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$TiC/Cr_{23}C_6$ Composite Coating on 304 Stainless Steel and Its Tribological/deteriorative Properties Investigation

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Abstract

The aim of this work is evaluation of corrosion behavior of SS 304 coated through TIG process. In this work, Ti tube cored with graphite powder was applied. Experimental processes were shown that the optimum parameters for coating procedure are voltage of 15V, current density of 120A and the speed of 2.1mm/s. Investigations on corrosion resistance of coating are shown that not only this composite coating can improve the tribological behavior of this type of stainless steel, but also there is an improvement in its deteriorative property. Moreover, it is observed that mass reduction in coating is 5 times lower than the base metal.

Keywords: Corrosion Resistance; TIG, Hardness; Wear Resistance; SS 304

1. Introduction

Stainless steels are highly applicable when the strength, toughness and corrosion resistance are required at the same time. However, weak tribological properties such as low hardness and wear resistance may restrict their applications [1-3]. Different processes have been designed in order to improve these properties in steel parts. Generally, these properties are called as case hardening. Case hardening is a process which has to be done at the final stages of manufacturing and after all steps including forming, machining and etc[4-7].

The general principle of this process is conversion of the sample surface into a hard phase[7]. Recently, several surface modification processes such as, physical and chemical vapor deposition, electron and laser beam deposition and Ion Implantation have been employed [8-10]. However, all these procedures require high production time. Likewise, a thin layer on the surface will from through these processes [11].

However, for depositing a relatively thick layer on the substrate, electron and laser beam techniques has to be employed which are capable to generate concentrated heat [9, 12, 13]. On the other hand, high primary price of equipment, the need for vacuum chamber and high production cost are among the parameters limiting their application.

Recently, TIG process has been applied for improvement of surface properties[14]. In this process, in order to produce high heat in a short time, a torch with suitable power is passed over the substrate[15, 16]. Consequently, a melted layer will be developed on the surface and because of rapid solidification of this layer; a metallurgical bond will form with the substrate[17, 18]. Saving in cost, material, energy and high accuracy of the procedure are amongst the most important advantages of this technique.

In this project, at first, the cored wire was produced using Titanium strip and graphite powder and later a composite layer was formed on the surface of SS 304 via TIG process. Finally, wear resistance, hardness and corrosion resistance of coating were examined.

2. Experimental Procedures

In this study, SS304 with dimension of 16 × 5 cm² and 10 mm thickness was selected as substrate. The chemical analysis of the specimen is highlighted in table 1. To begin with, the surface was cleaned from any kind of oil and pollution by polishing and alcohol washing. After that, in order to approach a smooth surface, 4 coating series with the length of 10 cm, were produced close to each other on the substrate through TIG process by provided cored wires.

Elements	Fe	Cr	Ni	C	Si	Mn	N	S	P
Portion (%)	70.99	18.00	8.00	0.08	0.75	2.00	0.10	0.03	0.05

Table 1. Chemical analysis of stainless steel (304).

Cored wires were applied in order to produce coating with intended chemical composition. Swaging and wire drawing machine (Figure1 and 2) were employed to produce these electrodes using graphite powder and Titanium strip (10 × 0.8 mm). Titanium strip and graphite powder are two fundamental constituents of the electrode. In order to increase the formability for drawing process, heat treatment for two hours at 780 °**C** was applied on it. Three wire drawing steps were utilized to produce cored wire electrodes. At the beginning, 30 cm Titanium strip was swaged to pass from the die and place within the grip of the machine. Swaging is the most difficult and sensitive operation in cored wire production and most of ruptures will take place at this level.

The external diameter of the die at the first drawing step was 5 mm which after passing of the strip it was transformed into the U-shaped (suitable for adding powder). The second die diameter was 4.1 mm. the U-shaped wire was crossed into containers filled with powder with two holes in front of each other and drawing was done that was caused powders were transmitted into the U.

3.5 mm diameter die was chosen as the final period of drawing which U shaped wire filled with powder was converted in to O shape and as a result, the electrode with diameter of 3.5 mm was produced which is suitable for welding (coating) process.

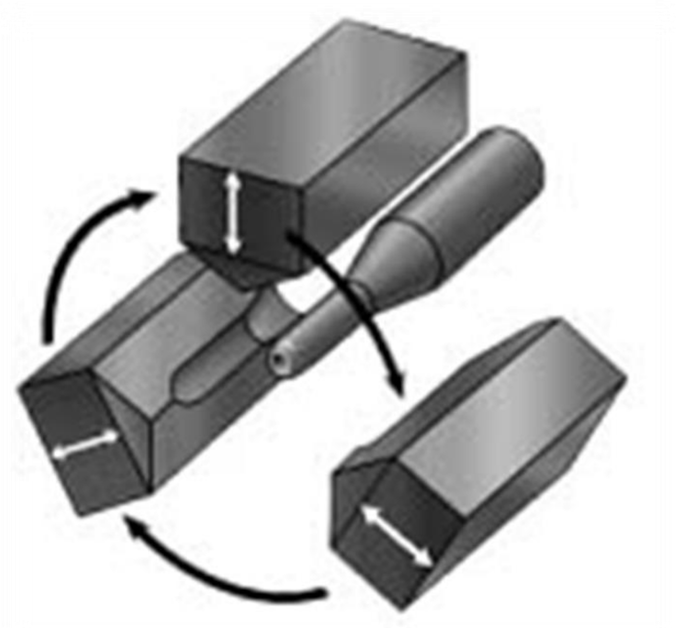

Figure 1. Schematic figure of swaging process.

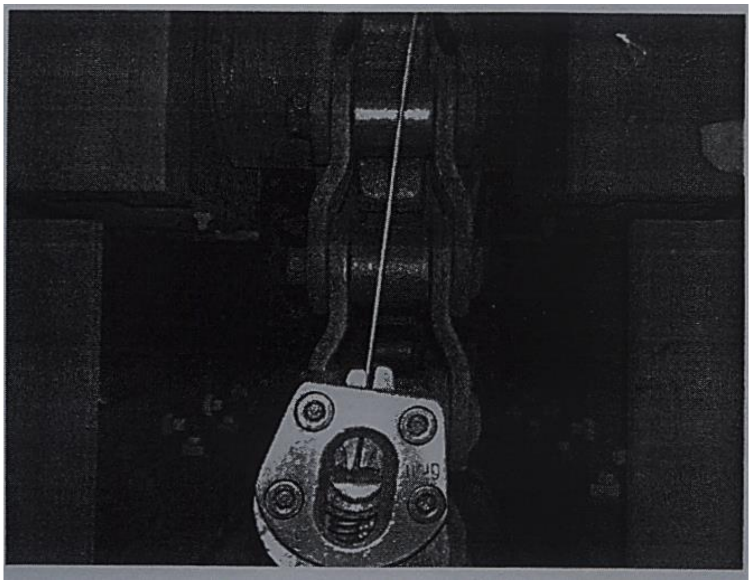

Figure 2. wire drawing machine.

Coating procedure via TIG process and cored wire filled with graphite powder was done which the related image is highlighted as Figure 3. Tungsten electrode with the diameter of 2.4 mm was chosen for this project. Also, DCEN was applied as the current polarity to reduce the heat at the tip of the electrode. Argon gas flow in this process was 12 lit/min for the efficient protection during the process. And the arc length was 2mm. According to the previous work of this research group [19], the voltage and Amperage of 15V and 120A, respectively and travel speeds of 1.03, 2.1 and 3.17 mm/min was chosen as optimum TIG parameters.

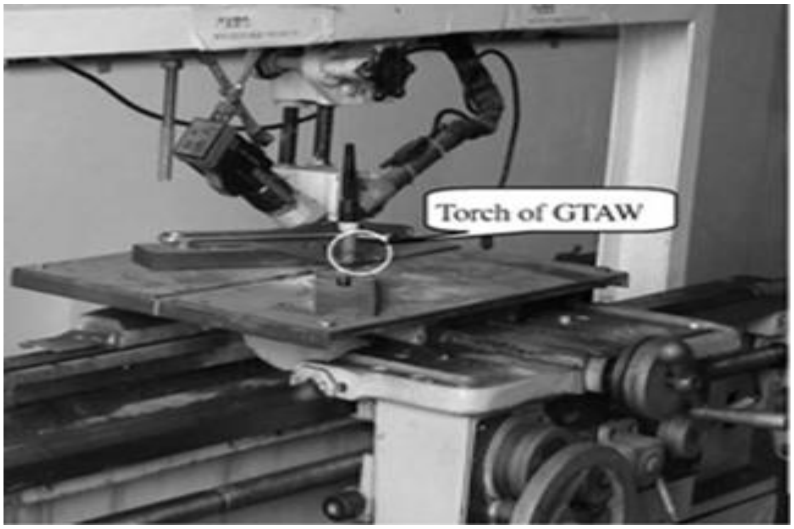

Figure 3. TIG Cladding Machine
(LS-18 Miller)

After this process, coated samples were sectioned for microstructure evaluation, micro hardness and wear test. Nital solution was applied as etch solution for microstructure observation. Also, micro hardness (Nikon QM) and pin on desk machine were applied to examine the hardness and wear resistance, respectively. In order to measure the hardness value, 100 gr loads were applied for 15 secs and for evaluation the corrosion resistance of coating, Polarization test (NaCl 3.5 %) was utilized. Moreover, microstructure assessment of surfaces after corrosion test was done via SEM (TESCAN Mira3).

3. Discussion and Conclusion

According to the results from previous work of this group [19], it was determined that main phases of the coating developed via TIG process, are TiC, $Cr_{23}C_6$, Fe_3C and austenitic texture which TiC, $Cr_{23}C_6$ are phases with black color while gray phase is Fe_3C and the white texture is Austenite. Also it is proved that there is just few amount of $Cr_{23}C_6$ [19].

1- The effect of deposition speed on microstructure

In this part, the effect of welding speed on the amount and size of the composed phases in the layer will be discussed. Figure 4 (a-c), illustrates different coatings produced by different welding speeds. As it is clear, the size and volume of TiC/ $Cr_{23}C_6$ particles is decreased by reduction of the heat input and consequently dilution rate as well as reduction in the amount of melted base metal. Therefore, it can be concluded that at higher speeds considerable amounts of TiC/ $Cr_{23}C_6$ is formed (as it is mentioned in the previous research of this group[19], supplied Cr is from the base metal and as a result, the amount of Cr in this carbide mixture will reduce because of the reduction in dilution rate.) which these particles will be bounded together during solidification and form larger phases, however by decreasing the welding speed, this phase would be better dispersed because of higher rate of base metal melting and the amount of large TiC/ $Cr_{23}C_6$ particles will be decreased[2] .

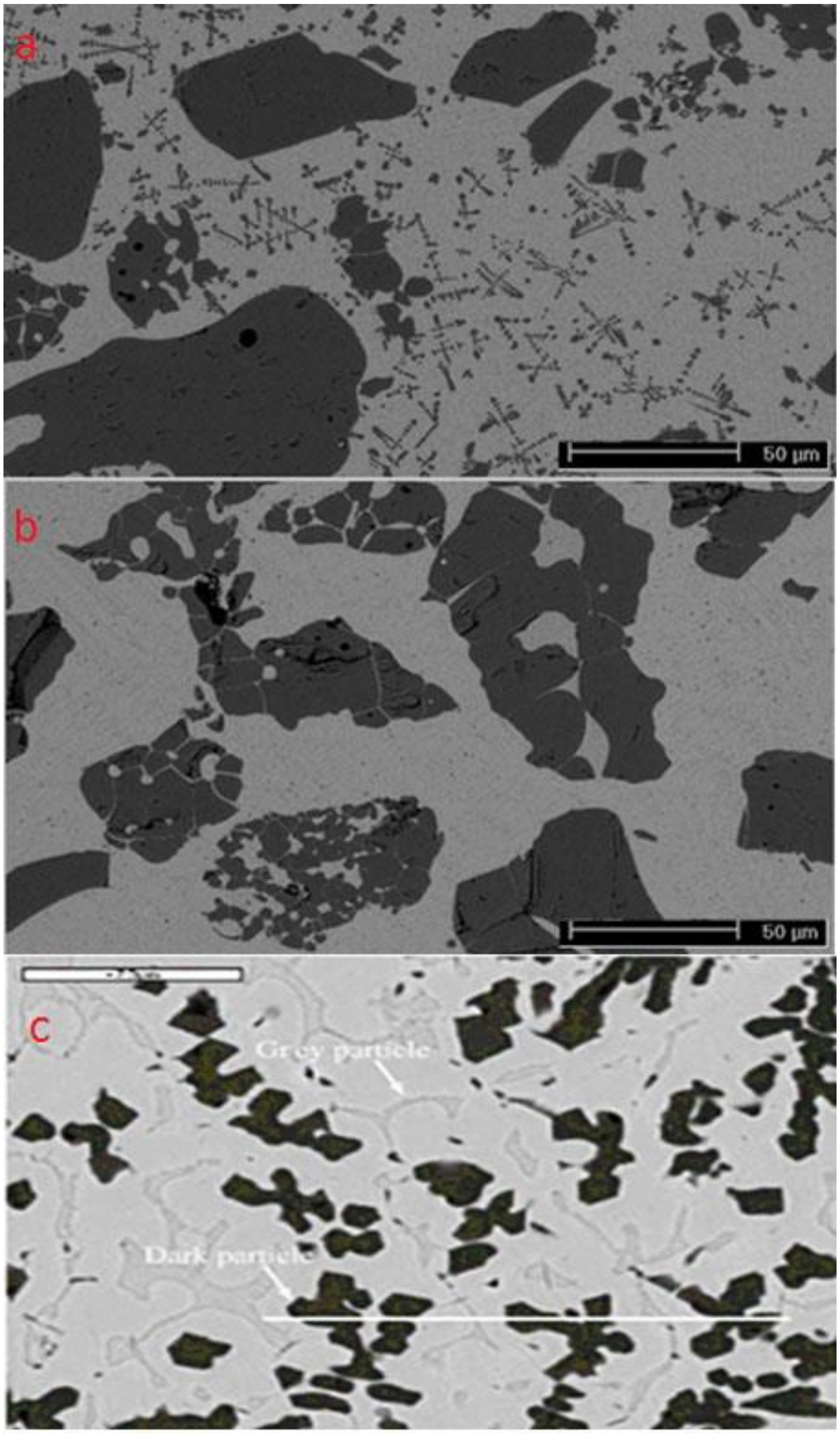

Figure 4.a) Microstructure of composite coating in the speed of 1.03 mm/s and current of 120 A (500x). b) Microstructure of composite coating in the speed of 2.1 mm/s and current of 120 A (500x).c) Composite coating microstructure in the speed of 3.17 mm/s and current of 120 A (1000x)[19].

2- The effect of speed on hardness and wear resistance

As it is proved in the previous work, the maximum level of hardness belongs to the composite coating developed by the current of 120A and speed of 3.17 mm/s (Figure 5). Also here it is determined that by increasing the welding speed because of reduction in dilution rate, there is an increment in the volume and amount of Ti/C phase in coating which causes hardness enhancement.

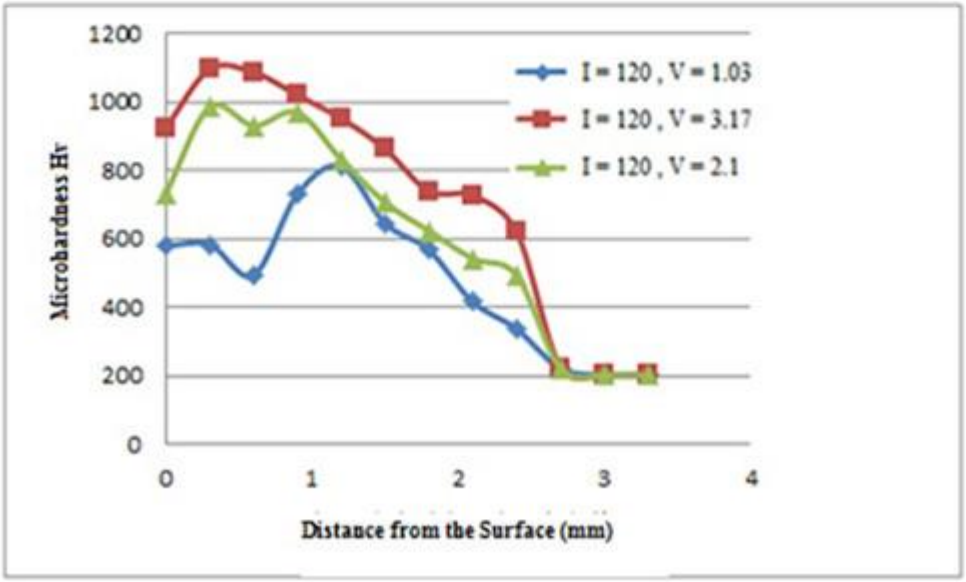

Figure 5. Changes in Microhardness Based on the distance from the coating surface at I=120A and different speeds.

Three parts of substrate, heat affected zone and coating are basically evaluated in these diagrams. Base on the previous work [19], Depending on the welding speed, hardness of coating would be between 3 to 5.5 times more than the substrate hardness and there is no specific trend in the hardness increment of coatings.

Wear test (pin on desk) was applied on samples coated by the current of 120A and the speed of 3.17 mm/s. friction coefficient of this sample compared with the sample without coat is

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almost 0.2 lower which this reduction with by increasing in hardness is related to the formation of mixed and hard phase of Ti/C in the coat which acts as lubricant and reduces the friction between two surfaces. As it can be seen in the weight loss diagram, the amount of weight loss in the coat after coating deposition is considerably decreased (Figure 5). As a result, the optimum condition would be the current of 120A and speed of 3.17 mm/s.

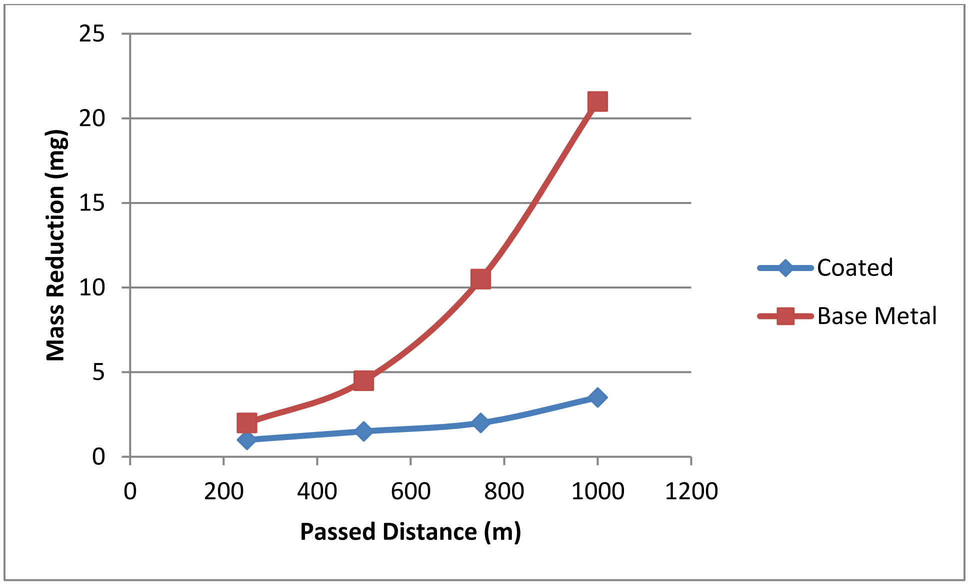

Figure 6. Mass reduction for the base metal and the coated sample

3- Corrosion resistance investigation of the optimal coating

Figure 7 shows the polarization behavior of coated and non-coated sample. It is clearly seen from the polarization diagram that the sample coated with the composite layer is over 0.08 V more positive or noble than the non-coated substrate. This shift of corrosion potential in the noble direction indicates an increased in thermodynamic stability of the coated specimen. Another marked feature observed from this polarization diagram is that the peak passivation current density for the coated sample is reduced by over 2 orders of magnitude when compared with the passive potential range of the substrate. It is due to the fact that the amount of Cr consumption (passivate parameter of stainless steel surface) for carbide formation in the composite coating is not high.

As it is mentioned in the previous work [19], the main carbide producer factor (black phase) is Ti element, as a result, very little amount of Cr content in the substrate is consumed for carbide formation and the majority of this element is remained as substituted element in the austenitic substrate. Consequently, there is no restriction for Cr element to play its key role for passive layer formation ($Cr_{23}C_6$) on stainless steel surface and beside its protective effect, this layer can develop the corrosion behavior of the coated sample.

Moreover, microscopic observation via SEM is shown that after coating deposition, there is an improvement in corrosion behavior of the surface in NaCl (3.5%), this phenomenon is also evidence implies there is no change in corrosion behavior of coating compared with the substrate.

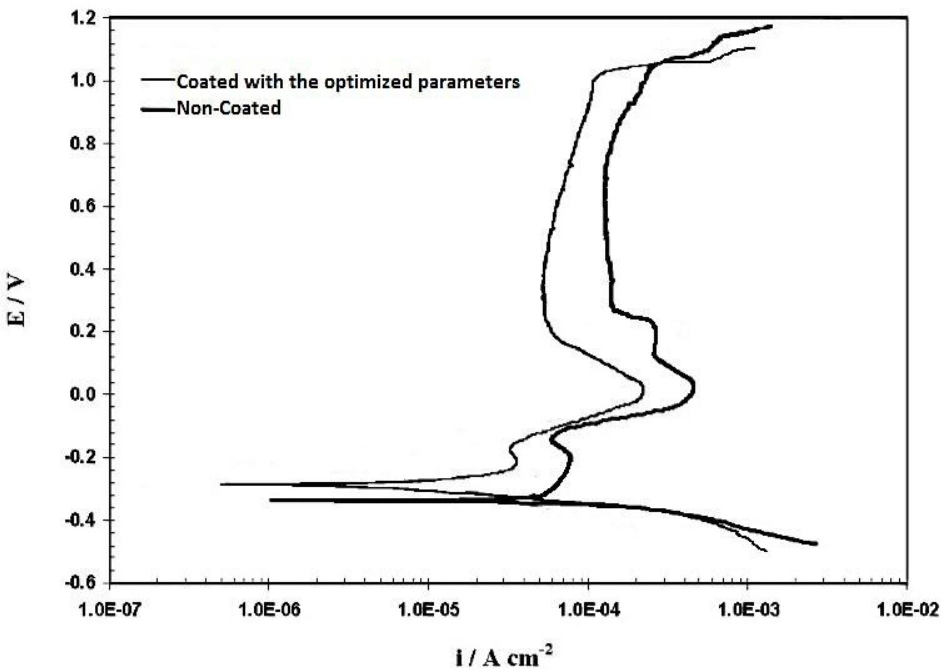

Figure 7. Polarization Curve in 3.5% NaCl solution.

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Conclusion

1. Experimental investigation implied that there is positive effect on corrosion resistance of material from produced coating layer; as a result, this process can be applied in order to develop a hard and wear resistance coating in order to improve tribological properties as well as deteriorative properties of SS 304.
2. The coating is mainly composed of TiC/Cr23C6/Fe. The microstructure of composite layer includes TiC and Cr23C6 particles besides traces of Fe3C in austenitic matrix.
3. Experimental results revealed 5 times decrement in mass reduction of coated substrate compared with the sample without coating which is due to adequate adherence of coating to the base substrate and much better wear resistance of composite coating compared with the base metal.
4. It is observed to be the best TIG parameters are voltage of 15V, 120A current density and travel speed of 2.1 mm/s.

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