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High temperature strength of ceramic moulds applied in the investment casting method

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Abstract

Ceramic casting moulds strength is an important factor, which influences the quality and properties of castings being produced by the investment casting method. It is especially important during mould pouring with liquid metal. Studies allowing determining the casting mould strength at high temperatures, that means at the ones at which the moulds are poured, are not numerous. None generally accepted (normalized) method for the assessment of such strength exists in practice. The new method of the ceramic moulds tensile strength investigation at high temperatures is described in the paper. Tests were performed at temperatures from 100 to 1100^{o}C. The ceramic moulding sand was prepared of modern materials: colloidal silica – being a binder – and highly refractory ceramic materials.

Keywords: Melted models, Ceramic forms, Strength, Colloid silicate

1. Introduction

The technology of casting production by means of investment casting has been already known for some centuries. This method is currently applied for production of multilayer moulds forming some sort of a shell. This technology is used for production of precise or artistic castings. The production process of precise castings consists of several technological operations:

- preparation of wax patterns and joining them into model sets,
- preparation of an investment compound,
- deposition of successive ceramic layers on the model,
- wax melting, the most often in an autoclave,
- drying of moulds at a temperature app. 50°C, holding moulds for some hours at temperatures from 400 to 1100°C,
- pouring with liquid metal, the most often in a vacuum furnace,
- casting knocking out and cleaning.

Production of ceramic moulds by an investment casting method consists of a cyclic process of immersing the wax model in liquid investment compound and powdering it with ceramic material of various grain sizes. After deposition of each layer, drying is applied. The number of deposited layers depends on the expected structural strength required of the mould. When all layers were deposited and dried the wax pattern is removed by melting. The quality of casting moulds and castings obtained from them depends – to a high degree – on a binding material being used in ceramic investment compound.

Hydrolysed ethyl silicate has been applied as a binder of ceramic investment compounds in the current technology [5,6,7]. Due to an alcohol character it changes from the sol state

to the gel one relatively fast, providing the layer proper strength. Alcohol, having a low evaporation temperature, is fast removed from the investment compound and mould layers formed from it. However, on account of the new regulation concerning the environment protection, this binder was substituted by the new one – on the basis of colloidal silica. This binder is not an excellent one and has certain essential drawbacks, e.g. it does not wet the model well, causing that the ceramic compound wrongly projects the wax surface. Being the water binder it changes into gel with difficulty (slower evaporation). To improve its wettability various kinds of wetting agents are used.

However, the water binging agent, based on colloidal silica, apart from being 'environment friendly' has other advantages too. One of the most important features is its long lifespan and not changing into the gel phase (contrary to the ethyl silicate binder). It can change its viscosity. When the viscosity increases the deposited layers are becoming thicker and thicker. It renders difficult their drying and can cause moulds breaking during this process. A dynamic viscosity of ceramic investment compounds is one of their most important feature which decides on the moulds quality and therefore it is constantly monitored.

In order to achieve the required strength – in case of an application of colloidal silica– it is necessary to evaporate the majority of water. As water content decreases the mould layer increases its strength. Thus, from the technological point of view, the knowledge of the dependence of the water fraction in the mould layer and its strength is needed.

2. Conception and performing investigations

Wax models (Fig. 1.a) of samples for testing ceramic moulds strength were prepared in the special metal matrix, into which investment compound was poured. Before pouring, ceramic 'tension members' (seen in Fig. 1a) enabling, in the further stages of experiment, the tensile testing of the ceramic sample were mounted in the matrix. When the investment mixture solidified, the sample (Fig. 1a) was taken out from the matrix and cleaned to remove feather edges. The sample is of a roll shape, with a special narrowing for forcing the cracking place in the mould undergoing stretching. Deposition of ceramic investment compounds on the wax pattern is being done in several cycles repeating alternately: depositing + powdering with matrix grains. Individual layer was of a thickness from 0.50 – 0.80 mm. The ceramic sample for strength testing is shown in Figure 1.b.

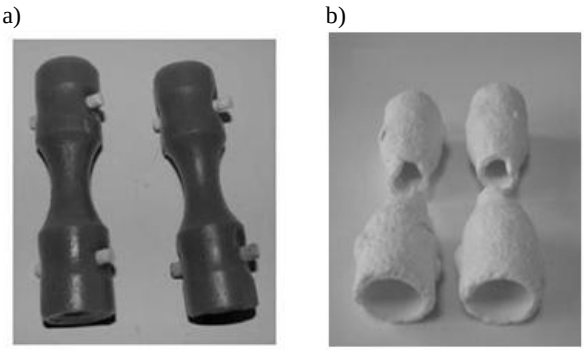

Fig. 1. a) Wax models, b) ceramic sample for testing strength at high temperatures

2.1. Preparation of the investment compound

The investment compound was prepared from colloidal silica acting as a binder and a highly refractory matrix material, aluminium oxide Al_2O_3. Fine-grained (#200) flour of aluminium oxide was added first into the binder. The suspension was mixed for 5 minutes, then aluminium oxide of slightly larger grain size (# 300) was added in small portions and mixed again to obtain the homogeneous mixture. The ceramic investment compound composition by weight was as follows:

- Ludox AM – 600g (25,98 %)
- Al_2O_3 (# 200) – 855 g (37,01 %)
- Al_2O_3 (# 300) – 855g (37,01 %)

After settling for 24 hours the compound was mixed again and then its kinematic viscosity was determined by means of the Ford's cup. Experiments were carried out at a temperature of 19 – 20^{o}C. Under such conditions the mixture outflow time from the Ford's cup via opening d = 4.0 mm was 35 – 45 s, which corresponds to the kinematic viscosity app. 150 mm^2/s.

2.2. Preparation of samples and drying them

Four layers of the ceramic compound and matrix were deposited on the degreased wax model (Fig. 1a). After each layer deposition the powder topping of fine-grained Al_2O_3 was added. To shorten the preparation time of the multilayer shell the successive layers were dried by the forced air circulation. When all layers were deposited, wax was removed from samples in an autoclave. The next step consisted of the samples drying at a temperature of 50^{o}C for some hours. Dried samples were annealed – according to the assumed program – for some hours in the furnace in the temperature range: 400-1100^{o}C. At lower temperatures the remains of the investment compound as well as the volatile components were removed from the mould. Higher temperatures caused sintering of the investment compound imparting the proper strength. Samples were cooled together with the furnace. After cooling they were subjected to the tensile strength testing at high temperatures in the range: 100 to 1100^{o}C.

2.3. Methodology of the strength R_m measurements at high temperatures

The ceramic compounds strength is of an essential importance in two main stages of the technological process. The first stage is during melting the wax pattern. At this stage the mould is only skin-dried in the surrounding conditions. This strength is called a strength in wet condition ('green strength'). Too low strength at this stage results in a tendency for moulds cracking. The second stage, in which the determined strength is required, is the process of the mould being poured with liquid alloy and the metallostatic pressure influence, which at insufficient strength causes mould cracks and the so-called 'metal escape'. The strength of the multilayer ceramic mould depends on several factors, including:

- grain composition of a matrix,
- temperature and a drying rate,
- kind of a binder used for the investment compound preparation,
- temperature and an annealing time,
- viscosity of a liquid ceramic investment compound.

The tensile strength R_m [MPa] of the tested ceramic mould is the ratio of the tensile force, which caused sample tearing, and the sample cross-section in the place of cracking. The sample shape 'forces' the appearance of cracks in its middle part in the place of the smallest cross-section.

The strength measurement at a high temperature is done in the tubular furnace in a way shown in Figure 3. The sample, together with ceramic tension members (4) and thermocouple (2) is placed in the furnace, as shown in the scheme. The sample is heated together with the furnace to the given temperature, after which the sample is torn under a load (3). Steel shots constituting the load of the tensile sample are gradually added to the hanging container. When the sample is torn, the load is estimated, the crack area is measured and the strength R_m is calculated.

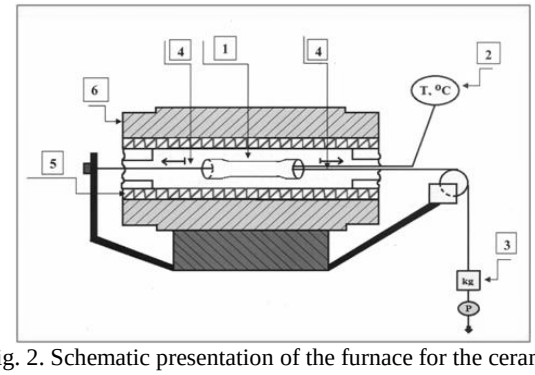

Fig. 2. Schematic presentation of the furnace for the ceramic moulds tensile tests at high temperatures: **1** – ceramic sample for R_m measuring, **2** – thermocouple, **3** – tension members system and variable loads, **4** – ceramic tension members, **5** – furnace heating element, **6** – outer furnace body

3. The obtained results

The obtained results of the ceramic moulds strength R_m examinations at high temperatures are presented in Figure 3. The analysis of data allows to state, that the higher strength is obtained for samples annealed in a multistage way at a temperature of 1100°C. Maximum strength achieved in this series was: R_m=0.9 MPa at tension, at t ≅ 450-500°C. When annealing was carried out at a lower temperature from the range: 400-700°C, the maximum strength was smaller: R_m=0.7 MPa. The maximum strength was then shifted to: t ≅ 620°C.

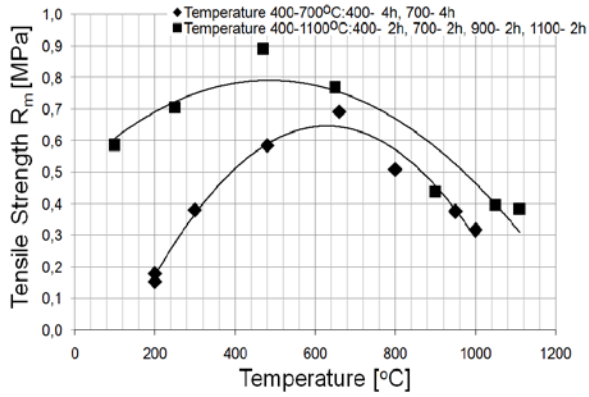

Fig. 3. Influence of a temperature on the strength of ceramic moulds annealed in the temperature range: from 400 to 700°C and from 400 to 1100°C.

4. Conclusions

The majority of the currently produced moulds in the investment casting technology are the so-called self-supporting moulds, it means moulds which are not located in boxes with dry sand to be poured. Thus, in such cases the ceramic mould strength is one of the most important parameters in this technology.

The new concept of the methodology of tensile strength examinations of such moulds at high temperatures is presented in the hereby paper. The obtained results, at the current stage of investigations, constitute only a fragmentary contribution. The broader studies are currently underway. The presented results allow to conclude that for each mould treatment, history of its annealing, there is a maximum on the graph: $R_m = f(t)$. The tested moulds achieved the highest strength at temperatures from the range: 450 – 650°C. The application of different binding materials will, for sure, cause shifting of R_m as well as the temperature value at which the strength maximum is obtained.

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