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Fabrication of Al7075 / B4C surface composite by novel Friction Stir Processing (FSP) and investigation on wear properties

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Abstract

Friction stir processing (FSP), a process, derived from the friction stir welding (FSW) process, is an emerging novel, green and energy efficient processing technique to fabricate surface composite. In the present investigation, FSP technique has been used for fabrication of surface composites, using aluminium 7075 as parent metal and Boron Carbide (B_4C) powder particles as reinforcement. , Aluminium 7075 has been selected as matrix phase, as being widely used by automotive and aerospace application and having the highest strength among all commercial Al alloys. In present paper, details about the fabrication of Al 7075-T651- B_4C surface composite for various combination of tool rotation, tool travel speed and number of passes have been discussed. The same being intended to improve hardness and thereby wear resistance. The fabricated surface composites are examined for microstructure using image analyser, and found friction stir processed zone with a few defects. It is also observed that the average hardness of friction stir processed surface composite was 40 – 70% higher than that of parent metal (75 – 80 HV). Wear Resistance is found to be improved by 100 % compared to parent metal. The increase in same is attributed to B_4C particles dispersed in aluminium matrix and grain strengthening mechanism.

Keywords: Surface Composite *Al 7075/B_4C, Friction stir processing, Wear, Friction stir welding.*

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1. Introduction

A composite material is a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. These unique characteristics of composites provide the engineer with design opportunities not possible with conventional monolithic (unreinforced) materials. The use of composites in the aerospace industry has increased dramatically since the 1970s. In line automotive industry faces many challenges, including increased global competition, the need for higher-performance vehicles, a reduction in costs and tighter environmental and safety requirements. The same has led to development in the field of the composite materials with their unique as said properties.

Many techniques had been reported for fabrication of surface composite (SC), but FSP has been identified as one of the most promising techniques. FSP is developed my Mishra et al[1, 2], which works on the same principle of friction stir welding (FSW). Conventional liquid phase processing techniques suffers from the limitation like, formation of intermediate detrimental phase and porosities due to elevated temperature process conditions, and requires critical control of process parameters to control the solidified structure [2]. To avoid such problems, the process should be carried out at a temperature below the melting point of the substrate as done in solid phase surface modification techniques. As, being one of the solid state surface modification technique, it has been used in the present investigation for fabrication of SC.

First SC has been synthesized via FSP route by Mishra et al.[1]. A composite layer ranged from 50 to 200 nm by reinforcing silicon carbide (SiC) particles in the Aluminum matrix have been obtained. The microhardness of the SC has been reported to be increased by two times compared to the parent metal. Later on many researchers have explored the area of surface composite fabrication using FSP. Among them, Hossein Bisadi et al. [3], has investigated the effects of processing parameters on particle dispersion and hardness in Al7075-alloy reinforced with TiB_2 micro-particles. They have reported 50 % increase in the micro hardness compared to the parent material. Devaraju et al.[4]has fabricated a hybrid SC using Al 6061 as parent material and reinforced the same with different mixture of the powder viz., SiC & Graphite (Gr) and Sic & Al_2O_3. Low wear rate has been observed in the Al–SiC/Gr surface hybrid composite due to mechanically mixed layer generated between the composite pin and steel disk surfaces which contained fractured SiC and Gr. It has been reported that the wear rate was $1/5^{th}$ of the parent material. R. Ramesh et al. [5] has studied the hardness and thereby wear resistance at various combination of rotational speed, travel speed and no. of passes for Al 7075/B_4C surface composite fabricated using FSP. It has been found that the average hardness of friction stir processed surface composite has been 1.5 times higher than base metal. Soleymani et al.[6]reported half volume loss in the wear test of the Al 5083/SiC composite formed using FSP compared to base metal. The increase in hardness and wear resistance have been attributed to fine dispersion of reinforcement particles in matrix and grain refinement of the matrix.

During FSP, particles are wrapped and flow together with plastic metal. Due to difference in the physical properties between B_4C particles and base metal, it is hard for the particles to travel with the trail left by the plastic metal[7]. That’s why B_4C particles cannot be easily dispersed and the agglomeration occurs. So, it is necessary to fabricate SC layer by higher number of passes, which softens the matrix each time & ensures better distribution.

In present work, Aluminium 7075 as being one of the stiffest and strongest aluminium alloy, has been used as matrix phase. Whereas, boron carbide (B_4C), as being third hardest material found on the earth has been used as reinforcement phase. Al 7075/B_4C composite has been formed using various combination of tool traverse speed (TS), number of passes and tool rotation speed (RS). Investigation of microstructure, microhardness and wear properties had been done for the SC formed.

2. Experimental Details

Experiments have been performed on conventional vertical milling center. As reported by Badheka[8], conventional milling machine can be used for friction stir welding of commercial aluminum and thereby for FSP also. Base plate for manufacturing of composite used is 6.5 mm thick Aluminum alloy 7075-T651 material with length & width of 100 mm. The chemical composition for the same is mentioned in table 1. For, reinforcement, a groove of 1.2(W) × 2.5 (D) × 100(L) mm was prepared using shaper machine and same was filled with reinforcement of boron carbide (B_4C) powder with size of 12 – 15 µm. Theoretically, which contains 12 – 15 % of volume fraction of the composite formed.

Table 1. Chemical Composition of Al 7075-7651

Si	Fe	Cu	Mn	Mg	Cr	Zn	Al
0.4	0.5	1.2-2.0	0.3	2.1-2.9	0.2	5.1	Bal.

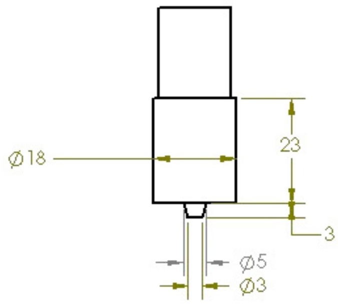
Table 2. Sample ID as per Parameters set

Sample ID	A3	C3	F3
TS (mm/min)	50	78	120
RS (RPM)		545	

A heat treated pin less tool of M2 grade steel as shown in Fig. 1(a), has been used for capping pass to close the groove cavity. A heat treated WC – Co (12%) tool having taper cylindrical profile pin, as shown in Fig. 1(b), has been used for stirring passes. Extensive loss of powder particles can occur if, FSP directly performed for stirring pass, once the particles are inserted into the groove. It can be efficiently reduced by applying a single capping pass on the hole with cylindrical tool that has no pin. Subsequently, powder particles packed in the cavity uniformly distributed with cylindrical tool with pin.

Three specimens were produced using constant tool rotation speed (TR) of 545 RPM, three number of passes and tool tilt angle of 3º. Tool traverse speed (TS) has been varied for the same. Parameter set alongwith each sample's unique identification number (ID) have been shown in Table 2. As per the standard metallurgical procedure, samples for the microstructural characterization are cut perpendicularly to the processed line at the center of the plate.

(a)



(b)

Fig. 1 (a) M2 tool steel tool for closing cavity (b) WC-12Co tool

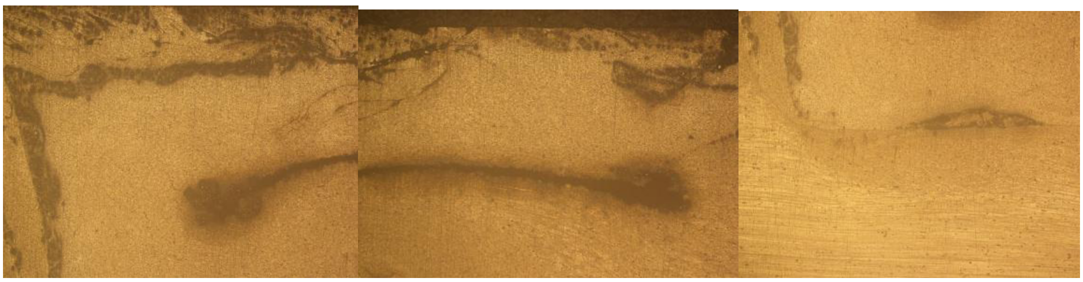
All observations of the nugget zone in the study referred to the central position of the processed nugget. The transverse cross section is polished down to 1 micron using diamond suspension and etched using Keller's reagent for optical micrographs and micro hardness. Microstructure images have been recorded at various magnifications for analyzing the powder distribution at different regions in the nugget using image analyzer and Scanning electron microscope (SEM). Investigation of micro hardness using vickers hardness tester has been carried out at 300 gm and dwell of 10 seconds. Wear test has been carried out for each sample at load of 60 N and readings of volume loss had been taken at regular interval of 400m travelling distance for total of 2000 m.

3. Results and Discussions

The results of above experiments are analyzed for microstructure, micro hardness across the processed zone and wear behavior. Specimens cut from the processed samples have been examined for macro structure and micro structure study.

3.1. *Microstructure observations*

Based on microstructural characterization of grains three distinct zones: nugget zone, thermo-mechanically affected zone (TMAZ), and heat-affected zone (HAZ), have been identified, as shown in Fig. 2. The microstructural changes in various zones are responsible for the post processing mechanical properties. Intense plastic deformation and frictional heating during FSP result in generation of a recrystallized fine-grained microstructure within stirred zone. Microstructures confirmed no partial melting in nugget region for all three TS. Accumulation of the B_4C particles, have been identified at some locations in nugget zone, caused by insufficient stirring. Fractured surface has been also been identified in the nugget region.



Nugget 50X Nugget – Center - 50X TMAZ- Nugget interface 50X

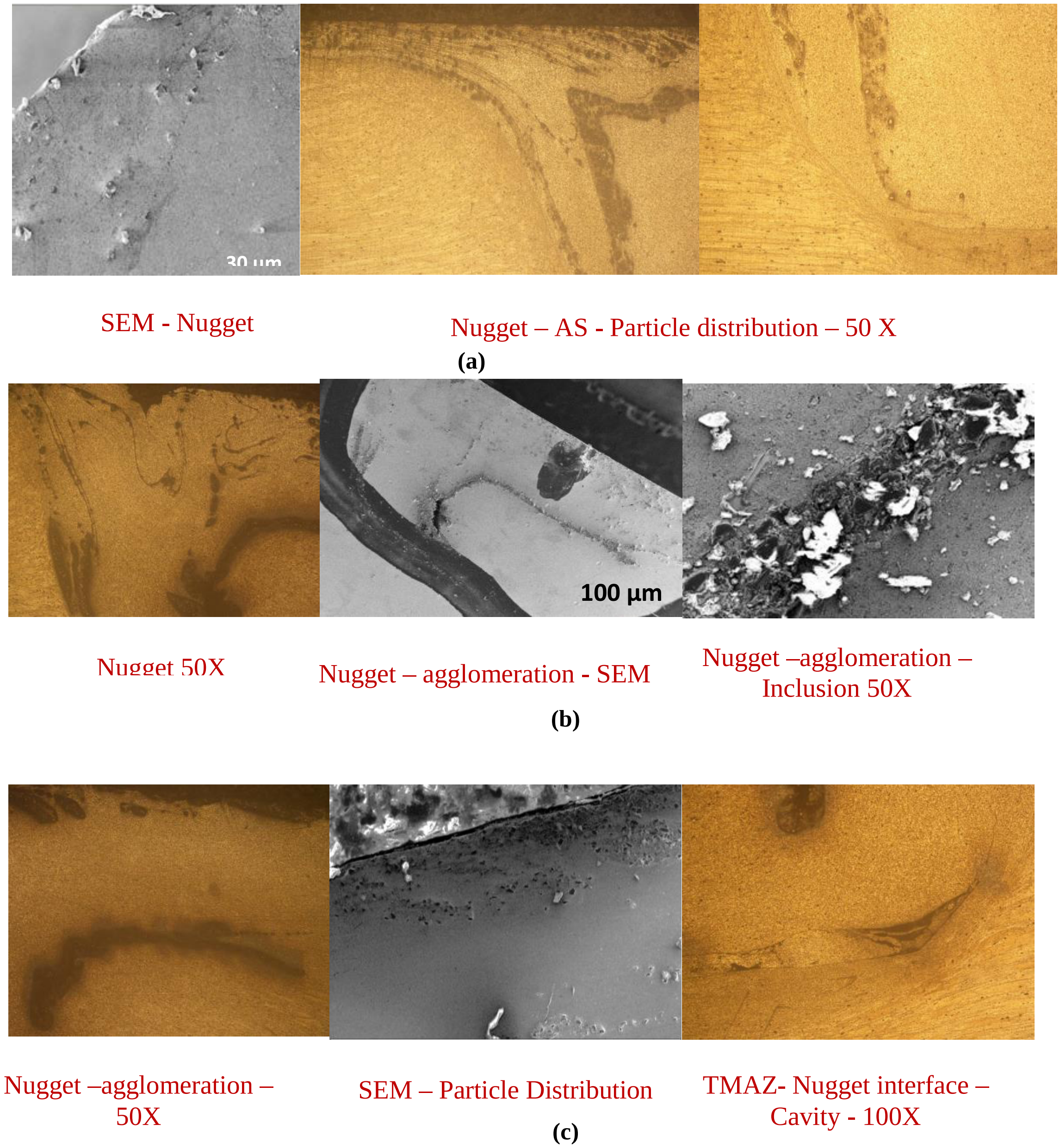


Fig. 2: Microstructure of friction stir processed Al 7075/B_4C composite for sample (a) A3 (b) C3 (c) F3.

In the present investigation of microstructure, it is observed that, powder has been accumulated on the advancing side (AS) of the processed zone, for each FSPed samples. Studies from Reynold[9] and Seidel & Reynolds[10] on FSW and FSP, show that, there is significant mechanical difference of the material flow from the advancing side to retreating side. Due to combination of tool rotation & linear movements, the probe shears the material from the advancing side (AS) and directs its flow to the retreating side (RS), under applied forging load supplied via shoulder. The AS experiences higher level of material stirring, which leads to more intense mixing of reinforcement particles. If the plunge force or rotation momentum is not sufficient to counteract the flow stresses produced by the material, it may not be able to lift the material. And as an effect the material may not be transferred from AS to RS, which leads to higher agglomeration AS.

Defects like porosity, worm hole etc., have been identified in specimens as a result of the low rotation speed. As reported by Mahmoud et al[11], very low rotation speed leads to insufficient stirring and hence defects are generated.

It has been also observed that as TS is increased, the powder distribution is reduced. Though, difference in the powder distribution is not much significant. It has been reported by Mahmoud et al.[11] that, the tool travelling speed had much less significant effect on the dispersion of the particles in the nugget zone. At the same time, they have observed higher agglomeration of SiC particals on advancing side for higher TS. In line for the samples processed at higher TS have been found to have higher agglomeration in AS. The best distribution has been achieved in the case of the sample A3 which is processed at lowest TS.

3.2. Micro hardness

Micro hardness has been recorded for all samples using vickers hardness tester at 300 gm load and 10 seconds of dwell time using ESEWAY Vickers Hardness Tester. The core hardness was measured by the indentation made at 1 -1.5 mm beneath the top surface in horizontal direction. For which the cross section was cut from the prepared sample. Average and peak hardness recorded are tabulated in the table no. 3. Average hardness has been calculated, by taking the average of 6 reading measured at an interval of 1 mm, on the both the side from the center of the nugget.

Table 3. Maximum and Average Hardness for various samples

Sample ID	Avg. Hardness	Max. Hardness	Standard Deviation
A3	133	144	6.5
C3	111	125	8.1
F3	103	112	4.7

From the table 3 it is observed that, average hardness along the top surface was found to increase by 40 - 70%, as compared to base metal (78 - 80 HV). In the same regards, the maximum hardness achieved are almost 70 to 90 % compared to the parent material.

3.2.1. Effect of TS on the Micro hardness

It has been observed that the as the TS is increased, micro hardness is reduced as shown in the fig. 3 for all the three parameter set. The reduction in the hardness was attributed to the reduction in the stirring time, as the TS is increased, which leads to lower particle distribution and also, reduction in the grain refinement.

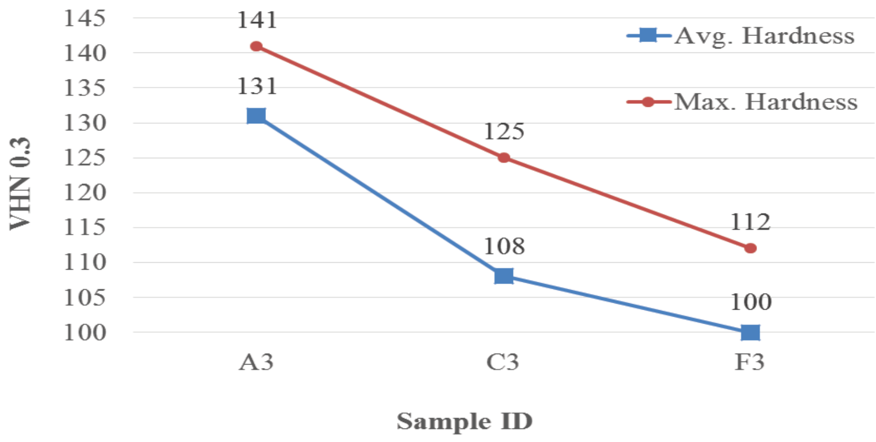


Fig 3. Effect of TS on the micro hardness

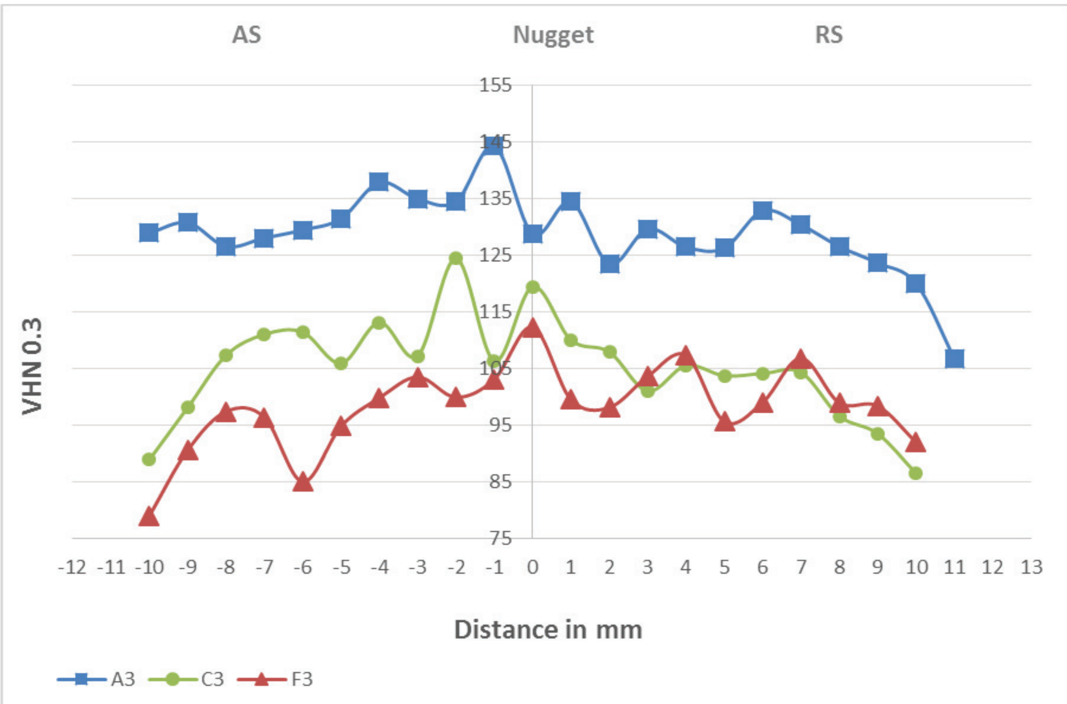


Fig.4: Macro hardness comparison for A3, C3 & F3

It is observed to have increasing trend in the micro hardness approaching towards the nugget region and reduction, as it approaches to HAZ region from the nugget center as shown in the Fig. 4. As discussed in microstructure study, grain refinement is evident in the nugget region whereas, larger and elongated grains, observed in HAZ area. This leads to reduction in hardness in the HAZ area. The reason for the increasing the hardness of Al 7075/B4C surface composite in nugget & TMAZ region are (i) Grain strengthening: refinement of the grain. (ii) Orowan strengthening: fine dispersion of the B_4C powder particles[12].

3.3. Wear

FSPed samples have been analyzed for wear testing at 60 N load on wear track diameter 100mm and for total travel distance of 2 kilometer. Square specimen of 6mm were cut from the parent material and processed samples from the center/nugget region of the plate for the same.

The mode of wear in the as-received Al 7075 and surface composite layer is both adhesive and abrasive. The rate of wear increased with increasing sliding distance in as-received Al mainly because of increased coefficient of friction. From the graph shown in Fig. 5, the volume loss of the base metal is observed to be approx. 180-200 % higher compared to processed samples. Among the processed sample F3 is having maximum wear of 8.35 mm^3 at the end of 2000 m, whereas the minimum wear of 7.23 mm^3 has been observed. The same is attributed to the microhardness observed in the previous section. As sample A3 is processed at lower TS, it exhibits the higher amount of the powders distribution and grain refinement, which leads to higher hardness and wear resistance.

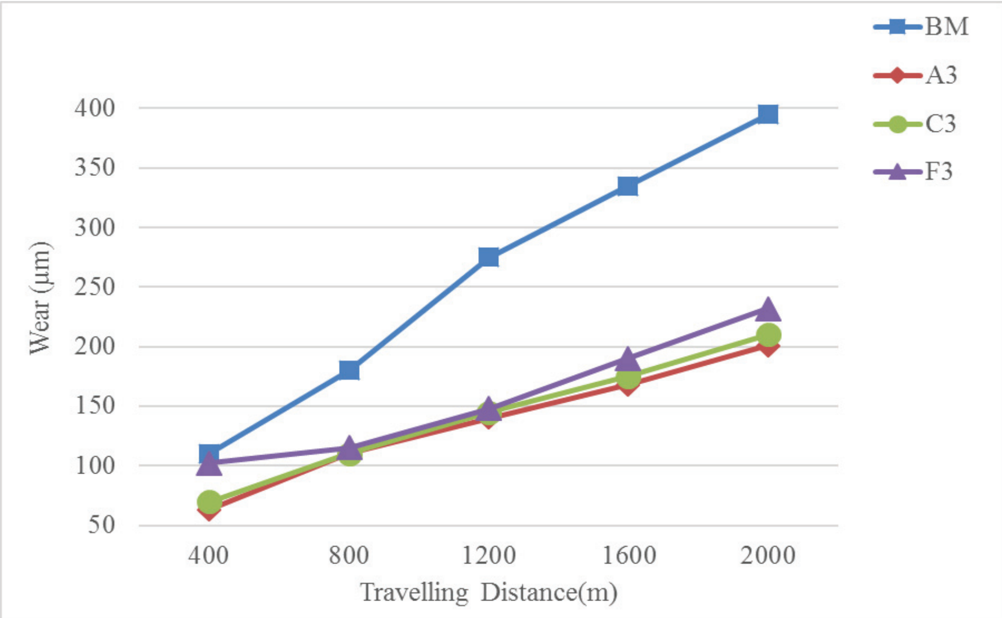


Fig. 5 Wear Comparison of processed specimen with base material

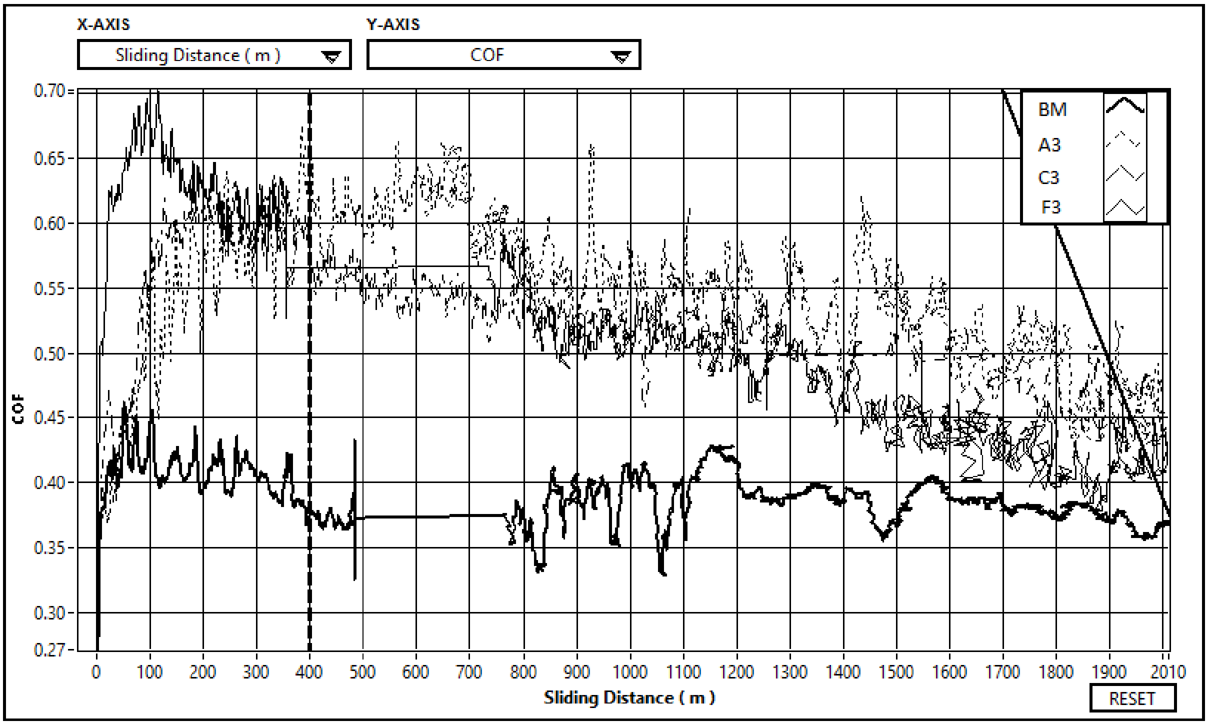


Fig. 6 COF Comparison of processed specimen with base material. BM = Base Metal

Coefficient of the friction (COF) has been observed to be lowest in the parent material whereas approximately 60 % higher for the processed sample which is 0.6 as indicated in Fig. 6. Higher COF is attributed to the B_4C powder particles reinforced in the matrix. It has been observed that sample A3 exhibits highest COF, even though same has observed to be having the highest wear resistance attributed to higher amount of distribution of the B_4C particles.

4. Conclusions

In the present study, surface composite has been successfully fabricated on aluminum sheets using FSP. FSP was performed on 7075 aluminum sheets with three different traverse speed. Effect of the same on the powder distribution, micro hardness and wear have been studied. Following conclusions were derived from test outcomes:

1. Tool travelling speed had much less significant effect on the dispersion of the particles in the nugget zone. Even though best powder distribution has been achieved in the sample A3 with lowest TS. Increase in the TS lead to insufficient stirring time and led to lower powder distribution.
2. There is reducing trend of micro hardness with increase in tool traverse speed because of reduction in stirring time and hence reduction in powder distribution and grain refinement. Highest hardness of 144 HV was recorded for sample A3, processed at TS of 50 mm/min.
3. Average hardness of Al7075/B_4C composite fabricated using FSP has been increased by 1.3 -1.6 times of the base metal, which was 75 - 80 HV.
4. Wear resistance of the sample A3, which is processed at lowest TS, is observed to be highest, even though having highest COF as 0.6. The same attributed to higher amount of distribution of the B_4C particles and grain strengthening mechanism.
5. With the help of microstructure study, finely dispersed particles were observed in the stir zone for the sample A3, processed at lowest TS. But still further experiment may be carried out for

improvement in the stirring and thereby powder distribution by altering more parameters like tool rotation speed, other powder filling pattern, more powder sizes, direction of each pass, tool tilt angle and number of passes.

5. Acknowledgement

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6. References

[1] R.S. Mishra, M. Mahoney, S. McFadden, N. Mara, A. Mukherjee, High strain rate superplasticity in a friction stir processed 7075 Al alloy, Scripta Materialia, 42 (1999) 163-168.

[2] R.S. Mishra, M.W. Mahoney, Friction stir processing: a new grain refinement technique to achieve high strain rate superplasticity in commercial alloys, in: Materials Science Forum, Trans Tech Publ, 2001, pp. 507-514.

[3] H. Bisadi, A. Abasi, Fabrication of Al7075/TiB 2 surface composite via friction stir processing, American Journal of Materials Science, 1 (2011) 67-70.

[4] D. Aruri, K. Adepu, K. Adepu, K. Bazavada, Wear and mechanical properties of 6061-T6 aluminum alloy surface hybrid composites [(SiC+ Gr) and (SiC+ Al 2 O 3)] fabricated by friction stir processing, Journal of Materials Research and Technology, 2 (2013) 362-369.

[5] R.R.a.N. Murugan, Microstructure and Metallurgical Properties of Aluminium 7075 – T651 Alloy / B4C 4 % Vol. Surface composite by Friction Stir Processing, Advanced Materials Manufacturing & Characterization, 13 (2013) 301-306.

[6] S. Alidokht, A. Abdollah-Zadeh, S. Soleymani, H. Assadi, Microstructure and tribological performance of an aluminium alloy based hybrid composite produced by friction stir processing, Materials & Design, 32 (2011) 2727-2733.

[7] K. Elangovan, V. Balasubramanian, M. Valliappan, Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy, The International Journal of Advanced Manufacturing Technology, 38 (2008) 285-295.

[8] V.J. Badheka, Utilisation of a Conventional Milling Machine for Friction Stir Welding of Commercial Aluminum, International Journal of German Welding Society 56 (2010) 6.

[9] A.P. Reynolds, Visualisation of material flow in autogenous friction stir welds, Science and technology of welding & joining, 5 (2000) 120-124.

[10] T. Seidel, A.P. Reynolds, Visualization of the material flow in AA2195 friction-stir welds using a marker insert technique, Metallurgical and materials transactions A, 32 (2001) 2879-2884.

[11] E. Mahmoud, K. Ikeuchi, M. Takahashi, Fabrication of SiC particle reinforced composite on aluminium surface by friction stir processing, Science and Technology of Welding & Joining, 13 (2008) 607-618.

[12] H. Xing, X. Cao, W. Hu, L. Zhao, J. Zhang, Interfacial reactions in 3D-SiC network reinforced Cu-matrix composites prepared by squeeze casting, Materials Letters, 59 (2005) 1563-1566.