A green core sand binder facilitating easy core removal from complex aluminum castings

Summary: *A non-toxic, biodegradable, water-soluble core sand binder was used to make large, complex cores on a slightly modified production cold box core machine. These cores were used to produce hollow, think-walled aluminum suspension arm castings by the low pressure, gravity flow semi-permanent mold method. After cooling, these cores could be removed from the castings without thermal aftertreatment or aggressive hammering. This process allows the commercial manufacture of complex aluminum and magnesium castings without damage or distortion from core removal – an improvement which increases product quality and reduces manufacturing costs.*

Introduction

Background. In the early 1990's, several of the authors working in research began the search for a new core sand binder for aluminum castings which would be significantly better than current binders. The attributes we felt needed improvement included:

- The elimination of odors and toxic gases from the core making process.
- The use of environmentally safe materials for the binder and all process steps.
- Recyclability of flawed cores to reduce scrap in core making.
- Comparable core strength and surface quality as binders in current use.
- Good shelf life and humidity resistance for cores.
- Reduced emissions of toxic gases during casting.
- Easy shakeout from aluminum or magnesium castings.
- Complete compatibility with modern thermal sand reclamation systems.
- Reasonable cost, comparable to current binders.

Early studies showed that good cores could be made from many materials not currently used in the foundry industry. Among them are starch, vegetable gums, polycaprolactone, chitin, polyhydroxy-(b)-alkynoates (PHBA) and various protein-based binders. However most of these core binders could not satisfy all of the above criteria. The best results were obtained from protein-based binders. Therefore, we concentrated our efforts on modifying and improving the material formulation and fitting the material process cycle to use it in a modern cold box machine.

Material development. To improve shakeout performance with metals having low casting temperatures, various metal oxide catalysts were used with the protein binders to accelerate binder breakdown from the heat of the metal. Favorable shakeout performance was achieved from many metal oxides and shakeout time decreased as more catalyst was added to the binder. An optimum catalyst amount was finally determined which did not interfere with other desirable characteristics of the binder but still accelerated core breakdown in casting aluminum and magnesium.

Simultaneously, the molecular nature of the primary core material was studied to determine the physical properties such as non-Newtonian viscosity, melting and solidification temperatures and physical form for optimum performance in cycling through 'cold box'machinery for core making. This is complicated since these types of materials consist of molecules with a molecular weight of around 200,000 and have many tertiary structural forms which give rise to different macroscopic physical properties. In other words, these molecules exhibit a 'history effect' depending on past temperature, hydration, pH and physical stresses which can change their properties. Eventually the best combination of physical properties and catalyst for thermal breakdown resulted in a tan-colored, dry flaked, powdered binder which was non-toxic and worked well for making strong cores. In fact, since the binder was made primarily from agriculturally-derived materials, it was literally safe to eat and was ingested on many occasions by the authors to demonstrate its safety. The binder is referred to as GMBOND®.

Process development. Since a new core binder material would be of little practical use to the casting industry if it required special core making machinery, our next step was to work with development engineers using commercial core machinery to fit the binder to the capabilities of existing core machines. We used a very basic, manually operated, non-computerized core machine and began blowing engine block and head waterjackets, disc brake rotors and other practical foundry cores. Our intention was to reduce the part-to-part machine cycle time to approximately 60 seconds per core. This goal was achieved by heating the core box to a temperature of approximately 100C in tests conducted at our laboratories in Michigan. The actual cycle time will vary somewhat with part thickness and the geometry of the core mold.

Hardening of cores occurs by drying the binder rather than by a chemical reaction of materials on the sand, and therefore several benefits accrue to the user. First the drying of binder is a simple process and insensitive to factors such as pH, acid demand value and other properties of the sand which may interfere with a chemical reaction. The core strength comes from the physical properties of the binder material itself, not from the operator’s success at producing a chemical reaction. New sand from many sources as well as thermally-recycled sand all produced strong cores in our tests. The useful properties of the binder derive from the complex properties of the large molecules used in the binder and their proper preparation. The only steps remaining in core making are to wet the binder and dry the binder, making core production chemistry very simple for the user.

A secondary benefit from the binder being merely dried and not reacted is that core making becomes reversible. This means that scrap cores having flaws need not be discarded, and therefore another type of foundry waste can be eliminated. Cores that do not meet production standards can be ground to pre-coated sand in a core grinder, screened and reused in core making. All sand in the core machine at shutdown can also be recycled – none is wasted. During three years of development, we recycled several tons of precoated sand repeatedly to make hundreds of cores in many different shapes. Naturally once the core is used in casting, the binder near the metal surface becomes pyrolized by the heat and core sand from casting must be recycled by thermal reclamation after casting.

A third feature of these cores is that despite being made from a water-soluble binder, the dried cores are highly resistant to surface deterioration at high relative humidity. This is an important characteristic in climates where high humidity can quickly deteriorate the surface quality of cores in one or two days to the point that they must be discarded. We have kept cores at ambient humidity in Michigan (often 90% in summer) for three to four years and they still have excellent surface smoothness with no sign of exfoliation of the surface layer of sand.

The process finally evolved from our studies can be run on any manual or computer-operated cold box-type core machine by simply cooling the sand before use, using tap water to wet the precoated sand, blowing the moist sand into a heated core box and purging the core with dry, heated air to dry it. Since the binder is non-toxic and the machine cycle requires only air and water to harden the core, the manufacturing environment becomes completely worker friendly. Toxic gases, scrubbers, gas capture hoods, etc. are no longer required in the core room, which also makes the core machine simpler to operate and maintain. Finally since the binder is water soluble, it is possible to clean the core box interior surface with a cloth and water, rather than solvents or by other methods. However in our experience this has not been necessary since we never observed binder build-up on the core box interior surface.

Pre-Production Development and Testing

Sand precoating and handling. The simplest method of using this binder industrially is to precoat new or recycled sand with the binder and store for later use. We used a simple muller system for precoating sand. The sand is first heated to 100C and then mixed in a conventional muller with a measured amount of tap water and dry powdered binder for approximately five minutes. The amount of water and binder will vary somewhat depending on the specific application and strength required for the cores, but the binder amount is usually slightly less than 1% by weight. Once dry, the coated sand looks and feels like uncoated sand and may be transported via pneumatic transporters or other conventional means to storage or use. If stored, the sand may be kept for months before use as long as it is kept dry. Naturally, since the binder is water soluble, it will wash off of the sand if the coated sand becomes wet.

At the time of use, the sand is cooled to about 18C and mixed with approximately 2% tap water in any low or moderate speed sand mixer. The actual amount of water used to remoisten the coated sand will depend on the amount of binder coating on the sand (by weight) and flowability considerations. The water must be precisely metered in this step, however most resin metering systems on mixers are adequate for this job. Naturally, since only water passes through these meters they remain clean and new while using this core system.

Measured core properties. Water jacket cores having several relatively flat areas were measured for surface hardness using a George Fischer core hardness tester. The values are given in Table 1 and are comparable to those from the same core made by the cold box process on our equipment.

Dog bone test samples were made in core boxes heated to approximately 100C. The dog bone samples had a failure area of 2.54cm x 2.54cm and were pulled to failure in a Thwing Albert tensile tester Model 1300024. Results showed that binder levels of 0.75% by weight in 55 AFS grain fineness lake sand gave tensile strengths nominally of 2Mpa, but strength could easily be adjusted over the range 2-6MPa. The value of 2Mpa is approximately the same strength found in our production cores made by conventional cold box phenolic/urethane/amine binders. In general, higher strengths were achieved from core samples made with finer-grained sands.

Production Rate Demonstration

Industrial scale-up. Production of cores in small numbers on small machines does not prove that a new technology is ready for foundry use. Production machinery must be used to prove this step and this machinery must be used at production speeds for full work shift intervals to assess the benefits and shortcomings of any new process. With this in mind, a production rate demonstration trial was designed using a Hansberg 60L production core machine at Teksid’s foundry in Carmagnola, IT. The core machine was modified to cool the sand before mixing and blowing into the core box; the core box was heated with a 12kW circulating oil heater, and the purge air was warmed with an air immersion electric heater. As modified, the machine could quickly be converted to production use for the phenolic/urethane/amine process or back to our protein binder process.

Target operating conditions. This machine was set-up to produce two 3.5kg suspension arm cores (right and left side) in a single machine cycle. The machine cycle could be varied to optimize the core strength and other properties, but the overall cycle time target was 60 seconds. To simulate production, cores were to be blown for an entire work shift with time off for lunch and other scheduled breaks during the day.

Core making results. After one day to set-up machine utilities and balance operation, we began making cores with a part-to-part cycle time of 65 seconds and with brief periods of faster and slower operation. By the second day of operation, the cores were being produced with a 2% scrap rate for the entire work day. These tests confirmed that the process could be run efficiently in slightly modified industrial core making equipment with only a few days of practice.

Casting and Shakeout

A challenging test casting. The cores were used to make a hollow automobile suspension arm as described recently (3). This part illustrates the new type of castings being used by the automotive industry to replace stamped steel parts, and is a challenge to produce profitably because it contains a relatively large core and thin (3-4 mm) walls providing little heat to break down the core for removal. Because of the importance of the part shape to give proper tortional performance under loads, it was also not possible to provide large openings in the casting for core sand shakeout. The largest opening in this casting was 2 cm diameter and all others were smaller. Thermal aftertreatment to remove the core from a part with such thin walls would result in a large loss of parts due to thermal distortion of the castings. Mechanical hammering of the part for core removal was also not feasible because safety critical parts must be of top quality and without surface damage or micro cracks from hammering.

Low pressure semi-permanent mold casting. The manufacturing method used to make the suspension arm was low pressure semi-permanent mold casting to get the metal quality necessary for this type of part. The reasons for this choice are:

- Bottom filling of metal at low speed and with low turbulence
- The possibility to use heat treatable alloys
- The ability to have a fast cooling rate, giving improved microstructure and tensile properties to the part
- Minimization of ingates and risers on the part for more efficient casting
- The feasibility of producing complex hollow castings with inexpensive cores

Casting the suspension arms with the GMBOND® new cores was straightforward with no thermoplastic deformation of the core due to the heat of the mold or the metal. This is important in casting a part with such thin walls. After decoring, the interior surface of the part was smooth even without using a core coating.

Core removal. After air cooling the casting for 30 minutes, the cores could be removed using compressed air combined with low intensity vibration, but with no hammering. This happens because the hot aluminum decomposes the core surface directly beneath the aluminum for easy blow out and the remaining, loosened core center is then broken and sand blasted from the casting by the combined shaking and air flow. The thin aluminum walls of the suspension arm make this a very challenging core removal task which could not be done quickly with most core systems. Other aluminum parts such as engine blocks and heads with greater metal to core ratios shakeout even easier because the cores are more completely decomposed by the heat.

Alternatively, the casting may be water quenched and the core removed in approximately 90 seconds with a water jet. This method works well because the pyrolized core sand near the metal surface has broken down from the metal heat and washes out immediately. The unburned center of the core remains water soluble and simply dissolves and washes away in the water. Washing the core from the casting has the added advantage of improving the environment in decoring operations by eliminating airborne dust and noise. The disadvantage of water removal, if the sand is to be recycled, is that it requires energy to dry the sand again before it can be thermally reclaimed. Other complex castings were also made and decored by one of these two methods.

Conclusions

As increasingly complex, cored aluminum castings are required, better core systems are necessary to enable their efficient manufacture. This paper describes such a new system for producing cores on modified, existing core machines. Using these cores it is possible to quickly decore complex and thin-walled aluminum castings without damaging the part because the binder has been engineered to decompose at aluminum casting temperatures. Using this binder and process, it is possible to recycle all scrap cores and to thermally recycle all core sand that can be recovered in such processes as semi-permanent mold and precision sand casting. By coating sand in-house, it is possible to completely eliminate all solid wastes related to the use of cores in these types of foundries. Also the core binder is completely non-toxic and biodegradable and core making can be done in a clean environment with nearly no noticeable odors. Beginning in the year 2000, this binder will be commercially available throughout the world.

CORE SCRATCH HARDNESS TEST
GMBOND™ vs. COLD BOX

GMBOND®	Avg.	sd.	n
Cope			
horizontal surface	61.25	10.64	8
vertical surface	62.25	6.53	8
Drag			
horizontal surface	59.70	5.96	8
vertical surface	64.38	9.50	8
COLD BOX			
Cope			
horizontal surface	62.87	4.50	8
vertical surface	64.37	2.67	8
Drag			
horizontal surface	59.70	4.60	8
vertical surface	62.25	7.42	8

Table 1

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Acknowledgements

The authors gratefully acknowledge the advice and encouragement of Paul Mikkola (Milford, N.H.) and Prof. Sergio Gallo (Turin, IT) and Yvonne Gombert for translations.

Note

This paper was originally presented at the CIATF Technical Forum, Düsseldorf, Germany, June 10-11, 1999.

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