Warm-Box Sand Coreroom Efficiency Improvement

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Metalcasters are faced with changes in environmental regulation, pricing pressure from their customer base, and rising raw material costs. Innovation, continuous improvement and the introduction of new technology are paramount to remain competitive and compete globally. In the process of making iron castings, Waupaca Foundry Inc. utilizes the warm-box process to produce mold inserts called cores to create internal features that cannot be formed by the green sand pattern. Warm-box cores are used predominantly for the production of gray iron ventilated brake rotor castings. To produce the cores, a bonding chemical called furan resin and a chemical accelerator called a catalyst are combined with silica sand. The sand mixture is introduced into a heated metal mold called a core box and partially cured until the outside surfaces harden sufficiently for removal of the core. The warm-box process is used globally by many competing foundries, however the technology and process of making cores varies. Waupaca Foundry reduced total manufacturing costs by utilizing new coremaking machines incorporating robotic automation, unique sand conditioning, and weight-compensated dry and liquid transport and addition systems for core sand recipe optimization. The new coremaking technology, combined with lean manufacturing systems improved productivity and quality and minimized raw material waste.

● **Key Word :** Warm-box core, Robotic automation, Core sand recipe optimization
● **Production Code :** Ventilated brake disc rotors
● **R&D Stage :** Mass production

1. Introduction

Waupaca Foundry, Inc. (WFI) commissioned a new warm-box coreroom during 2015-2016 at its Plant 2/3 facility in Waupaca, WI, USA. The coreroom was built to produce sand cores primarily for the production of approximately 85,000 ventilated disc brake rotor castings per day at the facility. The project consisted of several new technologies including: new coremaking machines designed and built at Waupaca Foundry, robotic automation, sand conditioning equipment utilizing plate heat exchangers, and dry and liquid material measurement and transport systems. Fig. 1 illustrates the entire process flow developed for this project.

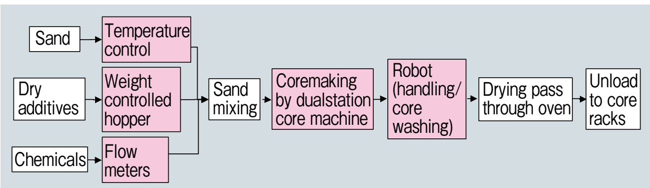


Fig. 1 Warm-box sand coremaking process

2. Equipment

2.1 Dual-station warm-box core machines and automation

WFI previously used single-station machines for core production. These coremaking machines could run two warm-box core patterns called core boxes at a time, one on each side of the machine. In order to improve productivity, a new core machine was developed by WFI that could run four warm-box core boxes at a time, two on each side of the machine. This doubled the production rate of the core machine. As cores are produced, a distended parting line or thin membrane of sand called a fin can be created where the two halves of the core box come together. In order to assure the quality of the finished casting, this parting line or any associated fin must be removed by using a de-finner which clears any obstruction. Robotic automation was utilized to remove the core from the de-finning station and apply a water based refractory coating called a core wash to protect the sand core during the iron pouring process. This was formerly a manual process with single-station core machines.

By automating the de-finning and core coating processes, WFI was able to realize manpower and equipment reductions. The single-station core machines could produce about 180 cores per hour with one machine operator. The new automated dual-station core machines could produce over 400 cores per hour, still with one machine operator. A total of six dual-station core machines with robotic automation on two lines were commissioned for this project, replacing thirteen single-station core machines and reducing the total number of machines and operators by 50%. (**Fig. 2**).

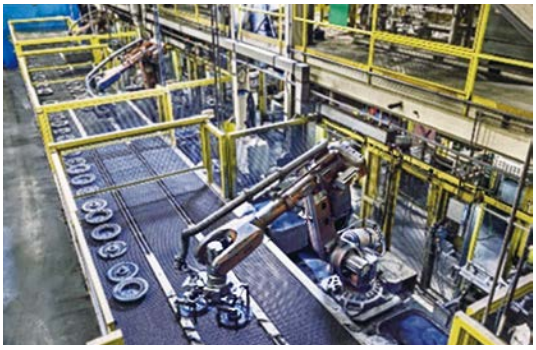


Fig. 2 Dual-station core machine with robot cell

2.2 Sand conditioning equipment

The warm-box coremaking process combines silica sand and wet or dry sand additives with a catalyzed furan-based resin in a mixer. Sand additives are used to enhance the core's ability to withstand the rigors of the iron pouring and solidification processes.

The mixture of sand, sand additives, resin and catalyst is delivered to the coremaking machine and blown into heated core boxes using pneumatic transport. The core boxes are typically heated to 200℃ in order to accelerate the reaction between the resin and the catalyst, causing the sand mixture to harden sufficiently to allow for the core to be extracted from the core box after a short dwell time.

The initial curing or hardening time for a brake rotor core is 18 to 20 seconds depending on the size, weight and geometry of the core being produced. The core surface hardness is proportional to its measured tensile strength. The tensile strength must be sufficient to eject the core from the core box and prevent distortion of the core. Following removal from the core box, the tensile strength of the core further increases as the resin fully cures.

As the resin curing temperature is a critical factor in the warm-box coremaking process, controlling the sand temperature is critical. Warm-box sand has a limited bench life once mixed with the resin and catalyst. Once the sand, sand additives, resin and catalyst are mixed together, the chemical reaction responsible for curing starts to take place slowly. If the ambient air temperature or the temperature of the sand is too high (over 29℃), the sand will start to cure prematurely affecting flowability of the sand mixture. This creates quality and production problems as the sand mixture begins to cure shortly after mixing and becomes unusable.

Consistent temperature control of sand in the coremaking process is a difficult challenge. The problem is magnified when disruptions occur in the foundry process that result in over-heating or cooling of the sand. Accurate temperature control is vital for efficient resin and catalyst mixing, and poor control can result in productivity loss, core and/or casting scrap and rework. Precise sand temperature control is also vital for optimizing the amount of costly resin and catalyst used in the process.

WFI desired to control the temperature of the sand entering the mixer to 24℃ (± 2℃), regardless of the temperature of the incoming sand or the ambient air temperature in the facility. Previously, water chiller systems were placed around the vessel that the sand was stored in immediately before mixing. Due to the insulating properties of sand, this arrangement could not adequately cool the material and a non-uniform temperature distribution existed inside the vessel.

WFI contracted Solex Thermal Science, a firm specializing in the design and construction of indirect plate heat exchangers, providing temperature control solutions for many industries and applications. In the Solex design, the working fluid is separated from the sand using a series of plates as shown in **Fig. 3**. Heated or cooled water provides the desired heat transfer as it flows through the internal passages in the steel plates controlling the sand temperature by conduction. As with conventional liquid or gas exchangers, the heat transfer fluid and product flows are countercurrent to gain greater thermal efficiency. Sand flow velocity and residence time through the heat exchanger is controlled by a mass flow vibratory feeder positioned below the plate bank, allowing very precise batch control.

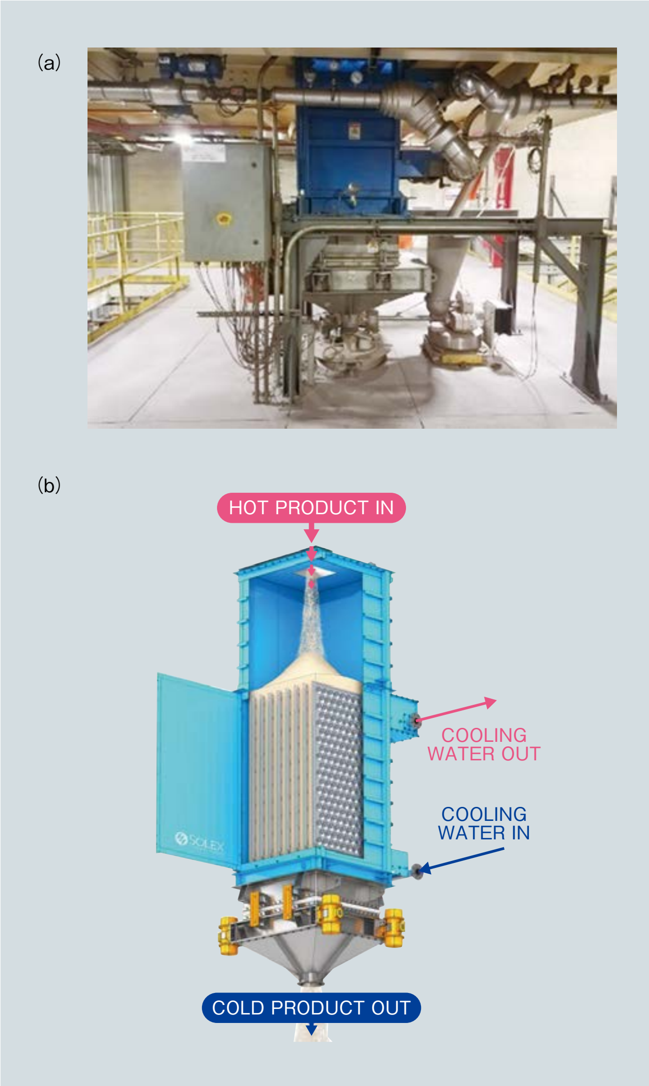


Fig. 3 Sand tempera ture control unit (a) actual (b) schematic (Courtesy of Solex Thermal Science)

2.3 Dry/liquid material measurement and delivery systems

WFI previously delivered dry additives by time and liquid additives based upon volume. While these were the most common additive delivery methods available, it was inefficient and limited the capability to optimize the sand core additive mixtures.

The new delivery systems for liquid materials (resin, catalyst and silane) utilize electric pumps to move the materials from their bulk storage vessels at a constant pressure and then meters the components into the mixing station utilizing mass flow meters.

The new delivery systems for dry materials (sand and sand additives) utilize pneumatic transporters from the bulk storage vessels and then meters the material into the mixing station using scales that measure the weight loss of the storage vessels (**Fig. 4**).

Resin temperature is continuously controlled in a recirculating loop to achieve stable viscosity to ensure consistent addition. The resin and silane are mixed at the point of use through a static mixer (**Fig. 5**). The on-demand system allowed for a reduction in silane usage. Previously, silane was pre-mixed in the resin and its effectiveness would fade over time as the material was used.

Fig. 4 Chemical flow meters

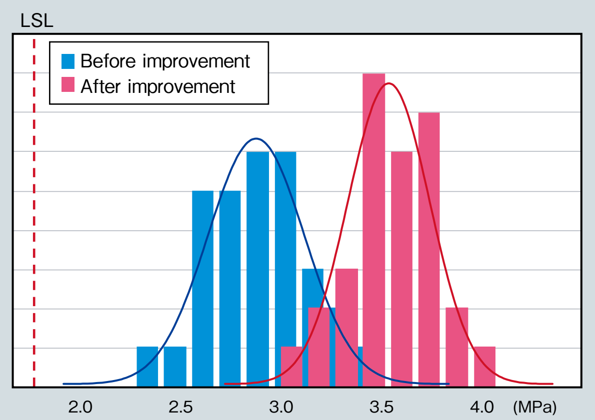
Fig. 5 Sand mixing system

With the combination of the two measuring and delivery systems, WFI was able to optimize the core sand mix recipe for each part number produced based upon the core weight, brake disc vent ring diameter and geometry. This was accomplished by first weighing the sand in the storage hopper prior to addition to the mixing vessel. The resin, catalyst, silane and sand additive additions are all adjusted automatically to compensate for the actual sand batch weight according to the specific recipe. Once all of the additions are calculated, the sand additives are delivered to the mixing vessel, followed by the resin, silane and catalyst. The sand mixer uses a high-speed, variable-frequency drive and can mix batches from 70 to 140 kg depending on the weight of the cores being produced. This allows the batch size to be optimized in order to eliminate bench life issues with the core sand mixture.

With the new additive delivery system, WFI delivers the mix of additives using both dry and liquid transport processes. The new technology precisely measures both dry and liquid additives to within 0.01%, resulting in significantly greater accuracy and less waste.

3. Conclusion

By implementing the new equipment and technologies described in this paper, WFI was able to reduce manufacturing costs associated with the production of warm-box sand cores in four ways: labor reduction; material reduction; quality cost improvement (**Fig. 6**); productivity improvement. Resin addition was reduced on average by 23% and catalyst use was reduced on average by 26%.



	Before improvement (old core production line)	After improvement (new core production line)
Total # of tests	30	30
Mean tensile strength (MPa)	2.89	3.53
Standard deviation	0.26	0.21
Ppk	1.50	2.81

Fig. 6 Core tensile strength capability histogram comparison

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