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Sand Binder Systems

Technical Paper

ASK CHEMICALS

Part II: Resin/Sand Interactions

Second of a 13-part series filled with useful and up-to-date information about sand binder systems.

There are certain things about foundry aggregates (sand) that need to be understood before the physical and chemical relationships between sand and resin binders can be examined. When something comprises 97–99% of anything it has a significant influence on the minor constituents. So, as you might suspect, foundry sand has a dramatic influence on the properties of the 1 or 2% of binder that it's mixed with and it has great impact on the properties of the cores or molds made from it.

In this second of ten parts we will examine the interaction between binder systems and foundry aggregates, and answer the questions that follow. How and why does a particular aggregate enhance or detract from the performance of the resin system in terms of resin reactivity and bonding performance? Which sand properties cause variations in core and mold quality and production? What's the "real cost" of the sand you use? Why consider alternative aggregates (see Table I) such as zircon, chromite, olivine, and carbon sand?

Table I - Comparisons of Foundry Base Sands

	Silica	Zircon	Chromite	Olivine	Carbon
Origin	USA	USA, Australia, N. Africa	S. Africa	Norway, USA*	USA
Color	White-Light Brown	White-Brown	Black	Greenish Gray	Black
Dry Bulk Density (lb/ft^3)	85-100	160-185	155-165	100-125	70
Grain Shape	Angular/Rounded	Rounded Angular	Angular	Angular	Rounded
Thermal Expansion @ 1600° (in./in.)	0.018	0.003	0.005	0.008	0.004
Fusion Point (°F)	2600 - 3200	3700-4000	3200-3600	2800-3200	None
Chemical Reaction	Acid-Neutral	Acid-Neutral	Basic-Neutral	Basic	Acid-Neutral
Grain Disribution (# Screens)	2-5	2-3	4-5	3-4	4
AFS Grain Fineness Number Ranges	25-180	95-160	50-90	40-160	65-90

*Washington, N. Carolina

Grain Distribution

A foundry aggregate (sand) is composed of innumerable particles ranging in size from 0.083–0.002 in. in diameter. Relatively speaking, these particles are "bigger," "average," and "smaller," with some particles so small they don't qualify as anything but powdery silt.

Separating the grains into eight segments by letting a representative sample fall through a series of screens with openings that get increasingly smaller, and plotting the individual weight of the fractions to form an xly graph of particle size versus individual weight will give a bell-shaped curve that represents the "Grain Distribution" (by size) for that sand.

A foundry sand with a minimum of powder-like grains is best because powder is very different, both chemically and physically, from larger grains. Fine sand tends to restrict interstitial paths through the sand, hindering the ability of gas generated from binder decomposition to pass between grains. The smaller particles also soften sooner than the larger ones, which can be good for expansion control, but bad for stability. Most importantly, fine sands have a surface area as much as 20 times that of coarser grains, thus requiring a disproportionately large amount of binder to cover the surface.

The critical thing about grain sizing is that the ratio of the sizes remains constant. Otherwise, the amount of resin required to uniformly coat their surfaces varies dramatically. Table II lists the surface area and bulk density of the sand fractions within a "screen distribution," and illustrates that smaller sand particles need more resin to cover them.

The larger the number of coated sand grains (with the proper grain distribution) that can be compacted into a given volume by fitting smaller grains between adjacent coarser grains, the stronger the core or mold and the better the surface finish of the casting. This is a key issue for precision sand casting production.

Table II - Density and Surface Areas of Carious Fractions of Rounded Grain Silica Sand

Mesh Size Passing	Retained	cc/gm	ft³/lb
20	30	50.16	24.48
30	40	70.95	34.63
40	50	100.31	48.96
50	70	142.05	69.33
70	100	200.09	98.05
100	140	284.09	138.65
140	200	401.81	196.11
200	270	568.18	277.31
270	325	742.12	362.20

Sand Segregation

Virtually every time a mass of sand particles are thrown, blown, piled, or discharged through any point not equipped with an anti-segregation device, it tends to separate or "unblend" into distinct segments of similar particle size. This phenomenon is known as sand segregation.

Segregation occurs because different sized and shaped particles tend to fly, roll, and travel differently. When blown out of a discharge orifice, larger grains travel a longer distance due to their greater mass and momentum. Then, when being discharged from the silo, the larger, rounder grains tend to roll, while the smaller, more angular ones tend to slide.

When flowing down a sloping sand surface and into a discharge hole, the lower mass of the smaller grains causes them to move further.

Relative particle shape also segregates large and small grains. For example, bigger grains tend to be more rounded and the smaller ones more angular or jagged. Angular particles lockup, so they neither slide nor compact as well as round ones do.

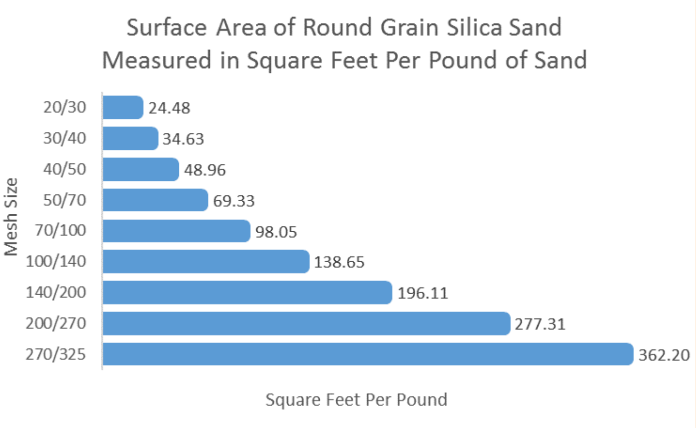
Sand also has the peculiar property of draining out of a discharge hole with only the sand grains directly over the hole moving down and out through it. This causes a "sand pipe" to form directly above the hole; extending all the way through the sand to the top of the pile. Grains adjacent to the pipe of moving sand grains tend to remain in place. As the pipe continually empties it is filled with more sand directly from the very top of the pile. As grains fall into the sand pipe hole, a cone-like funnel of sand forms at the top of the pile. It is centered directly above the discharge hole, with its sides at a 30 to 35° angle of repose.

As the sand continues to drain out of the sand pipe, grains on the surface of the funnel roll down it and into the drain hole (rathole). The rolling grains on the funnel surface spurt differing quantities of varying grain sizes into the drain hole, with the coarse, medium, and fine particles rolling together, with the smaller angular grains locking up onto the surface and the larger, rounder ones rolling more easily.

This non-uniform discharge of sand with constantly varying surface area results in fluctuating binder coating requirements. Since a constant amount of resin and catalyst are continually being applied to the sand's surface, the result is cores and molds that are unpredictably too weak or too strong because too much or too little resin is applied to the surface area of the particles being coated. Fig. 1 illustrates the typical surface area that exists on the sand surfaces of each fraction of the standard AFS/GFN screen distribution.

Besides strength variation, sand segregation often changes the catalyst requirements since the chemistry of smaller particles, which have the greatest effect on acid demand value, generally varies dramatically from that of the larger ones.

Fig. 1



Grain Surface Shape

Foundry grain shapes are classified as "compounded" (little grains sticking together to make a larger grain), "rounded" (like rough marbles), "sub angular" (not round, but not jagged), and "angular" (jagged).

Binders should provide a uniform coating that completely covers the grain surface to a uniform thickness. Rounder grains tend to coat better, need less resin, flow better, and give denser cores and molds, but they also can expand and cause veining defects.

Based on 2–3 gallons of resin being applied to sand with a surface area equivalent to 4.5 football fields per ton, it's amazing that billions of grains can be consistently and uniformly coated with a resin film only 1/10 the thickness of a human hair. Because angular grains are rough and jagged, about 25% more resin is required for adequate coating than for rounded grains (see Fig. 2).

More resin means more gas, more cost, and poorer coated sand flowability.

Fig. 2a - 70 GFN coarse carbon sand (American Colloid)

Fig. 2b - 80 GFN Japanese sand

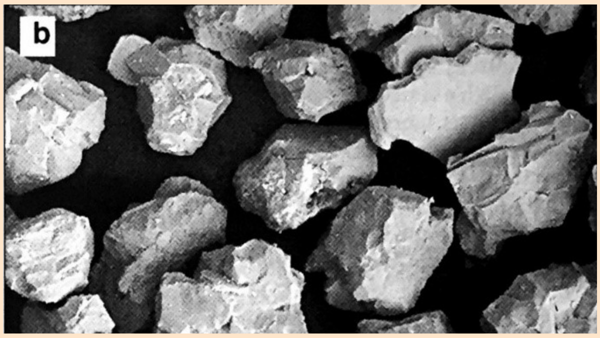


Fig. 2c - 80 GFN Texas sand

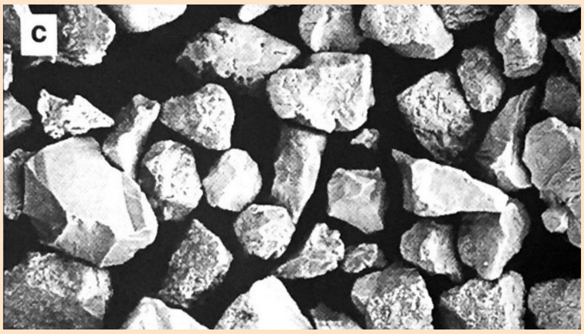


Fig. 2d - 90 GFN Oklahoma sand

Fig. 2e - 70 GFN California sand

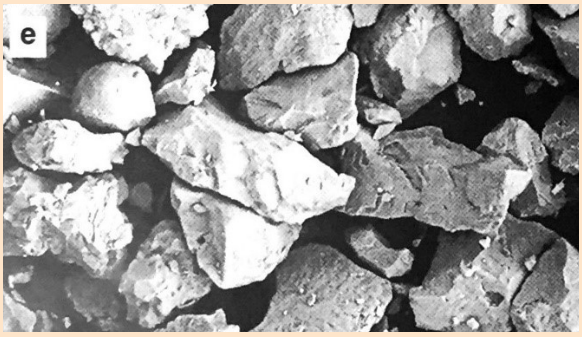


Fig. 2f - 65 GFN Illinois sand

Surfaces can vary from one type of sand to another (see Fig. 2). The round, smooth surfaces requires minimum binder to cover the surface with a uniform film thickness. The rough, angular surfaces require considerably more binder.

Chemistry

With the notable exception of olivine, the surface chemistry of larger foundry sand particles is neutral. Very little of the highly acidic or basic sand constituents are generally found on the surface of larger grains. Most of the “strange chemical elements” of foundry sand exist in the very fine particles– those which pass a 140 mesh screen.

The Acid Demand Value Test (ADV) is a titration procedure that gives a quantitative indication of the amount of acidic or basic material present in the sand mass. It is the industry standard. The catalyst component of the binder systems is generally the component that is adjusted to compensate for unusual chemistry. Sand constituents that undergo chemical transformation upon exposure to thermal reclamation temperatures, like calcium carbonate turning into lime, are a special consideration when thermally reclaiming lake sand.

Sand pH Test

pH is another indication of impurities found in sand. Although it is easier to run than ADV, it can be confusing since it only indicates the presence of water soluble elements in the aggregate and does not always correlate with ADV values.

Contaminants

Contaminants, or impurities, are anything different from the base aggregate. Impurities color silica sand, increase binder requirements for acceptable handling strength, and necessitate catalyst adjustments.

However, they might offer benefits like expansion cushioning, lustrous carbon minimization, and gas defect control. Strangely enough, impurities, like iron oxides and clays, might actually be advantageous from the casting producing standpoint, while other things like carbonates cause tremendous problems in thermal reclamations.

Table III lists the typical chemical impurities found in relatively pure silica sand and compares them to those found in lake sand, which is utilized by automotive foundries as their base sand. As long as the user of the sand is aware of the nature and quantity of the impurities, binder system and process adjustments can be made torn accommodate them.

Table III - Typical Chemical Consituents of Beneficiated Lake Sand and Silica Sand

	Lake Sand	Silica Sand
SiO^2	94.122	99.800
Fe^2O^3	0.483	0.011
Al^2O^3	2.370	0.050
K^2O	0.110	0.003
Na^2O	0.760	0.007
CaO	0.522	0.010
MgO	0.240	0.003
LOI	0.343	0.036
Fusion Temp. (°F)	2775	3125

Sand Permeability

There are two truths in producing defect free castings from resin bonded sand cores and molds. You can never vent enough and you can never have enough permeability in the resin coated sand. Impurities reduce permeability and necessitate more resin for adequate handling strength.

The amount of sand present on the screens finer than 140 mesh should only be high enough to control ferrostatic head induced penetration– typically less than 1.0%. Excessive fines may be an indication of poor handling during loading, shipping, unloading, or transport within the foundry.

Lack of permeability is one of the most negative aspects of utilizing higher AFS/GFN sand to improve casting surface finish. It is noteworthy that permeability testing data is not generally supplied, or tested for, as part of incoming shipment quality control due to rather poor test reproductivity.

Moisture

Water in any amount is bad for the resin's chemical reaction. When there is moisture from any source– binders, catalyst, additives, pattern surfaces, high relative humidity, etc., it needs to be addressed.

Water present in sand poses the greatest problem. Moisture from any source must be recognized and may need to be adjusted for in core and mold making processes. When there is more than 0.2% moisture found in the sand in winter and more than 0.1% in summer (because of the 10°C rule), it slows the reaction and produces a weaker resin bond.

When hot, damp air cools as moisture and condenses onto the surface of relatively cool sand, it normally goes undetected. This can lead to problems during the spring, fall, or rainy periods in summer. It impedes the binder/catalyst reaction when it condenses onto the raw sand and causes humidity degradation when it condenses onto and into a cold core or mold.

Durability

The ability of silica sand to be transported around the foundry, or make a core and mold, or be reclaimed without the grains losing their shape or breaking apart is durability. There are three ways the foundryman looks at durability.

- Thermal Shock Durability – This is a notable consideration in the metal casting process and in thermal reclamation. It is primarily related to the interior of the grain itself. The presence of impurities can change thermal expansion characteristics and the way expansion forces work on stress planes and points in the grain. The stress points and cleavage planes, formed when the sand cooled from magma, cause the grains to shatter or split when heated.

  Thermal shock durability can be assessed by looking at the sand under a light microscope and observing its color. Colored grains indicate the presence of various compounds that were included when the magma forming the sand cooled and solidified.

- Crushing or Splitting Durability – This is important in handling, coating, reclamation, and casting. Some sands are very friable, making them poor core and mold making aggregates. Microscopic granular examination under polarized light can reveal cleavage planes and stress cracks that indicate a tendency to split and/or crush when stressed.

- Surface Durability – This relates to how the grains attrit, or round-off, when blown or otherwise transported before or after coating. Surface durability really becomes a consideration when mechanical reclamation is utilized, or when the sand is transported or handled. Although smaller and powder-like grains can further disintegrate, these durability characteristics refer to larger and medium sized sand grains in the distribution.

Density

The more grains of resin coated sand you can cram into a given volume the higher the density and the stronger the core or mold will be. Round grains compact well and can provide about 8–10% greater density than angular sand.

Higher density solves many handling and casting problems, but it might lead to expansion defects and a reduction in permeability that could yield gas defects. When the density of an approximately 50 AFS/GFN silica sand core or mold is greater than 1.55 gm/cc surface penetration defects are rarely a problem. When the density of the core or mold making the casting is less than 1.40 gm/cc the casting will probably be scrap.

Expansion Properties

If silica sand has one drawback in foundry applications, it is the fact that it expands about 0.018 in./in. at its peak expansion temperature of 1,250°F. The thermal expansion is relatively smooth, but combined with the three abrupt silica crystalline phase changes, the growth stresses and cracks cores and molds.

Alternative foundry sands do not undergo multiple crystalline phase changes and have considerably less thermally induced expansion (olivine=0.005, chromite=0.004, and zircon=0.003 in./in.).

Heat Transfer

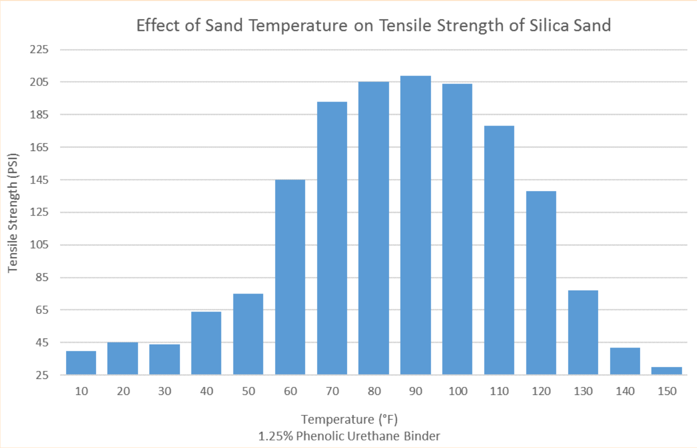
Sand aggregates are remarkable materials in terms of heat transfer and heat capacity. By way of oversimplified explanation, heat is transferred through sand primarily at grain contact points at a rate based on the coefficient of thermal conductivity and heat capacity of the aggregate. When the heat capacity is reached the grains begin to effectively transfer the heat to the ones at a lower temperature at a rate dependent on how efficiently the heat passes through the particle.

Silica has high heat capacity and moderate thermal conductivity. It absorbs a lot of heat and transfers it at a moderate rate through surface contact points on its crystalline grains. Olivine sand, considered “insulating,” has a high heat capacity and low thermal conductivity, absorbing a lot of heat and transferring it rather slowly through its amorphic crystalline structure. Both zircon and chromite have low heat capacities and relatively high heat transfer rates and are considered “chilling-type” aggregates.

Sand Temperature

A resin system cannot produce a quality core or mold without sand temperature control. Binder systems operate efficiently within a rather narrow range of temperatures, and many so-called “sand problems” are really temperature problems. Temperatures above 100°F or lower than 50°F cause innumerable process inconsistencies that result in a weak core or mold with low density. Fig. 3 is an excellent illustration of what sand temperature control means in terms of phenolic urethane no-bake strength.

Fig. 3



The “Real Cost” of Producing Castings from Resin Bonded Sand Cores and Molds

Except for some alloys, the resin binder system, on a per pound basis, is the greatest single raw material expense in a foundry. Some foundrymen think that applying expensive chemical binders to cheap sand will somehow lower their core and mold costs. Nothing could be less correct!

Although the binder is only 1–2% of the core or mold, you can benefit from binder reduction far more than you can from just about any other thing. You cannot measure real and total cost by simply calculating the raw material cost of a core or a mold. You need to determine the cost of the casting. You can make a better casting far less expensively with good sand than with cheap sand. Good sand takes far less binder and provides consistently superior, defect free results with a real benefit cost savings for using less binder, less catalyst, and less cleaning room labor.

What is your real core and mold cost in terms of productivity, quality, and reputation?

References

Fig. 2: ASK owned pictures

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