MANUFACTURING OF METAL - CERAMIC COMPOSITE LAYERS IN CASTS

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Abstract

This article describes how to improve the tribological properties of cast iron by local strengthening by ceramic layer, directly in the casting process. The research comprised test molds with a ceramic (composite) layer. The ceramic preform (insert with Al_2O_3) was made basing on proprietary development of geometric assumptions. The tests included measurement of resistance to abrasive wear under ASTM G 65-00 standard and some quantitative measurements were also made. The basic advantages of combining ceramics and iron alloy include, without limitation: high hardness of the mold on the working surface and resistance to abrasive wear; increased resistance of the element to impacts compared to solid ceramic elements, extended lifetime of the molds, cost reduction of operation of machine elements made with the casting method, thanks to the increased lifetime and durability of the elements.

Keywords: Casting, cast steel, alloy layer, ceramic

1. INTRODUCTION

The surface layers are made to obtain better properties, which cannot be assured by materials from one metal alloy. Most of the pressure comes from modern industry continuously breaking technological barriers and such extreme working conditions often cause premature wear of the machinery elements. The materials used must be characterized with growing resistance to abrasive wear in the surface layer of the mold, corrosion and high temperature of the working environment. An example could be a sliding bearing sleeve with high strength and sliding properties thanks to its low friction coefficient. The structural materials most frequently used in the machines are cast steel and cast iron. It would be impossible to reach abrasive resistance, hardness, tensile strength, impact strength and plasticity on such a high level with the use of cast iron or non-alloy casting steel only [1, 2].

The layers can be created in numerous ways. The process can be done by, e.g. thermal spraying, PVD coating, detonation spray coating, plating or hard facing. An interesting and competitive method of element surface processing and improving its properties is the layer mold technology [3, 4]. This method deserves special attention, because it brings about numerous advantages of the technology and properties of the layers obtained. The molding technology (mold cavity preparatory procedures) is fairly easy, the use of any additional equipment is not necessary and it is economic, because it is performed within one process [5, 6, 7, 8]. The layers are made very fast, their thickness is adjustable and they and can be coated on any surface of the mold. Furthermore the crack occurrence in the thermal impact zone is eliminated [9].

For the casting methods of producing alloy layers the mold surface must be appropriately prepared [10, 11]. Therefore, we can divide them into the following [12, 13, 14]:

- layers produced as a result of casting mold inserts (including without limitation bimetals),
- layers obtained by fusion of alloy components located on the mold surface by means of the cast metal heat,
- granular layers produced by infiltration of liquid metal alloy down inside the layer prepared on the mold.

Metals can be combined by diffusion or mechanically. In the case of mechanical combination of two materials we can already talk about a composite material.

A composite is a material produced from at least two components (phases) with various properties in such a way that it has better and/or new (additional) properties as compared to the components used separately or resulting from simple summarizing of such properties - a composite is an externally monolithic material, however with visible boundaries between its components [15].

Combining ceramics and iron alloys with casting method is a complex question resulting from more than double density difference between both materials.

The methods of obtaining composites in casts enable designing casts reinforced on the surface in zones or throughout their entire volume. They allow for obtaining products combining the properties of a selected cast alloy with “phases” (Al_2O_3), highly resistant to abrasion ceramic. Thanks to such solution it is possible to design elements of machines and devices locally reinforced with a ceramic phase. Its advantage is the limitation of the production costs resulting from the application of several technologies and the cost of the material used. In as much the scientific works on the ceramics-aluminium composites are known, in so far there is no such information concerning the composites of iron alloy - ceramics composites. The issue of producing composites or ceramic materials and iron alloys, and thus, the difficulties with their even distribution in the volume of the molten metal and with high temperature of the iron alloys inducing disintegration of the ceramic preforms and uncontrolled layout of ceramic grains in the cast volume [1,3,5].

The method of obtaining composite molds locally reinforced with hard ceramic particles will be presented in this paper.

2. OWN RESEARCH

The purpose of the research was the production of a ceramic insert to create a reinforced layer in a cast iron alloy. The research also included testing abrasive wear resistance and quantitative tests of the surface share (in the area tested) of ceramics in the part of the reinforced alloy.

The electrocorundum ceramic grains (Al_2O_3) or electrocorundum and carborundum mixture (SiC) with the maximum 10 % share of the latter in the overall volume can be used in the production of the preform (insert). The dimensions of the ceramic grains may fit in the range from 1.4 to 2.8 mm, which corresponds to F8 to F14 dimensions, according to FEPA standard. The ceramic grains in the preform can be joined with binding material based on water glass or synthetic resins used in molding compounds of the foundry sector. Such preform is fixed in the cavity of the mold (**Figure 1**) and gravitationally cast with liquid metal (cast iron or cast steel).

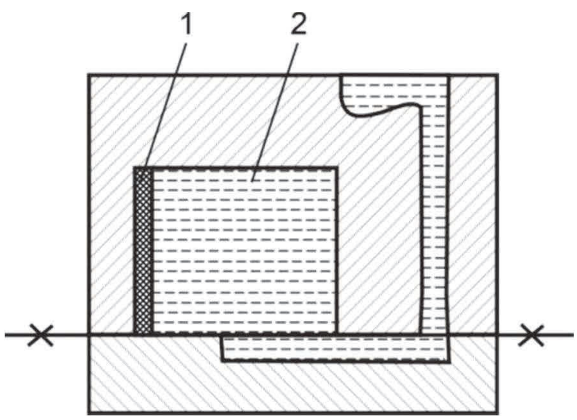

Figure 1 Forming of surface composite layers - founding method; 1 - composite premould; 2 - liquid metal

The preform’s structure is based on geometric dependencies [16]:

- side length of elementary cell $b = d + od$ mm,
- preform length $L = n_L b$ mm,

- preform width $S = \frac{\sqrt{3}}{2} n_S b$ mm,
- openwork of the profile $A = \frac{n_L n_S \frac{\pi d^2}{4} g}{L S g} 100$ %,

where:
n_L - number of openings on the preform's length,
d - opening's diameter (max. 20 mm), mm
od - space between openings (max. equal to preform's thickness), mm
n_S - number of openings on the preform's width,
g- preform's thickness,
L- preform's length,
s- preform's width.

The ceramic preform for the production of a reinforced layer in the cast iron mold, made as a cuboid profile from granular ceramic material with openings of 5 % to 25 % voluminous share, whereby the distance between the openings does not exceed the maximum preform thickness of 25 mm, while the preform's weight does not exceed 15 % of the weight of the mold‘s reinforced part.

For the tests presented herein, noble electrocorundum (alundum) containing 99 % Al_2O_3 was used. The binding material to join the grains was produced basing on water glass.

The structure of the ceramic preform used in the tests is as follows (**Figure 2**):

- side length of elementary cell - 30 mm,
- space between openings - 15 mm,
- opening diameter - 15 mm,
- preform's length - 60 mm,
- preform's width - 26 mm,
- insert's thickness - 15 mm,
- profile openwork A = 23 %.

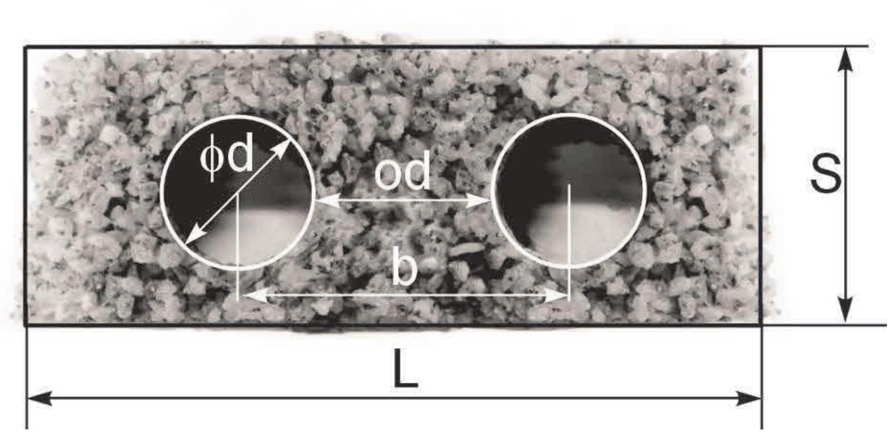

Figure 2 Ceramic insert to form the composite layer

Upon short annealing in ca. 500°C the preform was placed in the appropriate part of the mold. Then the mold was cast with liquid perieutectic cast iron of ca. 1450°C temperature. As a result, a good infiltration of the liquid metal into the preform is obtained, creating a composite metal-ceramic layer in the mold, which is resistant to abrasion to the thickness up to 15 mm.

In **Figure 3** a sample cast locally reinforced with a composite ceramic layer has been presented.

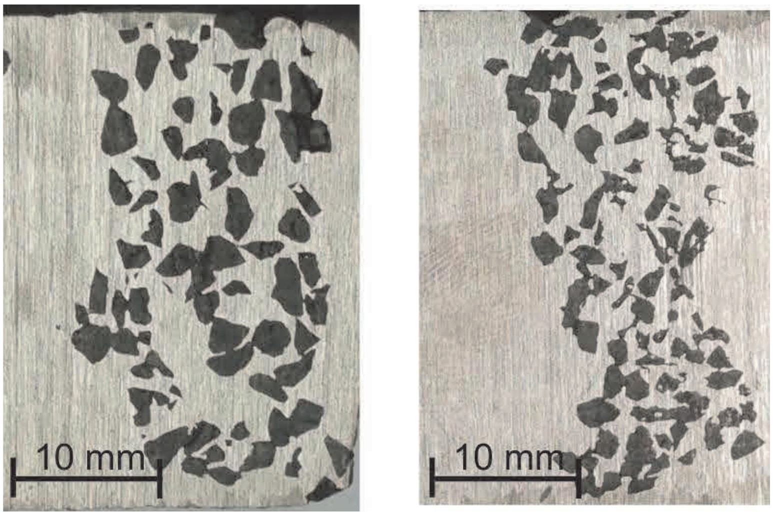

Figure 3 Casting with locally reinforcement produced layer

The research included quantitative measurement of the particle on the surface cross-section of the composite obtained, with the use of Nikon Nis-elements BR 3.10 program. In virtue of the tests carried out the highest percentage possible in relation to the surface to be reinforced could be determined. The results have been presented in **Table 1**.

Table 1 Percentage of ceramic particles in relation to the load carrying part of the mold

Sample	Surface of the sample	Surface of the particles	Surface occupied by the particles	Number of particles
1	611.61 mm^2	191.02 mm^2	33.25 %	138
2	536.08 mm^2	183.01 mm^2	31.10 %	130
3	666.33 mm^2	202.32 mm^2	33.85 %	132
4	432.09 mm^2	148.36 mm^2	33.19 %	99
5	846.12 mm^2	243.14 mm^2	30.41 %	98
6	552.86 mm^2	173.52 mm^2	29.16 %	111

Based on the research it has been found that the best density of particles in the cast is ca. 30 % of the surface which has been reinforced with the particles.

The research also included measurements of abrasion resistance with the use of device made under ASTM G 65-00 standard (**Figure 4**). Such device is intended to test the abrasion resistance of the metal-mineral type.

The basic technical details of the device:

- three-phase engine speed 600 rpm $\pm$ 10 rpm,
- the functional wheel's speed 200 rpm $\pm$ 10 rpm,
- the functional wheel's characteristic dimensions: diameter 230 mm, thickmess 25 mm, height of vulcanized rubber hoop 10 mm,
- sample load 130 N,
- abrasive material's streamflow: 500 g / min (dry sand).

The result of the trials carried out was the reduction of the samples' mass measured with accuracy up to 0.001 g. The test enabled determination of the mass reduction (Δm) for each of the surface composites obtained. The measuring results have been presented in **Table 2**.

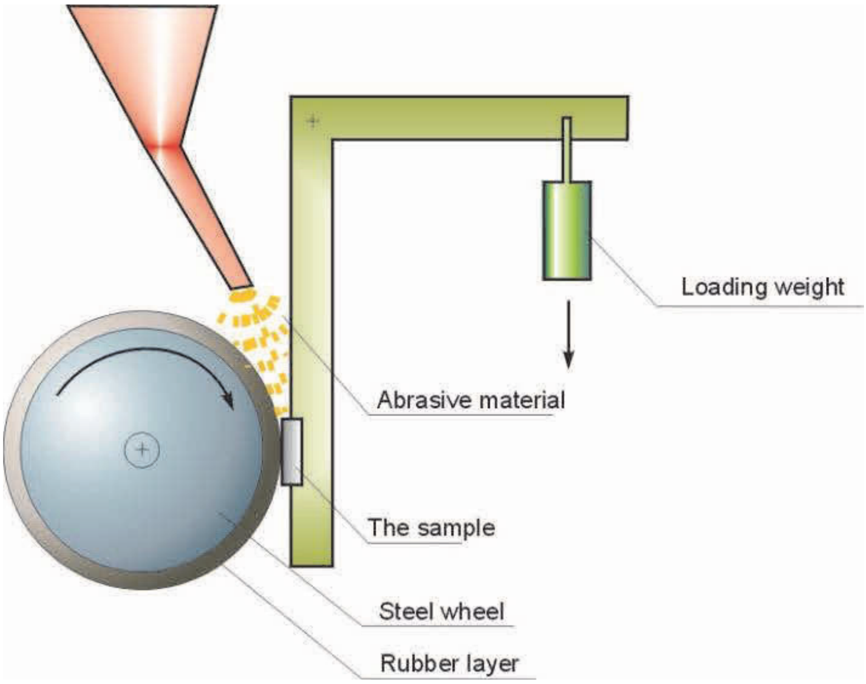

Figure 4 Flowchart of the abrasion resistance measuring device

Table 2 The results of abrasive resistance examination

Material	Average mass loss, g
Composite No. 1 (insert - F12, the density of grain 30 %)	0.122
Composite No. 2 (insert - F12, the density of grain 33 %)	0.117
Composite No. 3 (insert - F10, the density of grain 25 %)	0.170
Composite No. 1 (insert - F12, the density of grain 29 %)	0.149
matrix composite (cast iron)	0.231

Based on the observation of the composite produced, it has been noticed that the molten metal poured into the mould well penetrated between the insert particles, creating no local agglomerates and no discontinuation in the combination metal - Al_2O_3 particle have been noticed (good dampening - **Figure 4**). Based on the test of abrasive wear strength a significant increase of this property has been found, it has been noticed that during the tests the matrix (cast iron) was largely exposed to abrasion affecting the test result. More reliable measurements of abrasive wear strength should be carried out in conditions closer to real ones.

3. CONCLUSIONS

The method of producing ceramic inserts to create surface composite layer with Al_2O_3 enables to obtain a cast with locally increased abrasive wear strength. Maintaining some geometric assumptions assures the production of a composite in a desired point of the cast.

To obtain penetration (infiltration) of liquid metal through the preform, the following conditions must be met:

- the minimum openwork of the preform expressed by the percentage of openings in the volume of the ceramic preform is at least 5 %, preferably 15-25 %,
- the preform's weight should not exceed 10 % of the mold reinforced part's weight,
- single preform's thickness up to 25 mm, while the maximum distance between the openings in the preform should not exceed its thickness,

- the layout of the openings in the preform forms an elementary cell being an equilateral triangle.

The basic advantages of combining ceramics and iron alloy include, without limitation:

- high hardness of the mold on the working surface and resistance to abrasive wear;
- increased resistance of the element to impacts compared to solid ceramic elements,
- extended lifetime of the molds,
- cost reduction of operation of machine elements made with the casting method, thanks to the increased lifetime and durability of the elements.

REFERENCES

[1] DULSKA, A., BARON, C., SZAJNAR, J. The analysis of the effects of heat and mass movement during alloy layer forming process on steel cast. In *METAL 2016: 25th Anniversary International Conference on Metallurgy and Materials*, Brno, Czech Republic, May 25th - 27th, 2016. Ostrava: Tanger, 2016, pp. 110-115.

[2] DULSKA, A., STUDNICKI, A., SZAJNAR, J. Reinforcing Cast Iron with Composite Insert. *Archives of Metallurgy and Materials,* 2017, vol. 62, no. 1, pp. 365-367. DOI: 10.1515/amm-2017-0054.

[3] SZAJNAR, J., DULSKA, A., WRÓBEL, T., BARON, C. Description of alloy layer formation on a cast steel substrate. *Archives of Metallurgy and Materials*, 2015, vol. 60, no. 3, pp. 2367-2372. DOI: 10.1515/amm-2015-0386.

[4] ŽIC, S., DŽAMBAS, I., KONIĆ, M. Possibilities of implementing bimetallic Hammer castings in crushing industries. *Metalurgija*, 2009, vol. 48, no. 1, pp. 51-54.

[5] CZAJKOWSKA, A., STASIAK-BETLEJEWSKA, R. Quantification of the quality problems in the construction machinery production. In 9*th* *International Conference on Computing and Solutions in Manufacturing Engineering*. Brasov, Romania: CoSME'16, 3 - 4 November, 2016.

[6] CZAJKOWSKA, A., STASIAK - BETLEJEWSKA, R. Determinants of the machining process in the steel industry. In *Metal 2016: 25th Anniversary International Conference on Metallurgy and Materials*. Brno, Czech Republic, May 25th - 27th. Ostrava: Tanger, 2016, pp. 1763-1769.

[7] JONŠTA, P., VÁŇOVÁ, P., BROŽOVÁ, S., PUSTĚJOVSKÁ, P., SOJKA, J., JONŠTA, Z., INGALDI, M. Hydrogen embrittlement of welded joint made of supermartensitic stainless steel in environment containing sulfane. *Archives of Metallurgy and Materials*, 2016, vol. 61, no. 2, pp. 709-711.

[8] DZIUBA, S., INGALDI, M., KADŁUBEK, M. Use of Quality Management Tools for Evaluation of the Products' Quality in Global Economy. In 16th *International Scientific Conference Globalization and Its Socio-Economic Consequences*, Rajecke Teplice, Słowacja: *GLOBALIZATION AND ITS SOCIO-ECONOMIC CONSEQUENCES, 16TH INTERNATIONAL SCIENTIFIC CONFERENCE PROCEEDINGS*, PTS I-V, 2016, pp.: 425-432.

[9] STACHOWICZ, M., GRANAT, K. Possibilities of reclamation microwave-hardened molding sands with water glass. *Archives of Metallurgy and Materials,* 2014, vol. 59, no. 2, pp. 757-760.

[10] JEZIERSKI, J., JANERKA, K., STAWARZ, M. Theoretical and practical aspects of pneumatic powder injection into liquid alloys with a non-submerged lance. *Archives of Metallurgy and Materials*, 2014, vol. 59, no. 2, pp. 731-734.

[11] NUCKOWSKI, P.M., KWAŚNY, W., RDZAWSKI, Z., GŁUCHOWSKI, W., PAWLYTA, M. Influence of the repetitive corrugation on the mechanism occuring during plastic deformation of cusn6 alloy *Archives of Metallurgy And Materials,* 2016, vol. 61, no, 3, pp. 1261-1264.

[12] STABIK, J., CHOMIAK, M. Graded epoxy-hard coal composites: Analysis of filler particle distribution in the epoxy matrix. *Journal of Composite Materials,* 2016, vol. 50, no.26, pp. 3663-3677. DOI: 10.1177/0021998315623626

[13] STAWARZ, M. SiMo ductile iron crystallization process. *Archives of Foundry Engineering,* 2017, vol. 17, no. 1, pp. 147-152.

[14] XIAO, X., YE, S., YIN, W., ZHOU, X., XUE, Q. High Cr white cast iron/ carbon steel bimetal liner by lost foam casting with liquid-liquid composite process. *China Foundry,* 2012, vol. 9, no. 2, pp. 136-142.

[15] ERTÜRK, S., ÇAKIR, O., KUMRUOGLU, L., OZEL, A. Fabricating of steel/ cast iron composite by casting router. *Acta Physica Polonica A,* 2013, vol. 125, no. 2, pp. 452-453.

[16] Patent Application No. P.417657.