Effect of the Number of Welding Passes on the Microstructure and Wear Behavior of St52 Plain Carbon Steel Coated with a High Chromium-Carbon Electrode

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Abstract: This study investigated the effect of the number of welding passes on the microstructure, hardness, and wear behavior of St52 plain carbon steel coated with an E10-UM-60R electrode in accordance with the DIN 8555 standard using SMAW method. An optical microscope (OM) and a scanning electron microscope (SEM) were used, and an EDS analysis was carried out to examine the microstructure. The Vickers micro hardness test and a reciprocating wear test were also used to examine the hardness and wear resistance. The results showed that the structure on the surface of the coated specimens is consisted of M_7C_3 carbides in the eutectic field (γ+M_7C_3). In addition, the volume fraction of carbides increased in specimens that underwent two passes of welding relative to that in one pass-welded specimen. The reason for this was related to the decreased dilution of iron and increased dilution of chromium in the two-pass welded specimen and an increase in the volume fraction of M_7C_3 carbides. The increased percentage of carbides in the two-pass welded specimen increased the hardness and consequently the wear resistance relative to those in the one-pass welded specimen in a way that the surface hardness and weight loss in the wear test reached from 780 HV and 3.7 mg in the one-pass welded specimen to 910 HV and 2.5 mg in the two-pass welded specimen. Moreover, examining the wear surfaces indicated the occurrence of an adhesive wear mechanism in the specimens in a way that the adhesive wear rate decreased in the two-pass welded specimens.

Keywords: Hard Facing, Hardness, High Chromium-Carbon Electrode, St52 Plain Carbon Steel, Wear

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1 INTRODUCTION

Hard facing means welding a consumable material (welding wire, electrode, powder, etc.) onto a base metal to increase the wear and corrosion resistance, which the purpose of this process is to increase the longevity of the desired substance. In this process, a relatively thick layer of metal with hard metallic compounds such as carbides accumulates on the surface of the desired parts through different methods such as plasma spraying, laser coating, welding methods, and thermal spraying [1]. Hard facing is done through welding in agricultural and drilling equipment, mining industries, and other industries, to increase hardness and abrasive wear resistance combined with the impact of components. Alloys used to create a wear resistant layer on iron base metals (carbon steel and low alloy steel) are divided into two main categories: iron alloys and non-iron alloys. Iron alloys used for this purpose fall in the following two main categories: Fe-Cr-C base alloys and Fe-C-X base alloys (X is a carbide-forming element). Non-iron alloys being used also fall in two categories; namely, Cobalt base alloys and Nickel base alloys.

Due to their appropriate price and higher wear resistance, iron base alloys have attracted more attention compared to non-iron base alloys [2-3]. The presence of carbon and carbide-forming elements is necessary for alloy systems containing carbides. In these types of alloy systems, the combination and morphology of a carbide, its adhesion to the matrix, and the distribution of carbides play a very determining role in the wear properties of the alloy [4]. The hypereutectic Fe-Cr-C alloy has attracted a lot of attention due to its excellent wear resistance. M_7C_3 carbides often form in these alloys. Primary M_7C_3 carbides form at a high concentration of carbon. These types of microstructures have good wear resistance properties [5-6]. M_7C_3 carbides are widely used as reinforcing phases in composite coatings due to their perfect combination of high hardness, excellent wear resistance, as well as good corrosion and oxidation resistance [7]. Lin et al. investigated the effect of coating a high carbon chromium base alloy through the GTAW process. They found out that improvement in the wear resistance was resulted from a high volume fraction of $(Cr, Fe)_7C_3$ wear resistant carbides [8].

Chang et al. investigated the effect of coating the hypereutectic Fe-Cr-C alloy with different amounts of carbon. The results of their study showed that with the increased amount of carbon in the coating, the surface fraction of carbides increased, and the morphology of the primary $(Cr, Fe)_7C_3$ carbides changed from a blade-like to a rod-like [9]. In the present study, the effect of the number of welding passes on the microstructure, hardness, and wear behavior of St52 steel welded with a high chromium-carbon electrode is investigated using the SMAW method. To this end, the hardness, reciprocating wear, and microstructure analysis tests will be performed through optical microscopy (OM) and scanning electron microscopy (SEM).

2 EXPERIMENTAL METHOD

In this study, two sheets of St52 plain carbon steel with dimensions of 100 mm × 100 mm × 10 mm were used as the base metal, whose chemical composition is presented in “Table 1”.

Table 1 Chemical composition of St52 plain steel carbon and electrode in the current study (wt%)

	C	Mn	Cr	Si	Fe
Plain carbon steel St52	0.20	1.60	---	0.55	Bal.
E10-UM-60R electrode	4.30	---	35.0	---	Bal.

To perform the coating operation, an E10-UM-60R high chromium-carbon electrode, whose chemical composition is presented in “Table 1”, was used with a diameter of 3.25 mm in accordance with the DIN 8555 standard. Before coating, specimens were ground in order to remove the oxide layers, and then they were placed in an acetone solution. The electrodes were also dried in an oven at 300°C for two hours to remove their moisture. The specimens were then preheated up to 250°C before welding [10]. In order to investigate the effect of the number of passes, the coating operation was performed on the specimens in the form of a one-pass coating and two-pass coating using the SMAW method according to parameters presented in “Table 2”.

After welding, samples were prepared for microstructure analysis, hardness test, and wear test. After sanding and polishing, the samples were etched using a ferric chloride alcohol solution for 40 seconds in order to analyze their microstructure. The microstructure was analyzed using a Nikon optical microscope. An EDS spot analysis was also used to examine the dilution of the iron present in the coating.

Table 2 The welding parameters

Process	SMAW
Electrode diameter(mm)	3.25
Arc length (mm)	3
Voltage (V)	10
Number of passes	1 and 2
Current intensity (A)	133
Welding rate(mm/s)	1.4
Polarity	DCEP
Heat input of each pass (kJ/mm)	22.8

An X-ray diffraction (XRD) device model: Philips X Pert-MPD System, and the K_α ray of copper with a ($\lambda = 1.5404\mathring{A}$) were used to determine and approve the phases existing in the structure. The Vickers microhardness test was performed with a load of 500 g on the cross section of the samples from the coating towards the substrate in accordance with the ASTM E384-16 standard. After performing the wear test, the Vickers microhardness test was performed on the wear track of the samples as well. A reciprocating wear test was performed based on the ASTM G133-05 standard and in accordance with the parameters presented in “Table 3”. And finally, the wear surfaces were examined using a scanning electron microscope (SEM) model: ZEISS.

Table 3 The wear test parameters

Load	160 N
Wear pin	100Cr6 Bilbrig steel
Wear pin hardness	65 HRC
Sliding speed	0.15 m/s
Sliding distance	1000m

3 RESULTS AND DISCUSSION

3.1. The Microstructure of the Base Metal

The microstructure of the base metal, which contains ferrite and perlite, is presented in Figure 1.

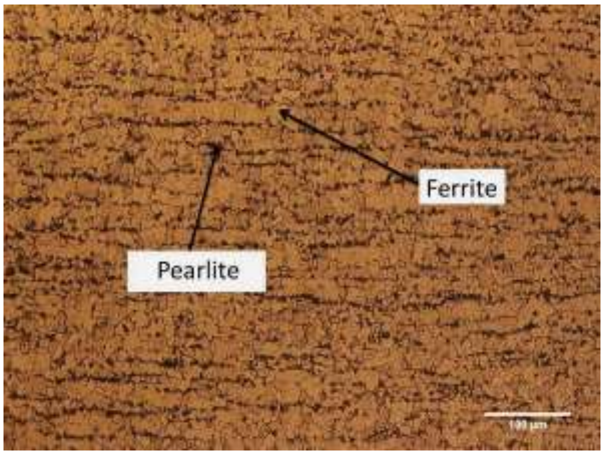


Fig. 1 Optical microscopy image of the base metal.

3.2. Microstructure of the Coating’s Surface after the Welding Operation

The microstructure of the surface of the specimens is presented in “Fig. 2” in the form of one-pass coating and two-pass coating. As can be seen, the structure of the specimens consists of M_7C_3 carbides in the eutectic matrix (γ+M_7C_3).

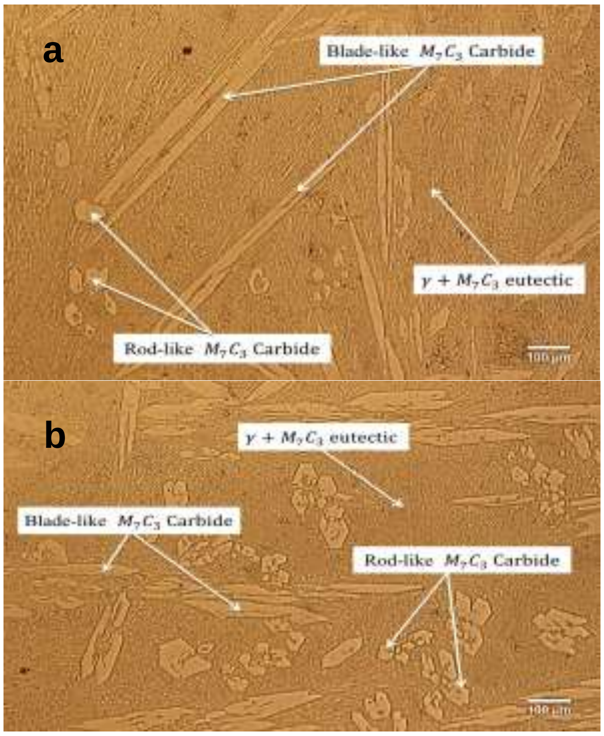
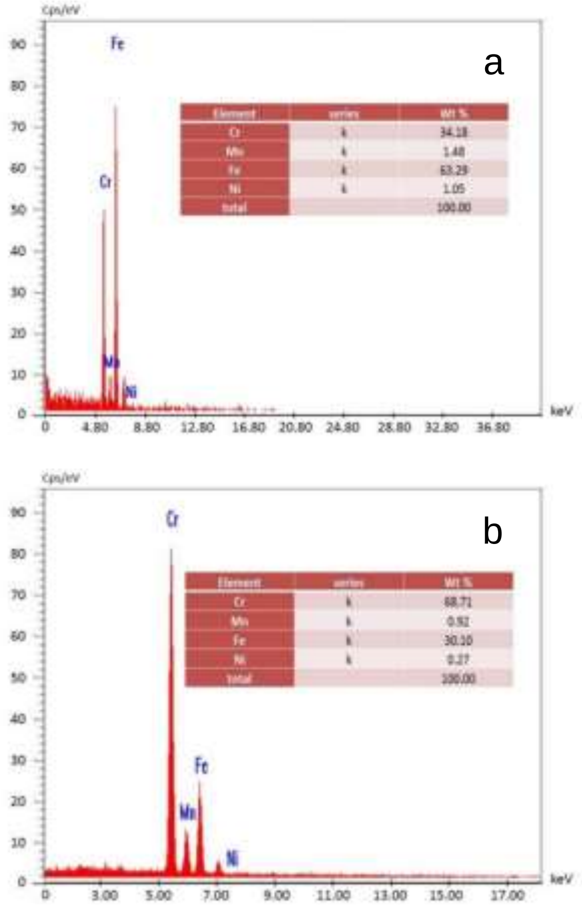


Fig. 2 Optical microscopy image of the surface after the welding operation: (a): one-pass and (b): two-pass.

In addition, examining the images indicates that the volume of carbides has increased in the two-pass state. Moreover, in the two-pass specimen, carbide morphologies are mainly of the rod-like type. The reason for this is related to the decrease in the iron dilution, which will be addressed in what follows. Previous studies have shown that primary M_7C_3 carbides form through two morphologies: the rod-like morphology and the blade-like morphology. In addition, as the carbon percentage increases, the morphology of M_7C_3 carbides increases from the blade-like morphology to the rod-like morphology [9].

Figure 3 shows an EDS analysis on the surfaces of one-pass and two-pass specimens. As can be seen, iron dilution has decreased in the two-pass specimen relative to that in the one-pass specimen, but the amount of chromium has increased. This leads to an increase in the percentage of chromium carbides on the surface of the two-pass specimen in comparison to that in the one-pass specimen, which is completely clear in “Figs. 2a and 2b”.



Element	series	Wt %
Cr	k	34.18
Mn	k	1.48
Fe	k	63.29
Ni	k	1.05
total		100.00

Element	series	Wt %
Cr	k	68.71
Mn	k	0.92
Fe	k	30.10
Ni	k	0.27
Total		100.00

Fig. 3 The EDS analysis on the surfaces of specimens: (a): one-pass and (b): two-pass.

The increased percentage of carbides due to the increased number of passes has also been proved in studies by other researchers. In a study conducted by Amini et al., on hard facing Mo40 steel using a 420 electrode, the percentage of carbides reached from 7% in the one-pass specimen to 11% in the two-pass specimen. These researchers have considered dilution changes as a factor changing the percentage of carbides [1]. Figure 4 shows an X-ray diffraction analysis on the surface of specimens. As can be seen, M_7C_3 carbides are observed in the austenite.

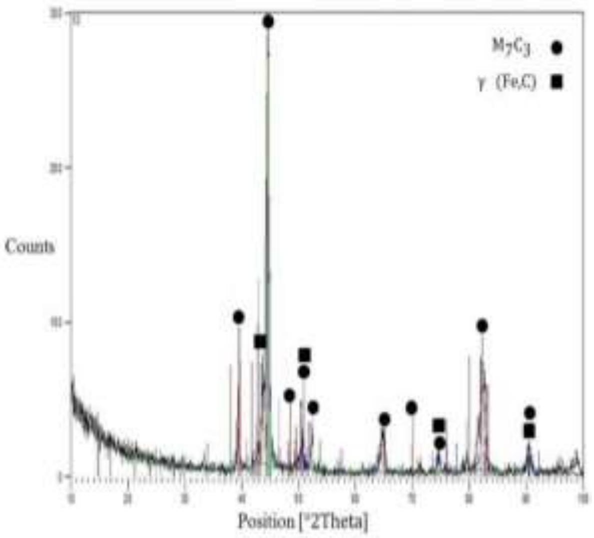


Fig. 4 XRD patterns of the surface of the specimen.

3.3. Hardness Testing

“Table 4” shows the results of the Vickers micro-hardness from the surface of coated specimens. As can be seen, the hardness degree has improved in the two-pass specimen in comparison to that in the one-pass specimen due to the decreased dilution of iron, an increased percentage of chromium, and consequently an increased percentage of chromium carbides. In a study conducted by Fan et al. on the effect of coating the ASTM A36 steel using a high chromium Fe-Cr-C hard facing alloy, they showed that hardness increased with the increased percentage of (Fe, Cr)23C6 carbides [11]. It has been observed in previous studies that hardness increases linearly with the decreased dilution of iron, and hardness increases from the interface between the base metal and the welding metal towards the coating surface [12]. Therefore, in the present study, due to the increase in carbides in the two-pass specimen, hardness degree has increased.

Table 4. Micro-hardness (Vickers) results from the surface of coated specimens

Sample	Hardness 1	Hardness 2	Hardness 3	Av.
One-pass	779	783	778	780
Two-pass	919	903	908	910

Figure 5 shows the results of the hardness test on the surface of specimens before and after the wear test. As can be seen, the hardness of specimens has increased after the wear test, which is due to the transformation of austenite into martensite during the wear test. Results obtained by other researchers show that local work hardening occurs during the wear process. The increased hardness after the wear test, is due to the transformation of austenite into martensite, which is due to the local work hardening during the wear process (this phenomenon is called “Stress Induced Martensite”) [13-14].

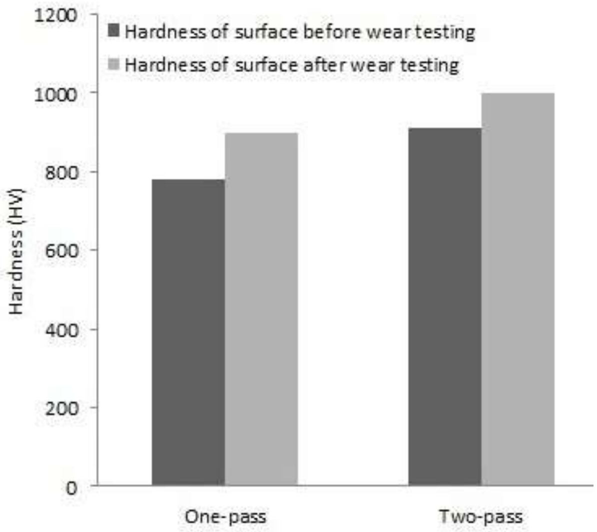


Fig. 5 The hardness (Vickers) results on the surface of specimens before and after the wear test.

3.4. Wear Resistance of the Specimens

Figure 6 shows the curve of the mass loss of the coated specimens within a distance of 1,000 m using a reciprocating wear method. As can be seen, a lower weight loss can be observed in the two-pass coated specimen compared to the one-pass coated specimen. This is due to the decreased dilution of iron in the two-pass specimen, in comparison to that in the one-pass specimen, which results in the increased amount of chromium. Therefore, more chromium carbides are produced and the hardness and consequently the wear resistance of the two-pass specimen improve in comparison to those of the one-pass specimen.

The wear test was also performed on the base metal (St52). Due to the fact that the base metal has a low hardness (155 HV), the weight loss of the base metal was obtained to be 50 mg in the wear test within a distance of 200 meters, which was very high in comparison to that of the coated specimens. Hence, the base metal (St52) is not suitable for industrial uses requiring a good wear resistance; and a hard facing operation is required to improve its wear resistance. In a study conducted by Lin et al. on the effect of coating a high carbon chromium base alloy through the GTAW process, the results showed that with an increase in the carbon percentage of the coating from 2.3% to 5.9%, the wear resistance improved due to the increased volume fraction of M_7C_3 carbides present in the coating [8]. In addition, in another study conducted by Coronado et al., they reported that the increased volume fraction of carbides improved the wear resistance [15].

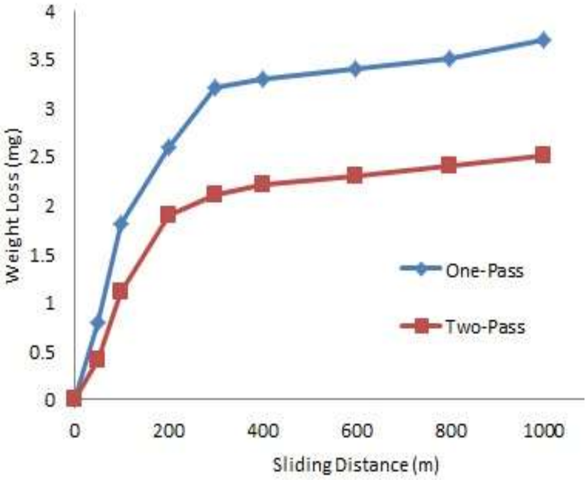
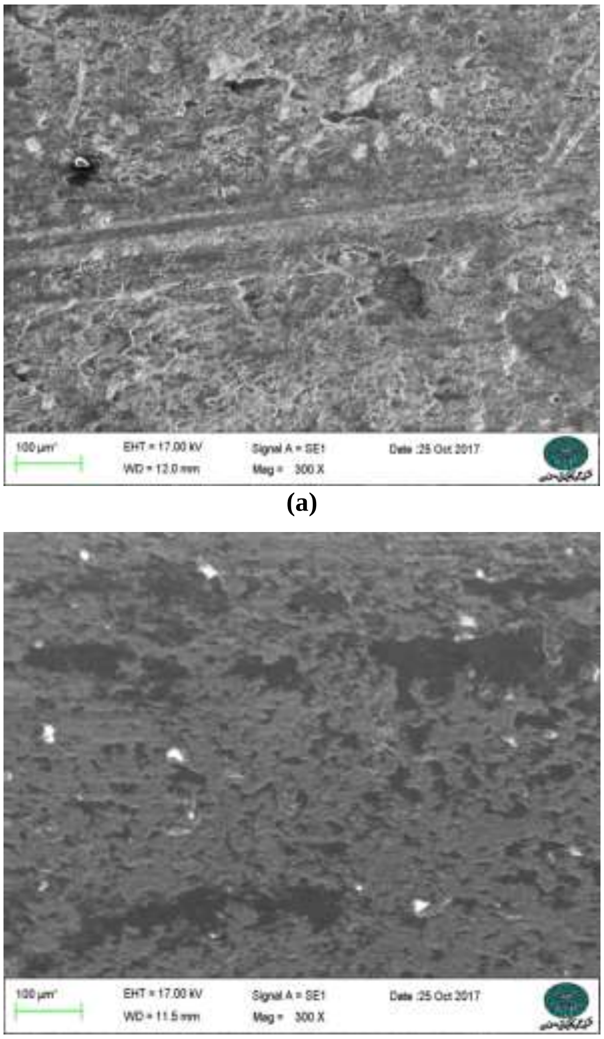


Fig. 6 Variation of the mass loss of coated specimens as a function of wear distance.

Figure 7 shows SEM images of the worn surface of specimens. The examination of the images suggests the occurrence of an adhesive wear mechanism in the specimens. As it is clear, the degree of adhesive wear has decreased in the two-pass specimen due to the increased percentage of carbides and the increased hardness in the two-pass specimen in comparison to those in the one-pass specimen. Therefore, the increased volume fraction of carbides and thus the increased hardness are factors that improve wear resistance in the two-pass specimen in comparison to that in the one-pass specimen.

In studies conducted by Fontalvo et al. on tool steels, an increase in volume fraction and a decrease in spaces between carbides resulted in a decreased adhesive wear rate [16]. In addition, adhesive wear is directly proportional to the applied force and inversely proportional to hardness [17]. Yang et al. considered the increased hardness in the steel surface the main factor in adhesive wear resistance [18]; therefore, in the present study, wear resistance improves due to an increase in the volume fraction of carbides and an increase in hardness, thus a lower degree of adhesive wear is observed in the two-pass specimen.



(a)

(b)

Fig. 7 SEM micrographs of worn- out surfaces of specimens: (a): one-pass and (b): two-pass.

4 CONCLUSIONS

1. The findings of the study showed that the structure on the surface of coated specimens consisted of M_7C_3 carbides in the eutectic matrix (γ+M_7C_3).

2. By increasing the number of passes from one to two, the degree of iron dilution in the coating decreases, while the chromium dilution increases. Thus, the percentage of chromium carbides increases in the two-pass specimen in comparison to that in the one-pass specimen, which increases hardness and wear resistance in the two-pass specimen in comparison to those in the one-pass specimen in a way that the hardness of the surfaces of the specimens reaches from 780 HV in the one-pass specimen to 910 HV in the two-pass specimen, and weight loss in the wear test reaches from 3.7 mg in the one-pass specimen to 2.5 mg in the two-pass specimen.

3. The dominant wear mechanism in the specimens is the adhesive wear mechanism. Adhesive wear decreases in the two-pass specimens due to the higher hardness and the increased volume fraction of carbides.

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