

INFLUENCE OF MICROSTRUCTURE ON THE HARDNESS BEHAVIOR OF AISI DUPLEX-2205 COMPOSITE LAYER BY TIG CLADDING

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Abstract. Duplex stainless steel (DSS) material with grade of AISI Duplex-2205 show a decrease performance under aggressive environment which may lead to unanticipated failure due to poor surface properties. Therefore, the surface modification of this material is important to increase the hardness and wear behavior for various applications in the automotive, aerospace and oil and gas industries. The surface modification using SiC ceramic powder with particle size of 60 μm by TIG torch technique has been developed on the surface of AISI Duplex-2205. The TIG torch was employed at different arc energy of 0.480, 0.768 and 1.440 KJ/mm. The composite surface layer was developed via deposition of ceramic particles into AISI Duplex-2205. Based on the experimental results, it was found that the composite layer attained a maximum hardness of 1245 Hv from substrate hardness of 250 Hv for TIG processed at 0.768 KJ/mm. The cross-sectional view of the melt pool for TIG torch melted processed showed a hemispherical shape due to the Gaussian energy distribution of the torch which has been known to have high energy intensity in the center region and gradually decrease to the borders of the fluid zone. The microstructure demonstrates the formation of the dendrite microstructure due to the complete fusing and re-solidification of SiC in the composite layer that contributes to the hardness enhancement. The formation of dendrites in the melt pool contributes to the hardness and wear enhancement of AISI Duplex-2205 which can be used for wear and high temperature applications.

Keywords: Microstructure, hardness, duplex-2205, composite layer, TIG torch

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Introduction

In recent years, composite surface layers have undergone continuous development as a result of the industry's growing demands and standards for surface wear resistance. By creating a composite layer on metallic components, it is possible to greatly increase their service life while lowering the cost of regeneration or replacement of damaged parts [1-4]. High mechanical properties, fatigue and oxidation resistance in extreme conditions, together with greater toughness and ductility, are all desirable characteristics of AISI Duplex-2205. These alloys are utilized often in a variety of industries, including the aerospace, chemical, and energy industries due to the combination of these characteristics [5-6]. However, this material experienced a low hardness and wear properties in the application. Due to this, it stands for a reason to choose a reinforcing material with excellent thermal stability to ensure strong wear resistance including both low and high temperatures. Silicon carbide (SiC) is particularly desirable for producing AISI Duplex-2205 composite surface layer because it has high hardness and strength, high melting temperature and high thermal stability.

TIG cladding method is commonly utilized for the production of composite surface layers. Numerous benefits of this technology include simpler process, low cost establishment, flexible in operation and economical in time, which lead to the potential of unique structures on the metal surface. These great features provide an improvement of the AISI Duplex-2205 without changing the chemical composition and characteristics of the base metal. The investigation conducted by the earlier researcher revealed the positive impact of TIG torch cladding of composite layer on the wear resistance of the steel surfaces [3,4,7]. The development of composite layer based on ceramic particles into steel surfaces has a high possibility due to formation of new microstructure of these alloys and increased wear resistance of the metal surface.

Munoz-Escalona et al. [8] earlier investigated the fabrication of SiC onto microalloyed steel surface utilising TIG torch cladding technology. According to the findings, the surface hardness of composite layer increased four times higher than substrate material. By adopting 75 μm SiC particle size rather than 1 μm SiC particle size, the width of the fusion zone was doubled. Another study by Brytan et al. [9] examined the effects of SiC powder on ferritic, austenitic, and duplex stainless steel that was melted using a laser surface alloying process. According to the findings, the laser alloyed layers created on the surface significantly increase wear resistance. Duplex stainless steel demonstrated the highest wear resistance. Based on this finding, the previous work has successfully produced an improvement of hardness by depositing SiC on materials other than duplex stainless steel and a different melting process.

Previous research carried out by Paraye et al. [10] investigated the effect of TiC ceramic particles reinforcement on the carbon steel using TIG torch process. As a result, the fusion zone's average hardness was 395 Hv, which is around 150% harder than base material. The cumulative effect of the deposited TiC particles and bainite microstructures is what gives this material its increased hardness. By employing the TIG alloying process, Padhee et al. [11] showed that the Al-TiC coating on magnesium alloy enhanced the surface's hardness from 60 Hv to 305 Hv. According to the SEM pictures, the TiC particles were dispersed in a matrix made up of an alloy of aluminium and magnesium. The dispersion of TiC particles in the matrix create a metal matrix-like structure in the composite layer. The aim of the following research is the production of AISI Duplex-2205 deposited with SiC ceramic particles using the TIG cladding process. This research work was performed to determine the

influence of microstructure on the hardness behavior of AISI Duplex-2205 composite layer via deposition of SiC ceramic particles by TIG torch cladding.

Materials and Methods

For the development of composite coating of AISI Duplex-2205, the SiC was initially placed on a substrate material with dimension size of 50 mm × 33 mm × 10 mm. Japanese companies of Outokumpu, Mitsui, Sumitomo, Tokyo has provided the AISI Duplex-2205 as a substrate material. This grade was chosen because it is less expensive and lighter than AISI 316L (pressure vessels). Additionally, AISI Duplex-2205 grades make for about 85% of the current duplex manufacture (Charles). In order to create a smooth surface for the sample, the surface of the substrate material underwent a milling technique to eliminate any undesirable material, such as swarf and production residues.

This study used silicon carbide (SiC) of 60 µm particle sizes to enhance the surface characteristics of AISI Duplex-2205. The SiC was deposited on the surface material for surface modification prior to TIG torch cladding. The SiC paste was created by adding distilled water (H₂O), two drops of polyvinyl acetate (PVA) and one drop of alcohol. The paste form was then applied to the surface material and heated in the furnace for 1 hour while maintaining a temperature of 80 °C in order to dry out the SiC paste and guarantee that the ceramic particles remained consistently to the substrate surface during the TIG torch cladding process. The flow diagram of the sample preparation of this work is shown in Figure 1.

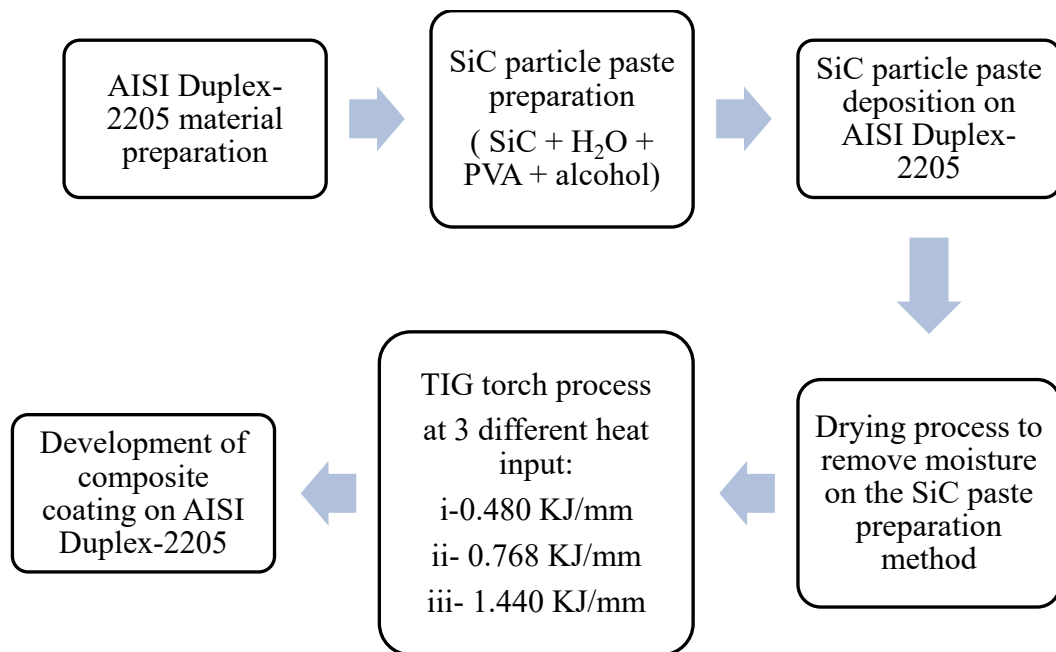


Figure 1: Flow diagram of the sample preparation for the deposition of SiC ceramic particles on the AISI Duplex-2205 surface.

The TIG welding equipment used to execute the TIG torch cladding includes a motion device that regulates the arc's movement at a specified rate between 1 and 2 mm/s. In order to cover the molten zone from oxidation and maintain the arc, a constant supply of high-quality

argon gas was also supplied into the molten pool throughout the scanning of the TIG arc at a rate between 15 and 25 L/min. Figure 2 depicts the experimental setup for TIG alloying utilising AISI Duplex-2205 and a layer of pre-deposited SiC on the AISI Duplex-2205. By varying the operating arc energy for 0.480, 0.768, and 1.440 KJ/mm, a various trial experiments were conducted to determine the best TIG torch cladding for composite layer development as shown in Table 1.

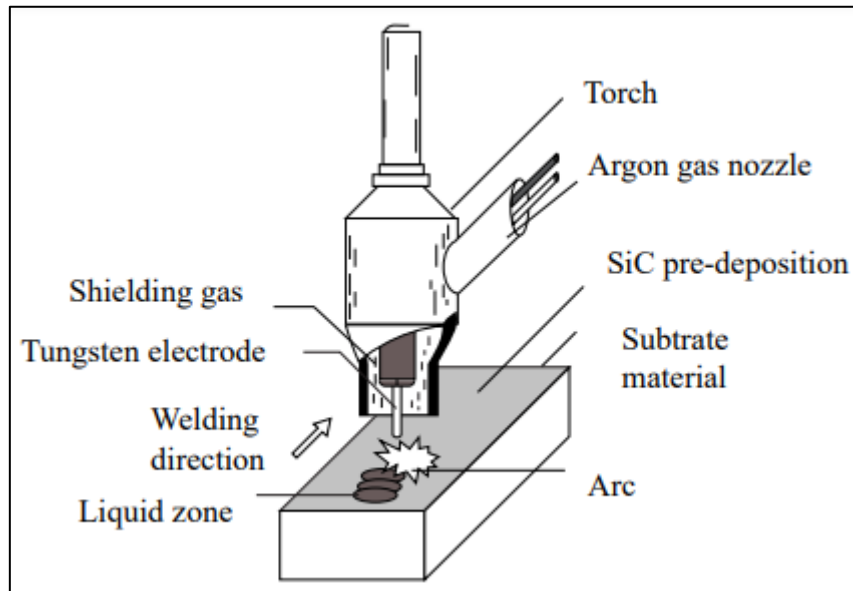


Figure 2: Schematic Diagram of the TIG torch Machine Experimental Setup

Table 1: Process parameter used in the experiment of TIG torch process for composite coating of AISI Duplex-2205

Exp. no.	SiC particle size	Arc energy
1	60 μm	0.480 KJ/mm
2		0.768 KJ/mm
3		1.440 KJ/mm

After development of the TIG torch composite layer on AISI Duplex-2205, the cross-section of the composite layer was segmented using wire EDM for scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), micro-hardness measurement and melt pool geometry. Figure 3 shows the cross-section image of the real sample for characterization analysis. Prior to hardness testing and SEM examination, the cross-section was polished according to standard metallography procedures. Energy dispersive spectroscopy was used to analyze the elemental distribution (EDS). A Vickers micro-hardness tester was used to measure the micro-hardness values on the surface of the composite layer of AISI Duplex-2205.

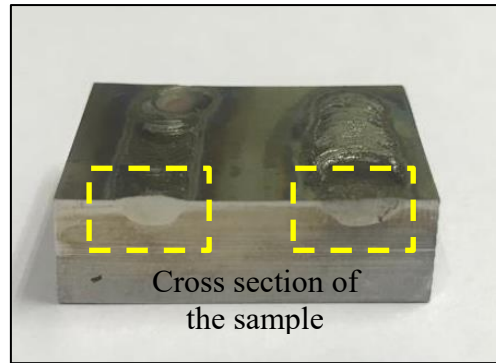


Figure 3: Image of the cross section of the real sample for characterization analysis

Results and Discussion

Microstructural and Elemental Analysis

Figure 4 shows the SiC ceramic with 60 μm size particle before the TIG welding process. The microstructure is observed under SEM machine with a magnification of X270. The SiC ceramic particles formed in various shapes consist of cubic and hexagonal structures.

Figures 5(a) to (c) illustrate the microstructural characteristics of AISI Duplex-2205 composite layer at various arc energy. For the EDX spectra results, all figures were labelled with zone A, B, and C. Based on the microstructural characteristics, it was discovered that the integration of SiC ceramic particles on AISI Duplex-2205 through TIG torch cladding, which leads to the development of dendritic microstructure, finally developed the hard surface of the composite layer.

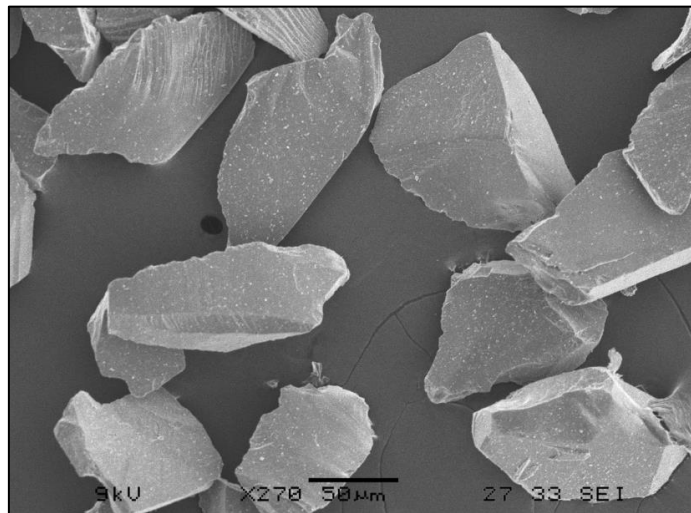


Figure 4: SEM micrograph of SiC ceramic with 60 μm particle size

It was discovered that the SiC particles not fused during TIG surfacing when 0.480 KJ/mm of arc energy was used, as shown in Figure 5(a). Due to the low arc energy, SiC did not fuse the way it should have, which caused variations in the precipitation of SiC particles not fused and fully fused through resolidification. In addition, the melt fluid thickens at this

lower arc energy, which allows melting to freeze in a relatively short period of time, delaying the probability of SiC particles completely precipitated in the composite layer [12].

The carbide precipitation with dendritic microstructure was severely observe with fine and highly populated form at the middle of the fluid zone at operating condition of 0.768 KJ/mm, as presented in Figure 5(b). According to earlier study by Maleque et al. [13], this phenomena encourages the material's hardness to be increased. Mridha & Dyuti [14] provided a similar explanation of the use of a carbon steel substrate with reinforced titanium powder during TIG torch melting. According to the surface hardness finding, dendritic development seems to be leading to increases in hardness (next section). Due to the high arc energy, the SiC particles dispersed in the liquid zone of the composite layer.

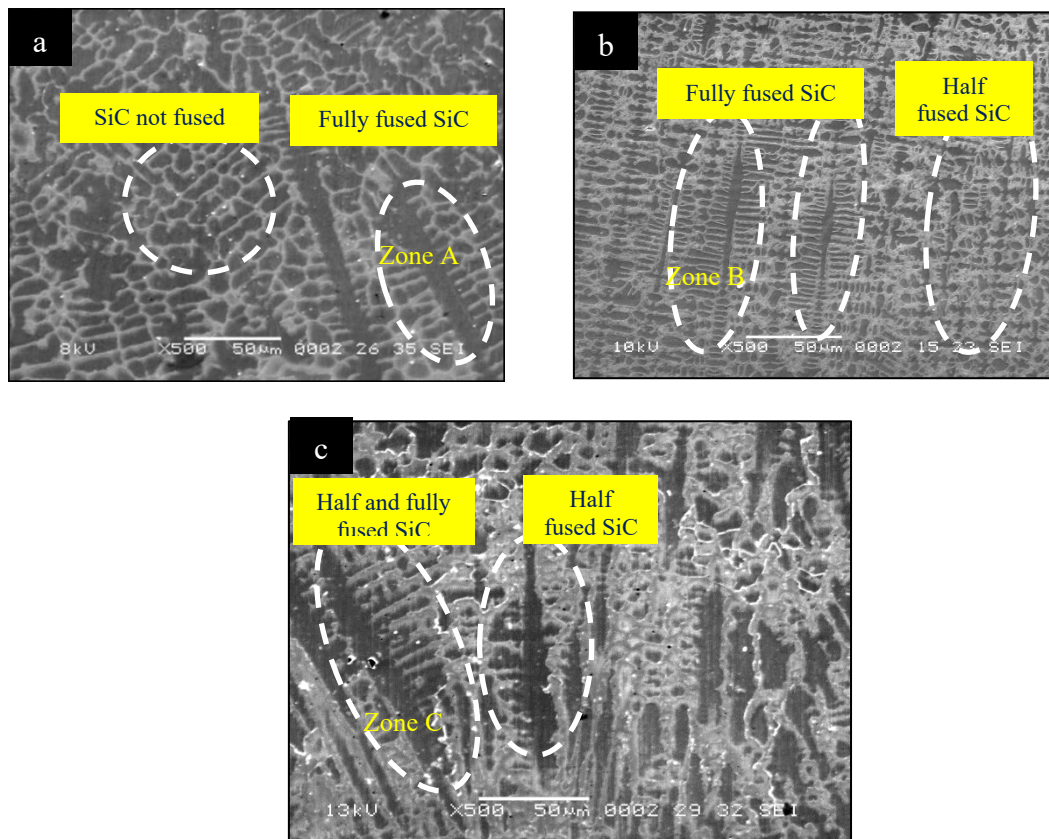


Figure 5: SEM images of AISI Duplex-2205 composite surface layer for sample processed at arc energy of (a) 0.480 KJ/mm, (b) 0.768 KJ/mm and (c) 1.440 KJ/mm

Due to a suitable heat source and significant substrate DSS and SiC dilution, the SiC in the AISI Duplex-2205 composite layer completely fused. The temperature variations in the liquid zone at the different location across the liquid zone are what cause the variance in carbide precipitation and dendritic structure. Prior research by Buytoz [15] claimed that the dendritic structure developed as a result of the significant discrepancy between the melting temperatures of iron and other phases created by the dissociation of SiC. According to past investigations by Zeng et al. [16], the stirring of the liquid zone by convection and Marangoni effects is another cause for the formation of dendritic structure.

The composite surface layer at a heat energy of 1.440 KJ/mm is depicted in Figure 5(c). The sample took longer time to solidify when it melted at a greater arc energy because

more SiC ceramic particles were dispersed in the melt pool. This phenomena is comparable to earlier research by Maleque and Adeleke [12]. The thicker dendritic microstructures may form more quickly due to the SiC ceramic particles has the potential to dispersed more quickly due to the high fluidity of the melting layer. It also demonstrates the lower density of dendritic growth in this melted layer, which is quite significant compared to earlier research by Bello et al. [17].

Figures 6(a) to (c) depicts the EDX spectra for the composite surface layer of AISI-Duplex-2205. It can be shown that the Si and C content acquired the percentages of 4.56% and 7.93%, respectively, at minimal arc energy of 0.480 KJ/mm (zone A in Figure 5(a)). As shown in Figure 6(b), the value raised to 11.11% for Si and 13.24% for C with greater arc energy of 0.768 KJ/mm, which was retained within the dendritic structure at zone B. The sample showed a lower proportion of Si (5.56%) and C (8.564%) at zone C in Figure 5(c) at maximum arc energy of 1.440 KJ/mm.

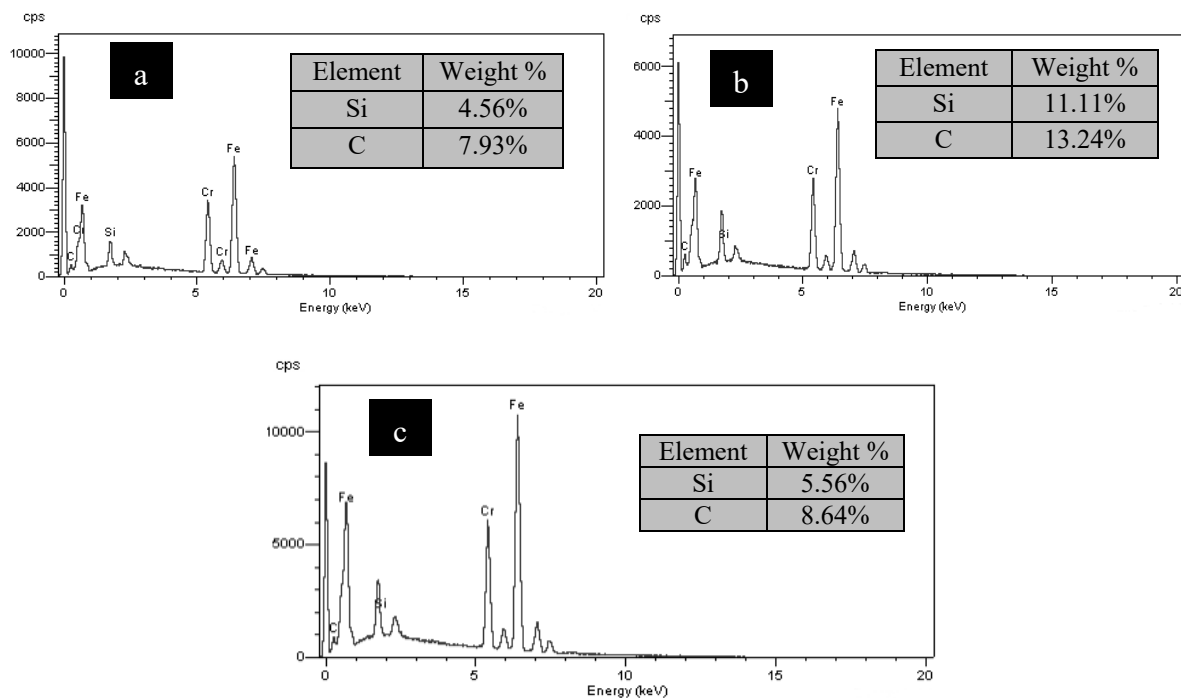


Figure 6: EDS analysis of AISI Duplex-2205 composite surface layer for sample processed at arc energy of (a) 0.480 KJ/mm, (b) 0.768 KJ/mm and (c) 1.440 KJ/mm

Surface Hardness and Melt Pool Geometry.

The top surface hardness of the AISI Duplex-2205 composite surface layer performed at various arc energy of 0.480 KJ/mm, 0.768 KJ/mm, and 1.440 KJ/mm is shown in Table 2. The lowest hardness value was obtained at arc energy of 0.480 KJ/mm by considering three different arc energies. This is related to the SiC particles' blend of incomplete and partial melting with substrate material and low dendritic growth population, as illustrated in Figure 5(a) (SEM result). It was inappropriate to use this minimal arc energy to accomplish melting the SiC ceramic particles in the substrate material. According to a similar explanation by Wang et al. [18], the melt pool's shrinking population of dendritic structures and altered coarse dendrite formation structure are the key causes of the hardness reduction.

The highest hardness of 1245 Hv was generated in the composite surface layer after manufactured with arc energy of 0.768 KJ/mm. As can be observed in Figure 5(b), the increased population of fine dendritic structure in the fluid zone is really provided the enhancement of hardness. However, the hardness value decreased to 673.6 Hv when manufactured at greater arc energy of 1.440 KJ/mm. This reduced hardness may be the result of a dendritic population that is less dense than that of a sample manufactured at 0.768 KJ/mm. This decrease in hardness value was caused by the combination of half fused and completely fused of SiC ceramic particles. The dissolving of SiC particles by vigorous agitation of the liquid zone with greater arc energy may also be the cause of the lower hardness development. Higher arc energy during melting resulted in more dilution and less SiC particle dispersion, which may be the cause of the reduction of hardness value. These hardness levels may have dropped because of the rapid speed of SiC particle dissolution. This outcome is in line with earlier research by Mridha et al. [19] employing low alloy steel that deposited with TiC ceramic particle using a TIG torch method.

Table 2 lists the melt depth of AISI Duplex-2205 composite surface layer at various arc energy. As can be seen, the melt depth improved as the arc energy increased from 0.480 KJ/mm to 1.440 KJ/mm, with a value between 1010 m and 1540 m. This outcome is consistent with the earlier research by Adeleke and Maleque [20]. Figures 7(a) to (c) demonstrate the hemispherical shape in the cross-section of the composite surface layer. Such a hemispherical melt shape is produced by the torch's Gaussian energy distribution, which is known to have high energy intensity in the centre and progressively diminish to the borders of the fluid zone. Mridha et al. [19] also made a similar finding with this circumstance.

Table 2: Top surface hardness and melt pool dimension of AISI Duplex-2205 composite surface layer for sample processed at different arc energy

Arc energy (KJ/mm)	Melt depth (μm)	Top surface hardness (Hv)
0.480	1010	650
0.768	1180	1245
1.440	1540	673.6

Figure 7 represents a cross-sectional view of a melt pool with a smooth surface, suggesting that the composite layer and the substrate material had a strong metallurgical interaction. The melt pool of the samples generated a smooth surface free of significant flaws at the processed composite layer with arc energy of 0.480 KJ/mm and 0.768 KJ/mm, as illustrated in Figures 7(a) and (b). However, as shown in Figure 7(c), several pores and cracks were found in the sample after processing at an arc energy of 1.440 KJ/mm. These flaws are probably the result of sluggish cooling and a high fluidity melt during the solidification process. Porous regions developed because the viscous melt was incapable to fill the pores. The releasing gas also created surface pores in the centre area, but these were quickly covered up by relatively less viscous melt in the area. Other research also gives support to this explanation.

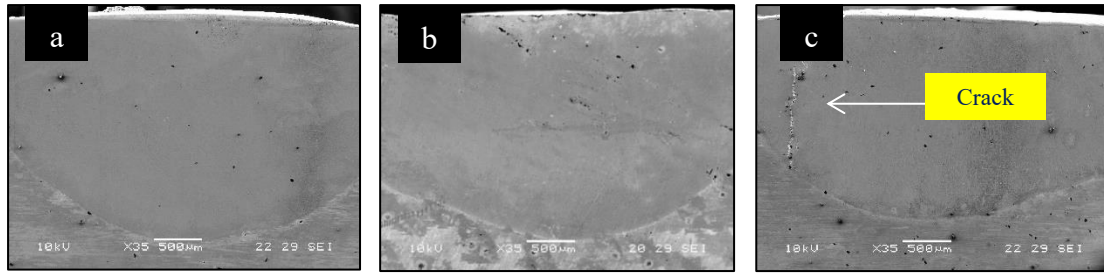


Figure 7: Cross sectional view of melt geometry of AISI Duplex-2205 composite layer for sample processed at arc energy of (a) 0.480 KJ/mm, (b) 0.768 KJ/mm and (c) 1.440 KJ/mm

Conclusions

The composite layer of AISI Duplex-2205 deposited with SiC ceramic particles using TIG torch cladding was successfully implemented on the hardness improvement. Further finding of the work can be summarized as following:

- The microstructural observation revealed that the integration of SiC ceramic particles with AISI Duplex-2205 leads to the development of dendritic microstructure and different population in the composite layer depending on the arc energy.
- The increment of hardness of the composite layer contributed from the formation of the dendritic microstructure consists of SiC ceramic particles.
- The highest hardness value of 1245 Hv achieved for composite layer processed at arc energy of 0.768 KJ/mm due to formation of dendritic structure with high population in the composite layer.
- At higher arc energy of 1.440 KJ/mm, a lower hardness value of 676.3 Hv obtained is due to a lower population of dendritic structures with several pores and cracks found in the composite layer.

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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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