

The influence of Cerafiber 10 ceramic fibre on strength properties of moulding material for investment casting technology

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Received 16.06.2009; accepted in revised form 22.07.2009

Abstract

The presented investigations have been aimed to determine strength properties of shell ceramic moulds produced on the basis of silica slurry with the matrix composed of MK75 silica flour and Cerafiber 10 aluminosilicate ceramic fibre, the chemical composition of the latter being 56% SiO₂ and 44% Al₂O₃. The sample material has been obtained by multi-layer spraying of ceramic slurry onto the pattern sets. The achieved results, concerning strength properties revealed during the controlled bending test performed by means of the four-point deflectometer, have been compared with the presented elsewhere results [16-19] for moulding material with grain or grain-fibre matrix, where TC E08 fibre produced by Thermal Ceramics (i.e. Kaowool HP-50-E-08 fibre) has been applied as a matrix component.

Keywords: Investment casting technology, Moulding materials, Fibre strengthening, Slurry

1. Introduction

The recent development of precision casting is based, inter alia, on fundamental quality changes in the production process of the thin-walled shell moulds. These changes refer mainly to the binders [1-3, 16] and to the less extent to the ceramic matrix materials [4, 5, 16-19]. The rudiments of shell moulding have been created by applying strong binders based on ethyl silicate. The transition from the block mould towards the thin, self-supported one has been a long process, and a series of problems had to be solved to withstand the severe demands required from this type of moulds. It should be noticed that the ethyl-based binders, which have been considered almost ideal because of their quick action and high bonding strength, nowadays have lost their privileged place due to the content of pernicious volatile organic compounds (VOC) and their further use is problematic in consideration of present law regulations [6]. Simultaneously to the enforced turn to

the ecologic binders based on water, the already well-known problems have to be faced once again: the poor wettability of wax pattern, the decreased strength during the stage of partial ceramization, and a long drying time both between applying the subsequent coats and during the final drying. A drop in the productivity of foundries after changing to the water binders enforced research works directed not only towards the reduction of drying time, but also towards finding the more general solutions.

The new generation of improved water binders has been initially designed to apply for the primary coats, the focus on improving the wettability by adding surfactants and antifoamers [3] and eliminating the material tendency to separate, warp or crack; then the turn for back up coats has come, with their priority feature – strength. Presently liquid polymers based on polyvinyl alcohols (PVA) for acid systems [7] or latexes for alkaline systems are introduced to the binders to improve strength and flexibility of moulds. Polymer-modified materials have become the object of

many patents, e.g. by Guerry [1] and Doles [8], and also of the domestic invention [9].

The new binders at first has been subjected to some restrictions (among other things they required for applying the fused silica matrix) which have been gradually overcome, the example of this being REMASOL ADBOND B or LUDOX AS-40 products. It is worth noticing that applying of polymer-modified binders slightly decreases the strength of moulds after burning (MOR2) due to the destruction of the organic phase, nevertheless it improves their flexibility and permeability.

The most popular latexes in precision casting are butadiene-styrene ones, which co-operate well in mixtures with colloidal silica and do not evolve pernicious substances during the burning of moulds. Latex polymers are added in small amounts, about 2% of binder mass. The drying time is from 4 to 6 hours. Latex protects the formerly built coats from the re-wetting, by binding the colloidal silica particles in the impregnating way during the drying process. After drying there arises the vapour-permeable, but water-impermeable layer which restricts soaking and quickens drying.

The most common gelation method used for precision castings is drying, during which the hydroxyl groups at the particle surfaces are concentrated because of water removing and form the oxosilane bounds (Si-O-Si). We can distinguish intermediate and final drying, the latter preceding the dewaxing process. The intermediate drying is much more important than the final one, because it is decisive for the shell quality [10]. Another way of improving the crack resistance of thin-walled moulds is their reinforcing i.e. introducing matrix components which can stop crack propagation. It is well-known that the crack resistance of ceramic materials can be significantly improved by introducing fibre into the ceramic matrix. The strengthening of ceramic moulds with glass fibre has been surveyed by Sapčenko et al. [11]. The materials 'modified' with polymer fibre have been studied by, inter alios, Jones and Yuan [2,12], with carbon fibre – by Naik and Corrigan [5], with ceramic fibre – by Vandermeer [13], with whiskers – by Preedy and Simpson [14]. For all the above mentioned analyses, the content of fibre components has usually not exceeded 12 wt%, and the most often it has ranged from 0.5% to 5% due to the rheologic changes in the obtained slurry.

For already several years the Foundry Institute of Czestochowa University of Technology has been carried out investigations concerning the possibility of strengthening the thin-walled self-supporting moulds for precision investment casting by introducing ceramic fibre into the material matrix. Simultaneously, the modification of binders by adding latex polymers is also explored. A series of reports [15-19] concerning these themes has dealt with the possibility of affecting mechanical and technological properties of the obtained moulding material by the addition of brand chopped and mechanically separated aluminosilicate fibre TC E08 produced by Thermal Ceramics Ltd (trade name Kaowool HP-50-E-08) of the following chemical composition: 53% of SiO₂, 47% of Al₂O₃.

2. Methodics and results of investigation

The purpose of the work has been determining the strength properties of ceramic shell moulds built on the basis of silica sol with the matrix composed of Cerafiber 10 ceramic fibre (chemical composition: 56% of SiO₂, 44% of Al₂O₃) and silica flour, the coats being applied by spraying method.

The multi-layer thin-walled ceramic shells has been prepared by spraying method, this way sequentially (spraying and drying) covering the low-melting pattern with ceramic slurry by means of the pneumatic spraying gun. The obtained ceramic material, after being separated from the low-melting pattern sets, has been cut into the specimens of about 170 mm length and about 18×10 mm cross-sectional dimensions. Strength tests have been performed by means of the four-point balance deflectometer according to the assumed methodics described elsewhere [15-19]. The examination results are presented in Table 1 and depicted in graphic form in Figs 1 and 2.

The fibrous-grain matrix moulding materials of various fractions of fibrous components (10, 18, or 50%) have been examined. The obtained results concerning their mechanical properties have been compared with the respective values achieved during the former experiments for the material containing TC E08 fibre, as well as with the results recorded for conventional grain matrix material. Table 1 presents the results for bending strength MOR1 and the work of fracture FI.

Table 1.
Results for MOR1 and FI

		MOR1 MPa	S _(MOR1) MPa	FI kJ/m ³	S _(FI) kJ/m ³
Grain moulding material		2.32	0.19	0.43	0.05
Moulding material with Cerafiber 10	Content of fibre in the matrix %	10	6.19	0.52	7.8
		18	9.81	1.34	29.8
		50	6.74	0.42	16.9
Moulding material with TC E08 fibre		5.71	0.29	7.10	0.70

Changes in bending strength MOR1 in relationship to the content of Cerafiber 10 fibre in the matrix are shown in Fig. 1.

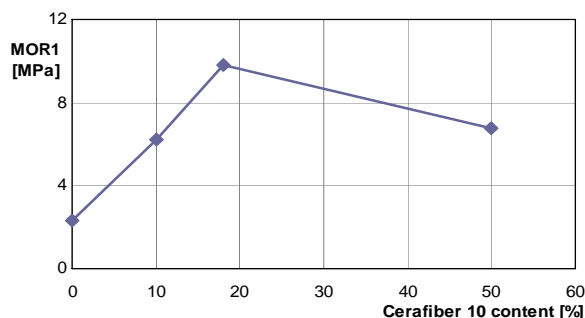


Fig. 1. Change of bending strength MOR1 of moulding material versus the Cerafiber 10 fibre content in its matrix

The maximum bending strength value equal to about 10 MPa has been obtained for the 18% Cerafiber 10 content in the matrix. It can be regarded as an evidence of a good co-operation between grain and fibrous matrix components for such a fibre fraction. The MOR1 results for the other materials reinforced with Cerafiber 10 fibre are lower and of similar values. They are about 6.2 MPa for 10% fibre content and about 6.7 MPa for 50% of fibre fraction in the fibrous-grain matrix.

The obtained results are supplemented with the values of the work of fracture FI with respect to the Cerafiber 10 fibre fraction in the moulding material matrix, Fig. 2.

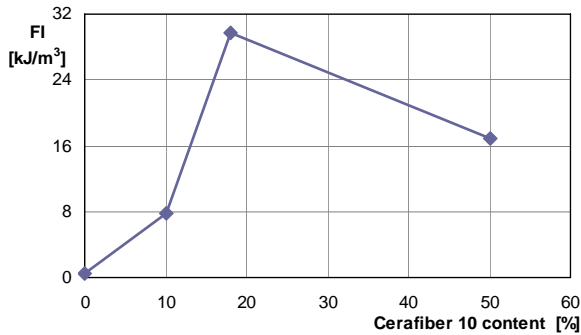


Fig. 2. Change of the work of fracture FI of moulding material versus the 10 fibre content in its matrix

The values of the work of fracture change with the change in Cerafiber 10 fibre fraction in the moulding material matrix from about 8 to about 30 kJ/m³. The minimum value has been recorded for the 10% fibre fraction, while the maximum one for 18% fibre fraction in the fibrous-grain matrix. A comparison of the behaviour of moulding materials containing various amounts of Cerafiber 10 in the matrix during the controlled bending test is presented graphically in the form of stress-strain (σ - ϵ) curves, Fig. 3. The areas beneath the curves represent the values of the work of fracture FI for each examined material. Although the materials containing 10% and 50% of fibre in the matrices exhibit similar MOR1 bending strength values, their respective FI values differ already by twice to the advantage of the material containing the greatest used amount of Cerafiber 10 fibre. The material of the greatest MOR1 value is characterised by the work of fracture value almost four times greater than the material containing 10% of fibre in its matrix.

Further graphic representation compares the bending test behaviour of the material containing 18% of Cerafiber 10 fibre in the matrix (i.e. this exhibiting maximum MOR1 and FI values from between the discussed above materials) and of both the material reinforced with TC E08 fibre which has exhibited the best strength properties during the previous investigations (i.e. that containing 35% of fibre in the matrix) and the pure grain matrix material. The observed differences in the course of σ - ϵ curves point to the significant increase of mechanical values, including MOR1 and FI, for moulding materials of fibrous-grain matrix as compared with conventional material of pure grain matrix. The differences between the values of strength parameters of both fibre reinforced moulding materials can be caused by the difference in chemical composition between Cerafiber 10 and TC E08 fibre, as

well as by the different fractions of the fibre itself in the material matrix.

The moulding material obtained as a result of multi-layer spraying the slurry onto the pattern sets, containing 18% of Cerafiber 10 fibre in the matrix, is characterised by almost four times greater bending strength MOR1 and several tens greater FI index than the material with the grain-only matrix.

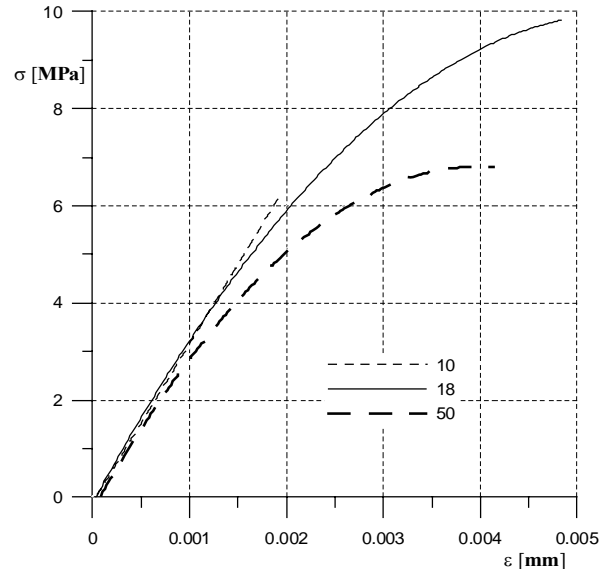


Fig. 3. The σ - ϵ curves for fibrous-grain matrix materials containing 10, 18, or 50% of Cerafiber 10 fibre

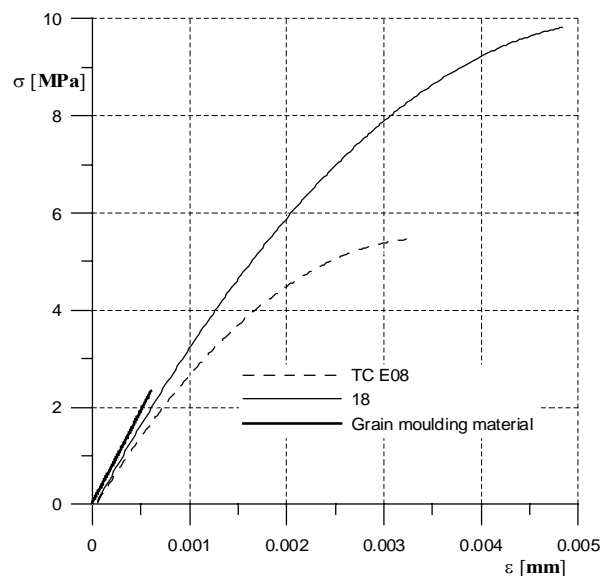


Fig. 4. The comparison of σ - ϵ curves for two fibrous-grain matrix moulding materials and a grain matrix one

3. Conclusion

Good co-operation between the matrix components of the material containing 18% of Cerabfiber 10 fibre in the matrix results in the highest values of bending strength MOR1 equal to about 10 MPa and of the work of fracture FI equal to about 30 MJ/m³. Also the MOR1 values of the other examined materials with various fibre content are definitely higher than the minimum required value determined by foundry practice to be about 2.4 MPa, thus allowing for practical application of these materials.

The differences between σ_{\max} values determined for individual examined materials results from the various content of Cerabfiber 10 ceramic fibre in their matrices. The course and the slope of the σ - ε curves determine the examined material resistance until the maximum deflection ending the test is reached. This makes the measuring test itself more sensitive to the changes in material composition.

Various results of strength parameters MOR1 and FI obtained for materials with various types of fibrous-grain matrices can be attributed to the difference in chemical composition between the Cerabfiber 10 and TC E08 fibre, as well as to the different content of the fibre itself in the matrices.

The material reinforced with Cerabfiber 10 fibre can be successfully applied for production of single castings of greater dimensions than those presently cast in self-supporting moulds for investment casting technology.

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