Modern core processes for the non-ferrous foundry

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THE term "Non-ferrous Foundry Practice", when used in the United States, actually refers to all types of metal cast with the exception of iron and steel. I am emphasizing this definition here specifically so that everyone understands we are discussing light metal alloys, 'exotic' elements (such as beryllium, titanium, etc.) as well as the normal copper-bearing alloys, brass and bronze. This latter category is usually normally thought of when non-ferrous practice is considered.

In the United States, non-ferrous foundry practice is an exteremely large segment of the foundry industry. According to the latest statistics, there were approximately 500 000 tons of copper-bearing alloys shipped during 1967. Light alloys, consisting mostly of aluminium and magnesium, amounted to nearly 800 000 tons. The total dollar value of copper, aluminum and magnesium castings has been in excess of $3 000 000 000 annually. Although the light alloys have not grown at as rapid a rate as expected since World War II, it was this sector of the foundry industry which provided the impetus towards most modern core practices. Aside from unit cost and some difficulties in the founding of these materials, the growth of this industry has had its problems in line with the acceptance or rejection of these castings by the automative industry. The ferrous foundry industry continued to become competitive as aluminium encroached upon its place in the automotive market. Lighter and more delicate castings made by iron foundrymen kept aluminum away from the greater part of the automotive engine casting business. In order to meet the competition of aluminium, the iron foundrymen have had to resort to modern processes for the production of cores, thereby adding still more impetus to the discovery of newer, more modern and automated binding methods.

The premise of this paper is not concerned primarily with scientific data presented with charts, diagrams or pinpointed factual tests; it is the authors' intention to lay before the National Metallurgical Laboratory of India cogent thoughts concerning the

SYNOPSIS

In this paper the statistics on non-ferrous foundry practice in the United States have been initially dealt with.

While presenting cogent thoughts concerning the rapid development of modern core practices the authors project how India can use the background of practical experience without going through the 'growing pains' that the western world's foundry practice has had to endure.

The importance of primary physical characteristics of the modern synthetic binders is dealt with in relation to collapsibility and with particular reference to aluminium and magnesium melting temperatures. A reference has been made concerning baking binders, particularly to the benefical applications of urea-formaldehyde resin binders. The importance of the sodium silicate process and the use of organic additives with the sand mixture to alleviate the collapsibility drawback of CO_2 cores is mentioned. The application of shell process with particular reference to the use of phenol formaldehyde resins, both liquid and solid, to form shell mould and shell cores is dealt with extensively. The advantages of the application of 'hot-box' process in 'non-ferrous' foundry practice are also explained and compared with the relative merits of the shell process.

rapid development of modern core practices. In this brief summary, India may use the background of practical experience without going through the "growing pains" that the western world's foundry practice have had to endure.

No modern core practice could have originated rapidly or become so easily accepted if it were not for the concurrent growth of the core binder industry. It is safe to say that today's thin-walled, light, non-ferrous alloys would still be difficult and more expensive to cast if it were not for solving the foundry problems through the use of synthetic binders. While the brass and bronze industries have not had to rely on these binders nearly to the extent that magnesium and aluminium have, the copper alloys also benefited from these new practices. While it is still possible for the copper alloys to be cast from

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cores bonded with vegetable oils, petroleum polymers pitches and other natural resinous products, modern synthetic binders provide more uniform, less gassy, and more economical media for the manufacture of these castings.

One of the primary physical characteristics of both aluminium and magnesium is the relatively low temperatures needed to melt them. While iron products must be heated to an excess of 2000°F before becoming castable, aluminium and magnesium become liquid at about 500°F less. At these lower temperature levels, much more energy is necessary to remove cores from castings since less binder is burned during founding. As you are all aware, the physical property measured to removing cores from castings is known as "collapsibility" to the foundry industry. Before the advent of synthetic resin binders, it was extremely difficult to remove cores from light alloy castings because the thermal requirement for binder destruction was greater than that contributed by the heat of solidification of the metal. Of course, the size and weight of the core, when compared to the casting wall thickness, is a most significant factor, however, the demands for *thick*-walled, *small*-cored castings are usually minor. A typical example of a *thin*-walled, *thickly*-cored casting is an aircraft engine oil sump. The resin industry provided binders which would easily collapse in a heavy core surrounded by light metals as thin as one-half inch. In the case of malleable iron castings, this controlled collapsibility prevented hot-tearing defects.

Baking binders

Urea-formaldehyde manufactured for many years as glues for the adhesive and woodworking industries was one of the first synthetic resins to be used for this purpose. Both water-borne and powdered urea-formaldehyde resins were substituted in normal core sand formulae at the expense of vegetable oils and core oils near the end of World War II. Soon afterwards, hardly any of the 'old fashioned' binders were used in magnesium and aluminium foundries.

While there were many drawbacks such as stickiness, odor, and 'bench life,' these difficulties were overcome through proper sand mixture formulation by the use of additives. Such materials as fatty acids, odor depressants and organic deliquescent liquids were employed. Proper collapsibility was quickly imparted to core sand mixtures destined for light alloy practice by the substitution of urea-formaldehyde in standard core sand mixtures. It was found that many beneficial side effects arose from the use of resins. When urea-formaldehyde was used as the main baking binder, it was found that lower baking temperatures and faster baking times were available to the foundrymen.

Since these binders did not cost much more than core oils, and in some cases could be used much more efficiently (on a solids basis), the uses of urea-formaldehydes pointed the way to the western foundrymen that faster and economic baking of cores was a reality; however, it is doubted that the thought of completely 'no-baking' of core binders was visualized at that time.

The use of urea-formaldehydes was a case of the binder fitting the process and not the process fitting the binder. Dielectric baking of urea-formaldehyde, known for many years, was now an accepted foundry fact with the advent of synthetic resins. While some foundries are still using this system for core manufacture, the growth of this process has been stunted by the still newer processes such as no-bake, hot box, cold box and shell core practices.

While urea-formaldehyde resins fit admirably into the non-ferrous and light metal foundries (and also the malleable iron practices) ; the use of the ferrous metals required a higher hot strength material. Standard RCI urea-formaldehyde resins can be produced by our associates at Madras.

Working with synthetics, the resin industry put forth the old 'workhorse' of the industry, i.e., phenol-formaldehyde, to aid the ferrous foundrymen.

A suite of water-soluble, one-step, phenolic resin binders was quickly adopted for areas where iron was cast.

Although the cost of these strong binders was higher than the normal vegetable oil-natural resin core oils, the speed of bake and the higher hot strength qualities of these products promoted their widespread use.

Smoother casting finishes and less cutting and washing were added reasons for the use of phenolics as substitutes for core oils.

The disadvantages hitherto overcome when using ureas were also surmounted with the phenolic systems.

Because of the necessity for higher baking temperatures, phenolics were never very successfully used in dielectric baking.

Acrylates are also used as core binders. These high-viscosity, low solids salts of polyacrylic acids provide adequate strength and minimum gas evolution. They appear to be satisfactory binders from a foundry standpoint. However, the film cost per unit of acrylic solids is quite high and similar results can usually be obtained by using more normal binders such as urea-formaldehyde or core oils, when a conventional cereal-water binder baking mixture is called for.

Sodium silicate process

As synthetic resins were further developed for use by the foundries, speed of manufacture and automation of processes were the prime targets. The CO_2 process developed well in advance of today's 'cold box', was in the author's opinion one of the most important advances since World War II. Today's newest development is this organic cold box process wherein a core is gassed to produce 'instant green strength'. Silicate cores, which have this same feature, have been in widespread use since the early '50's, and they have the one major feature that the cold box does not have : i.e., a non-toxic gassing media. The collapsibility draw-back of CO_2 cores has been alleviated by the judicious use of organic additives in the body of the sand mixture, but the bench life and hydroscopicity of silicates still leave

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them behind the cold box process in some applications. The authors feel that there will soon be a marriage between the CO_2 process and the cold box process, which will combine the best attributes of both without the necessity for extremely expensive equipment and especially designed equipment to handle toxic materials. While neither of these processes have made as great a headway in non-ferrous practice as in ferrous practice because of the much greater use of iron castings in automotive work, it is the consensus of opinion that a rapid non-baking core will be the standard throughout the foundry industry.

Shell processes

Mr Johannes Croning was responsible for the greatest contribution to modern core practices. Concurrently with the development of urea-formaldehyde in this country, he was working with phenol-formaldehyde in both shell molding and shell core making. The authors suspect that the mother of this invention was two-fold. Certain important considerations must have been : the lack of food-stuffs in Germany which made cereal binders ; soy bean oil ; and even linseed oil, products for human (rather than industrial) consumption ; and the destruction of antiquated foundries and the extreme difficulty in rebuilding them with the heavy industrial equipment needed to handle large molds and cores. Shell systems calling for light-weight bonded aggregates were much more portable and, therefore, did away with the necessity for equipping foundries with large cranes and ovens. An important side effect was that more accurate castings could be produced which needed much less machining.

The most common curing method used in the United States today for production of small and medium size cores is the method which utilizes a heated metal core box. Also, a considerable portion of the high-quality casting type is produced in molds prepared by the use of heated metal patterns. Both shell cores and hot box cores are made with this system.

Foundry sand, destined for shell cores, is usually of relatively pure and high-grade material. It is prepared by first drying and grading, and it is then coated with a thin film of phenolic resin. This resin is one which can be further polymerized either by heat alone or by the use of catalysts such as hexamethylene-tetramine. Today, most prepared shell is sand that is pre-coated to dryness and is free-flowing and non-dusty, although the powdered resin (used in the past was Croning process) is still being employed by a few foundries.

Different sands affect the properties of shell cores and molds in much the same way they affect other curing systems. Change in sand can alter the core density, core strength and speed of cure.

Also, different sands require different amounts of resin in order to produce cores of equal strength.

A round-grain silica sand provides higher tensile strength than does an angular silica of the same average grain size because the former contains less surface area and also compacts more readily.

It is unusual to find a finer sand (with more potential surface area than a coarser aggregate) giving a *higher* strength than the coarser one. This can be explained only when the fine sand, upon analysis, shows that its grains are clustered about three or four sieves—known as an unusually narrow screen 'spread'.

In general terms, however, the coarser the sand, the less fines it contains ; the more clay-free it is, and the rounder are its grains. These are the factors which contribute to higher strengths per unit of binding resin solids added to the mixture.

Sand is a poor conductor of heat. In normal foundry practice, this phenomenon is associated with the rate of metal solidification, shrinkage, metal segregation, etc. In the case of core making, however, and especially in the newer core processes, it is most important to realize that the ability of this poor heat transfer also has an effect on the rate of cure of the core.

An angular sand reaches its hot tensile strength more rapidly than a round-grained sand composed of more angular less-dense packing. Its heat transfer is more rapid.

Several different types of phenolic resin are in use today, and there are many variations and modifications of those types available. They are usually thermoplastic resins to which hexamethylenetetramine is added in order to convert them to thermosetting resins. Some 'one-step' resins not requiring a catalyst are also used.

As mentioned before, Johannes Croning used a powdered phenolic into which 'hexa' was blended. This blend was thoroughly mixed with dry sand and applied by gravity to a heated pattern to form a shell mold-half. It could not satisfactorily be blown, that is, compacted into a core box by means of compressed air because of resultant segregation of resin and sand.

As resin manufacturing and sand mixing techniques were improved using coated sands, much greater cure strengths were possible with lower proportions of resin.

The first coating processes were developed using the phenolic resin in a solution of volatile "thinners" such as alcohol and acetone. The resin could be relatively easily coated on the sand grains by mulling the liquid resin and sand without the application of heat to the sand mass. This was known as "cold coating" and found favour for a short time in the foundry industry. The obvious hazard of volatile flammable solvents in a foundry plus the relative expense of these non-film forming ingredients precluded its wide and long standing acceptance by the industry.

Since water is the least expensive, least hazardous, solvent, the natural transition from cold coating was to add water to the alcoholic solutions in order to bring about the desired safety and economic considerations. As soon as water was added to the solution, heat had to be applied to the sand mixture in order to drive it off and produce a free-flowing sand mixture. The resin manufacturers had to reformulate their binders to accommodate these new techniques. An added 'bonus' to this work was the greater strength obtained in the sand mixture due to the more efficient liquid coating techniques and the work on resin technology.

The process of warm coating is simply a thorough mixing of liquid (water bearing) resin, wax and hexa-

methylene-tetramine with sand, followed by thorough evaporation of the resin solvent accomplished by flushing with heated air. During warm coating, the sand enters the mixer at ambient temperature and is discharged at a higher temperature. The warm coating technique invariably leaves a small residual of alcohol which keeps the resin slightly soft for a considerable length of time. This effect tends to produce packing of coated sand during storage, "peel-back" during core and mold production, and sand-wall movement during metal pouring. Extended aeration during the coating procedure and after discharge from the mixture is sometime necessary to minimize this.

Warm coating, as to be expected, represented only a transitional period between cold coating and hot coating, the latter method being the most practical one in use today.

The choice between hot coating and warm coating equipment installations is also made largely on the basis of capacity required and cost of equipment. Those resins used in the hot coating process can be either in the water-borne liquid form or in the solid flaked form. The choice of resin types for hot coating is determined by the economics of the higher capital outlay required for proper handling of the liquid system, and the use of water-borne resin is generally limited to extremely large capacity installations.

The process of hot coating is one in which resin is thoroughly mixed with sand which is pre-heated to above the melting point of the resin, followed by "quenching" of the mixture to a temperature well below the melting point of the resin. Required wax and hexa additions are made at appropriate times during this procedure. Note that this is a procedure of decreasing temperature from start to finish.

Naturally, when a liquid resin is employed, the quenching process starts immediately upon resin addition as the solvents are "flashed off," but is completed by the addition of a smaller amount of water. In the case of solid (flaked) resin, the binder is melted and surrounds the sand grains before the quenching media are added. It is impossible to predict today whether the future resin for hot coating will be in a solid or liquid form. The factors which lend themselves to the use of solid materials such as less transportation costs per unit of film forming, material, ease of storage "package stability", etc. are countered by the lesser cost of liquids, the package stability of the liquid resin and the mechanical possibility of pumping and metering a liquid. RCI's Foundrez DR192, a liquid phenolic resin, is currently being marketed for shell molding by our associates in India.

The pattern for shell molds are quite expensive because they are operated at a relatively high temperature. Because of this, shell molding of small cores for non-ferrous work has been restricted to those foundries where relatively long runs are needed and standard production items are made by thousands.

Hot box process

The hot box process also requires heated core boxes, but the requirements are not as severe as for shells.

In the case of shell pre-coated sand, the resin must react at a relatively high temperature with the catalyst to polymerize it into a thermosetting film. When hot box mixtures are used, the resins for this system are much more pH dependent and the thermal input acts to speed up the reaction, but, not necessarily, initiate it. All hot box sand mixtures are "wet" in nature, but designed to have as much flowability as possible.

Hot box binders are not restricted to one series of synthetic resins as are the shell binders. Although liquid phenol-formaldehyde can be used, some of the hot box binders depend upon pH sensitive furfuryl alcohol and the inexpensive, fast-setting urea-formaldehyde polymers. Combinations of furane, urea, and phenol formaldehyde resins are not unknown—these combination types having been developed to fit certain specific foundry conditions.

The urea-furane resins are generally faster in curing but lacking somewhat in hot strength, as compared to the urea-phenols.

All of the resins are in water solutions, and they react with catalysts which change the acidity (or basicity) of the mixture. They are such that once the curing reaction is triggered by external heat, the reaction goes into the center of the core even after the core has been removed from the heated core box.

Most often, the urea-furanes are used where easy shakeout and production speed are important, and the urea-phenols (low in urea) where high hot-strength and slow gas evolution are required. So many varieties of urea-phenols are possible, with varying ratios of urea to phenol, that this type of product has recently taken two-thirds of the U.S. hot box binder market.

Both shell and hot box sands are easily compacted into core boxes with the aid of compressed air. Shell sand may be gravity applied to patterns, but hot box sand is not free flowing enough to be used in that way.

While these two systems are similar with respect to the molds and cores produced and with respect to their curing methods, each has peculiarities which suit it more favourably to certain areas of foundry practice.

Because both the hot box and shell processes are best suited to high production of small to medium size cores and molds, it is important that foundrymen realize fully the differences between them. Although special applications may violate the following generalities, it may be stated that with respect to the hot box process :

1. Resins have less drum storage stability.
2. Operations are more critically affected by impurity of sand and pH of sand.
3. Sand preparation and use is more critical with respect to sand temperature.
4. The prepared sand has much shorter usable life.
5. Prepared sand is not as blowable (flowable).
6. Cores more often require core wash.
7. Cores have less resistance to high humidity during storage.

8. Sand is easier to mix and requires less expensive mixing equipment.
9. Prepared sand is less costly per ton of sand.
10. Cores cure in about one-third the time of shell.
11. Cores evolve less total gas during pouring (in the case of solid cores).
12. Cores have better collapsibility.

Generally speaking, wherever 'shell' cores are now being used as solid cores, there is a good chance that hot box will be an improvement. In addition, where high production requirements will justify the extra core box cost, hot box can more than double production capacity per man or machine.

Hot box sands are more critical than shell sands because of the pH factor. Such aggregates as olivine and chromite are quite difficult to use in this process because of their chemical reactivity.

In summary, the modern processes for the production of cores in today's non-ferrous foundries center around those processes already developed for the ferrous foundries. Where light metals are employed, the accent on collapsibility has made it mandatory to consider the latest stream of technical information issuing from the synthetic resin producers. Other than that, the non-ferrous metallurgist has seen fit to keep up with the widening horizons opening to all foundrymen who are interested in making better castings for less money. It has been shown that hot box cores require about a ton and a half of sand be moved to make a ton of iron castings; while shell cores require only three-quarters of a ton to do the same job. This type of progress in foundry practice keeps our industry competitive with many other types of metal forming from welding to forging through explosive fabrication methods.

Discussions

Mr **U. P. Mullick** (Hope Johnstone and Sons, Calcutta): Will the author comment on the problems of recovery of the core sands with reference to the use of binders like resin etc. in preparation of the core?

Mr **O. Jay Myers** (Author): The reclamation of core sands (previously bonded with synthetic resin) usually does not entail any more difficulties than are present with core oil bonded sands.

It has been said that reclaimed resin bonded sand performs more nearly like new sand than core oil bonded sand does, but this point has never been substantiated by the authors.

Pneumatic, thermal and hydraulic reclamation are all used in recovered resin bonded core sand reprocessing.