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Microstructure development of low carbon steel surface hardfaced with chromium carbide alloy

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Abstract
In this investigation, the microstructure changes of 0.25% low carbon steel, which is hardfaced with high chromium white iron by a semiautomatic welding process was studied using OM, SEM and EDX analysis. Mechanical properties, such as hardness and wear rates, were also investigated. Four groups of samples were used in the study. The first group of samples was low carbon steel without any surface treatment. The second, third, and fourth groups of samples were selected from several hard-faced low carbon steel pieces with 3.0, 3.4 and 3.8 % of chromium contents in their hard-faced surface respectively. SEM analysis results show that the microstructure of the surface treated samples consist of a small amount of ferrite and a large amount of pearlite. EDS test shows that the chromium contents of both ferrite and pearlite have increased significantly. Increasing pearlite amounts and increasing chromium concentrations in every phase seem to increase the hardness from 280 to 495 HV30. Chromium content was increased in both pearlite and ferrite. This increase causes the phase's hardness to be increased. Also, there is a trace of M_7C type carbides that appeared in hardfaced surface with higher chromium content.

Key words: Low carbon steel, microstructure, phase, hardness, chromium, carbon

Introduction

Carbon steel is one of the base materials in metal structures in the machine industry and is divided into 2 groups depending on the intended use. The first group covers structural steels of higher quality and is used in the manufacture of components such as gears, shafts and other machine parts. The second group contains general-purpose steels and is produced in the form of sheets, pipes and other forms. These steels have a carbon content of up to 0.3 percent, so they are considered low-carbon steels. Low-carbon steel is used to manufacture the body of the equipment and parts of supports, joints, and fasteners, especially in the construction industry.

The working components of mining, agriculture, and road construction machines that work in an environment of excess abrasive wear are prepared with high-quality special steel and alloy. For example, high-chromium white cast iron and high-manganese steel are commonly used in mining equipment. However, due to the high cost of these alloys, they cannot be used in all parts that work in mechanical and abrasive environments. In such cases, low-cost low-carbon steel is often used for manufacturing of mining devices such as classifiers, separator, hydrocyclone, flotator etc. The alloys work in chemically active environments and abrasive action, so they wear out quickly and need to be replaced more often. To avoid this, the surface of low-carbon steel is coated with wear-resistant materials containing C, Cr, W, Mo,V and other elements. These elements improve the surface in two ways, solid solution strengthening and precipitation carbids and intermetalic compounds.

In production conditions, the method of improving wear-resistant coatings on metal surfaces via all kinds of electric arc welding is widely used [1-5]. Alloys prepared in the form of powder and wire with various quality elements are used for the surface quality improvement process. Among these quality materials, iron-carbon-chromium ternary alloy is the most commonly used. This is because this type of alloy is inexpensive but forms a wear-resistant chromium carbide phase when it is coated on a steel surface [1]. In practical conditions, chromium carbide containing F-Cr-C type alloys are widely used for coating mild steel to increase wear resistance [3, 4, 7].

There are many experimental and research works that were conducted on improving the surface of steel by coating it with high chromium white cast iron. These works are performed mostly for parts such as conveyor chutes, connection pins, and sliding bearing shafts [6].
The following research works have been carried out to improve the surface of low carbon steel with high chrome white steel and increase its wear resistance and other mechanical properties [3, 4, 5, 6]. These works investigated the results of coating low-carbon steel surfaces with different chromium contents by various methods of welding.

Materials and methodology

100x40x5 mm work specimen of low-carbon steel plates with 0.25 % C were used. The total plates are divided into 4 groups. The first group has not undergone any processing and is intended to be used as a basis for comparison (control group). The second, third and fourth groups of plates were selected from a nunber of hard-faced specimen with 3.0, 3.4 and 3.8 % of chromium contents respectively. Hardness values of each specimen were measured by microhardness HV30 unit. The surfaces of the selected specimen were grinded, polished and prepared using standard methods for evaluation by optical microscopy and SEM analysis. The number of sandpapers and 1 μm diamond powder were used for polishing the samples. The chemical composition of the phases of each specimen was evaluated by EDS analysis, and the results were compared with the results of the base steel group.
The microhardness of ferrite phase and pearlite structures were measured by a microhardness tester HV0.5 unit.
Abrasive wear tests were performed using the Pin on Disk method. Wear rate was expressed by weight per minutes or g/min.
The chemical contents and hardness of the specimen are shown in table 1.

Table 1.

Chemical contents and hardness of the specimen used in the study

№	Samples	Chemical content, %		Hardness, HV30	Wear rate g/min
		Carbon	Chromium		
1	Low carbon steel	0.25	0.3	280	1.45
2	Lower alloyed steel	0.37	3.0	425	0.85
3	Medium alloyed steel	0.42	3.4	460	0.65
4	Higher alloyed steel	0.48	3.8	495	0.5

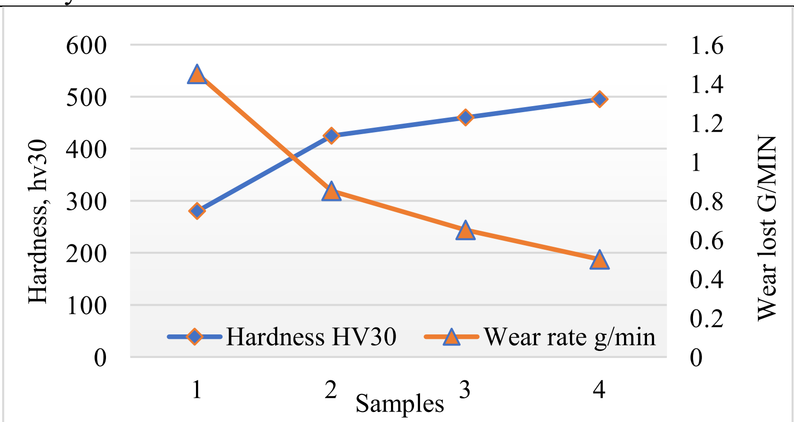

Figure 1. Hardness and wear lost of the samples

After surface treatment, wear rate of carbon steel with 3.8% of chromium had decreased from 1.45 to 0.5 g/min than low carbon steel with 0.3 % of chromium. Therefore, hardness is increased from 280 to 495 HV30.

Results and discussion

Microstructure

Figure 2 shows the optical microstructure of each untreated and treated samples. As can be seen from the optical microstructure images of all the workpieces, the microstructure of low carbon steel has been changed dramatically after the improvemental process. The structure of hypoeutectoid steel consists of pearlite and ferrite. After the improvement, it can be seen that the amount of pearlite increased significantly and the amount of ferrite decreased. This is explained by an increase in carbon content that was added by a coating process using high chromium white iron.

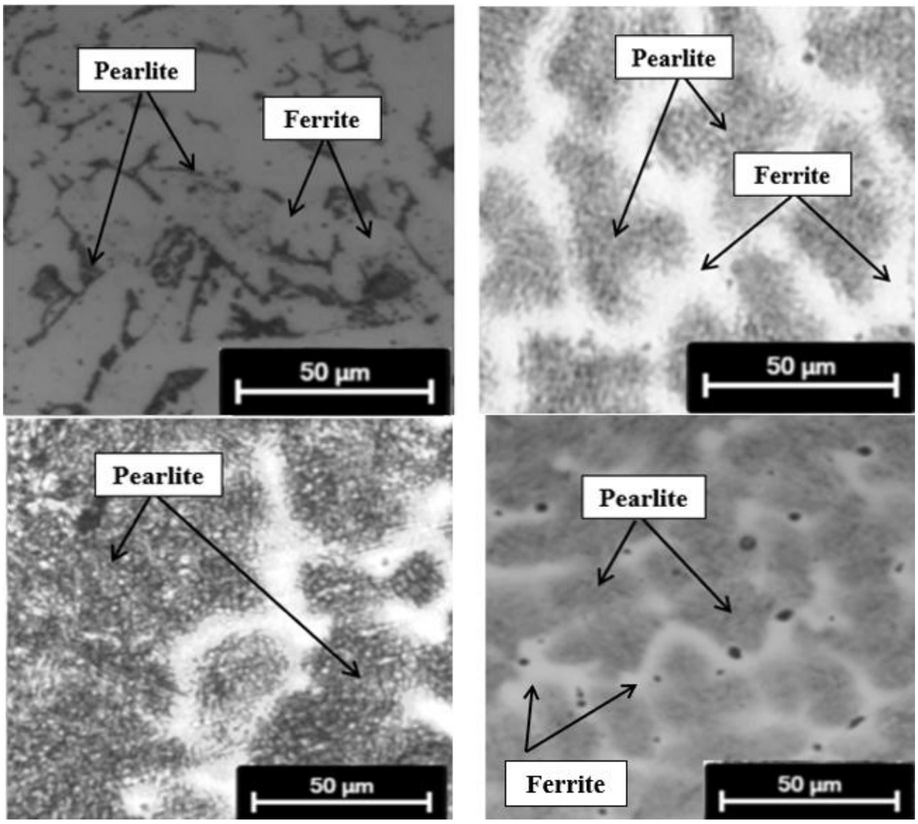

Figure 2. Microstructure of samples: a- sample1, b- sample 2, c- sample 3, d- sample 4

The ratio of ferrite and pearlite amounts was 80 to 20 in figure 2a. But after the treatment this ratio was changed increasingly. For example, in figure 2b it was 45 to 55 and 40 to 60 and 20 to 80 in figures 2c and 2d respectively. This is approved by SEM analysis in figure 3

SEM analysis

Figure 3 shows SEM images of four samples. In the SEM image of the sample1 (figure 3a), which has no surface treatment, the ferrite phase occupies the majority of the image field and there is very little amount of pearlite. However, after surface treatment by using of high chromium alloy, the ratio of pearlite-ferrite has changed greatly by increasing of amount of pearlite (figure 3b, c, d).

Increased amount of pearlite was caused by increasing of cementite (Fe_3C) or carbide phases ($(Fe, Cr)_7C_3$). Elemental contents of carbon and chromium in ferrite and carbide phases were estimated by SEM-EDX analysis.

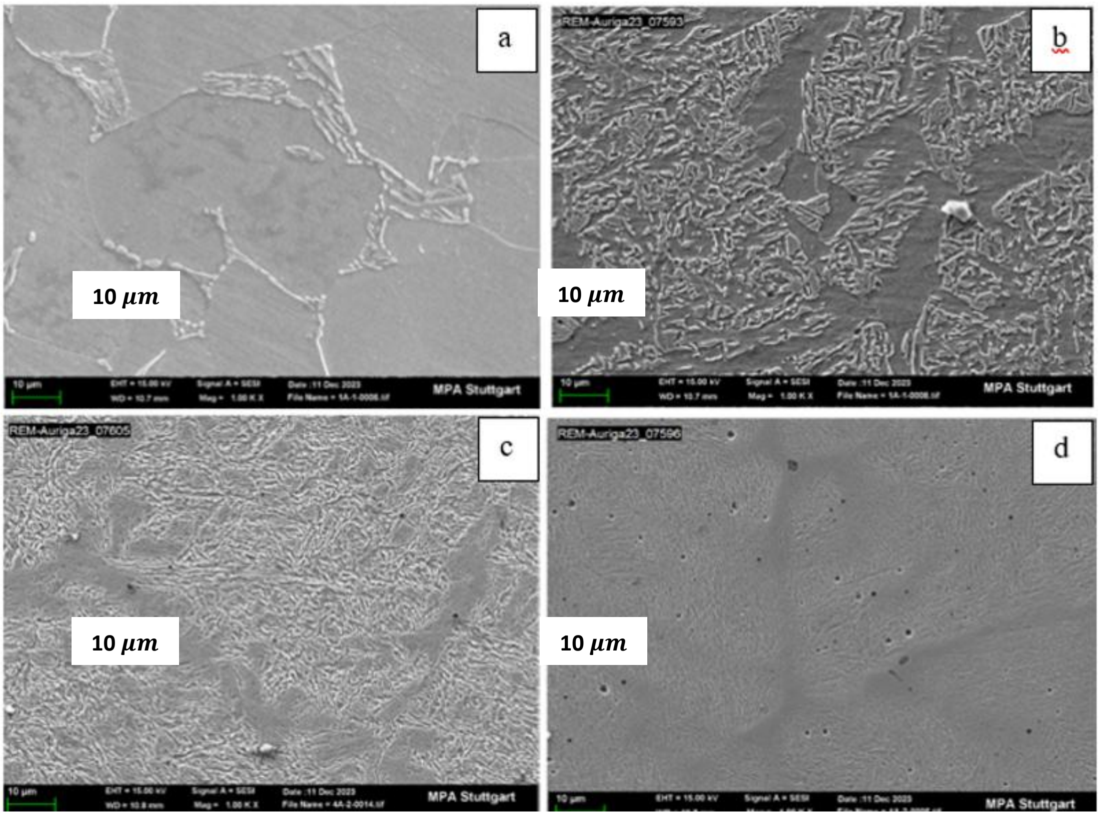

Figure 3. SEM images of the samples: a- sample1, b- sample 2, c- sample 3, d- sample 4

EDX analyses

EDX analyses were performed to show the changes of carbon and chromium contents in both of ferrite and carbide of the sample 4. On the SEM image totally 6 specific points (3 of ferrite and 3 of carbide) were selected for EDX analysis (figure 4). The results were obtained by a calculation of average of EDX results of the selected points and shown in Table 2.

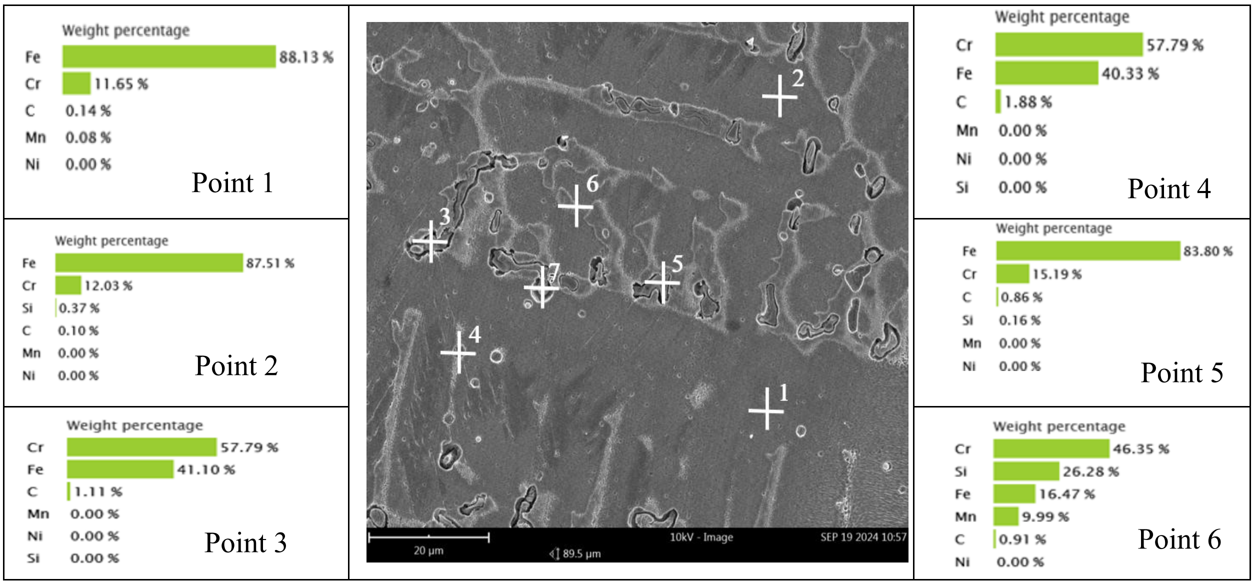

Figure 4. EDX point elemental analyses for sample 4

Table 2.

Chemical contents of ferrite and carbide phases for sample 4

Elements	Point 1 (Ferrite)	Point 2 (Ferrite)	Point 3 (Carbide)	Point 4 (Carbide)	Point 5 (Ferrite)	Point 6 (Carbide)	Average of ferrite	Average of carbide
C	0.14	0.1	1.11	1.88	0.86	0.91	0.37	1.30
Cr	11.65	12.03	57.79	57.79	15.19	46.35	12.96	53.98

Table 2 shows that carbon and the chromium contents of ferrite and carbide phases of the mild steel increased after improvemental surface process. This phenomenon can be explained by carbon and chromium atoms from high chromium alloy dissolve into both ferrite and carbide phases, simultaneously.

EDX elemental analysis of ferrite and carbide phases of the samples with different chromiun contents are shown in Figure 5.

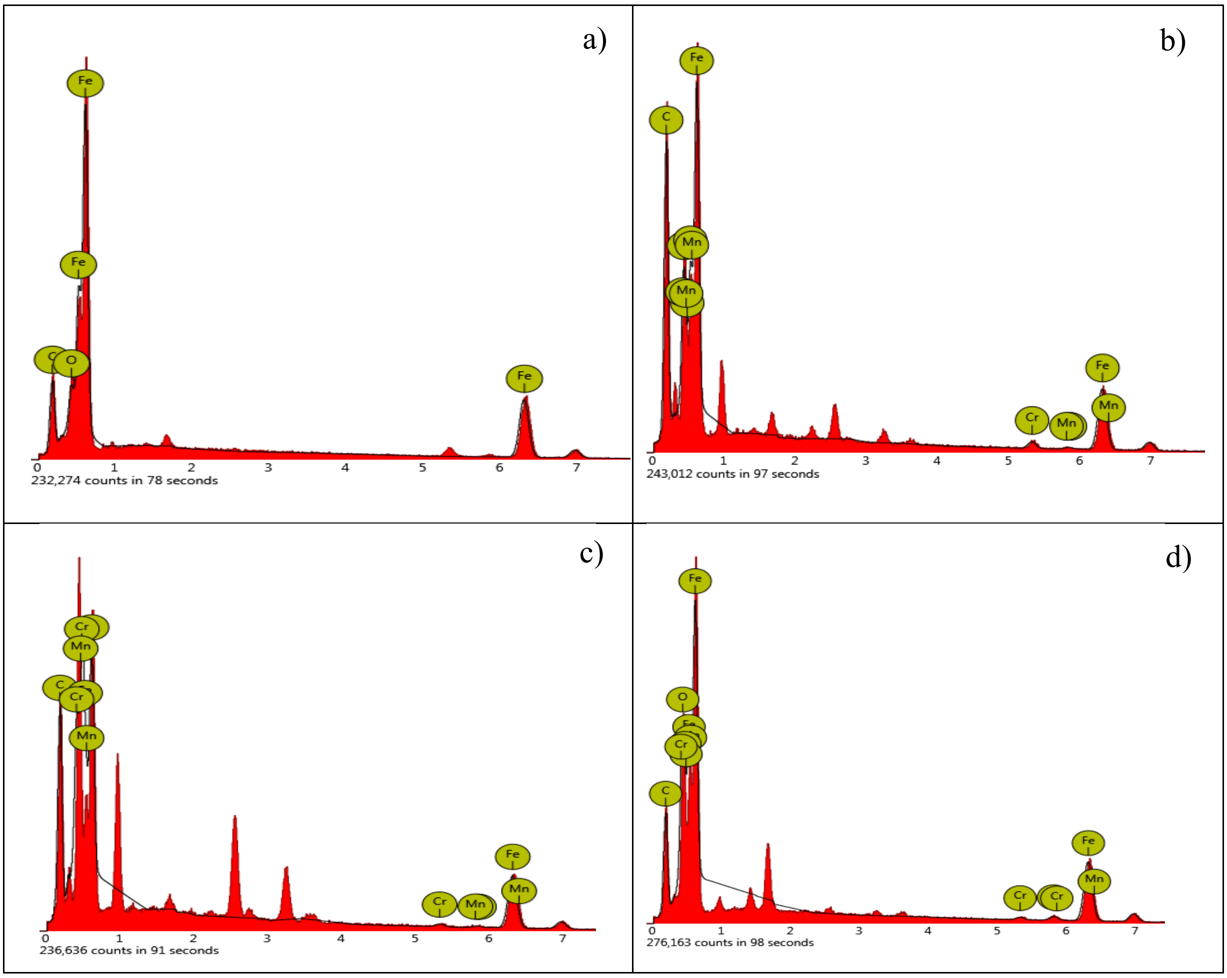

Figure 5. EDX elemental analysis of (a, b) ferrite and (c d) carbide phases of the samples with different chromiun contents

From figure 5 can be seen that: Ferrit phase of fure carbon steel plate has mostly Fe atoms (Figure 5a) while ferrit phase of coated surface has Fe, Mn, Cr and C atoms (Figure 5b). Carbide phases of coated surface has as many as Cr, Fe, C and Mn atoms (Figure 5c, d).

The microhardness measurement results of the samples are shown in Figure 6. Hardness values of both ferrite and pearlite of the samples show increased manner as theair carbon and chromium contents increased.

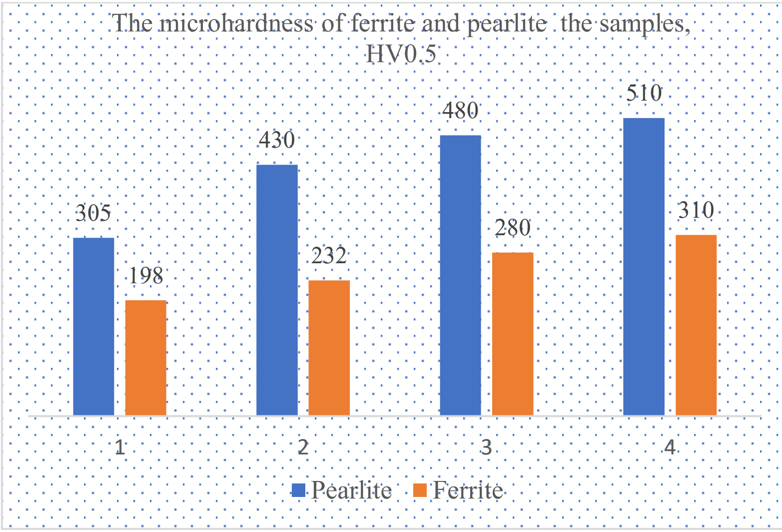

Figure 6. Microhardness of ferrite and pearlite of the samples with different contents of C and Cr

Conclusion

Surface treatment of low carbon steel with high chromium alloy dramatically affects mechanical properties such as hardness and wear resistance through an increase in quality, structure and phases of the surface. These results were obtained by a number of processes including:

1. After the coating treatment of low carbon steel surface, the content of chromium and carbon has been increased up to grade of medium carbon and low alloyed steel,
2. Implemented carbon increases amount of carbide and affects the hardness of the surface
3. Implemented chromium simultaneously dissolves into ferrite and carbide phases and causes an increase in both of hardness and wear resistance.
4. The dissolving process of chromium and carbon into low carbon steel surface increases the microhardness of phases and structure of the steel surface.
5. Low carbon steel can be used in hard and abrasive working conditions after the surface is treated with a cheap chromium carbid coating containing alloys like high chromium white iron.

Conflict of interests

The authors declare no conflict of interests.

Authors' contribution

O. G. writing original draft preparation and performed all study, P. B. and UL contributed ot the study, RY advising the calculation and review, G. U. advising the calculation and review. All authors have read and approved the final manuscript.

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