Effect of Austenite Transformation on Abrasive Wear and Corrosion Resistance of Spheroidal Ni-Mn-Cu Cast Iron

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Abstract

Within the presented work, the effect of austenite transformation on abrasive wear as well as on rate and nature of corrosive destruction of spheroidal Ni-Mn-Cu cast iron was determined. Cast iron contained: 3.1÷3.4 %C, 2.1÷2.3 %Si, 2.3÷3.3 %Mn, 2.3÷2.5 %Cu and 4.8÷9.3 %Ni. At a higher degree of austenite transformation in the alloys with nickel equivalent below 16.0%, abrasive wear resistance was significantly higher. Examinations of the corrosion resistance were carried out with the use of gravimetric and potentiodynamic method. It was shown that higher degree of austenite transformation results in significantly higher abrasive wear resistance and slightly higher corrosion rate, as determined by the gravimetric method. However, results of potentiodynamic examinations showed creation of a smaller number of deep pinholes, which is a favourable phenomenon from the viewpoint of corrosion resistance.

Keywords: Abrasive wear, Corrosion resistance, Austenitic cast iron, Ni-Mn-Cu cast iron, Martensitic transformation

1. Introduction

Corrosion and abrasive wear are the main source of the losses born by the industry. The problem especially concerns the machines working in aggressive environments. This is the reason why the materials linking high abrasive wear resistance with corrosion resistance are of great interest these days.

As for cast iron castings exposed to abrasive wear, their resistance is mainly decided by their hardness. Therefore, all structural components increasing hardness of cast iron increase, at the same time, its abrasive wear resistance. With this respect, martensitic matrix seems to be the most favourable. However, this structure does not guarantee the minimum crack resistance required in many cases. Then, longer service life can be reached by the castings with mixed austenitic-martensitic structure [1], [2], [3].

In turn, high-alloy materials with one-phase matrix are characterised by higher corrosion resistance. Among casting alloys, a typical representative of these materials is austenitic cast iron Ni-Resist containing 14 to 36% of nickel [4].

High content of costly nickel can be reduced by replacing it partially with cheaper manganese and copper to obtain austenitic cast iron Ni-Mn-Cu with corrosion resistance similar to that of Ni-Resist [5], [6].

Structure of the Ni-Mn-Cu cast iron can be modified, considering minimum nickel equivalent value of 16.0% [7]. In the alloys with $Equ_{Ni} > 16.0\%$, structure of raw castings is composed

of austenite only, with its thermodynamic stability increasing along with increasing nickel equivalent. During cooling of alloys with $Equ_{Ni} \leq 16.0\%$, only partial transformation of austenite to martensite takes place, with austenite content decreasing with the equivalent value.

A change of the structure resulting from austenite transformation should lead to higher abrasive wear resistance of cast iron. One-phase matrix of the alloy is usually more corrosion resistant than a multiphase matrix, so such a change can result in lower corrosion resistance of the material.

However, a question appears, to what extent a change of matrix structure, aimed at increasing abrasive wear resistance, will influence the corrosion mechanisms. The presented work attempts to answer this question.

2. Purpose, scope and methodology

In order to determine the relationship between austenite stability and abrasive wear resistance of castings, as well as its influence on course and nature of corrosion processes, five alloys (marked by the numbers from *1* to *5*) were examined, differing from each other mainly in nickel concentration. As a reference material, the alloy No. *6* was used, differing from the other ones in nickel and manganese concentrations.

Chemical analysis of the castings was performed by spectral method using a glow discharge analyser and a scanning electron microscope equipped with an EDS detector [6]. The obtained results together with calculated values of nickel equivalent Equ_{Ni} and eutectic saturation ratio S_C are given in Table 1.

Scope of the research included microscopic observations, as well as measurements of hardness, abrasive wear and corrosion resistance.

Microscopic examinations were performed using a scanning electron microscope. Brinell hardness was measured using a sintered carbide ball dia. 2.5 mm at 1838.75 N.

Abrasive wear examinations were performed using a T-07 tester. The test stand ensures indefinite kind of contact, wear with loose abrasive material and sliding motion giving technical dry friction at constant load [8]. The pressure of 44 N between a specimen (30 x 30 x 3 mm) and a counter-specimen, i.e. metallic disk coated with rubber of hardness 78 to 85 Sh rotating at 60 ± 2 rpm, was exerted by weights via a lever system. Time of the test was 10 minutes.

Corrosion examinations were carried-out by gravimetric method (measurements of mass reduction per time unit per surface area unit) and by potentiodynamic method. In both cases, the corrosive solution was 3% NaCl aqueous solution at ambient temperature [9].

Potentiodynamic measurements were taken in a fully automated, traditional three-electrode system. A saturated calomel electrode was used as a reference electrode, and a platinum electrode was used as a supporting electrode [10]. Corrosion resistance was evaluated on the grounds of corrosion current density (i_{corr}), polarisation resistance (R_p) and corrosion potential (E). The results were analysed on the grounds of the previously obtained results of gravimetric examinations [6].

3. Results and discussion

3.1. Abrasive wear resistance

Abrasive wear resistance of the examined cast iron ranged within 0.62 to 0.72 mg/m. These differences resulted from variable structure of the alloys, see Table 2.

In the alloys with nickel equivalent values exceeding 16.0%, abrasive wear of dynamic nature did not undergo significant changes. Small differences in mass losses of the specimens could result from inhomogeneous distribution of hollows left after chipped graphite particles (acting as grease containers and microbins accumulating wear products). This could influence the frictional action.

In the alloys with nickel equivalent values below 16.0%, the observed mass losses were much smaller. Reduction of mass of a specimen was, in average, 0.03 mg/m per each 1% of Equ_{Ni} decrease. In this group of the alloys, lower nickel equivalent value caused partial transformation of austenite to martensite which, significantly increasing hardness of the castings, resulted in their higher resistance to abrasive wear.

Table 1.
Chemical composition, nickel equivalent Equ_{Ni} and eutectic saturation ratio S_C

Alloy No.	Chemical composition [%]								Equ_{Ni} [%]	S_C [/]
	C	Si	Ni	Mn	Cu	Mg	P	S		
1	3.1	2.3	**9.3**	2.4	2.4	0.12	0.16	0.04	17.8	1.08
2	3.3	2.3	**8.2**	2.3	2.5	0.09	0.16	0.04	16.6	1.13
3	3.4	2.2	**7.0**	2.4	2.5	0.13	0.16	0.04	15.6	1.13
4	3.3	2.3	**5.8**	2.4	2.4	0.10	0.15	0.03	14.4	1.08
5	3.3	2.2	**4.8**	2.3	2.4	0.12	0.15	0.03	13.1	1.05
6	3.3	2.1	**5.5**	**3.3**	2.3	0.10	0.15	0.03	16.2	1.04

Table 2.
Effect of nickel equivalent Equ$_{Ni}$ on structure, Brinell hardness and abrasive wear resistance of cast iron

Alloy No.	Equ$_{Ni}$ [%]	Matrix composition Fe$_\gamma$ – Fe$_\alpha$ [% – %]	HB [/]	Abrasive wear [mg/m]
1	17.8	100 – 0	186	0.71
2	16.6	100 – 0	168	0.72
3	15.6	94 – 6	231	0.70
4	14.4	79 – 21	296	0.67
5	13.1	64 – 36	373	0.62
6	16.2	100 – 0	200	0.71

Fe$_\gamma$ – austenite,
Fe$_\alpha$ – martensite.

The above-mentioned differences are illustrated in Fig. 1 that shows cross-sections of the specimens of the alloys No. *1* to *5* after dynamic abrasive wear examinations. Differences in material losses caused by abrasive action are clearly visible. The largest losses were noted for the alloy No. *1* and the values regularly decreased towards the alloy No. *5*.
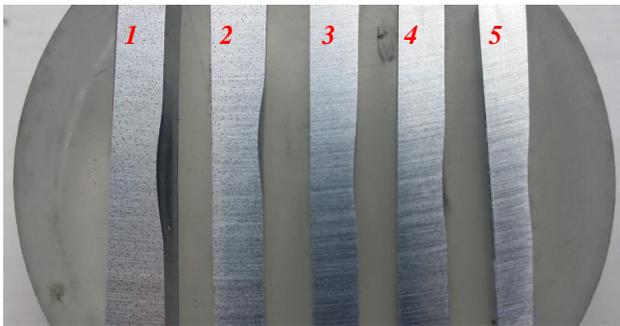

Fig. 1. Cross-sections of specimens *1* to *5* after wear test

3.2. Corrosion resistance

Results of gravimetric testing indicate the highest corrosion resistance of the alloys No. *1* and No. *2*, and the lowest corrosion resistance of the alloy No. *5* [6].

In the case of the alloys with Equ$_{Ni}$ close to the limit value (ca. 16.0%), corrosion rate for the alloy No. *6* (in spite of slightly higher equivalent value) was clearly higher than that for the alloy No. *3*, in average by 0.15 mm per year.

Results of electrochemical testing of the alloys *1* to *5* confirmed the differences in their corrosive behaviour. For potentiodynamic measurements chosen were the alloys: No. *1* (100% austenitic matrix), No. *3*, No. *6* (maximum stability of austenite) and No. *5* (the highest degree of austenite transformation). The measurements were taken after 1 hour and after 168 hours (7 days) of keeping the specimens in 3% aqueous NaCl solution, see Fig. 2. The following quantities were measured during the examination: cathodic-anodic transition E$_{K-A}$, stationary potential E', corrosion current density i$_{corr}$ and polarisation resistance R$_p$.
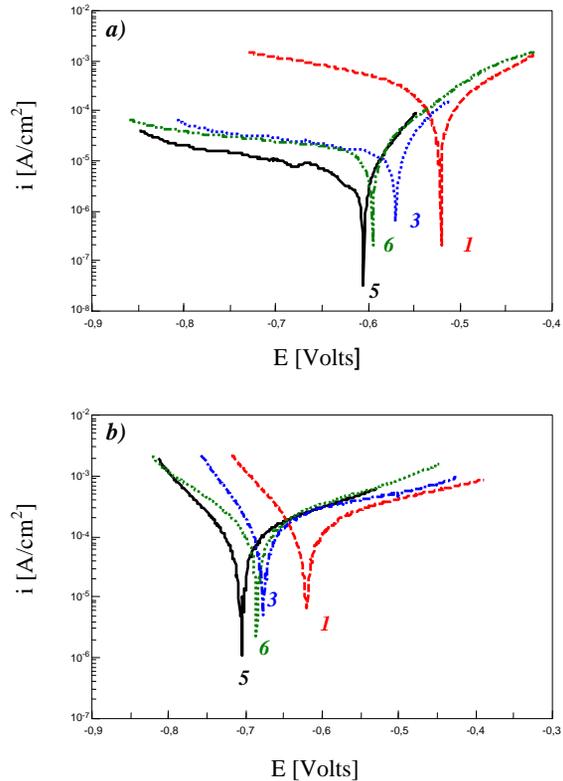

Fig. 2. Polarisation curves of the alloys No. *1*, *3*, *5* and *6* after: *a)* 1 hour, *b)* 168 hours of exposure in 3% aqueous NaCl solution

Values of the indices characterising corrosion process of the alloys No. *1*, *3*, *5* and *6* are given in the Table 3.

Table 3.
Indices characterising corrosion process

Alloy No.	E$_{K-A}$ [mV]		E' [mV]		i$_o$ [μA/cm^2]		R$_p$ [kΩ·cm^2]	
	1 hour	168 hours	1 hour	168 hours	1 hour	168 hours	1 hour	168 hours
1	-516	-620	-477	-468	168	155	0.2	0.2
3	-559	-681	-681	-533	23	127	1.5	0.2
5	-609	-705	-705	-603	9,4	108	2.8	0.2
6	-595	-690	-686	-574	64	138	1.1	0.2

The largest differences between the E$_{K-A}$ values were found for the alloys No. *1* and No. *5* (in average 93 mV after 1 hour and 85 mV after 168 hours). They indicate a differentiation of the electrode processes occurring on surfaces of the examined specimens. This results from inhomogeneity of chemical and phase composition of individual alloys.

Among the examined alloys, the highest values of stationary potential were measured for the austenitic cast iron No. *1*, both after 1 hour (E' = -477 mV) and after 168 hours (E' = -468 mV). The smallest values of E' were shown by the alloy No. *5* (the highest degree of austenite transformation) after 1 hour (E' = -705

mV) and after 168 hours (E' = -603 mV). Longer times of keeping the specimens in the corrosive solution caused a slight increase of stationary potential values, which should be noted as a favourable behaviour of the examined materials.

For the examined alloys, corrosion current density after 1 hour ranged from 9.4 to 168 μA/cm^2 and after 168 hours – from 108 to 155 μA/cm^2. The lowest values were measured for the alloy No. *5* and the highest values – for the alloy No. *1* after both the shorter and the longer exposure time. At the same time, the i_{corr} value increased (and R_p decreased) for the alloys in that partial austenite transformation occurred, along with growing transformation degree. Exemplary values of i_{corr} (and R_p) after 1 hour and after 168 hours were as follows: 9.4 and 108 μA/cm^2 (2.8 and 0.2 k$\Omega \cdot$cm^2) for the alloy No. *5*; 23 and 127 μA/cm^2 (1.1 and 0.2 k$\Omega \cdot$cm^2) for the alloy No. *3*; 64 and 138 μA/cm^2 (1.5 and 0.2 k$\Omega \cdot$cm^2) for the alloy No. *6*. For the austenitic alloy No. *1*, both values after 1 hour and 168 hours were close: 155 and 168 μA/cm^2 (ca. 0.2 k$\Omega \cdot$cm^2).

Surfaces of the specimens after potentiodynamic tests were different for individual alloys, see Fig. 3. The pictures show various types of corrosive destruction. In the case of the alloy No. *1*, losses of the nature of deep pits were mainly found near the boundaries of eutectic colonies (Fig. 3 *1^B* and *1^C*). In the alloy No. *5*, the corrosion losses were rather uniform and located on boundaries and inside eutectic colonies (near the martensite and graphite areas (Fig. 3 *5^B* and *5^C*).
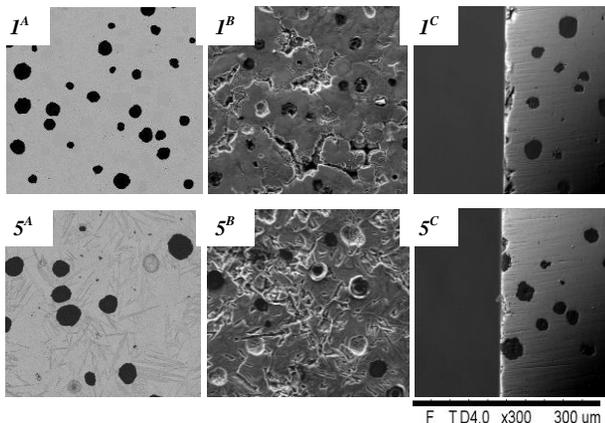

Fig. 3. SEM images of the alloys No. *1* and No. *5*: surfaces before corrosion tests, made by BSE technique (*1^A*, *5^A*); surfaces after potentiodynamic tests for 168 hours of exposure, made by SE technique (*1^B*, *5^B*) and cross-sections after potentiodynamic tests for 168 hours of exposure, made by SE technique (*1^C*, *5^C*)

4. Summary

In austenitic cast iron with nickel equivalent over 16.0%, no significant differences were found between abrasive wear resistances of individual alloys. Corrosion rates of these alloys, determined by the gravimetric method, were the lowest and comparable. However, the results of potentiodynamic examinations indicate creation of the damages like deep pits that could reduce service lives of the castings.

At a higher degree of austenite transformation in the alloys with nickel equivalent below 16.0%, abrasive wear resistance was significantly higher. At the same time, an increase of corrosion rate was found, as determined by mass reduction per time unit per surface area unit. However, the potentiodynamic results indicate creation of a smaller number of deep pits. With respect to service life of a casting, this should be noted as a favourable phenomenon.

Corrosion resistance is mostly decided by chemical composition, i.e. by nickel concentration, but not by nickel equivalent. This is confirmed by the results of corrosion tests, obtained by both methods for the alloys No. *3* and *6*. In spite of comparable Equ$_{Ni}$ values, the alloy No. *3* (with higher nickel concentration) shows higher corrosion resistance that the alloy No. *6* (with higher manganese concentration).

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