SURFACE HARDENING WITHOUT AND WITH THE TIC IMPREGNATION ON THE AISI 4340 LOW ALLOY STEEL UNDER THE TIG PROCESS

A. N. Md Idriss[1*], M. A. Maleque[1], M. A. Mohd Azhari[2], L. H. Paijan[3]

[1] Department of Manufacturing and Materials Engineering, Kulliyyah of Engineering, International Islamic University Malaysia, P.O. Box 10, 50728, Kuala Lumpur, Malaysia

[2] Faculty of Manufacturing and Mechanical Engineering Technology, University Malaysia Pahang Al-Sultan Abdullah 26600, Pekan, Pahang, Malaysia

[3] Faculty of Mechanical and Manufacturing Engineering Technology, University Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal Melaka, Malaysia

Corresponding Author's Email: ahmednazrin@gmail.com

Article History: Received 27 November 2025; Revised 22 December 2025; Accepted 15 January 2026

ABSTRACT: *One way to harden steel surfaces is through transforming their microstructural features within the top region by fusing high energy arc inputs. The main reason to have only a little depth layers to be hardened is because to increase their surface wear resistance. In this work the AISI 4340 low alloy steel surface was modified by the TIG arc source without and with the incorporation of TiC particles. Defects, microstructures and microhardness examined from those tracks were reported. No cracks were observed on both samples. The without reinforcement track showed columnar and equiaxed features on the resolidified melt while the heat affected zone was with the martensite. Both structural features from the unreinforced resolidified melt and heat affected zone gave track microhardness values constantly between ~ 500 HV to ~ 600 HV before reaching the undisturbed 300 HV substrate. Dissolution of TiC particle resulted precipitation of TiC particles at sizes, shapes and population. Embedded TiC particles within the molten pool improved microhardness between ~ 700 HV to ~1000 HV. In this work, increased of hardenability up to 3 times than the substrate is augmented to improve the wear resistance.*

KEYWORDS: *TIG, TiC, Defects, Microstructure, Microhardness*

1.0 INTRODUCTION

This surface modification via melting is a technique to create a hard layer on the metallic surface for the reason to reduce wear. Surface modification can be made either by using lasers, electron beam or TIG techniques. Either these high energy inputs, the properties of the formed surface can be tailored without or with the incorporation of reinforcing material. In the absence of reinforcing material the formed layer would entirely depend from the rapid solidification of the melt involving only microstructural changes. In contrast, adding reinforcing material while melting changes the composition content and microstructural features that far different than the substrate [1].

Successful results were reported from many research either without and with the incorporation of reinforcing material. Exceptional qualities were achieved when carbide were incorporated within the thin modified layer and so with the only modified layer via surface hardening [2-11]. Increasing the heat intensity increases the depth to width ratio of the melt. Shorter interaction time between the energy source and the substrate was obtained with high heat intensity, whilst preserving the melt quality. Heat inputs control the melt track property and defects [2,12] . Not only the interaction time that governs the melt pool sizes, the weaving pattern to disperse the melt is another technique to extend their geometry sizes [6]. The recommended strategy to harden the steel surface was by increasing the diode laser power at high speed. Adding alloying elements improvised the melt hardenability [3]. Dendritic features were prevailed on steel injected with nanosteel Fe-Cr-B powder under laser [5]. Microstructural refinement was successfully made via plasma transferred arc melted on the surface of ductile cast iron [11] With TIG melting hardness improvement was successfully made by the embedment TiC powder on steel surface [6] Entered SiC particle during surface melting lead carbon to oust and combined with titanium forming TiC. Remained silicon formed titanium silicide [8]. Due to the difference of densities, the lighter TiC than the heavier steel caused TiC to float to the top. Because of this hardness was higher near the melt pool surfaces than the bottom [10] TiC was successfully formed to reinforce magnesium alloy [13], titanium [14,15], graphite cast iron [16], stainless steel {17] ,bronze [18; 19] and aluminum [20].

Our investigation found no evidence of comparative analysis conducted on the microstructural and microhardness features of the without and with TiC incorporated low alloy steel. How far improvision and changes by embedding TiC on the steel surface against without the addition is yet to be explained. Changing only the surface layer without and with the addition of TiC are anticipated to increase the surface hardenability whilst saving the softer interior to serve energy absorption purposes. Therefor an investigation was conducted to compare the only surface hardened of the AISI 4340 steel under the TIG arc input against the same substrate with the incorporation of TiC particles. TiC was choosen because of its high hardenability, good in corrosion resistance, compatible with steel, low in thermal coefficient of expansion and low in thermal conductivity. Results pertaining to the melt sizes, defects, microstructural features and microhardness of between those samples were reported.

2.0 EXEPRIMENTAL WORK

The substrate used in this work was the AISI 4340 low alloy steel. This metal was cut to the dimension of 40 mm x 100 mm x 15 mm using an automated cutting saw machine. The chemical composition of that the AISI 4340 low alloy steel substrate is shown in Table 1. To prevent unnecessary injuries, sharp corners and burrs were removed by filling The steel was grounded using SiC abrasive paper and cleaned thoroughly to remove surface contaminants Rough surface by grounding is admired for preplacement because it facilitates the particulates adherence against the metal. The TiC particle size used in this investigation was between 45 μm to 100 μm and this property was provided by manufacturer. Their appearance was rather sharp and angular and non of them rounded as shown in Fig. 1.

Table 1. Chemical composition of the AISI 4340 low alloy steel

C	Mn	Si	S	P	Cr	Ni	Mo	Fe
0.38-0.43	0.6-0.8	0.15-0.3	0.04	0.035	0.7-0.9	1.65-2.0	0.2-0.3	Bal.

The particles weighing at 1 mg/mm^2 was added with PVA liquid and alcohol to form slurry. The mixture was preplaced on the surface of the cleaned substrate. Spreading was done using a thick plastic film by twirling the paste evenly across the surface. This was followed by placing the prepared substrate in the oven at 80^{o}C to remove the moisture from the mixture. Telwin and Miller TIG 165 was used to melt both without and with TiC particles sample. The energy used for melting was at 1344 J/mm (35V with 80A at 1 mm/s traverse speed) on both the without and with the TiC preplaced samples. Equation (1) was used to calculate the heat input of the produced tracks where the volt and current were denoted as *V* and *I* respectively. The TIG torch travelling speed was denoted as *S*. The heat absorption efficiency ;η, by the substrate during melting was at 48% [21]. The gas flow rate used to shield the melt pool against excessive oxidation was below than 20 lit/min. The illustration of melting the preplaced powder together with the substrate under the torch is shown in Fig. 2. The produced tracks were halved at the midway using the EDM wire cutting machine followed by grounding them up to the finest available SiC abrasive paper. The scratches were finally removed by polishing on the special cloth added alumina. Polishing was considered complete when a mirror-like surface appeared on the worked samples. Nital solution was used to etch both samples. Xoptron X80 series microscope and JEOL-5600 scanning electron microscope were used to determine the track defects and the microstructures. Microhardness test was conducted using Wilson Wolpert microhardness testing machine of 500 gf at 10 second indentation delay.

$$HI = \eta \frac{\mathrm{VI}}{\mathrm{S}} \tag{1}$$

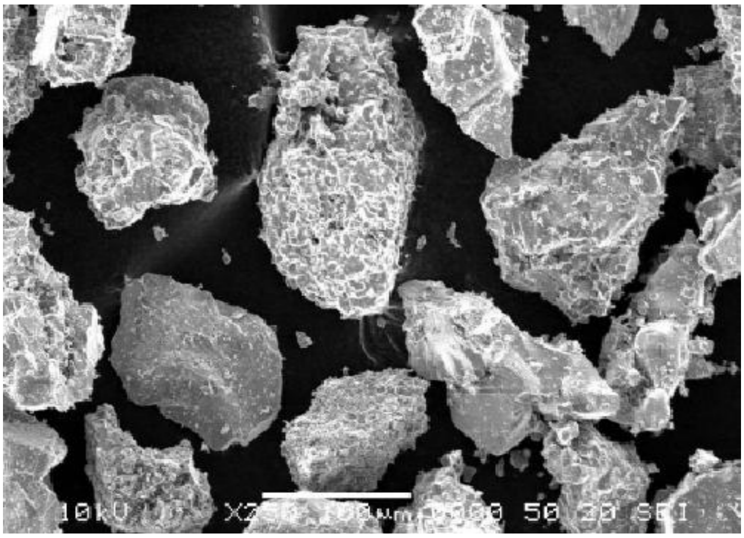

Figure 1. The morphology of the TiC particle

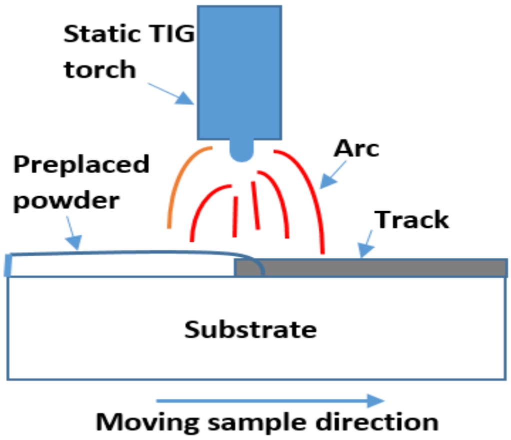

Figure 2. Traversed substrate to form the track under the TIG arc

3.0 RESULT AND DISCUSSION

Figures 3 and 4 exhibit the cross sectioned surface of the without and with TiC reinforced samples respectively. In general, no cracks were observed with these two tracks suggesting that TIG melting technique without and with TiC addition were compatible for surface transformation hardening. It is to be noted that the melt surface consists3 regions which are the (A) molten zone, (B) heat affected zone and (C) substrate in Fig. 3. In this work, the highest arc intensity at the middle of the molten pool showed the greatest melt depth of all and as the intensity decreases towards the edges, the melt depths become shallow on both tracks. The highest heat intensity in the middle can be seen from the mostly dissolved TiC particles as shown in Fig. 4 by a white arrow. With the reinforcement, particles were refrained from dissolution when the heat was less at the edges and because of this they remained agglomerated. This can be seen from many undissolved particles in dark spots in a box of Fig, 4. The farthest from the arc source lead viscous melt from the insufficient heat to dissolve just above the melt matrix interphase with remnants of embedded TiC particles. Obvious microstructural dissimilarity can be seen from the absence of precipitation took place without TiC added surface between Figs. 3 and 4.

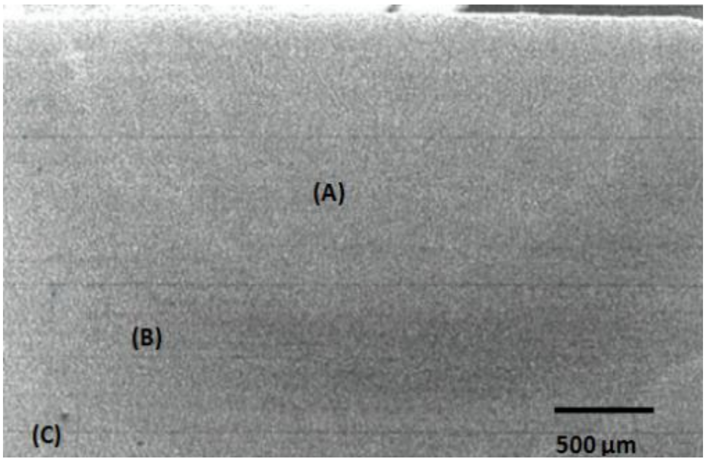

Figure 3. The micrograph of the without TiC track depicting (A) the resolidified melt, (B) HAZ and (c) undisturbed substrate.

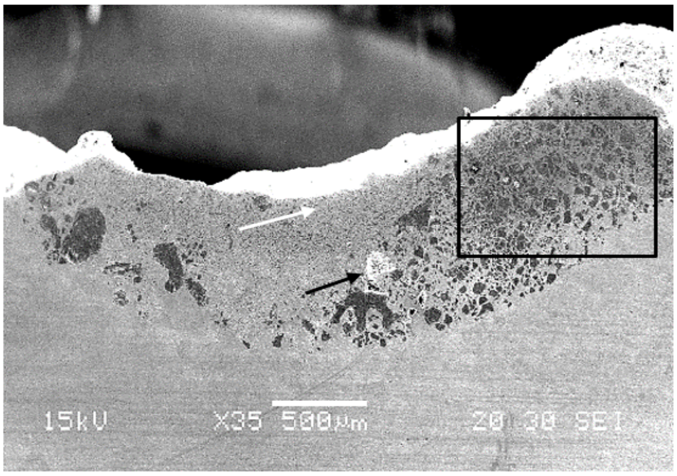

Figure 4. The track with TiC incorporated. The box indicates the agglomeration consisting undissolved particulates. Black arrow showing a pore.

The microstructural features of the surface hardened layer without the incorporation of TiC particle is shown in Fig. 5. This micrograph was an observation made at just above the melt matrix interphase in Fig. 3. It consisted of equiaxed (i) and columnar structures (ii). It was reported that the columnar and equiaxed sizes depended on the heat input and type of the melting methods [5]. The presence of these features is a clear indicator of fast melt solidification from the liquid state. The microstructural features of the TiC embedded within the low alloy steel matrix near the arc source is shown in Fig. 6. This was observed in Fig. 4. Successful dissolution of particles of the as-received 45 to 100 μm in sizes was seen from many reprecipitation below than 25 μm either in the form of globular (i) or flower (ii) types structure. Their presence and dispersion made the low alloy steel to be strengthened. The TiC growth is limited because of the rapid solidification by this TIG process. More TiC growth can be achieved if dissolution of particles at the edges and just above melt matrix interphase permitted by the introduction especially of higher energy inputs. Apart from sufficient time to allow precipitation, carbon and titanium concentration play an important role to expand TiC sizes, type and population.

This work showed that porosity was absent with the unreinforced sample and presence in places with the reinforced one. With a black arrow, Fig. 4 shows a large pore embedded within the TiC melt track. Pores were explained from the trapped gasses caused by the burnt binder during solidification. Formation of pores were also reported in several works [6,9]. Increasing the amount of binder increases the pore percentages [22,23]. Reducing the binder content or increasing the energy input to allow more time for the liquid to solidify are ways to reduce the porosity content.

ISSN 2180-1053 e-ISSN 2289-8123 Vol.18 No.1

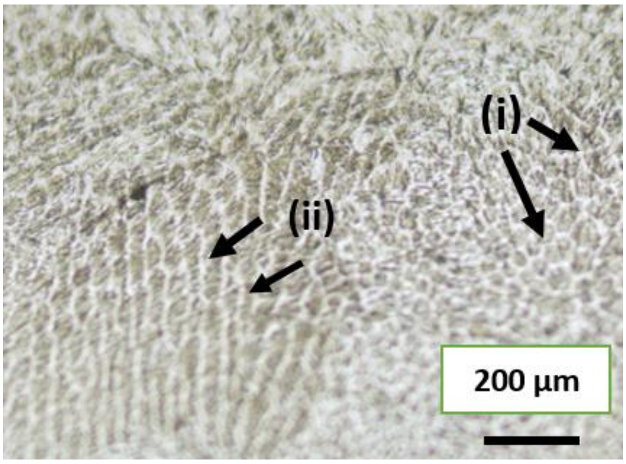

Figure 5. Micrograph of the without TiC addition showing the (i) equiaxed and (ii) columnar structures.

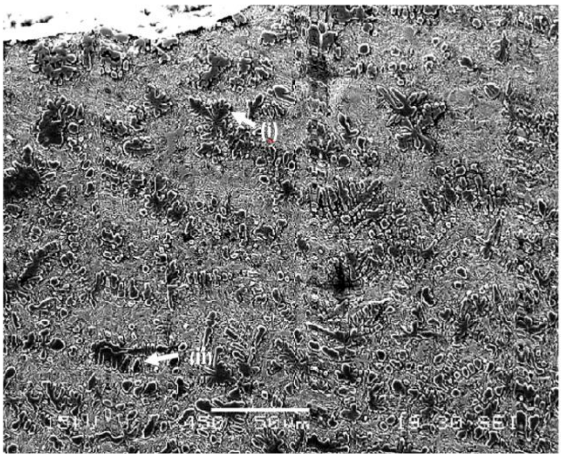

Figure 6. location near the arc source showing many reprecipitation of TiC structures with (i) of a flower type of TiC and (ii) globular.

With the powder preplacement technique, the track width and length deters the amount of powder being incorporated within the molten pool. Greater track width and length assures for more particles or powder embedded on the substrate surface. In this work, the TiC metal matrix composite layer was at an average of 3.3 mm width with a length of 38 mm. The preplaced powder was at 1 mg/mm^2. With this powder amount and track melted surface area, it is presumed that the incorporated TiC was 125.4 gram. This is why obvious clad height developed upon melting because of the carbide particle addition compared to the without TiC. Clad height in this work is described by the volume of metal observed above the substrate surface. The work used an estimated area to describe how much powder being embedded. Greater amount of powder weight over an area would provide more embedment across the track. The substrate is heavier either by extending the melt track lengths, increasing the number of multipass or by reducing the overlapping distances. In the preplacement technique, the amount of powder is fixed, dislike powder injection or by spool wire where their amount can changed during the melting process.

The microhardness profile of the sample without and with the incorporation of TiC particles fused under the TIG arc is shown in Fig. 7. The result showed that hardenability can be successfully increased at least over than 1.5 to ~ 3 times without and with the TiC incorporation than the 300 HV low alloy substrate. An about 2 times hardness than the substrate was associated with no weight gained of that the only the surface modified layer. However, the result showed up to about 3 times with an evitable of little escalated substrate weight gained because of TiC addition. In this work, the without TiC reinforcement showed no microhardness disparity between the melt zone and the heat affected zone. A consistent trend of ~ 500 to 600 HV was recorded from the melt surface followed by the heat affected zone up to 2.2 mm depth before the 300 HV undisturbed substrate. The columnar with equaixed within the melt pool and martensite across the heat affected zone evident the dissimilarity of hardness values than the substrate. Since hardness developed between 500 HV to 600 HV for the without TiC, it is possible to have only substrate quenching which can be achieved by lowering the interaction time between the heat input and substrate surface. Melting is crucially needed for dissolving and dispersing the introduced reinforcement or otherwise that the quenching could be preferable. Compared to the hardened steel layer using the diode laser, the TIG hardened depth in this work was about 4 times deeper [3].

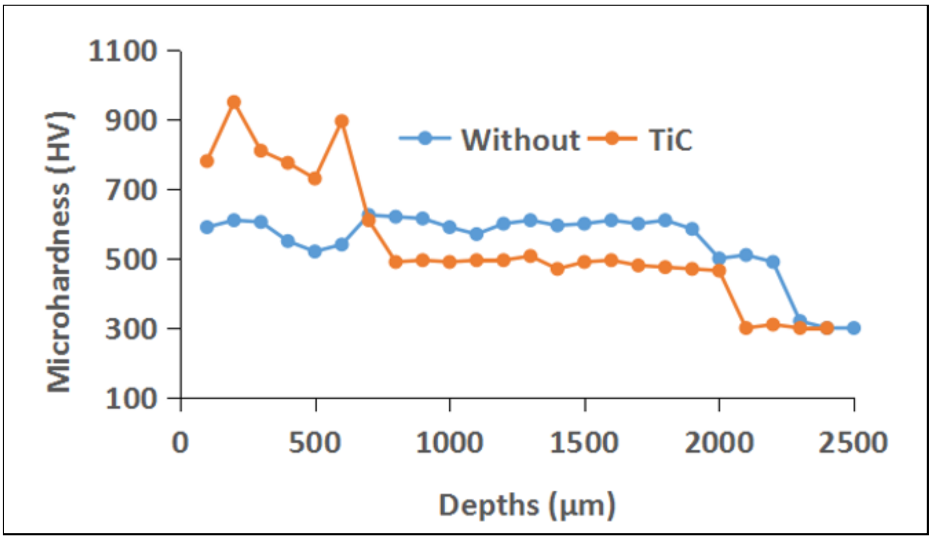

Figure 7. The microhardness profile of the without and with TiC addition of the Surface of the low alloy steel.

When the produced track is reinforced with TiC particles, the three groups of microhardness disparity was observed. The first group is the molten zone found between ~ 700 HV to ~ 1000 HV up to 0.6 mm of depth as shown in Fig. 7. Away, the heat affected zone and substrate received ~ 500 to 600 HV and ~ 300 HV respectively. The incorporation of TiC showed remarkable hardness improvement compared to the without the incorporation TiC sample and the substrate. The dispersion and reprecipitation into types, sizes and population TiC gave microhardness ~ 700 to ~ 1000 HV than the columnar/equiaxed with the martensite structures of ~ 500 HV to ~ 600 HV. Microhardness of TiC is at 3000 HV and when the particles is less, microhardness is reduced as can be seen in Fig, 7

Seeing the similar hardenability along the melt pool and the heat affected zone (without TiC), it is clear to reinforce the top layer with TIG which in our case by adding TiC particles. Adding TiC made further improvement of hardenability rather than without reinforcement [23,24]. Increased of microhardness increases the wear resistance [25].

4.0 CONCLUSION

In this experimental work the AISI 4340 low alloy steel surface was successfully modified using the TIG process without and with the incorporation of TiC particle. Crack free layers were achieved without and with the incorporation of TiC particles. Adding TiC increases the track weight evident from the high clad height compared to the without TiC addition. Surface hardening without the incorporation of TiC particles gave columnar and equiaxed structures within the resolidified zone while the heat affected zone had the martensite. The microhardness developed were at about 500 to 600 HV from the surface reaching the undisturbed 300 HV for the hardenend surface without TiC. Dissolved TiC particles dispersed the carbide mostly with the precipitated ones near the arc source with many remaining agglomeration at the edges and melt matrix interphase. Microhardness developed for the TiC metal matrix composite was about 700 to 1000 HV. Both samples showed increased of hardness between 1.5 to 3 times than the AISI 4340 low alloy steel substrate.

REFERENCES

[1] L. H. Paijan and M.A. Maleque, “Surface modification of duplex stainless steel with SiC preplacement using TIG torch cladding”, *Procedia Engineering*, vol. 184, pp. 737–742,2017.

[2] P.F. Mendez and T. W. Eagar, ”Welding processes for aeronotics”, *Advance Material & Processes*, vol. 159, pp. 39-43,2001.

[3] I. R. Pashby, S. Barnes and B.G. Bryden, “Surface hardening of steel using a high power diode laser”, *Journal of Processing Technology*, vol. 139, pp. 585-588, 2003.

[4] A. N. Md Idriss, M. A. Maleque, Z. Kamdi, N. Muhammad, A. Azhari, ”The effect of preheating and current con the development of mild steel clad layers via stick welding”, *Journal of Advance Research in Applied Mechanics*, vol. 119, no.1, pp. 112-120, 2024.

[5] S. Mridha, A. N. Md Idriss and T. N. Baker, “ Laser and GTAW torch processing of Fe-Cr-B coatings on steel ”, *Part II - Microstructure and Hardness, Material Science and Technology*, vol. 31, no.3, pp. 355-360, 2015.

[6] M. A. Maleque, A. N. Md Idriss, R. Naping, M.M. Rahman, and I. Efeoglu, “The influence of TiC dispersion and density on the microstructural features and microhardness fused by TiG arc process”, *Journal of Advance Research in Apllied Mechanics,* vol. 14, no.1, pp. 33-42, 2024.

[7] M. H. Abdul Kadir, M. Asmelash, A. Azhari, “Investigation on welding distortion in stainless steel sheet using gas tungsten arc process”, *Materials Today: Proceeding,* vol. 46, pp. 1674-1679, 2021.

[8] S. Mridha and T. M. Baker, "Metal matrix composite layer formation with 3 μm SiCp powder on IMI318 titanium alloy surfaces through laser treatment", *Journal of Materials Processing Technology*, vol. 63, no. 1-3,pp. 432-437,1997.

[9] S. Mridha, A. N. Md Idriss and T.N. Baker "Incorporation of TiC particulates on AISI 4340 low alloy steek surfaces via tungsten inert gas arc melting", *Advance Material Research*, vol. 445,pp. 655-660,2012.

[10] W. Xinghong, S. Song, Z. Zou and S. Qu, "Fabricating TiC particles reinforced Fe-based composite coatings produced by GTAW multi layers melting process",*Material Science and Engineering A*, vol. 441, no. 1-2, pp. 60-67,2006.

[11] B. Xiao, X. Yan, W. Jiang, Z. Fan, Q. Huang, J. Fang and J. Xiang, " Comparative study of the hardness and wear resistance of the remelted gradient layer on ductile iron fabricated by plasma transferred arc", *Metals*, vol. 12,no. 644, 2022.

[12] A. N. Md Idriss, S. Mridha and T. N. Baker, "Laser and GTAW torch processing of Fe-Cr-B coatings on steel Part 1 - Melt features", *Material Science and Technology*,vol. 30, no. 10, pp. 1209-1213,2014.

[13] L. A. Dobrzański, S. Malara, J. Domagala, T. Tański and K. Golombek, (2009) "Influence of the laser modification of surface on properties and structure of magnesium alloys", *Archives of Material Science and Engineering*, vol. 35, no.2, pp. 95-100, 2009.

[14] M. A. Maleque, and S. A. Adeleke, "Surface alloying of CP-Ti using preplaced Fe-C-Si powder by tungsten inert gas torch technique", *International Conference on Mechanical, Industrial and Materials Engineering*, pp. 668-673, 2013.

[15] Y. Liu, J. Li, and F. Xuan, " Fabrication of TiC reinforced Ni based coating by laser cladding", *Surface Engineering*, vol. 28, no.8, pp. 560-563,2012.

[16] E. R. I. Mahmoud and H. F. El-Labban, "Microstructure and wear behavior of TiC coating deposited on spheroidized graphite cast iron using laser surfacing, *Engineering Technology & Applied Science Research*, vol. 4, no. 5, pp. 696 – 701,2014.

[17] G. Rasool and M. M. Stack, "Wear maps for TiC composite based coating deposited on 303 stainless steel", *Tribology International* , vol. 74, pp. 93-102,2014.

[18] V. Joshi, S.S. Rathod, U.K., Dwivedi, O.P. Modi, B.K. Prasad, " Sliding wear behavior of heat treated (Al-Bronze) TiC in situ composite: Influence of the reinforcement phase and test conditions", *In the Proceeding of International Conference on Manufacturing Excellence (MANFEX),* Edited by K.M Soni et al., pp. 195-200,2013.

[19] J. J. Valencia, M. L. Tims, L. Nastac, " Bronze/TiC composites for friction drums", *Advance Materials & Processes: Metals Park*, vol. 160, no.11, 2002.

[20] W. B. Tang, C. H. Lu. and Y. P. Li, "Investigation on TiCp/Al composite coating by TIG cladding", *Applied Mechanics and Material*, vol. 490-491,pp. 29-33,2014.

[21] K,E. Easterling, Introduction of Physical Metallurgy of Welding, Butterworth-Heinemann, London, 1992.

[22] Ł. Szymańshi, E. Olejnik, T. M. Tokarski, P. Kurtyka, D. Drożyński and S. Żymankowska-Kumon, "Reactive casting coatings for obtaining in situ composite layers based on Fe alloys", *Surface and Coating Technology*, vol. 350, pp. 346-358, 2018.

[23] N. K. Paraye, S. P. Neog, P.K. Ghosh and S. Das, "Surface modification of AISI 8620 steel by in-situ TiC particle using TIG arcing", *Surface and Coatings Technology*, vol. 405, 126533, 2021.

[24] J. Singh, L. Thakur, and S. Angra,"Abrasive wear behavior of WC-10Co-4Cr cladding deposited by TIG welding process", *International Journal of Refractory Metals and Hard Materials*, vol. 88, 105198,2020.

[25] A. N. Md Idriss, M.A. Maleque and A. Afiq, " Synthetization of TiC surface hardening using TIG melting technique – The effect of working distance", *In the IOP conference series: Material Science and Engineering*, vol. 1244, no.1,012012,2022.