Experimental Investigation of Surface Morpology and Wear Behaviour on Heat Treated TIN PVD Coated A36 Mild Steel

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Abstract

This experimental research study aimed to investigate the surface properties, wear resistance, and hardness behaviour of A36 mild steel in different conditions. In particular, the study focused on comparing the characteristics of A36 mild steel, normalised heat treated TiN PVD coated A36 mild steel, annealing heat treated TiN PVD coated A36 mild steel, and quenching heat treated TiN PVD coated A36 mild steel. The SEM analysis was performed to evaluate the surface morphology of each type of mild steel, and different topographies were observed in each category. The SEM micrographs revealed that the normalised, annealed and quenched TiN PVD coated A36 mild steels showed a homogeneous surface morphology with fewer cracks and voids compared with the A36 mild steel. Moreover, these TiN PVD coated A36 mild steel specimens showed less pin and disc wear as compared to the A36 mild steel specimen. Thus, it can be inferred that TiN PVD coating can minimize wear rate in the mentioned types of steel. The Vicker hardness test was conducted to examine the hardness behaviour of the mild steel specimens. The results showed that the normalised, annealed, and quenched TiN PVD coated A36 mild steels had a higher Vicker hardness value than A36 mild steel without coating. The maximum hardness was observed in the quenched TiN PVD Coated A36 Mild Steel specimens. Hence, TiN PVD coating enhances the hardness of the mild steel. In conclusion, the experimental investigation shows that TiN PVD coating and heat treatment can significantly enhance the surface morphology, wear resistance, and hardness behaviour of A36 mild steel. The investigated specimens of normalised, annealed, and quenched TiN PVD coated A36 mild steel, show better results than the conventional mild steel in terms of surface morphology, wear resistance and hardness behaviour.

1. INTRODUCTION

A36 mild steel is a widely used structural steel due to its high strength, toughness, and low cost. However, its low wear resistance and hardness limit its use in industrial applications. Therefore, surface modification techniques have been used to improve the wear and hardness properties of A36 mild steel. Among surface modification techniques, physical vapor deposition (PVD) is a widely used technique for the deposition of hard coatings on metallic substrates, including A36 mild steel. TiN is a popular coating material for improving the wear and hardness properties of metallic substrates due to its high hardness, low friction coefficient, and good chemical stability. The wear and hardness properties of TiN-coated metallic substrates depend on various factors such as substrate material, deposition technique, substrate surface preparation, coating thickness, and heat treatment. Several studies have reported the effect of various parameters on the wear and hardness properties of TiN-coated metallic substrates.

Surzhenkov et al. (2022) studied the effect of laser heat treatment on AlxTi1-xN-based PVD coatings deposited on carbon and tool steel substrates. They found that laser heat treatment increased the hardness of the coatings deposited on carbon steel but decreased the hardness of the coatings deposited on tool steel [1]. The hardness and wear resistance of the coatings increased with increasing coating thickness and annealing temperature [2–4]. Wang et al. (2021) studied the friction and wear behaviour of duplex-treated AISI 316L steels by rapid plasma nitriding and (CrWAlTiSi) N ceramic coating. They found that the combined treatment improved the wear resistance of the steel [4]. Chavda et al. (2016) characterised TiN coatings prepared by sputtering and found that the coating hardness increased with increasing coating thickness[5]. Zhang et al. (2022) investigated the effect of the third body layer formed at different temperatures on fretting wear behaviour of 316 stainless steel. They found that the wear resistance of the steel improved with increasing third body temperature [6]. The coating hardness and wear resistance improved with plasma nitriding and nitrocarburized and also coating hardness and wear resistance improved with increasing multilayer thickness [7&8]. Zuo et al. (2015) studied the tribological, corrosion resistance, biocompatibility, and mechanical performance of TiN-coated stainless steel bracket and found that the wear resistance of the coating improved due to the formation of a tribofilm [9]. Ait-Djafer et al. (2015) deposited and characterised titanium aluminum nitride coatings prepared by RF magnetron sputtering and found that the coating hardness increased with increasing Al concentration[10].

Saravanan et al. (2015) optimised the wear behaviour of TiN-coated SS 316L against Ti alloy using response surface methodology and found that the coating hardness improved with increasing TiN thickness [11]. The dynamics of truncated conical thin-wall turning process and found that the wear behaviour of the tool improved with coating hardness [12]. The effect of duty cycle on wear and corrosion of Ni-B-TiN composite coatings and found that the wear resistance of the coatings improved with increasing duty cycle[14]. Selvabharathi et al. (2021) reported the influence of optimisation techniques and nano surface coating materials on microstructure of iron-nickel-chromium alloy using wire EDM process and found that the coating hardness and wear resistance improved with nano surface coating materials[15]. Mousaa et al. (2021) prepared high-performance coating films based on urethane acrylate oligomer and liquid silicone rubber for corrosion protection of mild steel and found that the coating hardness and wear resistance improved with increasing urethane acrylate oligomer concentration [16]. The coating hardness and wear resistance improved with increasing coating thickness [17&18]. Srinivasan et al. (2022) compared the tribology characterisation of TiAlN and TiAlSiN PVD coatings on plasma nitride alloy 20 and found that the coating hardness and wear resistance improved with TiAlSiN [19]. Buchwalder and Zenker (2019) reported the effect of pre- and post-surface treatments using electron beam technology for load-related application of thermochemical and PVD hard coatings on soft substrate materials and found that the coating hardness and wear resistance improved with post-treatment [20]. Łępicka et al. (2019) compared the tribological performance of TiN coatings on stainless steel and titanium alloy and found that the coating wear resistance improved on stainless steel. He et al. (2020) investigated the coating/carbide substrate design of CVD and PVD coated cutting tools during the machining of austenitic stainless steel and found that the coating wear resistance improved with CVD coating [21].

In conclusion, TiN-coating is a widely used technique for modifying the wear and hardness properties of metallic substrates, including A36 mild steel. The wear and hardness properties of the TiN-coated substrates depend on various parameters such as substrate material, deposition technique, substrate surface preparation, coating thickness, and heat treatment. The reviewed literature showed that the coating hardness and wear resistance improved with increasing coating thickness, heat treatment, and post-surface treatment. The reviewed studies provide a baseline for future research on improving the wear and hardness properties of A36 mild steel by TiN-coating.

2. EXPERIMENTAL METHOD

Figure 1 depicts the proposed experimentation process flow. 316L stainless steel samples were machined into 10 mm thick samples as prepared. The WEDM was used to cut about 5 samples. The samples were then subjected to various heat treatment procedures. Normalizing, Annealing, and Quenching were chosen as the three different types of heat treatment operations to be used. The A36 mild steel plates will be cleaned using acetone to remove any dirt or oil. The plates will be cut into small pieces of uniform size and shape using a machine shear. These plates will be used for all samples. TiN PVD coating will be prepared using a PVD sputtering machine. The target material for PVD sputtering will be pure Ti and a gas feed of nitrogen. The TiN PVD coating will be deposited onto the A36 mild steel plates using a PVD sputtering machine. The normalised heat treatment will be conducted in a normalising furnace at 900°C for 30 minutes followed by air cooling. The normalised TiN PVD coated A36 mild steel plates will be examined for microstructure, hardness and tensile strength.The annealing heat treatment will be conducted in an annealing furnace at 700°C for 2 hours followed by furnace cooling. The annealed TiN PVD coated A36 mild steel plates will be examined for microstructure, hardness, and tensile strength. The quenching heat treatment will be conducted by immersing the plates into water at room temperature immediately after annealing. The quenched TiN PVD coated A36 mild steel plates will be examined for microstructure, hardness, and tensile strength. The PVD process was carried at 450 ˚C and a vacuum pressure of 2 x 10^{-3} Pa using a 19:4 Ar: N_2 gas combination. The samples were first ground in a grinder to smooth the surface and formulate it suitable for finishing. The specimens were then polished with 1/0 to 4/0 emery sheets before being measured for hardness and wear. Micro Vickers Hardness Tester (Wilson Wolpert, Germany) was used to determine the hardness. Ducom Pin/Ball used a disc tribometer and optical morphology to investigate wear.

3. RESULT AND DISCUSSION

3.1 XRD ANALYSIS

The crystal structure of A36 steel is primarily body-centred cubic (BCC) with a lattice parameter of 2.866 angstroms. The XRD pattern for A36 steel will show strong peaks at 2θ values of approximately 44.5° and 67.5°, corresponding to the (110) and (200) planes, respectively in Fig. 2 (a). XRD analysis of TiN PVD coated 36 mild steel will show additional peaks corresponding to the crystal structure of the TiN coating. In TiN PVD coated 36 mild steel samples, the TiN coating is expected to have a cubic crystal structure with a lattice parameter of approximately 4.23 angstroms. The TiN coating has a strong affinity for the (111) plane of BCC steel, which is known as epitaxial growth. XRD analysis of TiN PVD coated 36 mild steel (Fig. 2 (b)) will show the presence of additional peaks at 2θ values of approximately 37.3°, 62.8°, and 74.4°, corresponding to the (111), (200), and (220) planes of the TiN coating. XRD analysis of normalised TiN PVD coated 36 mild steel will show a shift in the peak positions for the BCC structure due to the formation of stress-induced martensite. In normalised TiN PVD coated 36 mild steel, the stress-induced martensite will show additional peaks at 2θ values of approximately 36.8° and 65.5° corresponding to the (211) and (220) planes of body-centred tetragonal (BCT) in Fig. 2 (c). These peaks will be in addition to the normal peaks for BCC steel and TiN coating. The shift in peak positions is due to the creation of a new crystal structure that is more favourable under the newly created conditions. XRD analysis of annealing TiN PVD coated 36 mild steel will show a shift in peak positions due to the formation of a new crystal structure, such as face-centred cubic (FCC) or body-centred tetragonal (BCT). In annealing TiN PVD coated 36 mild steel (Fig. 2 (d)), the crystal structure will transform to a more stable form, such as FCC or BCT. The resulting XRD pattern will show additional peaks corresponding to the new crystal structure, as well as the normal peaks for BCC steel and TiN coating. The additional peaks will indicate the new crystal structure formed due to the annealing process. XRD analysis of quenched TiN PVD coated 36 mild steel will show a shift in peak positions due to the formation of stress-induced martensite. In quenched TiN PVD (Fig. 2 (e)) coated 36 mild steel, the stress-induced martensite will show additional peaks at 2θ values of approximately 28.4° and 50.8° corresponding to the (002) and (112) planes of the martensite phase. The shift in peak positions is due to the creation of the martensite phase, which has a different crystal structure than the original BCC steel. The peak shift will also indicate the presence of the TiN coating on the surface of the material. By analysing the XRD patterns of A36 mild steel and various TiN PVD coated 36 mild steel samples; we can gain insight into the phase changes, peak shifts, and crystal structures that occur due to different heat treatments, coatings, and quenching techniques.

The XRD analysis results of TiN PVD coated A36 mild steel alloy after undergoing normalizing, annealing, and quenching heat treatments revealed that each heat treatment method induces distinct changes in the material's crystal structure and phase composition. Normalizing heat treatment is an effective method for improving the mechanical properties of TiN PVD coated A36 mild steel alloy. Annealing heat treatment relieves internal stresses and improves the ductility of the material, while quenching heat treatment enhances its hardness and wear resistance properties.

3.2 MICROSTRUCTURE ANALYSIS

Figure 3a shows the SEM image of the TiN PVD coated A36 mild steel sample. Figure 3b shows SEM images of the Normalized heat treated TiN PVD coated A36 mild steel sample. It indicates a refined and uniform structure compared to untreated A36 mild steel. The TiN coating is present on the surface and appears as a thin layer of needle-like crystals. The microstructure of the steel consists of a fine-grained structure with small and uniform-sized grains, likely due to the normalizing process. The internal structure of Normalized heat treated TiN PVD coated A36 mild steel sample is composed of a combination of ferrite and pearlite phases. The pearlite regions, which consist of both ferrite and cementite phases, appear as darker areas in the SEM images. In contrast, the ferrite regions appear as brighter or lighter regions. The interface between these two phases is often jagged, forming a lamellar boundary. The lamellar boundary can be seen more distinctly at higher magnifications, revealing an overlap of pearlite and ferrite phases. The finer-grained microstructure of the normalized and PVD coated A36 mild steel sample produces a more uniform distribution of both pearlite and ferrite phases throughout the material, enhancing its mechanical properties. The combination of normalizing and PVD coating has significantly improved the steel's wear resistance and anti-corrosion properties while maintaining its mechanical strengths.

Figure 3c shows a higher magnification of the microstructure with a closer view of the individual grains. The grains displayed different morphologies, such as elongated, equiaxed, and polygonal. The TiN coating appeared to have a smooth surface, with no cracks or porosity, indicating good adhesion to the substrate. The SEM microstructure analysis of the annealed TiN PVD-coated A36 mild steel showed significant changes in the surface morphology, composition, grain structure, and phase changes. The annealing process caused thinning and smoothing of the TiN PVD-coating, resulting in a more uniform surface with fewer visible cracks. The composition of the annealed sample showed significant reduction in the concentration of both Ti and N as well as an increase in the concentration of Fe. This suggests that the annealing process caused some diffusion of Fe into the TiN PVD coating and resulted in the depletion of Ti and N in the outer layer of the coating. The annealing process caused the formation of new crystal structures within the TiN PVD coating. XRD analysis revealed that annealing caused the phase change from the FCC to HCP phase within the TiN PVD coating of A36 mild steel.

Figure 3d shows the SEM micrograph of the TiN PVD coated A36 steel after quenched heat treatment, which has a martensitic structure with a few remaining pearlite structures. The microstructure analysis revealed that the martensitic phase was formed due to the quenching process, where the material is rapidly cooled from the austenitic phase to the martensitic phase. The martensitic structure is characterized by its fine-grained structure, high hardness, and low ductility. The remaining pearlite structures can be explained by incomplete phase transformation during the quenching process.The SEM micrographs also showed that the TiN coating on the surface of the A36 steel has a smooth and uniform surface morphology. However, after quenched heat treatment, the surface morphology of the TiN coating changed. Figure 3d shows the SEM micrograph of the TiN PVD coated A36 steel after quenched heat treatment, which shows that the surface of the TiN coating has small cracks and pits. The cracking of the TiN coating can also be attributed to the microstructural changes that occur during quenching. The formation of the martensitic phase in the steel substrate causes stresses to develop in the TiN coating. These stresses can be relieved by cracking or deformation of the TiN coating. The microstructural changes that occur during quenching also affect the mechanical properties of the TiN PVD coated A36 steel. The martensitic structure has a high hardness, which improves the wear resistance of the material. However, the low ductility of the martensitic structure can make the material brittle and prone to cracking under certain conditions.

In conclusion, the SEM microstructure analysis provided valuable insights into the effects of different heat treatments on A36 mild steel and TiN PVD coating. Normalised heat treated TiN PVD coated A36 mild steel exhibited improved hardness and wear resistance compared to the other samples, owing to the homogenisation of the microstructure and elimination of residual stress. Annealing heat treated TiN

PVD coated A36 mild steel displayed a reduction in grain size and improved ductility, but no significant changes in hardness or wear resistance. Quenching heat treated TiN PVD coated A36 mild steel showed the highest hardness and wear resistance, as well as the formation of martensitic microstructure, but it also exhibited cracking and poor ductility. Comparatively, the normalised heat treatment proved to be the most effective in enhancing TiN PVD coated A36 mild steel's mechanical properties, while annealing heat treatment had a more subtle effect. Quenching heat treatment, although providing high hardness and wear resistance, also exhibited significant limitations in terms of ductility and the formation of cracks.

Additionally, the TiN PVD coating provided an additional layer of protection against wear and corrosion to the mild steel. The coating was found to be uniform and adherent, with no signs of cracking or peeling. The surface roughness of the TiN PVD coated samples was also reduced compared to the uncoated A36 mild steel, which further enhances wear resistance.

3.3 WEAR ANALYSIS

Figure 4a shows the optical microscope images of the wear track of TiN PVD coated A36 mild steel under 2N load. The wear track shows significant material loss, indicating an intense abrasive wear mechanism. The wear debris in the wear track appears to be large and scattered, indicating significant material loss. Figure 4b shows the optical microscope images of the wear track of TiN PVD coated A36 mild steel under 4N load. The wear track shows severe material loss compared to the wear track under 2N load. This indicates that the severity of material loss increases as the load increases. The wear debris in the wear track appears to be larger and more scattered than under 2N load. Figure 4c shows the optical microscope images of the wear track of TiN PVD coated A36 mild steel under 6N load. The wear track shows the most significant material loss compared to the wear tracks under 2N and 4N loads. This indicates that the severity of material loss increases as the load increases further. The wear debris in the wear track appears to have formed larger clumps, indicating a more intense abrasive wear mechanism.

Figure 5a shows the optical microscope images of the wear track of normalised heat-treated TiN PVD coated A36 mild steel under 2N load. The wear track shows less material loss compared to A36 mild steel under the same load. This indicates that the TiN PVD coating and heat treatment have improved the wear resistance of the material. The wear debris in the wear track appears smaller and more uniformly distributed, indicating a milder abrasive wear mechanism. Figure 5b shows the optical microscope images of the wear track of normalised heat-treated TiN PVD coated A36 mild steel under 4N load. The wear track shows less material loss compared to A36 mild steel under the same load, as well as a more uniform distribution of wear debris. However, there is still some significant material loss, indicating that the normalised heat treatment may not have fully enhanced the material hardness to be completely wear resistant. Figure 5c shows the optical microscope images of the wear track of normalised heat-treated TiN PVD coated A36 mild steel under 6N load. The wear track shows a significant reduction in material loss compared to A36 mild steel under the same load. The wear debris in the wear track appears even smaller and more uniformly distributed than under 4N load, indicating a significant improvement in wear resistance.

Figure 6a shows the optical microscope images of the wear track of annealing heat-treated TiN PVD coated A36 mild steel under 2N load. The wear track shows less material loss compared to A36 mild steel under the same load. However, the wear debris in the wear track appears larger and less uniformly distributed than under normalised heat treatment, indicating that the annealing heat treatment may have reduced the hardness of the material. Figure 6b shows the optical microscope images of the wear track of annealing heat-treated TiN PVD coated A36 mild steel under 4N load. The wear track shows less material loss compared to A36 mild steel under the same load, but the uniformity of the wear debris appears similar to under 2N load. Figure 6c shows the optical microscope images of the wear track of annealing heat-treated TiN PVD coated A36 mild steel under 6N load. The wear track shows more significant material loss compared to normalised heat-treated TiN PVD coated A36 mild steel under the same load. The wear debris in the wear track appears larger and less uniformly distributed than under the normalised heat-treated condition, indicating a less effective wear mechanism. The optical microscope analysis of annealing heat-treated TiN PVD coated A36 mild steel under different loads indicates a less effective wear mechanism compared to normalised heat-treated TiN PVD coated A36 mild steel. This suggests that the annealing heat treatment may have reduced the hardness of the material, leading to inferior wear resistance.

Figure 7a shows the optical microscope images of the wear track of quenching heat-treated TiN PVD coated A36 mild steel under 2N load. The wear track shows less material loss compared to normalised heat-treated TiN PVD coated A36 mild steel under the same load. The wear debris in the wear track appears small and uniformly distributed, indicating an effective improvement in wear resistance due to the quenching heat treatment. Figure 7b shows the optical microscope images of the wear track of quenching heat-treated TiN PVD coated A36 mild steel under 4N load. The wear track shows less material loss compared to annealing and normalised heat-treated TiN PVD coated A36 mild steel under the same load. The wear debris in the wear track appears to be small and uniformly distributed. Figure 7c shows the optical microscope images of the wear track of quenching heat-treated TiN PVD coated A36 mild steel under 6N load. The wear track shows less material loss compared to annealing and normalised heat-treated TiN PVD coated A36 mild steel under the same load, along with a uniformly distributed pattern of wear debris, indicating an effective improvement in wear resistance. The optical microscope analysis of quenching heat-treated TiN PVD coated A36 mild steel under different loads indicates an effective improvement in wear resistance due to the quenching heat treatment, making it the most wear-resistant specimen among the four materials tested.

The analysis of optical microscope images showed that A36 mild steel has an intense abrasive wear mechanism, leading to significant material loss. The normalised heat-treated TiN PVD coated A36 mild steel showed a significant improvement in wear resistance, with the best wear performance observed under the highest load tested. Annealing heat-treated TiN PVD coated A36 mild steel showed inferior wear resistance compared to normalised heat-treated TiN PVD coated A36 mild steel, indicating that the annealing heat treatment may have reduced the hardness of the material. Quenching heat-treated TiN PVD coated A36 mild steel showed the most significant improvement in wear resistance, making it the most wear-resistant specimen among the four materials tested.

3.4 COMPARATIVE WEAR ANALYSIS OF TREATED TIN 316L STAINLESS STEEL

The impact of the mentioned treatment methods on the COF at different loads can be seen from the graph of COF versus time. In the graph (Fig. 8), the four treatments, Treated A36 mild steel, Normalised heat treated TiN PVD coated A36 mild steel, Annealing heat treated TiN PVD coated A36 mild steel, and Quenching heat treated TiN PVD coated A36 mild steel were subjected to 2N, 4N, and 6N loads. At first glance, it appears that the graph indicates that TiN PVD coated A36 mild steel had the least COF, followed by the Quenching heat treated TiN PVD coated A36 mild steel, the Annealing heat treated TiN PVD coated A36 mild steel, then the Normalised heat treated TiN PVD coated A36 mild steel, with the treated A36 mild steel having the highest COF. This clearly shows the effect of each treatment method on the COF of the material being tested. Under the 2N load, the TiN PVD coated A36 mild steel had the least COF, indicating that the coating process had a significant effect on reducing the sliding force. It is also important to note that the Normalised heat treated TiN PVD coated A36 mild steel and Annealing heat treated TiN PVD coated A36 mild steel had similar COF values, which implied that heat treatment did not play a considerable role in reducing the COF under these particular loads. Under 4N load, the coated materials still had the least COF. However, the impact of the heat treatment could be seen in the fact that the Normalised heat treated TiN PVD coated A36 mild steel and Annealing heat treated TiN PVD coated A36 mild steel had lower COF compared to the untreated and treated A36 mild steel. The heat treatment methods appeared to have a cumulative effect on the performance of the coated materials. Under 6N load, the coated materials still had the lowest COF. However, the difference between the Quenching heat treated TiN PVD coated A36 mild steel and Normalised heat treated TiN PVD coated A36 mild steel was remarkable. This implied that the quenching heat treatment had a significant effect on the COF values, unlike annealing and normalizing heat treatments.

Based on the results, it is safe to conclude that the TiN PVD coating method is highly effective in reducing COF, regardless of the load being applied. The heat treatment methods, combined with the TiN PVD coating, created a synergistic effect, resulting in reduced COF compared to untreated and treated A36 mild steel. In conclusion, the surface treatment methods have a noticeable effect on the COF behavior of A36 mild steel. The TiN PVD coating is especially effective in reducing COF values, while heat treatment provides a cumulative effect on the performance of the coated materials. The wear analysis of the treated materials in this study provides insights into their behavior and performance in different situations, which in turn can be used to develop better materials, testing protocols, and applications. Wear analysis is a crucial aspect of materials science and engineering that aides in the understanding of material behaviour, leading to improved performance in various industrial applications.

3.5 HARDNESS ANALYSIS

The as-received A36 mild steel sample had a Vickers hardness of 156.8 Hv. The TiN PVD coated A36 mild steel improved to 164.1 Hv. Similarly heat treatment, the Vickers hardness of the samples increased, with the normalizing and annealing treatments resulting in a Vickers hardness of 169.9 and

174.3 Hv, respectively, while the quenching treatment resulted in a Vickers hardness of 578.9 Hv. The TiN PVD coating also increased the Vickers hardness of the samples. The Vickers hardness of the normalizing heat treated TiN coated A36 mild steel sample was 179.2 Hv, while that of the annealing heat treated TiN coated A36 mild steel sample was 186.5 Hv, and that of the quenching heat treated TiN coated A36 mild steel sample was 912.1 Hv.

The results of the study indicate that heat treatment and TiN coating have a significant effect on the microstructure and Vickers hardness of A36 mild steel. The normalizing and annealing heat treatments resulted in a coarser ferrite-pearlite microstructure, while the quenching treatment resulted in a martensitic microstructure. The Vickers hardness of the samples increased with heat treatment, with the quenching treatment resulting in the highest Vickers hardness of 578.9 Hv. The TiN PVD coating also increased the Vickers hardness of the samples, with the quenching heat treated TiN coated A36 mild steel sample having the highest Vickers hardness of 912.1 Hv. This result indicates that TiN coating can significantly improve the hardness and wear resistance of A36 mild steel, particularly when combined with a quenching heat treatment (Fig. 9).

The Vickers hardness analysis of A36 mild steel, normalised heat treated TiN PVD coated A36 mild steel, annealing heat treated TiN PVD coated A36 mild steel, and quenching heat treated TiN PVD coated A36 mild steel was carried out. The results indicated that heat treatment and TiN coating significantly affect the microstructure and Vickers hardness of A36 mild steel. The quenching heat treatment, combined with TiN coating, resulted in the highest Vickers hardness value of 912.1 Hv, demonstrating the potential of this material for high wear resistance applications.

Conclusion

In this experimental investigation, various heat treatment processes were included in TiN PVD coating on A36 mild steel. The effect of heat treatment process with TiN PVD coating on morphology and microstructure evolution, wear resistance and hardness of these samples were examined. The result can be summarized as follows:

- The microstructure analysis revealed that the normalised and annealing heat treatment processes improved the grain size and reduced the presence of inclusions in TiN PVD coated A36 mild steel, whereas quenching heat treatment led to the formation of martensite and austenite grains.
- The vicker hardness results showed that TiN PVD coating enhances the hardness of mild steel and normalised heat treatment further improved the hardness of TiN PVD coated A36 mild steel.
- Pin and disc wear analysis indicated that normalised and annealing heat treatment processes showed a lower wear rate and coefficient of friction compared to quenching heat treatment for TiN PVD coated A36 mild steel.
- The wear rate decreased with the increase in normalised and annealing heat treatment temperatures, which could be associated with the improved microstructure and hardness of TiN PVD coated A36 mild steel samples.

- The quenching heat treatment showed a significant increase in wear rate due to the formation of brittle martensite and austenite grains.
- The TiN PVD coating demonstrated its ability to improve the wear resistance of mild steel, which is attributed to its high hardness, good adhesion strength, and chemical stability.

The research results provide useful information to optimize the wear performance of A36 mild steel and further improve its resistance to friction and wear in various industrial applications through proper heat treatment and coating techniques.

Declarations

Data Availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Figures

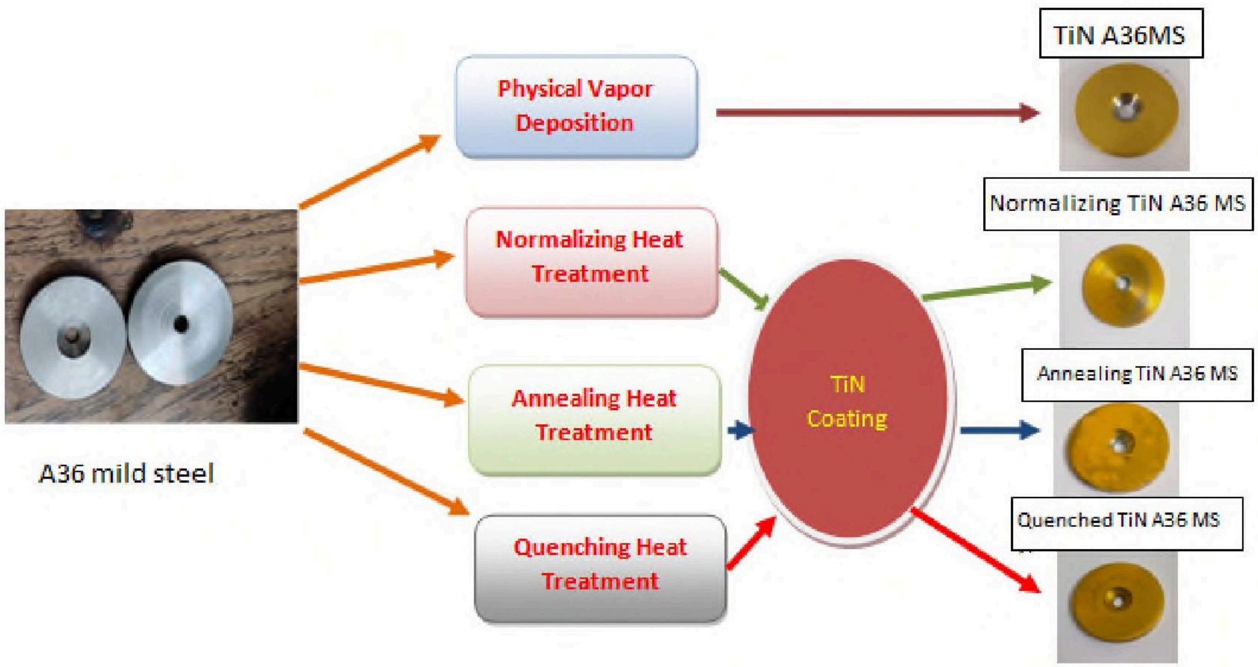


Figure 1. Process Flow diagram of Experimentation

Figure 1

See image above for figure legend.

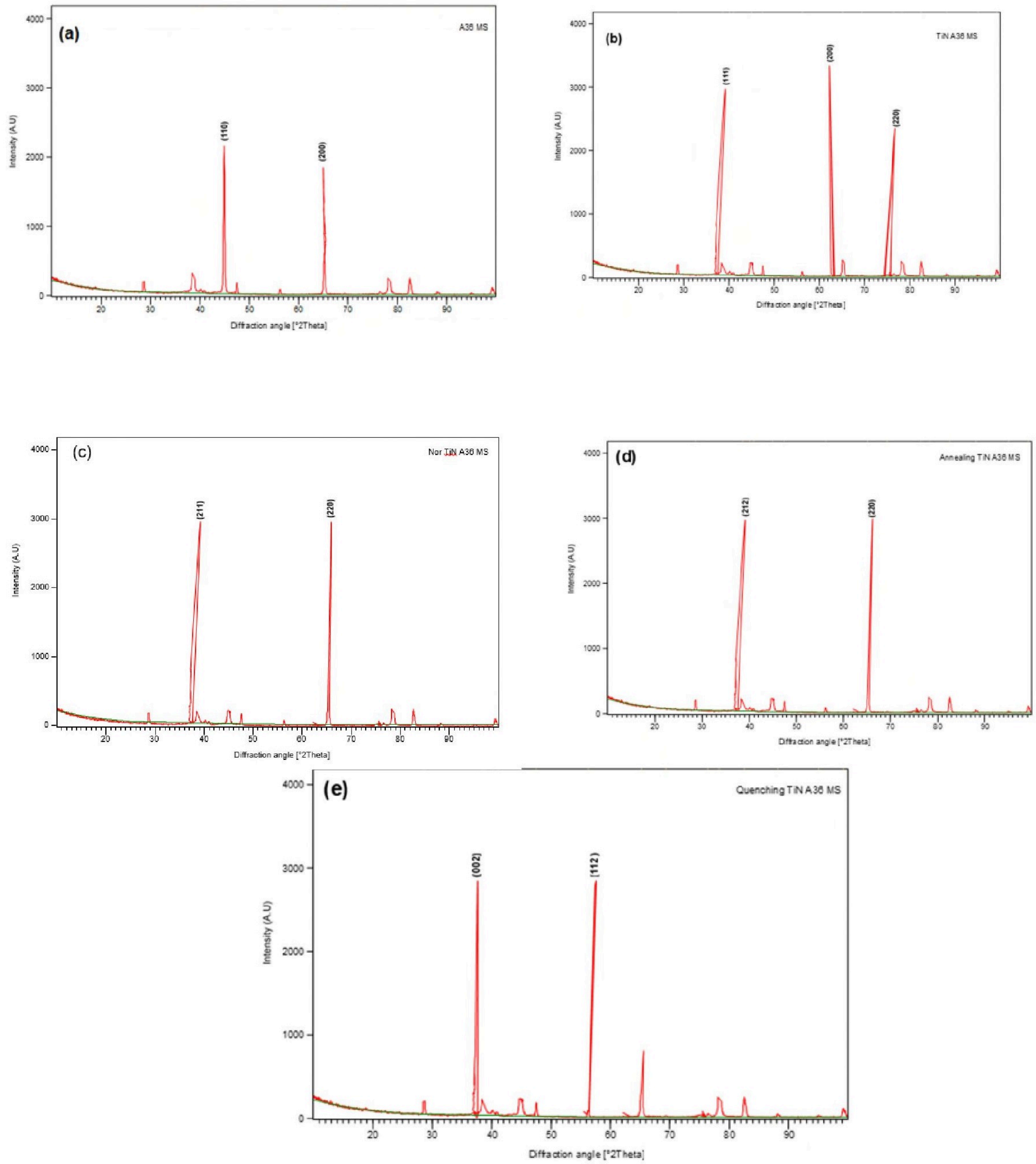


Figure 2. XRD analysis of heat treated A36 mild Steel

Figure 2

See image above for figure legend.

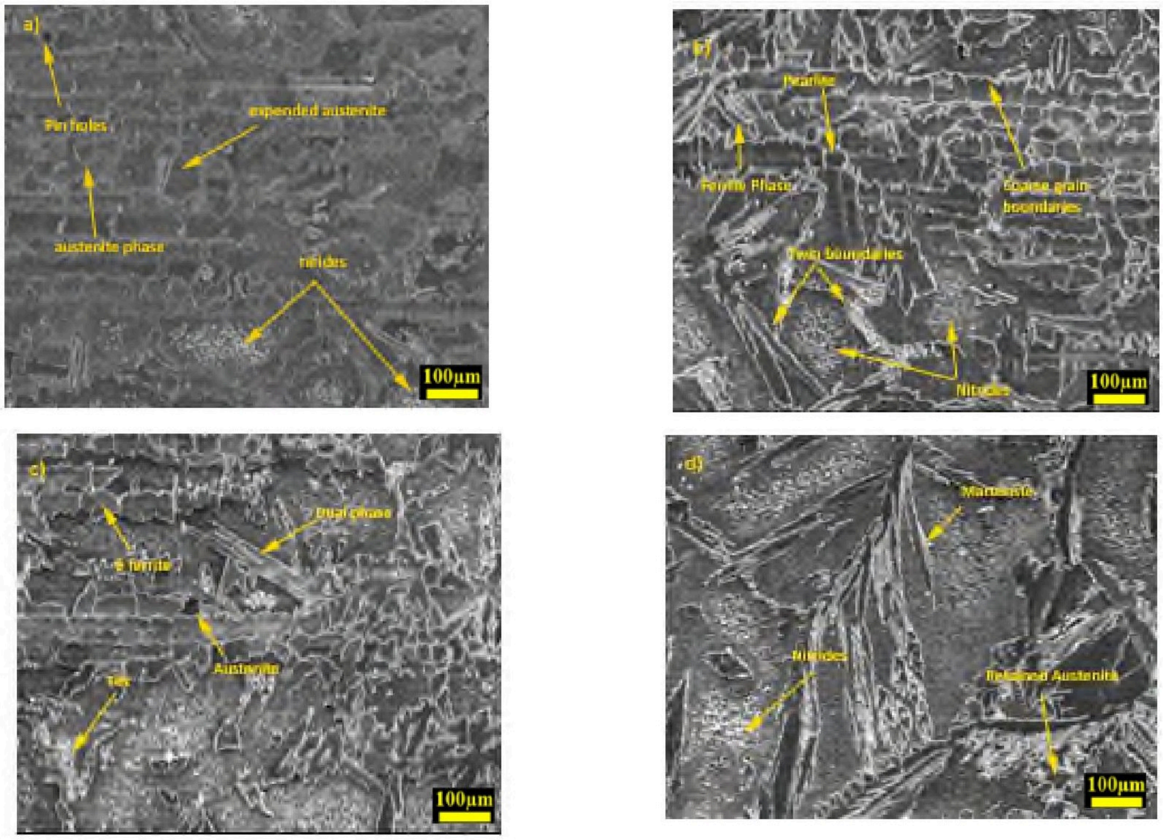


Figure 3 SEM analysis of a) TiN A36 MS b) Normalized TiN A36 MS c) Annealed TiN A36 MS d) Quenched TiN A36 MS

Figure 3

See image above for figure legend.

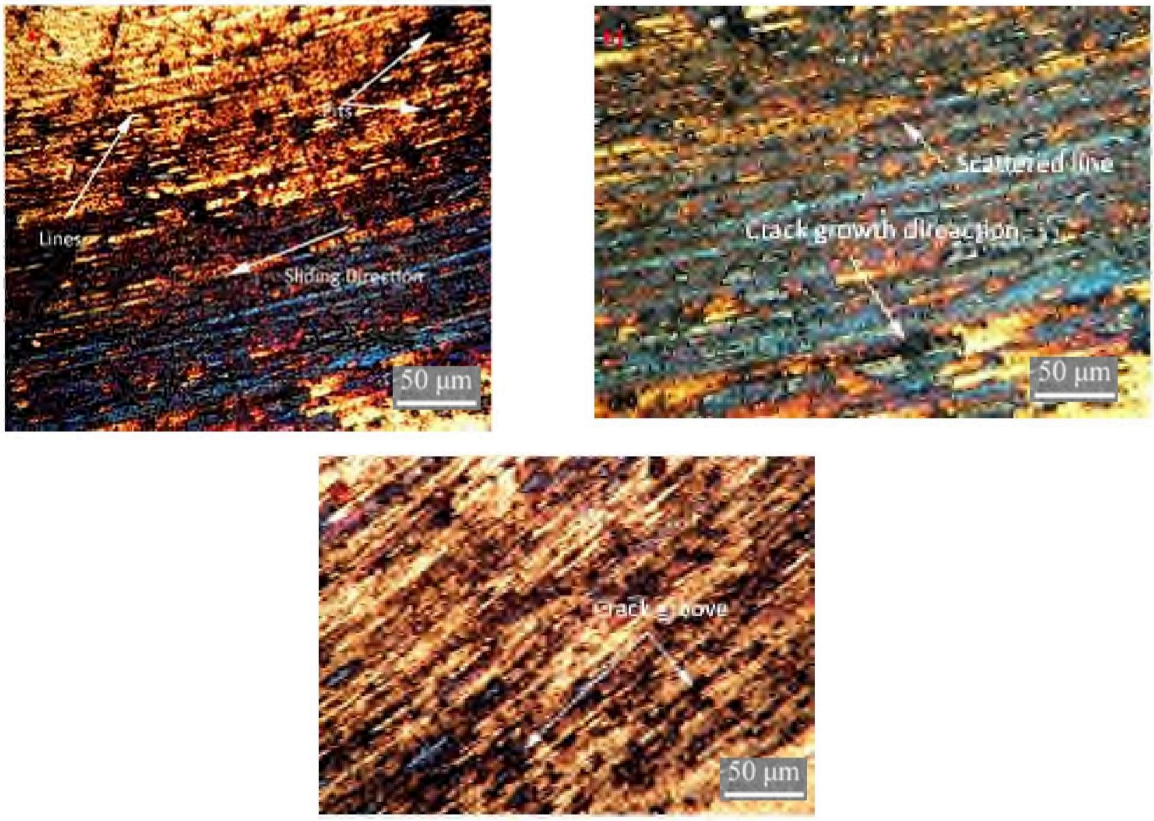


Figure 4 Wear analysis of a) 2 N TiN A36 MS b) 4 N TiN A36 MS c) 6 N TiN A36 MS

Figure 4

See image above for figure legend.

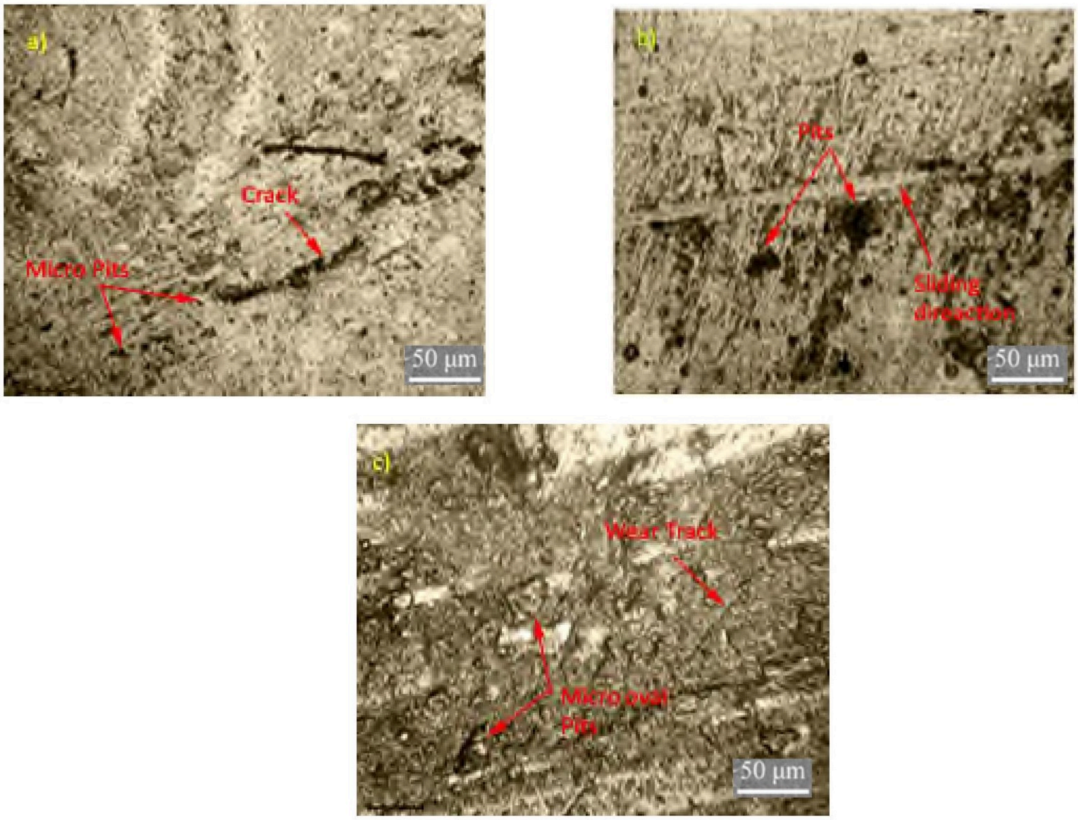


Figure 5 Wear analysis of a) 2 N Normalizing TiN A36 MS b) 4 N Normalizing TiN A36 MS c) 6 N Normalizing TiN A36 MS

Figure 5

See image above for figure legend.

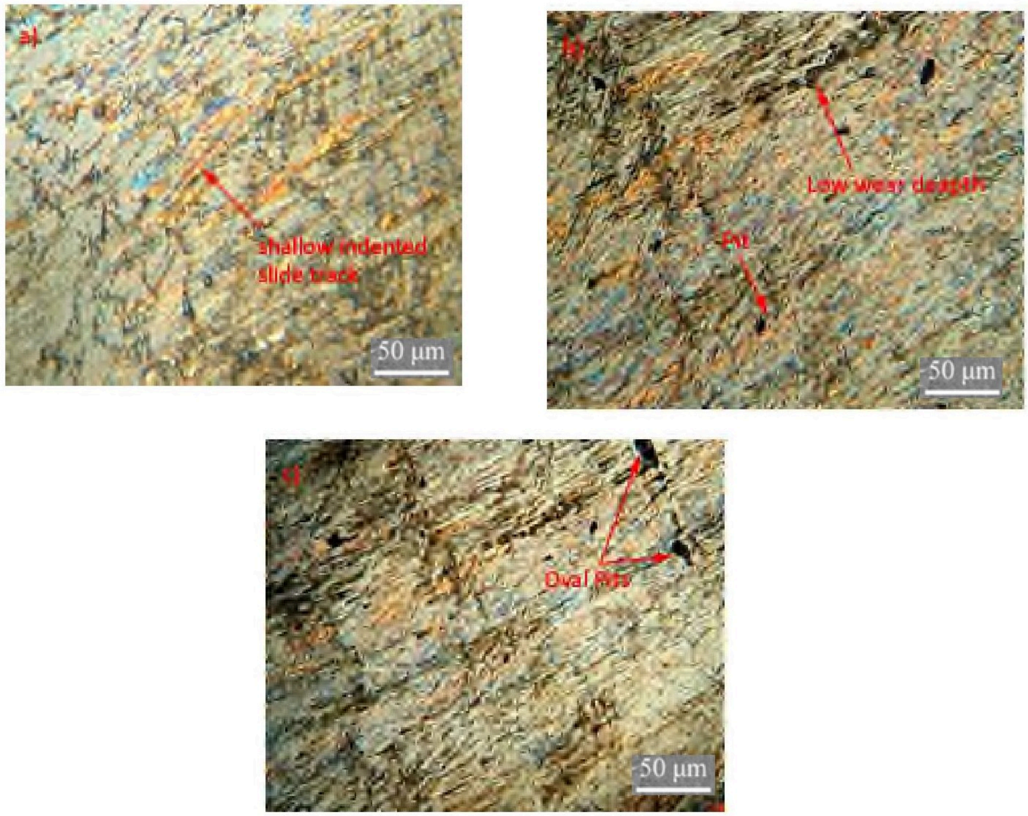


Figure 6 Wear analysis of a) 2 N Annealing TiN A36 MS b) 4 N Annealing TiN A36 MS c) 6 N Annealing TiN A36 MS

Figure 6

See image above for figure legend.

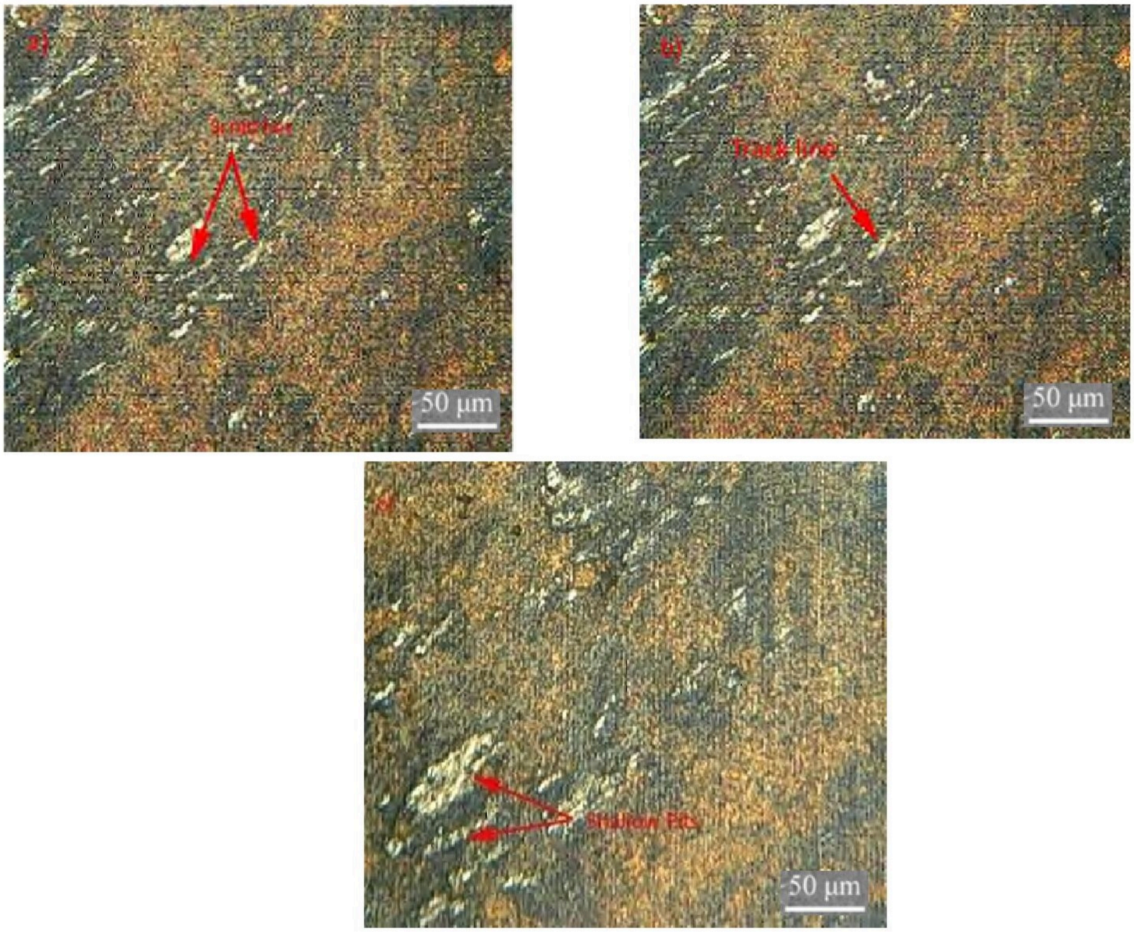
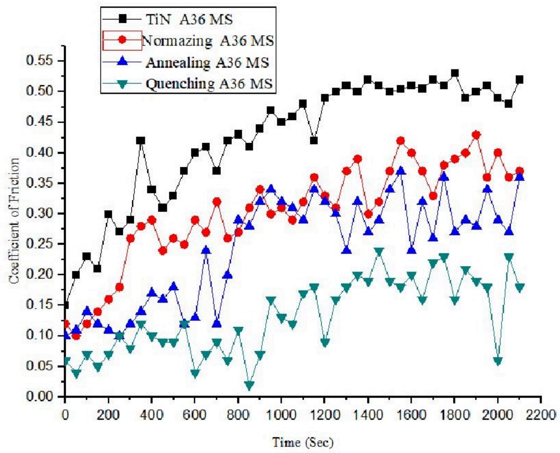


Figure 7 Wear analysis of a) 2 N Quenched TiN A36 MS b) 4 N Quenched TiN A36 MS c) 6 N Quenched TiN A36 MS

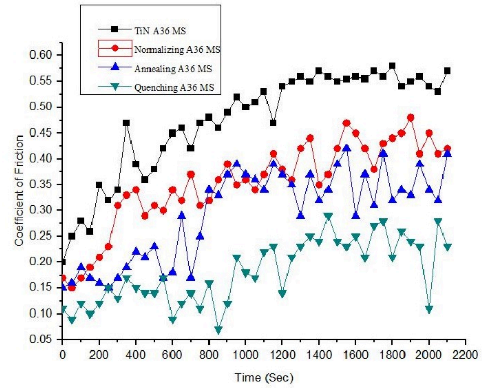
Figure 7

See image above for figure legend.

a)



b)



c)

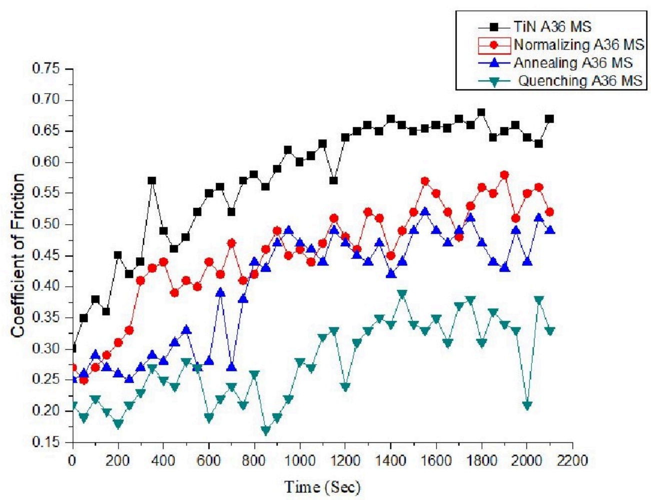


Figure 8 Coefficient of friction VS time of Treated A36 Mild steel at a) 2 N b) 4 N c) 6 N

Figure 8

See image above for figure legend.

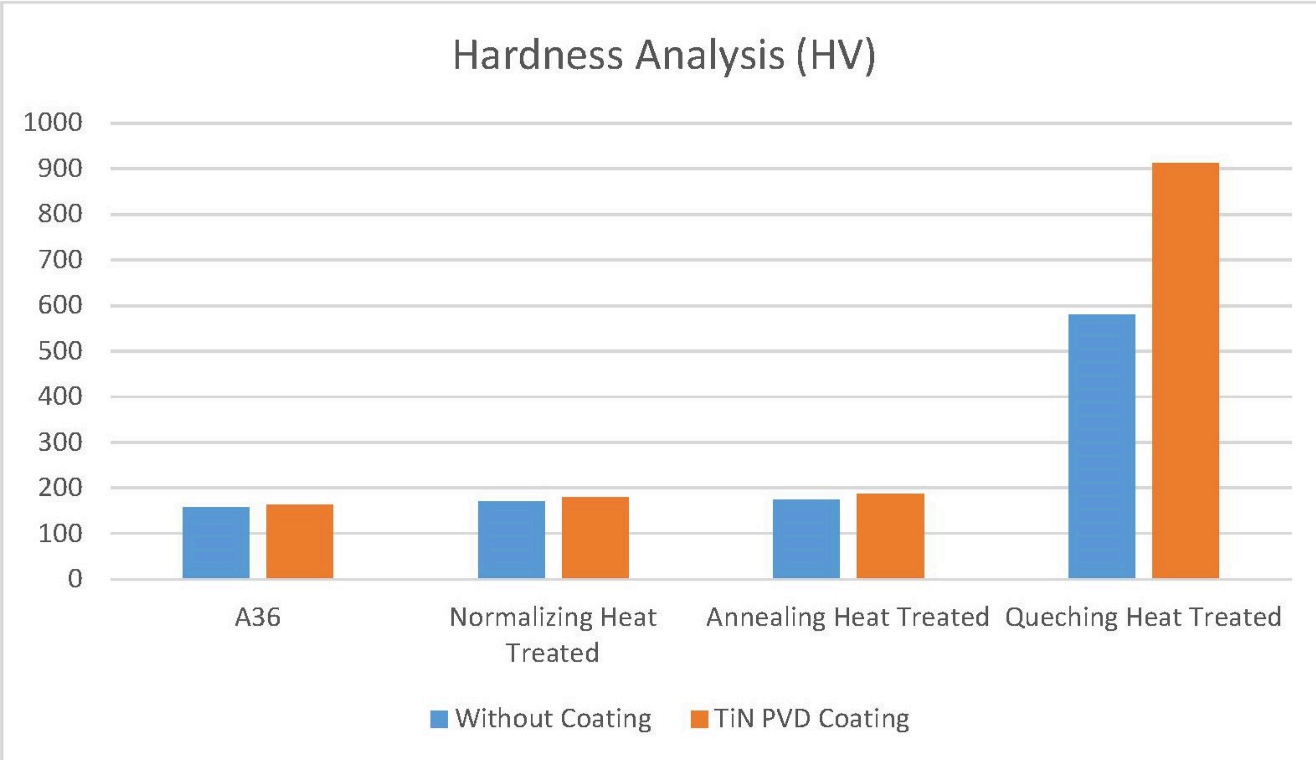


Figure 9 Hardness analysis

Figure 9

See image above for figure legend.