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Investigation of field temperature in moulds of foamed plaster

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Abstract

Plaster moulds used in precision foundry are characterized by a very low permeability which, in the case of classic plaster moulds, equals to about 0,01÷0,02 m^2/(MPa·s). One of the most effective methods for increasing the permeability is a foaming treatment. Another characteristic feature of plaster is its very good insulating power which has influence on the process of solidification and cooling of a cast and also on a knock-out property. This insulating power is a function of thermophysical properties of plaster which, in turn, depend mainly on the mineralogical composition of the mould material, its bulk density as well as on the temperature of the pouring alloy. In the case of a foamed plaster mould an increase of the degree of foaming increases its porosity which causes a change in its thermophysical properties, thereby increasing susceptibility of the mass to overheating. The susceptibility of the plaster layer surrounding the cast to overheating is favorable because it makes it easier to knock-out of the cast by immersing the hot mould in cold water. Thermal and phase tensions that are created during this process cause fast destruction of plaster. This paper describes our investigations aimed at the determination of the dependence of the mould temperature field on the time of the cast stay in the mould, as recorded in a process of an unsteady heat flow. The determined data were planned to be used for estimation of the technological properties of the plaster mould. The tests were carried out using the plaster α-Supraduro and Alkanol XC (foaming agent). The test mould had a diameter of Ø 120 mm with centrally situated mould cavity of Ø 30 mm. Plaster moulds with a degree of foaming 20; 32,5 and 45% and comparatively from non-foaming plaster were tested and their temperatures were measured at the distance x=2; 9; 21; 25;27; 30 mm from the mould cavity within 25 min. Analysis of the results leads to the conclusion, that the highest effectiveness of heating and overheating of a mould made of a foamed plaster occurs at the degree of the plaster foaming equal to S_S=45%. The results obtained can provide the basis for the elaboration of the best plaster mould properties, and thus to increase the technology effectiveness.

Keywords: Innovative foundry technologies and materials, Precision casting, Foamed plaster process, Foamed plaster mould

1. Introduction

Castings from plaster moulds are characterized by high dimensional accuracy, very good shape pattering and small surface roughness. This makes it possible to limit and sometimes to completely resign from machining.[1,2,3]

Except undisputed advantages, there are also some disadvantages of plaster moulds, the most important being their very low permeability. The latter equals to about 0,01÷0,02 m^2/(MPa·s) in the case of conventional plaster mould process.[4]

An increase of permeability of plaster moulds can be achieved by [1,2,5,6]:

- physico-chemical treatment (Antioch process),
- foaming treatment with foaming agents addition and appropriate mixing technique,
- additives that shrink during drying, evaporation of physically bound water or thermal decomposition.

Considering the advantages and disadvantages of the above methods from the point of view of the quality of the cast surface, the time-consuming mould preparation and the degree of complication of the technology, a conclusion can be drawn that the best one is the foamed plaster technology.[5]

Another characteristic feature of a plaster mould is its very good insulating power.[7] It has, among other factors, important influence on the process of solidification and cooling of the cast; hence, also on the final structure of the alloy. This insulating power is a function of thermophysical properties of plaster, in a sense of parameters connected with heat exchange between the cast and the mould. First of all, they depend on the mineralogical composition of the mould material, its bulk density and the temperature of the pouring alloy.

In case of a foamed plaster mould the most important agent that has influence on its thermophysical properties is the air introduced into plaster.[6,7] As the degree of foaming increases, its porosity also increases, which changes, among others, its thermal conductivity λ as a result of a change of radiation through the pores of plaster and heat conduction through the pore-filling air. These relations are subtle and difficult for theoretical estimation, Therefore, it is necessary to experimentally determine the temperature gradient in the area of the filled mould. The obtained dependences of temperature on time are a basis for calculation of the thermophysical parameters of plaster for a given degree of its foaming.

Character of changes of the mould temperature, thus its susceptibility to local overheating, also has significant influence on the cast knock-out process. In case of plaster moulds this process is realized by immersing a hot mould in cold water. Then thermal and phase tensions are generated and cause fast destruction of the plaster.[4,8] Effectiveness of this process increases with temperature of the mould. Thus, a short time of the cast stay in mould and a low thermal conductivity, which secures substantial overheating of the plaster layer around the cast, are favorable.

Thermophysical properties of plaster can be determined under the conditions of either steady or unsteady heat flow. Although the investigation under the conditions of unsteady heat flow is more difficult, it much better shows real conditions existing in the mould.

2. Methodology and scope of tests

Dependence of temperature of foamed plaster moulds on time of stay casting in its was registered in process of unsteady heat flow. Its was included time measuring from moment of pouring of mould with liquid alloy and time of solidification and cooling of casting

2.1. Materials

The following materials were used in our investigations:

1. Plaster α–SUPRADURO provided by Börgardts company of the following properties (in accordance with the producer's certificate):
   - bending strength after 24 h – 9,5 MPa
   - setting time: start t_p – 11 min end t_k – 15 min 30 s
   - water/plaster ratio W/G=33 – Ø 120 mm
2. Deionized water
3. Alkanol XC – sodium alkylnaphthalenesulfonate (foaming agent)
4. Sodium citrate (setting delay agent)
5. Silumin AlSi11

2.2. Test shapes preparation

Slurry preparation

To the water solution, containing an adequate amount of the foaming agent (Alkanol XC) and setting delay agent (sodium citrate), plaster was added in the amount which ensured the formation of a slurry with a water/plaster ratio of W/G=0,56.
The resulting mixture (slurry) was stirred with a hand-mixer for 60 s and next exposed to foaming , using high speed mixer, for the period that ensured appropriate degree of foaming. The foaming slurry was then subjected to a process of homogenization to unify the size and distribution of air cells.[5]

Test shapes preparation

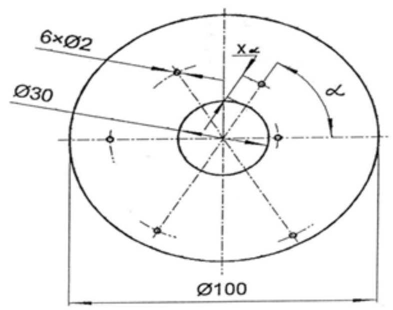
The homogenized slurry was poured into matrixes of Ø100x50mm. After the setting began, the excess of slurry was pushed aside and the top surface of the prepared shape was leveled. Shapes were removed from the matrixes after setting (about 40 min.) and dried in an open air for 12 h.

Six holes were drilled in each dried shape by means of a drilling pattern to place thermocouples. The arrangement of the holes is presented in Fig. 1.

A test shape Ø100x50 mm has a port of Ø30 mm in the axle. After mounting the shape on a test stand, the port, as a mould cavity, was casted with a liquid alloy

Finished shapes were dried at 140 °C to a constant mass (20 h). After drying, the shapes were cooled in a desiccator at the temperature of 100 °C.

Insulating shapes were prepared analogically, but in the upper shapes instead the port of Ø30 mm the sprue of Ø8 mm and ports for thermocouples were made. The lower shapes were prepared without holes.



α	Xα
0°	2
60°	9
120°	15
180°	21
240°	27
300°	30

Fig.1. Scheme of spacing the holes for thermocouples in the test mould.

2.3 Test stand

Investigations were carried out on a test stand consisting of the following elements:

- a stand for measuring temperature at the marked sites of the plaster mould.
- a computer equipped with program MULT 4.05 provided by AMBEX
- record amplifier
- meter of the temperature of pouring alloy

The test shape *1* was placed between insulating shapes made from the foamed plaster of the same degree of foaming. In order to minimize an axial heat flow, the faces of these shapes were additionally secured with insulating discs *4* made of an aluminosilica fibre. The upper insulating disc *4* and aluminosilicate paper *5* were fitted after filling the mould with liquid alloy AlSi11

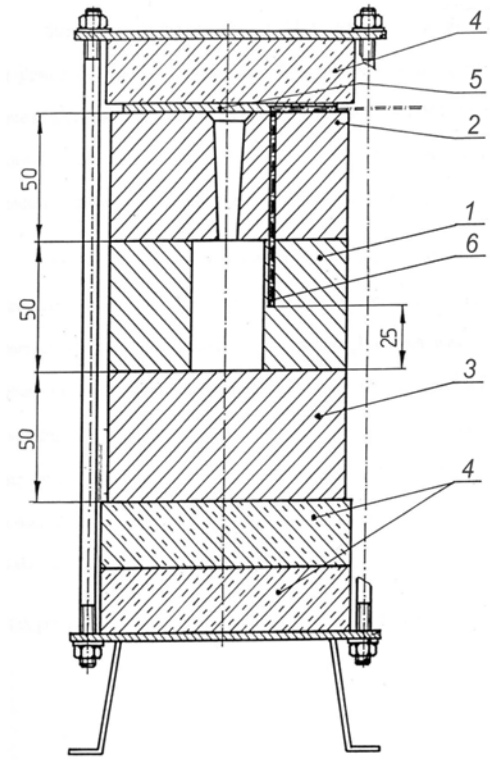


Fig. 2. Test mould: 1 – test shape (mould), 2 – upper insulating shape, 3 – lower insulating shape, 4 – insulating disc, 5 – aluminosilicate paper, 6 – thermocouple.

2.4. Assembling of test stand

Finished shapes were arranged in stacks according to the pattern presented in Fig. 2. At the same time thermocouples NiCr-NiAl were installed and connected to a measuring system.

The temperature of the mould was 70°C at the moment of pouring the alloy.

2.5. Pouring the test mould

The alloy AlSi11 was melted in the electric box furnace at the temperature 830 °C in a steel spoon lined with an aluminosilicate fibre. After taking out the spoon the temperature of the melted silumin was measured. After cooling to the temperature about 760°C the mould was filled gravitationally.

2.6. Scope of investigations

Preliminary investigations.

Preliminary investigations included:

- investigation of plaster in a crude state; it included determinations of: granulality, normal consistency, start and end of the setting time, linear dilatations of plaster and bending strength and permeability in a set state,
- determination the best composition of plaster and the conditions of its preparation.

Basic tests.

Basic investigations comprised measuring of the temperature in steady places of the mould that was casted with the alloy in the function of time.

The investigation was made using the shapes with 3 degrees of foaming: S_S=20; 32,5; 45%. For comparison, an analogous investigation was made for a non-foaming plaster shape S_S=0%

3. Discussion

3.1. Preliminary investigations

Properties of plaster in a crude state:

- mesh fraction 0,1 mm: 0,09%
- water/plaster ratio W/G=0,33 (at Ø 120±5 mm)
- setting time: start t_{wp}=10,0 min end t_{wu}=15,0 min
- linear dilatations: α=0,015%

Table 1
Properties of plaster after drying to the constant mass (according to PN-80/H-11072 and PN-83/H-11073).

	Degree of foaming S_S, %			
	0	20	32,5	45
Bending strength R_g^u, MPa	7,3	5,42	3,31	2,01
Permeability P^u, $m^2/(MPa \cdot s)$	0,01	0,064	0,088	0,12

Composition of plaster slurry and conditions of its preparation

On the basis of the investigations, it was found out that the best slurry composition designed to foaming was as follows:

- water/plaster ratio: W/G=0,56
- content of Alkanol XC: a=0,16%
- content of sodium citrate: x=0,005%

Also the following optimum parameters for foaming were determined:

- revolutions of foaming mixing n_m=3000 r.p.m,
- revolutions of homogenization n_u=750 r.p.m.

Mixing time was fixed individually for every degree of plaster foaming.

3.2. Basic tests

The temperature field in the mould, defined by a dependence t=f(τ) for various distances from the mould cavity x, are presented for S_S=45% and comparatively for S_S=0% (Fig. 3 and Fig.4, respectively).

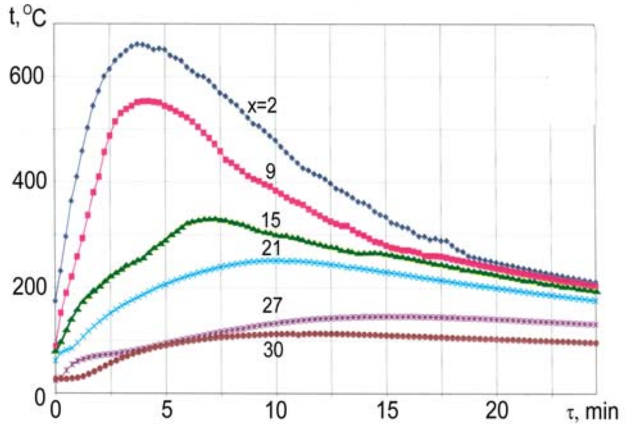


Fig. 3. Dependence of temperature of a mould of foamed plaster on the cast cooling time τ for: x=2, 6, 15, 27 and 30 mm and S_S=45%.

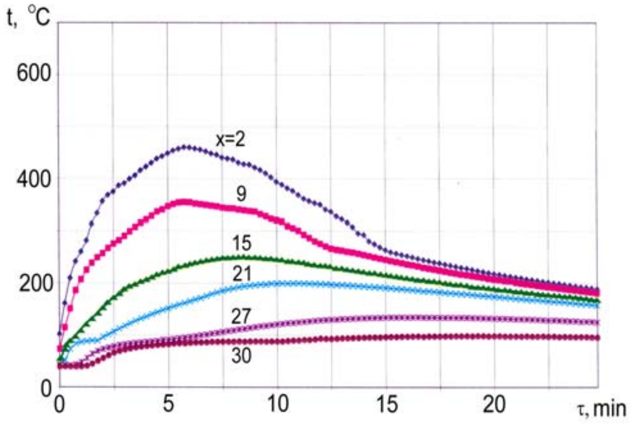


Fig. 4. Dependence of temperature of plaster mould on the cast cooling time τ for: x=2, 9, 15, 21, 27 and 30 mm and S_S=0 %

The analysis of the presented graphs indicates that the dependences t=f(τ) for various distances x are characterized by the appearance of an extremum with a value decreasing with increasing the distance from the mould cavity x.

The analysis of the above dependences for a foamed plaster of different degree of foaming and for S_S=0 reveals a similar character of them, but also underlines quantitative differences both in the value and location of the extremum. Location of the extremum, defined in terms of the values of time, is the smaller, the higher the degree of foaming and the shorter the distance x. It clearly proves that there are significant differences in thermal properties of the mould material.

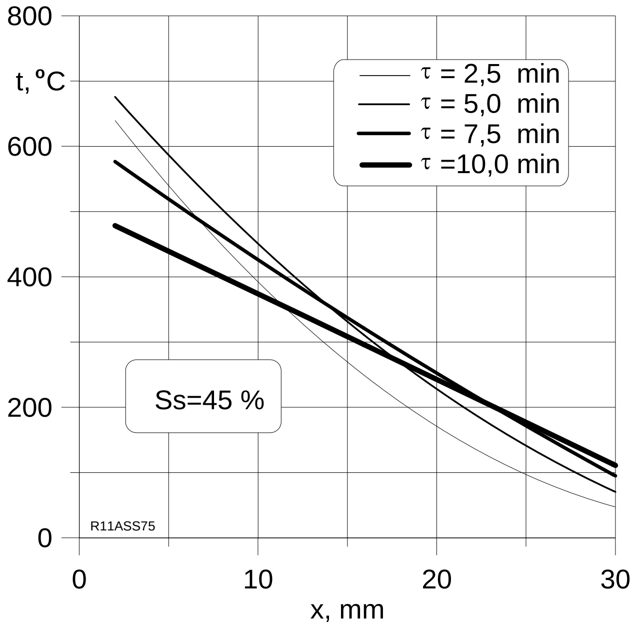


Fig. 5. Dependence of temperature of a mould of foamed plaster t on the distance x for: τ = 2,5; 5,0; 7,5 and 10,0 min and S_S = 45%.

Further estimation of thermal properties of the tested mould is based on the analysis of the dependence t=f(x) for various cooling times of the cast, for example presented for S_S=45% and S_S=0% in Fig. 5 and Fig.6, respectively.

Comparative analysis of graphs shown in both figures unequivocally permits to claim that in case of longer cast cooling time τ and higher degrees of plaster foaming S_S, higher gradients of temperature are observed (higher gradients of temperature usually cause higher tensions in the mould material), so in our case they should make a cast knock-out from the mould easier.

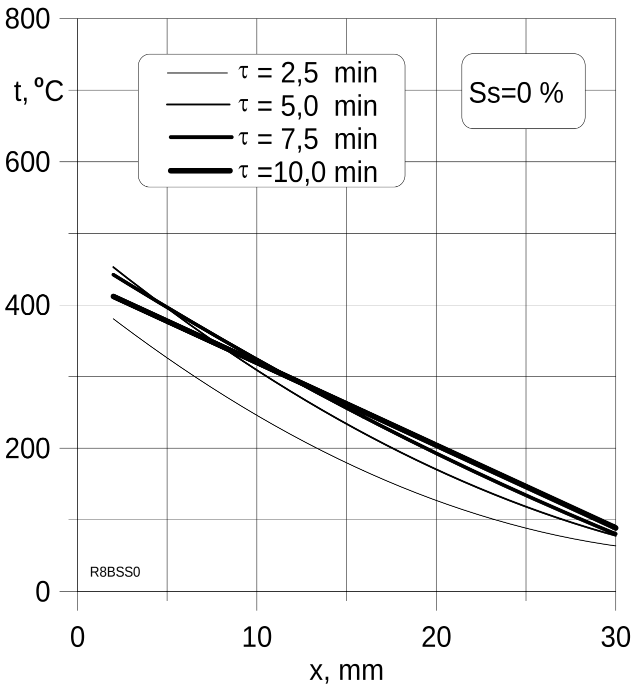


Fig. 6. Dependence of temperature of plaster mould t on the distance x for: τ = 2,5; 5,0; 7,5 and 10,0 min and S_S = 0 %.

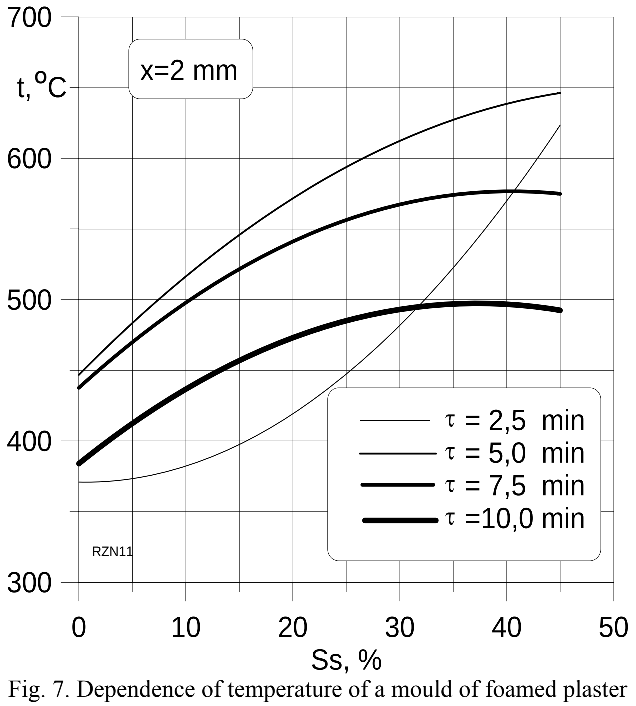


Fig. 7. Dependence of temperature of a mould of foamed plaster on the degree of foaming S_S for: τ = 2,5; 5,0; 7,5 and 10,0 min and x = 2 mm.

Upon analysis of the dependence t=f(S_S), shown in Fig. 7, it can be concluded that an increase of the degree of plaster foaming causes bigger overheating of the internal layers of the mould. Dynamism of this process is dependent on cooling time and decreases with an increase of the degree of plaster foaming.

The analysis of the influence of the degree of foaming S_S on the dependence t=f(x), shown in Fig 8, proves that the highest value of the temperature gradient is observed in the surface layer of the mould with high degree of foaming.

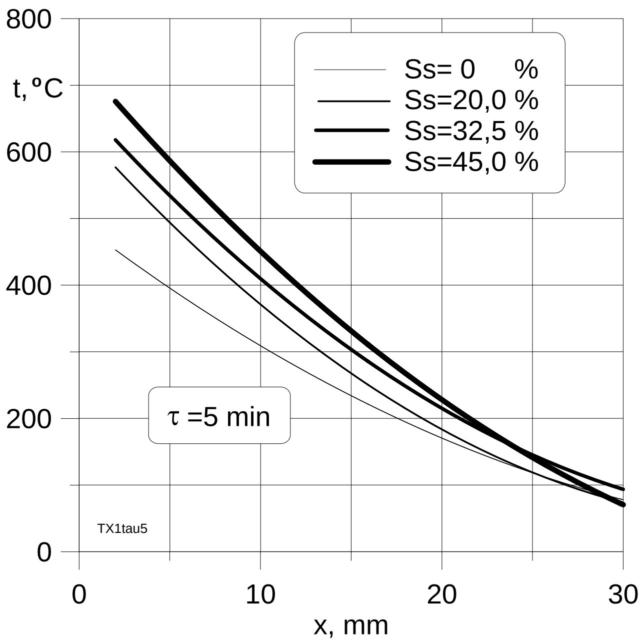


Fig. 8. Dependence of temperature of a mould of foamed plaster on the distance x for: S_S=0; 20; 32,5 and 45 % and t = 5 min.

It can be concluded from the above analysis that the degree of plaster foaming exerts a strong influence on the thermal properties of plaster and its increase is favorable for the sake of convenience of a cast knock-out from the mould, and thereby reduction of the cycle of casting production.

4. Conclusions

1. The highest intensity of heating and overheating of a mould of foamed plaster occurs at the degree of the plaster foaming S_S=45%.
2. A change of the degree of the plaster foaming can be useful in time control of solidification of the castings of aluminum alloys.
3. Application of a stable foamed plaster technology permits to obtain the anticipated, adequate thermal properties of the foamed plaster mould of and to increase the efficiency of this technology.

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