

Microstructure Characterization of Al-TiC Surface Composite Fabricated by Friction Stir Processing

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Abstract. Titanium carbide (TiC) is an exceedingly hard and wear refractory ceramic material. The surface properties of the material are very important and the corrosion, wear and fatigue resistance behaviour determines its ability and applications. It is necessary to modify the surface properties of the materials to enhance their performance. The present work aims on developing a new surface composite using commercially pure aluminum and TiC reinforcement powder with a significant fabrication technique called friction stir processing (FSP). The metal matrix composite of Al/TiC has been developed without any defects formation to investigate the particles distribution in the composite, microstructural changes and mechanical properties of the material. The microstructural observations exhibited that the grain refinement in the nugget compared to the base metal and FSP without TiC particles. The developed composite properties showed substantial improvement in micro-hardness, friction factor, wear resistance and microstructural characteristics in comparison to parent metal. On the other side, the ductility of the composite specimens was diminished over the substrate. The FSPed specimens were characterised using X-ray diffraction technique and revealed that the formation of AlTi compounds and the presence of Ti phases in the matrix. The microstructures of the samples illustrated the uniform distribution of particles in the newly developed metal matrix composite.

1. Introduction

In recent years, metal matrix composites (MMC) have found increasing demand for several of applications in various industries of electronic packaging, aerospace, structural members and transportation industries [1]. Because of their specific properties of the particulate reinforced metal



matrix composites are of special and attained an interest owing to their low price, ease of fabrication and isotropic properties. However, aluminum alloys in general not suitably firm or strong for many applications and their reinforcement is required for ductility. It is found that, metal matrix composites which are related to aluminum and its alloys (Al-MMCs) led to larger elastic modulus, high specific strength, excellent wear, fatigue resistance and high thermal creep brought them fit for excellent manufacturing applications [2,3]. Contrary, aluminum MMC composites also agonize from loss of ductility and toughness because of the mixing of brittle ceramic reinforcements, which will affect their properties and thus applications. These also have benefits for many applications in which only surface and its related applications play an important role such as wear resistance. The presence of reinforcement particles in the matrix generates very attractive properties which are not achieved by other category of materials [4,5]. The incorporation of the reinforcement particles of fine and constant thermal particulates are dispersed in a matrix is resulted in obtaining higher mechanical properties. The fabrication of MMC are challenging for manufacturers and till today there are numerous MMC fabrication techniques developed including of hot pressing, friction stir processing(FSP), casting, and sintering [6-9].

The advanced joining method of friction stir processing is a comparatively solid-state process of novel technique owing to flexibility, very simple joining technique and low-cost tooling. Moreover, it has involved extensive consideration from the materials and manufacturing researchers for microstructural and hardness changes, and it was developed from the principle of FSW [10-12]. The FSP process is remarkably simple and easy process in which a non-consumable heat treated high carbon steel revolving tool designed specially with profile of shoulder and pin is put into a single part of material and transverse lengthways the joint and resulted in making changes of stirring and breaking of grains in as weld nugget zone owing to involving of localized thermal exposure and severe plastic deformation of mixing of material. Friction stir processing attains several applications for developing of surface composites, microstructural modifications and grain refinement of aluminum cast alloys [13, 14]. The conventional fusion welding techniques are failed to fabricate these alloys successfully and resulted in poor performance of the welds. The other welding techniques such as solid state welding of friction stir welding [15], friction welding [16-31] and explosive welding [32], are contemplated. However, friction stir welding and FSP process have specific properties to fabricate the metal matrix composites. Many researchers are reported the different methods to prepare a reinforced composite surface by means of friction stir processing. Among them most commonly used technique is preparing a dotted punch over the top layer of the substrate and deposits the powder reinforcements above the plate and inside the groove and then makes the composite by friction stir processing along the grooves [33, 34]. According to the previous studies, processing parameters, number of grooves and its size, and the direction of the friction stir process, number of passes have influence over the number density and distribution of the reinforcement particles in the zone formed by FSWed process. The present study aim to be the evaluation of microstructural characterization and mechanical behavior of the commercially pure aluminum plate reinforced with TiC powder particles. The wear properties of the FSPed surface have been carried out. The reason for choosing the TiC was owing to its excellent physical and mechanical properties, and its high chemical conductivity, low price and easy to make the powder form. The developed composite were evaluated by micro-hardness and X-ray diffraction techniques to characterize its performance and properties.

2. Experimental Procedure

The materials which are rolled commercially pure (CP) aluminum sheet with a thickness of 5 mm were cut into the dimensions of 50 mm wide and 150 mm in length substrate, and the minimal elemental composition of the substrate is given in table 1. Thereafter, the top layer of the substrate prepared with wire brush to remove the oxide layers and cleaned with acetone to remove dirt, oil, etc. The centre of the substrate were drilled a holes in depth of 2 mm and 2.5 mm in diameter. The schematic view of the grooves design and its pattern over the substrate are depicted in figure 1. There are total 40 holes are made to deposit the TiC powders along the centre axis of the substrate with an

equal spacing between them. The deposited reinforcement TiC particles were primed as it contains 99 percent purity and the particles average size is $10\ \mu\text{m}$. The FSP tool was made with EN 31 series high carbon steel with highly wear resistant, the tool's elemental composition is provided in Table 1. FSWed processing tool is having

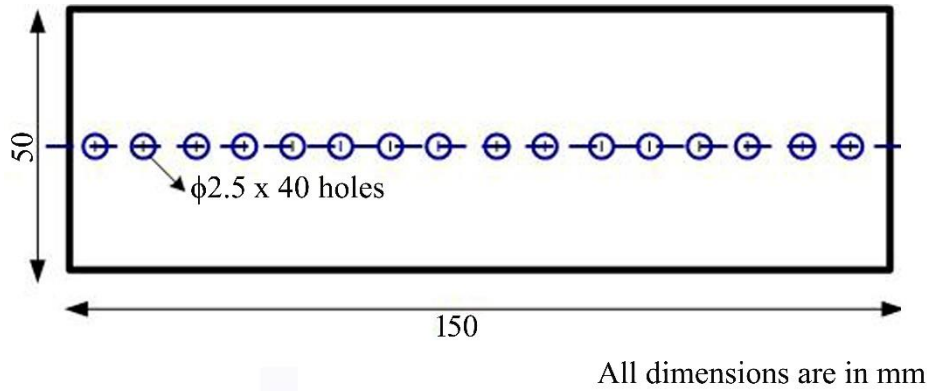


Figure 1 A schematic representation of FSP specimen

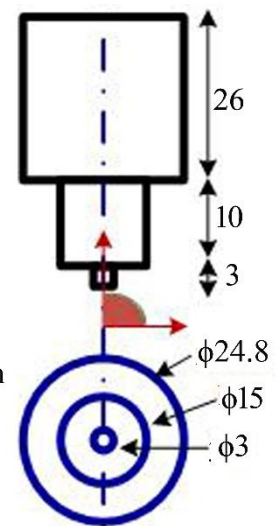


Figure 2 A schematic representation of FSP tool

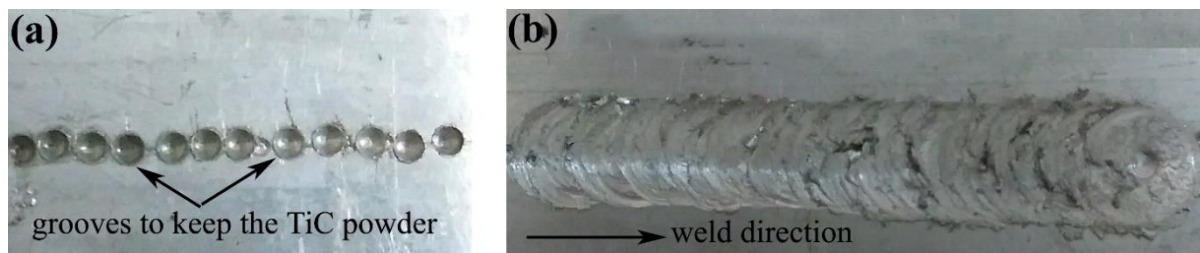


Figure 3 Photograph of the (a) base metal with grooves to house the TiC reinforcement powder (before welding), and (b) after FSP, the appearance of the weld

Table 1 Chemical composition of the substrates and FSP tool materials used in the present study (wt.%)

Element	C	Si	Cu	Mn	Mg	Cr	Zn	Sn	Ti	Fe
Aluminum (1050)	-	0.25	0.05	0.05	0.05	-	0.05	-	0.03	0.40
EN31	0.834	0.332	0.019	0.072	0.063	0.005	0.047	0.005	0.022	Balance

The FSW tool has consisting, 15 mm of shoulder diameter, 3 mm of pin diameter and 3mm of pin length. The FSWed tool angle was fixed with a 2.5° tilt angle during FSP process. The schematic representation and dimensions of the FSP tool is illustrates in figure 2. To enhance the tool strength heat treatment process has been done with a heating temperature of 820°C in 1 hour duration in a box furnace, and then quenched in oil to attains its hardness, and then subjected to tempering at 100°C for 1 hour and then subjected to air cooling.

The friction stir processing was carried with the processing conditions of rotating speed 1000 rpm, feed rate 20 mm/min, tilt angle of 3° and weld length of 100 mm after filling the grooves with TiC power particles. The appearance of the substrates before welding (with grooves) and after welding is exhibited in figure 3. The FSPed specimens were separated in the transverse direction and samples are prepared and smoothed the burs on belt grinder to remove the burrs, and standard metallographic procedure of emery papers and using alumina polishing and diamond polishing with 1µm diamond paste on disk polishing machine was followed to prepare the samples for microstructural characterization. To evaluate the welds performance, the weldments were tested through Vickers hardness test is done to invention the material hardness at altered location in microscopic level. The digital Vickers micro hardness tester was used to measure the Vickers micro hardness along the cross-section of the FSP samples abrupt to the tool traverse way with a 200 g load for 15 sec dwell time to obtain the hardness profiles across different regions. The cross sectional samples and as welded samples were characterized with X-ray diffraction (XRD) analysis technique for revealing the phases, which are tend to form in the composite during welding. The wear test also conducted as per the ASTM B611-85(2005) standard test. The base metal and the developed composite wear tests were studied by abrasive wear test. The size of the samples used was 75x25.4x12.5 mm³ and 80 µm size of sand particle. The wear rates were performed at 225rpm with 300 revolutions for the three types of loads of 500g, 1000g, 1500g and 2000g. The abrasive particles prepared the AFS 50/70 quartz grain sand and the sand flow rate used as 350g/min. The weight loss and volume loss for each and every specimen were tested the weights for the duration of 1 hr after the test completion.

3. Results and Discussions

The macrographs of the FSPed sample appearance of the top surface after welding are illustrated in figure 4. The starting of the welds shows smooth surface and uniform crowns formed and there is no evidence of defects (see figure 4a). The smooth weld can be seen up to 40 percent of the weld length. The remaining weld length consists of different types of weld defects which can be seen visually above the top of the welds. It is due to the effect of processing parameters and also the incorporating of TiC powder particles into the weld. In general during FSP, friction between the substrate and tool pin the heat produced and stirring action influences the material flow around the pin and deliberated main factor that causes the initiation of defects. When the welds produced below the rotating speed 1000 rpm and feed rate 20 mm/min, there are groove like defects observed due to the insufficient heat input into the welds. Whereas, a large amount of flash ejected outside of the stir zone unevenly when the rotating speed and feed rate are 1000 rpm and 20 mm/m, respectively. The welds showed good appearance at optimum conditions with the micro level surface defects which cannot be avoided during FSP of composite using TiC particles. At the end of the welds a minor defects of surface opening and slightly weld over weld flash has been observed as exhibited in figure 4b and c. furthermore, it is being detected that at low welding speed and feed rate formation defects of grooves and over flash attributed to the low heat input and low frictional heat for plasticization of the metal during the FSP process. However, the traverse speed increasing trend and feed primes to a lowering the nugget zone size and increase the roughness of the surface and the amount of the material removal rate increases. The cross sectional view of the macrostructures shows the nugget formation and width of the stirring zone looks like similar for all samples. There is no evidence of defects in the weld nugget like tunnel or voids defects are perceived and a uniform distribution of particles and homogeneous friction stirred zone is obtained. The FSP has been carried on base metal without incorporating the TiC powder and with TiC powder with the same welding conditions. In general TiC reinforcements are shows less plastic in nature and cause a formation of wider processed zone over the nugget of the base metal. Figure 5(a) illustrates the macrostructure of the processed nugget of the cross section of the FSPed Al/TiC composite. The micro-level defects are detected very rarely for some samples where the TiC particles are not completely dissolved into the aluminum matrix and/or an excess amount of TiC particles comes close together and might have obstructed the regular flow of the material flow. In the same figure it is identified that differentiate of the formation of altered regions of

thermo mechanically affected zone (TMAZ), and stir zone (SZ) adjacent to the substrate metal and TMAZ interface. The magnified view of microstructures are taken from the three different zones (see figure 5a) to characterize the metal matrix composite of aluminum and TiC particles bonding. The surface MMC layer is exhibited the formation of strong bonding to the substrate metal and there is no formation of imperfections were noticeable at weld interface and stir zone. The stir zone microstructure consists of proper form of grains and modification in its nature, grain

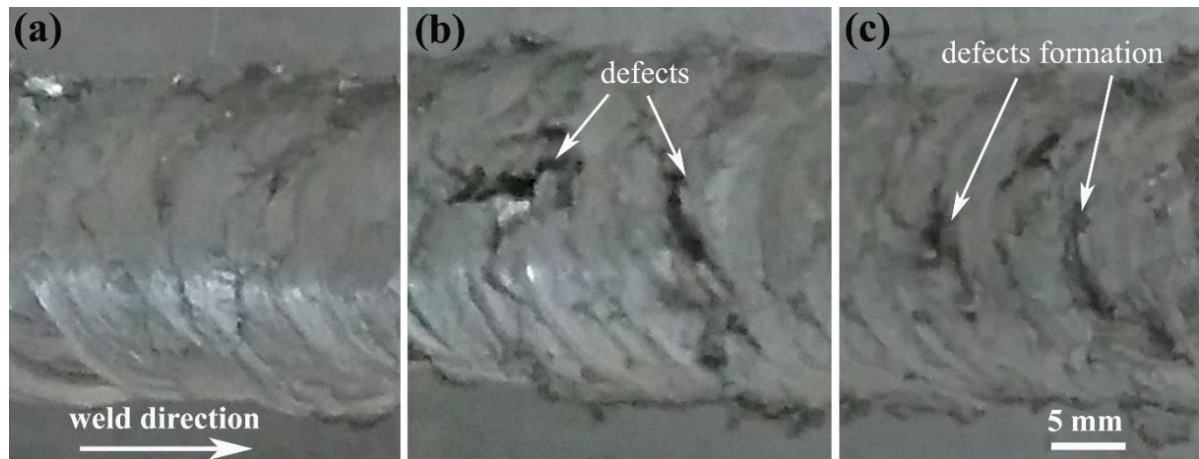


Figure 4 Macrograph of the FSP stir zone with and without defects formation along the length of the stir zone (a) start of the FSP (no defects), (b) middle of the FSP and (c) end of the FSP zone.

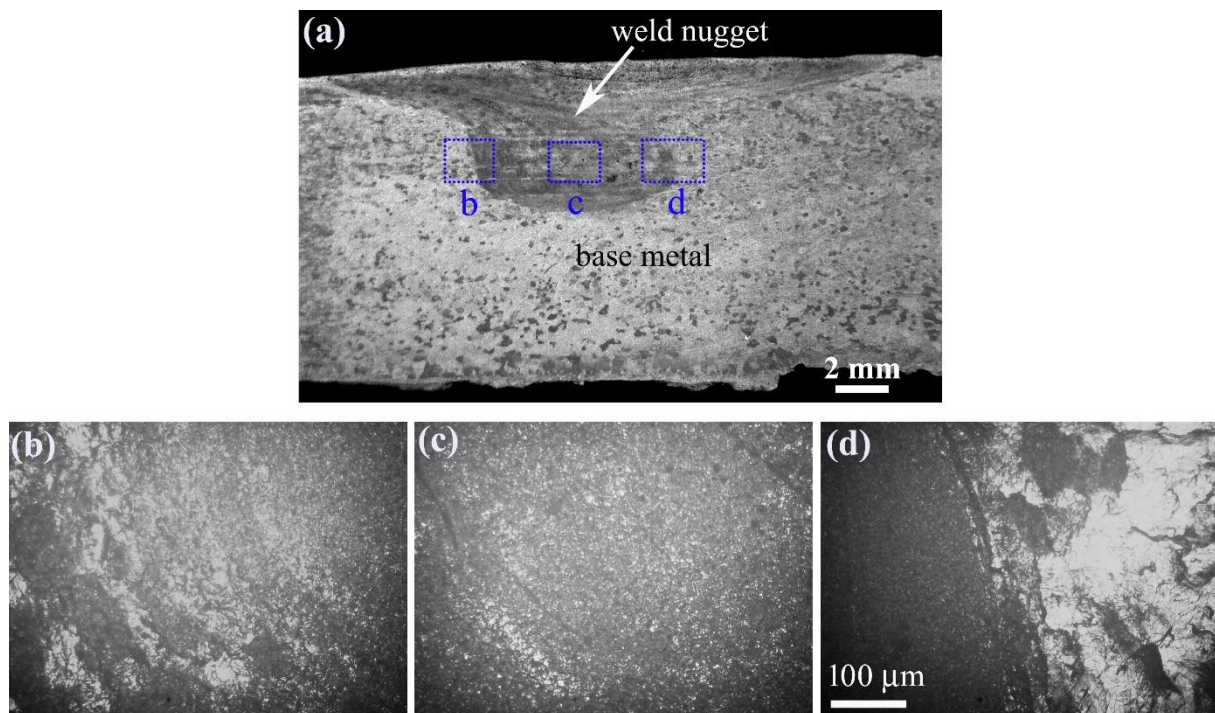


Figure 5 Cross-sectional view of the friction stir processing nugget zone (a) macro structure, and microstructures at both sides of the nugget (b) nugget left side, (c) stir zone and (d) nugget right side

Density and grain improvement occurred where the composite's grain size was refined and transmuted to an equiaxed and equal size with uniformities microstructure formation. It is observed that, the base metal microstructure without TiC particles refined to finer grains in the nugget stir zone. The size and shape of the processed nugget grains were further reduced due to the TiC reinforcement particles addition and finer than the other zones of the microstructure. The formation of substantial changes in the microstructures indicates the temperature rise and plastic deformation in respective zones have been generated appropriately extraordinary enough by friction stir processing due to the dynamic recrystallization effect, also the effect of pinning showed the reinforcement particles had contribution over the grain refinement [35,36]. The SZ/TMAZ interface and the TMAZ/base metal (see figure 5b-d) clearly indicate the change in grain size which is gradually increasing from stir zone to base metal. The higher magnification of the microstructures exposed the constant spreading of TiC reinforcement particles in the aluminum matrix and also observed that some of the FSPed samples exhibited the particles agglomeration in different regions in the SZ of the matrix and created the micro level clusters. However, the formation of micro clusters act as micro sized particles and are uniformly distribution of them in the matrix which are easily achieved by the friction stir process. [36]. It is also observed that the surface composite around the micro sized particles confirms the formation clear interface, which signs the good bonding among the TiC reinforcements and aluminum alloy.

Figure 6 illustrates the micro-hardness distribution of the Al/TiC composite along the joints cross section of the FSWed nugget across the different zones. The microhardness values varied between the various zones and the base metal hardness was 42 HV and after friction stir processing without adding of TiC particles was raised to around 4 HV, which was owing to the grain refinement in the nugget and also because of the fragmentation and distribution of precipitates. In similar way it was observed that the drastic improvement in the microhardness of the substrate matrix which is strengthened with TiC particles. The reason for increase in hardness due to the direct strengthening contributed to the composite matrix by the adding of hard and strong reinforcement particles which entertainments to the delay dislocation movement [30]. It is markedly noted that the impact of these particles is more prominent since TiC reinforcement is in micro scale and even reached to nano scale during processing and well distributed by friction stir process. It is also expecting another reason for hardness improvement is microstructural changes in the stir zone. It is well fact that the refined grain size led to raise the hardness according to Hall-Petch relation. In case of composites which are developed by FSP are mainly resulted in pinning action of dislocations and cause to delaying grain growth [37]. The Al/TiC composite specimens were analyzed with XRD technique of the revealed the compounds of Ti and TiAl (shown in figure 7), which are not cause to harm the composite and aid to strengthen the mechanical properties and wear properties of the matrix. Figure 8 illustrates the wear properties of the base metal, empty pass and developed Al/TiC composite. It is perceived that, the wear rate has been gradually improved through the increasing load, and wear rates of the three conditions are similar up to the 1000 g, and then wear rate of the TiC composite suddenly reduced and showed highest wear resistance properties compares to the base metal and direct FSP welds.

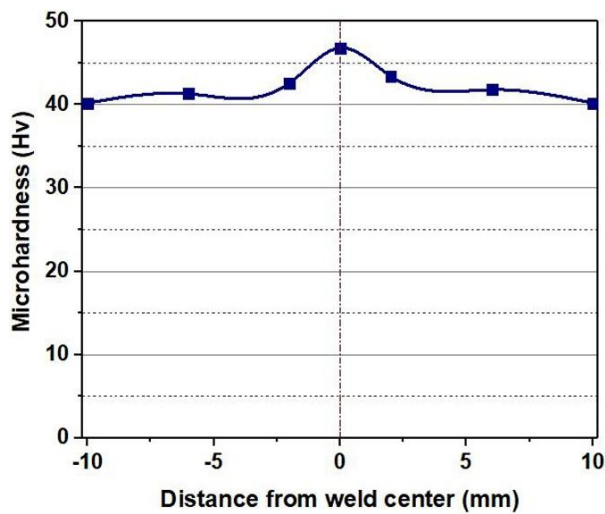


Figure 6 Micro-hardness of the FSP welds across the weld nugget

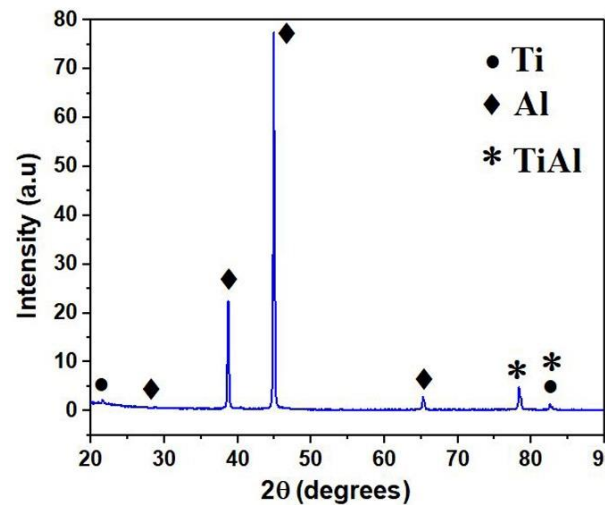


Figure 7 The welds X-ray diffraction analysis showing the formation of compounds in weld zone

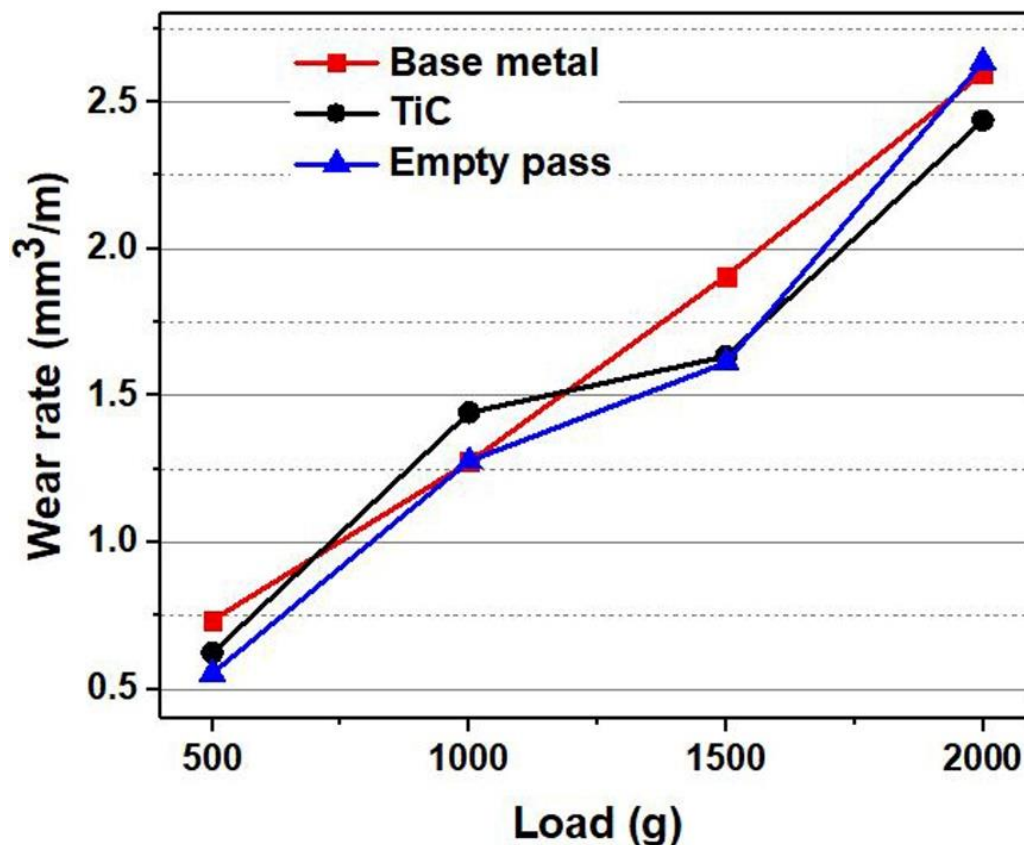


Figure 8 Effects of TiC reinforcement on wear rate of the Al/TiC composite at different loads

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4. Conclusions

In the present investigation, the fabrication and microstructural characterization, mechanical and wear properties of the Cp-Al/TiC hybrid composite surface which is developed by FSP have been studied. The developed composites are free from defects formation and exhibits the microstructural changes with the tremendous improvement in the processed zone. The appearance of surface defects of groove and over flash formation defects are observed for the low heat input welds. The particles distribution was uniform in the metal matrix enhanced the micro-hardness distribution and achieved highest hardness in the stir zone compare to the remaining zones. The highest hardness leads the contribution of equi-axed micro clusters which homogenised in the matrix and the effect of dynamic recrystallization and pinning of the dislocations density. The grain size was gradually increasing from the base metal to the stir zone in the processed nugget. The XRD analysis revealed the micro clusters are the formation of TiAl compounds which are formed in the metal matrix, and these are contributed in the recording of highest peaks of the hardness. The incorporation of TiC reinforcements substantially improves the wear resistance due to the proper mixing of TiC reinforcements in the Al/TiC composite over the base metal and FSPed metal.

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