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Development of a technology for the production of ceramic moulds with reduced thermal conductivity to control the solidification of thin-walled castings

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Abstract

During the project a technology of making ceramic moulds using aluminosilicate microspheres was developed. According to the developed technology, ceramic samples were used to determine thermal conductivity in the temperature range of 500°C to 850°C. In this temperature range, thermal conductivity is about 0.5 W/mK. Strength measurements were conducted using a four-point bending technique. The strength of the developed ceramics and typical ceramics made from molochite materials is similar. Computer simulations facilitated the design of experimental moulds. The recording of Al alloy cooling curves in rectangular insulated and non-insulated moulds allowed for comparison of the thermal parameters of both types of moulds (i.e. ceramics). There was also a castability test performed using the moulds with a "grille" model with 1.5 × 1.5 mm channels, which determined the effect of increased material insulation on the number of properly filled mesh of the mould.

Keywords: *ceramic moulds, aluminium alloys, thermal conductivity, thin-walled castings, microspheres*

1. Introduction

During the solidification process a shrinkage phenomenon occurs which could lead to porosity defects in castings. Proper preparation of the mould geometry and selection of suitable technology eliminates shrinkage cavities from the casting. Another possible solution includes the use of standard insulation or exothermic insulation. Also the chills could be used to obtain the desired temperature gradient. In the investment casting process where ceramic layered moulds are used for the isolation of certain regions a special insulating lining is applied. The special lining could be replaced with a ceramic compound with reduced thermal conductivity.

Ceramic materials used in the manufacture of layered moulds have a thermal conductivity value in the range from 4 to 8 W/mK. Using the ceramic material, including microspheres which have a low thermal conductivity, it is possible to isolate selected areas of the mould. The ceramic material can be applied multiple times until desirable thermal properties are achieved. This method can be used in the production of thin-walled castings, where the use of known methods does not produce the expected result.

The article describes the production of layered ceramic moulds with reduced thermal conductivity, designed to control the solidification of thin-walled test castings.

2. Experimental

Steps of the conducted laboratory experiments:

– measurements of thermal conductivity of standard molochite-based and insulated microsphere-based ceramics,

– determining basic parameters of the microspheres used,

– measuring flexural strength of both ceramics,

– selection of geometry of wax patterns,

– computer simulations in Flow3D: cooling curves and castability test,

– making two types of ceramic moulds for cooling curves recording,
– making moulds with “grille” for castability test,
– filing the moulds with liquid metal and recording cooling curves,
– performing castability test.

2.1. Materials

The bulk density of used microspheres (Fig. 1) is about 0.4 g/cm^3. According to the producer, thermal conductivity of microspheres is 0.07 ±0.03 W/mK. Softening point is 1220 ±10°C and melting point is 1495 ±10°C.

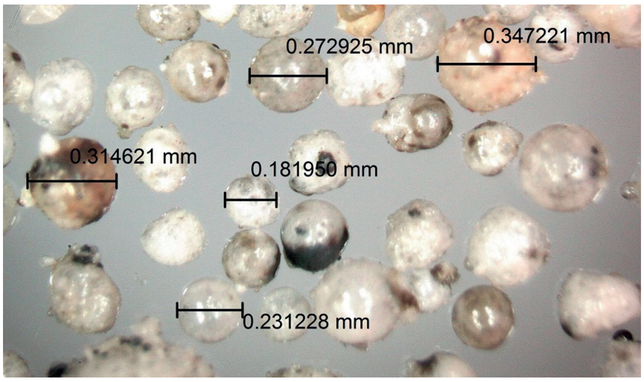


Fig. 1. Microspheres used in experiments

Particle size distribution measurement of microspheres were performed using Mastersizer 2000 laser particle size analyzer (Fig. 2).

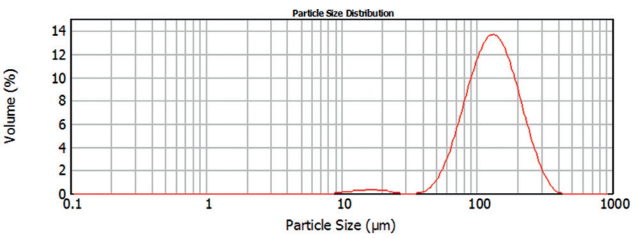


Fig. 2. Particle size distribution of microspheres (average size: 0.126 mm)

The first type of ceramic layered moulds is made of molochite material used in the casting of brass and aluminium alloys. The liquid ceramic slurry is prepared from the molochite flour (0−0.044 mm) and silica binder (Ludox PX30). The first two layers of the mould were made using ceramics with a particle size of 0.1−0.3 mm, followed by sand with a particle size of 0.5−1 mm (7 layers). The second ceramic type, with reduced thermal conductivity, was obtained by replacing molochite ceramics with microspheres of particle size 0.16–0.30 mm for all layers, with the same slurry. The last layer in both cases was applied with fine molochite ceramics to maintain a uniform emissivity of the surface of the samples [1,2]. Figure 3 shows the test sample of the thermal conductivity measurements. The samples for thermal conductivity measurements were made in silicone rubber moulds in a similar way to the way ceramic moulds are made. They had a diameter of 62 mm and thickness of 6 mm and 9 mm.

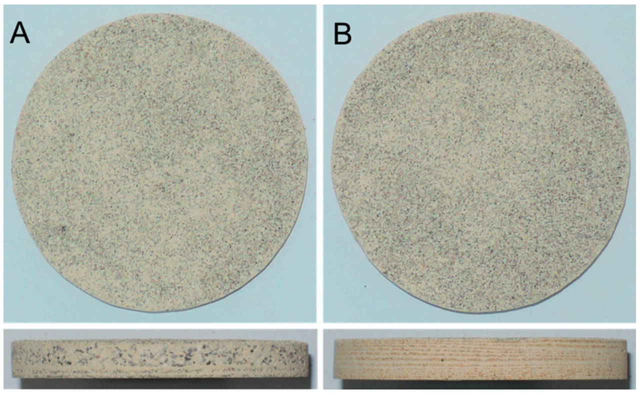


Fig. 3. Samples for thermal conductivity measurements: typical molochite ceramics (A) and with microspheres (B), thickness: 9 mm

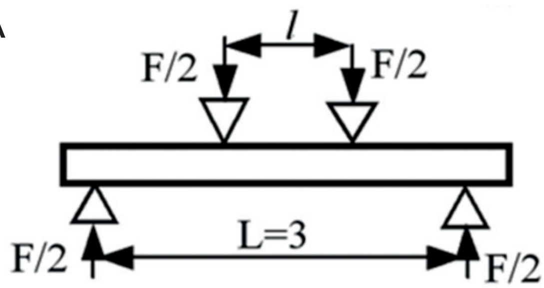
2.2. Flexural strength measurements

The strength of the prepared ceramic samples (Fig. 4b) was tested using a measuring device developed by the Foundry Research Institute, based on the four-point loading arrangement (Fig. 4a) of a ceramic specimen with 60 × 20 × 7 mm dimensions at selected temperatures ranging from ambient to 1100°C. A uniform load provided between the central supports greatly facilitates finding the critical defects that may occur at random in the sample [3]. The results are listed in Table 1.

Table 1. Results of flexural strength measurements

	Molochite		Microsphere	
Temperature, °C	650	900	650	900
Flexural strength (average), MPa	3.33	4.41	3.32	4.34

A



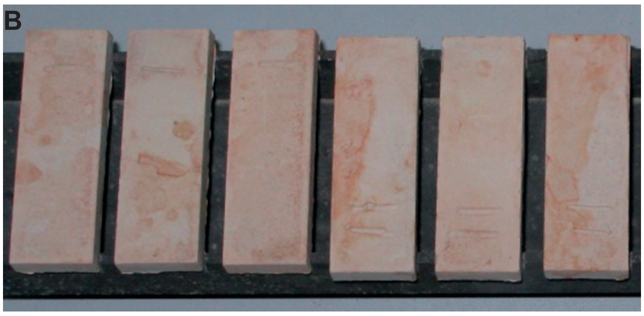


Fig. 4. Principle of four-points bending test: scheme (A), samples (58 × 20 × 7 mm) (B)

2.3. Thermal conductivity measurements

The thermal conductivity tests were performed using the measurement method described in patent No. 210610, "Apparatus for measuring thermal conductivity of ceramic materials" [4]. The experimental set is shown in Figure 5. During the measurement, the ceramic sample floated on the surface of liquid tin. To determine the coefficient of thermal conductivity, the temperatures of the lower and upper surfaces of the sample were measured. The thermocouple inserted into the side wall of the graphite crucible was used to measure the temperature of the bottom surface. The upper surface temperature was measured by a pyrometer. For the calculation of the coefficient λ the following equation is used:

$$\lambda = \frac{(Q/\tau)d}{A(t_b - t_t)} \tag{1}$$

in which:

Q – amount of heat transferred in time τ through sample, W

λ – thermal conductivity, $Wm^{-1}K^{-1}$

d – thickness of sample, m

A – surface area of sample, m^2

t_b, t_t – temperature of the bottom and the top of the sample, K.

The value of Q/τ can be calculated from the Stefan-Boltzmann law, which determines the total power radiated to half-space by the unit area:

$$(Q/\tau) = \eta\sigma T^4 \tag{2}$$

in which:

η – emissivity,

σ – Stefan-Boltzmann constant, $5.6704 \cdot 10^{-8}$ $Wm^{-2}K^{-4}$,

T – absolute temperature, K.

The measured temperature is the average temperature calculated from the lower and upper surface temperatures. Resulting values of thermal conductivity, presented in Figure 6, were used for computer simulations.

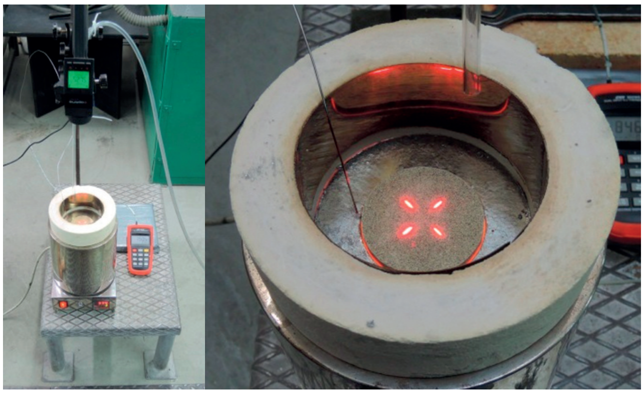


Fig. 5. Experimental set for thermal conductivity measurements

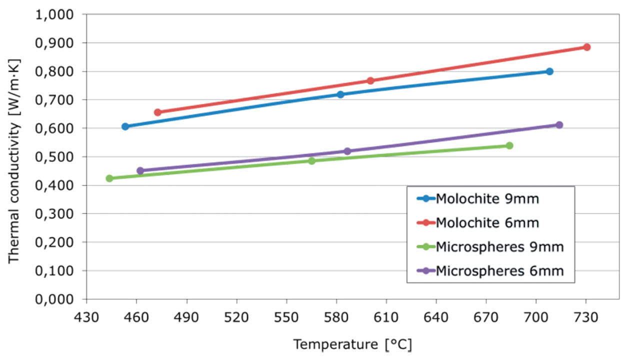


Fig. 6. The results of measurements – thermal conductivity as a function of temperature

2.4. Computer simulations

For simulation of cooling curves in Flow3D a rectangular mould (dimensions of 100 × 47 × 27 mm) were chosen, insulated and non-insulated (Fig. 7). At the geometrical center a measuring point was set. Virtual mould for castability test consisted of two identical "grille" patterns (length of 190 mm, cross-section of channels: 1.5 × 1.5 mm) of which one is non-insulated and other one is insulated. Simulations of cooling curves and castability tests were carried out using data for AlSi9Mg alloy [5,6].

Figure 8a shows a CAD model of a ceramic mould cavity for the sample for castability test and marked areas which represent the two ceramic materials. The blue color stands for standard molochite material, green color – a ceramic with reduced thermal conduc-

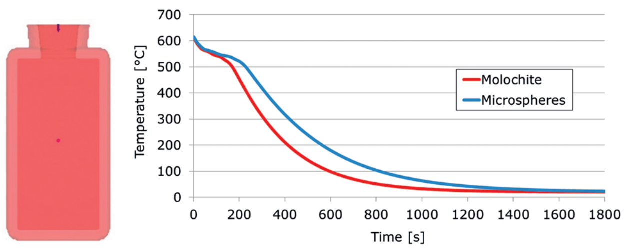


Fig. 7. Wax pattern and ceramic mould (left) and recorded cooling curves for both types of moulds – results of simulation

tivity. The simulation was performed to show the flow characteristics of liquid AlSi9Mg alloy in the test samples. The mould temperature was set at 500°C, liquid alloy temperature at 650°C. The boundary conditions have been selected according to the actual conditions of the laboratory tests. A filling process is shown in Figure 8b and 8c. Figure 8d shows the height of the metal flow in the area of both cavities [7,8].

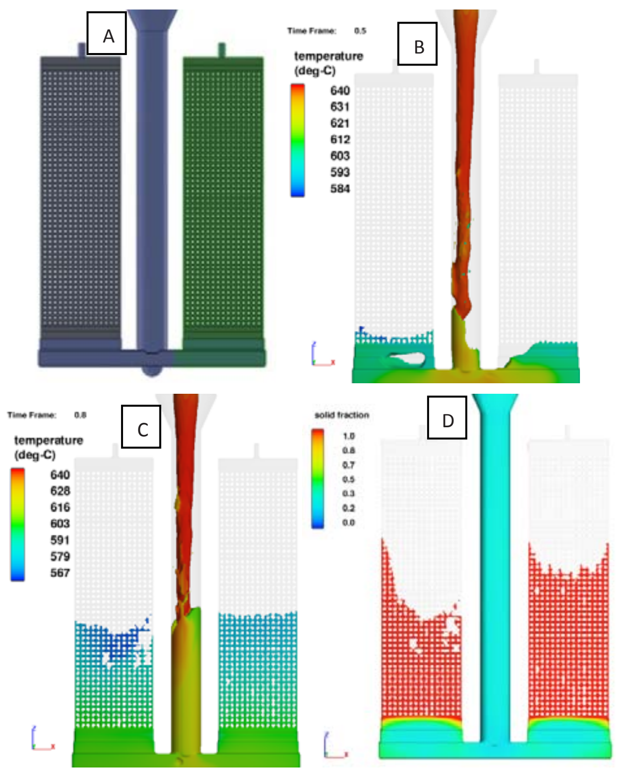


Fig. 8. A – CAD model of the mould with a "grille" (blue part represents typical molochite-based ceramics and green part is microsphere-based) and result of simulation, B, C – filling process; D – coldshot solidification during filling process t = 1.2 s)

2.5. Cooling curves recording and castability test

Two types of ceramic moulds (insulated and non-insulated) for cooling curves recording were made using the lost wax technique [7] and with the same ceramics composition as described in section 2.1. The same method was used to make moulds for the castability test. Temperature was measured using PtRh30-PtRh6 thermocouples that were placed in small quartz tubes secured in moulds. Graphtech GL820 was used as a recording device. Cooling curves are presented in Figure 9.

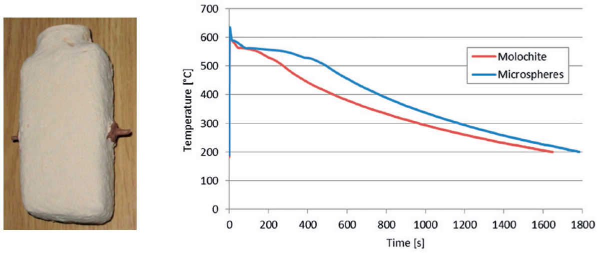


Fig. 9. Ceramic mould and recorded cooling curves for both types of moulds – real results

Using the SolidScape 3D-printer, test models with an element size of 2.2 × 2.2 mm and dimensions of channels 1.5 × 1.5 mm were printed. Then the models were used to prepare a silicone mould for manufacturing of wax patterns. The gating assembly was prepared as siphons with two symmetrically attached wax patterns. The first pattern was covered with molochite ceramics, the second with microsphere-based ceramics. The test result is shown in Figure 10 and Table 2.

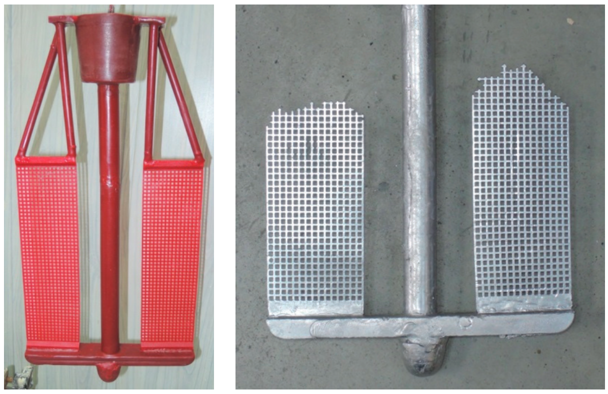


Fig. 10. Wax pattern, ceramic mould and resulting casting of castability test (left: non-insulated, right: insulated)

Table 2. Results of the test as a number of properly filled cells

No.	Number of properly filled cells	
	Non-insulated mould	Insulated mould
1	426	492
2	196	248
3	495	549

3. Summary

The article presents the first attempt to use microsphere-based ceramics for investment casting. Therefore some research has yet to be conducted in order to evaluate the usefulness of the new material for control in the solidification process of thin-walled castings.

The developed technology of making isolated ceramic moulds indicates that there is no significant difficulty in replacing typical ceramic materials with microspheres. The strength of such ceramics does not differ much from typical ceramics used for casting aluminium alloys. The cooling curves obtained for both types of ceramics show expected differences in the cooling rate. The castability test indicates that insulated parts of moulds are filled to a higher degree compared to non-insulated parts.

Acknowledgements

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