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Dilatometric examination of moulds with plaster binder

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Abstract

Investigations concerning thermal expansion of moulding materials with plaster binder have been performed for two mixture compositions of Authors' own design, as well as for the material used in jewellery industry under the Prima-Cast trade name, and for ThermoMold 1200 moulding material. The results of dilatometric examinations of these materials, carried out within the temperature range from about 20°C to 650°C by means of the DA-3 automatic dilatometer, have been compared. An analysis of this comparison has revealed that it is the matrix composition which is decisive for the magnitude of dimensional changes of moulds, and that applying components which do not exhibit polymorphic transformations reduces dimensional changes of a mould during its thermal treatment.

Keywords: Plaster mould; Precision casting; Artistic casting

1. Introduction

Calcium sulphate occurs in nature as a mineral gypsum, i.e. calcium sulphate dihydrate $CaSO_4 \cdot 2H_2O$, or in the anhydrous form called anhydrite [1]. If mineral gypsum is heated, it partially loses water and at the temperature of 120÷130°C transforms into the calcined gypsum (commonly known as plaster or plaster of Paris) $CaSO_4 \cdot 0,5H_2O$, which easily takes water and then hardens. If heating process is continued, the material turns into anhydrous calcium sulphate. The occurring transformations are accompanied by changes in crystal structure of the material and related changes in its density. These alterations are of rapid character and result in an increase of internal stresses within the material of the mould [1-4], so that, if the heating rate is inappropriate, they can lead to the deformation of mould cavity or cracking of the mould [5, 6].

Moulds with plaster binder are applied in artistic casting, jewellery industry, dental prosthetic, and small batch production of nonferrous metal items. There is a great variety of industrially produced moulding materials developed for particular technologies [3, 5, 6] which regard the great sensibility of a plaster mould to the improper thermal treatment, as well as the demands of quality and dimensional accuracy. These materials are mixtures of plaster, refractory, and additions modifying mechanical and technological properties of the mould.

For preparing plaster moulding material one can use calcium sulphate hemihydrate (alpha, beta, or a mixture of both). The β form of the material has a flocculent appearance and crystallizes in the form of a very fine crystals. The β form exhibits worse strength properties as compared with the α form which is of a compact crystal structure.

Mechanical and technological properties can be controlled by adding the following substances [1-6]:
- asbestos, glass fibre – improves strength;
- silica flour, talc, silica sand – modify the volume changes during the bonding process. They reduce the content of plaster in the material thus influencing mainly the technological properties;
- clay, kaolin – increase cohesiveness, influence the material bonding time and increase permeability;
- lime, cement – allow for controlling changes in the coefficient of thermal expansion of the material.

2. The purpose and the methods of examination

The purpose of the work is the assessment of the influence of a temperature change on the mould dimensions during technological process involving dewaxing, heating, and burning out of the plaster-bound block ceramic mould.

Dilatometric measurements for the moulding materials with plaster binder have been carried out for four mixtures: two of them being proposed by the Authors (their composition given in Table 1), the subsequent two – ThermoMold 1200 and Prima-Cast – coming from industrial production. All moulding materials have been prepared in the same way. Distilled water of temperature 21÷24°C has been used for obtaining a slurry. After weighting the proper quantities of dry components and water, the powder has been gradually added to the water during hand mixing for about 30 seconds. Then according to the recommendations of ThermoMold 1200 and Prima-Cast manufacturers the mechanical mixing has been applied for 3 minutes followed by air bubbles removing for 2 minutes. Total time of preparing the material has been 9-10 minutes. The prepared mixtures have been introduced into the matrices, each with cylindrical cavity of 7 mm diameter and 50 mm height. Air has been again removed from the material contained in the matrix by means of a bell jar vacuum chamber at the pressure of 720 mm Hg for one minute. The obtained cylindrical specimens, about 7 mm in diameter and about 50 mm high, made of the examined materials have been subjected to a controlled cycle of heating and cooling according to the Fig. 1.

Table 1.
Composition of moulding materials with plaster binder

Component	Quantity, g	
	Material 1*	Material 2**
„Tempo" casting plaster	3000	3000
Al_2O_3 < 0,04 mm	5000	-
SiO_2: 0,1/0,16/0,2	1000	5000
ZrO_2 < 0,04 mm	10	-
SiO_2 < 0,056 mm	-	1000
plasticizer	500	-
retardant	14	-

* water/plaster ratio 1.9
** water/plaster ratio 2.0

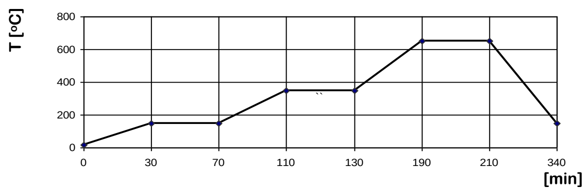

Fig. 1. The heating curve according to the NovaFlow&Solid program.

3. Description of the obtained results

The investigations performed within the temperature range from about 20°C to 650°C have given dilatometric curves as shown in Figs 2-5.

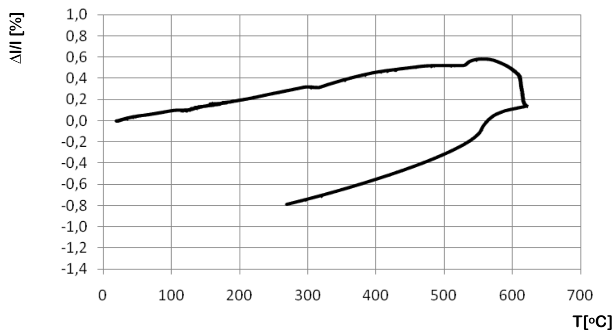

Fig. 2. Dilatometric diagram – ThermoMold 1200 moulding material

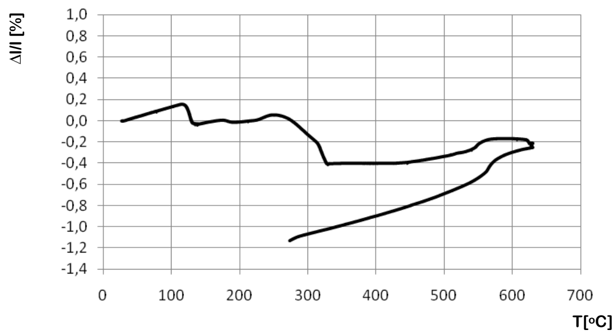

Fig. 3. Dilatometric diagram - Prima-Cast moulding material

The following figures (Figs 4, 5) represent the course of dilatometric curves for the material of Authors' design with Al_2O_3 matrix and SiO_2 matrix, respectively.

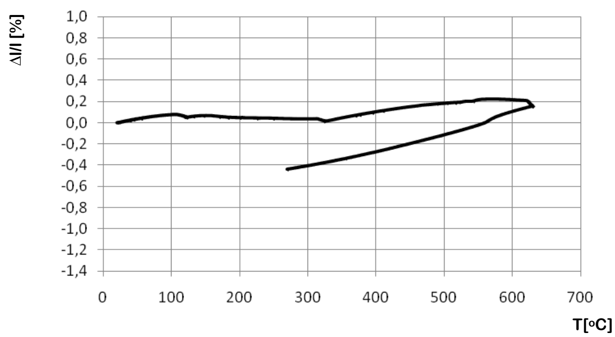

Fig. 4. Dilatometric diagram - material No. 1 of Authors' design containing Al_2O_3 matrix

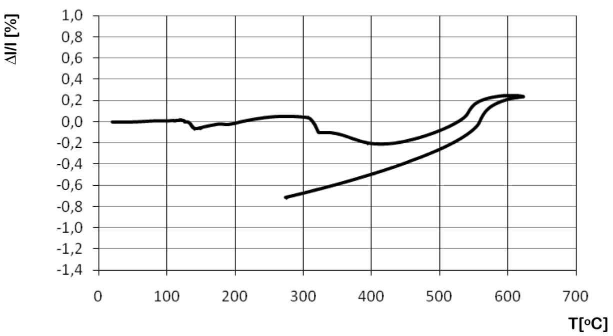

Fig. 5. Dilatometric diagram - material No. 2 of Authors' design containing SiO_2 matrix

The obtained results of dilatometric changes presented above in Figs 2÷5 are juxtaposed in graphic form in Fig. 6.

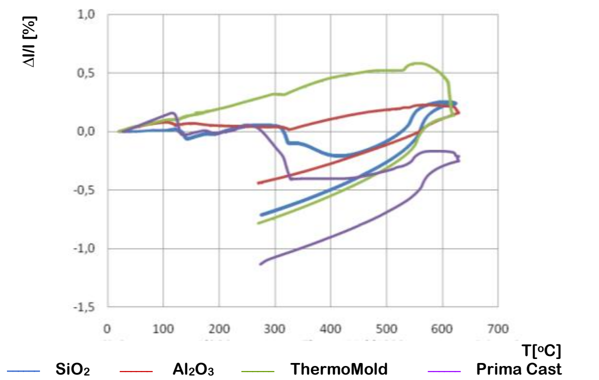

Fig. 6. Juxtaposition of dilatometric changes in the examined materials

The parts of dilatometric diagrams representing the behaviour of moulding material within the temperature range of dewaxing, i.e. from about 20°C to 150°C are compared in Fig. 7.

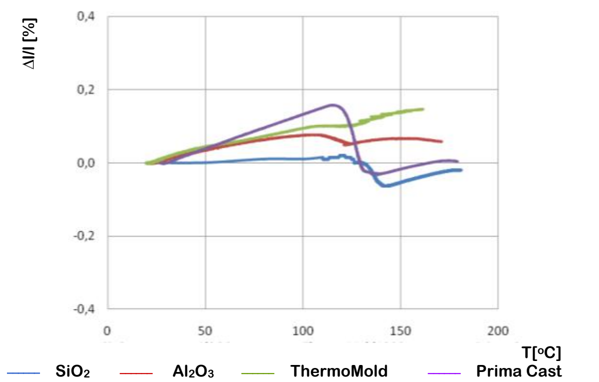

Fig. 7. Dimensional changes in moulding materials at the stage of dewaxing

Dilatometric diagram of ThermoMold 1200 moulding material shown in Fig. 2 is characterised by nearly linear course of the heating curve within the temperature range of 20÷550°C. It has been recorded that at 550°C the material reaches the maximum of dimensional increase equal to about 0.6% of the initial dimensions.

Above 550°C up to about 620°C a significant reduction of specimen dimensions have been observed, and the dimensional change drops down to 0.1% of the sample dimension prior to heating.

Cooling of the ThermoMold 1200 material to the pouring temperature recommended by the manufacturer has resulted in further reduction of the examined sample dimensions by about 0.7% of its initial dimensions at the ambient temperature.

The nearly linear course of heating curve exhibits however some peculiarities if the heating within the temperature range of 20÷150°C is considered in detail (Fig. 7). The mould of ThermoMold 1200 moulding material enlarges its dimensions by about 0.1% up to the temperature of about 110°C. Between 110°C and 125°C dimensional changes are not observed. Only above the temperature of 125°C the mould again expands during further heating, according to the previous description.

Unfortunately, as the exact composition of the ThermoMould 1200 matrix is not disclosed, it has not been possible to ascertain the reason of such a behaviour of the material during the heating and cooling cycle.

The evidently different course exhibits a curve representing the behaviour of a mould made of Prima-Cast moulding material during the cycle of heating and cooling which is characteristic for the process of investment casting of metals and alloys (Fig 3). The heating of a material sample from the initial temperature of 20°C up to about 120°C results in its dimensional growth by about 0.15% at the end of this temperature range (Fig. 7). The expansion proceeds in a linear manner. Further heating of the mould results in rapid decrease of its dimensions to the value of relative length increment equal to -0,03% at the temperature of about 140°C. Within the subsequent temperature range, 140÷270°C, the material slowly changes its relative dimension increment from -0.03% to 0.05%. This is rather a small change as compared with the one taking place within the temperature range 270÷320°C, which in turn leads to the decrease in mould dimensions, their relative decrement value reaching -0.4% of the initial values. Then the linear change of dimensions is observed above 440°C to 540°C, where the relative dimensional decrement changes from -0.4% to -0.3%. The dimensional change by 0.1% of initial values occurring at the narrow temperature range 540÷545°C, after which the total relative dimensional decrement equals about -0.2%, can be considered as a rapid one. Further dimensional changes proceed as a result of cooling the sample of Prima-Cast moulding material. Finally, at the temperature of about 300°C the material reduces its initial dimensions by about -1.5%.

The observed dimensional changes result from the internal structure of mould built of the Prima-Cast mixture. The matrix of the material contains quartz and crystobalite, and the binder is composed, generally speaking, of plaster. Heating of the plaster-bound material is accompanied by its shrinkage related with the dehydration of plaster. If the plaster is heated above 105°C, the loss of crystal water occurs according to the following formulae:

$$2(CaSO_4 \cdot 2H_2O) \rightarrow (CaSO_4)2 \cdot H_2O + 3H_2O \qquad (1)$$

$$(CaSO_4) \cdot 2H_2O \rightarrow 2CaSO_4 + H_2O \qquad (2)$$

The phenomenon of shrinkage due to dehydration process can be seen for Prima-Cast moulding material in Figs 3 and 7. Dimensional changes occurring within the temperature range 450÷570°C can be most probably attributed to the polymorphic transformation of β-quartz into α-quartz. This statement is confirmed by the recorded magnitude of the dimensional change equal to about 1.3% which is characteristic exactly for this transformation. The behaviour of moulding material No. 1 of Authors' design during its heating is quite interesting. The composition of the material is known, its matrix is of Al_2O_3, i.e. the material which does not undergo the polymorphic transformations, along with zirconium flour and silica sand. Fig. 4 presents the course of dilatometric curve for the designed material No. 1. Expansion by about 0.1% has been recorded within the temperature range from about 20°C to 110°C. Above the latter temperature a shrinkage has been observed, most probably due to dehydration, dimensions of a sample are brought back to the initial magnitude and the material remains in the state similar to the initial one up to the temperature of about 330°C. Only above this temperature a gradual expansion of the mould material takes place and reaches the maximum value of the relative length increment equal to about 0.2% recorded within the temperature range 550÷630°C. The dimensional changes characteristic for transformation of β-quartz into α-quartz at about 570°C have not been observed. The lack of apparent evidence of this transformation can be explained by the complex composition of the material. The small fraction of silica sand in the material matrix and dimensional changes of other components can nullify the dimensional effect of polymorphic transformations occurring in silica sand. Cooling of the material involves contraction, which at the temperature of 300°C brings the total relative dimensional change to the value of -0.4%.

The last of the analysed materials is the moulding material No. 2 designed by Authors, which matrix consists of silica sand and silica flour. Similarly as for previously discussed materials, contraction occurs around the temperature of 120°C due to dehydration. Dimensional changes within the temperature range 180÷310°C are most probably caused by the transformation of α-crystobalite into β-crystobalite. The data found in publications indicate that relative dimensional changes during this transformation can reach the value of about 1.5%, which is also reflected in the course of dilatometric curve presented in Fig. 5. Above the temperature of 410°C gradual expansion of the material takes place, its rate being intensified within the temperature range of about 540÷550°C, and finally the magnitude of relative dimensional change reaches about 0.25% at 600°C. This is a result of the transformation of β-quartz into α-quartz.

As far as magnitude of dimensional changes is concerned, the greatest relative increase at the temperature of 600°C, equal to 0.6% of initial dimensions, is observed for the ThermoMold 1200 moulding material, while the greatest contraction at this temperature has been noticed for the Prima-Cast moulding material, for which it equals to -0.3% (Fig. 7). The mixtures No. 1 and No. 2 of Authors' design exhibit a similar magnitude of expansion at the temperature of 600°C equal to about 0.3% of initial dimensions. There is, however, a distinct difference between the materials of Authors' design and the commercially available ones, which lies in the apparent smoothness of dimensional changes exhibited by the former ones. The material No. 1 with Al_2O_3 matrix can be characterised by quite small internal stresses generated during dimensional changes, because these changes do not happen rapidly. This mixture also should exhibit better behaviour within the temperature range 20÷120°C, i.e. during dewaxing (Fig. 7). The increased expansion of the material within this range will reduce the effects of internal stresses occurring due to wax expansion within the mould and prevent it from damage.

4. Conclusion

The performed investigations concerning dimensional changes of moulds with plaster binder applied in investment casting for producing micro-castings made of the medium-melting alloys allow for the following conclusions:

- composition of the examined material matrix is decisive for the dimensional changes of moulds within the temperature range of 20÷650°C;
- the content of SiO_2 in the form of both quartz and crystobalite results in dimensional changes of moulds proceeding at the polymorphic transformation points. The magnitude of these changes can be controlled by the selection of a proportion between matrix components and by applying components which do not exhibit polymorphic changes (ZrO_2, Al_2O_3);
- industrially produced moulding materials ThermoMold 1200 and Prima-Cast exhibit the relative dimensional contraction by -0.7% and -0.15%, respectively, at the recommended pouring temperature of 300°C.

Further investigations are intended in view of the possibility of applying the designed materials in the field of micro-casting production.

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