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Advancements in Materials for Three Dimensional Printing of Molds and Cores

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Abstract

Three dimensional printing of sand molds and cores is changing the way castings are produced. During the last five years major advances in equipment have allowed metal casters to realize castings designs at faster speeds than ever before. The elimination of tooling for mold and cores assemblies, has allowed the industry new flexibility in design optimization, reduced labor, increased dimensional accuracy and eliminated some defects associated with core assembly. While the equipment has been advancing, the materials used for printing have been very limited. The University of Northern Iowa has conducted new research into increasing the number of materials available for printing. These materials include regionally available resins, aggregates, and additives. These new materials have the ability to reduce the cost of printing and increase the number of applications while improving the casting quality. Veining defects in heavy iron or steel castings once prevalent on printed sand molds can be eliminated with engineered sand additives. Solidification rate and penetration defects can be addressed with specialty molding aggregates. This research has allowed the users of printed sand molds and cores to realize the potential of their sand printers and improve the quality of the castings they produced. The paper will detail the experiences with regionally available materials and compare their properties and performance with conventionally supplied materials.

Keywords: *Additive manufacturing, molding materials, 3D printing, bonded sands.*

1. Introduction

Three dimensional printing of cores and molds has come of age. Metal Casters are now able to drastically reduce lead times for pattern tooling while taking advantage of design freedom never before envisioned. Additive manufacturing for metal castings, AD4MC represents one of the most significant developments in metal casting technology in years.

The basic process introduced over twenty years ago has gained significant ground over the last two years. The technology once used exclusively for prototype low quantity is now being used for production cores and molds. The ability to produce very complex core assemblies has replaced a significant amount of manual labor not just in the core room but also in casting finishing operations. Single piece cores are replacing core assemblies that were manually glued in fixtures and mudded to seal joints.

90% of cores produced in North America utilize the phenolic urethane no-bake of cold box resin system. This robust process provides long working times and bench life along with good mechanical strength and compatibility with additives.

Almost all of the current three dimensional sand printers utilize the furan resin system catalyzed by sulphonic acid. Furan resins were very popular during the 70's and 80's in the foundry industry because of their high productivity and strength levels but price fluctuations and uncertain availability moved the foundry industry towards urethane and phenolic resins. The furan system is still used in foundry applications worldwide and has achieved a fair amount of market stability. It is available in several forms from several North America resin suppliers. It develops high tensile strengths while providing excellent shakeout and sand release from internal passageways.

While research continues on printing urethane or phenolic resins, furan systems remain the predominant systems in 3DP4MC applications. Recent testing has shown that although the furan sands are acid catalyzed, thermal reclamation effectively neutralizes the acidity of the sand making it compatible with phenolic urethane systems.

1.1 Equipment Technology

The equipment technology for AM4MC has been advancing at a tremendous rate. Developed by MIT researchers in the late 1980's it was licensed by three companies based in Germany. Zcorp had developed a resin system based on sodium silicate but ceased its sale and support of the printers in 2013. The remaining company split into what are the two largest manufacturers of sand mold printers. The first generation sand printers were introduced in the early 2000's are already reaching the end of their service life considered slow and inflexible. The second generation machines introduced in the late 2000's were two to three times as fast and twice as large. New equipment introduced in 2015 are touted to be twice as large again and four times as productive as the second generation equipment. North America suppliers have responded to the German made equipment with robotic arm printers promising to lower the cost of printed sand at a fraction of the price of larger units. The newest company to enter the market promises to combine very fast print times, low cost of equipment with freedom to use conventional sands and resins. This has the potential to lower the cost of printing sand to a point easily justifiable by even small foundries.

2.0 Materials Evaluated

Ten aggregates were evaluated for the binderjet printing process. A list of the materials evaluated is contained in Table 1.

Table 1 Aggregates tested

Sample	***Aggregate***
1	Silica M4000
2	Carbo Accucast ID50-K
3	Carbo Accucast LD70
4	ORC Chromite
5	Ceramsite
6	Cerabeads
7	Fused silica (crushed)
8	Incast 70
9	Incast 8-
10	Manley "Acti Sand"
11	Carbo 100/140

2.1 Mechanical Properties

Mechanical properties included Bulk density as defined by the AFS 1130-00-S [1], Tapped density per 1131-00-S, Surface area per AFS 1108-00-S, Grain shape or Coefficient of Angularity per AFS 1126-00-S, Base permeability per AFS 1119-00-S, and non-standard tests including angle of repose, material flow rate and penetration force. The penetration force was determined by measuring the resistance of a 1"(25mm) plate being pushed into a container of the material. The maximum force and penetration distance at the maximum force were recorded for all samples along with the sand displacement in pounds per inch.

Mechanical Properties Results

The untapped and tapped bulk density results are shown in table 2. With the exception of the specialty aggregates such as the ceramics and mullites, it can be observed that the untapped density of the silica sand samples are typically in the range of 1.4-1.6 g/cc. However, looking at the tapped density results, it can be observed that certain aggregates are arranged better upon tapping when compared to others. This largely depends on the grain shape factor of the aggregate. Silica M4000 has a tapped bulk density of 1.769 g/cc, which is the highest among the silica sand aggregates. Carbo 100/140 aggregate has a tapped density of 1.510 g/cc. The other silica sand aggregates are observed to range between 1.6-1.7 g/cc.

Table 2 Untapped and tapped bulk density results for all aggregates

Aggregate	***Bulk Density (g/cc)***	***Tapped Density (g/cc)***
Silica M4000	1.554	1.769
Carbo Accucast ID50-K	1.819	2.070
Carbo Accucast LD70	1.424	1.694
ORC Chromite	2.694	3.015
Ceramsite	1.839	2.007
Cerabeads	1.422	1.723
Fused silica (crushed)	0.989	1.256
Incast 70	1.516	1.673
Incast 80	1.445	1.620
Manley "Acti Sand"	1.438	1.623
Carbo 100/140	1.41	1.510

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References

[1] American Foundry Society, Mold And Core Test Handbook (2015)