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Effect of Polymorphous Transformations of Quartz on Properties of Synthetic Moulding Sands

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Abstract: The study discusses the problem of the choice of moulding sand components in respect of their behaviour in contact with molten metal. Investigations of the phenomena that take place at high temperatures enable evaluation of the applicability of moulding sand composition under the actual foundry's operating conditions, resulting in elimination of casting defects caused by moulding sand.

Keywords: Foundry engineering, Moulding, Moulding mixture, Moulding sand.

I. INTRODUCTION

Mouldability of sand mixture means the state of moulding sand in which it possesses properties optimum for moulding operation [1]. The "traditional" methods of the measurement of moulding sand properties enable, in principle, determination of the sand mouldability, while actual operating conditions are detemined basing on practice and observations of raw castings. The casting surface defects are caused by molten metal, its temperature and erosive effect. The defects of erosion type are formed in these parts of mould where metal has the highest rate of flow; on the other hand, the defects caused by changes of the dilatational (volume) character and by stresses can be formed within the entire mould cavity.

Silica sand, being used most frequently as a base material of moulding mixture, is the most important component as regards changes of mould volume. The main constituent of this sand is silica (quartz and its variations). Crystalline silica occurs in the form of quartz, tridymite and cristobalite in high- and low-temperature modifications. The polymorphous transformations that take place between the main variations, i.e., quartz, tridymite and cristobalite, are transformations related with structure rebuilding, and as such they proceed very slowly and laboriously, which is best proved by occurrence of all these variations at ambient temperature, although thermodynamically stable is in this system only quartz.

The transformations of high- and low-temperature forms are transformations with structure rebuilding. They proceed very easily and rapidly, specially the transformation of low-temperature β-quartz into high-temperature α-quartz, which is an irreversible reaction, proceeding at a high rate.
A number of quartz transformations [2-6] proceed in the following way:

- On cooling, at a temperature of 1713°C α-cristobalite precipitates; at a temperature of 1 470°C it undergoes transformation combined with rebuilding into α-tridymite; the latter one, in turn, at a temperature of 870°C also undergoes a transformation with rebuilding into α-quartz. At a temperature of 572°C, α-quartz is transformed (a transformation with dislocation) into β-quartz.

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- The remaining transformations with dislocation, like α-tridymite into β-tridymite and α-cristobalite into β-cristobalite, occur at temperatures of 120 and 160°C, respectively.

In terms of the moulding sand dilatation, the most important is the transformation of β-quartz into α-quartz, proceeding at a very high rate at a temperature of 572.4°C. At the point of transformation one can observe a sudden "jump" of density (β-quartz 2.51 g/cm^3, α-quartz 2.655 g/cm^3), accompanied by a change in the coefficient of thermal expansion. The changes of dilatational character taking place during this transformation amount to about 1.4% (linear elongation). These are the changes relatively small, compared with the dilatational changes which occur during the transformation accompanied by rebuilding of α-quartz into α-tridymite and amount to about 14%, remembering that this transfomation is proceeding very slowly because of very strong ionic bonds between Si^{4+} and O^{2-}.

On entering mould cavity, the liquid metal gives up the heat to moulding sand. Raising of temperature causes changes in sand properties through changes in its volume, and hence through formation of stresses in the mould. There are parts of surface in mould cavity in the state of stress, formed due to a layer-like distribution of temperatures, causing different degrees of volume changes in the moulding sand. In foundry practice there are no such foundry moulds in which the surface layers of the sand could dilate without any obstacle. The highest stresses formed as a result of impeded dilatation occur in the case of large, flat and continuous surfaces of mould cavity. They cause detachment of sand layers (of higher temperature) from the layers lying deep inside the mould (lower temperature), which results in the formation of casting defects. Investigations of this type lead to a conclusion that the formation of stresses in moulds after pouring of the said moulds with molten metal is a serious drawback in making "sound" castings without surface defects.

Yet, there is another aspect of this problem. When metal is solidifying, a growth of its volume is observed during passing from the liquid into a solid state (the liquidus curve). This causes casting deformations reproduced from the deformations of mould cavity. The possibility of using such moulding sand in which the dilatation (compression) stresses would be capable of counteracting the reversely directed metal stresses would enable elimination of casting defects and deformation.

The predominant character of sand as a base material of moulding mixture has served as a starting point in development of a theory of moulding sand behaviour determined by dilatometric changes proceeding in the sole sand only. However, closer investigations enabled consideration of joint effect of changes having their origin in both sand and binder (bentonite) [5]. This is particularly important in sands characterised by high content of binder. Bentonite, earlier than sand, undergoes dilatation (lower temperature), to undergo sintering next. The calculated dilatation curve for moulding sand containing 15% by weight of bentonite is shown in Fig. 1.

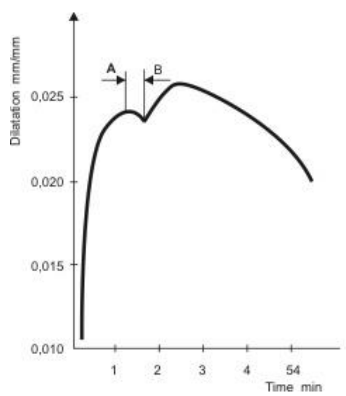

Fig. 1. The theoretical thermal dilatation curve of moulding sand containing 15% of Western Bentonite [5].

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A - predominant dilatation of bentonite, B - predominant dilatation of sand

To choose the composition of moulding sand, very complicated, multi-graph diagrams, plotted for individual moulding sand systems are used (Figs. 2 and 3). Unfortunately, this method does not allow for changes which occur during operation under real conditions (at high temperature), which results in the necessity of making frequent tests to determine casting sensitivity to the formation of surface defects caused by moulding sand.

II. Methods And Research

Investigations were carried out on moulding sands prepared from moulding materials used most frequently in production of iron and steel castings, i.e., sands from Krzeszówek and Zębiec, and medium-grain sand from Bukowno, bentonites - Bentomak and ZGM. The content of binder (bentonite) was 5, 7, 10%, the sand humidity was 2, 3, 4 and 5%. The choice of these materials was based on the results of basic research determining the technological properties. Samples for the measurement of free dilatation (I.O. method) and dilatation under loading (Dietert furnace) were prepared following the specification made by H. Dietert et al. [3].

For dilatometric examinations 19 san-ds most representative of the whole system (72 sands) were selected.
For each of the selected sands the following examinations were made:

1. Measurement of free dilatation (I.O. method)
   a) At a temperature of 500°C;
   b) At a temperature of 600°C;
2. Measurement of dilatation under pre-liminary loading (Dietert method)
   a) At a temperature of 500°C;
   b) At a temperature of 600°C.

The temperatures, at which the examinations of both free dilatation as well as dilatation under preliminary loading were made, depended on temperature of the poly-morphous transformation of quartz (β-quartz into α-quartz at a temperature of 572.4°C).

In investigations carried out by the above mentioned techniques, standard cylindrical specimens of dimensions Ø 286 × 50.8 mm were used. The specimens were prepared in an appropriate sleeve, using specially designed rammer, which compacted the sand with three rams of a 3,175 kg bob falling from the height of 66.7 mm, in accordance with H Dietert's specification. The specimens before testing of the thermal dilatation were dried in a furnace.

The measurement of dilatation under preliminary loading was carried out in H Dietert's furnace. The specimen was placed in the chamber of a furnace heated to the required temperature by eight sillite rods (resistance furnace), fixed on a movable mandrel. The axial thrust on the specimen is provided by aligning plates. The dilatation was measured by a spring sensor, which every 1 minute gave readings of changes in specimen length. The measurement started at the moment when the specimen was introduced into the furnace, the preliminary loading of 1 pound/inch^2/0.0073 MN/m^2 was applied, and the sensor recording increment in length was set to zero. Besides the measurement of dilatation, also increment in the force of impeded dilatation was read out from the recording unit.

The increment in force of the impeded dilatation and the increment in specimen elongation were applied every 1 minute for the time of 11 minutes. After the lapse of 12 minutes the specimen was fractured by the applied load and the value of compression strength was read out at a given temperature.

In processing the results of dilatation measurements, the dilatation of the Dietert furnace system was allowed for.

III. The Results Of Investigations

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Examples of the processed results of examinations were compiled in Tables 1 and 2 given below. Sand composition: sand from Krze-szówek, Bentomak, water.

Effect of temperature on dilatation and increment of stress in moulding sand of the following composition: 95% sand from Krzeszówek, 5% Bentomak, 2% water (water/clay 0,4).

Table 1. Effect of temperature on dilatation and increment of stress in moulding sand.

No	Temperature ^{o}C	R^{t}_{c} 10^{-1} MN/m^2	Δ R^{t}_{c} 10^{-1} MN/m^2	Δl mm
1	200	4.73	0.146	0.05
2	300	4.86	0.124	0.056
3	400	5.11	0.194	0.128
4	500	6.13	0.262	0.255
5	600	11.11	0.316	0.358
6	700	13.28	0.263	0.29
7	800	26.54	0.309	0.256

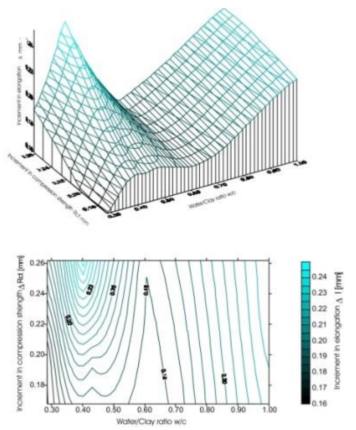

Fig. 2. Relationship between increment in compression strength ΔR_c^t and increment in elongation Δ l in function of water-clay (w/c) ratio for sands of the following composition: Bentomak binder and sand from Krzeszówek. Temperature 500°C

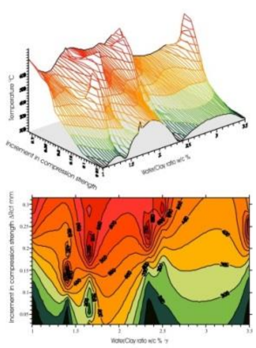

Fig. 3. Relationship between increment in stress ΔR^t_c water/clay ratio and temperature [6-8].

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Table 2. Relationship between increment in stress ΔR^t_c, water-clay ratio (w/c) and temperature [6]

No	Temp °C °C	c/w	ΔR^t_c MPa/cm^2
1	200	1.66	0.031
2	200	1.4	0.088
3	200	2.33	0.095
4	200	3.5	0.097
5	200	1	0.102
6	200	2.5	0.146
7	300	1.66	0.119
8	300	1.4	0.089
9	300	2.33	0.153
10	300	3.5	0.175
11	300	1	0.153
12	300	2.5	0.124
13	400	1.66	0.139
14	400	1.4	0.182
15	400	2.33	0.153
16	400	3.5	0.276
17	400	1	0.207
18	400	2.5	0.194
19	500	1.66	0.026
20	500	1,4	0.168
21	500	2.33	0.189
22	500	3.5	0.201
23	500	1	0.231
24	500	2.33	0.189
25	500	3.5	0.201
26	500	1	0.231
27	500	2.33	0.189
28	500	3.5	0.201
29	500	1	0.231
30	500	2.33	0.189
31	500	3.5	0.201
32	500	1	0.231
33	500	2.33	0.189
34	500	3.5	0.201
35	500	1	0.231
36	500	2.33	0.189
37	500	3.5	0.201

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38	500	1	0.231

IV. CONCLUSION

Analysis of the obtained results enables the following conclusions to be drawn:

1. The greatest thermal dilatation possess the sands which include in their composition the sand from Krzeszówek. Probably in this case of decisive importance is not the sand granulation but the shape of grains and the content of polymorphous quartz variations.
2. The Polish ZGM bentonite causes greater dilatation than Bentomak. Most probably, this is caused by lower content of montmorillonite (about 47%), characteri-sed by low sintering point.
3. The greatest thermal dilatation possess the sands with water-clay ratio (w/c) amounting to about 0.2.
4. The values of increments in both length as well as stress, reaching the level of 1% and 0.3 MPa, respectively, are very high. Unfortunately, until now, they have been disregarded during analysis of the technical feasibility of casting production prepa-ration.
5. Construction of 3D diagrams enables observation of changes in volume and stress forming in moulding sands operating under high temperatures,
   Analysis of these diagrams is much simpler than of the complicated diagrams used so far.

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