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Microsegregation of Elements in Steel Composite Reinforced with Ceramic

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Abstract

The paper presents results of research on steel castings GX120Mn13 (L120G13 by PN-89/H-83160), zone-reinforced by elektrocorundum particles (Al_2O_3), with a grain size from 2 to 3.5 mm. Studies revealed continuity at interface between composite components and formation of a diffusion zone in the surface layer of electrocorundum grains. In the area of this zone, simple manganese segregation and reverse iron and chromium segregation were found. The transfer of these elements from cast steel to electrocorundum grains resulted superficial depletion in aluminum and oxygen in this area. No porosity was observed at the interface between two components of the composite. We found it very beneficial from an exploitation point of view, as confirmed by the study of resistance to abrasive wear.

Keywords: Composite materials, Cast reinforced, Cast steel, Ceramic materials, Abrasive wear

1. Introduction

Casting composites are materials composed of at least two interconnected materials of different physical and chemical properties. One of them is the matrix, others are reinforcement [1,2]. This distinguishes composites from conventional casting alloys. Combinations of metal alloys (with relatively high plasticity, strength, thermal also electrical conductivity) with another materials, e.g. ceramics (high temperatures resistance, high hardness, strength and low elongation), makes it possible to obtain hybrid materials with much better functional properties than in the case of typical casting alloys [3,4].

Today, a fairly wide spectrum of casting composites is used, and their classification can be based on different criteria. Due to the fact that reinforcing phases have a positive effect on improvement of functional properties of casting composites, therefore most often they are usually classified by to type of amplifying phases [5]. The first kind are castings with continuous amplification phases, most often long fibers. The second are castings with discontinuous reinforcing phases, usually particles or thread crystals, short fibers. Compared to first, the second kind of composites are easier to formation and less expensive to produce. Moreover, it's possible to formation such castings during potential plastic working [6].

Strengthening of castings is mainly used in the case of non-ferrous metal alloys (mostly aluminum alloys). Porous shapes are used, most often made of SiC and Al_2O_3 particles and fibers. However, their porosity is so low that in the process of producing castings they must be pressure infiltrated [7-13]. Therefore, it’s a method that cannot be used for production of large steel castings.

In the case of iron-carbon alloys, methods of surface saturation of castings with alloying elements are mainly used [14,15] or, as was the case with the works carried out at the Department of Foundry Silesian University of Technology, creating composites of surface layers using the technology of bimetallic layered castings (layered composites) [16,17]. However, the layer thicknesses of increased abrasion resistance obtained by these methods do not exceed a few millimeters.

2. Subject, purpose, scope and methodology of the research

The subject of work are castings made of Hadfield cast steel GX120Mn13 by ISO, hereinafter referred to as L120G13 acc. to PN-89/H-83160 standard, reinforced with zones of hard particles of elektrocorundum (Al_2O_3), hereinafter referred to as corundum (granulation from 2.0 to 3.5 mm), to a depth of several centimeters - Fig. 1. From a practical point of view, the increased resistance to abrasive wear should be positively influenced by good adhesion between the individual components of the composite. Due to the above, a series of tests at the interface between two phases of the composite was carried out. They included microscopic observations, chemical composition tests and reasearches of abrasive wear.

The microscopic observations were made using Hitachi TM3000 and FAI Quanta 250 Scanning Electron Microscopes.

Analysis of chemical composition was performed using the spectral method, using the GDS 750 QDP Leco analyzer and the SEM Quanta 250 FAI equipped with an EDS detector. The WDS detector was also used for comparative purposes.

Measurements of abrasive wear resistance were carried out using a T-07 tester [18]. The testing station provided an undefined type of contact, wear with loose abradant (F90 corundum according to ISO 8486:1998), sliding type of movement ensuring dry technical friction under load. The pressure F of the sample (dimensions 30x30x3 mm) to the counter-sample (metal disc covered with rubber with a hardness of 78-85°Sh, rotating at a speed of 60 ± 2 rpm) was exerted by weights with a lever system and amounted to 44N. The test duration was 10 minutes (600 rotations).

All tests were carried out on at least three samples from different castings.

3. Results and discussion

3.1. Structure and microsegregation

The macroscopic observations indicate full infiltration in the reinforcement area of the space between the ceramic particles with liquid metal. Figure 1 shows a photograph of a fragment of casting surface perpendicular and parallel to axis of reinforcement. In both cases, the complete continuity of casting structure at the reinforcement boundary is visible.

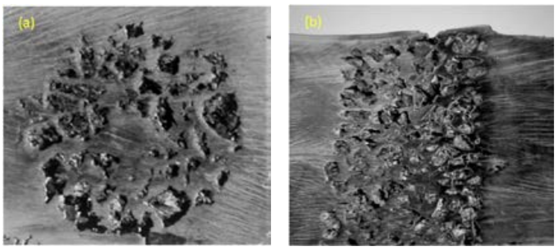

Fig. 1. A fragment of the casting surface: a) perpendicular, b) parallel to reinforcement axis

Microscopic observations confirmed no porosity at interface between two components of the composite. Figure 2 presents SEM photos showing contact area of both phases. At the surface of electrocorundum grains, a thin diffusion layer with a thickness of about 6 μm is visible. This indicates high-temperature diffusion processes occurring during solidification and cooling of castings.

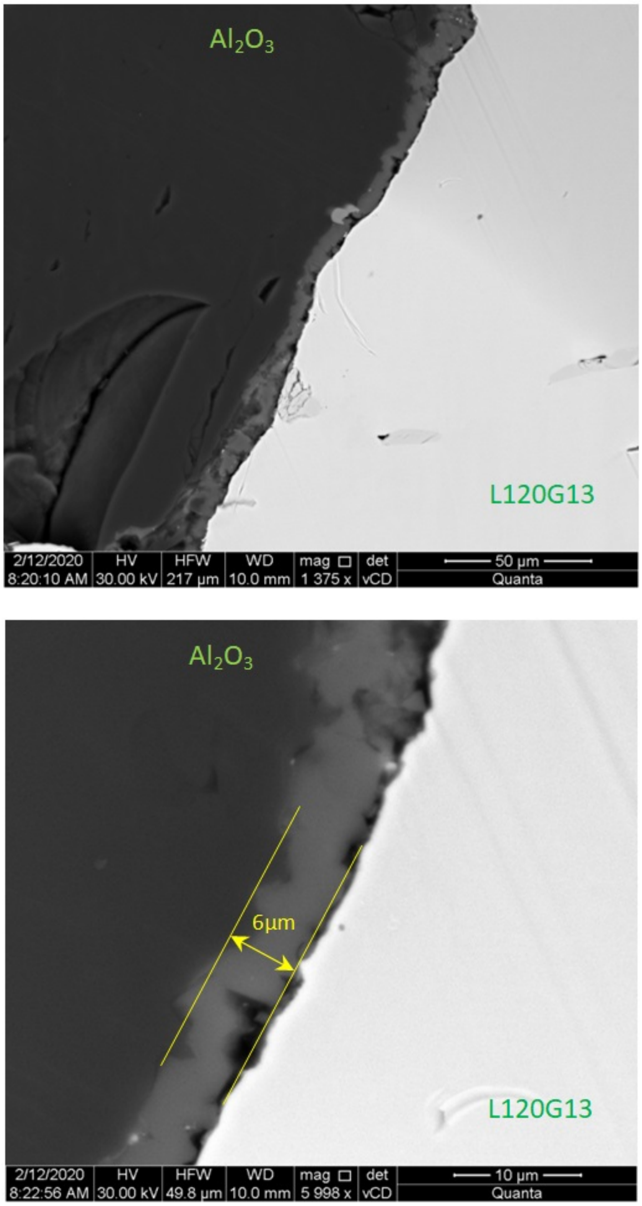

Fig. 2. The layer at surface of corundum grain in the composite, from the top: enlargement 1375x and enlargement 6000x

According, a series of chemical composition measurements was carried out in the boundary areas of both phases. Figure 3 presents a photo showing the area of contact of both components of the composite with the EDS measurement areas marked (sample measurement sites). A WDS detector was used for comparison. Average measurement results are presented in

Table 1. Additionally, a chemical composition of cast steel matrix was determined by spectral method (average content of elements: 1.30 % C; 0.65% Si; 13.83 % Mn; 1.00% Cr; 0.90% Ni; 0.07% P; 0.06% S).

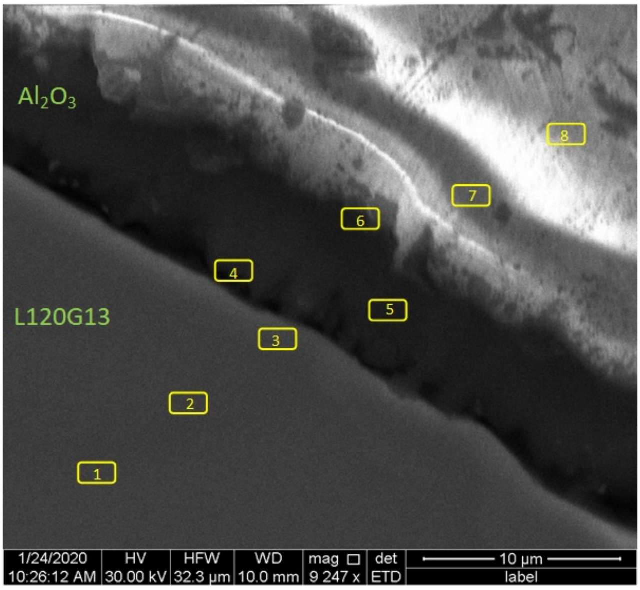

Fig. 3. The area of boundary between phases of the composite with marked EDS measurement places

It has been observed that some elements undergo segregation. As can be assumed, it's caused by diffusion processes occur during solidification and cooling of the casting. Manganese shows simple segregation, while in the case of iron and chromium reverse segregation was found. These elements transferd from liquid alloy to the top layer of corundum grains, causing its depletion in aluminum and oxygen. For comparative purposes, microscopic observations and point measurements of the chemical composition were made on the cross-section of corundum grains (previously incorporated with resin) - Fig. 4. At their surface, however, no layer was found like that was observed at surface of corundum particles in composite. Also on the cross-section of these grains (both inside and near the surface), distribution of aluminum and oxygen didn't change. Average results of chemical composition analysis are presented in Table 2.

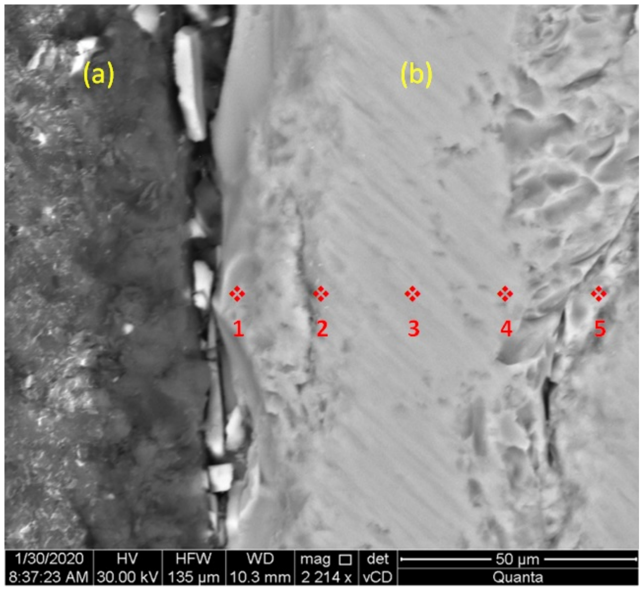

Fig. 4. The corundum grain embedded with resin: a) resin, b) corundum with EDS measurement points marked

Table 2.
Averages results of EDS analysis of chemical composition in the contact area between corundum grain and cast steel

Measur. No	Chemical composition [$\%_{mass}$]					
	Al	O	Ti	Si	Mg	Ca
1	**53.86**	**45.23**	0.72	-	0.12	0.07
2	**52.96**	**47.00**	0.31	0.15	-	-
3	**51.81**	**46.03**	0.92	-	0.09	-
4	**54.21**	**45.31**	-	0.23	0.14	0.11
5	**53.45**	**45.72**	0.71	-	-	0.12

Table 1.
Average results of EDS analysis of chemical composition at the interface between corundum and cast steel

Measur. No	Chemical composition [$\%_{mass}$]													
	L120G13								Al_2O_3					
	Fe	C	Si	Mn	Cr	Ni	P	S	Al	O	Ti	Si	Mg	Ca
1	81.08	1.33	0.70	13.98	1.20	0.87	0.05	0.07	-	-	-	-	-	-
2	84.09	1.45	0.69	12.54	1.03	0.83	0.03	0.08	-	-	-	-	-	-
3	86.79	1.18	0.71	9.03	1.15	1.00	0.04	0.10	-	-				
4	12.56	-	-	10.02	0.97	-	-	-	21.21	10.25	-	0.23	0.14	0.08
5	3.50	-	-	12.06	0.68	-	-	-	26.45	35.72	0.71	-	-	0.02
6	0.44	-	-	15.04	0.26	-	-	-	38.33	40.68	0.05	-	0.08	-
7	-	-	-	3.03	-	-	-	-	52.85	45.77	-	0.08	-	0.05
8	-	-	-	-	-	-	-	-	53.81	46.58	0.25	0.11	-	-

3.2. Abrasive wear

Tests of abrasive wear resistance carried out with the T-07 equipment showed a clear increase in abrasive wear resistance of zone-reinforced cast steel castings in comparison with steel castings. Results are presented in the graph in Figure 5, as abrasive wear rate [mg/m]. Wear rate of the composite was approximately 70% lower compared to unreinforced cast steel.

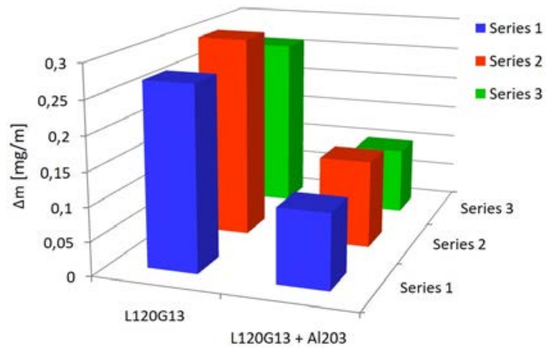

Fig. 5. Rate of abrasive wear of cast steel and composite

Then abraded samples were microscopic observed. No faund the presence of damages at interface between the composite components - Fig. 5. This proves a very durable connection formed between cast steel and corundum, that has been formed during solidification and cooling of castings.

4. Conclusion

Guarantee of a high-quality composite is strong connection at interface between its components. This should enable obtaining high service life, related in term of abrasive wear for exemple.

In L120G13 cast steel composite, zone-reinforced with electrocorundum grains, it was possible due to diffusion processes occurring during casting process. In the subsurface zone of grains, simple manganese segregation and reverse iron and chromium segregation were found. The transfer of these elements from cast steel to the surface of electrocorundum grains caused their simultaneous depletion in aluminum and oxygen. As a result, no porosity was observed at interface between two phases of composite.

The abrasive wear resistance tests showed a very high operational durability of the obtained composite. Abrasive wear resistance turned out to be 70% higher, compared to steel casting results.

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