

The investigation of properties of investment casting moulds reinforced with ceramic fibre

M. J. Nadolski*, Z. Konopka

Department of Foundry, Technical University of Częstochowa, Armii Krajowej St 19, 42-200 Częstochowa, Poland

*Corresponding author. E-mail address: nadzii@mim.pcz.czest.pl

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Abstract

Increasing of strength and permeability of the thin-walled investment casting ceramic moulds was the main goal of this work. Its essence is a new concept of the mould reinforcement, i.e. the full or the significant replacement of grain silica materials by fibrous aluminosilicate materials. An addition of ceramic fibre increase the permeability and green strength value of the ceramic shell mould material which allows for safe burning out of the pattern set.

Keywords: Investment casting, Ceramic mould, Permeability, Bending strength

1. Introduction

Precision casting allows for accurate reproducing of complicated details and achieving high degree of dimensional accuracy of products both in the mass and the low-series production, thus being cheaper alternative to forging and machining of metals. Making of ceramic mould is a fundamental part of precision casting process and will be now shortly described for its conventional form. The basic step consists in immersing a low-melting pattern into a multi-component ceramic slurry consisting of the refractory ceramics and the binder, then stuccoing the wet coat with additional grain refractory material and leaving it for drying. While drying, the binder coagulates to a cross-linked gel fixing the dispersed refractory ceramic filler. Dipping, stuccoing and drying cycle is repeated as necessary until the required thickness of the shell is achieved. The individual layers can be made of ceramic materials different in shape and size. The rule is that the primary coat should be made of finer materials than the back up coats. Other differences can refer to the binder type, ceramic filler type and its quantity in a slurry. All this factors can strongly influence the rheologic characteristics of a slurry. The common principle is that the primary coat should be

made of materials of the best quality because it would be in the direct contact with the molten metal and should provide for both accurate surface reproduction of the pattern and chemical stability at the metal-mould interface.

The final thickness of the mould for investment casting can vary from about 3 to about 12 mm due to the diversity of materials used for mould construction [10] and to the required number of ceramic coats. Usually 5 to 7 coats is applied [11]. The ceramic moulds, however various with regard to their construction, should satisfy multiple requirements and exhibit the following properties:

- proper strength of the green mould during the pattern set removing;
- sufficient strength at elevated temperatures (on pouring the alloy);
- suitable thermal shock resistance;
- high chemical stability (resistance to chemical reaction at the metal-mould interface);
- sufficient permeability;
- dimensional stability [7].

The following parameters are checked at the stage of the mould construction in order to ensure adequate properties of the mould:

- pH, viscosity, and density of the ceramic slurry;
- conditions of applying coats: humidity, temperature, time, air motion [5, 6].

The strength properties of the investment casting mould can be described in various ways [8]. The following parameters could be helpful: fracture index, deflection, cracking index based on the work of fracture measuring, but the most often the permeability is measured and the modulus of rupture (MOR) is determined for three stages: the stage of partial ceramization occurring before burning of the mould (MOR 1), the stage after burning and cooling the mould to a room temperature (MOR 2), and the stage under the elevated temperature conditions (MOR 3) [9]. The MOR index is usually determined from the three-point bending test, which can be reasonably extended to the four-point bending test giving more data describing the mould material behaviour [7, 8, 9]. Scientific records suggest also other new methods of estimating the strength of moulds for investment casting, e.g. the wedge test [10].

Conventional shell mould is to the great extent susceptible to cracking and delamination during the low-melting pattern set removing (burning out or dewaxing). For that reason the strengthening of the shell moulds by adding 0.5 – 5 wt-% of fibrous materials such as glass, nylon, and others is not a new idea. But the significant replacement of grain silica materials with the fibrous aluminosilicate materials is quite a new concept of the reinforcement structure itself and this constitute the essence of the undertaken theme. The investigations have been carried out to find the answer to the two important questions. The first of them has been if introducing such a fibrous substance changes advantageously the mechanical properties of a green mould, i.e. the mould before burning. The second one has been how this addition would influence other technological properties of the mould (permeability, deformation susceptibility, thermal expansion) [1, 2, 3, 4].

2. Methodics of examination

The purpose of the work has been developing of a new type of ceramic moulding material intended for construction layers of thin-walled moulds for investment casting technology and determining the relationship between the composition of the examined materials and its mechanical and technological properties. The examinations has been done according to the orthogonal design of the second order for four various mass fractions of the material components: ceramic fibre, silica flour, binder, and latex modifier LBS3030.

The matrix of the material has been the mix of silica flour and chopped aluminosilicate fibre in various proportions. Water solution of colloidal silica Sizol 0-30 of pH equal to 9.9, density of 1.209 g/cm³, and dynamic viscosity 8 mPas has served as a binder. The binder fraction has ranged from 50 to 70%. Latex modifier LBS3030 has been added to the slurry in the amount from 3 to 8% to improve fibre dispersion in the slurry. Slurries with different additions of ceramic fibre (Thermal Ceramics E 08-B.V.80) have been applied by spraying on the plastic pattern slabs of dimensions 250×300 mm at the spraying laboratory stand. For each sample both the first and the subsequent coats have been made of the same material. The pattern slab have been surrounded

with the 12 mm high rim which has enabled the thickness control of the coat and allowed for determining the end of coating process. The number of layers has been different for different slurries, but the total thickness of each sample has been the same and equal to 12 mm. Temperature, humidity and air motion over the samples have been controlled while drying the sprayed material. After the demanded thickness of the ceramic sample has been achieved, the pattern slabs have been burnt out in the laboratory drier at 473 K. The test material prepared in this way has undergone the permeability and bending tests, as well as the dilatometric examinations. The permeability has been measured for ceramic specimens prepared of the sprayed material after heating it up to 1293 K and cooling to the room temperature by means of the LPiR1 electric device with a sleeve attachment for specimens of such a type. The integral sleeve and a specimen loaded with the 4 kg loading ring have been mounted on the device head (Fig. 1). The arithmetic average of five measures has been assumed as a resulting permeability value.

Also 10×20×200 mm specimens for bending tests have been cut from the green test material and examined for the MOR1 parameter using the four-point loading system (Fig. 2).

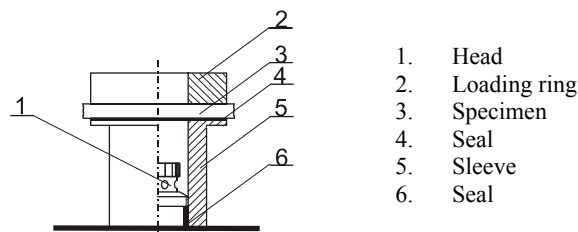


Fig. 1. Head adaptation of the LPiR device

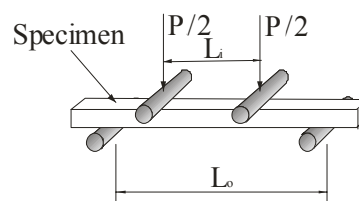


Fig. 2. The four-point bending test

The cubicoidal specimens for dilatometric examinations have been also taken from the selected grain, grain-fibre, or fibre ceramic materials. Examinations have been performed by means of the absolute optical dilatometer LS-4 for the temperature range 293-1293 K according to the PN-68/H-04500 Standard 'Dilatometric Testing of Metals and Alloys'.

3. The description of the achieved results

The addition of ceramic fibre and the employed method of applying the ceramic layers on the pattern set reduce the density of the shell material promoting the origination of the skeleton spatial structure with many voids. The influence of ceramic mould density on its MOR1 strength can be seen in Fig. 3.

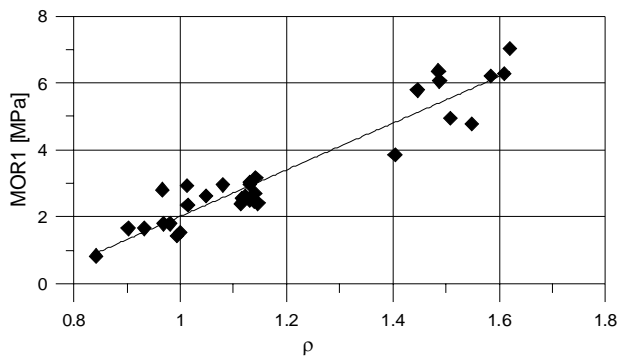


Fig. 3. The influence of the shell mould density on its MOR1 strength

The relationship between the permeability of the mould, reflecting its skeleton structure, and the MOR1 is shown in turn in Fig. 4.

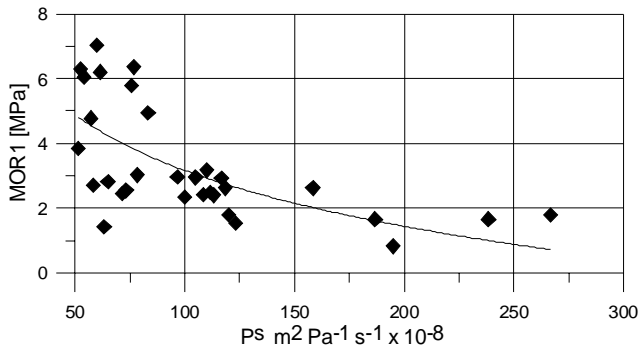


Fig. 4. The influence of the shell mould permeability on its MOR1 strength

Figures 5, 6, and 7 present characteristic changes of linear dimensions for three types of mould reinforcement: the grain, the grain-fibrous, and the fibrous one. It can be seen that the specimens with pure fibrous reinforcement behave in a different manner during their heating and cooling than the ones containing silica grains. The pure fibrous material almost does not expand up to 1293 K, in higher temperatures it shrinks, and after the heating process it changes its dimensions in a permanent way due to the sintering process and changes of the fibre arrangement. The lack of the curve jumps over the heating/cooling range indicates that no allotropic transformation occurs within this range. The linear contraction is rather high (5%). In the case of grain silica material a progressive increase of the linear dimensions is observed, meanwhile a jump caused by the polymorphous transformation of silicon ($\beta \rightarrow \alpha$ at 846 K), however not very distinct, can be found, and then on cooling the dimensions return almost to the initial values.

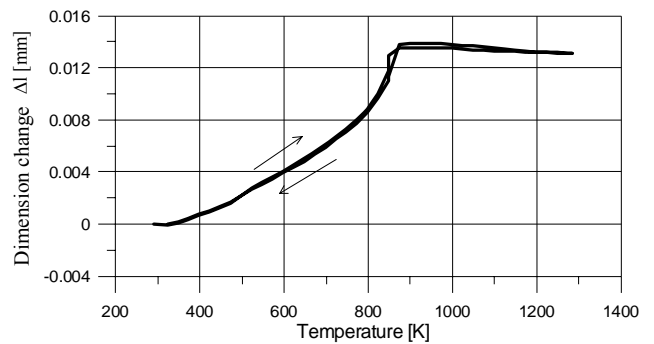


Fig. 5. Dilatogram of the grain mould material

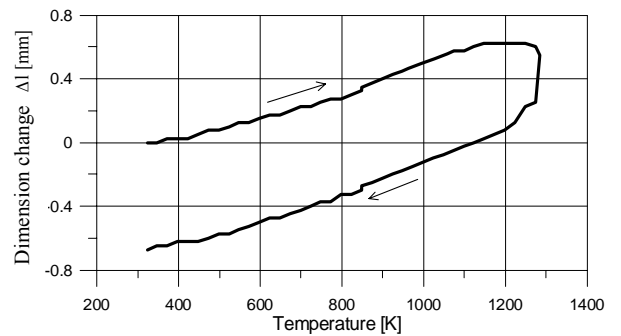


Fig. 6. Dilatogram of the grain-fibrous mould material (25% and 75%, respectively)

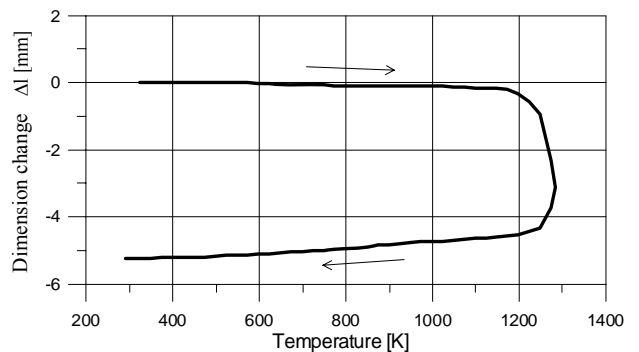


Fig. 7. Dilatogram of the fibrous mould material

The materials which contain mixtures of aluminosilicate fibre and silica grains behave in an intermediate manner: an increase in length occurs on heating, at 1293 K a distinct shrink can be seen and further the length decreases slowly on cooling. The permanent change of linear dimensions is lower and equal to about 0.6%.

4. Conclusions

An addition of ceramic fibre to the ceramic moulding material distinctly increases the permeability value of the ceramic shell, thus promoting the gas evacuation from the mould. Simultaneously the density of the mould decreases with an increase in the fibre quantity, what results from the skeleton structure characterised by the increased porosity occurring. Voids in the inter-fibre spaces cause, from the one hand, the decrease in the bending strength (MOR1), but from the other hand the reinforcing influence of fibre can be observed. As a result, the strength decrease is not great, and the strength value is comparable with the one achieved by grain moulding materials. This allows for safe burning out of the wax pattern sets.

Dilatometric examinations show that the presence of fibre causes greater dimensional changes of the mould, which is a negative result. Such a disadvantageous behaviour of grain-fibrous (25/75) and fibrous material during the thermal treatment of the mould can be considered as a problem as far as precision casting production is concerned. Nevertheless the moulds reinforced with ceramic fibre can find a wide range of application in the field of artistic casting, where the dimensional accuracy is of less significance.

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