Molding Sands

The major production of castings is in sand molds. Molds for making a ton of castings may require 4 to 5 tons of molding sand. The sand-metal ratio may vary from 10:1 to 0.25:1, depending on the type and size of castings and molding method employed. In any case, the tonnage of sand which must be handled in a sand-casting foundry is large, and its quality must be controlled to make good castings.

Several different types of sand are used for molding. Sand-casting processes involving molds made of green sand, dry sand, core sand, cement-bonded sand, shell-molding sand, and others have been described in an earlier chapter.

INGREDIENTS OF MOLDING SANDS

Molding sands are mixtures of three or more ingredients. A green sand contains clay and water, as well as the principal sand constituent, SiO_2. These three components provide the bulk and plasticity required of the molding sand. Other materials may be added to the sand mixture to enhance certain of the properties.

Sand

Granular particles of sand, that is, SiO_2 principally, comprise 50 to 95 per cent of the total material in a molding sand. In different molding 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

The chemical composition of the sand-grain portion of typical molding sand is given in Table 5.1. Generally, the purest silica sand, 99.8+

Table 5.1 Chemical composition of typical sands

Constituents	Washed silica sand*	Washed and dried silica†	Typical bank sand‡	Western bentonite bonded silica sand§		Typical lake sand
				New	Used	
Loss on ignition, %	.....	....	1.02	0.28	0.12	0.80
C, %	.....	....	.....	0.13	0.59	
Free iron, %	.....	....	.....	.....	0.97	
Ferrous iron, %	.....	....	.....	0.44	0.68	
Ferric iron, %	.....	....	.....	0.00	0.12	
Total iron, %	0.10	....	.....	0.44	1.77	
Al_2O_3, %	0.39	....	.....	1.32	0.63	
SiO_2, %	99.08	99.80+	92.09	95.79	95.54	95.0+
TiO_2, %	0.43					
Total $Al_2O_3 + Fe_2O_3$, %	.....	....	6.09	.....	.....	2.0
CaO, %	.....	....	0.58	.....	.....	0.60
Alkali, %	.....	....	.....	.....	.....	0.20
MgO, %	.....	....	0.22	.....	.....	0.40

*New Jersey Silica Sand Co.

†Ottawa silica sand.

‡Great Lakes Sand Co., Juniata.

§A molding sand, from F. L. Orell, Jr., "The Constitution of Discarded Molding Sand," Steel Founders Society of America Report 23, 1950.

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 sands. Average fineness of the sand grains establishes the fineness of the molding sand as a whole, and the grain size distribution affects many of the sand properties, as pointed out later. The shape of sand grains may be rounded, angular, or subangular, depending on their geologic history. Typical sand-grain shapes are illustrated in Fig. 5.1. Compounded grains are agglomerated particles of angular or subangular sands. In molding sands as they are used in foundries, the sand grains are of mixed origin. Some came initially from new molding 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 due to the action of heat and moisture in the mold.

Clay

Molding sands may contain about 2 to 50 per cent of clay. With a suitable water content, it is the principal source of the strength and

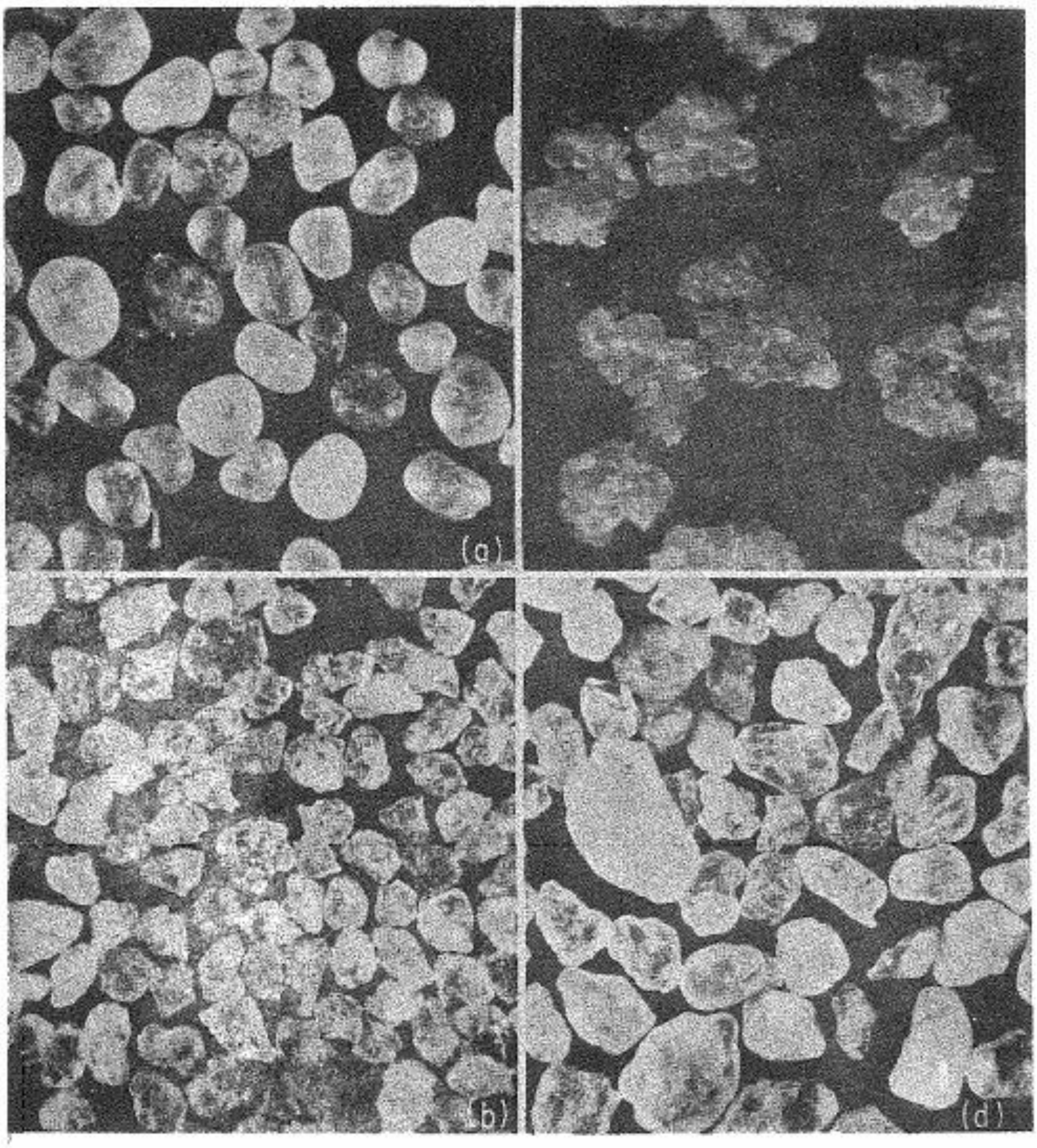


Fig. 5.1 **Sand grain shapes. (*a*) Rounded sand grains, (*b*) angular sand grains, (*c*) compounded sand grains, (*d*) subangular sand grains. (*From AFS.*[1])**

plasticity of the molding sand. Clay is thus the *bond,* or *binder,* of molding sands. In some mineral deposits, clay and sand occur mixed in proper proportions, so that the sand can be mined and used directly for molding. It is then referred to as a "natural molding 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."[2]

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

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

The first two types are the most commonly used. Table 5.2 lists some of their differences in chemical composition, atomic structure, base exchange characteristics, swelling and shrinkage tendencies, and refractoriness. A clay coating of the sand grains contributes many of the clay properties to the molding-sand aggregate.

Water

Water, present in amounts of about 1.5 to 8 per cent, activates the clay in the sand, causing the aggregate to develop plasticity and strength. Water in molding sands is often referred to as *tempering* water. The water is adsorbed by the clay up to a limiting amount. Only that water rigidly held (adsorbed) by the clay appears to be effective in developing strength.[2] The rigid clay coatings of the grains may be forced together, causing a wedging action and thus developing strength.[2] Additional water, however, can act as a lubricant, and makes the sand more plastic and more moldable, though the strength may be lowered. Thus control of the water percentage in the aggregate is very important. Water may engage in ion exchanges with the clay if dissolved minerals are present.

Special Additives

Besides the three basic ingredients, other materials may be present in molding sands. They are often referred to as *additives* and are used to develop some specific property. These materials will be briefly defined here.

Cereals

Cereal binder, as used in the foundry, is finely ground corn flour or gelatinized and ground starch from corn. Cereals may be used in molding sands for increased green or dry strength or collapsibility in amounts up to 2.0 per cent.

Clay mineral type	Composition type	Base exchange	Refractoriness (softening point)	Swelling due to water	Shrinkage due to loss of water	Particle size and shape
Montmorillonite Class IA, western bentonite Source: Wyoming, South Dakota, Utah	$(OH)_4Al_4Si_8O_{20}\cdot nH_2O$ Ex: 90% montmorillonite, 10% quartz, feldspar, mica, etc.	High. Na is adsorbed ion, pH = 8–10	2100–2450 F	Very high, gel-forming	Very high	Flake size of less than 0.00001 in.
Montmorillonite Class IB, southern bentonite Source: Mississippi	$(OH)_4Al_4Si_8O_{20}\cdot nH_2O$ Ex: 85% montmorillonite 15% quartz, limonite, etc.	High. Ca is adsorbed ion, pH = 4–6.50	1800 F+	Slight, little tendency to gel	Very high	Flake size of less than 0.00001 in.
Kaolinite Class IV, fire clay Source: Illinois, Ohio	$(OH)_4Al_4Si_4O_{10}$ Ex: 60% kaolinite, 30% illite, 10% quartz, etc.	Very low	3000–3100 F	Very low, non-gel-forming	Low	Fire clays are often ground and therefore may be relatively coarse or may be ground to a flour
Illite Class III, grundite Source: Grundy, Ill.	$(OH)_4K_y(Al_4Fe_4Mg_4Mg_6)(Si_{8-y}\cdot Al_y)O_{20}$	Moderate	2500 F±	Low, non-gel-forming	Moderate	

* Adapted from R. E. Grim and F. L. Cuthbert.[2]

Ground Pitch

Pitch is a by-product of cokemaking, being distilled from soft coals at about 600 F and above. Pitch is used in amounts up to 3.0 per cent to improve hot strength or casting finish on ferrous castings.

Asphalt

Asphalt is a by-product of the distillation of petroleum. It is used for the same purposes as pitch.

Sea Coal

Sea coal is a finely ground soft coal used in molding sands for cast irons, principally for the purpose of improving the surface finish and ease of cleaning the castings. Sea coal may be specified by proximate and ultimate analyses conventionally used for coal. A typical example is given in Table 5.3. The sea coal is usually ground to a fineness similar to that of the molding sand in which it is used. Percentages employed in sands are about 2 to 8 per cent.

Graphite

Synthetic or natural graphite may be used in percentages of 0.2 to 2.0 per cent for the purpose of improving the moldability of the sand and the surface finish of the castings.

Gilsonite

This material is a solid asphaltic mineral, mined in Utah and Colorado, sufficiently volatile so that it functions much as sea coal does in causing improved casting finish.

Fuel Oil

Fuel oil is sometimes used in very small percentages, of 0.01 to 0.1(per cent, and seems to confer improved moldability to the sand.

Wood Flour

Ground wood flour or other cellulose materials such as cob flour, cerea hulls, and carbonized cellulose may be added in amounts of 0.5 to 2.(per cent to molding sands. They may function to control the expansioı of the sand by burning out at elevated temperature. They also caı improve collapsibility and flowability of the sand.

Silica Flour

Pulverized silica, finer than 200 mesh, is called silica flour. It ma be used in amounts up to 35 per cent for the purpose of increasing ho strength of the sand. It also increases the density of the sand for resisting metal penetration.

Table 5.3 Example of sea-coal specification

PROXIMATE ANALYSIS (MOISTURE-FREE), %	
Volatile matter (VCM)	36–40.0
Fixed carbon (FC)	55–60
Ash	3–5
ULTIMATE ANALYSIS	
H	5.6%
C	80–85%
N	1–3%
O	6–8%
S	0.8% max
Ash	3–5%
Ash fusion point	2780 F

Iron Oxide

Fine iron oxide is used in small percentages in some sands to obtain added hot strength.

Perlite

Perlite is an expanded aluminum silicate mineral, useful in small percentages, 0.5 to 1.50 per cent, to obtain better thermal stability of the sand. It may also be used as a riser insulator.[4]

Molasses, Dextrin

Cane or blackstrap molasses, unrefined and containing 60 to 70 per cent sugar solids, may be used for increased dry strength of the sand and edge hardness of molds. Dextrins may be used for the same purpose.

The foregoing list of sand additives is by no means complete, and a number of others may be used.

Description of Sand, Silica and Zircon Sands

In general, sand is described as mineral grains having a size of 0,05-2 mm. great majority of foundry sands are in the form of SiO_2. In some cases, additives such as mica, feldspat, ilmenite, magnetite, zircon, olivine are added to SiO_2 in very small amounts. The use of silica as molding materials in foundry is attributed to several reasons such as ease of availability (can be found easily), low cost and high resistance to liquid metal effects or refractoriness.

Another sand type used in foundry is zirconia or zircon sand. Zircon has high refractoriness, high heat conductivity, high density and low thermal expansive values. Due to high thermal conductivity, metal cast into molds made of zircon sands solidify faster. Density and heat conductivity of zircon is twice as that of silica. This means that heat absorption capacity and conductivity of zircon is twice as that of silica. These properties enables foundryman to control the solidification process, therefore zircon sand can be used as chill and can provide economic advantages.

Bonding Materials

Bonding materials in foundry sands are divided into two categories: 1) Inorganic bonding agents, 2) Organic bonding agents.

The most widely used inorganic bonding agents in foundry sand are clays; among those the most widely preferred one is bentonite.

Bentonite contains 85-95 % montmorillonite minerals, it can change ions and has a very fine grain size. It is a plastic clay with a chemical formula of $4(OH)_4.Al_4Si_6O_2.nH_2O$. Montmorillonite is a three layers clay mineral. There is one aluminium layer between two silica layers. The width of layer is 100-300 times the thickness. The high specific surface of montmorillonite increases its bonding ability.

Bentonites are divided into two groups depending on the changeable ions: 1) Na-bentonite, 2) Ca-bentonite

Na bentonite is found less in the world and with the addition of water it expands 5-6 times in comparison with the dry volume. Dues to these properties, it is preferred more than Ca bentonite. With ion exchange, the calcium bentonite can be converted into sodium bentonite or vice versa (eg. With soda activity Ca bentonite+Na_2CO_3 Na bentonite+$CaCO_3$). As the exchangeable ions are located outside the silica-alumina structure unit, the exchange reactions do not change the structure.

Natural and Synthetic molding sand

Natural molding sand:

This is ready for use as it is dug from the ground. Good natural molding sand are obtained from Albany, New york etc.

The following average compositions are seen in natural molding sand:
65.5% silica grains, 21.7% clay content, 12.8% undesirable impurities.

Too much clay content and other impurities fill up the gaps between the sand grains. This will hinder the necessary passage of steam and other gases during pouring of the mold.

Synthetic molding sand

Synthetic molding sand is made by mixing together specially selected high quality clay free silica, with about 5% of clay. They are tailor made to give most desirable results.

Some of the advantages of synthetic molding sand are:

1. Refractory grain sizes are more uniform, 2. Higher refractoriness (= 3000°F), 3. less bonding agent is required (about 1/3rd of the clay percentage found in natural molding sand), 4. More suitable for use with mechanical equipment

Advantages of natural molding sand: 1. moisture content range is wide, 2. molds can be repaired easily

GENERAL PROPERTIES OF MOLDING SANDS

From a general viewpoint, the molding sand must be readily moldabl and produce defect-free castings if it is to qualify as a good one. Certai specific properties have been identified, and testing procedures adapte for their quantitative description. The AFS "Foundry Sand Hand book"[1] sets forth the standard conditions of testing the sand propertie Those properties of most obvious importance include:

1. Green strength. The green sand, after water has been mixed into it, mus have adequate strength and plasticity for making and handling of the mold
2. Dry strength. As a casting is poured, sand adjacent to the hot meta quickly loses its water as steam. The dry sand must have strength t resist erosion, and also the metallostatic pressure of the molten metal, o else the mold may enlarge.
3. Hot strength. After the moisture has evaporated, the sand may be re quired to possess strength at some elevated temperature, above 212 F Metallostatic pressure of the liquid-metal bearing against the mold wall may cause mold 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 mold to evolv a great deal of steam and other gases. The mold must be permeable, i.e. porous, to permit the gases to pass off, or the casting will contain gas holes.
5. Thermal stability. Heat from the casting causes rapid expansion of the sand surface at the mold-metal interface. The mold surface may then crack, buckle, or flake off (scab) unless the molding sand is relatively stable dimensionally under rapid heating.
6. Refractoriness. Higher pouring temperatures, such as those for ferrous alloys at 2400 to 3200 F, require greater refractoriness of the sand. Low-pouring-temperature metals, for example, aluminum, poured at 1300 F, do not require a high degree of refractoriness from the sand.
7. Flowability. The sand should respond to molding processes.
8. Produces good casting finish.
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. Is reusable.
11. Offers ease of sand preparation and control.
12. Removes heat from the cooling casting.

In addition to features listed above, the following properties must also be controlled strictly because features 1 to 12 are determined by them.

13. Moisture content

14. Clay content

15. Grain/Particle shape, average size and size distribution

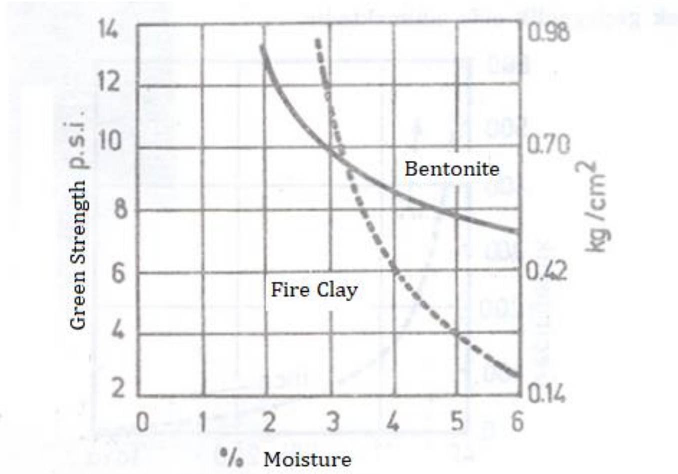
16. Purity

1. Green Strength

As it is described above, green strength is the strength values immediately agter adding water, mixing and molding. This is the strength required during preparation of the mold and for maintaining the shape of the mold cavity when the liquid metal is poured. Compressive strength (kg/cm^2) is measured on the standard test specimen.

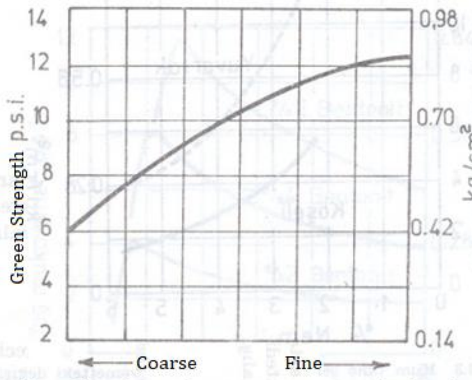
The following factors control the green strength; 1) average particle size, 2) particle shape, 3) type and amount of binder, 4) moisture (water) content and 5) particle size distribution range or packaging ratio.

- Decreasing sand particle size increases the strength because contact surface area of sand increases with decreasing size.
- Round sand provides higher strength because of high packaging ratio.
- Increasing the amount of bonding agent increases the strength.
- The effect of bentonite and fire clay on green strength is shown in below figure.

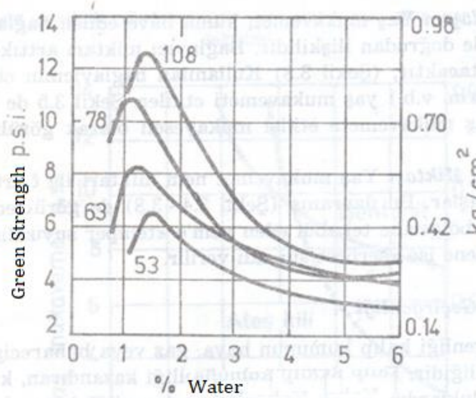


The effect of bentonite and fire clay on green strength

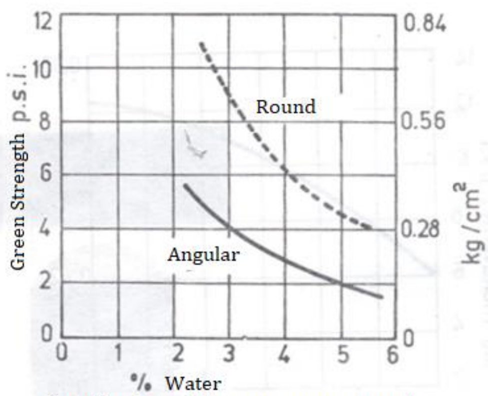
Green strength first increases with increasing water content, then it starts to decrease with further water content. The moisture that falls into increasing strength region is called as temper water and the moisture that falls into decreasing strength region is called as free water.



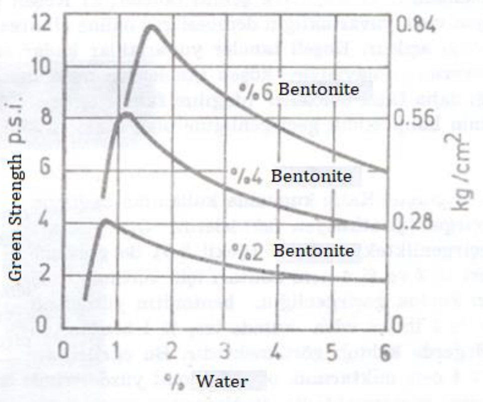
The effect of sand particle size on green stregth of sand molds



Variation of green stregth with varying AFS number (Particle size)



The effet of sand shape on green strength



The effect of water content on green strength of molding sands having various amounts of bentonite

2. Dry Strength

In general, the dry strength and the green strength of the molding sands are similarly affected by the same factors.

3. Hot Strength

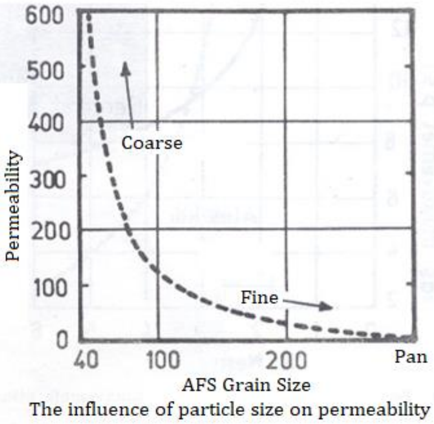
Hot strength is affected similarly by some factors listed above but there are some exemptions: in literature sands having angular shape gives higher hot strengths.

4. Permeability

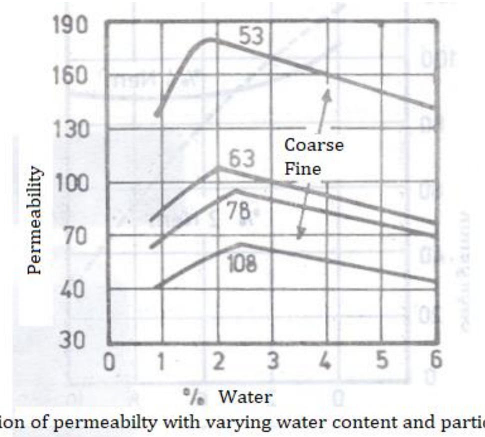
It is the spaces (pores) between the sand grains which provides permeability to mold sand. There are five factors that controls the permeability; 1. Particle size, 2. Particle shape, 3. Bonding agent type and its amount, 4. Water content and 5. Particle distribution range (D_S-D_L).

Permeability increases as the interlacing gap between the sand grains increases. The permeability is expressed by a number associated with the rate of passage of air through the sand under standard pressure.

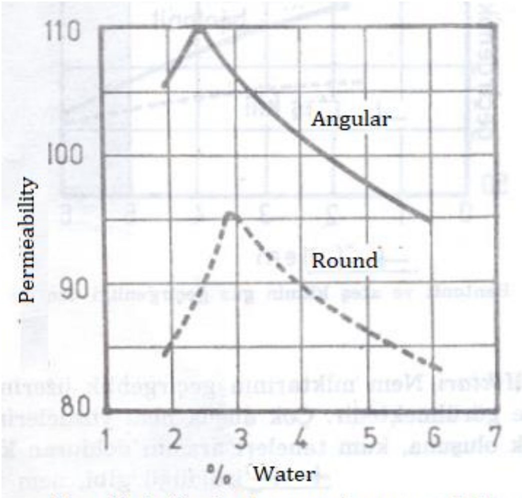
- Decreasing particle size decreases permeability.
- Water up to a certain degree (temper water) increases the permeability, beyond this value it reduces the permeability.
- Round grains/particles increases permeability because of the continuous nature of pores (interconnected) in this type of sands. In the case of angular sands, pores are not connected with each other and there are dead pores/pockets in the structure. Although it provides loose packaging, permeability is lower than round grains.
- Bonding agents have very small particle size and fill the pores between sand grains thus increasing amount of bonding agents decreases the permeability.



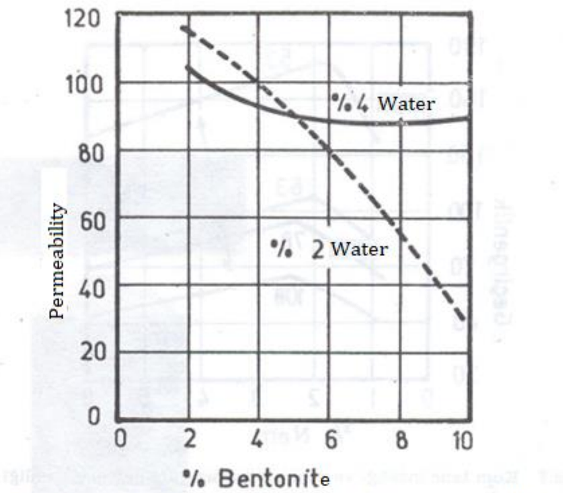
The influence of particle size on permeability



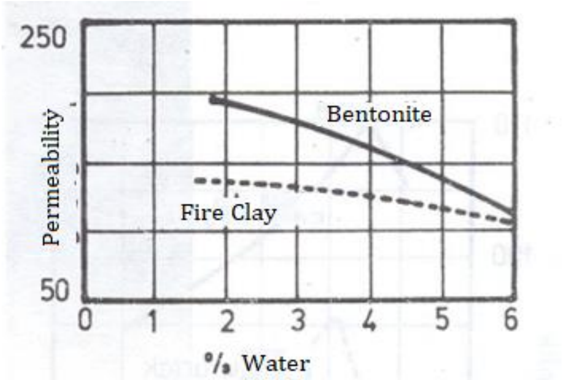
Variation of permeabilty with varying water content and particle size



The effect of grain shape on the permeability



The effect of bentonite and water content on permeability



The effect of bentonite and fire clay on permeability

5. Particle Size

The effect of particle size of the molding sands was explained while other properties were examined. Briefly, in the case of presence of certain amount of binder and moisture, fine sand will have higher strength and it is less permeable than coarse sand. As the grains become finer, the casting surface will be smoother. AFS No Calculation which is the measure of grain fineness is shown this chapter.

6. Clay Content

The effect of the type and amount of the binder added to the mold sands on the properties was mentioned in the examination of the previous properties. The amount of clay in the mold sand is measured by a standard experiment and the amount of AFS Clay is named. The amount is described as particles that do not precipitate at the rate of more than 2.54 cm per minute in the suspension in water. The particles in question include clay as well as fine silica and all constitute the total amount of AFS clay.

AFS Clay Content

For testing purposes, the AFS clay in a molding sand is defined as "particles which fail to settle one inch per minute when suspended in water. These are usually less than 20 microns, or 0.0008 in., in diameter." The latter definition includes all very fine material, fine silica or silt, as well as the clay mineral present, and the total percentage of these particles is called the AFS clay content of the sand.

The clay determination begins with a 50-g sample of dried sand. The 50-g sample is put into a wash bottle and washed according to the following procedures:

1. Add 475 ml distilled water and 25 ml caustic soda solution (25 g per liter).
2. Agitate 5 min with mechanical stirrer or shaker, dilute with water to a height of 6 in. (marker of bottle), and let settle 10 min.
3. Siphon off 5 in. water, dilute again to 6 in. height, and let settle for 10 min.
4. Siphon off 5 in. water, dilute again to 6 in. height, and let settle for 5 min.
5. Repeat step 4 enough times so that, after standing 5 min, the water is clear.
6. Remove the remaining sand grains from the bottle, dry, and weigh. The loss in weight of the original 50 g sample multiplied by 2 gives the AFS clay percentage in the sand. The clay must be removed from all sands containing more than 1 per cent clay if it is intended to perform the AFS sieve analysis test on the sand.

Analysis of the clay content of molding sands is also performed by the hydrometer method and a chemical method given in Refs. 1 and 5.

AFS Sieve Analysis

The size and distribution of sand grains in a sand is determined with the AFS sieve analysis test. A dried 50-g sample or the sand-grain residue from the clay-content determination is used. The latter may be less than 50 g. The sample is placed on top of a series of sieves and shaken for 15 min. The sieve numbers and size of openings are given in Table 5.5. After the shaking period, the sand retained on each sieve and the bottom pan is weighed, and its percentage of the total sample determined. Two uses are made of these data. First, a distribution curve showing the total per cent retained on each sieve may be plotted as in Fig. 5.7, or the cumulative percentage curve showing the total per cent obtained

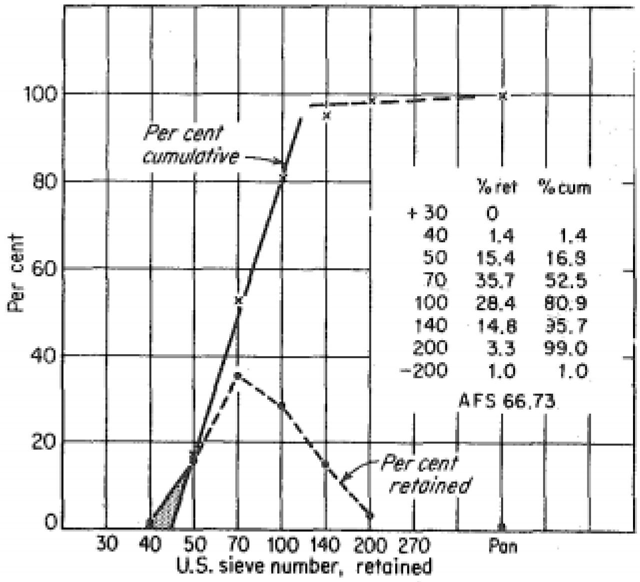


***Fig.* 5.7** Graph of per cent retained on each sieve vs. sieve number. Data taken from Table 5.6. This sand has a high average fineness number, 173, and might be used for nonferrous castings. Usually, the distribution curve looks more like a probability curve for most ferrous molding sands.

*Table 5.5 Screen scale sieves**

U.S. Series equivalent No.	Tyler screen scale sieves, meshes per lin in.	Openings, mm	Openings, in., ratio $\sqrt{2}$, or 1.414	Permissible variations in avg opening % ±	Diam wire, decimal of an in.	Mesh openings, microns
4	4	4.699	0.187	3	0.065	4760
6	6	3.327	0.132	3	0.036	3327
8	8	2.362	0.0937	3	0.035	2362
12	10	1.651	0.0661	3	0.032	1651
16	14	1.167	0.0469	3	0.025	1167
20	20	0.833	0.0331	5	0.0172	833
30	28	0.589	0.0232	5	0.0125	589
40	35	0.414	0.0165	5	0.0122	414
50	48	0.295	0.0117	5	0.0092	295
70	65	0.208	0.0083	5	0.0072	208
100	100	0.147	0.0059	6	0.0042	147
140	150	0.104	0.0041	6	0.0026	104
200	200	0.074	0.0029	7	0.0021	74
270	270	0.053	0.0021	7	0.0016	53

*From American Foundrymen's Society.[1]

The word "mesh" in terms of measuring "wire cloth" means "the number of openings per lineal inch." The term "mesh" in a technical usage is meaningless unless the diameter of the wire is given, so that the opening can be determined. The size of opening is the measure of the product, and the mesh and diameter of wire are used only as a means of determining the size of opening. The term mesh is secondary, and its use should be discontinued as much as possible.

There is a fixed ratio between the different sizes of the screen scale. This fixed ratio has been taken as 1.414, or the square root of 2 ($\sqrt{2}$). For example, using the U.S. Series equivalent No. 200 as the starting sieve, the width of each successive opening is exactly 1.414 times the opening in the previous sieve. The area, or the surface, of each successive opening in the scale is double that of the next-finer sieve, or one-half that of the next-coarser sieve.

which is coarser than any particular screen may be plotted. Second, the average grain fineness may be computed. An example of the computation is shown in Table 5.6. The percentage retained on each sieve is multiplied by a factor which is the size of the preceding sieve; i.e., the actual size of sand grains retained on one sieve is that permitted to pass through the preceding sieve. The products of sieve numbers multiplied by factors are summed. Then the average grain fineness number is equal to the sum of the sieve number and factor product divided by the total percentage of sand grains retained in the sieve set and pan. By definition, the AFS grain fineness number is the average grain size, and it corresponds to the sieve number whose openings would

Table 5.6 ***Typical calculation of AFS grain fineness number***

U.S. Series equivalent No. sieve	Amounts of 50-g sample retained on sieve		Multiplier	Product
	Grams	Per cent		
6..............	......	.....	3	
12..............	......	.....	5	
20..............	......	.....	10	
30..............	......	.....	20	
40..............	0.7	1.4	30	42.0
50..............	7.7	15.4	40	616.0
70..............	17.85	35.7	50	1785.0
100..............	14.2	28.4	70	1988.0
140..............	7.4	14.8	100	1480.0
200..............	1.65	3.3	145	462.0
270..............	.....	.....	200	
Pan..............	0.5	1.0	300	300.0
Total.............	50.0	100.0	...	6673.0

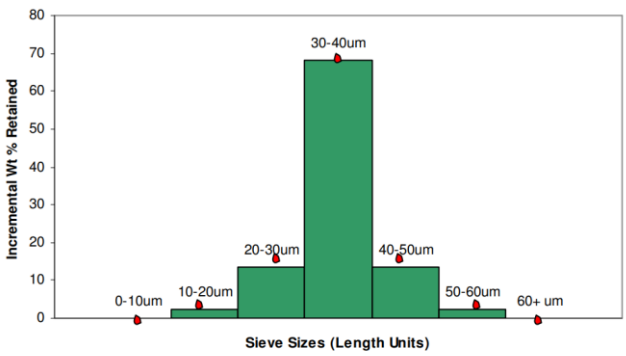
$$\text{AFS No.} = \frac{\text{total product}}{\text{total per cent retained}} = \frac{6673}{100} = 66.73$$

just pass all the sand grains if all were of the same size. This number is a convenient means of describing the relative fineness of sands, most foundry sands being from about 40 to 220 in average fineness. Most sand properties, however, depend on the size distribution as well as average size. The fineness test makes possible the evaluation of both factors. Other methods of describing the average size and distribution of particles are given in Refs. 12 and 13.

AFS Standard Sand

Sometimes a standard sand is described for comparison tests; for example, the effectiveness of different binders or mixing procedures might be studied. The AFS sand standard is defined as a washed and dried silica sand, AFS fineness number of 50 ± 1, with 100 per cent through a 40-mesh sieve, 95 per cent through a 50-mesh and remaining on a 70-mesh sieve, and the balance retained on a 100-mesh sieve. Another finer sand is sometimes used as a secondary standard.[1]

Approximately 90% of the molding sands are retained on five or six adjacent sieves.



Effect of Sand Conditioning

Effective molding-sand preparation usually consists of certain steps including:

1. Removal of foreign material, principally fines, metal, and hard lumps, as the sand is prepared for reuse.
2. Adequate mixing and tempering. Mulling or other mixing of the sand to distribute the clay, water, and additives should be continued until optimum sand properties are developed. Certain mixers are much more potent than others. Undermixed sand may have a very nonuniform distribution of ingredients.
3. Aerating, consisting in separating sand grains and in fluffing up of the sand by riddling, screening, or beating the sand, is practiced to promote better molding results.
4. Control of sand temperature. Cooling of sand is desirable since hot sand over 100 F causes molding difficulties, e.g., sticking and drops.

These steps are performed with more or less mechanical equipment of the type described in Chap. 4. Conditioning is complicated by the fact that the sand is continually being contaminated with core lumps, metal drippings, scale, and wires, as well as being decrepitated by the action of heat. Metal and lump contamination can be reduced by magnetic separation and screens. Accumulation of fine material can in part be controlled by its removal through exhaust systems under the dusty conditions of the shakeout. However, burnt clay and dilution by core sand can be corrected only by additions of clay and other additives to keep the sand properties at the desired level. Green strength and other properties and the combustible material in the sand are lost as the sand is reused unless such additions are made to recover the losses. The clay and other materials added for each cycle of mixing is about 0.15 to 1.00 per cent of the weight of the sand or about 2 to 20 lb of clay per 2000-lb batch, depending on the size of castings being made. The returned sand is of unknown moisture content, and additions for tempering at the proper water percentage must be made.

Adequate mixing requires the proper use of mixers. A mulling time of 4.5 to 6.0 min is required for mullers of the type shown in Fig. 4.14 to develop the bond for the clay. The centrifugal-type muller (Fig. 4.15) requires about 1.0 to 2.0 min. Overmulling can result in excessive heating of the sand, but more often the sand is hot, and mulling will cool it by water evaporation, especially if the muller is equipped with cooling blowers. Other types of mixers have optimum mixing periods. Any of the equipment must be properly adjusted. After mulling, some sand systems contain storage facilities to take advantage of the fact that some sands seem to improve with time. The mulling effect is considered in Ref. 42.

Before use in molding, aeration is a helpful practice. Aeration may be accomplished by riddling on ¼-in. mesh screens, mechanically, by vibrating screens, or by other devices. Aeration improves the molding qualities of the sand and the casting finish.

MOLDING-SAND TYPES

Sands are classified as natural or synthetic molding sands on the basis of their clay bonding material. A natural sand is one containing sufficient AFS clay as mined from the sand pit so that it can be used directly, needing only to be tempered and conditioned. A synthetic sand, however, is one artificially compounded by mixing sand grains and clay of the selected types considered. Natural sands came first in the chronological development of the foundry industry. Their present advantages consist in the simplicity of their preparation, handling, and use. Synthetic sands have the advantages of lower cost in large volume, widespread availability, and the possibilities of sand reclamation and reuse. Some typical specifications for natural sands are given in Table 5.8.

Listed in Table 5.9 are some properties and mixtures of synthetic sands. A more complete description of one ferrous molding sand is provided in Table 5.10 in which many properties are given quantitative values supposed to be favorable for producing good lightweight gray-

Table 5.8 Sand specifications on some natural sands

Property \ Sand use	Iron	Iron	Heavy brass or iron	No. 00 Albany, small and medium brass	No. 1 Albany, brass and small iron
AFS fineness......	70–80	70–80	23–27	180–200	110–130
Fineness class.....	4	4	8	2	3
Clay content, %...	15–18	22–30	17–19	11–13	12–15
Clay content class.	F	G	F	E	E
Grain shape.......	Subangular	Subangular	Subangular	Subangular	Subangular
Grain distribution.	5:4:3	3:4:3	1:4:7	7:4:0	2:4:2
Moisture, %......	6	7	7	6	6
Permeability, min.	75	40	250	10	15
Compressive strength, psi, min............	7.0	12	10	5	8
Sintering point, °C, min............	1200	1200	1250	1050	1075

iron castings. The latter table is a very complete picture of a particular sand.

Sand Definitions

Certain terms are used in connection with molding sands that should be understood. Definitions are given below. Some of them are standard taken from AFS references, whereas others are modified according to the authors' experience.

Silica Sand

White washed and dried silica sand grains of high purity 99.8+% SiO_2.

Bank Sand

Sand from glacial or sedimentary deposits occurring in banks or pits usually containing less than 5 per cent clay and used in synthetic sands and core sands. In the Great Lakes area these sands usually contain less than 2.0 per cent clay and consist of rounded silica grains in size ranges of 60 to 70, 70 to 80, 80 to 90, and 90 to 100 AFS and over. The sand grains are usually not white because of impurities.

Lake Sand (or Dune Sand)

A subangular sand, from the Great Lakes area, and especially dune and bottom deposits, substantially free of AFS clay and of 45 to 50

Table 5.9 Typical synthetic-sand practices for small- and medium-weight castings

Clay	Clay-sand type			
	Saturated bentonite	Subsaturated bentonite	Unsaturated	
			W. bentonite	Fire clay
Base sand	60–70 AFS, 4-screen	60–70 AFS, 4-screen	50–70 AFS, 3- to 4-screen	55–65 AFS, 4-screen
AFS clay, %	9–14	7–10	3–6	11–16
True clay, %	8–12	6–8	3–5	10–14
% H_2O, free	+20	+30–50	+50–100	+50–100
Green compressive strength, psi	14–20.0	10–14.0	5–9.0	7–11.0
Green shear strength, psi	4–6.0	3.0–4.0	1.5–2.5	2.0–3.0
Avg mold hardness	84–90	82–88	74–86	76–86
Dry compressive strength, psi:				
W.-bentonite-bonded	Usually >100	>100	>80	
S.-bentonite-bonded	40–80	40–80		
Fire-clay-bonded	....	....	....	60–80
Bulk density, lb/cu ft:				
Freshly riddled	50–65	45–60	40–55	50–65
Fully rammed	100–110	100–110	100–110	110–120
Deformation, in.	0.010–0.020	0.020–0.030	0.025–0.040	0.020–0.035
Total combination, %:				
Fe	5–10	5–10	....	6–12
Cu-base	2–6.0	2–6.0		
Al-base	1.5–2.5	1.5–2.5		
Special additive	Sea-coal cellulose	Sea-coal cellulose	Cellulose	Cereal or dextrin

50 to 60, 60 to 70 AFS fineness. Lake sand is usually not white because of impurities.

System Sand

Any sand employed in a mechanical sand preparation and handling system.

Heap Sand

Sand thought of as being heaped on the floor when it is prepared for use.

Table 5.10 An example of a sand for cast iron

Green Properties			
Moisture, %	4.9	Green compression, psi	18.5
Mold hardness:		Green deformation, in./in	0.016
Top	88.0	Sand toughness	296.0
Bottom	90.0	Density, lb/cu ft	92.5
Permeability, cu cm	48.0	Flowability, %	68.5
Dry Properties			
Dry compression, psi	85.0	Combustible material, %	10.94
Air-set strength, psi	28.0		

U.S. sieve No.	*Percentage retained*
6	
12	
20	0.3
30	0.5
40	1.9
50	9.8
70	24.2
100	27.7
140	13.8
200	6.1
270	2.1
Pan	1.8

Clay content, %	14.8	AFS grain fineness No	77.4

Hot Properties

A sintering point, F	2350
Hot strength, psi:	
500 F	99.0
1000 F	76.0
1500 F	193.0
2000 F	38.0
2500 F	3.0
Spalling at 2500 F:	
1 min	No cracks
2 min	Few hair cracks
12 min	Many medium surface cracks
Hollow confined expansion at 1500 F, in./in	0.02
Pin penetration at 2600 F for 12 min	Very little penetration; diam of pi larger at bottom than at top
Maximum hot gas pressure at 2000 F, in. water	20.0
Sand used to produce lightweight watertight iron castings	

*From H. W. Dietert.[17]

Facing Sand

A specially prepared sand used next to the pattern and backed up witl heap or system sand.

Backing Sand

Molding sand used to back up facing sand and not used next to th pattern.

Bonding Sand

Sand high in clay content used to add clay to a molding sand.

Sharp Sand

A sand substantially free of bond. The term has no reference to grain shape. Lake sands are sometimes referred to as sharp sands.

Sand Additive

Any material added to molding sands for a special effect.

Loam

A mixture of sand, silt, and clayey particles in such proportions as to exhibit about 50 per cent sand grains and 50 per cent silt and clay. A material used for loam molding of large gray-iron castings.

Dry Sands

Preceding sections were limited in discussion to the nature of green molding sands. Dry-sand molds have certain desirable features, namely, greater strength and rigidity, thermal stability, and the elimination of defects attributable to water in the sands. Large and heavy castings, because of metallostatic pressure on the mold and the long period during which they may remain molten, require exceptional thermal stability of the mold. Certain metal defects, such as pinholing, can be eliminated in troublesome castings if the mold is dried.

Since the sand is green for molding, its properties are similar to those discussed for green sands. Usually, the sand is tempered on the wet side because this brings out additional dry strength, as was illustrated in Fig. 5.11. Certain ingredients may be added for special effects. Silica flour is extensively used for added hot strength and resistance to erosion. Pitch is often used for greater strength and improved surface finish of iron castings. Some of these variations are indicated in Table 5.11, where some dry-sand molding mixtures are listed. These sands are greatly dependent for their dry strength on their clay and water content and the hardness to which they are rammed.

Mold Coatings

For some castings, the sand surface of a mold is altered after the pattern is drawn by applying a mold surfacing material. This material is called a mold wash, mold coating, spray, blacking, or similar name. The benefits claimed for their use include better surface finish, greater ease of cleaning the casting, and fewer casting-surface defects. Application to the mold surface is usually done by spraying, swabbing, or painting

Table 5.11 ***Examples of dry-sand mixtures***

Sand type	Sand green base	Clay binder	Other additives	Comments
Steel, general facing.	Silica sand, 40–60 AFS fineness	7% western bentonite	14% silica flour, molasses water	Temper heavy w water and use s ficient dextrin or n lasses; bake at 60(until dry
Steel, heavy.........	50% new silica sand, 40–60 AFS fineness, 50% reclaimed system sand	7–8% fire clay, 1–2% western bentonite	2–3% silica flour	Temper heavy w water; bake at 65(until dry
Gray iron, general...	40% new silica, 50–60 AFS, 60% old sand of same source	3–6% western bentonite	1.0–2.0% pitch, 1.0–1.5% cereal	Temper to good wo able moisture. T: ical sand properti 8.0–10 psi green strength, 90–120 p meability, 4–5% moisture. Bake 350–450 F
Steel, air-dry........	New or reclaimed silica sand, fineness 40–60 AFS	3.5% western bentonite	5% silica flour, 1.25% cereal	3.5–4.5% moisture, air-dry open mold

of wet materials and sometimes by dusting dry materials. Mold coatin which have been found useful are listed in Table 5.12. Generally, it simpler for foundrymen to purchase proprietary mixtures than to m their own washes. The coatings listed in Table 5.12 are suspended water. However, many mold washes are made which use liquids su as kerosene, some core oils, or other organic media of suspension.

Other Molding Aggregates

This chapter has largely been concerned with green molding san Some other aggregates such as core, shell, air-set, and silicate-bond

Table 5.12 ***Water-base mold coatings***

Description	Western bentonite	Silica flour	Graphite	Dextrin	Cereal	Water	Remarks
General purpose......	1.5%	59.4%	....	1.5%	....	37.5%	+0.1% sodi benzoate
Cast iron............	0.8%	....	31.1%	1.30%	....	66.7%	+0.1% sodi benzoate
Cast iron and brass....	4 parts	....	100 parts	......	4 parts	100 parts	+0.1% sodi benzoate
Steel................	4 parts	100 parts	....	3 parts	....	100 parts	+0.1% sodi benzoate
Gray iron............	......	....	x	......	....	x	Slurry testing 35–40 Bé