INFLUENCE OF THERMAL INPUT ON MICROSTRUCTURE AND WEAR PROPERTIES OF SURFACE ALLOYED DSS WITH SIC BY TIG MELTING TECHNIQUES

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Abstract. In arc TIG torch welding, thermal input is important because it affects the thermal efficiency and quality of the welded materials. A change in the microstructure with the deposition of ceramic particles can have a direct effect on the improvement of wear properties of a surface alloying using various thermal input of TIG torch welding. This work is required due to the limitation of AISI Duplex-2205 which has weaknesses in wear properties during application. In this work, this material was surface alloyed with addition of SiC ceramic powder with particle size of 100 µm and melted using different thermal input of TIG torch melting heat source to improve the microstructure and wear properties. Microstructural analysis, micro-hardness and wear properties were conducted on this material at different thermal input conditions. The obtained microstructural examination was correlated with corresponding hardness and wear properties, which were determined from morphological, hardness value on the top surface and wear rate evaluation. The highest hardness with value of 1600 Hv and wear rate with value of 2.3 x 10^{-4} mm^3/Nm was obtained in the sample fabricated under thermal input of 0.768 KJ/mm. The microstructural changes observed on the surface alloyed DSS with the formation of dendrites microstructures due to re-solidification between AISI Duplex-2205 and SiC ceramic particles which indicated the good hardness properties against wear degradation in tribological applications.

Keywords: Thermal input, microstructure, wear, surface alloyed, TIG torch

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1. INTRODUCTION

Surface alloying is a frequently used technique to enhance the surface characteristics of agricultural implements, mining operation components, soil preparation equipment, and others [1]. By adding powder with pertinent composition, steels can be surface alloyed. During this process, the alloy powder and a thin film of the substrate material's surface are concurrently disintegrated and quickly coagulated to create a packed surface coating that is metallurgically linked to the substrate. Chromium, titanium, and tungsten are a few alloying elements that may be added before base materials are alloyed [2]. Hard facing alloys have been extensively employed in high-energy density sources such as electron beam, plasma arc, and laser process [3-4]. Tungsten inert gas arc (TIG) melting process is one of the most efficient and cost-efficient welding deposition processes for use in wear applications. This technique provides a several advantages such as great deposition rate, great mobility, flexible, low cost, and compatible with a variety of materials [5-6]. A unique option for non-equilibrium material synthesis and the production of rapidly coagulated delicate microstructures with expanded solid solutions of alloying elements was made possible by TIG surface alloying in conjunction with rapid heating and freezing rates.

AISI Duplex-2205 duplex stainless steel (DSS) has the conjunction of great strength, excellent corrosion and heat resistance at 400 – 500 °C. Thus, it has been enormously used in fields such as petrochemical, automotive, aerospace and chemical manufacture [7]. However, DSS has deficiencies, such as its adverse hardness and wear properties. These are the elements that restrict the application of this material in wear conditions. In order to encompass the application of DSS, the improvement of its hardness and wear properties have been taken into account and noteworthy investigations have been conducted [8-9]. Producing preservative coatings is deliberated to be an appropriate and applicable surface modification approach to improve the hardness and wear properties of DSS [5-10].

Moi et al. [11] investigated the influence of arc energy input on the weldment without any addition of reinforcement of TIG specimens on 316 L austenitic stainless steel. In this work, three different heat input have been studied for various arc input of 0.75, 0.90 and 1.05 kJ/mm. Based on the finding demonstrates that the welded joint fabricated using 0.75kJ/mm shows the higher tensile strength and hardness value compared to other heat input. This condition is caused by the presence of smaller dendrite and low capacity interdendritic spacing in the weldment. Another work by Amuda and Mridha [12] studied the effect of arc energy input between 0.205 and 2.050 kJ/mm on microstructure and hardness of TIG weldment on AISI 430 ferritic stainless steel. It was discovered that controlling the grain size and microstructural features of the alloyed layer requires a low arc energy rate. At various energy heat inputs, the fusion zone's dendritic martensitic development was observed. The hardness values across the welds show the presence of carbide and the grain growth has decreased as heat input increases. Based on the work, it appears that soft zones with an integrating drop in the micro-hardness value have been produced by heat input levels greater than 1.5 kJ/mm.

The aforementioned studies indicate that thermal input is the important factor resulting in the material’s hardness properties of surface alloying process. It also demonstrates that the hardness properties are associated well with the microstructural transformation of the surface alloying. By now, there were very limited investigations concerning the effect of thermal input on microstructure and wear properties for surface alloying DSS using ceramic particulates and TIG torch melting techniques. In this work, a SiC/DSS surface alloying was conducted on DSS substrate using TIG torch melting method to improve wear properties of DSS. The effect of thermal input on the surface alloying was studied. The microstructure and elemental analysis were characterized. From this work, it is devoted to provide a new idea for the fabrication of surface alloying using ceramic particulates as the reinforcement for DSS surface and melted using TIG torch melting techniques.

2. MATERIALS AND METHODS

The rectangular shape of duplex stainless steel (DSS) with grade of AISI Duplex-2205 of size 50 mm x 33 mm x 10 mm have been chosen as a work piece in this investigation. The DSS plate's surface undergoes a milling procedure to remove any undesired material, such as swarf and manufacturing remnants, and create a consistent, flat surface for the sample. The sample was then carefully cleaned in acetone and running water after being ground using silicon emery paper.

The ceramic silicon carbide (SiC) particulate with particle size of 100 μm was utilized in this investigation as an alloying reinforcement to improve the surface features of DSS. Prior to TIG torch arc melting process, the SiC was deposited on the surface material for the purpose of surface alloying. By mixing two drops of polyvinyl acetate (PVA), one drop of alcohol and distilled water into the SiC particulates, the paste form was created and uniformly applied on the surface DSS. To remove the moisture and guarantee that the ceramic particles affixed inevitably to the substrate surface during the TIG arc melting process, the sample was dried in the oven for 1 hour while maintaining a temperature of 80 °C.

TIG arcing was used as a heat supply for the surface alloying process between the SiC paste and substrate material. In order to commence relatively more amount of heat on the substrate and avoid the contamination on the surface alloyed DSS, the tip of the electrode was placed at 1.0 mm above the surface of the sample, while commercial argon gas with 99.98% purity was used. Shielding gas with flow rate of 10 L/min was found to be an appropriate composition to avoid any putting out of the ceramic particulates. The illustration for the surface alloying using TIG arcing with the reinforcement of SiC has been shown in Figure 1. The surface alloying was implemented at varying thermal input as shown in Table 1. TIG melting techniques arcing was performed using an automatic travel guide to maintain the transverse speed steady during the surface alloying process. The thermal input (Q) was estimated as per equation 1, considering thermal input efficiency (n) as 0.48 [8]. This equation is according to BS EN 1011-1:2009.

$$Q = \frac{n \text{ x } C\,(A) \text{ x } V(V)}{T(mm/s)} \tag{1}$$

Based on the Equation (1), the symbol is expressed as C is the current, V is the voltage and T is the travel speed.

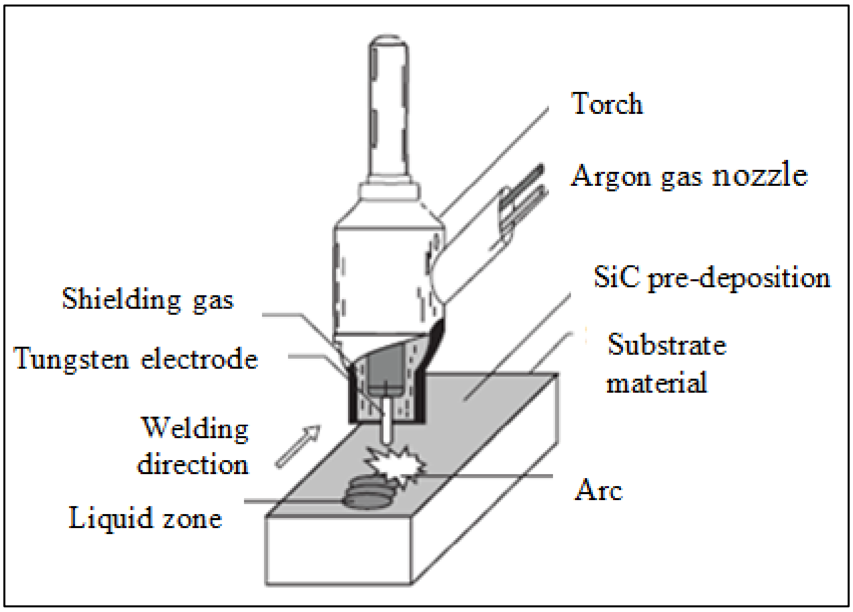

Figure 1: Ilustration of the TIG torch machine experimental setup

Table 1: Process parameter for various thermal input of TIG melting techniques

Sample	Current (A)	Voltage (V)	Travel Speed (mm/s)	Thermal input (KJ/mm)
1	100	20	2	0.48
2	80	40	2	0.768
3	100	30	1	1.440

First, sandpaper with different grit sizes of 120, 240, 320, 600, 800, 1200, and 2400 were used. This was followed by polishing operations on the sample using 0.3 µm and 0.05 µm alumina powder. Finally, the etching process was carried out using a Kalling's no. 2 solution (100 ml ethanol, 100 ml HCL and 5 gram $CuCl_2$) for 5 seconds. Scanning electron microscopy (SEM) using model JEOL JSM 5600 and energy-dispersive X-ray (EDX) spectroscopy using model ISIS were used for characterizing the microstructure and determining the presence of silicon and carbide.

A pyramid diamond indenter with a 500 gf load and a 10-second indentation period was used in a Vickers micro-indentation hardness tester (model: Wilson Wolpert) to measure the hardness values. By measuring the micro-hardness value at the middle region of the cross section, the hardness value of the surface alloyed of cross-section layer was determined. Each sample underwent five indentations, and the average measurement was considered as a result.

The surface alloyed DSS were wire cut by an EDM machine to a smaller size of 15 mm x 15 mm with a thickness of 6 mm for the wear test. Emery paper is used to smooth the contacting surface (overlapping tracks) of the TIG torch melting surface and remove any oil or fragments before testing. The sample is then set on the steel holder, which will hold it in place, while an alumina ceramic ball is connected to the ball holder as a counterpart substrate. Figure 2 shows the illustration of a reciprocating wear test machine. The wear test under dry condition is conducted using reciprocating tribo-meter with ball-on-disc mechanism. The constant load of 30 N and oscillation of 5 Hz for 10 minutes were used according to ASTM D6079. Furthermore, the worn mechanism after wear test is examined under SEM to scrutinize the worn surface morphology.

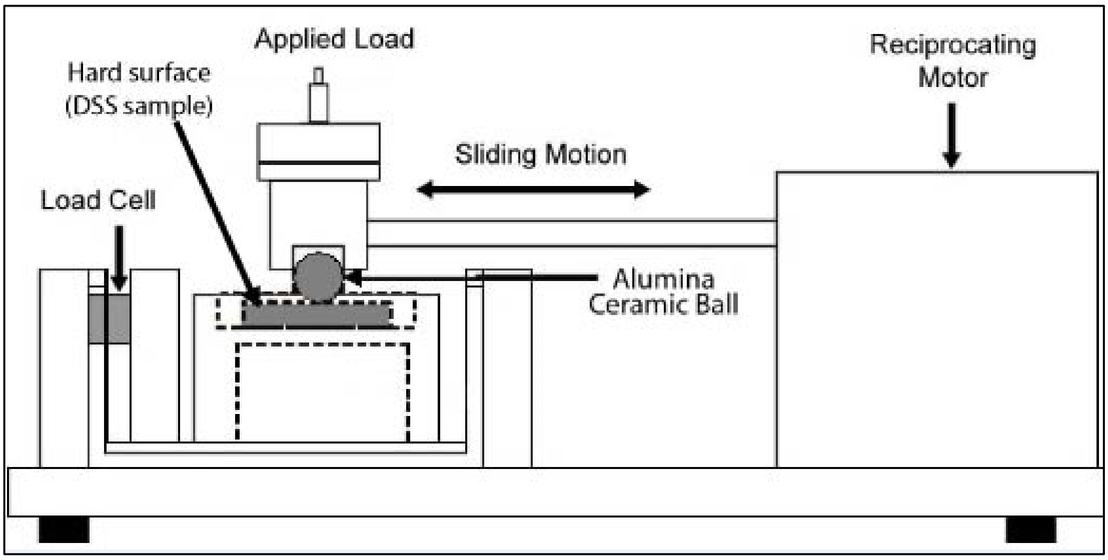

Figure 2: Illustration of reciprocating wear test machine

3. RESULTS AND DISCUSSION

3.1 Microstructural and Elemental Analysis

The cross-section microstructure of the surface alloyed DSS for various thermal input is shown in Figure 3. It can be seen that the re-solidification of SiC into DSS material exhibited various dendrite microstructure capacities depending on the thermal heat input. Figure 3(a) shows that surface alloyed DSS at thermal input of 0.480 kJ/mm, the SiC particles melted and dispersed within the matrix and after re-solidification seem to be black shaded equiaxed type or disrupted dendritic structure. At lower thermal input, the SiC particulates dissolved within surface alloyed DSS matrix along with the partially melted and complete melted surface of the steel substrate. Since, the melting temperature of SiC (2730 °C) is tolerably greater than the melting temperature of DSS (1420 °C), during the coagulation of the surface alloying, the dissolved SiC began to form equiaxed structures. Within the DSS matrix, there were several areas with disrupted dendritic structures where the cooling rate was fairly fast [13].

For a higher thermal input of 0.768 kJ/mm as depicted in Figure 3(b), the SiC particles are completely melted with very fine and highly populated embedded in the DSS matrix within the surface alloyed DSS. This outcome is in line with earlier research by [14] reveals that the increment of current and voltage promotes the material's hardness to be increased. The increase in hardness as discussed in microstructural observation is caused by dendritic development. Due to a suitable heat source and significant dilution between substrate DSS and SiC particulates, the SiC in this sample completely melted. On the contrary, in surface alloyed DSS using 1.440 kJ/mm (Figure 3(c)), as thermal input is excessively high, the employed heat becomes very aggressive to melt the entire SiC particles in the surface alloyed DSS. Therefore, this condition promotes a higher dissolution of SiC ceramic particles, leading to incomplete dissolved SiC and prolonged solidification time. Additionally, it indicates that there are less dendrites forming in this surface alloyed DSS compared to other samples.

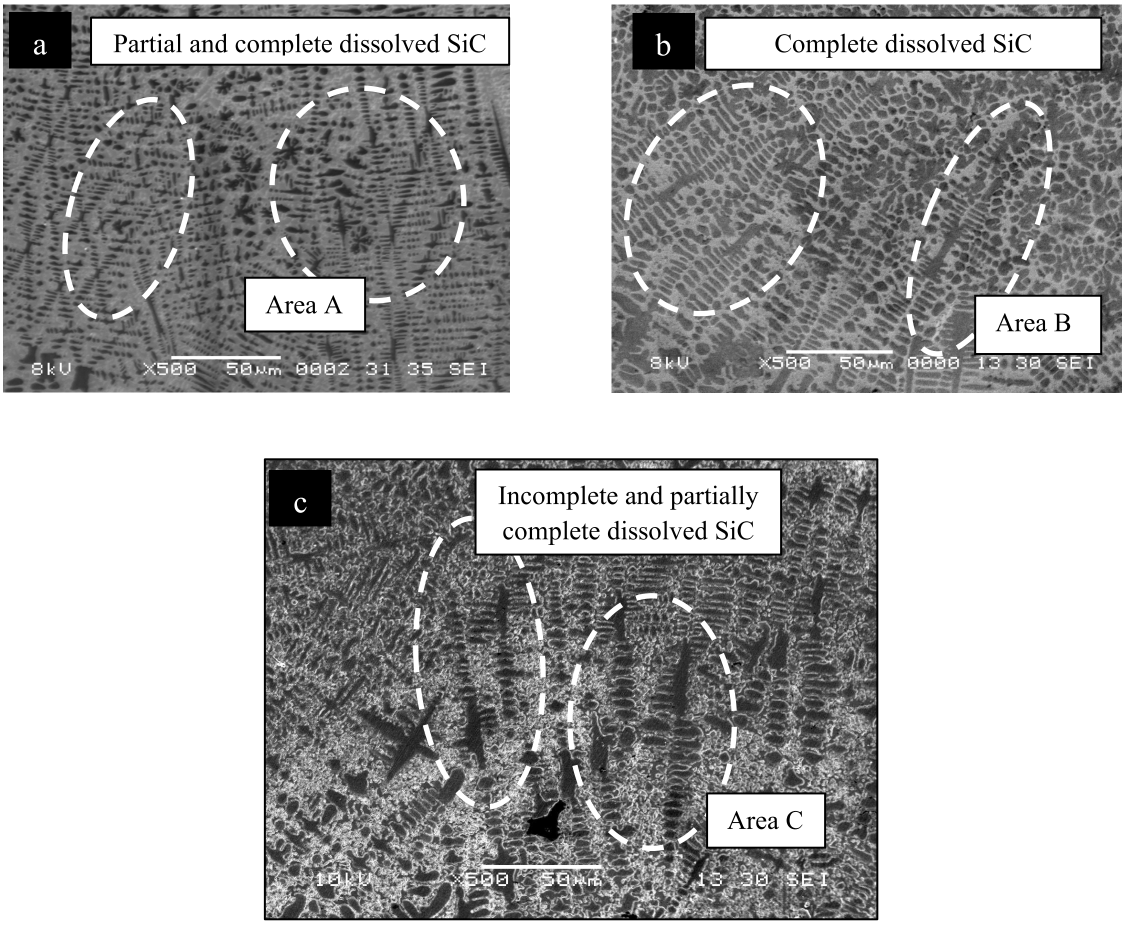

Figure 3: SEM micrograph of surface alloyed DSS for sample fabricated at thermal input of (a) 0.480 KJ/mm, (b) 0.768 KJ/mm and (c) 1.440 KJ/mm

The EDX spectra for surface alloyed DSS at various thermal inputs is shown in Figure 4. According to the EDX spectra presented in Figure 3(a), area A contains 7.82% Si and 9.93% C. Meanwhile, area B in Figure 3(b) consists of 17.21% Si and 16.85% C showing the highest hardness in this sample. This result was associated with the high SiC concentration at thermal input of 0.768 kJ/mm. Nevertheless, the reduced SiC concentration at area C with 5.06% Si and 10.87% C in Figure 3(c) to be caused by a higher thermal input of 1.440 kJ/mm. This elemental analysis gives support that the dendritic structure containing silicon and carbide particulates in the surface alloyed DSS.

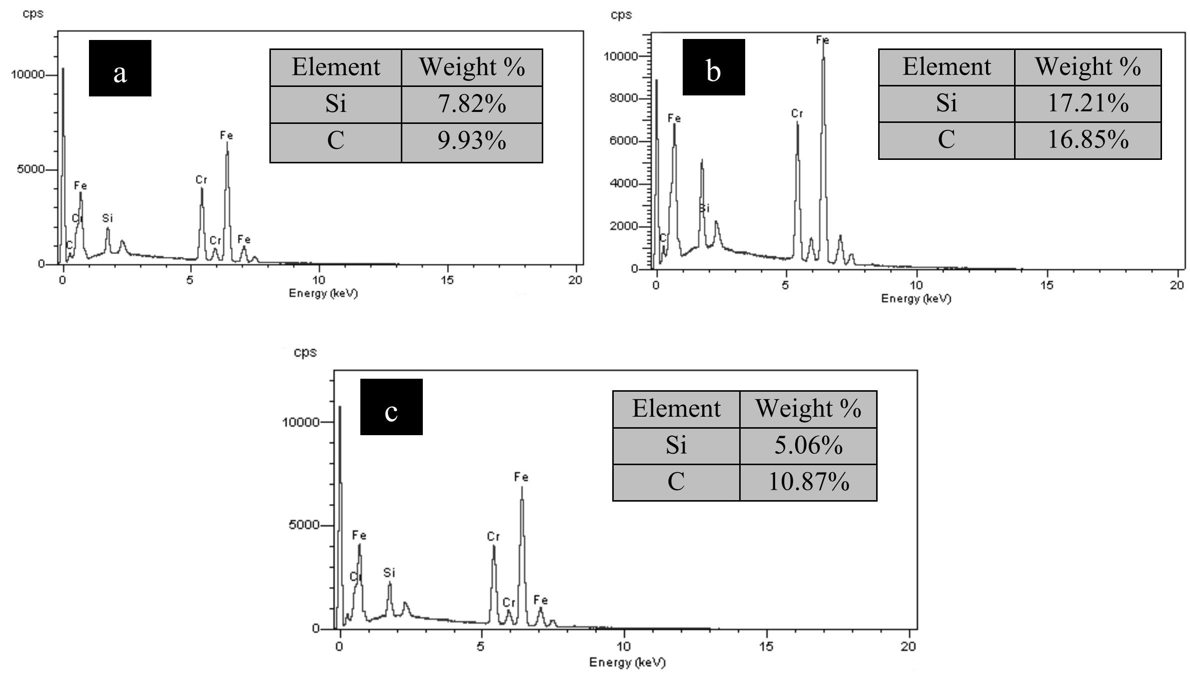

Figure 4: EDX spectrum of surface alloyed DSS for sample fabricated at thermal input of (a) 0.480 KJ/mm, (b) 0.768 KJ/mm and (c) 1.440 KJ/mm

3.2 Hardness of DSS Sample

Table 2 shows the hardness value on the middle region of the cross section for surface alloyed DSS. From the table, the hardness result for surface alloying DSS using 100 µm SiC particulates are 720, 1600 and 1100 Hv for 0.48, 0.768 and 1.44 kJ/mm, respectively. Generally, the hardness value increases with an increase in thermal input supplied during TIG torch melting process and the trend matches the microstructural results. As can be seen, the surface alloyed DSS using thermal input of 0.48 kJ/mm exhibited a lower hardness value which was probably due to assortment of partial and complete melting of the SiC particulates with lesser capacity of dendrite formation. It was insufficient to use this lower heat input to complete melting the SiC particulates in the DSS matrix.

However, when the thermal input increased to 0.768 kJ/mm, the hardness in the middle region of the cross-section surface alloyed DSS increased with value of 1600 Hv. This is believed to occur due to higher capacity of fine dendrite structure in DSS matrix as can be seen in Figure 2(b). However, when fabricated under higher thermal input of 1.44 kJ/mm, the hardness value reduced to 1100 Hv. This lower hardness might be due to lower capacity of dendrite microstructure compared to sample fabricated at 0.768 kJ/mm. This decrease in hardness value was contributed by the partial and incomplete melting of SiC particulates as shown in Figure 2(c). The dissolving of SiC particles by vigorous stirring of the fluid melt resulted in more dilution and less SiC particle dispersion with greater heat input may also be the cause of the lower hardness development. This outcome is in line with earlier research by [15] employing TIG torches to pre-placed ceramic particles of TiC into low alloy steel.

Table 2: Top surface hardness and wear rate of surface alloyed DSS for sample fabricated at thermal input of (a)0. 480 KJ/mm, (b) 0.768 KJ/mm and (c) 1.440 KJ/mm

Thermal input (KJ/mm)	Hardness of middle region (Hv)	Wear rate x 10^{-4} (mm^3/Nm)
0.480	720	4.1
0.768	1600	2.3
1.440	1100	3.6

3.3 Wear Evaluation

Surface alloyed DSS wear rate for thermal inputs of 0.480, 0.768 and 1.440 kJ/mm are shown in Table 2. As can be seen, the wear rate is higher for samples processed at 0.480 kJ/mm with lower thermal input compared to those processed thermal input. This is related to the sample's hardness value, which was discussed in the hardness results. It was evidently demonstrated that a lower thermal input of 0.480 kJ/mm led to a lower hardness owing to low temperature melt, which in turn led to a lower SiC dissolution rate and a smaller dendritic capacity.

The wear rate value decreased by 2.3 x 10^{-4} mm^3/Nm at a higher thermal input of 0.768 kJ/mm. According to the discussion of the microstructural results, the lower wear rate value in these samples was thought to be associated to a higher hardness and increased dendritic capacity. However, the wear rate rose when the thermal input reached 1.440 kJ/mm. This is directly related to the sample's reduced dendritic capacity and lower hardness.

Figure 5 displays the alumina ceramic ball-tested dry reciprocating worn surfaces of the substrate DSS and surface alloyed DSS at various thermal inputs. Figure 5(a) illustrates the extreme abrasion, plowing, and grooves present on the substrate DSS's worn surface. However, for surface alloyed DSS fabricated at 0.480 kJ/mm, the worn surface was marginally improved. It was discovered that the sample's worn surface had a mild ploughing pattern as shown in Figure 5(b). This behavior was caused by a reduced capacity of dendrites and a lower hardness of SiC ceramic particles in the surface alloyed DSS.

Additionally, as shown in Figures 5(c) and (d), the sample processed at thermal inputs of 0.768 and 1.440 kJ/mm, respectively, showed the considerable improvement. Evidently, for the samples indicated, moderate and mild wear surfaces and smooth abrasion marks have been formed. There is no sign of brittle deformation or coating particle separation, indicating a strong link between the interface of the melted SiC ceramic particles and the DSS matrix. Another researcher [16] has made a comparable observation on low alloy steel that has TiC particles pre-placed in it. The SiC particle, on the other hand, plays a significant role in hardness and resistance to plastic deformation. Furthermore, better wear properties are produced by the bonding between intermetallic compound and DSS matrix.

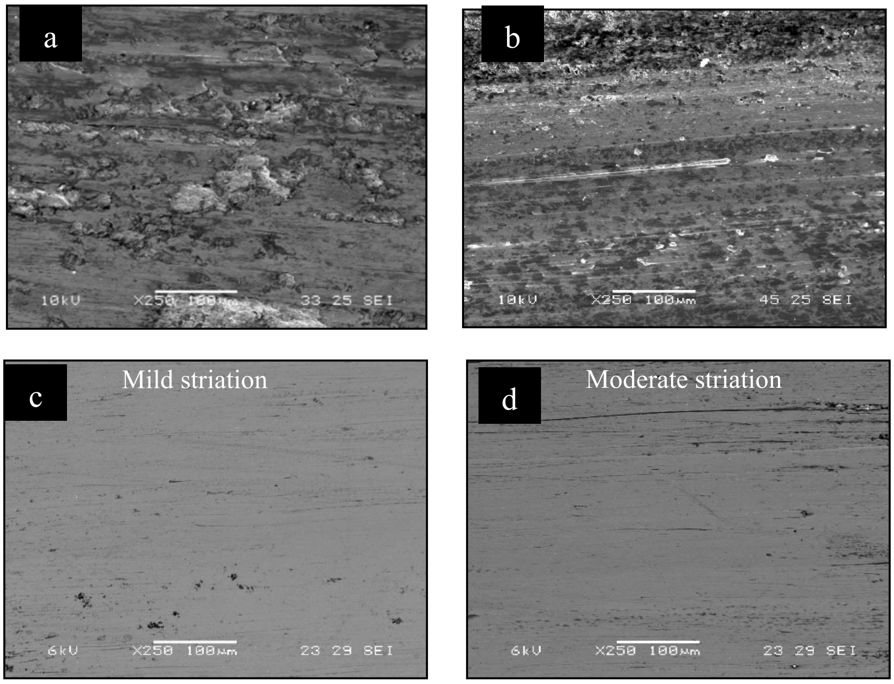

Figure 5: Worn mechanism of surface alloyed DSS for sample fabricated at thermal input of (a) substrate DSS, (b) 0.480 KJ/mm, (c) 0.768 KJ/mm and (d) 1.440 KJ/mm

4. CONCLUSIONS

The surface alloying of the AISI Duplex-2205 with the addition of 100 µm SiC particulates and melted using TIG torch techniques have been successfully achieved. Thermal input plays an important role in providing the best quality of surface alloyed DSS. The following conclusions can be drawn from this study;

- The SiC particles melted and dispersed within the DSS matrix and after coagulation seem to be dark shaded equiaxed type or disrupted dendritic structure forming a surface alloyed DSS.
- Fine and high capacity of dendrite microstructure in the surface alloyed DSS, achieved at thermal input of 0.768 kJ/mm, increased the highest hardness to values as high as 1600 Hv as compared to the hardness of the as-received DSS that was 250 Hv.
- The surface alloyed DSS reduced the wear rate to less than half of the wear rate of the substrate DSS, contributed from thermal input of 0.768 kJ/mm.
- The worn mechanism of surface alloyed DSS showed very mild abrasive wear compared to substrate DSS which demonstrated very severe wear with ploughing marks.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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