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Sand Binder Systems



Technical Paper

Part I: Practical Aspects of Resin Binder Processes

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

Whenever binder-related training sessions are held, a lot of discussion and interesting questions arise. Following is a list of most frequently asked questions (in no particular order). It could very well be entitled, "The Foundry Industry's Top Ten Questions about Binder Processes."

1. How much tensile strength is enough to make good cores and molds, as well as good castings?
2. What is the most often encountered binder process or resin-related defect?
3. Which is the most important part of the process to control?
4. Which binder system makes the best castings?
5. Which process is easiest and/or cheapest to run?
6. Which process or resin system is the "best" from an environmental standpoint?
7. What kind of sand and quality control tests do I need to run on my resin coated sand process? Does reclamation change the tests that need to be run?
8. Should our plant run more than one binder system? How does a green sand system react to having different chemical binder systems mixed in with it?
9. What problems do I have when I recycle and/or reclaim and/or reuse my resin binder system? Which system, if any, is the best one to do that with?
10. What kind of adjustments do I have to make to my green sand system if I want to use the reclaimed sand for core production?

These are 10 excellent questions. Some may appear to have simple answers. However, none of them is easily answered.

In this technical paper's entirety, this series will provide the answers to these, and other binder questions. In the last installment, we will answer each of the 10 questions or, in some cases, offer an opinion based on the expertise of the co-authors.

Binder Systems Are Really Part of a Process

As strange as it sounds, foundrymen don't make a core or mold with sand or resin or machines or even people— you make them with a process.

The "magical" transformation of a foundry binder system's sticky, resin coated sand into a predefined, dimensionally accurate shape appears so simple to the operating foundryman that he thinks little about the process. This process is rarely thought about until something goes wrong with it.

Foundry cores and molds are made utilizing resin coated sand prepared by a number of different processes that use all sorts of different binders with unique chemistries; catalysts of varying strengths and physical forms; sands of different purities and chemical compositions, size distributions, and grain shape; all sorts of additives; simple to sophisticated machinery; and people who have very different backgrounds, experience, and expertise.

Process Understanding Leads to Positive Change

The old adage "if it ain't broke don't fix it" probably had merit in the 1960s and even the 1970s. However, that attitude has proven to be a real detriment to manufacturing in the 1980s. In the 1990s continuous change is so evident in leading manufacturing operations that it is normal and expected.

Although rather gradual change has been occurring in core and mold making operations since World War II, significant change resulted from the first oil embargo in 1973 and especially from the second oil embargo in 1979. These events created a sudden awareness of the energy requirements utilized by processes in our manufacturing sectors. "Energy efficient" became the buzzword and a benchmark for any manufacturing system.

The beginning of the energy efficient 1980s coincided with the maturation of no-bake and cold box core and mold making processes. Consequently, smaller, more flexible foundries quickly switched to these technically refined and energy efficient processes. Large, capital intensive operations could not change immediately, but they started to engineer all future programs with energy conservation as a primary consideration.

The North American sales of heat activated binders started to decline as the conversion to energy efficient and room temperature cured binder systems progressed. The year 1979, when the sales of room temperature binders surpassed the heat activated materials, marked the beginning of a new metalcasting industry that was willing to change to more efficient and technically advanced core and mold making systems.

The era of environmental awareness and corporate liability followed that of energy awareness into the mid and late 1980s. Foundrymen started to look at their binder systems in a different way. Now "exposure limits," "long term affects," and "disposal" were the buzzwords. To the foundryman, the primary binder process consideration became environmental impact, government regulations, fear of lawsuits, and long term liability. These issues seemed even more important than efficiency, cost, or even product quality!

The Clean Air Act Amendments were legislated in 1990. The legislation created the most expensive regulatory burden ever passed on to the manufacturing sector, and it became the biggest driver for binder process selection and process component modifications. Virtually every component of every foundry process, particularly resin binder systems, has been modified to meet new air, water, and solid discharge standards. Almost every change has resulted in increased cost, reduced efficiency, and significant process conversion expense.

The metalcasting industry has painfully but successfully dealt with all these changes.

Causes of Process Variation

The most important thing to establish in any process is consistency. Once consistency is established, variation can be detected and measured.

Each resin binder process is affected differently by things that don't seem to be a part of the process. Some of these parameters include ambient temperature, pattern surface temperature and cleanliness, temperature and viscosity of resin components, moisture from any source, contaminants, unexpected temperature changes, and not-so-apparent elements of resin bonded sand core and mold making processes. Even weather conditions are significant.

To have a process run under control, each component of that process must be clearly identified. Then the effects of subtle or dramatic variations in these components must be fully understood.

We'll look at these seemingly insignificant, but important, elements that operate within and outside of the process— the things that need to be identified, watched, and controlled in order to make the process run consistently. Some are obvious, but most are not. These elements can exert a degree of influence that can vary dramatically from system to system.

Practical Considerations for Controlling Variances

The following is a partial list of the more important variables that can affect binder process performance. Although these will be discussed when the individual systems are covered, these elements are common to each system and important enough that they should be summarized at this point.

Sand: Some of sand's important characteristics are grain shape, smoothness of grain surface, screen distribution, sand density, contaminants, and grain fineness number (GFN). Most foundries are looking at finer sands are you? Are you reclaiming a poor grade of sand? If so, why? It's not cheaper in the long run.

Sand Segregation: Sand always segregates when it is moved. Unless this phenomenon is controlled it can cause more "unexpected" process variation than any other aspect of core and mold making. Martin Marietta's movie explaining the causes and effects of sand segregation is strongly recommended.

Sand Transport: You should make every effort not to air transport sand for great distances. It's bad enough that most sand is blown into sand storage silos from bulk transports, but when sand is blown through a series of bends, it really gets banged up. Figs. 1a & 1b give a comparison of an angular sand after it was conveyed a long distance through closed circuit steel piping by high pressure air. Note the particles of fine sand debris in Figure 1b that resulted from the grains banging together and breaking apart. To minimize sand surface attrition utilize belts, bucket elevators, or low air volume air transport systems.

Fig. 1a



Fig. 1b



Temperature: Although temperature has tremendous effect on all resin processes, it is, undoubtedly, the most important operating parameter in any no-bake process. Remember that temperature is, in effect, a catalyst for the no-bake processes and determines performance characteristics of heated pattern processes.

Temperature Ranges: Heated pattern processes need to be controlled to 50°F across the pattern surface. No-bakes should operate between 70° and 100°F. At temperatures above 100°F solvents in the binders evaporate prematurely and the coating gets gummy. The result is blowability problems. At temperatures lower than 70°F the resin component becomes very viscous, making it difficult to pump and especially difficult to mix with the catalyst and other component chemicals.

The 10°C (18°F) Rule: Each 18°F increase in temperature causes the resin to react twice as fast. Each 18°F decrease causes the resin to react half as fast. Therefore, each 18°F change in the operating temperature of a no-bake binder system causes the no-bake work and strip time to be doubled or halved.

Blending Resin with Other Liquid

Components: Most metalcasters think the most difficult aspect of coating sand is smearing the resin over the surface of the sand grains. Not me! The toughest thing about properly coating sand is mixing the binder with other liquid components such as catalysts and/or coreactants.

Accurate proportioning and rapid mixing of components is especially difficult when the sand surface is cool, and nearly impossible if it is under 50°F.

In-line Resin Heater: An in-line heater incorporated into your incoming resin line, just before the pump, helps control resin temperature, resin viscosity, and component blending. Although many commercial units have been sold for this purpose, it's simple to make your own heater with an electric direct immersion heater, which should have the cal rod sized for the volume throughput of your pump based on the heating energy requirements of a 40 viscosity motor oil.

Sand Heaters: Do you run your sand heater at the same temperature all year long? You should adjust it four times a year. In the spring, summer, and fall the heater should be set for the highest expected ambient temperature of that season, and in the winter for some reasonable temperature-like 70° to 80°F.

Sand Heater By-pass: Do you have a sand by-pass around the sand heater so that it does not operate when unneeded? Compressed air fluidizes the sand in order to transport it through the sand heater/cooler. But compressed air is eight times the cost of electricity per unit horsepower and should only be utilized when necessary. Just cut a hole in your day silo and weld a pipe to the hole during the next shut-down to by-pass the heater.

Sticking: Core and mold making productivity is hindered by sticking more than by any other single factor. Experienced machine operators know this all too well. Sticking doesn't just happen. It begins when a few gummy sand grains remain because they aren't as well cured as those that pull away with the core or mold. Once it starts, it worsens progressively as sand builds up on the surface of the pattern. Eventually, the core or mold making process slows down because the surface being produced is too rough to be acceptable, or it breaks, or it will not easily part from the tooling surface. When any of these things happen, "sticking" is said to have occurred.

An excellent way to counter sticking on no-bake patterns is to use a release-soaked paint-store mitten (with a rubber glove insert to protect the skin) to apply release agent to the sticking areas. This concentrates the release in areas where it is needed and has the additional benefit of rubbing away the few grains that initially stick.

Pattern Temperature: When they know the tooling is cool, experienced operators "turn up the catalyst" on nobakes, gas longer with cold box, or just throw away the first few cores. Low temperature is rarely a consideration with heated pattern processes, but low pattern surface temperature can be a serious problem with no-bake systems. The best way to counter sticking is to stop it before it begins by heating the surface of the cold box and no-bake pattern.

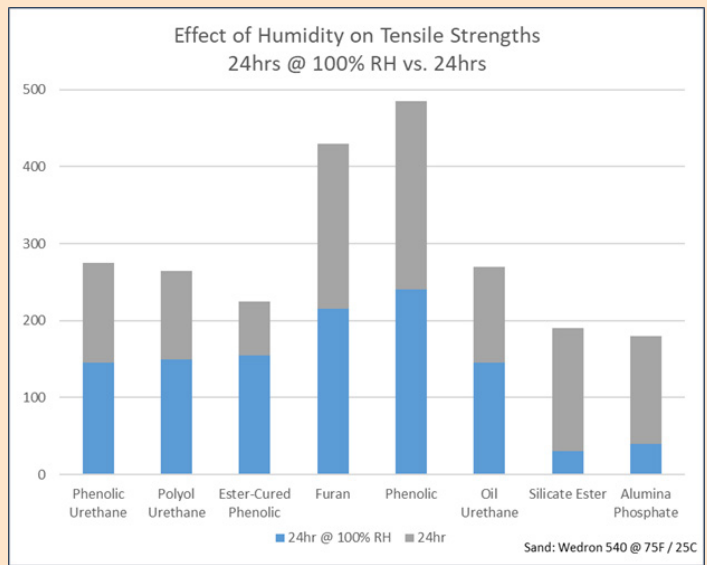
A space heater blowing on the nobake tooling can heat the pattern surface and, with the addition of a couple of fans, the work area as well. It is also a great idea to preheat your cold box tooling with your heated purge air. Nothing starts off a cold box process better than warm tooling (about 125°F).

Moisture: Moisture can be a real enemy of many resin binders. Its effects, in combination with hot sand and high ambient temperature, are especially devastating to binder performance. The impact of the 10°C (18°F) rule previously mentioned is multiplied when moisture becomes a consideration.

Vendor recommendations regarding moisture are based on laboratory testing performed at 72°F, and 36% relative humidity. Their published results are not based on foundry conditions of 100°F and 100% relative humidity. To convert lab results to conditions in the foundry, apply the strength loss from the laboratory moisture test, double it for the increase in temperature, and double it again for the increase in humidity. In other words, the effect of moisture on a rainy, hot summer day at 90°F might be four times the loss in strength compared to laboratory values obtained at 72°F and controlled 37% relative humidity.

Humidity: All binder systems lose strength when exposed to 100% relative humidity conditions. Fig. 2 shows the amount of tensile strength loss that occurs after a 24 hour exposure to 100% relative humidity (typical of a rainy day situation).

Fig. 2



Another thing to keep in mind is that cooler-than-ambient-temperature sand causes moisture to condense on it. Moisture definitely condenses onto cool sand when the humidity is high and the temperature drops.

Binder Classifications and Categories - A comprehensive explanation of resin systems cannot be considered complete without the following tables:

Table I: The year that the hinder systems that are still being used in large seale commercial production were introduced into the market.

Table II: Shows the past, current, and future sales of binder systems in North America. In 1960 there were only silicate, shell, and core oil with core oil as the major system. 1980 shows shell at its peak, no-bakes well established, and cold box starting; at this point the room temperature cored process has just passed the volume of heat cured systems. With the exception of shell, which had become stable with its very broad small used base, 1990 shows dominance by the room temperature cured systems and the real emergence of the phenolic urethane cold box process. The forecast for binders into the next century shows expanding markets for cold box and the new binder processes. However, unknowns could upset these forecasts. Further and severe reduction in the formaldehyde standard might eliminate hot box, the SO₂ system might capture a larger segment of the cold box market, or some-one might develop an inorganic that really works like an organic.

Table III: Classifies the systems by cure mechanism- acid, base, or other.

Table IV: Classifies them as "Heat Cured", "Cold Box", and "No-bake."

Remember - Resin hinders are not stand-alone materials. They are a part of a process and will work only as well as the process itself.

Table I - Core and Mold Processes DI and GI	
Aproximate Commerical Introduction	Process
1950	Core Oil
1950	Shell; Liquid and Flake
1952	Silicate/CO ₂
1953	Airset Oils
1958	Phenolic Acid Catalyzed No Bake
1958	Furan Acid Catalyzed No Bake
1960	Furan No Bake
1962	Phenolic Hot Box
1965	Oil Urethane No Bake
1967	Phenolic CO ₂ Cold Box
1968	Phenolic/Urethane/Amine Cold Box
1970	Silicate Ester Catalyzed No Bake
1977	Furan SO ₂
1978	Polyol Urethane No Bake
1978	Warm Box
1982	FRC SO ₂
1983	Epoxy SO ₂
1984	Phenolic Ester No Bake
1985	Phenolic Ester Cold Box
1992	Alumina Phosphate

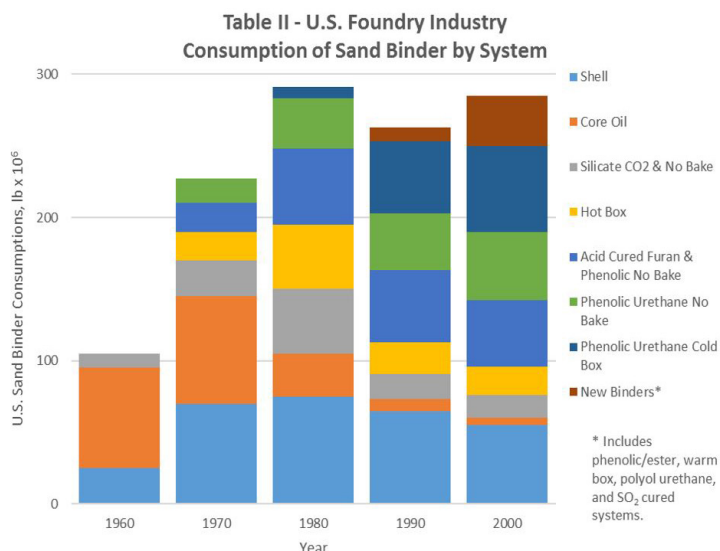


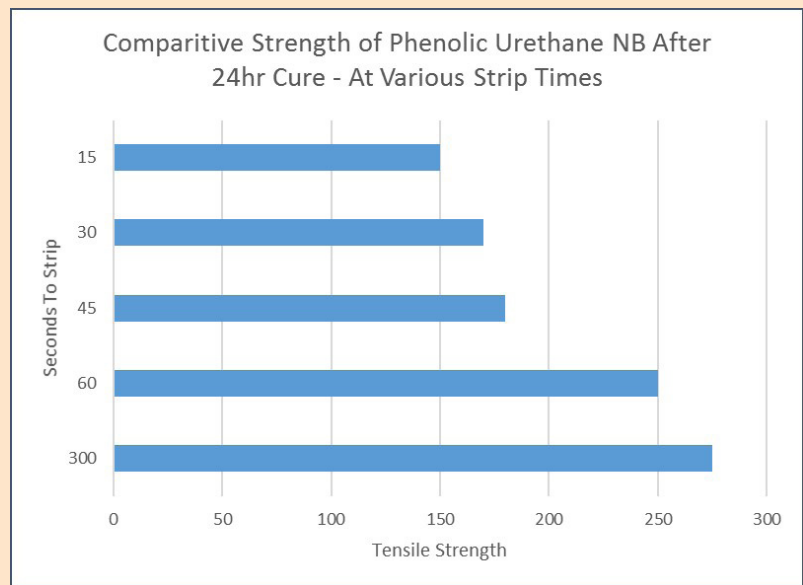
Table III - Foundry Core Binders		
No Bake	Cold Box	Heat Cured
Furan & Phenolic/Acid	Acrylic Epoxy SO ₂ (FRC)	Hot Box - Furan & Phenolic
Phenolic/Ester	Furan SO ₂	Warm Box - Furan & Phenolic
Oil Urethane	Phenolic Urethane Amine	Shell
Phenolic Urethane	Aester Cured Phenolic	Core Oil
Polyol Urethane	Sodium Silicate CO ₂	Aluminate Silicate
Alumina Phosphate	Phenolic CO ₂	
Silicate Ester		

Table IV - Foundry Core Binders			
Acidic		Other	Basic (Alkiline)
Silicate CO ₂ (dehyd+acid).	SO ₂ Acrylic/Epoxy (slight acidic, FRC/acid)	Silicate NB (basic) -Saponification -Dehydration	Phenolic Ester NB -Potassium Salt Residue
Warm Box	Furan Acid NB		Phenolic Ester CB
Phen/Furan		Shell (neutral) - Hexa Addition	(Addition)
Hot Box Phen/Furan	Phenolic Acid NB	Core Oil (neutral/oxidation)	Oil Urethane NB -Urethane+Oxidation
SO ₂ Furan	Phenolic CO ₂		Phenolic Urethane Amine NB & CB -Slightly Basic -More Catalyst/More Basic
			Alumina Phosphate (acidic to start, pH goes >2 to 5)

Ovens with too little air volume circulation act like a steam bath for resin bonded cores and molds. The lower the drying air temperature the better. Some foundries use ovens with very high volumes of air heated to less than the boiling point of water to dry water-based refractory coating. When comparing hot and cold tensile strength of no-bake binder systems after being coated with a water-based wash and then dried at 450°F you will see a significant loss in handling strength at the elevated temperature. A vacuum chamber drying booth set over a conveyor line is a unique and effective way to remove refractory coating carriers and residual solvents from water sensitive cores without subjecting them to a harmful steam bath.

The “Price” of Rapid Curing: Few foundrymen realize that the slower you cure a resin binder (within reason), the greater the resin bonded sand’s strength and humidity resistance. The increases in strength of a given binder system using a slower cure speed is illustrated in Fig. 3. It illustrates how a phenolic/urethane no-bake using a fixed amount of binder and the same sand is considerably stronger when the curing reaction is slowed.

Fig. 3



The relatively low humidity degradation resistance of the “instantly cured” amine vapor catalyzed phenolic/urethane cold box is, in all probability, due to the differences in curing rates.

Sand Additives: These need special consideration. Know their physical properties and what they are supposed to do for the process. How long have you used a particular additive? Has purchasing changed suppliers of the material thinking it’s “all the same?” Is there nothing better on the market now?

Refractory Coatings: More problems are caused by misapplication of refractory coatings than are solved by their use.

There are five keys to the successful application of a refractory coating:

- The penetration of the coating into the sand core or mold surface to a depth of two to three sand grains.
- Complete surface coverage with a thickness of one to ten mils of coating above the surface of the sand.
- Applying multiple coats of contrasting colors.
- Application of the coating to a warmed sand surface.
- Complete drying of the coating in as low a humidity and temperature as possible and with as much air volume as possible.

Lack of sufficient refractory penetration into sand voids and/or excessive thickness of the coating over the surface often results in spalling defects found in the cope areas of the castings.

Do you apply the coating to a cold surface? If you do, condensed solvents and moisture may create defects. Heat the surface before coating application and make certain that the wetting agent surfactant has been adjusted for the proper amount of penetration into the warmed sand surface.

Do you apply your coating at the correct time? The “right time” for cold box is “right away,” and for other processes the “right time” is when it has finished curing.

A forced air tunnel oven, simple quartz heating tubes or heating elements suspended above the sand surface as it travels on the roller conveyor, as shown in Fig. 4, are good ways to preheat the surface before coating.

Fig. 4



If the surfaces are to be “torched” it needs to be done with a flame mixed with compressed air. Heating the surface with the yellow flame from an unmixed natural gas line is slow, ineffective, and expensive.

Type of Refractory Coating Carrier: Because of environmental regulations all foundries will eventually convert to water-based coatings, but these require special curing and handling. When they are applied to cold surfaces they can create serious defect problems because moisture will condense on the sand behind the heated, relatively non-permeable coated surface and later contribute to gas related defects. Core and mold strength increases when light off washes are burned and decreases with water-based coatings that are applied and dried unless the surface is carefully preheated.

References

Fig. 1, 2, 3: ASK owned pictures

Fig. 4: Updated picture taken at Ashland Foundry & Machine

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