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Cast High-Manganese Steel – the Effect of Microstructure on Abrasive Wear Behaviour in Miller Test

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Abstract

The results of the modification of austenitic matrix in cast high-manganese steel containing 11÷19% Mn with additions of Cr, Ni and Ti were discussed. The introduction of carbide-forming alloying elements to this cast steel leads to the formation in matrix of stable complex carbide phases, which effectively increase the abrasive wear resistance in a mixture of SiC and water. The starting material used in tests was a cast Hadfield steel containing 11% Mn and 1.34% C. The results presented in the article show significant improvement in abrasive wear resistance and hardness owing to the structure modification with additions of Cr and Ti.

Keywords: Austenite high manganese steels, Microstructure, Abrasive wear resistance, Miller slurry machine test

1. Introduction

High-manganese austenitic steel containing about 1÷1.4% C and 11÷19% Mn is included in the group of materials resistant to wear under high dynamic loads, and as such is used in the industry for, among others, castings operating under harsh conditions of wear (hammers, beaters, lining of mills, elements of crushers for metal ores and other minerals). Additionally, the paramagnetic properties of austenitic matrix present in this material extend the range of applications to other numerous sectors of industry, including power engineering and defence [1, 2]. Widely used for castings, high-manganese steel contains 11÷14% Mn, and after its inventor is called Hadfield steel [1-4].

To improve the properties of this cast steel, including its wear resistance at low loads, some alloying elements are introduced in the following amounts: 1.5÷2.5% Cr, 0.9÷1.8% Mo, up to 3÷4% Ni (according to EN 10349:2009) [5-9]. Studies are also conducted where, to improve the resistance to abrasive wear of cast manganese steel containing 6% Mn, the addition of 1% Mo is introduced [1]. Depending on the amount of alloying elements, especially the carbide-forming ones, stable complex carbide phases are formed in the austenite matrix. This type of matrix modification in the cast high-manganese steel extends the application range of this material to include castings operating at variable loads. The article describes changes in the microstructure and abrasive wear resistance of cast high-manganese steel containing 11÷19% Mn due to the introduction of elements such as Cr, Ni and Ti.

2. Experimental

Studies were carried out on cast high-manganese steel grades melted in industrial environments in an electric arc furnace. The chemical composition of the cast steel used for tests is shown in Table 1.

Table 1.
Chemical composition of the examined cast steels

Grade	sample	C	Mn	Si	P	S	Cr	other
		wt. %						
GX120Mn13	**A**	1.34	11.0	1.04	0.047	0.011	0.07	0.02%Ni
GX120Mn13	**B**	1.13	12.7	0.60	0.028	0.02	0.02	0.82%Ni
GX120Mn13	**C**	1.2	13.0	2.4	0.03	0.02	0.2	1.5%Ti
GX120MnCr18-2	**D**	1.28	17.6	0.51	0.054	0.007	2.2	0.09%Ni

The cast high-manganese steel was subjected to solution heat treatment in water from a temperature of 1080 °C. Then, specimens were prepared for microstructure examinations and Miller test.

Metallographic examinations of the steel in as-cast condition and after heat treatment were carried out using a Neophot light microscope and scanning electron microscope equipped with an EDX attachment. Tests of abrasive wear resistance were performed in a Miller machine applying a 16-hour test cycle [10]. The abrasive medium was mixture of SiC in water in a ratio of 1:1. The total load applied onto the sample in one test cycle was 22 N. As a measure of the wear resistance, a relative cumulative weight loss was adopted. Hardness measurements were taken by Vickers method on the tested cast steel after heat treatment, while hardness of phases present in the cast steel microstructure was measured under a load of 20 G using Hanemann hardness testing instrument.

3. Experimental results and analysis

The microstructure of the investigated cast steel

In the initial state, the microstructure of cast high-manganese Hadfield steel (1,0÷1,4% C and 11÷14% Mn) without the additions of Cr and Ti consisted of manganese austenite, alloyed cementite $(Fe,Mn)_3C$, phosphorus eutectic and non-metallic inclusions. Introducing the austenite stabilising element, i.e. nickel, did not change the as-cast steel microstructure. The application of heat treatment (solutionising) to the cast steel modified with nickel resulted in the formation of purely austenitic matrix, resembling common types of cast Hadfield steel (Fig.1). Modification of cast steel with 0.82% Ni did not increase the alloy hardness (Table 2).

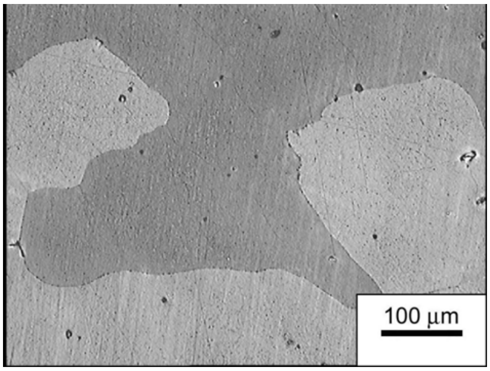

Fig. 1. The microstructure of the investigated GX120Mn13 cast steel with 0.82% Ni after the heat treatment

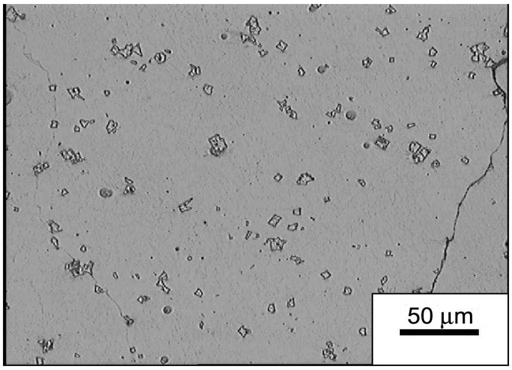

Fig. 2. The microstructure of the investigated GX120Mn13 cast steel with 1.5% Ti after the heat treatment

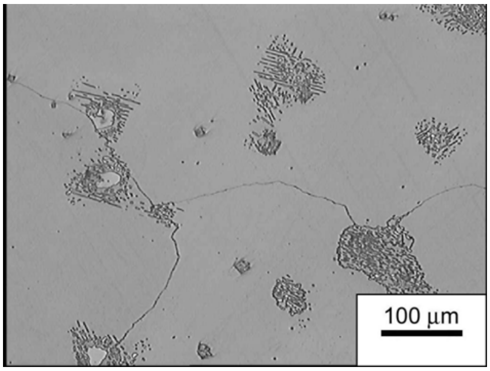

Fig. 3. The microstructure of the investigated GX120MnCr18-2 cast steel after the heat treatment

With the addition of titanium (1.5%), the as-cast microstructure was composed of a high-manganese austenitic matrix and primary titanium carbides evenly spaced therein. Besides primary carbides, very small amounts of alloyed cementite were also observed to occur along the grain boundaries (Fig. 4). During heat treatment, these precipitates were characterised by very high stability. The solution heat treatment leads to a dissolution of alloyed cementite, owing to which, after the completed treatment, a composite structure consisting of an austenitic matrix and primary faceted titanium carbides is obtained (Fig. 2). The microhardness of thus formed titanium carbides is comprised in a range of 3600÷4000 μHV_{20}.

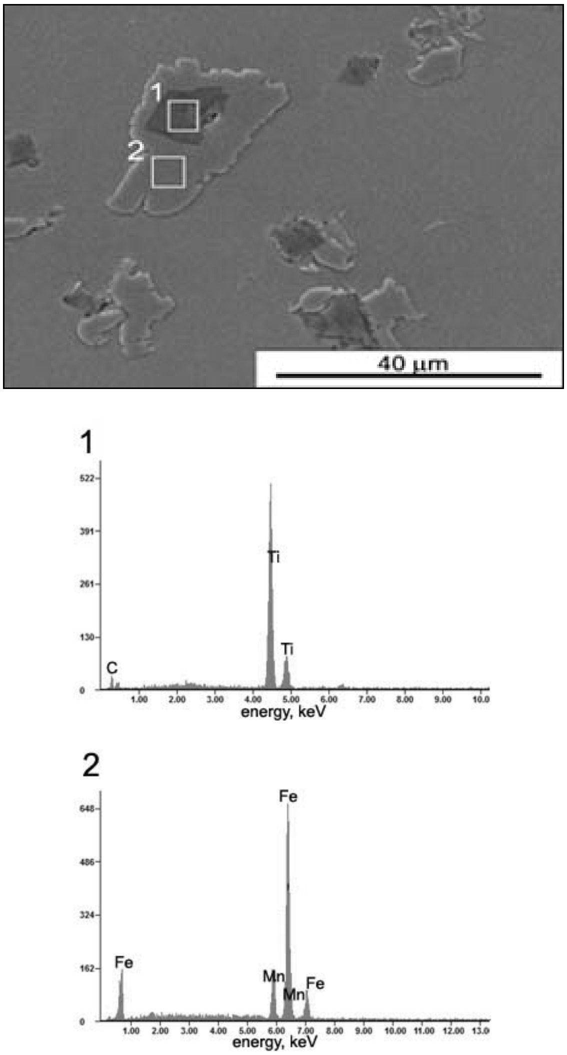

Fig. 4. Microstructure of GX120MnCr18-2 with 1.5% Ti, SEM - EDS

Table 2.
Hardness of the tested materials (after solution heat treatment)

Material	Hardness [HB]	Microhardness, [μHV_{20}]	
		austenitic matrix	carbide phases
A	205	420	-
B	198	420	-
C	256	580	3600÷4000
D	270	403	1750

In the cast GX120MnCr18-2 steel, the addition of 2.2% Cr leads to the appearance in the austenitic matrix of complex carbides enriched in chromium. These precipitates appear in two types of morphology: small acicular and large compact. Their microhardness amounts to about 1750 μHV_{20}. On the other hand, in cast Hadfield steel containing 1.4% Cr, the microhardness of complex carbide phases is approximately 1610 μHV_{20}. Standard heat treatment of cast high-manganese GX120MnCr18-2 steel with the addition of chromium can not dissolve all the chromium-rich carbides (Fig. 3). It is only the temperature increase during solution heat treatment that leads to their total dissolution.

The abrasive wear resistance in a mixture of SiC and water

Changes in the weight of cast steel examined in Miller test are shown in Figure 5 and 6. In the case of common cast Hadfield steel and cast steel modified with the addition of nickel, a clear stabilisation of weight losses after 12 and 16 hours of the test was observed (Fig. 5). The lowest abrasive wear resistance in a mixture of SiC and water, characterised by total weight loss, was observed in the cast high-manganese Hadfield steel containing 1.34% C and 11% Mn. In this case, the relative cumulative weight loss was 0.67 g. By approximately 23% lower wear rate was observed in the cast steel modified with nickel additions. The highest abrasive wear resistance was obtained in the cast Hadfield steel containing the addition of 1.5% Ti. The relative cumulative weight loss was 0.31 g, which means two times higher wear resistance of this cast steel compared with the common cast Hadfield steel grade. Also in this alloy, a stabilisation of the weight loss was observed starting from the fourth hour of the test cycle. The abrasive wear resistance of cast GX120MnCr18-2 steel used for crusher plates was by about 20% higher compared with the cast GX120Mn13 steel (Fig. 6).

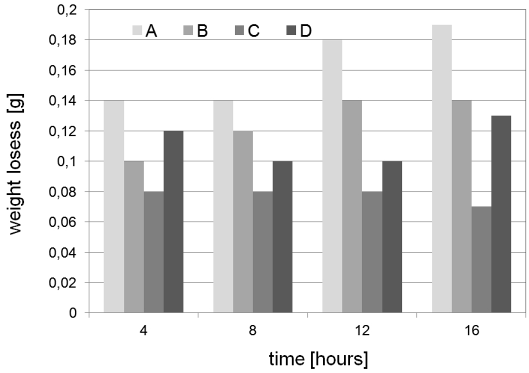

Fig. 5. Changes of weight losses of investigated cast steels during the wear test

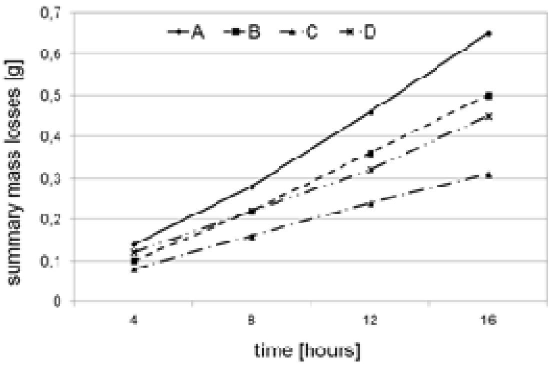

Fig. 6. The relative weight losses observed in the tested cast steels

After complete abrasion test, the surface of the tested cast steel showed some signs of heavy plastic deformation (among others - the “furrowing” effect), reflecting the reciprocating movement during abrasion test [11]. Additionally, after a visual inspection of the surface of the cast GX120MnCr18-2 steel, the presence of porosity was stated (Fig. 7). In spite of this, the abrasive wear resistance of this material was superior to the common grade of cast Hadfield steel and to the cast steel modified with nickel additions (0.82%).

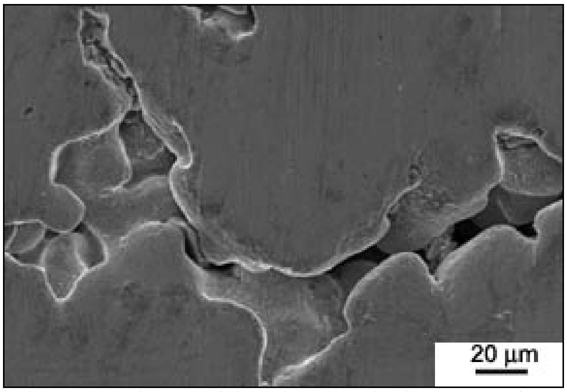

Fig. 7. SEM image of the microporosity in worn surface GX120MnCr18-2 cast steel after the test

4. Conclusions

- In the cast high-manganese steel with the addition of chromium, the austenitic matrix in as-cast state and after solution heat treatment contains precipitates of carbides characterised by two different morphologies: acicular and compact. The microhardness of complex chromium-rich carbides amounts to about 1750 μHV_{20}, while in the cast Hadfield steel with titanium additions, carbides have a hardness of about 3600÷4000 μHV_{20}.
- Standard heat treatment of cast high-manganese steel with the addition of chromium (2.2%) can not dissolve all carbides rich in Cr and Mn.
- The presence of undissolved carbide phases in the austenitic matrix increases the abrasive resistance in a mixture of SiC and water compared to the common cast GX120Mn13 steel grade.
- The introduction to cast steel of carbide-forming elements, i.e. 1.5% Ti and 2.2% Cr, increases the cast steel hardness resulting in a lower rate of abrasive wear.

Acknowledgments

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