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Effect of the Electrocorundum Particles Type on Infiltration and Wear Pates of Composite with Manganese Cast Steel Matrix

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Abstract

The subject of the research were castings made of GX120Mn13 manganese steel, zone-reinforced with electrocorundum. The study determined the effect of the type of electrocorundum (ordinary Al_2O_3 and zirconium Al_2O_3+ZrO_2) on the degree of infiltration and abrasive wear of the reinforced areas of the castings. Computed tomography showed that the use of zirconium electrocorundum for strengthening, compared to ordinary corundum, resulted in a higher degree of infiltration of the reinforced zones of the castings and lower porosity in these areas. This was probably due to the better wettability of Al_2O_3+ZrO_2 particles by the liquid alloy, caused by the zirconium content in the electrocorundum. Lower porosity of the reinforced zones resulted in a lower abrasive wear rate of the samples, but the differences were small. Therefore, the resulting defects did not have a significant impact on the wear rate of the reinforced zones of the casting. The key factor in this respect was the introduction of electrocorundum into cast steel, which, regardless of its type, increased resistance to abrasive wear by approximately 70%. This is very important for the operational durability of this type of castings, taking into account the economic aspect.

Keywords: Foundry composites, Manganese steel, Corundum, Infiltration, Abrasive wear

1. Introduction

The working elements of machines and devices (e.g. impactors, fighting plates, hammers, linings, etc.), currently used in the energy industry, mining, construction and recycling, are subject to increasingly higher requirements regarding mechanical properties [1-3]. Until now, better properties of these constructions have been obtained most often by improving materials during their production. This mainly applies to manganese steel, martensitic steel, chromium steel and chromium cast iron [4]. Manganese steel deserves special attention among them. This is due to their special properties regarding strengthening during crush as a result of the creation of the twinning in the austenite structure (their hardness increases to approx. 500 HB and resistance to abrasive wear) [5]. Despite this, conventional methods of improving materials obtained as a result of the introduction of alloying elements in the foundry process or heat treatment prove insufficient. For this reason, alternative methods of strengthening castings are increasingly being used, by introducing ceramic phases using in-situ and ex-situ methods [6,7]. Most in-situ techniques are based on the phenomenon of infiltration of moldings containing substrates for the formation of carbide phases. In turn, the production of ex-situ composite castings involves the production of ceramic preforms that are poured with liquid alloys. Most often, the reinforcing layers obtained using these methods do not exceed a few millimeters. However, the research carried out so far indicates the possibility of obtaining composites with ceramic reinforcement zones of up to several centimeters, and thus significantly improving their operational durability [8].

Electrocorundum (Al_2O_3) and silicon carbide (SiC) deserve special attention among the ceramic materials used in the industry. Due to the very high hardness, translating into high resistance to wear and universal availability, the tests used electrocorundum. Several types of electrocorundum should be distinguished: noble (white) - 99% Al_2O_3, semi-pnoble (gray) - 97% Al_2O_3, ordinary (brown) - 95% Al_2O_3 and to approx. 3% TiO_2, chrome (pink) - 95% Al_2O_3 and up to 1% Cr_2O_3 and zirconium 75-80% Al_2O_3 and up to 20-25% ZrO_2 [1]. Of the above ceramic particles, the most commonly used and most available on the market is the ordinary electroorundum. In turn, in terms of properties, the best hardness, mechanical strength and ductivity is characterized by zirconium electrocorundum [1].

In connection with the above, GX120Mn13 manganese steel was used in the tests, which was reinforced with particles of ordinary grey and zirconium electrocorundum during the casting process. The aim of the study was to determine the influence of the type of electrocorundum particles on the degree of infiltration and wear of the composite.

2. Materials and methodology

2.1. Materials

The subject of research was castings made under industrial conditions using the gravity casting method into sand moulds. GX120Mn13 manganese steel casting (according to the standard EN 10349:2011) was used for casting. Before casting, cylindrical inserts with a volume of approx. 22 cm^3 were placed in the casting mould cavity, containing particles of ordinary brown electrocorundum (Al_2O_3) and zirconium electrocorundum (Al_2O_3 + ZrO_2) of the same fraction (approx. 1.0-1.5 mm – avg. 1.75 mm).

After casting process, the casts were heat treated by solution heat treatment. The castings were annealed at 1050°C for 5 hours and then rapidly cooled to obtain an austenitic matrix.

2.2. Methodology

The test samples were prepared using high-pressure water jet cutting technology, followed by a SL20 dual-axis CNC machine tool and a Secotom-15 precision cutter cooled with liquid.

The chemical composition analysis was performed based on the results obtained by spectral analysis using a GDS 750 QDP glow discharge analyser and X-ray energy dispersive spectroscopy using a SEM Quanta 250 with an Oxford Instruments EDX detector.

In order to assess the internal consistency of the samples, XTC analysis was performed using a GE Phoenix v|tome|x m 300/180 computed tomography scanner. The volume reconstruction of the samples was performed using Phoenix Datos|x 2.7.2 software, which utilised the FDK (Feldkamp-Davis-Kress) backprojection algorithm, including beam enhancement correction. The reconstruction results were analysed using VG Studio MAX 3.3 software.

Abrasion resistance was determined using the pin-on-disc method on a Struers tester. The measurements consisted of abrading samples with a diameter of 25 mm and a height of 30 mm, pressed with a force of 30 N, on a water-cooled diamond disc (grain size 45–53 μm). The measurements were carried out in six cycles. Each 5-minute cycle corresponded to a distance of 175 m. Therefore, each sample was abraded for 30 minutes over a distance of 1050 m.

The results presented in this paper represent the average value obtained from at least three measurement trials.

3. Results and discussion

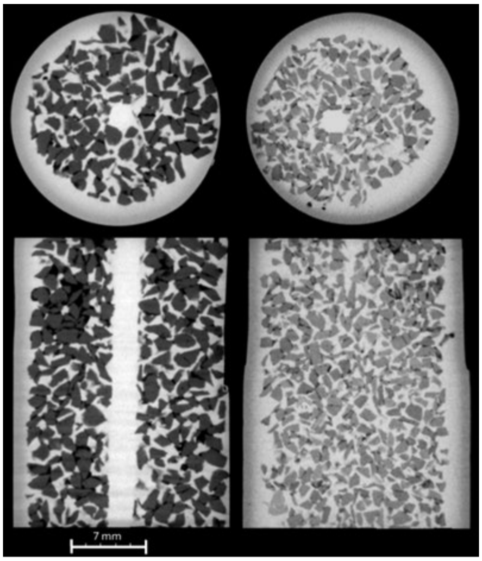
The prepared samples were subjected to chemical composition analysis, both in the matrix and in the electrocorundum particles. The results are presented in Table 1.

Table 1.
Chemical composition of samples from castings reinforced with ordinary and zirconium electrocorundum

<table>
<tr><th colspan="8">Average chemical composition [%$_{mass}$]</th></tr>
<tr><th colspan="8">matrix GX120Mn13</th></tr>
<tr><td>C</td><td>Mn</td><td>Cr</td><td>Ni</td><td>*Si*</td><td>P</td><td>S</td><td>Fe</td></tr>
<tr><td>1.32</td><td>13.55</td><td>1.15</td><td>0.93</td><td>0.68</td><td>0.06</td><td>0.02</td><td>rest</td></tr>
<tr><th colspan="8">ordinary electrocorundum (brown)</th></tr>
<tr><td colspan="3">Al</td><td colspan="2">Ti</td><td colspan="3">O</td></tr>
<tr><td colspan="3">50.20</td><td colspan="2">1.30</td><td colspan="3">48.50</td></tr>
<tr><th colspan="8">zirconium electrocorundum</th></tr>
<tr><td colspan="2">Al</td><td colspan="2">Zr</td><td colspan="2">Ti</td><td colspan="2">O</td></tr>
<tr><td colspan="2">45.25</td><td colspan="2">12.05</td><td colspan="2">0.55</td><td colspan="2">42.15</td></tr>
</table>

After preliminary macroscopic analysis, cylindrical samples were prepared for further testing using various mechanical processing techniques. In order to determine the degree of infiltration of the reinforced zones, tomographic tests were carried out, consisting of scanning samples with different types of ceramic particles, followed by visual cross-sectional and longitudinal sections. Figure 1 shows sample visualisations for samples containing ordinary and zirconium corundum. Image analysis showed that the most defective areas were found in samples containing regular brown electrocorundum particles (Fig. 1a), while the least defective areas were found in samples containing regular zirconium electrocorundum particles (Fig. 1b).

The results obtained during scanning were analysed in terms of porosity using the Porosity/Inclusion Analysis module with the From Defect algorithm in VG Studio MAX 3.3 software. This allowed the creation of spatial models (reflecting actual samples) for further analysis



(a) **(b)**

Fig. 1. Visualisation of cross-sectional and longitudinal sections of samples containing electrocorundum: a) ordinary (grey), b) zirconium

Based on these results, graphs illustrating the variability of porosity distribution along the sample axes were prepared, together with sample models, examples of which are shown in Figure 2. This relationship was defined as the correlation between porosity and the height of individual samples (h = 30 mm). Areas of increased porosity, indicating increased density of empty spaces, were defined as defects. The vertical dotted line on the graph represents the average porosity value recorded along the scanned samples. In order to obtain a more complete picture of the distribution of internal defects, models visualising the size and distribution of porous areas were added to each of the graphs.

Analysis of the results obtained indicates that in the case of steel reinforcement with Al_2O_3 particles, the average porosity values of the samples were significantly higher, amounting to approximately 7.0% (Fig. 2a). The lowest average porosity of the samples, approximately 0.7%, was obtained for composites reinforced with Al_2O_3+ZrO_2 particles (Fig. 2b). These differences were most likely due to the better wettability of zirconium electrocorundum particles with liquid alloy (compared to ordinary brown electrocorundum particles). This was facilitated by the presence of zirconium in the ceramic particles [9].

The course of the porosity distribution curves along the axis of the samples (curves along the vertical dotted line) indicates their uneven distribution. The greatest deviations were found for samples containing standard base electrocorundum, while the smallest deviations from the average porosity value were found for samples containing zirconium electrocorundum. The variability of the distribution of defective areas is also confirmed by models visualising their distribution (Fig. 2). Furthermore, the type of ceramic particles was found to influence the size of the defective areas (Fig. 2). The largest defective areas were observed for samples reinforced with ordinary electrocorundum (Fig. 2a), while the smallest were found for samples reinforced with zirconium electrocorundum particles (Fig. 2b).

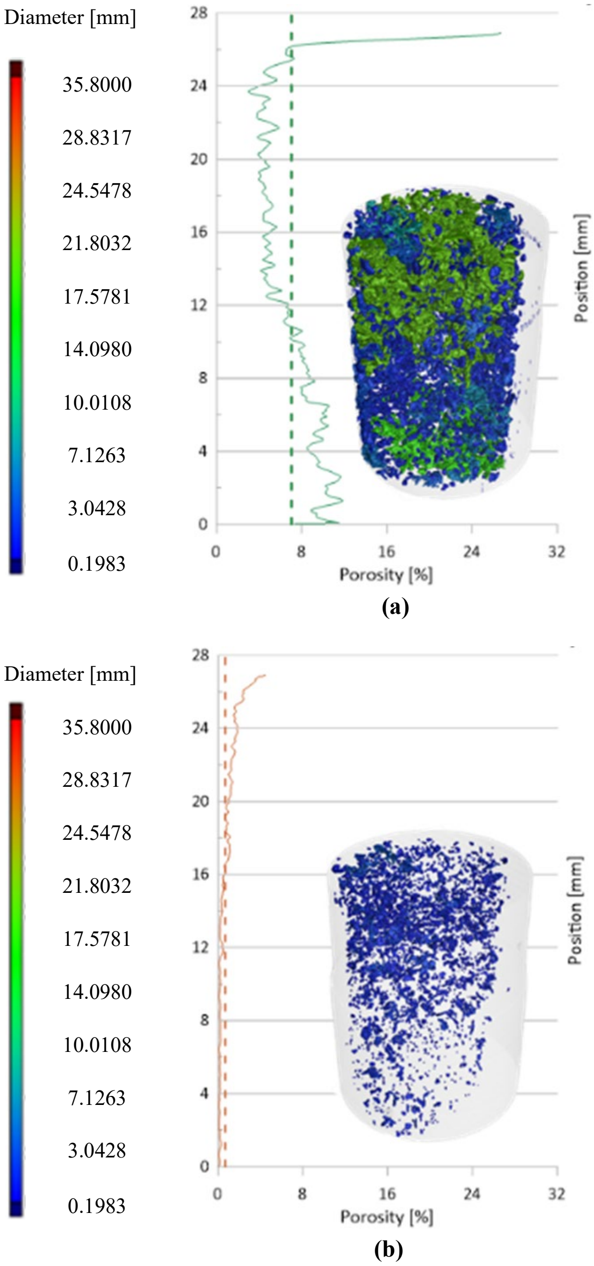
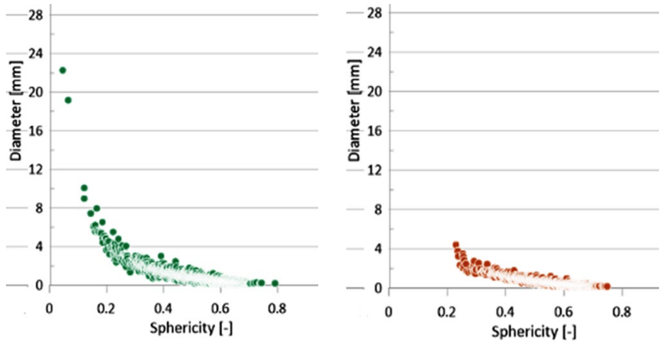


Fig. 2. Change in porosity along the axis of scanned samples. The dotted lines indicate the average longitudinal porosity value for samples containing electrocorundum: a) ordinary (brown), b) zirconium

XCT scanning also made it possible to determine the correlation between shape (sphericity) and the size of porous areas (Fig. 3).



a) b)

Fig. 3. Correlation between shape (sphericity) and size of defective areas for samples containing electrocorundum: a) ordinary (brown), b) zirconium

It can be observed that the sphericity of defects decreases with increasing defect size. In samples containing zirconium corundum, the defects were significantly smaller and more spherical, occupying a much smaller volume in the samples.

Abrasion resistance tests confirmed the strong positive effect of reinforcement on abrasion resistance [8]. This resistance was expressed as the abrasion rate coefficient (mg/m). The measurement results are presented in Table 2.

Table 2.
Average porosity and abrasive wear rates

	Sample type		
	GX120Mn13	GX120Mn13 + elektrocorundum	
		Al_2O_3	$Al_2O_3+ZrO_2$
Porosity [%]	-	7.00	0.70
Wear rate [mg/m]	2.31	0.79	0.74

The average abrasive wear rate coefficient for samples made exclusively of cast steel was 2.31 mg/m. In contrast, for samples reinforced with Al_2O_3 it averaged 0.79 mg/m, and for samples reinforced with Al_2O_3+ZrO_2, it averaged 0.74 mg/m. The results confirmed that reinforcing cast steel with ceramic particles increases the abrasive wear resistance of the composite in the reinforced zone by approximately 70% compared to the unreinforced zone [8]. Differences between the wear rate coefficients of samples reinforced with electrocorundum indicate slightly lower wear of samples reinforced with zirconium electrocorundum. This is mainly due to the lower porosity of the reinforced zones (caused by a higher degree of infiltration resulting from better wettability of Zr-containing particles) and slightly better mechanical properties.

4. Conclusions

- The reinforcement of GX120G13 cast steel with ceramic particles caused the formation of defects in the form of porosity in the reinforced areas. The type of particles was the decisive factor influencing porosity. The lowest porosity was obtained in areas reinforced with Al_2O_3+ZrO_2.
- Lower porosity in the reinforced areas of the casting was facilitated by better wettability of Al_2O_3+ZrO_2 particles by the liquid alloy (due to the Zr content), which resulted in a higher degree of infiltration in these areas.
- Lower porosity in areas reinforced with Al_2O_3+ZrO_2 resulted in a slightly lower rate of abrasive wear, but not to the same extent as the reinforcement itself. Therefore, the addition of electrocorundum to cast steel, regardless of its type, significantly increased the abrasive wear resistance of castings (by approx. 70%).

References

[1] Dulska, A., Kilarski, J., Studnicki, A. & Szajnar, J. (2019). The use of electrocorundum for the production of composite layers in iron castings. *Stal Metale & Nowe Technologie*. 61-68. (in Polish).

[2] Mierzwa, P., Olejnik, E. & Janas, A. (2012). Modern composites to replace traditional casting materials. *Archives of Foundry Engineering*. 12(spec.1), 137-142. ISSN (1897-3310).

[3] Zygmuntowicz, J., Tomaszewska, J., Żurowski, R., Wachowski, M., Piotrkiewicz, P. & Konopka, K. (2021). Zirconia–alumina composites obtained by centrifugal slip casting as attractive sustainable material for application in construction. *Materials*. 14(2), 250, 1-15. https://doi.org/10.3390/ma14020250.

[4] Sobczak, J. (2013). *Foundryman's Handbook. Contemporary Foundry*. Kraków: Publishing House of the Polish Foundrymen's Technical Association. (in Polish).

[5] Allende-Seco, R., Artigas, A., Bruna, H., Carvajal, L., Monsalve, A. & Sklate-Boja, M.F. (2021). Hardening by transformation and cold working in a hadfield steel cone crusher liner. *Metals.* 11(6), 961, 1-11. https://doi.org/10.3390/met11060961.

[6] Szymański, Ł., Szala, M., Peddeti, K., Olejnik, E., Biegun, K., Tęcza, G., Bigos, A., Sobczak, J., Sobczak, N., Żak, K. & Krella, A. (2026). Slurry and cavitation-erosion resistance of steel-ceramic composites manufactured using in-situ and ex-situ techniques. *Materials Letters*. 403, 139461, 1-4. https://doi.org/10.1016/j.matlet.2025.139461.

[7] Zhang, Z., Chen, Y., Zhang, Y., Gao, K., Zuo, L., Qi, Y. & Wei, Y. (2017). Tribology characteristics of ex-situ and in-situ tungsten carbide particles reinforced iron matrix composites produced by spark plasma sintering. *Journal of Alloys and Compounds*. 704, 260-268. https://doi.org/10.1016/j.jallcom.2017.02.003.

[8] Medyński, D. (2023). Effect of corrosion on wear resistance of the composite based on GX120Mn13 cast steel zonally reinforced with particles*. Archives of Foundry Engineering.* 23(3), 133-139. DOI: 10.24425/afe.2023.146675.

[9] Sulima, I. (2008). *Selected physicochemical aspects of obtaining metal/ceramic connections*. Annales Academiae Paedagogicae Cracoviensis. Studia Technica II.