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Effect of SiC Particle Size on Hardness and Wear Behavior of TIG Melted Hard Surface Layer AISI Duplex-2205 Steel

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Abstract:

The formation of hard surface layer on AISI Duplex-2205 steel provides a protective coating against wear application. In the present work, SiC particle size with average sizes of 20 µm, 60 µm and 100 µm were used as surface preplacement to AISI Duplex-2205 surface. The purpose of the study is to evaluate the influence of different SiC particle size melted at heat input of 768 J/mm on hardness and wear behavior. The surface characterization, hardness and wear behavior were conducted using scanning electron microscopy, Vickers micro-hardness and reciprocating wear tester, respectively. Characterization of the TIG melted layer reveals the existence of new phases containing a dendritic structure. The surface hardness developed 4 to 6 times higher than substrate hardness (250 Hv) depending on the dendrite population. The SiC particle size of 100 µm produced lower friction value of 0.37 and wear rate of 2.3 x 10-4 mm3/Nm compared to 3.2 x 10-4 mm3/Nm for 20 µm particle size. The improvement of wear properties is correlated well with the increased hardness value of TIG melted hard surface layer AISI Duplex-2205 steel.

Keywords: *Duplex-2205 Steel, hardness, SiC particle size, TIG torch*

I. INTRODUCTION

Duplex stainless steel (DSS) is widely used materials due to various advantages, which includes its superior mechanical properties, inexpensive manufacturing cost and ease of fabrication.However, DSS facing some disadvantages in the service due to lower hardness and poor wear resistance when exposed to tribological applications. Recently, the DSS grade of AISI Duplex-2205 grade has attracted a lot of attention due to this grade is low cost and weight savings (pressure vessels) compared to austenitic AISI 316L. In addition, the AISI Duplex-2205 grades represent nowadays about 85% of the total DSS production [1]. In order to widen the application, this material is necessary to withstand the continuous tribological conditions without wear and damage of the materials such as bearings, valves and pumps where one contacting metal surface moves relative to the other [2]. To improve the efficiency and service life, this material required treatments to enhance the surface characteristics in terms of hardness and wear behavior by the formation of new hard surface layer.

The incorporation of ceramic materials to produce a hard surface layer is a attractive method because it can tailor the surface to meet the requirements for various applications. This approach considered as a new development of surface modification that involves dispersing ceramics particulate into the metal surface. Surface melting by incorporation of ceramic particles can produce a hard surface layer that can enhance the surface hardness and tribological behavior of material [3]. In this process, the ceramic particles with a suitable composition deposited uniformly onto the surface of the metal surface. Previous researchers discovered that incorporation of ceramic particles such as tungsten carbide, WC [4], titanium carbide, TiC [5] and silicon carbide, SiC [6] with the metal surface through melting process can improve the hardness and behavior of substrate material. Due to good chemical stability, high melting point and high hardness of SiC, it can be used as coating reinforcement for surface modification to improve the surface properties [6]-[7]. In order to melt ceramic particles and substrate material, the heat sources such as laser cladding, electron beams or tungsten inert gas (TIG) torch are used to produce the hard surface layer [8].

TIG is one of popular and cleanest melting processes for surface modification. The heat input is needed to melt the workpiece by striking an electric arc with the metal surface [9]. The most advantages of the melting process is the elimination of interfacial incompatibility of the base material based on their nucleation and growth from the parent matrix phase. This TIG surface melting process is simpler and cheaper to establish, less time consuming and flexible in operation compared to laser cladding process [10]. In previous work by Lailatul and Maleque [11] demonstrated that hardness of DSS material has improved by melting of 20 µm SiC particle size and substrate material using TIG torch process. The improvement developed hardness about 2 to 4 times higher than substrate DSS. It was demonstrated that the improved surface DSS produced better wear behaviour with lower coefficient of friction (about 2 times lower) and wear weight loss than the substrate DSS.

In this paper, the SiC ceramic particles were preplaced on AISI Duplex-2205 steel and melted using TIG torch process. This study used three different SiC particle sizes (20, 60 and 100 µm) at constant heat input of 768 J/mm to investigate the effect of SiC particle size on the microstructural features, microhardness and tribological properties of AISI Duplex-2205 using TIG torch melting.

II. EXPERIMENTAL PROCEDURE

Duplex stainless steel (DSS) with a grade of AISI Duplex-2205 was used in this study. The shape of this material was rectangular, supplied by Outokumpu, Mitsui Sumitomo, Tokyo Japan. The material was cut into a smaller size of 50 mm x 33 mm x 10 mm using electrical discharge machine (EDM). The ceramic particle used in this study was silicon carbide (SiC) supplied by Innovative Pultrusion Sdn. Bhd. This particle was used for surface preplacement of substrate AISI Duplex-2205 steel. The silicon carbide comprises of three different particles sizes with average sizes of 20 µm, 60 µm and 100 µm. The reason of using a variation of particles size is based on fine particle size (20 µm), intermediate particle size (60 µm) and coarse particle size (100 µm) as mentioned by Maleque et al. [12]. These variations are required to observe the effect of different particle size on the DSS surface characteristic in terms of microstructure, hardness and wear behavior.

In order to meet this requirement, the SiC ceramic particle was preplaced on the surface of substrate material before TIG torch melting. The SiC powder was weighed at the proportion of 0.5 mg/mm^2 was mixed with two drops of binder poly (vinyl acetate) and preplaced onto the dry surface of substrate material. The binder was used to prevent the powders from blowing away during TIG process under the flow of argon gas [8]. In order to remove the moisture before TIG torch process, the preplaced sample was dried at 80 ºC in the oven for 1 hour. This is importan to vaporize the binder before TIG torch process and to keep the SiC particle size preplaced on the surface during TIG melting process[13]. After drying process, the preplaced sample was allowed to cooled down at room temperature before TIG process.

The melting process was conducted using Telwin Technology TIG 165 machine at constant heat input of 768 J/mm. During melting process, the 99.9 % pure argon gas was used as a shielding gas to protect the melt track from excessive oxidation. A tungsten thoriated electrode was used to strike an arc between the electrode and preplaced sample. The single track of TIG melted layer was conducted for surface characterization while multiple tracks, with 50% overlapping for wear testing.

After TIG torch melting process, the sample was ground and polished using 0.05 µm alumina paste. Then, the sample was etched using Kalling’s reagent for 10 seconds and washed thoroughly with running water to reveal the microstructure. After that, the microstructural features of the hard surface layer was analyzed using JEOL JSM5600 scanning electron microscope (SEM). The Wolsen Wolpert Vickers micro-hardness test was carried out using pyramid

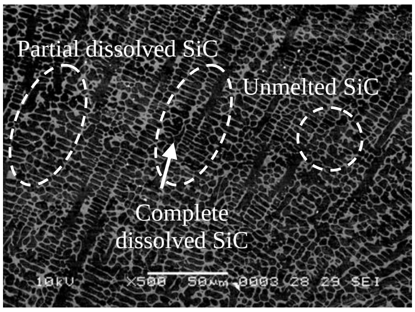
May – June 2020
ISSN: 0193-4120 Page No. 1392 - 1397

diamond indenter with a 500 gf load and 10 seconds indentation delay. The wear test without lubricant was conducted using ball-on-disc reciprocating tribometer with a frequency of 5 Hz and constant load of 30 N for 10 minutes according to ASTM D6079. The alumina ceramic ball with diameter of 6 mm and hardness value of 2000 Hv was used as counter-part material due to its high hardness.

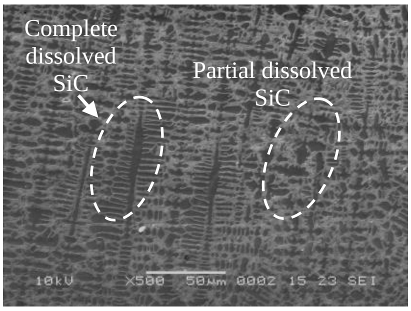
III. RESULTS AND DISCUSSION

A. Microstructural features of TIG melted hard surface layer

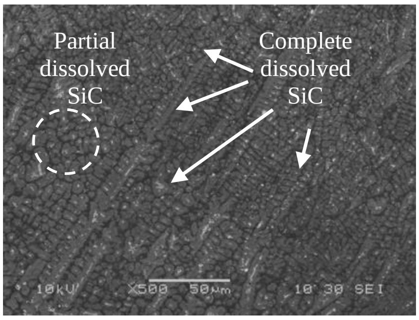
Microstructural features of TIG melted layer using different SiC particle size is shown in Figs. 1 (a-c). The SEM result revealed that the incorporation of SiC into AISI Duplex-2205 exhibited various dendrite microstructure population depending on the SiC particle size. Considering the 20 µm of SiC as the smallest particle size, the dendrite formation is fine and thin structure as shown in Fig. 1(a). It can also be seen that the population is low with a mixture of partial, un-melted and complete dissolved SiC in the melted layer. As compared to 60 µm particle size, the sample exhibited higher SiC population and distributed homogeneously in the matrix of AISI Duplex 2205 steel as shown in Fig. 1(b). Moreover, the larger particle size of 100 µm exhibited more compact SiC population and dissolved uniformly in the melted layer as shown in Fig. 1(c). This phenomenon is contributed by larger particle size resulting in more ceramic particles melted and dissolved in AISI Duplex 2205 steel matrix.



(a)



(b)



(c)

Fig. 1. SEM micrographs for TIG torch melted hard surface layer using SiC particle size of (a) 20 µm, (b) 60 µm and (c) 100 µm

B. Vickers micro-hardness profile of TIG melted hard surface layer

The micro-hardness values plotted against the melt depth from surface using different SiC particle size is shown in Fig. 2. The measurement was taken from the middle of the TIG torch melted AISI Duplex 2205 steel downwards into the depth of the melt pool. The surface hardness produced 4 to 6.5 times higher than substrate hardness (250 Hv) depending on the dendrite population. It is believed that dendrite formation contributes to the increment of hardness value as discussed earlier in SEM results.

The hardness profile shows a gradual decreasing trend from the top melted surface to the bottom of the melt pool which believed to be related to a decreased dendrite population. It is also confirmed by previous researchers [14]-[15]. It can be seen that the lowest surface hardness of 1000 Hv was achieved in the sample using 20 µm SiC particle size. This is attributed to the mixture of unmelted, partial and complete melting of SiC particulates on AISI Duplex-2205 with a low population of dendrite formation as shown in Fig. 1(a). Furthermore, the surface hardness increased to 1300 Hv using 60 µm SiC particle size due to a more compact and higher population of dendrite formation compared to 20 µm SiC particle size. The highest surface hardness value of 1644 Hv was achieved in the sample using 100 µm SiC particle size. This is believed to be contributed by the larger SiC whereby larger particle size are dispersed and distributed homogenously in the AISI Duplex 2205 steel matrix and very high dendrite population in the microstructure as shown in Fig. 1(c).

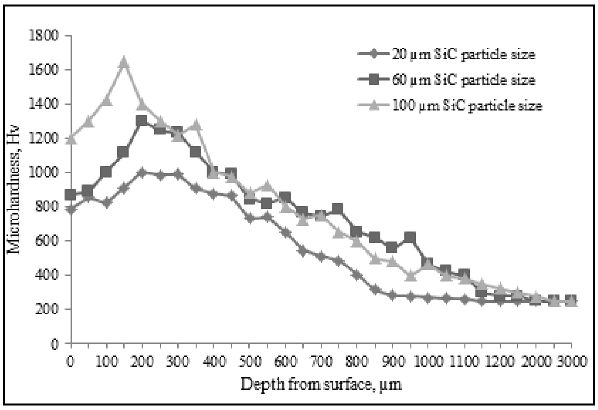


Fig. 2. Hardness profile for TIG torch melted hard surface layer using 20 µm, 60 µm and 100 µm SiC particle size.

C. Wear rate and coefficient of friction of TIG melted hard surface layer

Figure 3 shows the wear rate of TIG torch melted layer at heat input of 768 J/mm using different SiC particle size of 20 µm, 60 µm and 100 µm. It was found that the highest wear rate was obtained in sample 20 µm SiC particle size with wear rate value of 3.2 x 10^{-4} mm^3/Nm. For 60 µm SiC particle size, the wear rate value is 3.0 x 10^{-4} mm^3/Nm, while for 100 µm SiC particle size attained the lowest wear rate value of 2.3 x 10^{-4} mm^3/Nm. This is attributed to the formation of higher hardness due to the high population of dendrite structure. The main reason for this phenomenon contributed by the larger particle size of 100 µm producing a compact and well distributed of dendrite population in the melted layer.

Figure 4 shows the average coefficient of friction (CoF) of TIG melted layer for 20 µm, 60 µm and 100 µm SiC particle size at heat input of 768 J/mm. It was revealed that the highest CoF of 0.45 was obtained in sample 20 µm SiC particle size, while for 60 µm SiC particle size, the CoF value reduced to 0.43. Furthermore, the 100 µm SiC particle size attained the lowest CoF value of 0.37. This is attributed from the higher hardness due to the high population of dendrite structure. This phenomenon coincides from previous finding which described that the presence of TiC particle in titanium alloy had successfully reduced the CoF of the material due to the enhancement of hardness values [14]. The obtained results support the use of SiC ceramic particle as a barrier to the load and rubbing action from alumina ceramic ball to the AISI Duplex 2205 steel matrix. SiC ceramic particle is responsible for the reduction of the contact area on the matrix with the counter-face material of alumina ball, thus minimizing the rubbing effect of the TIG torch melted layer.

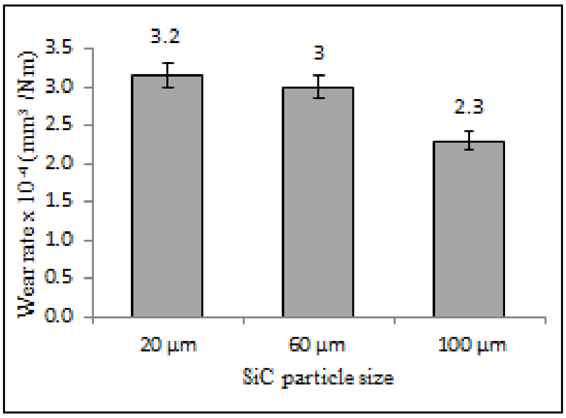


Fig. 3. Wear rate for TIG melted hard surface layer using 20 µm, 60 µm and 100 µm SiC particle size

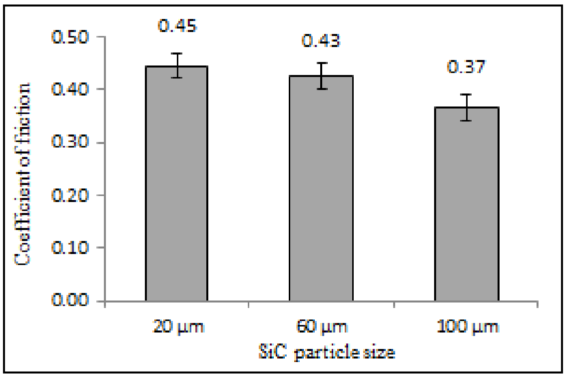


Fig. 4. CoF for TIG melted hard surface layer using 20 µm, 60 µm and 100 µm SiC particle size

IV. CONCLUSION

In present work, the TIG melted hard surface layer successfully developed with the incorporation of SiC ceramic particles on AISI Duplex-2205 surface via

May – June 2020
ISSN: 0193-4120 Page No. 1392 - 1397

TIG torch process. The characterization results reveal the existence of new phases containing a network of dendrites and precipitated SiC particles. The significant improvement of hardness can achieved between 1000 to 1644 Hv. The wear resistance of the TIG torch melted layer has improved with the reduction of wear rate and CoF indicating the hard surface layer able to withstand the wear reciprocating action. The hardness and wear behavior of TIG torch melted hard surface layer found to increase with the increment of SiC particle size. This phenomenon is contributed by larger SiC particle size resulting more ceramic particles melted and dissolved in DSS matrix.

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TEST Engineering & Management

May – June 2020
ISSN: 0193-4120 Page No. 1392 - 1397

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