difficult to detect, and often only discovered during machining operations.

Causes:
- Mould dilation.
- Lack of feed metal to promote directional solidification.
- Metal chemistry.

Microshrinkage:
generally occurs below the casting surface as minute cavities that can be confused with pinhole porosity.

It appears as an open structure in the cellular matrix but dendrites may not always be present. Usually occurs in heavy section castings, and is more often found in areas furthest from the riser.

Causes:
- Conditions that create mould wall movement (mould dilation).
- Metallurgical factors.
- High pouring temperatures.

Dispersed shrinkage:
a number of shrinkage cavities in the same general area of the casting, but of a much larger size than micro shrinkage, and usually with an irregular surface.

Dispersed shrinkage can substantially reduce the structural strength of a casting.

Causes:
- Mould dilation.
- Mould cracking.
- Partial mould run out.
- Irrupted pour.

Centreline Shrinkage:
an internal shrinkage defect which occurs along the isothermic centreplane of flat, plate type casting sections. It is longitudinal with a dendritic appearance.

Casting structural strength is drastically reduced by this defect.

Causes:
- Inadequate feeding system.
- Exceptional mould hardness.
- High moisture content.
- High pouring temperature.

NB EXPERIENCE HAS SHOWN THAT MOULD DIATION IS THE MAJOR CAUSE OF SHRINKAGE DEFECTS IN GREENSAND MOULDING.

Prevention of Shrinkage:
- Produce a uniformly dense mould to prevent mould dilution.
- Do not pour too fast and create pouring impact.
- Ensure Cope and Drag are firmly clamped and/or weighted to prevent mould movement.
- Metal chemistry must be right, it is well known that alloying elements

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The best paper in this series has been the subject of cold seating systems, to be published later this year.

7. Hot tearing

Additive decomposition or partial burn-offs of organic promoters or their decomposition products or organic promoters may also be caused by the large reaction of the metal with hydrogen, which is released by excess hydrogen in the system or in the hot metal. The large reaction of the metal with hydrogen may also be caused by the presence of excess hydrogen in the system or in the hot metal.

Evolution of Harmful Elements

Hydrogen in steel and other ferrous alloys is released by the large reaction of the metal with hydrogen, which is released by excess hydrogen in the system or in the hot metal. The large reaction of the metal with hydrogen may also be caused by the presence of excess hydrogen in the system or in the hot metal.

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