Tribological Characteristics of Steel/TiC surface composite fabricated by Friction Stir Processing

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Abstract – The present work aims to fabricate surface composites on plain carbon steel by using solid state surface modifying technique named Friction Stir Processing (FSP). Titanium Carbide (TiC) particles was applied on the surface and modified by FSP in order to produce composite surface. The effect of three different tool rotational speeds (600, 800 & 1000rpm) on the wear behavior of the surface composite were studied. FSP modified composite surface has shown that significant improvement in friction and wear reductions in compared with base alloy. The friction coefficient of the processed composite samples was not shown any significant changes with changing of tool rotational speeds.

Keywords: Steel, Titanium Carbide (TiC), Hardness, Wear, Friction Stir Processing (FSP)

1. INTRODUCTION

Low Carbon steel are widely used in structural, defence, automotive applications due to their excellent properties such as hardness, strength, toughness and wear resistance [1]. However, hard and high wear resistance required in the load bearing and severe wear applications. Recent days, to enhance the surface of the steel new surface modifying technique FSP is used extensively. Several researchers were reported that FSP has been used for surface modification of low melting materials such as Aluminium, magnesium, copper and its alloys [2-4]. The working principle of FSP technique and fabrication of surface composites by this method is explained in our previous studies [5-7]. Very limited research has been carried out on the high melting temperature materials such as cast iron, carbon steels, Titanium alloys etc. P. Xue et al., (2016) [8] have reported that the tensile properties of the processed steel were improved in compare with base material. Shivram Thapliyal and Dheerendra Kumar Dwivedi, (2016) [9] investigated the effect of graphite particles on wear properties of cast nickel aluminium bronze and found that the surface composite has higher wear resistance than base alloy and without graphite particles processed alloy. The graphite particles act as a solid lubricant during wear test as a result lower wear rate with lower coefficient of friction was observed. A.R Khademi and A. Afsari, (2017) [10] fabricated the surface composite by inserting nano sized TiB_2 particles on steel surface and studied the mechanical properties of the composite surface. Hardness and tensile strength of the composite surface were improved in compare with base alloy. By decreasing with tool traverse speed and with constant tool rotational speed processed composite specimen were good in strength due to better distribution of nano particles in the alloy. Less than 600nm ultra fine grains were formed in Steel/TiC surface composite by FSP [11]. B. Sattari et al., (2018) [12] studied the effect of number of FSP process on wear properties on the steel surface. The wear rate was decreases with increase in number of passes. However, variation in the FSP passes there was no significant change in friction coefficient. R.A. Seraj et al., (2016) [13] observed that initial ferritic pearlite microstructure of the AISI52100 steel was transformed into martensite with retained austenite of microstructure in the stir zone of the processed region. The hardness of the processed region was 15 times higher than base steel. K. Selvam et al., (2016) [14] showed that FSPed austenite steel exhibit better erosion and corrosion resistance than base steel due to higher stability of passive layer in the processed surface. A. Ghasemi-Kahrizsangi et al., (2015) [15] fabricated Mild Steel/Al_2O_3 surface nano composite and studied the effect of different rotational speeds and traverse speeds on hardness of modified surface. With increase in rotational speed and number of FSP passes the micro hardness of the surface composite was increased to 350Hv due to uniform particle distribution in the alloy. The grain size of the modified surface was reduced to 2µm from base alloy grain size of 15 µm. TiC is extensively used as the reinforcement particles because of high hardness, good wear resistance, high melting point and chemical stability [16]. In this paper FSP is used to produce steel surface composites by adding of TiC particles on the surface and then processed. The effects of tool rotational speed and tool traverse speed on the hardness and wear properties were investigated.

2. MATERIALS AND METHODS

The steel plate of 5mm thickness with its chemical composition of 0.45C, 0.5Mn, 0.4Ni, 0.4Si was used as a base alloy. The plates were cut into rectangular samples of 5mmx80mmx200mm. Commercially available Titanium Carbide (TiC) particles with average size of 20µm was used as reinforcement. The SEM micrograph of these particles is shown in Figure 1. A groove size of 1mm width and 1.5mm depth was made on the plate. The reinforcements were mixed in the acetone and it was made in form of slurry and tightly packed on the grooves. Prior to filling of particles, the grooves were cleaned with acetone. The prepared steel plates were fixed on the hydraulic fixture of the FSW machine. FSW machine capacity of 11 kW, 40kN (Make: RV machine tools, Coimbatore, India) was used for fabrication of surface composites. FSP tool was made of Tungsten carbide material with shoulder diameter of 20mm, pin diameter of 6mm and pin length of 2 mm were used. The experimental plan is presented in Table 1. The FSP tool dimensions and fabricated tool is shown in Figure 2 (a) and (b) respectively.

After processing the workpieces were cut cross sectionally to the FSP direction and studied the microstructure of the composite. For microstructural studies standard metallographic procedure has been adopted and studied through optical microscope and scanning electron microscope. The Vickers micro hardness tester was used for measurement of hardness of base alloy and composite samples as per ASTM standard. The micro hardness values of specimens were measured along the cross section of the processing direction at the load of 100g with a dwell time of 10s. The dry sliding wear tests of the base alloy and processed samples were studied through a pin on disc tribometer (Make: DUCOM, Bangalore, India) and the tests were conducted as per ASTM G99-04 Standard. The 8mm diameter pin samples were extracted from the middle of the processed region. The counterpart of the disc was made of hardened EN-31 steel. All the wear tests were conducted at sliding speed of 1 m/s under normal load of 30N for sliding distance up to 2000m. The test samples were cleaned with acetone before and after the test and weighed to an accuracy of 0.01mg by electronic weighing balance. All wear tests were repeated two times and an average of two were taken.

Table 1. FSP experimental details

Experiment Name	Tool Rotational Speed (rpm)	Fixed Parameters
Steel/Without TiC	800	Tool tilt angle- 1° No. of passes - 2 Plunge depth - 0.15mm Tool traverse speed 50mm/min
Steel/TiC	600	
Steel/TiC	800	
Steel/TiC	1000	

3. RESULTS AND DISCUSSIONS

3.1. Microstructure

Figure 4 shows the microstructure of cross section of stir zone of modified composite surface. The refined grain size was observed on the processed region. The SEM image (Fig 5 (b)) shows the hard TiC inclusion in the base alloy. The dark region and bright region indicated that the inclusion of reinforcements in the base alloy.

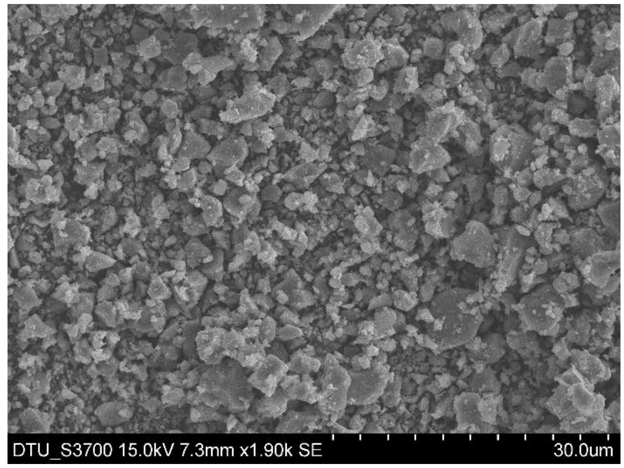

Figure 1 SEM image of TiC particles

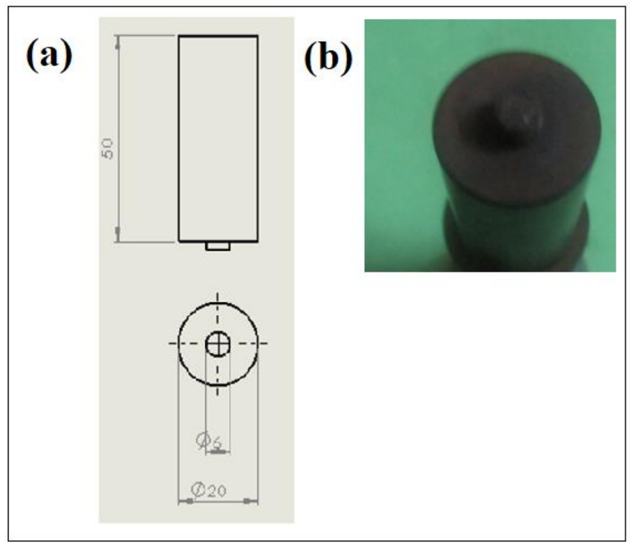

Figure 2 (a) Tool dimensions (b) Fabricated tool

3.2 Hardness

The hardness of the base material and cross section of processed composite samples using with different tool rotational speeds is shown in Fig. 4. During FSP plastic deformation occurred in the stir zone due to heating of the material through tool rotational speed, traverse speed and friction between tool shoulder & workpiece. The tool rotational speed and traverse speed are important process parameters for generation of heat during processing. Selecting suitable tool parameters improves the processing condition, uniform dispersion of reinforcement particles in the base alloy, refinement of grain size and removing the oxide layers during processing. The strain rate of the material is increasing with increase in heat generation during processing.

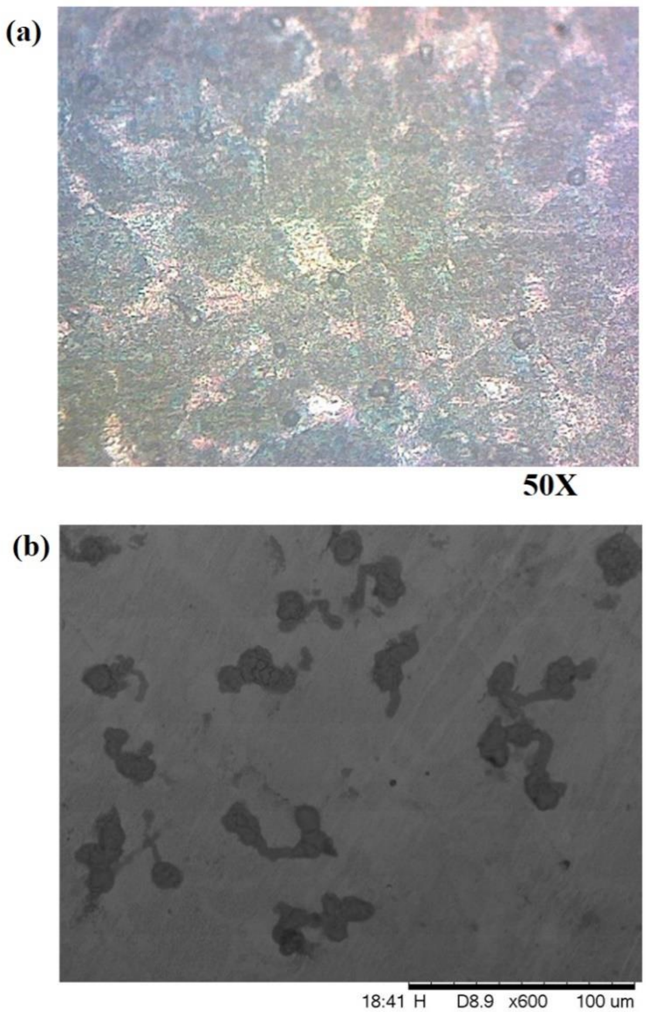

Figure 3 Steel/TiC composite surface (a) Microstructure (b) SEM image

The following relationship shows that the increase in tool rotational speed increases the heat generation [17].

$$\frac{T}{T_m} = K\left(\frac{\omega^2}{\vartheta x 10^4}\right)^{\alpha} \ldots\ldots\ldots\ldots (1)$$

Where T_m is the melting point of base alloy, K and α are constants, υ is the tool rotational speed. With increase in tool rotational speed the heat input also increases as result of larger volume of plasticized material produced due to the stirring of the tool pin. With increase in heat ratio (ω^2/ν) leads to increasing of temperature in the stir zone. The grain coarsening may take places with increase in excessive heat generation, which results in adverse properties of the material. The plunge depth and tool tilt angle provided the sufficient friction action between tool and workpiece. A similar type of studies reported that with the increase in rotational speed decreases the mechanical properties of the material after certain speed.

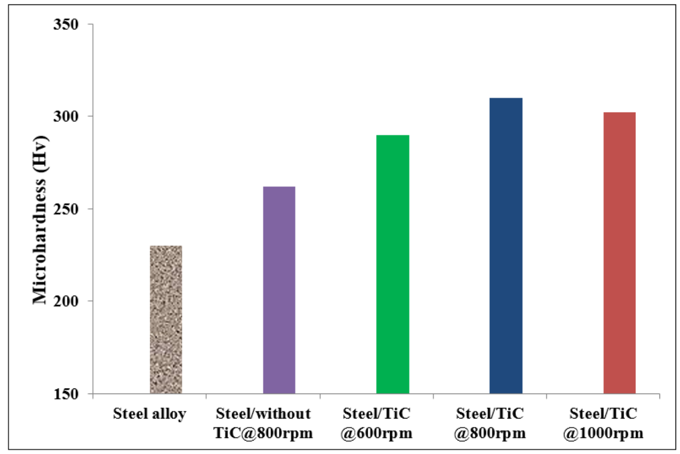

Figure 4 Micro hardness value of FSPed samples

3.3 Wear Properties

The variations of wear rate with sliding distance of the base material, unreinforced composite surface, reinforced composite surface processed with different tool rotational steed is shown in Figure 5. The wear resistance of the composite surface is higher than the base alloy and unreinforced composite sample. The main reasons for decrease in wear of the composite surfaces were the hard TiC particles act as a load bearing element, the difference in coefficient of thermal expansion between steel & reinforcement alloy and grain refinement of the base alloy. The variation in the friction coefficient of composite with a normal load is shown in Figure 6. The average friction coefficient of the composite sample has lowest value of 0.4 and the base material friction coefficient is 0.6. During the wear test the pull-out iron particles formed oxide layers which reduces the friction coefficient. Besides, that TiC particles act as a solid lubricant and formed a tribo film layer during wear test which reduces the friction coefficient.

4. CONCLUSIONS

In this study, Low carbon steel surface composite was successfully produced by FSP by introduction of TiC reinforcement particles on the surface. The hardness and wear resistance of the composite surface exhibited higher than without particles processed steel and base material. The composite surface processed with tool rotational speed of 800 rpm exhibited the highest hardness value of 316 Hv and minimum wear rate of 0.0128mg/m. With increase in tool rotational speed above 800rpm the hardness of the composite samples was not improved. The variation of friction coefficient was not shown any significant change in wear rate of the composite sample. The TiC particles formed a tribo film layer during wear test which is responsible for reduction of friction coefficient in the composite surfaces.

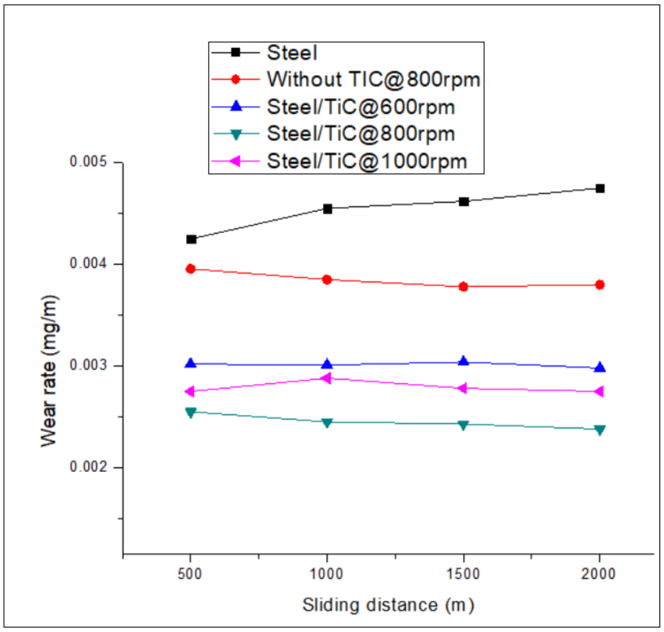

Figure 5 Variations of wear rate with the sliding distance

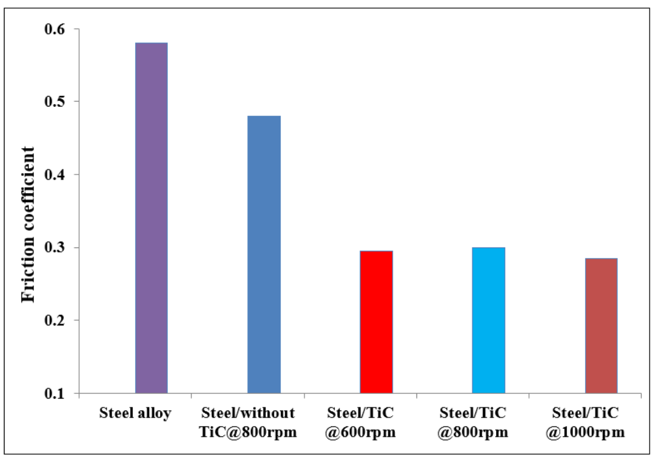

Figure 6 Friction coefficient of composite specimens

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