Foundry Sand Reclamation

An Overview of Foundry Mold Making Operations and a Review of Sand Reclamation Methods Including Emerging Electrotechnologies

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FOUNDRY SAND RECLAMATION

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BACKGROUND

Because of current environmental regulations, the disposal of waste foundry sand which may contain hazardous chemicals and/or metals has become difficult and expensive. One alternative to the dumping of waste sand is the sand reclamation process which "cleans" the sand to a degree sufficient to allow its re-use in the foundry operation. Several different reclamation processes exist which creates some confusion as to which system or combination of systems provide optimum results.

OBJECTIVE

As foundries represent a significant load to many utilities, this report has been prepared to present the basic principles of foundry molding and coremaking processes and the reclamation of these sands. The objective of this report is to provide the utility engineer with an overview of mold making operations and sand reclamation to assist in communications with his foundry customers and to enable him to discuss the use of electric fired sand reclaimers with the industry. Although there are few electric thermal sand reclaimers in use worldwide, these units do offer some unique advantages.

APPROACH

This report is based on a review of existing foundry literature and discussions with prominent foundry sand reclamation experts.
RESULTS

The report covers current molding and coremaking processes, both clay-bonded and chemically-bonded, describing the advantages, disadvantages, and unique characteristics of each. The report also covers the three principal methods of sand reclamation, mechanical, thermal, and wet, presenting the advantages and disadvantages of each. The report also covers recent advances in this technology and discusses the programs CMP is working on to develop and demonstrate electric fired reclaimers.
ABSTRACT

Current environmental regulations have created a situation where the disposal of waste foundry sand has become difficult and expensive. One solution to this problem is the use of a sand reclamation system which "cleans" the sand to a sufficient degree to allow re-use of the sand in the foundry sand system. A large number of sand binder systems are in use for various reasons of cost and performance characteristics. There are also three main methods of sand reclamation and combinations of these. A basic understanding of these technologies will allow a utility engineer to communicate better with his foundry customers.

The principal binder system used in foundries is bentonite clay. When properly mixed with sand and water, the clay forms an adhesive film around the individual sand grains allowing compaction to form a rigid mass. After pouring with molten metal, the sand is easily removed in a mechanical "shake-out" procedure. The main advantages of this system, known as "green sand molding" are high production capabilities and low cost.

Chemically-bonded, or "no-bake", sands use chemical binders that cure to form rigid molds by the use of heat and/or a chemical catalyst. These systems generally provide more precise dimensional tolerances and better surface finish; however, production rates are lower and costs higher.

Sand can be reclaimed by thermal, mechanical, or wet scrubbing processes. Thermal systems alone are adequate for the reclamation of chemically-bonded sands. Most thermal systems in the U.S. are gas fired; however, electrically fired thermal systems are in use in Canada and Europe. CMP is endeavoring to initiate a project to demonstrate an electric resistance sand reclaimer in a domestic foundry to introduce the technology to the American foundry industry.
Clay bonded sands require the combination of mechanical and high temperature thermal reclamation for greatest efficiency. A high temperature, infrared system is being developed with the help of EPRI/CMP for use in this application.
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Section 1

SUMMARY

Many different sand binder systems are in use in the foundry industry with each having its own unique set of cost/performance/quality characteristics. The vast majority of sand molds are made with clay-bonded, or "green" sand. Clay and water, and often other additives, are mixed with the sand, and mechanically or pneumatically compacted to form a rigid mold. Green sand molding provides high production rates and acceptable dimensional and surface quality performance.

No-bake sand systems use chemical binders that are cured either by the addition of a catalyst or the application of heat. These systems generally feature lower production rates, with excellent surface finish and dimensional tolerance capabilities. A very large number of different systems are on the market, each featuring different binder/catalyst chemistries; however, the basic principle of chemical curing is similar for all.

Some of the organic systems can pose environmental problems and careful selection and use is required. Binder chemistry is a rapidly advancing field, and the reader is advised to follow the trade literature or call the CMP foundry office for up-to-date information.

In recent years it has become increasingly difficult and costly for the operating foundryman to dispose of foundry waste sands, particularly if they contain hazardous chemicals and/or metals. A number of sand reclamation processes have been developed to minimize the amount of sand that requires disposal. The goal of all of the processes is to "clean" the waste sand to a sufficient degree to allow re-use back into the foundry molding and coremaking.
processes. Three primary types of reclamation systems are in general use:

- Dry Reclamation
- Wet Reclamation
- Thermal Reclamation

Dry reclamation systems utilize the mechanical attrition or scrubbing principle to remove clay and organic coatings. They can be used with all common types of sand; however, they do not achieve the degree of cleanliness attained with other systems.

The wet systems rely on a wet scrubbing action to clean the sand. While effective in cleaning, maintenance is high and water discharge is an environmental problem. These considerations have limited their application in recent years to sands employing water soluble sodium silicate as a binder.

Thermal reclamation systems heat the sand to temperatures high enough to burn off the organic binders. Thermal systems used in the U.S. are generally gas-fired, although electric thermal reclaimers suitable for processing chemically bonded sand are in use in Canada and Europe. Thermal systems are particularly appropriate for organically bonded sands, but the higher temperature gas fired varieties may also be used for clay bonded sands. Consensus among industry sand reclamation authorities is that a combination thermal/mechanical system will provide the best results overall.

EPRI/CMP is participating in the development of a high temperature infrared system for application with clay-bonded sands. In addition, CMP is working with the foundry industry in a endeavor to initiate a project to demonstrate
an electric resistance sand reclaimer for processing chemically bonded sands.
Section 1

INTRODUCTION

Due to environmental regulations, the disposal of waste foundry sand has become one of the most pressing problems for the foundry industry in recent years because of the high disposal costs encountered and difficulty in finding disposal sites. These considerations have been the driving force for the development of a number of technologies for the reclamation and reuse of waste foundry sand. Considerable research work continues, and the technology is fluid at the present time.

Because some of the reclamation technologies are based on electric heating, and because foundries represent a significant load to many utilities, this report has been prepared to present the basic principles of foundry molding and coremaking processes and the reclamation of these sands. While not intended to make a foundry engineer out of the utility engineer, the report should provide sufficient fundamentals to allow interaction with the foundry customer.

The report begins by reviewing current sand reclamation technologies. Industry consensus is that a combination thermal/mechanical system will provide optimum performance.
At the present time, thermal units in operation in the U.S. are gas fired. However, electric fired sand reclaimers are in use in Canada and Europe for processing chemically bonded sands. The EPRI Center for Materials Production is currently arranging a demonstration of this technology at a selected U.S. foundry.

The reclamation of clay-bonded sands (green sand) requires higher treatment temperatures, up to 1600° F. CMP is presently working with an innovative industrial organization to develop a high-intensity infrared reclamation unit. Initial research work looks very promising, and arrangements are being made to install a prototype unit in a production foundry.

Also included in the report are descriptions of the most common molding and coremaking processes and a short bibliography for the reader's reference.

As mentioned above, sand reclamation is a rapidly advancing area of foundry technology, and the reader is advised to refer to the foundry trade magazines for the most recent status of the process or contact the CMP Foundry Office.
SAND RECLAMATION

Introduction

The conventional metalcasting process, in which molten metal is poured into sand molds, exposes the bonded sand to high temperatures which burn out the binder and leave a residue which is detrimental to the reuse of the sand for making additional molds. In the past, this used sand was simply discarded. However, economic and environmental concerns now make it desirable to process the sand in a manner which makes it suitable for reuse in the foundry.

Sands and Binders

Although many types of binders and sands are used in the foundry industry, the vast majority of molds and cores are made using either the "Green Sand" process or the "Organic No-Bake" process.

The "Green Sand" process uses clay and water as the binder system. Generally the sand used is silica, and carbonaceous additions such as seacoal are often added to promote good surface finish. This is the type of sand/binder practice
used in high production operations such as automotive foundries.

The "Organic No-Bake" process uses chemically setting organic binders such as furan and phenolic compounds. Again, the most commonly used sand is silica, although specialty sands such as zircon and chromite are frequently used to promote good surface quality and accurate dimensions in the castings. This family of binder systems is used in jobbing foundries producing smaller numbers of castings from an individual pattern or design.

Definitions

Sand reclamation is the physical, chemical or thermal treatment of foundry sands so that they can be safely re-used in place of new sand in molding and coremaking mixes.

True reclamation treats and cleans all the individual grains within the sand mass, whereas reconditioning, as practiced when regenerating green system sands, treats and partially cleans the mass as a whole. Some forms of reclamation such as dry mechanical attrition are more like reconditioning than true reclamation as little work and cleaning is performed on the individual sand grains.

Function of Sand Reclamation
-- Reduce all lumps to sand grain size. The sand grain size distribution of the reclaimed sand should be the same as that of the new sand as purchased.

-- Remove all tramp materials such as metal particles, slag, refractory particles, etc.

-- Remove all binder coatings, either inert or active, from the grains.

-- Remove fines to an acceptable level.

**Satisfactory Performance**

-- Reclaimed sand must be dry and at an acceptable temperature.

-- Reclaimed sand must bond as well as, and have similar molding and coremaking properties, as the new sand.

-- Reclaimed sand must produce castings with quality equal to those produced with new sand.

Ideally, a sand reclamation system would process sand at a
maximum yield and return the sand in such condition that it
would be suitable for re-use with any binder while producing
castings with no defects -- and do all of this at low cost!
This is difficult and expensive to achieve, and in practice
compromises are made. For the majority of applications, a
small amount of residual bond and small amounts of impurities
can be tolerated. It is not possible for any one single
reclamation system to handle all the binder systems and
reclaim them well enough for re-use in all other systems. A
combination of two or more reclamation systems may be
required when multiple binders are used. Generally, the purer
and cleaner the reclaimed sand, the higher is its utilization
in mixes and the lower the requirement for new sand
additions (2).

Need for Reclamation

A number of factors have combined to generate a growing need
for sand reclamation -

-- The increasing cost of new sand and the need to
conserve available sources of high quality sand.

-- The increasing cost of used sand disposal. Dump
sites are becoming fewer, further from the
foundries and increasingly costly. It was reported
at a recent international conference on recla-
mation and reuse of foundry sands that one half of all landfills in the USA will close by 1992.

- Stricter environmental controls which make disposal of foundry waste more difficult and expensive.
- High consumption of new sand with the use of chemically bonded sands. Without reclamation these systems can consume 2-5 tons of new sand per ton of castings produced.

Justification for Reclamation

The driving force for considering sand reclamation has always been the economics of saving on the cost of new sand. In recent years, the high cost of disposal has entered significantly into the equation. Sand reclamation is usually justified when -

- Large quantities of new sand are used in the foundry.
- New sand costs are higher than average due to shipping charges.
- Dumping of waste is difficult and/or expensive.
One base sand and a single binder system are used throughout the foundry. When several binders and sands are utilized, the used sand has a complex composition and generally does not respond to a single reclamation processes.

**Potential Benefits of Reclamation**

- Savings from reduced purchases of new sand.
- Savings in sand dumping charges.
- Possible cost savings due to reduced binder levels.
- Possible cost savings due to the reduction of in-plant storage of both old and new sand.

**Potential Liabilities of Reclamation**

- Capital cost of reclamation plant.
- Cost of maintenance, repair and replacement of equipment.
- Operational costs of reclamation plant.
Reclamation Processes

Three methods of sand reclamation are commonly used:

Thermal Reclamation
Burns away and removes all organic binders and materials in the sand. Inorganic binders are not removed, and actually may become fused on the sand grains. Thermal reclamation units may be either electrically heated or gas fired (Figure 1).

Figure 1 - Schematic Drawing of Electric Thermal Sand Reclamation System
Thermal reclamation removes all of the organic and carbonaceous materials in the sand. Compared with mechanical attrition, it is an expensive process because, in addition to the usual pre-crushing and metal removal treatment, the sand is heated to approximately 500-800°C (932-1475°F) and then cooled for re-use. Various types of equipment are used for thermal reclamation such as rotary kilns, fluidized beds and shaft furnaces. Fluidized bed systems are now very popular as there are no moving parts, processing is efficient and some cooling can be achieved.

The quality of the reclaimed sand is equal to that of the new sand provided that no inorganic material such as clay or iron oxide is present. Treatment at the higher temperatures listed above could cause fusion of these materials to the sand grains thus lowering the refractoriness of the sand.

In thermal systems, efficiency is achieved by operating twenty four hours a day—seven days a week. Under these operating conditions, even a small unit processing one ton/hour will produce 8,000 tons/year of reclaimed sand.

**Electric vs. Gas Reclaimers**

Thermal reclaimers using electric power offer some unique advantages over gas fired units. The units do not require
large quantities of air to support combustion, and since fuel is not burned in the reclaimer, contamination of the sand with products of combustion is not possible. Complete reclamation is achieved at lower temperatures (500°F), minimizing thermal shock cracking and reducing heat loss. Further, lower temperature operation avoids the unwanted silica phase change from Quartz to Cristobalite. Additionally the reclamation process can be programed to integrate with plant power demands to give optimum load factor and limit peak power.

A disadvantage of operating at the lower temperature, however, is that some of the volatile organic compounds driven off the sand may not be fully burned in the reclamation unit proper. In these cases an afterburner may be required to meet local air quality standards.

**Dry Reclamation**

Dry reclamation processes first crush the lumps to grain size. Mechanical abrasion then removes part of the binder from around the sand grains. Released fines are separated and removed by dry classification.

With dry pneumatic systems, relatively dry sand (less than 1% moisture) is prepared by crushing the sand to individual grain size and removing metal particles. The used sand is then propelled by air and blasted against a metal target.
plate (Figure 2). The impact of the sand scrubs off the clay coating from the surface of the sand grain, and the resulting fines are removed to a dust collector. A typical reclamation plant consists of several scrubbing cells arranged sequentially (Figure 2) and the degree of cleaning is regulated by the feed rate through the reclaimer.

Figure 2 - Schematic Drawing of Individual Cell of Dry Pneumatic System

Figure 3 - Schematic Drawing of Dry Pneumatic Reclamation System
only partial cleaning of the sand occurs, even with long scrubbing cycles. The minimum clay content is about 2.0% which is quite suitable for a new sand addition replacement in green system sand or a clay bonded facing sand mix. It is not sufficiently clean, however, to be used alone in core or chemically-bonded mixes. Because of the mechanical nature of the scrubbing process, yield of reclaimed sand is only 75-90% and the large volumes of dust generated require collecting, handling and disposal.

**Wet Reclamation**

Scrubbing in water washes or dissolves binders from the sand. Loose clay is readily suspended in water and a vigorous scrubbing action releases the clay coatings from the sand grains. Released binder and fines are separated and removed by washing or classification. The cleaned sand is dewatered and dried as shown in Figure 4.

Wet reclamation cleans clay bonded sands very efficiently and the reclaimed sand is almost equivalent in purity and cleanliness to new sand. It can, therefore, be used in place of new sand in molding and some core mixes.

High water requirements (2000 gal/ton of sand) and the need to treat and clarify the water before recirculation and disposal are major operating problems with wet reclamation systems. In addition, capital cost of the equipment is high
and a large amount of floor space is required.

Figure 4 - Schematic Drawing of Wet Reclamation System

Applications

Clay Bonded Sand
Reclamation of clay bonded sand (green sand), which is used by 70-80% of all foundries, is usually limited to that portion of the sand that would normally be discarded (Approximately 10%). The remaining sand, approximately 90%, contains appreciable amounts of active bentonite (clay) and other green sand additives such as cereal, cellulose or
carbonaceous materials. It is desirable to "save" these additives. This bulk of the sand is therefore simply recycles as the "sand" of the sand system, thereby utilizing these remaining binders and additives.

The discarded sand is generally reclaimed by the dry pneumatic process. The reclamation systems used typically break down agglomerates, remove calcined clay and adjust moisture and temperature. Dry reclamation is ideal when the reclaimed sand is to be recycled as described in the last paragraph since the calcined clay is removed while appreciable amounts of active clay remain.

Wet reclamation is also sometimes used for clay bonded sands resulting in pure and clean reclaimed sand. However, such cleanliness is not normally necessary for a green system sand, and the high cost and problems associated with wet reclamation greatly reduce the feasibility of this approach.

**Organically Bonded Sands**

Chemically-bonded sands utilizing organic binder systems comprise the bulk of molding and coremaking sands used in the jobbing sector of the foundry industry. These sands generally lend themselves to reclamation because the binder plus catalyst content of the sand is lower, generally not exceeding 2%, therefore there is less binder to be removed.
sands into the United States has produced a new set of requirements for sand reclamation processes. Because of the high alkalinity of the binders, the importance of controlling the residual alkali content of the reclaimed sand is of utmost importance. Recent work in the United States has shown that all types of reclamation processes have a favorable effect on sand quality, although a thermal/mechanical process did not produce the same favorable effect realized with sodium silicate systems. In fact, heating to 260ºC (500ºF) appeared to lower rebonding strength. As in the case of sodium silicate sand reclamation, additional research work is required.

**Quality Considerations (4)**

Reclaimed sand should be evaluated in the same manner that a sand from a new source would be evaluated. The screen analysis of the reclaimed sand should be close to the new sand used in the process. With a very angular sand, the reclamation process will produce a more rounded grain and the grain size distribution will be somewhat finer. Unless the fines are controlled, the sand the sand will have a finer overall grain size. As the fineness of the reclaimed sand changes, the binder requirements change.

Loss-on-Ignition (LOI) is an important test in organically-bonded sands. Standard AFS (American Foundrymen's Society)
procedures should be used. A number of important factors should be considered when running the LOI test. The sample should be dried first to make sure that no moisture is driven off and read as LOI. In sands that contain large amounts of active clay, the burning of the LOI sample will drive off chemically-bonded water from the clay and this will be read as LOI, when in reality, it is not an organic loss. The metallic content should be kept to a minimum since small metallic particles will oxidize and gain weight, resulting in a false LOI reading.

The content of active and dead clay is another important consideration in reclaimed sand. Both types of clay will lower permeability of the reclaimed sand and may react with catalysts and accelerators in chemically-bonded systems. Standard AFS procedures should be employed.

Metallic content is important in any acid cured chemically-bonded system. If the metallic content is high, the acid catalyst will react with the metal, resulting in insufficient catalyst to cure the sand properly.

Depending of the binder system employed, other tests used in reclamation system evaluation are low-power microscopic examination, rebonding tests, gas evolution, sulfur content and nitrogen content.
In the final analysis, the ultimate test is to pour castings with the reclaimed sand core or mold and evaluate the results. The casting surface should be as good as that produced with new sand, and the reclaimed sand must not result in a higher scrap rate.

Trends in Reclamation (5)

Current trends in sand reclamation fall into three categories:

-- Green sand back into green sand systems.

-- Chemically-bonded sands back into chemically-bonded systems.

-- Total sand reclamation - reclaimed sand that can be re-used with any binder system.

More foundries are beginning to look at the possibility of using sand reclamation to maintain their green sand system at a high quality level. By running a portion of their green sand through a scrubber and returning the scrubbed sand to the system, they can maintain a higher quality single system sand. In some steel foundries, the sand that is scrubbed in this manner is used to make facing sand utilizing the retained active clay for more economical operation.
Jobbing foundries are looking at reclaiming chemically-bonded sands for re-use in chemically-bonded systems. Higher freight and disposal costs are making reclamation in smaller foundries more economically feasible. Reasonably priced reclamation systems are now available off-the-shelf from several manufacturers.

One of the most intriguing recent trends is the concept of using thermal units to calcine refuse sand from the foundry. The calcining unit must be backed-up with some type of post scrubbing unit to remove the dead clay. The sand grain surface under the residual binder is still in good shape — only the coating must be removed. In most cases additional separation steps are required because used sand is often mixed with other foundry refuse such as furnace dust and refractories. In most foundries, the amount of discarded sand is substantial, consisting of typically 30-40% core sand and 60-70% molding sand. If this sand is not reclaimed it must be replaced with costly new sand additions.

One final potential trend is the concept of centralized sand reclamation plants serving industrial centers with several foundries. One large reclaimer, operated by some central agency or authority, could process the sands from all of the foundries in the area. While problems exist with different binder systems, grain finenesses and the separation of specialty sands, the concept has considerable merit.
Overview

As described earlier, most castings are produced in sand molds primarily because this is the lowest-cost method available. There is, however, a wide range of sand molding and coremaking systems available that offer different characteristics. Selection of a molding or coremaking system depends primarily on the metal being poured, the type of casting being made, the availability of molding aggregates, the mold and core making equipment owned by the foundry, and the quality requirements of the customer. An understanding of the basic characteristics will enable the reader to better evaluate the various systems available and understand their relationship to the overall operation of a particular foundry.

Molding and coremaking systems may be classified, for convenience, into the following categories:

- Green Sand
- Organic No-Bake
- Shell
- Hot Box
- Warm Box
- Cold Box

Because most foundries use several binder systems in the normal course of their production, it is difficult to
accurately determine the percentage of castings made in any given process. However, a rough estimate can be obtained from earlier published work (6) and interviews with industry personnel. As illustrated in Figure 5, almost half of the castings manufactured are produced in the green sand process. These processes will be discussed individually below:

![Pie chart showing the percentage of castings made in different processes. Green sand: 48.0%, No-bake: 24.0%, Shell: 8.0%, Other: 6.0%, Co2 mold: 4.0%, Investment: 10.0%]

Figure 5
Major Molding and Coremaking Processes
Green Sand Binders

Western Bentonite - Western bentonite is the type of clay that is preferred for use in casting the higher temperature metals, particularly steel. It is basically a montmorillonite, or hydrated aluminum silicate clay in which some of the aluminum atoms are replaced by sodium atoms. Thus it is frequently referred to as "sodium bentonite". Western bentonite imparts high levels of green and dry strength to the sand mold, and develops a high degree of plasticity, toughness and deformability when properly "mulled" (mixed) with water. Western bentonite also swells when "mulled" with water, thus acting as a cushion between sand grains and reducing sand expansion defects such as scabs and buckles. It also is "durable", that is it can be reused many times in a system sand with a minimum of new additions required.

Southern Bentonite - Southern bentonite differs from western bentonite in a number of ways. It also is a hydrated aluminum silicate clay, however some of the aluminum atoms have been replaced with calcium rather than sodium atoms. It is frequently called "calcium bentonite". Southern bentonite develops higher green strength but lower hot and dry strengths than western bentonite. Sands bonded with southern bentonite are more flowable and can be compacted to higher densities. Southern bentonite is also less durable, and is generally used with lower melting point metals such as cast
iron. It is common practice to blend mixtures of both bentonites to achieve the desired properties.

Additives - Most green sand molds are made with silica sand and, while silica is inexpensive, has some shortcomings with regard to casting surface finish. To minimize problems in this area, and number of additives are normally used in the process. These can be classified as follows:

- Carbonaceous
- Cellulose
- Cereal

Carbonaceous additives are primarily used in cast iron production to provide a reducing atmosphere at the mold-metal interface which minimizes oxidation of the metal and the burn-on defect. Materials commonly used are seacoal (a finely ground bituminous coal), Gilsonite (natural asphalt) and proprietary petroleum based products.

Cellulose is added to control sand expansion defects and broaden the latitude of moisture control. Cellulose also lowers hot strength and improves shakeout properties. It is normally added as wood flour, ground nut shells, or ground cereal husks.
Cereal additives are adhesive when wetted and act as a binder. They are frequently used to improve the ability to "draw" or pull out deep pockets. Because cereals volatilize when heated, they can cause gas defects in the castings. Cereals are normally added as corn flour, dextrin, and other starches.

**Organic No-Bake Binders (3)**

**Furan Acid Catalyzed No-Bake** - The basic component of furan no-bake binders is furfuryl alcohol. These binders can be modified with urea, formaldehyde, phenol, and other additives to improve properties. The speed of curing is adjusted by varying the amount and/or type of acid catalyst used. Furan binders provide a high degree of dimensional accuracy and resistance to mold-metal interface defects. They also impart excellent tensile and hot strength making them useful for flaskless molding applications.

**Phenolic Acid Catalyzed No-Bake** - Phenolic no-bake resins are phenolic/formaldehyde resins with a molar ratio of less than 1:1. These resins can also be modified to improve properties. The properties attained are similar, though slightly lower, than those of the furan resin systems. Cost is usually somewhat less. Resins of this type contain free phenol and free formaldehyde, and can cause odor problems during the mixing operation. Adequate ventilation is
required.

**Ester-Cured Alkaline Phenolic No-Bake** - This system is a two-part system consisting of a water-soluble alkaline phenolic resin and liquid ester co-reactants. Physical strengths achieved are not as high as with the acid-catalyzed systems, however, distinct advantages are achieved in the reduction of veining defects in gray iron castings and in excellent resistance to erosion. The rate of gas evolution is low thus minimizing gas defects. Since both the resin and co-reactants are water soluble, clean-up is simplified.

**Silicate/Ester Catalyzed No-Bake** - This system consists of a sodium silicate binder and a liquid organic ester hardening agent. High ratio binders with a SiO₂/Na₂O contents of 2.5-3.2/1 are used. The esters are materials such as glycerol diacetate or triacetate or ethylene glycol diacetate. Curing takes several hours. Properties exhibited are moderate strength, low rate of gas evolution, excellent degree of plasticity and good erosion resistance. Little or no smoke or fume is evolved during pouring.

**Oil Urethane No-Bake** - These binders, also known as oil-urethane, alkyd-urethane, alkyd-oil-urethane, or polyester-urethane, are three component systems exhibiting a unique two-step curing mechanism. The three parts are an alkyd oil type resin, a liquid amine/metallic catalyst, and a
polymeric methyl di-isocyanate. The first curing step produces a urethane coating on the sand that allows stripping of the mold and handling; the second step provides a full cure to withstand the conditions imposed by the molten metal. This unique two-step curing process results in unmatched stripping characteristics and provides a good method for producing large cores and molds that require long work and strip times.

**Phenolic Urethane No-Bake** - This binder consists of three parts, a phenol formaldehyde resin dissolved in a solvent, a polymeric type isocyanate also dissolved in a solvent, and an amine catalyst. The type and amount of catalyst determine the set-up time. The reaction is a one-step reaction resulting in a urethane bond throughout the sand mass. Properties include moderate strength, good erosion resistance, and good flowability. This binder can sometimes result in pinhole gas defects in ferrous castings, and iron oxide additions are made to minimize this problem.

**Polyol-Isocyanate System** - The polyol-isocyanate system is similar to the phenolic urethane system previously described except that the ingredients are specially selected and blended to allow decomposition at lower temperatures. This allows successful use in the production of aluminum and magnesium castings where the pouring temperatures are too low to allow the use of the previously described systems. For the
same reasons that make this system good for the low
temperature alloys, it is not recommended for ferrous alloys.

Shell process
The shell process, also known as the Croning process, uses
sands coated with phenolic novolac resins and hexamethylene-
tetramine ("hexa"). The sands may be "warm" coated using
liquid or dissolved resins, or "hot" coated using solid
resins. Hot coated sands are generally more flowable. When
the coated sands are placed in contact with the heated
pattern in the shell machine, a thermosetting bond forms. The
thickness of the shell developed is a function of the pattern
temperature and dwell time. The excess sand is then dumped.

The shell process offers superior dimensional reproduction
capabilities and the flowability of the sand allows intricate
cores to be produced. Various additives can be used to
further improve performance. In addition, the bench life of
the coated sand is infinite thus eliminating sand removal and
clean-up at the end of each shift.

Hot Box Process
The hot box process utilizes a liquid thermosetting binder
and a latent acid catalyst. These components are mixed with
the sand and blown into a core box. The heat from the core
box causes the catalyst to release acid which results in a
very rapid cure; in the order of 10 to 30 seconds. There are two main types of hot box binders; furan types containing furfuryl alcohol, and phenolic types containing phenol. Both types also contain urea and formaldehyde. Because of the rapid cure rate, these binders are extensively used in the automotive industry for producing intricate cores and molds that require good tensile strengths for low cost gray iron castings.

Warm Box Process
The warm box binders are similar to the hot box binders except that the catalyst materials are different and allow the cure to take place at a lower temperature. Copper salts are generally used as catalysts rather than the nitrates or chlorides used in the hot box process. This chemistry difference allows production of cores giving good dimensional accuracy and excellent erosion resistance.

Core Oil Processes
Core oil binders are used in combination with water activated cereal to provide a small amount of green strength. This allows the sand mix to be blown or rammed into the core box and removed. The core is then oven-baked to develop tensile strength. Several types of oil can be used including linseed oil, vegetable oil, urea formaldehyde and resole phenolic. A
small amount of western or southern bentonite is often added to provide additional green strength.

The long baking cycle tends to make these binders quite inefficient from an energy standpoint which has relegated these binders to the category of "old fashioned". However, the high quality cores that are produced, and the flexibility of the process for making small quantities of cores, have resulted in the continued use of sizable quantities of these binders (Fig. 5).

**Cold Box Processes**

Cold box processes, by definition, feature a curing mechanism that occurs at room temperature. The sand-binder mix is blown into a core box and cured by passing a gas or vapor catalyst through the sand mass. The several different binder-catalyst systems in general usage will be described below:

**Phenolic Urethane Cold Box** - The phenolic urethane cold box system is a three part system consisting of a phenolic resin, a polymeric isocyanate, and a tertiary amine vapor catalyst. Sand that has been coated with the first two parts is blown into a core box at room temperature. The amine vapor is then passed through the core box followed by an air purge to remove all traces of amine. The exhaust should be scrubbed chemically to remove the amine. This is an excellent high
production system providing excellent surface finish on the castings.

**SO₂ Process (Furan/SO₂)** - This process can be described as a rapid-curing, gas-activated, furan no-bake. Furfuryl alcohol base resins mixed with organic hydroperoxides and methanol diluted silane form the binders. After blowing into the core box, the introduction of SO₂ results in the formation of complex acids which cure the resin. These sands exhibit excellent flowability and cores can be produced with substantially lower blow pressures. The resulting cores are highly accurate and can be produced in very complex, intricate shapes.

**Free Radical Cure (FRC) Process** - This is actually a family of processes that includes all acrylic and acrylic-epoxy binders. The binders are cured with an organic hydroperoxide and sulfur dioxide. Properties can be varied considerably by selecting different binder compositions. The most beneficial properties realized with these systems are good anti-veining characteristics and a minimum of pinhole gas defect problems.

**Phenolic Ester Cold Box** - This system consists of two parts: a water-soluble alkaline phenolic resole resin and a volatile ester vapor co-reactant. Sand is coated with the resin and blown into the core box. The liquid ester is vaporized and injected as a gas through the sand mix. Most of the ester is
consumed by the curing reaction, minimizing the amount of air purge required. Castings made with this system exhibit good surface finish, and minimum amounts of erosion and veining. Coatings are required to prevent penetration defects, however, additives such as iron oxide and sugar are not required to control veining and nitrogen defects.

**Sodium Silicate/CO\textsubscript{2} Process** - This system utilizes sodium silicate as the binder which is cured with carbon dioxide gas which makes it an inorganic system. Silicate binders are odorless, non-flammable, suitable for all types of work, usable with all types of molding aggregates, and are environmentally acceptable in that they produce no harmful emissions upon pouring or shakeout. The main difficulty with their use has been with problems with hot tearing and difficult shakeout due to the high retained strength developed. The favorable environmental characteristics of these binders will insure expanded use in the future.

**Cautionary note**

As can easily be seen from the above discussion, the subject of mold and core binders is quite complex and should be approached accordingly. Hans Heine, Technical Editor, *Foundry Management and Technology* states the following (\textsuperscript{5}): “A number of factors combine to regulate a resin sand’s coating capability, usable life of the coated sand, rate and effectiveness of cure, bonded sand strength, and
"castibility." Only an astute, experienced no-bake foundryman, or one who has been properly trained, can appreciate the dramatic influences that time, humidity, equipment variations, and especially temperature have on the operation's success or failure."
Section 4

REFERENCES

1. P. R. Brawler and M. F. Burditt "Is the Profit Line the Bottom Line in Sand Reclamation?" Modern Casting, Vol. 78, No. 5, May 1988, p. 27.


