THE MECHANISM OF FORMATION AND DEVELOPMENT OF DEFECTS IN HADFIELD STEEL

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ABSTRACT

This paper is directed at solving the problem metallurgiists and material engineers face during the application of hadfield steel. It was established that fast cooling of this steel should be undertaken at a temperature range of 600 – 800°C so as to eliminate the intensive process of carbide formation.

A relationship between the amount of precipitated carbides and hardness was numerically developed to allow for the correct assessment of the structural state of this steel using the hardness value.

1. INTRODUCTION

In the developing and developed countries of the world, the mining industry is playing a crucial role in their national economy. Majority of countries depend (especially the developing nations) on revenue generated from the export of their mineral resources. Therefore, due to the pressure on this industry, all the machineries and equipment used in mining, processing and transportation of these mineral resources are intensively attacked by wear and tear. Also, the development of mining industry will necessitate a parallel development in the railway industry, construction and other allied industries. In that context, application of materials that can resist wear and tear is an actual problem for majority of these countries. In order to solve this problem, in 1882, Sir Robert Hadfield developed this steel which bears his name. Being austenitic, this high – manganese steel is extremely tough and shock - resistant, although relatively soft, it nevertheless, wears extremely well.

The reason for such apparent paradoxical situation is that mechanical disturbance causes the surface layers of the steel to become extremely hard (work hardening) so that the resultant component has a very hard wear resistant case.

This steel because of its universally acclaimed wear resistant properties is used mainly in the rock crushing machinery, dredging equipment and track – work points and crossings.

Because of the usefulness of this steel, research into ways of improving further its application properties at present in this steel becomes an ardous task due to the formation of defects which mainly are associated with the peculiarity of its crystallization during cooling in a mould and with heat treatment of components made from it.

The main defects of this steel are the micro – and macro cracks. The reasons for the formation of these cracks are not yet well understood.

The aim of this work, therefore, is to study the influence of cooling rate and heat treatment on the formation of the structure and properties of this steel. In order to achieve the above aim, the influence of temperature and holding time on the concentration of elements and on the structure of the steel is studied. Also studied is the influence of cooling rate on the mechanical properties of castings.

2. EXPERIMENTAL PROCEDURE

All the specimens usea were melted in an induction furnace in the atmosphere of pure argon. The Hadfield steel alloy is of standard composition containing the following elements: 1 – 1.3%C (average), 12.5 – 13.8%Mn, 0.3—0.9%Si, 0.08-0.12%P and 0.01-0.011%S. The pouring temperature was stabilized at 1410-1450°C. Mechanical testing i.e.

hardness test was carried during a standard method at temperatures of 20°C and 60°C.

Samples were analysed in the as – cast state and after cooling from 900°C in a mould, air, and water. The cooling rates were varied from 0.92°C/min to 2.4.10°C/min. Heat treatment was carried out on a step wise rate as follows: at 500°C for 2 hours, at 700°C for 2 hours, at 1050°C for 2 hours and quenched in water. The structures were analysed using microscope. "Neophot – 21", electron microscope JSM – 35.

The crystallization process of the steel was studied with the air of differential thermal analysis unit. Process of dissolution of carbides during heating was observed in a scanning electron microscope type JXA – 50A equipped with a resistance furnace which maintained the constant heating of the sample.

3. RESULTS AND DISCUSSION

According to the Fe – Mn – C equilibrium diagram, the structure of a hadfield steel at room temperature is supposed to undergo certain changes due to the disintegration of austenite. In practice, due to the small rate of diffusion processes, phase transformation do not proceed to the end. In that case, the results of theoretical analysis sometimes deviate from the ones obtained in practice. Figure 1 shows the volume fraction changes of 13.6 – 3 % of the carbides when the cooling rate is increased from 0.92°C/min to 2.4.10°C/min. The average sizes of the carbide particles and the austenite grain also decrease. The stability of austenite decreases due to the formation of carbides and the enrichment of austenite with manganese and carbon. This results in the partial transformation of pearlite and martensite in castings cooled at 0.92°C/min and 16.7°C/min. Quenching in water air result into the formation in the structure of the castings mainly austenite and carbides (Fe, Mn) ZC which are formed on the grain boundaries. The hardness of the castings cooled slowly is of the value of 260 HV, while those quenched in water and air had a value of 170HV. Hot cracks was developed in the castings cooled in water and air due to the high coefficient of linear expansion and relatively low plasticity of austenite. The volume fraction of the cracks when the castings were cooled in air is 0.3%, while that of the castings quenched in water stood at 3.3%.

Alternatively, in the castings cooled at a rate of 16.7°C /min, cracks were not observed. After reheating, the castings at a temperature of austenization – 1050 – 1100°C and quenching in water, it was observed that the castings cooled in the mould at 0.92°C/min and those quenched in water were the most attacked by cracks. In the first cast, the cracks were spread along the grain boundaries, while in the later case, they are concentrated in the areas of overlapping of the carbides along and inside the grain boundaries.

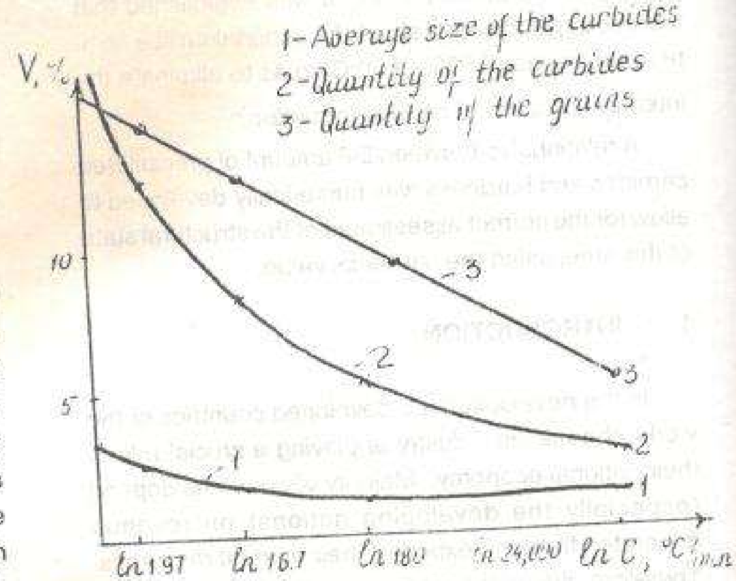

Fig. 1 The influence of cooling rate on the structure of headfield steel.

This work establishes the fact that the areas of overlapping of carbides are the potential areas for the initiation and development of cracks in hadfield steel.

The experiment carried on using the furnace in the chamber of a scanning microscope type JXA – 50A shows that when castings were heated up to 600°C no visible changes in them were noticed. At about 700°C appeared small carbide particles in the austenite grain. At 1000°C, these carbide particles started to dissolve in the metallic matrix. And the needle – like carbides overlapped inside the grain and in the pearlite colony were dissolved with the formation of pores. In areas of overlapping of these monolith carbides, formed pores of sizes approximately the same with the sizes of the carbides.

Upon cooling the castings at an average rate of $50^0C/min$, these castings. This result shows the fact that during reheating of this steel, in its structure form pores with sizes that varies depending on the sizes of the carbides in the as – cast structure.

In the presence of thermal stress which always occurs during quenching, these formed voids become the centre of nucleation of cracks. And the higher the size of the pores, the more the changes of formation of cracks.

According to the Fe – Mn – C equilibrium system, these monolith carbides are supposed to form at 1050-650^0C.

Experiment on the influence of isothermal holding at temperatures of 500, 700, 800, 900 and 1000°C shows that holding at these temperatures increases the volume fraction of carbides formed in castings cooled in water and air. Although, this increase in the amount of carbides depends on the heating temperature. At 11 hours holding time, the volume fraction of these carbides is 12-14%. At higher temperatures (600, 900, 1000°C) the volume fraction of the carbides do not change. At 500°C after 11 hours holding time, there was no disintegration of austenite observed, it was only the hardness value that changed, and in the structure compact and needle – like carbides and pearlite colony were observed. A relationship between the amount of precipitated carbides V and the hardness HV was observed after "stop – Hardening" at the corresponding temperature.

$$HV = 158 + 6.2\,(\%C) = 0$$

$$r = 0.9_20$$

$$n = 20$$

The same type of relationship exists in the as – cast state of the castings which allow their structural state to be evaluated using these values.

Figure 2 shows these relationship as obtained during the study. Heating of the castings at 100 – 1000°C at long holding times shows that the carbides do not fully dissolve in the austenite. Electron microscope analysis shows that these carbide inclusions look like a ledeburite eutectic according to the visual composition of its internal structure. Their structure consists of iron, manganese. Phosphorus was not observed in them.

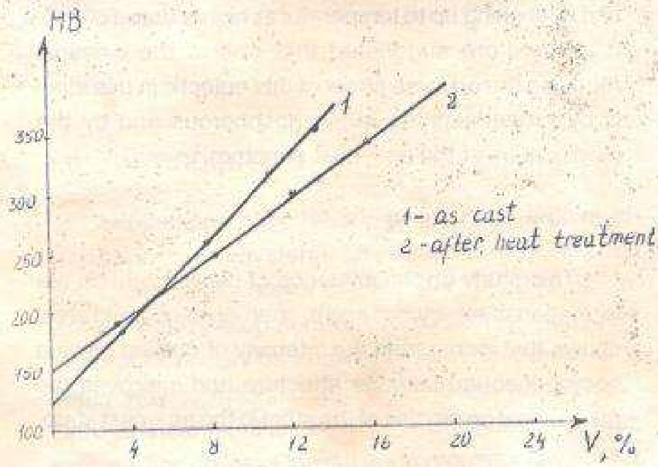

Fig. 2 The relationship between the hardness and the quantity of carbides in hadfield steel.

According to the Fe – Mn – C equilibrium phase diagram this steel at room temperature is supposed to have a single phase austenitic structure.

As in the melted steel phosphorous and sulphur were present, these elements constrict the austenite range and lower the dissolution of carbon in austenite. This again signifies the fact that the character of solidification of castings in practice differs from the one obtained during equilibrium conditions.

The differential thermal analysis of this steel shows that the crystallization started with the precipitation of austenite at 1395 – 1390°C when cooled at a rate of 5°C/min. At about 1200°C, austenite was fully precipitated. At 1180 – 1960°C, eutectic reaction took place which was manifested in a heating effect observed on the cooling curve. It was also observed that about 35, 5% of manganese ledeburite existed in the structure.

The results of the metallographic analysis very well agreed with experimental results and it showed that after hardening from 1000 – 1100°C, 1 , 2% Volume fraction of carbides was observed in the structure of this steel.

Figure 3 shows these eutectic carbides along the boundaries of hot cracks. This illustrates the fact that the presence of this low melting eutectic is another reason for the formation of hot cracks during the solidification of this steel and also during hardening and quenching up to temperatures higher than 1600°C. It is therefore suggested that one of the ways of reducing the adverse affect of this eutectic in this steel is by proper refining from phosphorous and by the modification of the as – cast structure.

4. CONCLUSION

This study on the influence of cooling rate on the formation of structures and properties of hayfield steel shows that increase in the intensity of cooling gives a homogeneous austenite structure and improves the mechanical properties of the steel in the as – cast state.

It was observed also that carbides dissolve during heating and quenching and in the areas of their overlapping form pores.

The most intensive process of carbide formation takes place at 800°C and at temperatures higher than 600°C. This necessitates the fast cooling of castings at these temperature ranges in order to increase their mechanical properties.

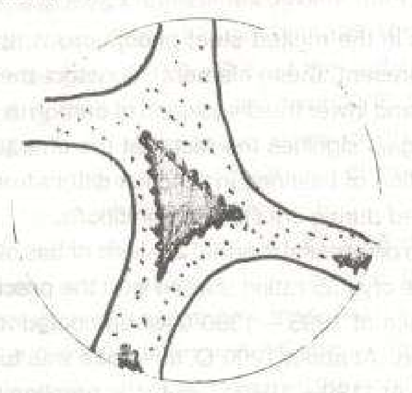

Fig. 3 The form of cracks formed in the place of eutectic carbide nucleation.

It was also observed that eutectic transformation takes place in this steel at 1160 – 1180°C and it is the cause of the formation of undissolvable carbides during successive heat treatment. The formation of this carbide non – homogeneity is caused by the lowering of the dissolution of carbon in austenite and by the construction of the austenite range due to the high concentration of phosphorous in the steel.

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FIGURES

Figure 1 The influence of cooling rate on the structure of hadfield steel.

Figure 2 Relationship between the hardness and Quantity of carbides in hadfield steel.

Figure 3 The form of cracks formed in the place of nucleation of carbide eutectic [X500]