Study on Wear for Aa6082 Based Hybrid Surface Composites Fabricated Via Friction Stir Processing

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Abstract
Friction stir processing (FSP) is claimed to be very prominent solid-state method to produce hybrid surface composite (HSC). Mainly, surface composites are the material which provides better surface properties such as wear resistance. In this study focus has been made on fabrication of HSC via FSP. For this, two types of tools (having tilt angle 3 degree and 5 degree) are used with the combination of different types of process parameters such as no. of passes, pattern of tool rotation, various combinations of weight percentage ratios of reinforcement particles, different tool rotational speeds and feed rates(tool traverse speed). Aluminum alloy AA 6082 is selected as a matrix material and Silicon Carbide and Graphite particles are used as a reinforcement particles to fabricate HSC. Only FSPed surfaces (without addition of reinforcement particles in matrix material) are also prepared to study the wear behavior of it with above parameters. Wear of both of surfaces (HSC & FSPed surfaces) are compared with the wear of the matrix material.
Keywords: Friction stir processing, Hybrid surface composite, AA 6082, Sillicon carbide, Graphite, Wear.

Introduction

Composite materials hvae been emarged as an alternative of conventional alloys or metals in many day to day life applications due to its capability to provide good amount of mechanical and tribological properties along with light weight in comparison to conventional alloys and metals. Among all types of composites Metal matrix composites are having the higest focus in the field of mechanical engineering applications. In many mechanical engineering applications only surface properties such as wear resistance is required rather than volumetric properties. In these cases fabrication of surafce metal matrix composites becomes important. Surface composites are the materials which will have matrix material and reinforcement particles (secondary elements) altogether on the surface of the plateas shown in figure 1. When two or more reinforcement particles are added into matrix material's surface, it is called as hybrid surface composite(HSC).

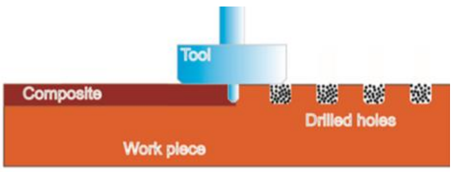

Figure 1. Shows Surface composite (Sharma et al., 2015)

Fabrication of surface composites can be done through many methods such as cladding, laser beam technology, thermal spraying, Friction stir processing etc. Among these all friction stir processing(FSP) is the only method that is the solid state process which does not have any liquid to solid transformation. Due to unavailability of phase transformations the chances to have defects and interfacial reactions is no where in FSP. Apart from that chemical stability (Hassan et al., 2012), dimensional stability at high temperature(Sharma et al., 2018), improvement in the corrosion resistance (Mahoney et al., 2006), reduction of the porosity of castings (Mahoney et al., 2006), good strength to weight ratio (Gobikannan et al., 2016) are the other advantageous poins of FSP. In addition to that FSP is a green technology which means no welding fumes and dusts are generated in atmosphere (Węglowski et al.,2018).

Frction stir processing produces surface composites in which the FSP tool is used (Figure 3). Figure 2 shows the schematic arrangement of tool and matrix material.

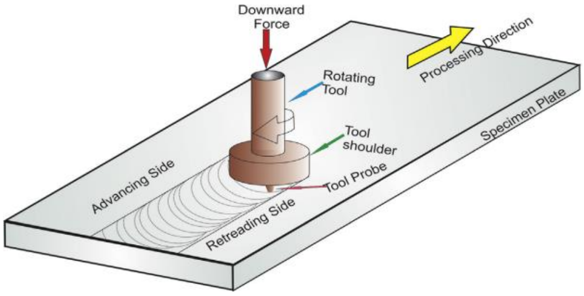

Figure 2. Shows Schematic illustration of FSP technique (Sharma et al., 2015)

Figure 3. Shows FSP tools (Rathee et al., 2016)

In FSP, the reinforcement particles are added into the surface of the matrix material either by hole method or the groove/slot method as shown in fig. 4 (a) and (b).

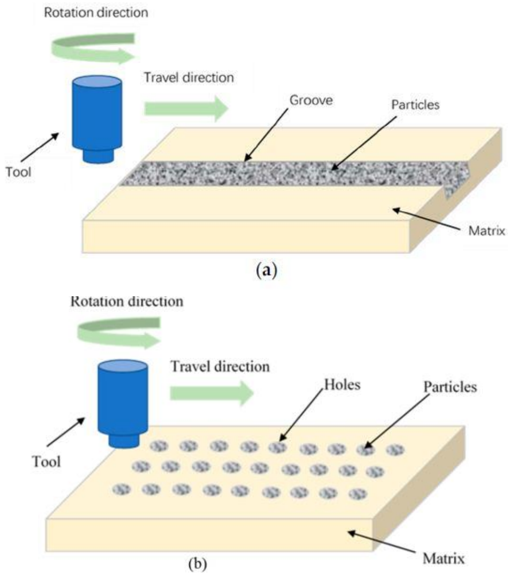

Figure 4. Shows methods to add reinforcement particles in Matrix material for FSP process. (Li et al., 2019)

After addition of reinforcement particles pinless tool (figure 3) will be rotated and processed in traverse direction (capping pass) on the surface of matrix to cover up the grooves/slot or holes. So the particles can not be escaped.. And then FSP tool with pin (figure 3) will be rotated on the same surfaces to have stirring effect to distribute the reinforcement in matrix material in order to make surface composites. Figure 5 and 6 shows various process parameters of FSP process. Apart from these direction of rotation of tool, number of passes, pin profile are also considered as the process parameters.

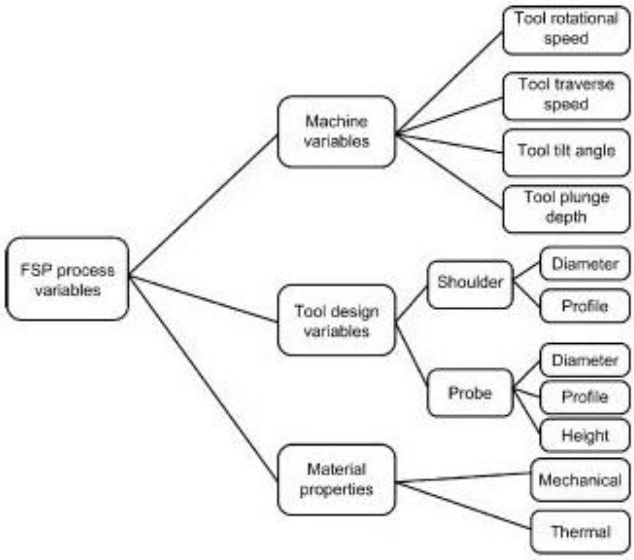

Figure 5. Shows FSP process variables (Sharma et al., 2015)

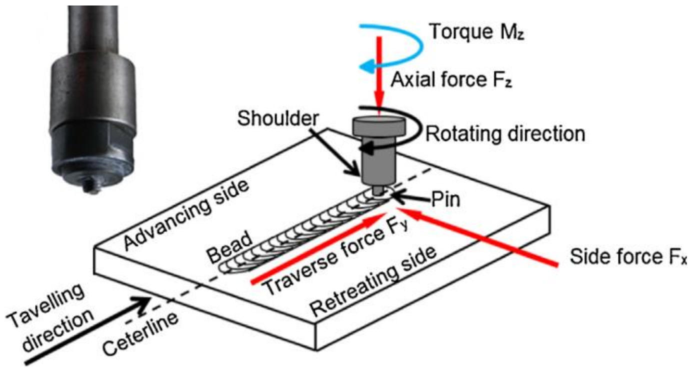

Figure 6. Shows Machine variables (Sharma et al., 2015)

Alidokht et al. (2019) selected A356 as a matrix material and SiC and MoS_2 were used as a reinforcement particles. The groove method was implemented by authors. They found improved wear resistance and uniform particle distribution. Hosseini et. al. Selected AA5083 as a matrix material and carbon nano tubes as a reinforcement particles to check tensile strength with increasing volume fraction of carbon nanotubes. Srinivasu et. al worked on A356 material with boron carbide and MoS_2 holes method to add secondary particles. They found increament in hardness and wear resistance. Parumandla et al. (2018) selected AA6061-T6 as a matrix material. While as a reinforcement Al_2O_3 and SiC particles were used with the groove method. In this study wear resistance of surface nanocomposites was found increased with increasing volume percentage of reinforcement. Akbari et al. (2019) Worked on A356 as a matrix and SiO_2 and Al_2O_3 as a reinforcement particles added into square groove. They found hardness improvement and uniform distribution of the particles. Rejil et al. (2012) Worked on AA6360 with TiC and B_4C particles. V groove was made for addition of reinforcrmrnt particles. They studied the microstructure and sliding wear behaviour of the fabricated hybrid surface composite. Soleymani et al. (2013) studied on AA 5083 matrix material with SiC and MoS_2 as the reinforcement particles with groove method of addition. They found the largest increase in wear resistance in hybrid surface composites, followed by FSPed and base metals. Sharma et al. (2019) worked on AA6061 with B_4C and MoS_2 as a reinforcement particles. They found that with more reinforcing particles, wear resistance is increased. Aruri et al. (2013) used AA6061-T6 as matrix, SiC and Graphite particles as reinforcement. Increased microhardness, lower wear rate and decreased tensile properties were resulted. Kumar et al. (2014) worked on AA6082 with the magnesium and flyash as the reinforcement particles. It was found that the addition of fly ash increased the tensile strength, addition of Graphite lead the tensile strength and hardness to decrease. Dinaharan et al. (2014) studied on AA6061 with Al_3Ti, Al_3Zr reinforcement particles. He found that Friction Stir processed specimen with intermetallic reinforcement resulted in improved wear resistance. Devaraju et al. (2013) selected AA-6061-T6 as a matrix material. SiC and Al_2O_3 was selected as a reinforcement particles. In this study The optimum value for rotational speed and proportion of reinforcement were found using Taguchi Method, Significant improvement in wear was observed at the optimum conditions. In another study the same authors selected SiC with Gr, SiC with Al_2O_3 as a reinforcement particles. In this study he found Uniformly distributed reinforcement help achieve better properties, Addition of graphite as opposed to alumina reduced hardness but increased the wear resistance. Sudhakar et al. (2015) selected AA7075 as matrix and B_4C with MoS_2 as reinforcement material. In this study Hybrid surface composites showed better properties of wear resistance, Ballistic resistance as compared to the base metal. Miranda et al. (2013) chosen AA 5083 H111 as matrix and SiC with Al_2O_3 was selected as reinforcement. Outcomes of the study were (i) for SiC reinforcement, tool wear was present, although sound composites were Produced. (ii) An approach of using a consumable tool with prefilled reinforcement has shown to enhance particle retention. This also avoids defects and produces sound Composites, The consumable tool approach is suitable for various combinations of reinforcements. In this study AA6082 is selected as matrix and SiC with Graphite particles as reinforcement. The objectives of this study are to identify the effects of number of passes, pattern of tool rotation, tool tilt angle on wear.

Materials And Methods

Medium-strength aluminium alloy 6082 has the highest corrosion resistance of the 6000-class alloys and the highest strength. The superior strength of AA6082, a relatively new alloy, has caused it to displace AA6061 in number of applications. For this study 5 mm thick sheet of AA6082 has been selected.

In the production of tooling parts, H13 steel is a type of tool steel that is frequently used. High hardness, excellent wear resistance, and good toughness are some of its best qualities. So H13 tool steel has been selected to make various FSP tools. Diffirent tools produced by H13 tool steel are shown in below figures 7,8, and 9.

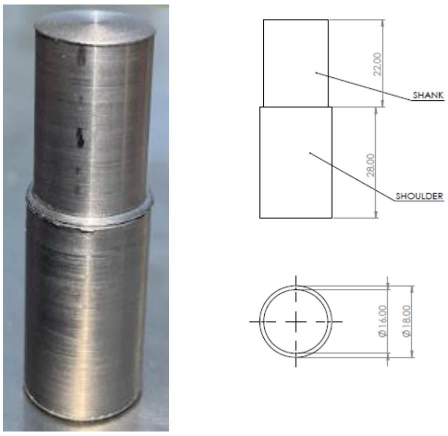

Figure 7. Shows pinless tool (forcapping passes)

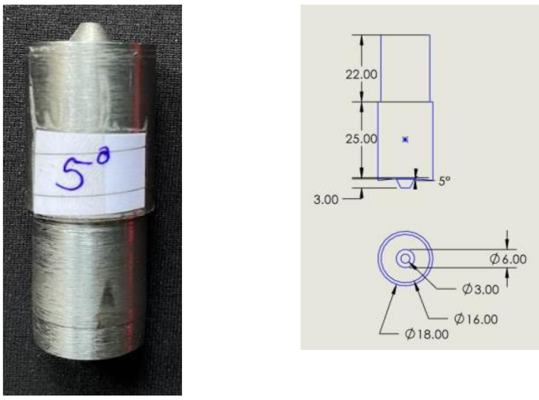

Figure 8. Shows FSP tool with 5° tilt angle

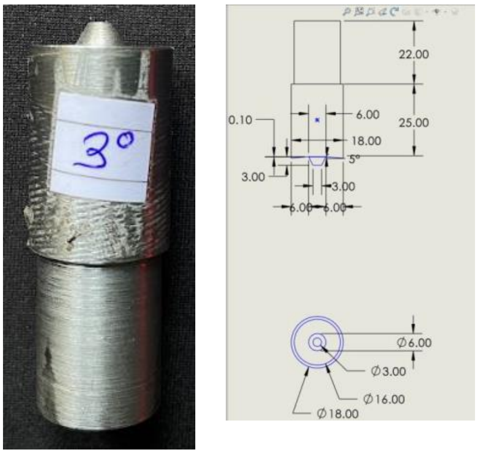

Figure 9. Shows FSP tool with 3° tilt angle

By using above tools different coupons starting from coupon number 1 to 10 are prepared. Coupon no. 1 belongs to the coupon cut from matrix material itself without any kind of processing on it. Coupon no. 2 to 6 belongs to Hybrid surface composite prepared via FSP. Coupon 7 to 10 belongs to Friction stir processed surfaces of matrix material without addition of reinforcement particles. For fabrication of coupons no. 2 to 10 various parameters such as tool tilt angle, number of passes, pattern of tool rotation (direction of tool rotation during passes), and weight proportion of SiC and Garphite are considered.

For coupon no. 2 to 6, to produce hybrid surface composites reinforcement particles such as Sillicon carbide and Graphite has been selected. Sillicon carbide(SiC) particles can be used as reinforcement in a variety of materials because of their high strength and stiffness, good thermal stability, low density, abrasion resistance, and chemical resistance. As the Graphite particles plays a role of a solid lubricant, it has been selected as a secondary elements. Mess size for selected SiC particles were 140 (105-150 micron) while for Graphite it was 400 (37-45 microns). Acetone has been used as a carrier medium for making the paint cum paste type of mixture of SiC and Graphite particles into the holes made on AA 6082 plate materials before application of capping pass. Acetone has high volatality(low melting point) and high viscosity(capacity to penetrate reinforcement particles upto depth of the hole) with compared to other chemicals of its class, which makes it superior to use as a carrier medium. The holes produced on the surface of AA6082 have the size of 1.6 mm diameter and zigzag pattern as shown in figure 10. The depth of each hole is 2 mm. Outer periphery of each hole is 1 mm apart from nearby holes' outer periphery. In 121 mm of length of each coupon total 108 holes were produced. After making holes paint cum paste type mixture of SiC and graphiet particles with acetone is applied within these holes by hand laping with high pressure. After that capping pass with the help of pinless tool is to be completed to cover the holes so particles can not be escaped from holes during next stirring passes.

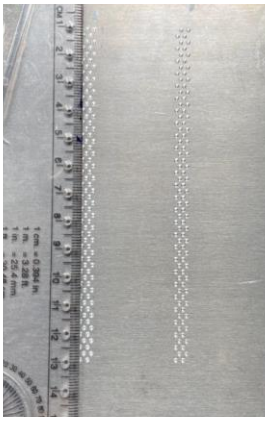

Figure 10 Shows pattern of holes made for fabrication of HSC

Matrix material AA6082 is considered as a coupon number 1. Coupon number 2 to 6 are hybrid surface composites fabricated via Friction stir processing route. Tool rotational speed and tool traverse speed for all this HSC coupons are 2000 rpm and 30 mm/minute respectively. For coupon no. 2,4, and 5 , tool with tilt angle of 3° is used, while for coupon 3 and 6 tool having tilt angle 5° is used. Coupon 2 and 6 are prepared with 2 number of tool passes, while coupon 3,4, and 5 are prepared with 3 tool passes. For coupon 2,3,4 and 6 , during all the tool passes tool rotational direction is clockwise. For coupons 5, during all first and third passes tool rotational direction is clockwise and during second pass tool rotational direction is anti clockwise. For coupon 2 to 5 the weight percentage for mixture of reinforcement particles is same having 90% SiC and 10% Graphite. While in coupon 6 both the particles are mixed in equalweight content. Coupon 7 to 10 are Friction stir proccessed AA6082 surfaces which are produced by penetrating and stirring of FSP tools in matrix material AA6082 without addition of reinforcement particles. Coupon 7 is prepared with 1 clockwise pass, 2000 rpm tool rotational speed,ioi and 30 mm/min tool traverse speed by 5 degree tilt angle tool. Coupon 8 is prepared with 3 clockwise passes, 2200 rpm tool rotational speed, and 60 mm/min tool traverse speed by 3 degree tilt angle tool. Coupon 9 is prepared with 2 clockwise passes, 800 rpm tool rotational speed, and 170 mm/min tool traverse speed, by 3 degree tilt angle tool. Coupon 10 is prepared with 3 clockwise passes, 800 rpm tool rotational speed, and 170 mm/min tool traverse speed by 3 degree tilt angle tool. The summary of all coupons is shown in Table 1.

After fabrication of all coupons , 3 button shaped samples are removed from each coupon for the wear measurement. The size of the button shaped material is 10 mm diameter and 5 mm thickness (matrix material plate). The location on the coupon from where these 3 samples are removed is shown in figure 11 (i) The wear samples were prepared for wear testing as per the ASTM G99 standard as shown in figure 11 (ii).

Figure 11. Shows (i) Location on the coupon from where samples for wear testing are cut. (ii) cut sample and prepared pin for wear testing

Table 1. Shows Summary of process parameters for prepared coupons (Matrix material / HSC / FSPed)

	Coupon number	Tool rotational speed(rpm)	Tool traverse speed (mm/min)	Tool tilt angle (degree)	Number of passes	Direction of tool rotation during passses	Weight % of SiC and Graphite
Matrix material	1	-	-	-	-	-	-
Hybrid Surface Composite	2	2000	30	3	2	C-C	90 % SiC 10 % Graphite
	3	2000	30	5	3	C-C-C	90 % SiC 10 % Graphite
	4	2000	30	3	3	C-C-C	90 % SiC 10 % Graphite
	5	2000	30	3	3	C-A-C	90 % SiC 10 % Graphite
	6	2000	30	5	2	C-C	50 % SiC 50 % Graphite
FSPed AA6082	7	2000	30	5	1	C	-
	8	2200	60	3	3	C-C-C	-
	9	800	170	3	2	C-C	-
	10	800	170	3	3	C-C-C	-

In Direction of tool rotation during passes column C means clockwise, A means anticlockwise.

Table 2. Shows result of wear testing for all samples

Coupon no.	Pin no.	Wear (µm)	Average Wear (µm)
1	1	90	87
	2	89	
	3	81	
2	1	48	46
	2	41	
	3	50	
3	1	50	62
	2	62	
	3	73	
4	1	45	39
	2	30	
	3	41	
5	1	48	57
	2	67	
	3	55	

Coupon no.	Pin no.	Wear (µm)	Average Wear (µm)
6	1	40	53
	2	53	
	3	67	
7	1	111	105
	2	112	
	3	91	
8	1	54	61
	2	64	
	3	65	
9	1	78	82
	2	64	
	3	104	
10	1	75	83
	2	83	
	3	89	

Using a pin-on-disc apparatus, as per the ASTM G99 standard ,the samples are tested for wear testing under fixed loading conditions of 15 N at 400 rpm with a sliding distance of 890 meter. EN31 steel plate is used as the disc's material.

Macroscopic examination is carried out for cross section area of one of the HSC surface to identify the presence of reinforcement particle under the top surface of the coupon. Along with that microscopic examination also was carried out to identify presence of SiC and Graphite particles on surface.

Results and Discussion

From each coupon three samples(pins) were prepared for wear testing. The results of wear tests for all three samples of each coupon along with the average wear in µm is shown in table 2. Several observations are noted by comparing the results of wear test done for all samples (Matrix material / HSC material / FSPed surfaces)Below are the findings for Hybrid Surface composited surfaces. (From coupon number 2 to 6)

Effect of number of passes

To identify the effect of number passes on wear, firstly results of wear for coupons 1, 3 and 6 are compared and secondly results of wear for coupons 1, 4 and 2 are compared and shown in figures 12 and 13.

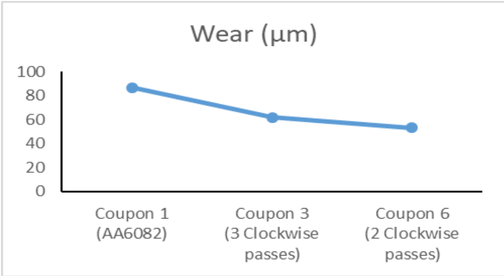

Figure 12. Shows comparison of wear between coupons 1, 3 and 6.

Figure 13. Shows comparison of wear between coupons 1, 4 and 2.

Above results indicated that In HSC, wear decreases due to number of passes in comparison to Matrix material AA 6082. Due to stirring passes the reinforcement particles get better distribution which provides highr resistance to wear.

Effect of direction of passes

To identify the effect of direction of passes on wear, results of wear for coupons 1, 4 and 5 are compared and shown in below figure 14.

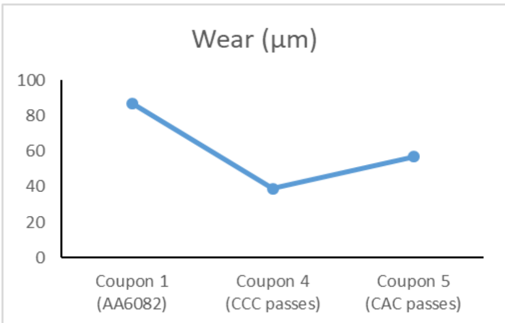

Figure 14. Shows comparison of wear between coupons 1, 4 and 5.

These results indicates that in HSC , wear decreases due to number of passes in comparison to Matrix material AA 6082. Wear is less in coupon 4 where all 3 passes are clockwise(CCC) with comparison to coupon 4 where 3 passes are in alternate direction(CAC).

Effect of tool tilt angle

To identify the effect of tool tilt angle on wear, results of wear for coupons 1, 3 and 4 are compared and shown in below figure 15.

Figure 15. Shows comparison of wear between coupons 1, 3 and 4.

These results indicates that HSC prepared by FSP tool having 3° tilt angle gets lower wear in comparison to FSP tool having 5° tilt angle. This happens due to more pressure applied by 3° tool in comparison to 5° tool on the matrix and reinforcement material so it can't be escaped from coupon during friction stir processingand provide more wear resistance.

Below are the findings for Friction stir processed (FSPed) surfaces on AA6082 (From coupon number 7 to 10).

Effect of FSP with 5° tool

To identify the effect of use of 5° tool during FSP on wear of AA6082 , results of wear for coupons 1 and 7 are compared and shown in below figure 16.

Figure 16. Shows comparison of wear between coupons 1 and 7

In FSPed AA 6082 surface prepared with 5 degree tool more wear is observed than the Matrix material AA 6082. This happens as stirred material gets more room to come out from surface due to less pressure by tool on workpiece.

Effect of FSP with 3° tool

To identify the effect of use of 3° tool during FSP on wear of AA6082 , results of wear for coupons 1 and 8 are compared and shown in below figure 17.

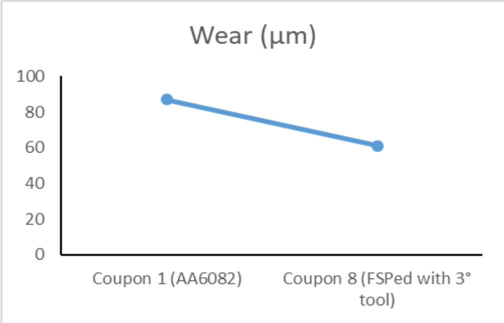

Figure 17. Shows comparison of wear between coupons 1 and 8

In FSPed AA 6082 surface prepared with 3° tool less wear is observed than the Matrix material AA 6082. This is due to less tilt angle so tool applies more pressure on material and materail remained within the surface and fills the voids kind of defects in matrix material if any.

Effect of number of passes

To check the effect of number of passes during FSP on wear of AA6082, results of wear for coupons 1,9 , and 10 are compared and shown in figure 18.

In FSPed AA 6082 , decreament in wear is observed for more number of passes in comparison to Matrix material AA 6082.

Figure 18. Shows comparison of wear between coupons 1,9 and 10.

The findings of macroscopic and microscopic examinations are discussed below.

Cross section of the prepared HSC coupon is examined macroscopically. The surface having reinforcement particles are clearly visible along with the penetrated pin area with the naked eyes. To explore pin penetrated area and to find out availability of reinforcement particles in the depth from the top surface of AA6082 matrix material, cross section was examined under 5X magnification. It is shown in below figure 19. In this figure the shape of the pin is clearly visible with secondry particles in surface area as well as pin penetrated area.

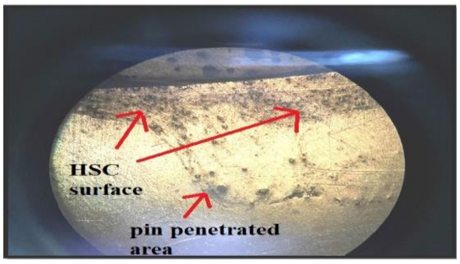

Figure 19. Shows 5X magnified c/s of the HSC coupon showing penetrated pin area.

Also the processed surface of HSC is examined under microscope with 500X magnification to identify the presence of secondary particles on the surface of it as shown in figure 20.

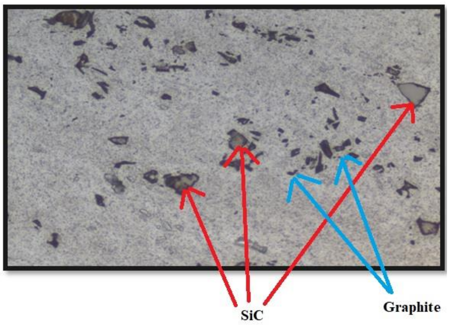

Figure 20. Shows 500X magnified surface of HSC prepared via FSP.

Conclusions

From this study it is found that the process parameters such as tool tilt angle, number of passes, and direction of rotation of tool patterns have significant effect on wear behaviour of FSPed surface as well as HSC fabricated via FSP route. It also can be concluded that FSP gives prominent results in order to increase the wear resistance by adding the reinforcement particles in the top surface of matrix material. Only FSPed surfaces also shows improvement in wear resistance with compared to AA 6082 only, as it refines the grain structure as well as it reduces the residual defects of the matrix material by filling the material in cavities.

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