International Journal of Nanoelectronics and Materials
IJNeaM
ISSN 198-5761 | E-ISSN 2232-1535

Effect of TiC Nanoparticles Deposition on UNS S31803 Surface Using Tungsten Arc Melting Method

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Received 15 September 2023, Revised 1 October 2025, Accepted 27 October 2025

ABSTRACT

This study focused on the application of nanoceramic particles in reinforcing the surface properties of UNS S31803 steel through the deposition of titanium carbide (TiC) nanoparticles of 5 nm and 10 nm using the tungsten arc melting process. Despite the advantages of UNS S31803, its soft material and low wear resistance are significant disadvantages to its application in engineering. The objective is to determine how various melting processes affect the composite coating layer in terms of hardness and wear resistance. The process involved precise control over tungsten arc melting conditions, with a constant arcing current of 140 A and pulse frequencies of 15, 20, and 25 Hz to achieve a nanoparticle dispersion and distribution. Microstructure, hardness, and wear behavior were analyzed by Field Emission Scanning Electron Microscopy (FE-SEM), Energy Dispersive X-Ray Spectroscopy (EDX) analyzer, Vickers micro-hardness testing, and reciprocating wear tests. The results indicate that 5 nm TiC nanoparticles, which were treated at 140 A using 25 Hz, achieved the best results with a high element composition of 91.6%, maximum microhardness value of 415.96 Hv, and minimum wear rate of 1.01 x 10^{-5} mm^3/Nm with shallow surface grooves. The present work makes significant contributions to industries that would wish to improve the durability of wear resistant components since it makes a contribution to improvements in sustainability and material science.

Keywords: *Nanomaterials, titanium carbide, nanocomposite coating, surface modification, tungsten arc melting*

1. INTRODUCTION

Nanomaterials are materials with a nanoscale structure, typically between 1 to 100 nanometers. It generally has unique properties at this very fine scale that distinguish it from bulk material. These include improved mechanical strength, electrical conductivity, thermal stability, and even optical behavior. These are due to the enhanced surface properties and the small sizes, which become important at the nanoscale material [1,2].

In the manufacturing industry, nanomaterials are transforming various processes and products. Graphene and carbon nanotubes are some of the nanomaterials utilized for making parts used in automobiles and aerospace stronger and lighter. Nanoparticles are incorporated into paints and coatings to make them better in performance. Innovation and efficiency during manufacturing occur due to these advancements, and more efficient and high-performance, and sustainable products are achieved [3].

The various advantages offered by nanomaterials make them an extremely suitable material in a wide range of industries. Nanomaterials have enhanced mechanical properties like greater tensile strength, durability, and wear and corrosion resistance. All these make nanomaterials extremely suitable for application in high-tech construction and manufacturing. Moreover, high-performance protective coatings based on nanomaterials can enhance material and structural life at a reduced maintenance cost [4].

Nanotechnology, in general, is revolutionizing all fields of new technologies and developing existing technologies. Its ability to improve the properties of materials and new applications drives research and development in all fields, and it is one of the research areas for researchers and engineers all over the world. Tiwari et al. 2021 [5] studied the effect of nanoparticles on friction stir-welded aluminum alloys. They analyzed how the nanoparticles affected the mechanical properties and the weld joint quality. The outcome of the experiment was that the life and strength of the joint were significantly enhanced by adding nanoparticles, which made the welds suitable for harsh working conditions. The study acknowledges the potential for nanomaterials to sustain the enhancement in the performance of friction stir welding, and that this can open up access to high-end fabrication processes and material performance.

Nanoparticles are very fine particles, less than 100 nanometers, due to their small sizes and high surface area. In composite coatings, the nanoparticles improve the performance of the material being coated remarkably. The nanoparticles are small enough to deposit and distribute more evenly in the coating, which improves adhesion, durability, and wear and corrosion resistance. Ceramic nanoparticles consist of a variety of materials like aluminum oxide [6], titanium dioxide [7], and silicon carbide [8], with unique characteristics suitable for particular coating purposes. New opportunities to enhance material performance and function in emerging technology are offered by the potential to tailor the size and composition of nanoparticles [9]. Higher use of nanocomposites based on the enhanced properties, depending on the nanoscale structures, is recognized by earlier researchers. The research is concerned with having control over the process of synthesis to achieve the required properties in the final product. It also identifies some of the techniques used to synthesize nanocomposite ceramic powders and highlights the central relationship between nanoscale features and the behavior of the overall performance of the material [10].

Surface modification is a technique used to improve the performance of materials by modifying their surface characteristics. Nanoparticles have developed an effective approach for surface modification owing to their distinctive properties, including enhanced surface properties and remarkable mechanical properties. Incorporating nanoparticles into surface coatings can substantially enhance the hardness, wear resistance, and overall durability of materials.

Apart from that, surface modification by the use of melting processes also involves the application of nanoparticle composite coatings on the substrate material. Methods of carrying out this process involve the use of tungsten arc welding. The substrate material is prepared and cleaned to ensure the adhesion of the coating. The nanoparticles are dispersed evenly and applied to the substrate. The coating is subsequently melted onto the substrate through a high-temperature arc upon welding, adhering correctly and spreading evenly the nanoparticles. The properties of the coating are enhanced through heat treatment and surface finishing in post-welding procedures. The process results in considerable enhancements of the mechanical and tribological performance. Cooke et al. 2024 (11) studied the application of a high-temperature arc via TIG welding to improve the mechanical properties of AISI 1020 steel, with notable improvement in hardness and wear resistance along with nanoparticle dispersion.

To explore new approaches and functionality on the surface modification techniques and due to the limitations of comprehensive studies on the tribological behavior of TiC nanocomposite coatings, this study will explore the influence of differing sizes of TiC nanoparticles, 5 nm and 10 nm in size, deposited on the UNS S31803 surface using tungsten arc melting techniques in an effort to develop a nanocomposite coating. Previous studies have investigated TiC-based coatings; however, the coatings were applied to different substrate materials and employed alternative deposition methods. Therefore, this study is to evaluate the performance of TiC nanocomposite coatings specifically on UNS S31803 using tungsten arc melting, which has not been comprehensively explored. This new coating is believed to improve the coating hardness and wear rate of the UNS S31803 surface and worn surface mechanism. The technique provides an effective surface modification composite coating process with melting processes for the extension of the coated component's life span by abrasive wear failure.

2. MATERIALS AND METHODS

2.1 Raw Materials and Nanocoating Preparation

For the TiC nanoparticles, pre-deposited ceramic powder of UNS S31803 grade steel plate of size 50 mm x 35 mm x 10 mm. The substrate surface underwent abrasive grinding by SiC emery paper of grades 60 to 240 for the smooth surface of the sample. Then, the sample was properly cleaned in acetone and flowing water to eliminate impurities such as oil and grease. TiC nanoparticles with sizes of 5 nm and 10 nm were utilized as nanoparticle reinforcement in this study for the purpose of enhancing the surface properties of UNS S31803 grades. The comparisons are required to influence the different nanoparticle sizes on the surface characteristics in terms of morphology, hardness, and tribological properties.

Prior to tungsten arc melting, ceramic nanoparticles were deposited on the surface substrate for surface modification. The nanoparticles were mixed with a small amount of ethanol, distilled water, and polyvinyl acetate (PVA) to form a paste. The addition of the PVA is a function as a binder to ensure that the TiC paste adheres to the substrate's surface during the flow of shielding gas in the tungsten arc melting process. A uniform layer in the paste form was then applied on the substrate surface and was subjected to 1 hour heat treatment in the furnace at 80 °C.

2.2 TiC Deposition on UNS S31803 Using Tungsten Arc Melting Process

A tungsten arc melting was used to develop the composite coating with the current arcing at 140 A and pulse rate from 15 to 25 Hz. This study aims to investigate the influence of these parameters on the microstructural and wear properties of UNS S31803. It specifically examined the effects of two different nanoparticle sizes, 5 nm and 10 nm, as well as various influencing factors. During the tungsten arc melting process, 15 L/min argon gas is used as a shielding gas to prevent air from entering the molten pool. The deposited TiC nanoparticles were arc-melted on the surface of the UNS S31803 plates. The detailed conditions for the tungsten arc melting are displayed in Table 1.

The tungsten arc melting schematic diagram of melting for surface modification procedure with 50% overlapping was performed to cover the whole surface of the UNS S31803 plate to form a nanocomposite coating, as shown in Figure 1. Meanwhile, Figure 2 shows the UNS S31803 surface after developing a nanocomposite coating. Moreover, the cross-section samples were cut using an EDM wire cut. The crosssections were ground and polished with sandpaper ranging from 60 to 1200 grit, subsequently undergoing cloth polishing with an alumina suspension until achieving a mirror finish. Then etched with Kalling's reagent to reveal the microstructure. The microstructure and elemental analysis were performed through Field Emission Scanning Electron Microscopy (FE-SEM) and Energy Dispersive X-Ray Spectroscopy (EDX) analyzer, respectively. The EDX analysis was performed to study the distribution of different elements present in the composite coating layer.

Table 1 Tungsten arc melting parameters used in the nanocomposite coating layer of UNS S31803

Exp. no	Nanoparticle size (nm)	Current (Amperage-A)	Pulse rate (Hz)
1	5	140	15
2			20
3			25
4	10		15
5			20
6			25

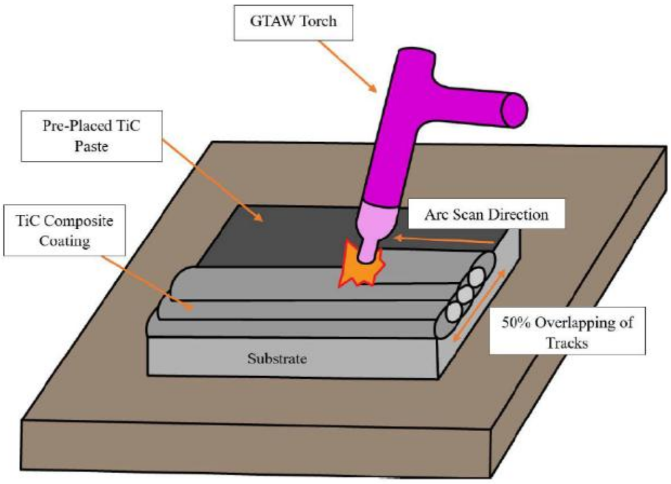

Figure 1. Schematic diagram of tungsten arc melting and track shifting scheme to obtain a large area coating by 50% overlapping.

Figure 2. The nanocomposite coating sample on UNS S31803 grade steel plate with 50% overlapping weldment.

2.3 Vickers Micro Hardness

The hardness values were measured using a Vickers microhardness indentation tester with a diamond indenter, applying a 0.5 kgf force load and a 10-second indentation time. Meanwhile, the microhardness measurements were carried out at various points along the surface composite coating of UNS S31803 grade steel plate with the addition of TiC nanocomposite coating. The hardness values assessed from different regions were plotted concerning the distance from the top surface into the substrate material. The highest value was recorded as a result of the indentation result across the depth profile in the nanocomposite coating. Fifteen indentations were conducted for each sample towards the substrate material.

2.4 Reciprocating Wear Test

For the reciprocating wear test, the grinding and polishing machine was used to flatten the surface of the substrate's overlapping tracks. The substrate's weight was measured both before and after the test to determine the weight loss. A ball-on-disc reciprocating wear test was conducted using a 6 mm diameter Al_2O_3 ceramic ball served as the counter face against the nanocomposite coating, and the test conditions specified in Table 2. Before the dry wear tests, the surface specimens were ground and polished with different grit sandpapers. The wear rate of the substrate was calculated using the standard formula as shown in equation 1 [12]. Subsequently, the resulting worn surfaces were subjected to analysis using FE-SEM equipment.

$$\text{Wear rate} = \frac{\text{Weight loss }(g) / \text{Density }(g/mm^3)}{\text{Normal load }(N) \times \text{Reciprocating distance }(m)} \quad (1)$$

Table 2 Wear test condition

Specimen	Liner motion reciprocating wear test condition
Applied load	20 N
Frequency	15 Hz
Wear test duration	15 minutes
Counter-part body	6 mm Al_2O_3 ceramic ball

3. RESULTS AND DISCUSSION

3.1 Microstructural Characterization

Nanoparticles of different sizes can demonstrate unique behaviors and interactions with their surrounding matrix, resulting in variations in substrate properties. The goal of this study is to compare the effect of TiC nanoparticle size on morphology and elemental composition in nanocomposite coatings of 5 nm and 10 nm, and on their overall performance and properties.

The influence of TiC nanocomposite coating of varying size (5 nm and 10 nm) on morphology was reflected in Figure 3. Furthermore, EDX analysis was carried out to examine the elemental composition of the TiC nanocomposite coating presented in Figure 4. The results indicate that the pulse rate significantly influences the morphology of the composite layer, particularly with the incorporation of TiC nanoparticles.

TiC nanoparticle with 5 nm size and a pulse frequency of 15 Hz was employed (Figure 4a). The elemental composition was 74.9%, as the small particle size improved dispersion in the nanocomposite coating, resulting in increased dispersion and elemental content. Subsequently, by increasing the pulse rate to 20 Hz, the elemental composition rises to 80.6%, as illustrated in Figure 4(b). The elevated pulse rate increases the distribution efficiency, while the nanoparticle enhances the population of TiC in the nanocomposite layer. Further on, at 25 Hz, the maximum pulse rate, elemental composition was maximum at 91.60% (Figure 4c) as the rise in the pulse rate facilitated the formation of a higher population of TiC nanoparticles, thus forming a maximum concentration and homogeneous distribution in the nanocomposite coating.

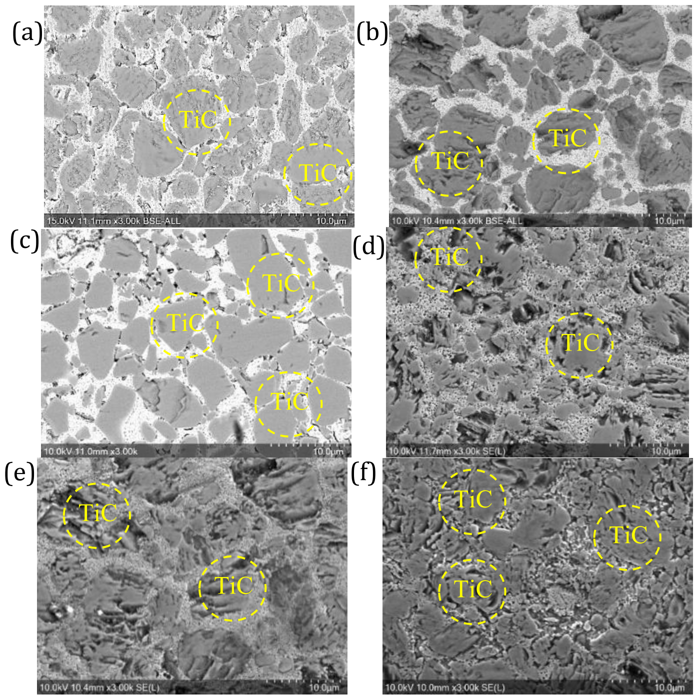

Figure 3. The cross-section morphology of the composite coating UNS S31803 with different TiC nanoparticle sizes and pulse rate: 5 nm (a) 140 A 15 Hz, (b) 140 A 20 Hz, (c) 140 A 25 Hz and 10 nm (d) 140 A 15 Hz, (e) 140 A 20 Hz, (f) 140 A 25 Hz.

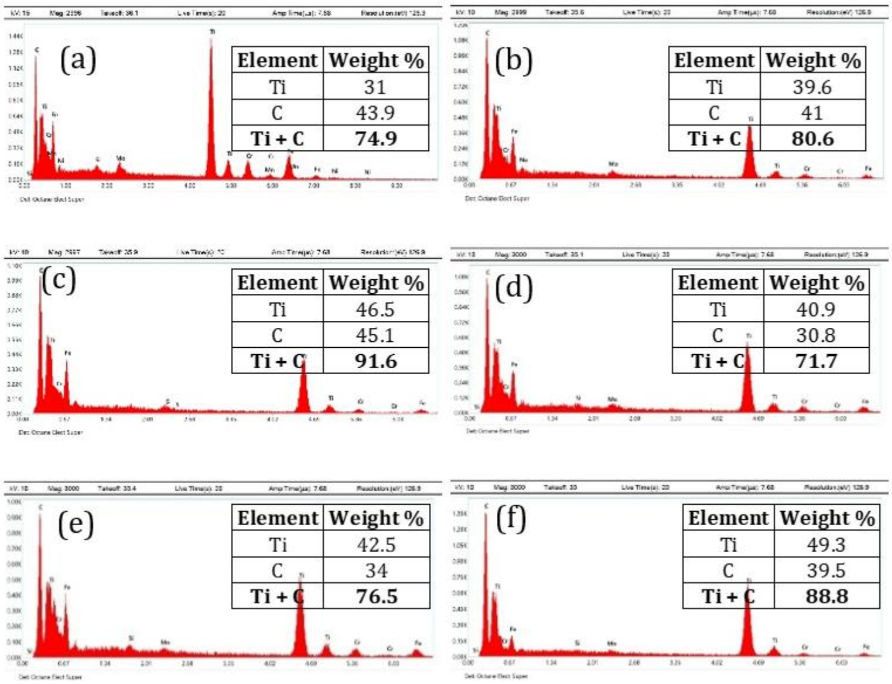

Figure 4. EDX analysis for TiC composite coating at different TiC nanoparticle sizes and pulse rate: 5 nm (a) 140 A 15 Hz, (b) 140 A 20 Hz, (c) 140 A 25 Hz, and 10 nm (d) 140 A 15 Hz, (e) 140 A 20 Hz, (f) 140 A 25 Hz.

Subsequently, for the 10 nm, the elemental composition was observed to be 71.70% at a pulse rate of 15 Hz, as shown in Figure 4(d). The larger nanoparticle size leads to a decreased surface area-to-volume ratio compared to 5 nm. This reduction limits the pulse rate of 15 Hz to uniformly disperse and effectively interact within the substrate matrix. Then, increasing the pulse rate to 20 Hz, the elemental composition increased to 76.5% (Figure 4e). Although the higher pulse rate enhances bonding between the TiC nanoparticles and the substrate, the 10 nm nanoparticles restrict the full incorporation into the nanocomposite coating layer. Afterward, at the maximum pulse rate of 25 Hz, the elemental composition reached 88.8% (Figure 4f). The maximum pulse rate strengthens the interaction between the nanoparticles and the substrate. However, the larger particle size results in a slightly lower elemental composition. Although the increased energy input at this rate improves bonding, the size limitation diminishes the overall effectiveness of the process.

Therefore, by comparing these observations, it is evident that the TiC nanoparticle with a size of 5 nm achieved superior dispersion and higher elemental composition, whereas the 10 nm, due to their larger size, contributed to a lower TiC population and lower overall effectiveness. Previous research has shown that nanostructured TiC powders produced through mechanical alloying demonstrate similar patterns, where smaller particle sizes result in enhanced elemental compositions attributed to better dispersion and interaction with the material [13]. The significance of these findings refers to their implications for enhancing the characteristics of TiC nanocomposite coatings. Moreover, the findings indicate that the optimum elemental composition was achieved with 5 nm at 140 A with 25 Hz, as shown in Figure 4(c), exhibiting the highest population of TiC nanoparticles, suggesting that adjusting to this parameter can further improve the substrate properties.

3.2 Vickers Microhardness

Microhardness measurements were conducted at the cross-section in several areas from the upper surface of the nanocomposite coating to the substrate region, revealing the impact of TiC nanoparticle sizes of 5 nm and 10 nm under the same current and varying pulse rate settings, as shown in Figure 5. The substrate microhardness served as a baseline at 259 HV to compare the TiC nanocomposite coating. That is to say, the addition of TiC nanoparticles migrates deeper into the substrate as the pulse rate increases, leaving the surface layer highly reinforced with the nanoceramic particle deposition.

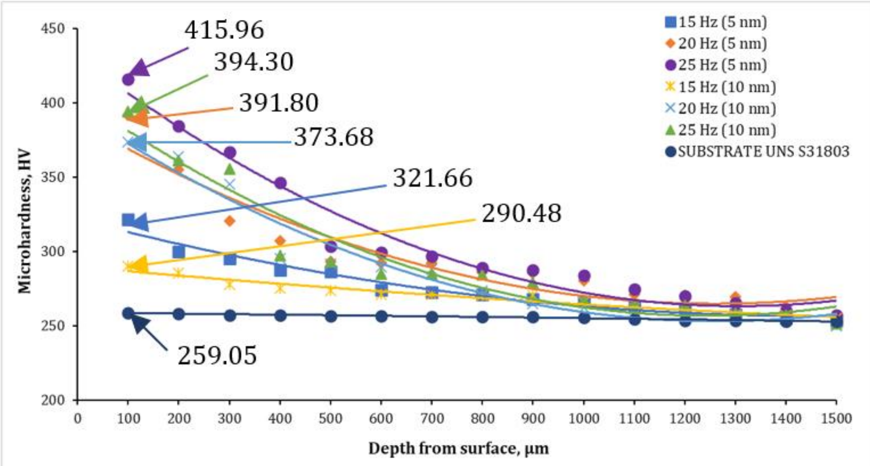

Figure 5 Microhardness profile of TiC nanocomposite coating using different tungsten arc melting process parameters for 5 nm and 10 nm.

The findings indicated a significant enhancement in hardness for the 5 nm as the pulse rate was increased. At a pulse rate of 15 Hz, the hardness was measured at 321.66 HV, which is attributed to the moderate deposition efficiency at this lower setting. While the TiC nanocomposite coating reinforces the surface, the bonding with the UNS S31803 matrix is not optimized, resulting in moderately higher hardness. Following this, as the pulse rate was increased to 20 Hz, the hardness exhibited a significant improvement of 21.8%, reaching a value of 391.8 HV. This higher pulse rate allowed better deposition of the TiC nanoparticles onto the surface. The enhanced reinforcement by the nanoparticles and UNS S31803 matrix improved the surface hardness. Subsequently, increasing the pulse rate to a maximum of 25 Hz, the hardness further increased by 29.3% with a value of 415.96 HV. At this highest pulse rate, nanoparticles are embedded and produce a uniform distribution throughout the layer. The smaller nanoparticle size enhances surface concentration, thereby maximizing hardness. Additionally, it allows more TiC nanoparticles to deposit into the substrate surface, which improves hardness even more, especially at higher pulse rates.

However, at 10 nm TiC nanoparticles, the hardness was slightly less than that of the 5 nm. Hardness of 290.48 HV was observed at 15 Hz pulse rate, which is the lowest hardness observed. This is due to the less efficient deposition process at the lowered pulse rate, decreasing the reinforcement concentration in the surface layer. As a result, the top layer exhibited decreased hardness and lower durability. Then, when the pulse rate was increased to 20 Hz, the hardness value went up drastically to 373.68 HV, indicating an increase of 28.7%. The deposition efficiency was improved by this pulse rate, resulting in a more uniform distribution of nanoparticles in the nanocomposite coating layer as well as stronger bonding in the matrix, which was the reason for this increase in hardness. Increasing the pulse rate to 25 Hz increased the hardness to 35.7%, at 394.3 HV. The highest deposition efficiency occurred under this pulse rate, which enabled the 10 nm nanoparticles to be buried deeply and evenly distributed in the nanocomposite coating layer. However, despite this improvement, the 5 nm nanoparticles performed better than the 10 nm nanoparticles.

In conclusion, the nanoparticles exhibited the highest hardness of 415.96 HV by 5 nm at a pulse rate of 25 Hz. The lowest hardness value of 290.48 HV was obtained with 10 nm at a pulse rate of 15 Hz. The results show that nanoparticle size has a significant influence on microstructural properties of the nanocomposite coating, with small-sized nanoparticles leaning towards high surface hardness by more intimate dispersion and the highest TiC nanoparticle in the matrix. The research by Farvizi et al. 2023 (14) investigated the effect of various Al_2O_3 particle sizes (1 µm, 0.3 µm, and 80 nm) on the microstructure and properties of NiTi type composite coatings deposited by laser cladding. The finer structure and enhanced microhardness were realized with particle refinement of Al_2O_3. The highest microhardness value of 636 HV was found in the composite with the Al_2O_3 particles of 80 nm, while 1 µm and 0.3 µm particles of the composite have varied between 460 HV to 525 HV. The addition of nano-sized Al_2O_3 particles produced higher martensite and $NiTi_2Ox/Ni_3Ti$ phases that improved the mechanical properties of the composite.

3.3 Wear Rate Analysis

The reciprocating wear test results for TiC nanocomposite coating of 5 nm and 10 nm sizes demonstrated significant differences in wear resistance, as illustrated in Figure 6. The substrate wear rate served as a baseline at 5.24 x 10^{-5} mm^3/Nm to compare the TiC nanocomposite coating. Wear rates of the 5 nm showed significant enhancements with increased pulse rates. At 140 A with 15 Hz, the wear rate was obtained at 3.53 x 10^{-5} mm^3/Nm. The wear rate decreased substantially to 2.02 x 10^{-5} mm^3/Nm at 20 Hz. Additionally, at 25 Hz, the wear rate decreased to 1.01 x 10^{-5} mm^3/Nm. The results indicate that the higher population of the 5 nm nanoparticles leads to a more uniform and strengthened nanocomposite coating layer, thereby improving wear resistance.

In contrast, the wear rates for the 10 nm exhibited an opposite trend. At a current of 140 A and a pulse rate of 15 Hz, the wear rate was 3.02 x 10^{-5} mm^3/Nm. Notably, at 20 Hz, the wear rate escalated to 4.03 x 10^{-5} mm^3/Nm. This increase at 20 Hz may be explained by uneven nanoparticle distribution during deposition, which affected the nanocomposite coating. At 25 Hz, the wear rate decreased to 1.51 x 10^{-5} mm^3/Nm. The larger size of the 10 nm nanoparticles allows for deeper penetration into the coating, which improves the structural stability of the coating and reduces wear. However, the penetration is not as deep as that of the 5 nm, resulting in slightly higher wear resistance.

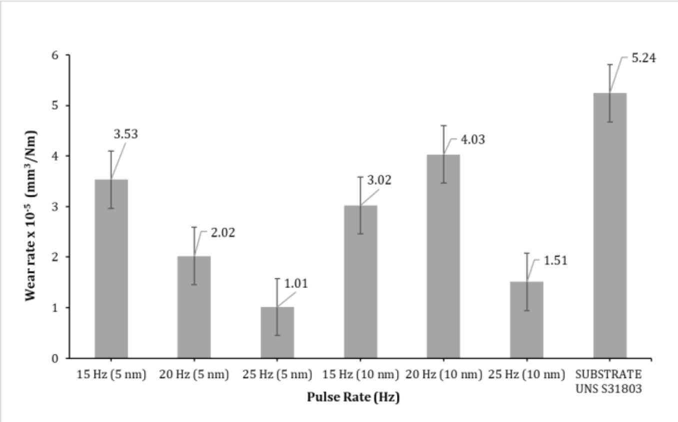

Figure 6 Wear rate of TiC nanocomposite coating using different tungsten arc melting process parameters for 5 nm and 10 nm.

As a result, both 5 nm and 10 nm TiC nanoparticles have improved the wear resistance of the nanocomposite coating layer. The 5 nm offer high wear resistance owing to the finer dispersion and higher population of TiC nanoparticles, leading to a more reinforced surface layer. The highest wear resistance was achieved with 5 nm at 25 Hz with a wear rate of 1.01 x 10^{-5} mm^3/Nm with the superior ability to reduce wear rates and enhance surface hardness among larger particles, making it ideal for wear-resistant applications. These findings are consistent with Wang et al., 2017 (15), who employed an Al 6061-T6 substrate and WC powder. The process was resistance seam welding, with particle sizes of 80 nm, 3.5 μm, and 55 μm. The results were that the 80 nm particle size exhibited the greatest wear resistance. Also, the rate of wear was seen to decrease with higher sliding distance. The wear mechanisms of the coatings varied significantly due to the distinctly different behaviors of the WC particles.

3.4 Worn Surface Analysis

The finding shows that the size of the TiC nanoparticles and the tungsten arc melting parameters have a significant influence on the wear behavior and resistance of UNS S31803. Figure 7 shows the FESEM image of the worn surface of the UNS S31803 substrate. This image serves as a baseline to compare the wear behavior of the TiC nanocomposite coatings, where wear tracks and deep grooves are clearly visible due to the absence of the nanocomposite coating. Figure 8 (a-f) shows FESEM images taken at x100 magnifications to examine the worn surface behaviour of the TiC nanocomposite coating on the UNS S31803 surfaces. The images depict the formation of wear tracks on the surface of the nanocomposite coating layer.

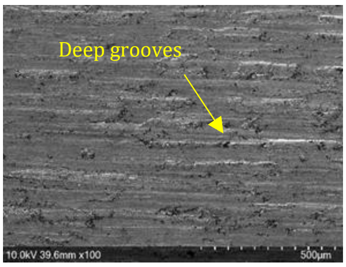

Figure 7. Worn surface for UNS S31803 substrate.

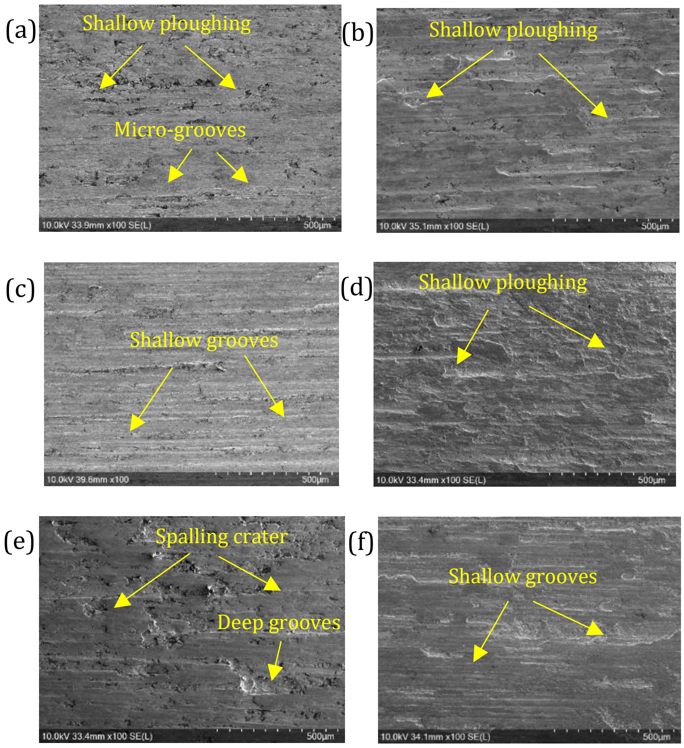

Figure 8. SEM image of the TiC- UNS S31803 reinforced surface with different sizes and pulse rate: 5 nm (a) 140 A 15 Hz, (b) 140 A 20 Hz, (c) 140 A 25 Hz and 10 nm (d) 140 A 15 Hz, (e) 140 A 20 Hz, (f) 140 A 25 Hz.

The wear mechanisms of 5 nm TiC nanoparticles vary according to the parameters. Therefore, at 15 Hz (Figure 8a), shallow ploughing and micro-grooves are indicative of abrasive wear. The wear resistance is moderate because of limited nanoparticle interaction and bonding, resulting in dominant shallow ploughing. Afterward, by increasing the pulse rate to 20 Hz (Figure 8b), it produces shallow ploughing. The increased pulse rate enhances nanoparticle distribution within the UNS S31803 matrix, thereby reducing abrasive forces. As a result, wear resistance is enhanced compared to 15 Hz. Then, at the maximum pulse rate of 25 Hz, as shown in Figure 8(c), shallow grooves indicative of minimal wear mechanisms are observed. The surface exhibits variation in roughness, and the increased pulse rate facilitates nanoparticle abrasion and hardness, minimizing material removal. The dispersion of the nanoparticles imparts a wear-resistant surface with minimal damage. Thus, 25 Hz offers the optimal balance of wear resistance and surface integrity and is therefore adequate for long-term performance.

The 10 nm TiC nanocomposite coating also has varying wear surface characteristics. At 15 Hz in Figure 8(d), shallow ploughing was observed, which indicated abrasive wear mechanisms. Less surface reinforcement was caused by poor distribution and bonding of the nanoparticles at this parameter. Then, at 20 Hz (Figure 8e), the surface exhibited spalling craters and deep grooves, which are features of intensive abrasive wear mechanisms. Non-uniform dispersion caused severe surface degradation and material loss. Then, increasing to pulse rate to 25 Hz (Figure 8f), the wear surface presented shallow grooves, indicating fewer wear mechanisms. Pulse rate increase facilitated nanocomposite coating and surface consolidation, thereby improving surface resistance and reducing wear. Among the 10 nm TiC nanoparticles, at a 25 Hz pulse rate, it exhibited minimum surface damage and better resistance.

The wear mechanism reveals that ploughing and abrasive wear are the prevailing processes in this sample. These observations are in line with previous work, in which it was demonstrated that the inclusion of SiC ceramic particles in duplex stainless steel decreased the wear rate by below 50% relative to that of the substrate due to a thermal heat input of 0.768 kJ/mm [16]. In a different investigation by Debta & Masanta. 2023 [17] examined a TiC-Co-nY_2O_3 TIG-clad layer on a Ti-6Al-4V alloy plate. The nano-Y_2O_3 without cladding was worn the most, while 2 wt% Y_2O_3 was worn the least. Since TiC-Co cladding had lower wear resistance than nano- Y_2O_3 cladding, its worn surface area was larger. Poor plastic deformation resistance was featured by ploughing furrows, minor scratches, and delaminated layers on worn surfaces.

Therefore, the 5 nm TiC nanoparticles demonstrated the best results at a pulse rate of 25 Hz, producing shallow grooves, minimal wear mechanisms, and enhanced surface integrity. In the same way, for the 10 nm, the pulse rate at 25 Hz was also optimal, exhibiting shallow grooves and minimal wear mechanisms. The findings indicate that increased pulse rate at 25 Hz enhances nanocomposite coating dispersion and bonding, leading to superior surface performance for both nanoparticle sizes.

4. CONCLUSION

The following findings can be taken from the current investigation;

a) TiC nanocomposite coating deposited on UNS S31803 surface and melted using the tungsten arc melting method has reinforced the surface properties.
b) Optimum surface hardness and wear resistance are achieved when 5 nm TiC nanoparticles are employed under a current of 140 A and a pulse rate of 25 Hz. These results indicate that the UNS S31803 surface's hardness and tribological characteristics are significantly enhanced when nanoparticle size and processing conditions are precisely controlled.
c) The optimum process parameters method has been successfully developed:
    i) Surface hardness and wear rate - The best process parameters are at 140 A with 25 Hz for a TiC nanoparticle size of 5 nm. The maximum hardness value achieved was 415.96 HV, and the lowest wear rate measured was 1.01 x 10^{-5} mm^3/Nm. This means that reducing the size of the nanoparticle with an optimal pulse rate enhances surface reinforcement and wear resistance.
    ii) The main wear mechanism showed a shallow groove in the optimal sample, which was produced at 140 A with a 25 Hz pulse rate using 5 nm TiC nanoparticles. The worst sample was from 140 A at 20 Hz, which exhibited spalling craters and deep grooves with 10 nm particles.

ACKNOWLEDGMENTS

The funding of this study was sponsored by FRGS/1/2023/TK10/UTEM/02/1 and FRGS/1/2023/FTKIP/F00554. The authors are also grateful to Universiti Teknikal Malaysia Melaka (UTeM) for the assistance that made this research feasible.

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