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Effect of Number of Passes on Mechanical and Wear Properties of Friction Stir Processed Al 1050 Alloy

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ABSTRACT

Friction stir processing Technique is used to modify the surface layer and improves the micro-structural modification and enhances the mechanical & wear properties of the material. In this study the effect of number of FSP passes on the Aluminum 1050 alloy was studied. The grain refinement of the matrix was obtained after each FSP pass. With increase in FSP passes decreases the grain size of the matrix alloy and more homogeneous grain refinement occurs on the stir zone. The hardness, tensile strength and wear rate of the processed region was evaluated and found that enhancement of hardness, tensile strength and wear resistance of the samples with increase in passes due to finer refinement of the grain size in the stir zone.

Keywords: *Aluminum; Frictions Stir Processing; Single and Multiple Passes; Hardness & Wear Analysis.*

1.0 Introduction

Aluminum alloy is widely in automobile, aircraft and structural applications due to their excellent mechanical properties and low weight to strength ratio. Most of the engineering components depend upon the surface of the material[1].The surface layer of the material can be improve by various techniques like Equal channel angular processing (ECAP), High pressure Torsion (HPT), Cyclic channel die compression (CCDC), Accumulate roll bonding and Friction Stir Processing [2-3]. Recently great attention is given to the FSP Technique for surface modification due to simple process and the thickness of the surface can be obtain in several millimetres. The specially designed rotating non consumable hardened tool with shoulder and a pin is plunging in the workpiece and tool is traversed along the length. The friction between the tool shoulder and the material causes localized heating and softens the material on the processed region. The pin causes the stirring of the material and forms equiaxied region [4].

Rao et al. [5] studied the effect of multi-pass FSP of hypereutectic Al–30Si alloy and found that the corrosion resistance of the material was decreased due to the reduction of grain size and silicon particle sizes and increase in homogeneity of microstructure. Fadhalah et al. [6] studied the effect of overlapping of the Al6063 by multi pass FSP and found that with increase in passes improves the mechanical properties of the Al alloy. Barmouz et al. [7] fabricated the Cu/SiC composites by multi pass friction stir processing and found that the grain size of the copper matrix was reduced with increase in FSP passes. The mechanical properties of the composite were enhanced due to uniform dispersion of reinforcement particles in the matrix due intense stirring of the material. Balasubramanian et al. [8] studied the effect of tool pin profile and shoulder diameter on the Friction Stir Welded Al6061 aluminium alloy and found that square pin profiled tool produced defect free Welded joint with higher tensile properties.

Vijayavel et al. [9] studied the influence of shoulder diameter to pin diameter (D/d) ratio on tensile strength and ductility of friction stir processed LM25Al -5% SiC metal matrix composite. The D/d ratio 3 is produced defect free processed region with enhanced hardness and

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tensile strength in compare to other D/d ratio composites. The optimum D/d ratio breakups the SiC particles in the finer and equal size and distributed uniformly in the matrix. In this present work FSP is used to modify the surface layer of Al1050 alloy. The effects of number of passes on the mechanical properties and wear resistance were investigated.

2.0 Materials and Methods

Aluminium 1050 alloy with 10mm thickness was used for FSP. A hardened tool made of H-13 with a shoulder of 18mm diameter with square pin profile and the pin length of 5mm was used for FSP. Fig. 1(a) shows the dimensions of the FSP tool and Fig. 1(b) show its schematic diagram of the tool. The FSW machine with the capacity of 11 kW and 40kN was used to modify the surface layer of the material. The workpiece materials were clamped on the specially designed hydraulic fixture. After number of preliminary trials the tool rotational speed and traverse speed were fixed at 1000rpm and 40mm/min respectively. Three different specimens namely one pass, two pass and three pass were prepared. For multi passes the advancing and retreading side of the workpiece was changed after every pass. For each pass the work piece was allowed to cool to the room temperature. After the FSP, the cross sections of the specimens were examined through optical microscope. The samples were polished with different grades of emery sheets and etched with keller's reagent and examined the stir zone of the processed layer.

The micro hardness values of the cross section of the stir zone of FSPed regions were measured using a load of 100g with dwell time of 10s. The tensile specimens were prepared along FSP region by wire cut EDM as per ASTM standard. Fig. 2 shows the tensile test specimen dimensions. Tensile specimens were examined through computer controlled tensile testing machine at speed of 1mm/min. To evaluate the wear behaviour of the processed samples pin on disc tribometer (make DUCOM) was used. Cylindrical wear test specimens of 10mm diameter were cut from the middle of the processed region and the wear tests were conducted as per ASTM G99-04 standards. The wear tests were performed against hardened EN-24 steel disc at an ambient temperature. Before each wear test specimen and the disc were cleaned with acetone. The sliding velocity and normal load kept constant at 1.5m/s and 40N respectively at the sliding distance of 3000m. At 500m interval the wear test samples were weighed to an accuracy of 0.01mg. Wear rate were calculated as a ratio of weight loss to sliding distance. The coefficient of friction between pin and disc was determined by measuring the frictional force with stress sensor. The wear samples are examined through SEM for understanding the wear behavior of the processed surface layer and compared with base material.

Fig 1: (a) Dimensions of FSP Tool (b) Schematic Diagram of the Tool

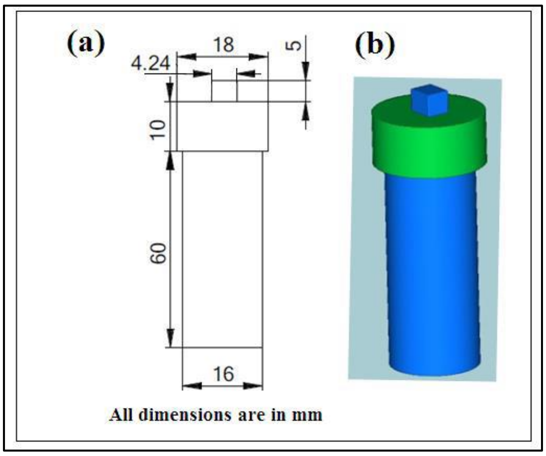
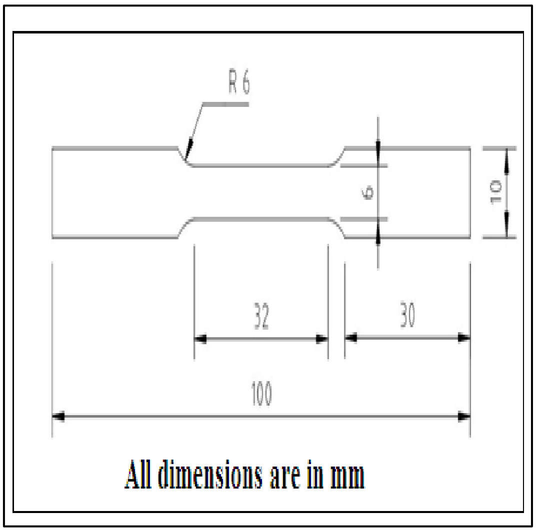


Fig 2: The Tensile Test Specimen Dimensions



3.0 Results and Discussions

3.1. Hardness and tensile strength

During FSP the tool pin the intermixing and refinement of the grain size in the matrix. The material in moving towards advancing side of the stir zone and the shoulder provides sufficient frictional force for heat generation. Further increase in FSP pass the grain size of the material was reduced. During the second pass the tool rotational direction was changed for uniform refinement of grains. The average grain size of the base material was approximately 54μm. After one pass the grain size of the specimen was reduced about 16μm. After three pass the grain size was reduced about 11μm. Fig. 3 shows the Optical micrograph of stir zone of three pass FSP sample. It clearly seen that the uniform refinement of the grains. The hardness mainly depends upon grain size, microstructural factors and dispersion strengthening. In addition hardness also depends upon in the FSPed Al alloys were FSP process parameters, number of passes and tool shoulder to pin diameter ratio. The hardness of base alloy and processed samples are shown in Fig. 4. The average of three hardness value was taken for experimental purpose. As per Hall-petch relationship the hardness of the material is increased due to finer grain size. Similar results reported by Mahmoud [10] for increase in hardness of FSPed A390 Al alloy.

Fig 3: Optical Micrograph of Stir Zone of Three Pass FSP Sample

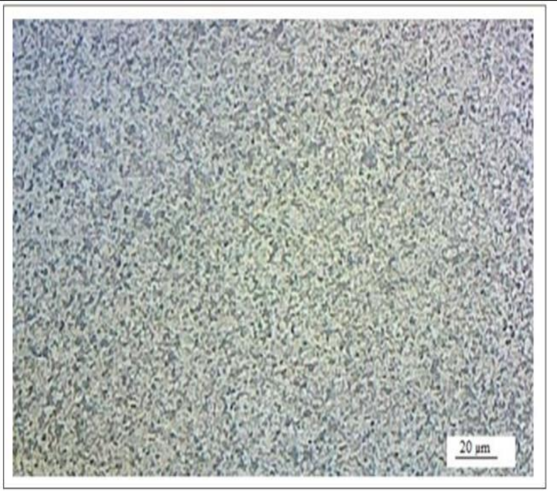


Fig 4: Microhardness of the Stir Zone of the Processed Samples

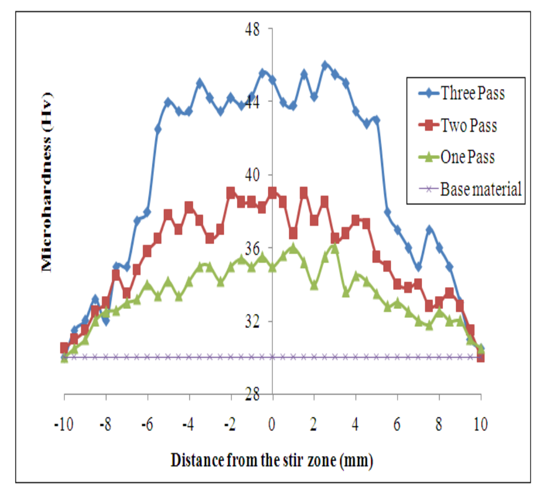
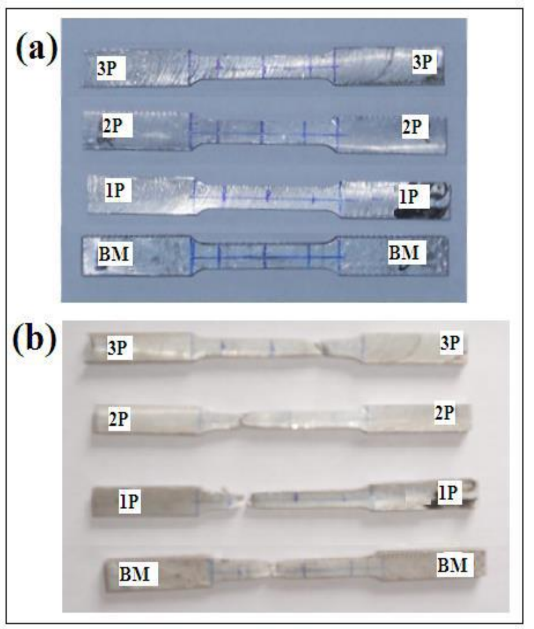
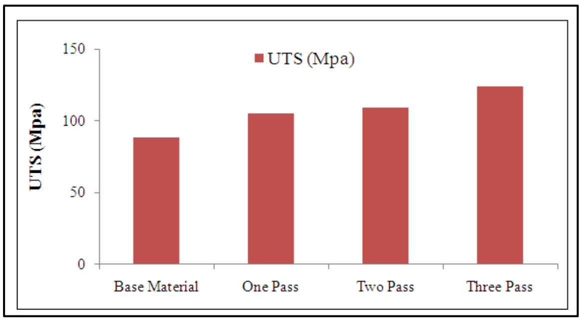


Fig 5: Tensile specimens (a) Before Test (b) After Test



The tensile specimens before and after testing are shown in Fig.5 (a) and (b) respectively. The Ultimate tensile strength (UTS) of the three pass FSP specimen was improved about 37%. The base material Ultimate tensile strength was about 90±2Mpa.The detailed tensile strength of the FSPed samples are displayed in the Fig. 6. The tensile strength of the processed samples mainly depends upon the grain refinement and dislocation strengthening mechanisms.

Fig 6: Tensile Test Results



The maximum tensile strength was achieved in the three pass sample. Tensile properties are mainly depends upon the grain size of the material. As per Hall-petch relationship the tensile strength of material is inversely proportional to grain size. The relationship of the tensile strength and grain size states that

$\sigma s=\sigma o+Kyd-1/2$ ------- (1)

Where σs and σo are constants, d is the average grain size. Fig. 7 shows the fracture surfaces of tested tensile specimens. In all the samples ductile fracture was observed. FSPed samples observed that finer dimples and uniform size, which reveals that uniform elongation. However three pass samples shows the very finer dimples which indicate that refined grain size of the material. Similar results reported by Yadav and Bauri of FSPed Aluminium [11].

3.2. Wear properties

Fig. 8 shows the schematic diagram of pin on disc experimental set-up. The macro image of the wear test specimens are extracted from the processed region is shown in Fig.9.The wear rates of the processed samples and base material are shown in Fig. 10. This reveals that the wear resistance of the processed samples is higher than base material. Three pass wear sample has highest wear resistance than one pass and two pass samples. Hardness of the processed samples is higher than base material. As per Archard relation harder materials has lesser wear rate than softer materials at same frictional condition. Archard's equation states that [12]

Q=kW/H ---- (2)

Where Q is volume of material removed, W is the applied load and H is the hardness. Fig.11 shows the relationship between hardness and wear rate. It clearly shows that increase in hardness of the material reduces the volume of material from the surface. The enhancement of wear resistance of the FSPed composite samples is due to finer refinement of grain size. Fig. 12 shows the typical variation of friction coefficient with sliding distance of base material and stir zone of the processed material. The average friction coefficient of the base material was to be 0.55 and the fluctuations absorbed throughout the sliding distance. The friction coefficient of three pass wear specimen exhibited to be 0.35, which is lower other samples. Which it is indicated that with increase number in FSP passes lowers the friction coefficient and the low fluctuation curves observed when compare to base material. The worn surface of the base material shows that the abrasion marks, delamination marks, cracks and deeper surface pits (Fig. 13(a)). In the three pass sample SEM image shows that plastic flow lines, delamination wear and traces of oxidation wear (Fig. 13(b)). The material removed from material is entrapped in between pin and the disc causes the two body wear mechanism to three body wear mechanism which results in reduction of friction coefficient of the three pass specimen.

Fig 7: Tensile Fractographs (a) Base Material (b) One Pass Specimen (c) Three Pass Specimen

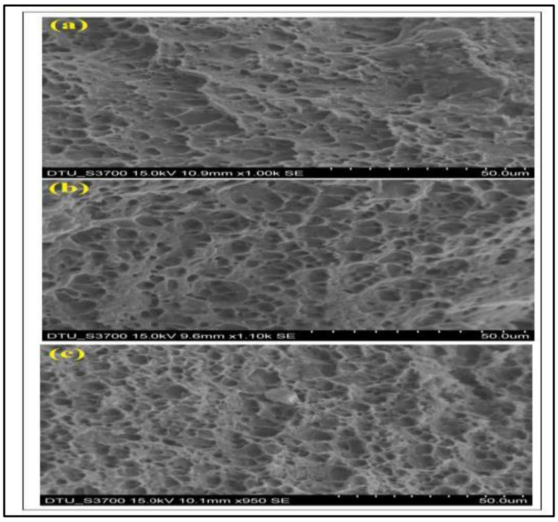


Fig 8: Typical Pin on Disc Wear Test Set-Up

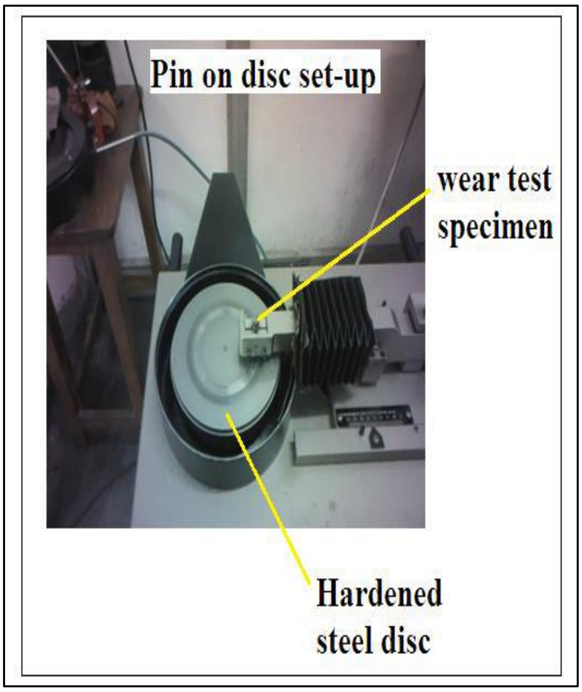


Fig 10: Change in Wear Rate with Sliding Distance of Base Material and FSPed Samples

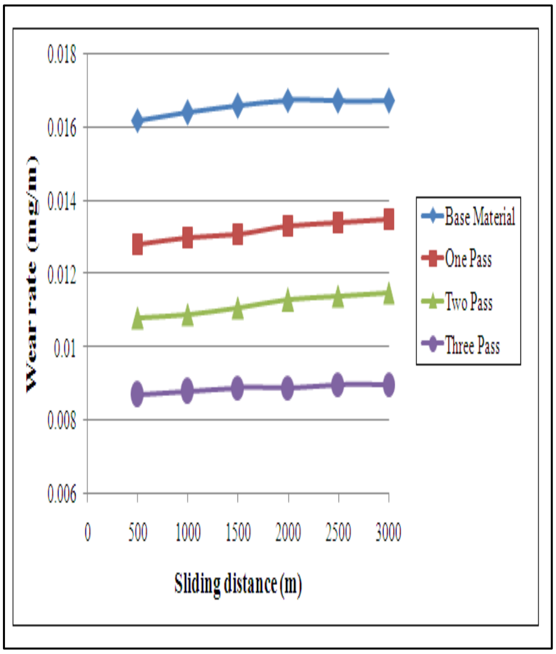


Fig 9: Typical wear Test Specimens Extracted from the Processed Surface Layer

Fig 11: Change in Wear Rate of Base Material and Fsped Samples Vs Microhardness

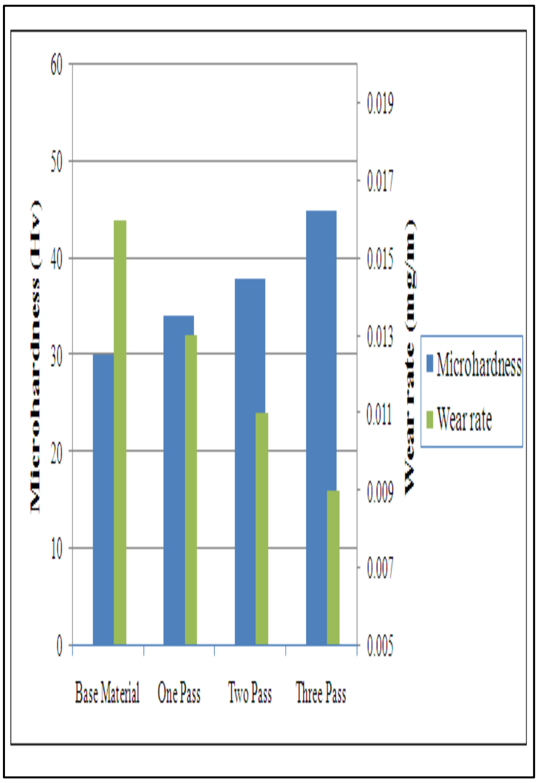


Fig 12: Varation of Friction Coefficient Vs Sliding Distance in (a) Base Material (b) Fsped One Pass Sample (c) Fsped Three Pass Sample

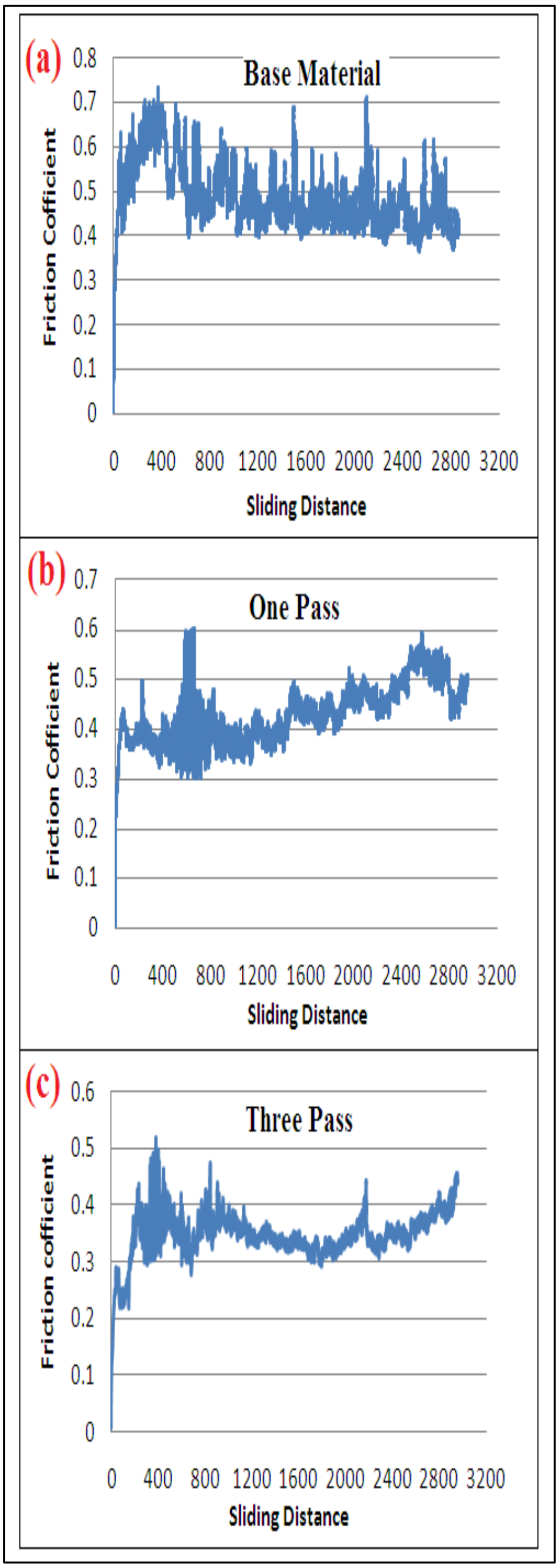
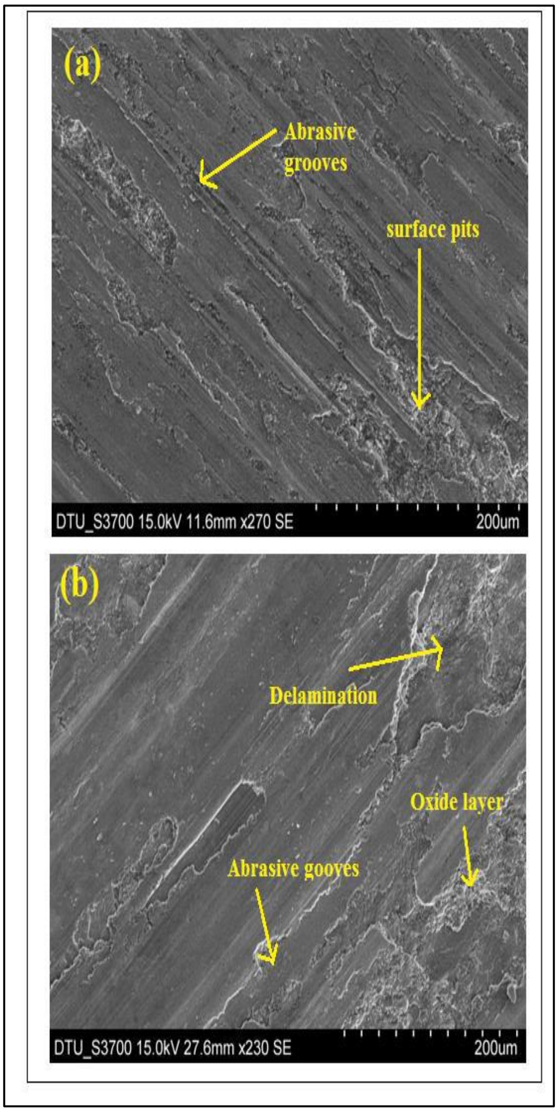


Fig 13. SEM Image of Worn Out Surface of (a) Base Material (b) FSPed Three Pass Specimen



4.0 Conclusions

In this present investigation an attempt has made to study the effects of FSP passes on mechanical and wear properties of the FSPed Al alloy were investigated and the following conclusions are derived.

1. Friction stir processing Technique is an effective Technique to modify the surface layer of the material.
2. By increasing the FSP passes the stir zone of the processed material exhibited finer and homogeneous grain size.

3. The FSPed samples exhibited better hardness and tensile strength than base material.
4. The maximum microhardness and ultimate tensile strength of three pass specimen was achieved in stir zone were 45±22 Hv and 124±2 Mpa respectively. The wear behaviour of the FSPed samples significantly improved.
5. The three pass sample exhibited lower friction coefficient with improved mechanical properties.

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