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The Role of Recycled Ceramic Material Obtained from the Ceramic Layered Moulds Used in the Investment Casting

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Abstract

The article presents the role of the ceramic layered moulds used in the investment casting method with new (certified) and recycled material from ceramic moulds (CM) after casting process. The materials that were obtained are mainly aluminosilicates and S_iO_2. The investigation of changes in the quality of ceramic moulds (including the recycled ceramic material) includes the chemical composition of the ceramics as recovered ceramic material, changes in the particle size of the layered covering material, the gas permeability during the pouring of liquid metal, and the creation of the porosity are presented. Than the thermophysical parameters and dimensional accuracy of the casting manufactured in the new ceramic layered shell moulds were analysed. Additionally the global cost savings and improved ecological conditions in the foundry and its surroundings was estimated.

Keywords: Recycling, Ceramic mould, Investment casting

1. Introduction

Investment casting is an industrial process based on lost-wax casting. The casting mould consists of ceramic layers. The ceramic layered shell mould in the investment casting process have a major influence on the quality of manufactured castings [1]. The dimensional accuracy and the surface quality are the primary objective in this manufacturing technology. Ceramic moulds dimensional distortions are the reason of approximately 60% of overall errors of the casting manufactured mainly with the use of aluminosilicates [2, 3]. Based on the quality of the castings the amount of the ceramic moulds with aluminosilicates has increased at least 40% of the global investment casting production compared to moulds based on the S_iO_2. In addition to the quality of manufactured castings in the sustainable production very important are the environmental aspects affecting human health [4, 5].

2. Research methodology

The laboratory trials include the special dilatometric analysis of the test samples to achieve the thermal expansion parameter of the ceramic mould samples with the dimensions of ϕ20x60. The Olympus stereo microscope was used for the evaluation of the ceramic grain size. Additionally the laser measurement of the changes in the particle size and the porosity using mercury porosimetry was checked at random ceramic moulds from the WSK Rzeszow company.

The thermal conductivity λ was evaluated based on the cylindrical ceramic samples. The gas permeability test was carried out mainly on the laboratory stand shown in the Figure 1.

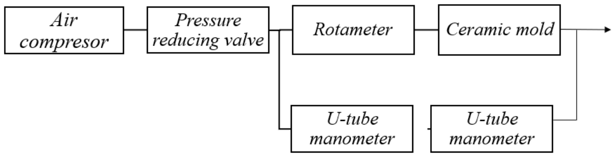

Fig. 1. The block diagram of the gas permeability test

Table 1.
Materials used to next layers ceramic mould

Nr ceramic layer	Molochite N	Molochite R	S_iO_2 N	S_iO_2 R
1	Molochite (new)	Molochite (new)	S_iO_2 (new)	S_iO_2 (new)
2	Molochite (new)	Molochite (new)	S_iO_2 (new)	S_iO_2 (new)
3	Molochite (new)	Molochite (new)	S_iO_2 (new)	S_iO_2 (new)
4	Molochite (new)	Molochite (recycled)	S_iO_2 (new)	S_iO_2 (recycled)
5	Molochite (new)	Molochite (recycled)	S_iO_2 (new)	S_iO_2 (recycled)
6	Molochite (new)	Molochite (recycled)	S_iO_2 (new)	S_iO_2 (recycled)
7	Molochite (new)	Molochite (recycled)	S_iO_2 (new)	S_iO_2 (recycled)
8	Molochite (new)	Molochite (recycled)	S_iO_2 (new)	S_iO_2 (recycled)

3. Research analysis of the influence of recycled ceramic moulds on the casting quality

3.1. Verification of the chemical composition of the samples of ceramic moulds

The changes in the amount of S_iO_2 in the aluminosilicates of recycled material were found. The amount of S_iO_2 increased from 22% to 25,7% due the transition of the certain amount of the binder to the crystalline state. The total content of the Al_2O_3 + S_iO_2 has slightly changed and in practice that has no effect on the thermal expansion of the ceramic mould.

3.2. The evaluation of the ceramic mould porosity

The use of the mercury porosimetry based on the capillarity effect shows very low porosity in the range of 26-28%. The samples of recycled ceramic mould material shows the porosity at similar range 26,5-29%.

3.3. Verification of the particle size of the clean and recycled ceramic moulds material

A new material with the grain diameter of ~ 0,9 mm and a recycled material recovered in the laboratory device using the hammer crushing method, there was a significant fragmentation of the material to the average of 0,5 mm grain size. When the recycling process of the ceramic mould was conducted in the laboratory (150 mm diameter rollers, the gap between the rolls of 1.2 mm), there was no difference between the grains of a new and recycled material. The rolling mill was used in the Warsaw University of Technology.

For the determination of the particle shape the method commonly used in the powder sintered technology was partially adopted [6]. The shape of the grains was presented by the value of W_k later called the size ratio. W_k value is defined as the ratio of the circumference of grain to the circle inscribed in the outline of the grain. For the evaluation of the W_k value a special software available from the Olympus microscope for the image analysis of each particle was.

An exemplary outline of the grains is shown in figure 2.

Ceramic grains have been given a contractual mark, depending on the size of the size ratio:

- $1 < W_k < 1{,}21$- grain shape close to a circle (circular)
- $1{,}21 < W_k < 1{,}34$ – globular grain shape
- $1{,}34 < W_k < 1{,}74$ – edgy grain shape
- $1{,}74 < W_k$ - fragmented grain shape

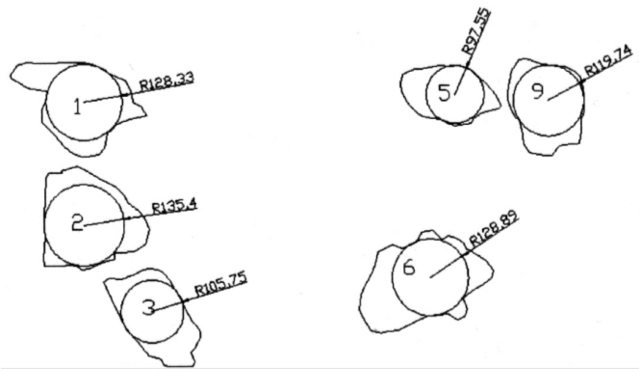

Fig. 2. An exemplary outline of a few grains of the aluminosilicate Remasil (recycled)

On the basis of 30 grains sifting obtained:
a) Remasil (new aluminosilicate) - the edgy shape of grains avg. $W_k \sim 1.42$
b) Remasil (recycled) - edgy grain shape avg. $W_k \sim 1.43$
c) Molochite N - edgy shape of the grain avg. $W_k \sim 1.48$
d) Molochite R - edgy grain shape avg. $W_k \sim 1.42$
e) S_iO_2 N - edgy shape of the grain avg. $W_k \sim 1.35$
f) S_iO_2 R - grain shape similar to the globular shape avg. $W_k \sim 1.34$

And for the S_iO_2 - 20% of ceramic material have a circular shape and about 30% of the particles have a globular shape.

3.4. Gas permeability of ceramic moulds

The evaluation of the possibility of multiple recycling of the ceramic material needs a set of further laboratory trials regarding the permeability (gas permeability). The verification was carried out on the laboratory stand presented on the fig. 1. The test was commenced in the 20 °C temperature. The following results were obtained

1. For ceramic mould with molochite N, K = 0,58 [cm^4/G·min] - the average for the two parties (12 pieces of ceramic mould)
2. For ceramic mould with molochite R, K = 0,46 [cm^4/G·min] - after two recycling cycles.

In the previous studies has been established that for K <0,2 [cm^4/G·min] we can obtain a cold shot type casting defect [7, 8, 9]. The results are the average of two types of conducted studies.

3.5. The evaluation of the thermophysical parameters

The laboratory trials was carried out on the cylindrical ϕ26x17 shape samples based on aluminosilicate, with 6 mm thickness. The samples was heated inside by the heating element at a rate of about 5 °C/min to the temperature of 900 °C.

Using the Fourier equation after appropriate transformations the thermal conductivity coefficient λ was obtained.

$$\lambda = \frac{P \cdot \ln \frac{d_2}{d_1}}{2 \cdot \Pi \cdot L(T_1 - T_2)} \left[\frac{W}{m \cdot K} \right] \quad (1)$$

where:
λ - thermal conductivity
P – heating power of the heating element [W]
L – length of the active element [m]
T_1- temperature value on the d_1 diameter [K]
T_2- temperature value on the d_2 diameter [K]
$d_1 > d_2$

For several tested samples at the granularity of 0,5 to 0,8 mm (layer material) for molochite R the average value λ_{avg} was approximately 0,70 W/m·K was obtained and for the new λ materials (molochite N) the value ranged from 0,58 to 0,65 W/m·K.

3.6. The evaluation of the castings quality in terms of accuracy (quality) of the ceramic mould

The evaluation of the dimensions of the castings (Fig. 3.) was performed for the low-alloy chrome steel castings. The verification of the dimensional length was based on the parameter Y = L-M. This parameter shows the influence of CM on the quality of castings. The value of L = (L1 + L2) / 2 was checked, and M is average dimension of the wax model height.
Fallowing results of the Y parameter was obtained:

1. The castings made on the basis of molochite N, $Y_{avg.}$=0,88 mm, standard deviation σ = 0,298, 6σ = 1,78
2. The castings made on the basis of molochite R, $Y_{avg.}$=0,93 mm, σ = 0,32, 6σ=1.89

Additionally the value of R_a (the primary indicator of the surface roughness) for both types of castings was evaluated:

1. The castings made on the basis of molochite N – R_a=4,15 µm (average result of 15 trials)
2. The castings made on the basis of molochite R - R_a=4,69 µm (average result of 20 trials)

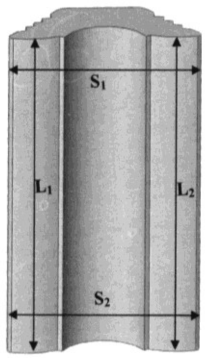

Fig. 3. The test casting

4. The impact of the recycled ceramic moulds based on the aluminosilicate on the economic and ecologic aspects

The dorm production delivers approximately 800 Mg of precision casting, which results the amount of over 1000 Mg used ceramic and the amount of used aluminosilicate may be up to 400 Mg. By using the recycled ceramic materials the reduction of the energy consumption used in manufacturing 1 kg of ceramic mould by approximately 5 MJ (research of the Warsaw University of Technology). Based on the assumption that to produce 1 kWh, the thermal contribution is about 9 MJ [10, 11]. With the estimated value of 40% used recycled aluminosilicate which is about 160 Mg that could save approximately 88000 kWh of energy. We need to remember that with the primary energy carrier which is the bituminous and lignite coal, the creation of 1 kWh falls the emissions of approximately 800 g of CO_2, approximately 7g SO_2, and 3g NO_x. That avoids a significant environmental pollution. That ecological damage have influence on the health. The production of 1 kWh is giving the 4 USD/1 kWh of ecological damage and for the 88000 kWh is near 350000 USD. Additionally coal energy have great impact on the global warming which is counted to be even 88000 kWh x 12 $USD_{avg.}$ [12].

5. Summary

Application in the production processes of ceramic layered moulds the recycled aluminosilicate results in lost-wax casting significant of technological, financial and ecological effects:

1. The dimensional accuracy and surface quality as measured by the Ra parameter is similar to certificated aluminosilicates.
2. The gas permeability during the pouring of the liquid metal does not change for both types of moulds
3. The thermal conductivity λ is similar for, new and recycled material
4. The use of the recycled materials gives significant savings in the energy consumption, approximately 88,000 kWh per year
5. The reduction of the emission of CO_2, NO_x and SO_2 in significant quantities results in improvement of human health and reduces the greenhouse effect. The estimated amount of CO_2 reduction in approximately 800 g / 1 kWh x 88000 kWh
6. Recycling aluminosilicate can significantly reduce the cost of the production in the investment casting foundry
7. The thermophysical properties of ceramic moulds manufactured using recycled materials are comparable to the moulds from the new ceramic materials
8. Dimensional accuracy and the surface quality acquired by using new and recycled materials is similar and ensures the production of high quality castings

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