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Effect of Heat Treatment on Change Microstructure of Cast High-manganese Hadfield Steel with Elevated Chromium Content

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Abstract

Cast Hadfield steel is a material with high resistance to abrasion, provided, however, that it is used under the conditions of high dynamic loads. To increase the wear resistance of the alloy under the conditions in which no large pressures are operating, carbide-forming elements are introduced to the alloy. However, this leads to the precipitation in castings, mainly at the grain boundaries, of increased amounts of complex carbides. The heat treatment of cast Hadfield steel consists in solutioning to obtain a purely austenitic structure with no carbide precipitates. Changes in microstructure as a function of the changing temperature of the solution treatment were traced in hammers for crushers cast from high-manganese steel with an addition of chromium (1.7% C, 16% Mn and 1.4% Cr). It has been found that the use of the solution treatment temperatures much higher or prolongation of the solutioning time (compared to standard heat treatment) does not lead to the formation of a purely austenitic structure.

Keywords: Heat treatment, Solution treatment, Microstructure, Cast high-manganese steel

1. Introduction

Cast high-manganese steel containing 1.2 % C and 12 % Mn is known as cast Hadfield steel. Due to the high wear resistance during the operation under dynamic loads, while maintaining good toughness, high-manganese steel castings are widely used in the power industry and in processing of various materials for components of crushers, mills and construction machinery (lining plates, hammers, jaws, cones). At light loads, or when abrasion with e.g. sand is used, the wear resistance of this cast steel is comparable to cast carbon steel. Since these are usually massive castings with a wall thickness greater than 100 mm, often during their solidification, a strong segregation occurs (mainly of phosphorus, carbon and chromium). The effect of segregation of elements leads to a differentiated structure on the casting cross-section, which in turn can lead to a reduction of its functional properties, fracture toughness – in particular [1 ÷ 8].

In its typical embodiment, this steel in as-cast condition is characterised by an austenitic microstructure with precipitates of alloyed cementite and the triple phosphorus eutectic of an Fe-$(Fe,Mn)_3C$-$(Fe,Mn)_3P$ type [7], which appears when the phosphorus content exceeds 0.04 % [1]. It also contains non-metallic inclusions such as oxides, sulphides and nitrides (Figs. 1, 4). This type of microstructure is unfavourable due to the presence of the $(Fe,Mn)_xC_y$ carbides spread along the grain boundaries [1,8 ÷ 12].

Table 1.
Examples of the chemical composition of cast austenitic manganese steel and chemical composition of the examined cast steel[1 ÷ 6]

Designation	Chemical composition, [wt%]							
	C	Mn	Si	P	S	Cr	Ni	Mo
GX120Mn13	0.9÷1.05	11.5÷14	≤1.0	≤0.07	≤0.03	-	-	-
	1.12÷1.28	11.5÷14	≤1.0	≤0.07	≤0.03	-	-	-
	1÷1.4	12÷14	0.3÷1	≤0.10	≤0.03	≤1.0	≤1.0	-
GX120Mn13H	1÷1.4	12÷14	0.3÷1.0	≤0.1	≤0.03	0.6÷1.3	-	-
	1.05÷1.35	11.5÷14	≤1.0	≤0.07	≤0.03	1.5÷2.5	-	-
	0.7÷1.3	11.5÷14	≤1.0	≤0,07	≤0.03	-	3÷4	-
GX120Mn13M	1÷1.4	12÷14	0.3÷1.0	≤0.1	≤0.03	≤1.0	≤1.0	0.1÷0.2
	0.7÷1.3	11.5÷14	≤1.0	≤0.07	≤0.03	-	-	0.9÷2.1
	1.05÷1.45	11.5÷14	≤1.0	≤0.07	≤0.03	-	-	1.8÷2.1
Chemical composition of the examined cast steel								
GX170MN16H	1.7	16	1.4	0.067	0.003	1.4	0.07	-

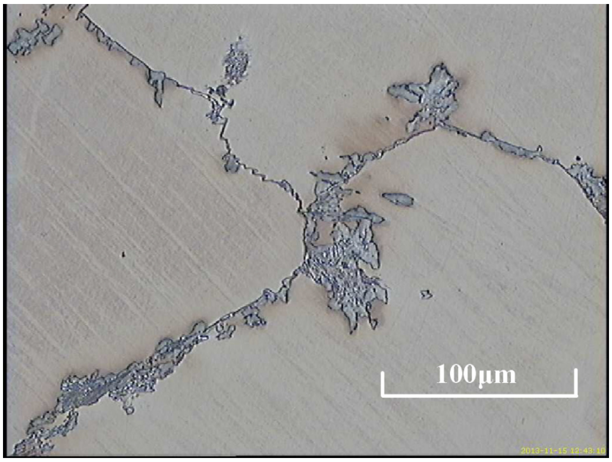

Fig. 1. Cast Hadfield steel; austenitic matrix with precipitates of acicular alloyed cementite; nital etching

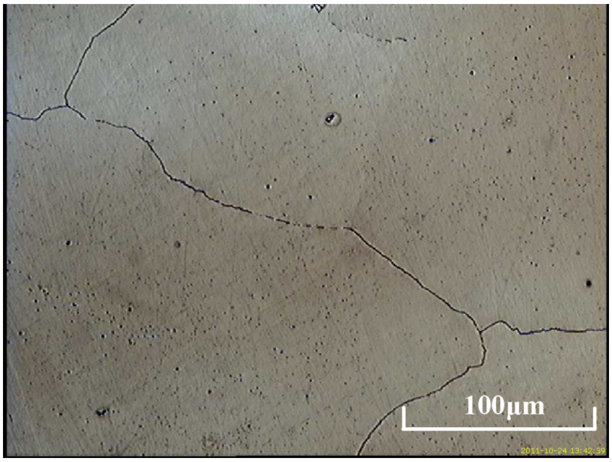

Fig. 2. Cast Hadfield steel after solution treatment in water; austenitic matrix free from the precipitates of alloyed cementite spread along the grain boundaries; nital etching

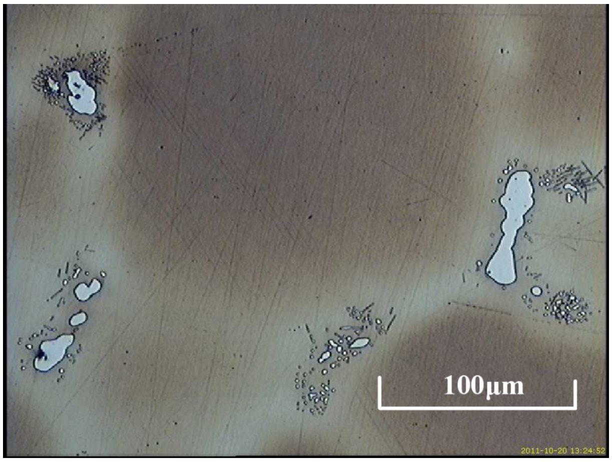

Fig. 3. Cast Hadfield steel after solution treatment in water; austenitic matrix with carbides undissolved or precipitated during heat treatment spread along the grain boundaries; nital etching

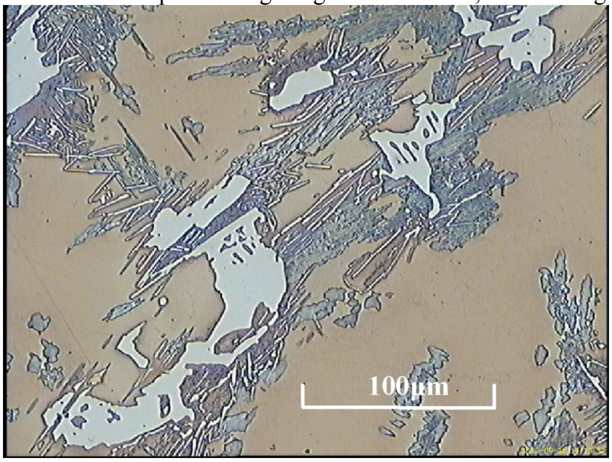

Fig. 4. Cast Hadfield steel with chromium addition (1.4% Cr); austenitic matrix with numerous precipitates of the acicular alloyed cementite; nital etching

Combined with the effect of non-metallic inclusions, these carbides clearly reduce the ductility of cast Hadfield steel. According to Z. Stradomski [9], the precipitation of carbides at the grain boundaries makes the impact strength of cast high-manganese steel decrease even ten times. For this reason, the aim to be achieved during heat treatment (the heat-treatment of Hadfield steel castings involves solutioning and cooling in water) is to produce a purely austenitic microstructure, i.e. free from the carbide precipitates (Fig. 2). While in the case of castings with small wall thickness (<50 mm), producing a microstructure of this type is not difficult, in thick-walled castings, the inside part of the walls may contain carbides undissolved or precipitated during heat treatment, distributed along the grain boundaries (Fig. 3) [8, 10÷12].

The effect of segregation and precipitation of acicular carbides is even more pronounced in the alloys which, to improve the abrasion wear resistance, are enriched with strong carbide-forming elements such as chromium or molybdenum (Table 1) [1÷6]. Changes in chemical composition lead to an increased precipitation of complex carbides in castings, mainly at the grain boundaries (Fig. 4). This effect induces stress formation during solidification and cooling of castings and may lead to brittle fracture not only during the casting operation but even as early as during the manufacturing process.

2. Test materials and methods

The test material were hammers for crushers with a wall thickness of 90 mm cast from high-manganese steel whose chemical composition is given in Table 1. Test specimens were cut out from the middle of the casting wall thickness, and then subjected to solution treatment. Some samples were treated at three different temperatures, i.e. 1100, 1150 and 1200 °C, one batch for 40 minutes, another batch for 80 minutes. Other samples were solution treated at a temperature of 1150 °C with the time of heat treatment extended to 4 hours (in 30 minute steps). From thus prepared samples, the metallographic sections were prepared, the chemical composition of the visible carbides was examined, and microhardness of the matrix and precipitates was measured.

3. Test results

The results of observations made by light microscopy, coupled with the measured microhardness of matrix (390 μHV_{20}) and of the precipitates (1600 μHV_{20}) and with chemical analysis of the visible lamellae (Table 2), enabled concluding that the microstructure of the examined as-cast steel consists of an austenitic matrix and alloyed cementite $(Fe,Mn,Cr)_3C$ present in the form of lamellae (Fig. 4).

Table 2.
Examples of the chemical composition of alloyed cementite

	Chemical composition of the visible precipitates [wt %]	
C	$12^{\pm 2.1}$	$14^{\pm 2.2}$
Fe	$59^{\pm 1.7}$	$57^{\pm 1.7}$
Mn	$24^{\pm 0.9}$	$24^{\pm 0.9}$
Cr	$5^{\pm 0.4}$	$5^{\pm 0.4}$

Solution treatment of the cast high-chromium Hadfield steel carried out at 1100, 1150 and 1200 °C for 40 minutes does not lead to a purely austenitic structure. The cross-sections of metallographic specimens show the presence of undissolved cementite visible against the austenite background.

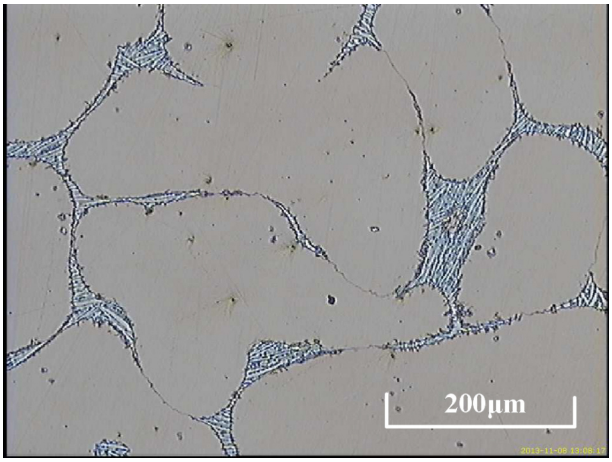

Fig. 5. Cast Hadfield steel after solution treatment in water (1200°C/80 minutes); austenitic matrix with undissolved carbides spread along the grain boundaries; nital etching

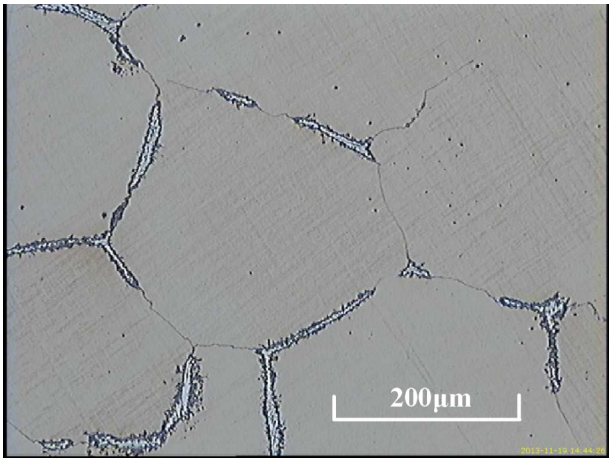

Fig. 6. Cast Hadfield steel after solution treatment in water (1150°C/240 minutes); austenitic matrix with undissolved carbides spread along the grain boundaries; nital etching

Prolongation of the solution treatment time at these three temperatures up to 80 minutes has also proved inefficient as regards the formation of a purely austenitic structure. Figure 5 shows an example of the microstructure of the examined cast steel solutioned at 1200 °C for 80 minutes. The only effect of treatment under these conditions is slight increase in the hardness of the matrix to about 410÷440 μHV_{20}. Solution treatment of samples at 1150°C for the time as long as 240 minutes causes further slight increase in microhardness of the austenitic matrix up to 460÷480 μHV_{20}, while the metallographic sections still show the presence of undissolved cementite present along the austenite grain boundaries.

Figure 6 shows an example of microstructure obtained in the examined cast steel as a result of the solution treatment for 240 minutes.

4. Conclusions

1. The as-cast microstructure of Hadfield steel with an elevated chromium content is composed of an austenitic matrix and alloyed cementite $(Fe, Mn, Cr)_3C$ present in the form of lamellae.
2. Increasing the solution treatment temperature to 1200 °C, or prolonging the time of solution treatment to 240 minutes does not lead to the formation of a purely austenitic structure.
3. The as-cast matrix microhardness assumes the value of about 390 μHV_{20} and thus is similar to the hardness of austenite in a common-type cast Hadfield steel (about 370 μHV_{20}).
4. Increasing the solution treatment temperature to 1200 °C or prolonging the time of this treatment to 240 minutes raises the hardness of the austenite to $460 \div 480 \mu HV_{20}$.

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