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Evaluation of Collapsibility of Selected Core Systems

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Abstract

There are mainly two different ways of producing sand cores in the industry. The most used is the shooting moulding process. A mixture of sand and binder is injected by compressed air into a cavity (core), where it is then thermally or chemically cured. Another relatively new method of manufacturing cores is the use of 3D printing. The principle is based on the method of local curing of the sand bed. The ability to destroy sand cores after casting can be evaluated by means of tests that are carried out directly on the test core. In most cases, the core is thermally degraded and the mechanical properties before and after thermal exposure are measured. Another possible way to determine the collapsibility of core mixtures can be performed on test castings, where a specific casting is designed for different binder systems. The residual strength is measured by subsequent shake-out or knock-out tests. In this paper, attention will be paid to the collapsibility of core mixtures in aluminium castings.

Keywords: Foundry, Foundry cores, De-coring, Knocking-out, Collapsibility

1. Introduction

In the foundry industry, there are two basic principles of core production. The first is that the mixed mixture of sand, binder and additives is poured and then packed/compacted in a core box (metal, wood, or plastic core box). Curing then takes place depending on the binder system technology. The second most common method is to inject the semi-liquid mixture into the core box using compressed air. 3D core printing technology is also on the rise, finding high application mainly in parts of castings with shape complexity [1, 2, 3].

Depending on the production technology, the binder systems have specific mechanical properties after thermal exposure. Cores bonded with organic-based resins have high strengths after curing, shelf-life, and low thermal degradation temperature, which is associated with excellent disintegration after casting. A significant disadvantage is an ecological impact on the environment. On the other hand, inorganic mixtures are nowadays used mainly because

of their minimal environmental impact, where hazardous substances are only formed during casting and cooling of the castings. On the other hand, they do not have the same mechanical properties as organic binders. For aluminium alloy castings, due to the lower heat load achieved, the more effort is usually required to remove the sand cores from the castings. In the case of resin-bonded sands, the heat introduced during the casting process is sufficient to break the surface layer of the core [4, 5, 6].

Measurements of disintegration can be made directly on the manufactured test cores, where, after heat exposure for a period, the mechanical properties of the cores will decrease. The reference values are then compared with the results obtained for the mechanical properties of the cores after thermal exposure [7, 8].

This article will focus on the collapsibility of selected foundry mixtures and their parameters. Also, the knocking-out test will also be described here.



2. Materials and methods

2.1. Knocking-out test design

In order to evaluate the collapsibility of core mixtures, it was necessary to design a knock-out methodology for cores. This test was derived from the VŠB-TUO test methodology for evaluating the collapsibility of moulding mixtures with sodium silicates. Using a mandrel placed in a laboratory tamping device, the number of hit of a well-defined force was measured. Castings with cores were inserted between the knocking mandrel and the shaft. A weight of 6.8 kg fell freely from a height of 50 mm, resulting in an applied force on the core of 3.3 Joules. The mandrel was designed to be both taller than the length of the test casting and smaller in diameter than the square opening of the casting. This shape was chosen because of the need for full penetration through the test casting (core).

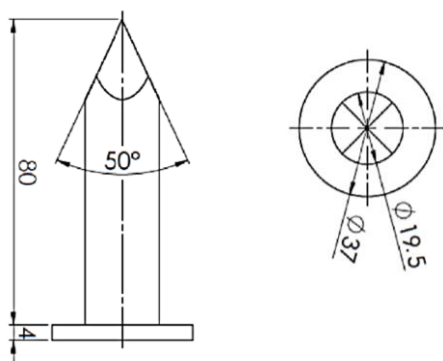


Fig. 1. Mandrel used in collapsibility testing.

2.2. Design of test casting for knock-out test

In order to determine the friability of the selected mixtures, it was necessary to design and define a test casting that could be inserted between the discharge mandrel and the ramming head. Therefore, casting with an average wall thickness of 5.0 mm and dimensions of 32.5 mm × 65 mm × 60 mm, and a mass of 196 g was designed to simulate the production of thin-walled castings with relatively massive cores that do not experience sufficient core heating (see Figure 2). The mass ratio between cores and metal was approximately 1:2.

The principle was to significantly limit the thermal destruction of the core mixtures by the mass of metal. The low core heating is then the cause of poorer cleanability of the castings, or poorer collapsibility of mixtures with organic binders. The castings were made from an aluminium alloy with the chemical composition AlSi7Mg0.3 verified by the producer. The pouring temperature was set to 720 °C ± 5 °C.

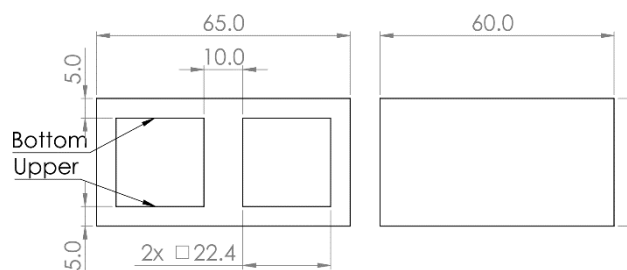


Fig. 2. Dimensions of the casting

In order to verify the design of the test castings, casting and solidification simulations were performed in MAGMA Soft, where the program evaluated the high soundness of the tested castings (see Figure 3).

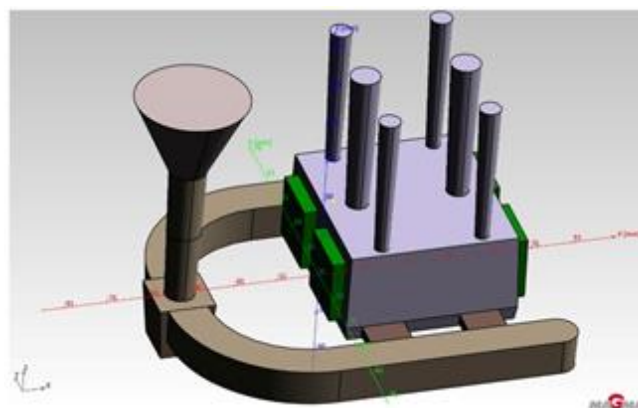


Fig. 3. 3D model from the MAGMA simulation program

2.3. Production of sand cores

Four different core systems were used to verify the possibility of using core mixtures: Resin coated sand (RCS), GEOPOL, Furan resin, and 3D-printed sand bounded with furan resin. For each binding system.

Cores from RCS (marked CB20B) and GEOPOL (marked W 303) were produced on a laboratory shooting device LUT from Morek Multiserw with a metal core box with three cavities. Due to the different properties of these binder systems, the production parameters are different, but natural and recommended by the manufacturer. The following are the production parameters:

RCS mixtures:

- core box temperature 280 °C, shooting time 2 sec., curing time 120 sec., shooting pressure 2 bar, due to manufacturer's secrecy.

GEOPOL mixtures:

- core box temperature 150 °C, shooting time 6 sec., curing time 120 sec., shooting pressure 6 bar, binder dosage 2%

Furan cores were produced by the conventional method of production, with 1 % of binder and 0.35 % of the catalyst from the amount of binder, where a mixture was poured into the core box and then compacted by three standard punches by the LUA-2e/Z device. Although chemically bonded cores are not normally compacted in this case, it was desirable to do so in order to comply with the production conditions. Two sizes of sand were selected for the research.

The cores produced by 3D printing were printed on a 3D printer by the FDB method (furan direct binding) from ExOne, with 1.25 % of furan binder and 0.21 % of the catalyst (for winter season) from the amount of binder hereafter these cores are referred to as 3DSP.

2.4. Surface quality represented by surface roughness

The evaluation of roughness was carried out on the Keyence VHX 6000 digital zoom microscope with a zoom range of 20x up to 2000x. Figure 3 shows the evaluated lengths on the casting area. The measured area was photographed and evaluated according to the valid ISO EN 4288:1998 standards. The measurement parameters and cut-off were as follows: evaluated length 4 mm, wavelength (λ_c) = 0.8 mm, shortwave filter (λ_s) = 2.5 mm. Evaluated length values have always been taken from three points, red rectangles.

Table 1.

The basic parameters of tested cores

Parameters	3DSP	BG 21	BG 27	CB20B	W303
Medium grain size d_{50} [mm]	0.14	0.19	0.23	0.20	0.24
Degree of homogeneity S [%]	68.75	62.50	60.00	68.03	62.13
GFN acc. to AFS [-]	97	69	60	69.49	57.77
LOI (loss on ignition) [%]	1.20	1.14	1.12	1.79	0.28
Transverse strength [MPa]	0.92	3.45	2.67	4.47	7.36

The medium grain size measured by the manufacturer is relatively consistent with the measured results. The degree of homogeneity, expressing the homogeneity of the sand, is lowest for furan cores (BG 27). On the other hand, the highest values were obtained for furan cores (3DSP), which were printed on a 3D printer, and RCS mixture (CB20B).

The RCS cores show the highest loss on ignition at 1.79%, which is the highest of all the mixtures used. This is indicative of a high resin dosage. The lowest measured values of the LOI parameter were measured for cores bonded with geopolymer binder.

The transverse strength, also known as 3 points bending strength test, was performed on rectangular specimens of 22.4 x 22.4 x 170 mm. The strengths were tested on Morek Multiserw devices, named LRU-2e. The highest measured strengths were recorded for the cores bonded with GEOPOL, with strengths

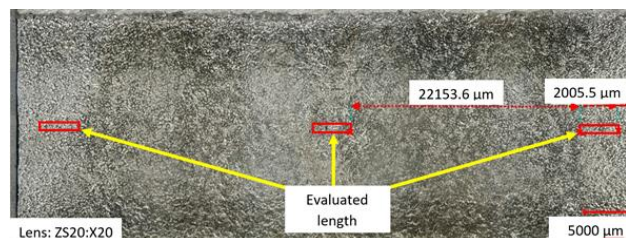


Fig. 4. Evaluated area of the casting

Evaluation of roughness was carried out on photographs that were made up of partial figures using the "stitching" function to match the length for measuring roughness according to valid ISO standards. Subsequently, roughness values were obtained from five inserted lines on one evaluated length. All the data from the evaluated lengths were averaged to get the average roughness of one casting.

3. Results and discussion

3.1. The basic parameters of tested cores

For the purpose of the research, tests of selected moulding mixtures were carried out. Individual mixtures were tested for medium grain size (d_{50}), degree of homogeneity (S), AFS parameter, loss of ignition, and 3 points bending strength (transverse strength). Each test was evaluated on 3 samples of each mixture. The results are presented in Table 1.

averaging 7.36 MPa. This is thus a very efficient binder system for core production. In contrast, the lowest strengths were exhibited by cores produced by the 3D printing method, with an average strength of only 0.92 MPa. However, it should be noted that the shape complexity of the cores is virtually unlimited.

3.2. Surface roughness

The smallest roughnesses were obtained using cores made from RCS (CB20B) blend. Coated sand mixtures have excellent surface-quality properties. This is guaranteed by the higher binder dosage compared to the other mixes evaluated. The high degree of homogeneity is also influential. On the other hand, the highest roughness values were measured for surfaces where cores produced

by 3D printing were used. It was expected that a relatively high amount of binder combined with the finest sand would produce a fine compact surface.

The degraded surface quality may be due to very low transverse strength, where the core was unable to resist erosion and the effects of the liquid aluminium alloy. Furan blends (BG 21 and BG 27) achieve the same surface roughness. Grain size does not have a significant effect on surface quality. The cores bonded with GEOPOL binder showed approximately the same surface roughness values as the furan resin cores.

However, the binder dosage must be taken into account, as in this case, it was the lowest of all the mixtures tested and the mean grain values were the highest. This demonstrates the high effectiveness of these mixtures, as confirmed by the measured transverse strength values.

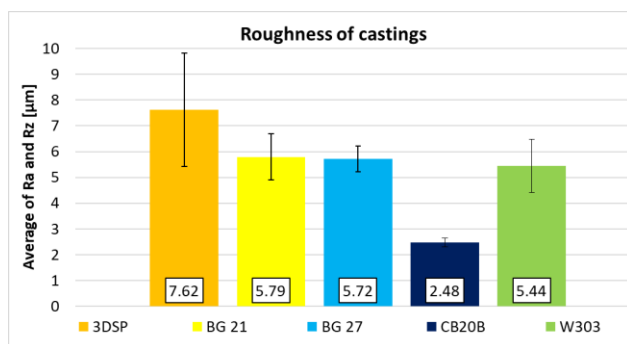


Fig. 5. The roughness of the castings

3.2. Evaluation of collapsibility by knocking-out test

Based on the above-mentioned core collapsibility test, practical collapsibility tests of the selected core mixes were carried out, which are shown in Figure 6, where the average number of knocks of the four values are given. The lowest number of knocks was measured on furan cores produced by 3D printing technology. Thus, on average, approximately 6 strokes were required to remove the core from the casting. The high collapsibility of these cores was expected depending on the measured transverse strength values. Furan cores produced by conventional methods show excellent collapsibility properties. The cores achieve relatively high strengths at optimum binder dosage and have good surface properties.

In contrast, the highest number of knocks was observed for cores bonded with the GEOPOL binder. Approximately 46 knocks were required to knock out these cores. Again, there is a huge correlation between the transverse strengths. With minimal binder content, they achieve high strengths, and the surface quality of the casting cavities is comparable to that of furan resin cores. RCS mixtures are a certain landmark. These have shown the second-highest strengths and the best surface quality of the castings. The collapsibility then ranges between furan and GEOPOL cores.

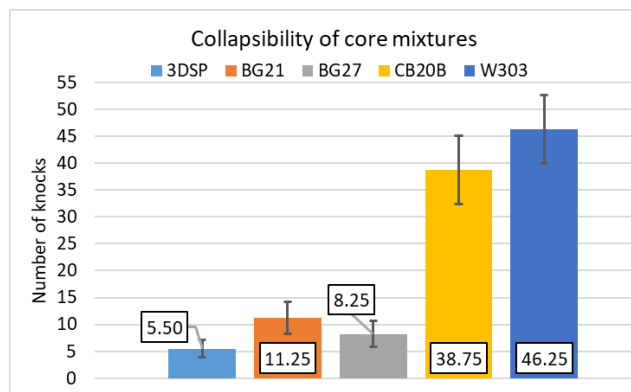


Fig. 6. Collapsibility of core mixtures in graphical representation

4. Conclusions

The work focused on the collapsibility of selected core mixtures. Three binders, furan resin, resin-coated sand, and GEOPOL binder were selected for the research. The manufacturing process for each binder was carried out using 3D printing of furan cores, shooting mixtures of cores into the hot box, and the conventional core manufacturing method.

The measured results then show that furan cores with a suitably chosen sand fraction are suitable to be used in the formation of cavities in aluminium castings. The relatively high strengths of these cores combined with good surface quality and excellent collapsibility are highly desirable in the foundry industry. However, this technology runs into the problem of environmental impact. It is, therefore, necessary to resort to a certain alternative in the form of inorganic binders such as GEOPOL binder. Although the disintegration rate of thin-walled castings is low, the cores achieve high transverse strengths using minimal binder content and providing good surface properties to the castings. A certain correlation between transverse strength and total core collapsibility can also be observed. As the transverse strengths increase, the number of knocks required to remove the core from the casting also increases.

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