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# Investigation on Mechanical and Metallurgical Characteristics of Friction Stir Welded Al-Mg-Si Alloy Reinforced with Fly Ash

**Rahul Biradar[1,]* andSachinkumar Patil[2]**

*[1, 2] School of mechanical Engineering, REVA University Bengaluru Karnataka, India – 560064*

***Abstract.***In this research paper, a successful attempt is made by using friction stir welding (FSW) joint of aluminum alloy 6082-T6/fly ash reinforcement. A 6 mm thick base material plate is welded by making a throughout novel cylindrical hole on the weld line. It results that tunnelling defect is formed its due to the larger size of hole diameter of both the sides of the base material plates. Further the welds are characterized by optical microstructure (OM), scanning electron microscopy (SEM) fractography analysis, mechanical and microstructure features. Fractography analysis shows that ductile mode of failure occurs. Obtained the good ultimate tensile strength (UTS) and yield strength (YS) of 464 MPa and 380 MPa respectively

***Keywords:****FSW; AA6082-T6; Fly ash cenosphere; Microhardness; Tensile; and Microstructure properties*.

## 1. Introduction

AA6082-T6 alloy consist of Al-Mg-Si ternary alloy with good corrosion resistance properties. It’s under the category of non-ferrous materials. AA6082-T6 alloy has an excellent weldability and very specific strength. It has other advantages such as high ductility and formability. Various superior weld strength of aluminum alloys such as 2000 and 7000 series, but 6000 series alloys are continuously welded by traditional welding technique like TIG and MIG [1-3]. Compared to traditional welding technique, friction stir welding (FSW) joints are stiffer and stronger in joints. Therefore, FSW is majorly used in aircraft, marine and automobile sectors [4,5]. FSW technique isinvented by The Welding Institute (TWI). Thistechnique mainlyworks on frictional heating at the flat surfaces of twoplates are joined. Further, theFSW tool pin majorly consists of probe and shoulder. Through frictional heat by a tool rotation, the material is being joined rapidly [6-9]. There are four different microstructural regions that are formed by a friction stir welding process, like, nugget zone (NZ), thermo-mechanical affected zone (TMAZ), heat affected zone (HAZ), and base material (BM) [10,11]. During welding NZ region experiences fine and equiaxed grains. Therefore, it exhibits equiaxed dynamically recrystallized grains (DRX) structure. It results from the excess heat and severe plastic distortion from the welding tool is exerted. Due to the exposure of high temperature, the base materials strengthening precipitates are dissolved into the nugget region. [12]. When grains are significantly dissolved into the nugget region, which is close to the TMAZ zone. There is no recrystallization taking place in TMAZ. In HAZ region the temperature experiences lower than the nugget region. Depending on the materials and temperatures, the precipitates are affected to dissolve. As a result, the welds' mechanical features, like microhardness and ultimate tensile strength (UTS), are lower than base material. Specifically, it results the coarser precipitates are refined. [13]. By increasing the traverse speed, increases the weld joint strength. It’s due to decrease the time for precipitate dissolution. The weld joint efficiency is referred to as the strength of the base alloy. It’s reported that by applying water cooling during the welding process may increase the tensile characteristics. Then effectively it reduces the heat [14,15]. In addition, to investigate the microscopic and mechanical characteristics of AA6082-T6/FAC of FSWed joint.

## 2. Materials and experimental methodology

In this research study, 6082-T6 aluminum alloy is utilized as base material, and FAC is used as reinforcement. Chemical composition of aluminum alloy 6082-T6 and fly ash are stated below Table 1&2. Aluminum plate of 100 x 50 x 6 mm dimensions are cut in to EDM machine. FSW tool is used for H13 tool steel material, tool hardness of 48 HRC. A square shape tool is used and FSW set up as depicted in Fig. 1. Both the base material plate is filled with fly ash throughout the hole. A rotation speed of 710 rpm and traverse speed of 25 mm/min are used as process parameter. The fabricated joints are considered from the cross-section perpendicular to the welding direction for microstructural analysis. Transverse tensile test is performed at TUF-C-1000 kN. Vickers microhardness is conducted on Wilson VH1102 hardness tester.Wear resistance is performed at Ducom pin on disc wear set up, optical microscopy is conducted on model Olympus BX53M metallurgical microscope. Scanning electron microscope (SEM) and fracture analysis is carried out by SEM Vega3 LMU Tescan machine. The different grade (1/0, 2/0, 3/0 and 4/0) of emery papers are used to reduce the scratches and then alumina and diamond polishing were carried out by using disc polishing machine. Kellers's etchant is used to reveal the surface morphology and to observe the other constituent phases.The polished samples were etched intoKellers's etchant for 15 s.

**Table1. AA6082-T6 chemical composition**

| Element | Cu | Mg | Si | Fe | Mn | Zn | Ti | Cr | Others | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| Weight % | 0.027 | 0.95 | 1.17 | 0.28 | 0.54 | 0.05 | 0.010 | 0.19 | 0.05 | Balance |

**Table2. Fly ash chemical composition**

| Element | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | $TiO_2$ |
|---|---|---|---|---|---|
| Weight % | 60.46 | 32.91 | 1.68 | 1.26 | 1.14 |

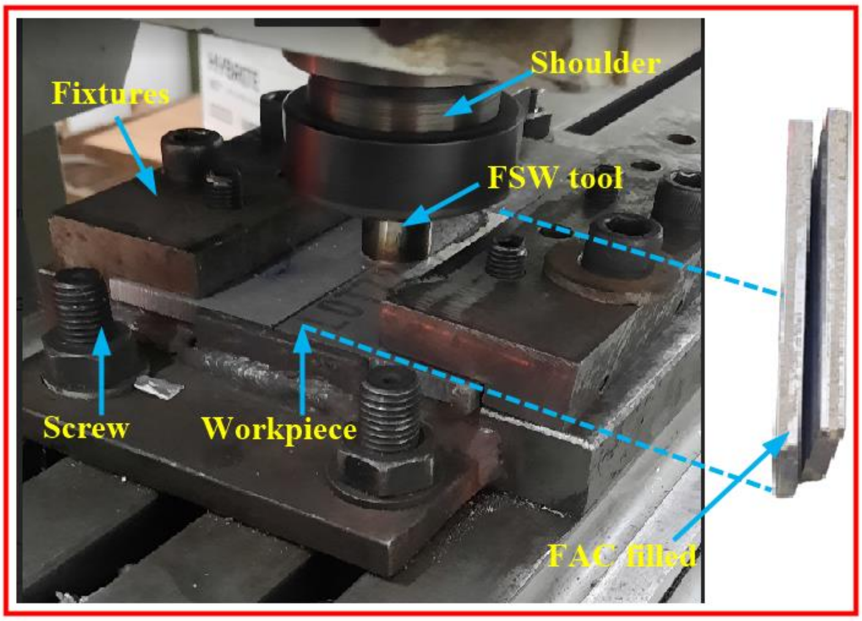


**Fig. 1. FSW tool set up**

### 3. Results and discussion

### 3.1 Microstructure of FSWed joints

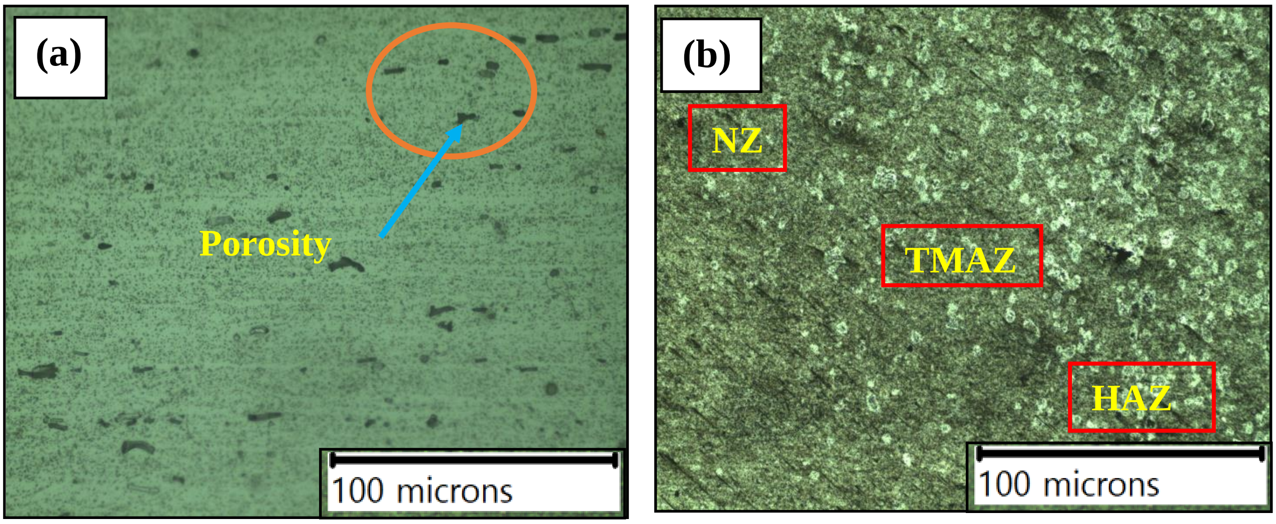


**Fig. 2 Optical microscope of (a) base material AA6082-T6, and (b) FSW of AA6082-T6/fly ash joint.**

The base material of AA6082-T6 as shown in Fig. 2a. Maximum precipitates are diluted in α- Al matrix. It results the material hardening and gradually reduces in the ductility. The FSW joint of AA6082-T6/fly ash, in the nugget region as shown in Fig. 2b.In nugget region the precipitates aresignificantly dissolved.It's due to greater amount of frictional heat and continuous tool stirring. In FSW, noticed the small tunnelling defect, it's due to the inappropriate groove size. The variations in the grain size and their orientation joints have identified. A distinct interface between the nugget region and TMAZ region of the joints can be noticed.

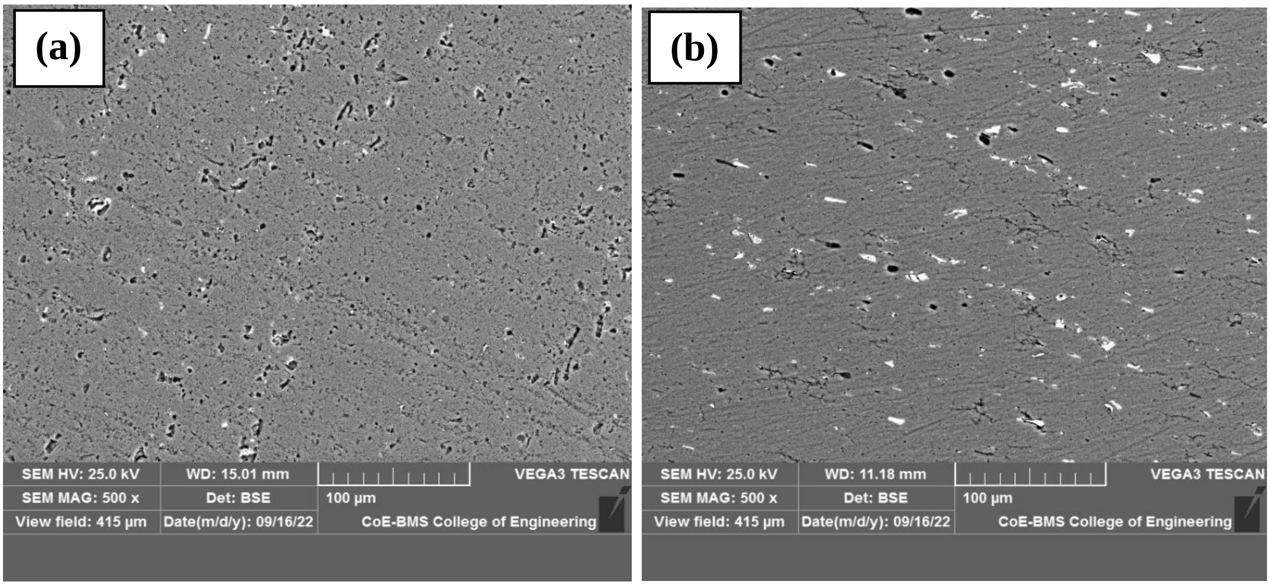


**Fig. 3 SEM image (a) base material AA6082-T6, and (b) FSW joint of AA6082-T6/fly ash in nugget region.**

SEM photomicrograph of base material AA6082-T6 as shown in Fig. 3a. The precipitates are clearly visible in all the regions. The Fig. 3b exhibits FSWed joint of AA6082-T6/ fly ash. The fly ash is significantly dispersed in the nugget region.The effective flow of material is observed continuously in the nugget region. It results from the tool shoulder's forging action, and it forces the alloy in downward motion. Grains are having more stress in advancing side than on the retreating side it's due to fusing of the material with FSW tool pin geometry. In nugget zone grain size is very small in advancing side. It experiences the higher strain among all the FSWed region, and it undergoes DRX mechanism. It's due to plastic deformation by the FSW tool pin. More plastic deformation isoccurring in the nugget region. Therefore, it provides the heterogeneous material mixing, and it significantly affect the weld strength.

### 3.2 Microhardness characteristics

Microhardness of AA6082-T6/fly ash weld joints across the weld of 0.5 mm distance from the weld center. It's a heat treatable aluminum alloy and it depends on the presence of precipitates. Microhardness of material is inversely proportional to hall petch relations. Therefore, fine and equiaxed grains are produced. It's because of significant plastic deformationin the nugget region that refines the grain. Heat is more at nugget region during processing. In nugget region, the material is soft around the tool pin and significant material mixing is observed. Effective heat is provided for appropriate compacting of the base alloy. It prevents the precipitates are dispersed in TMAZ and HAZ region. Hence, dispersion of precipitates are softening the corresponding region. Maximum microhardness of 83 HV is obtained in nugget region as depicted in Fig. 4.

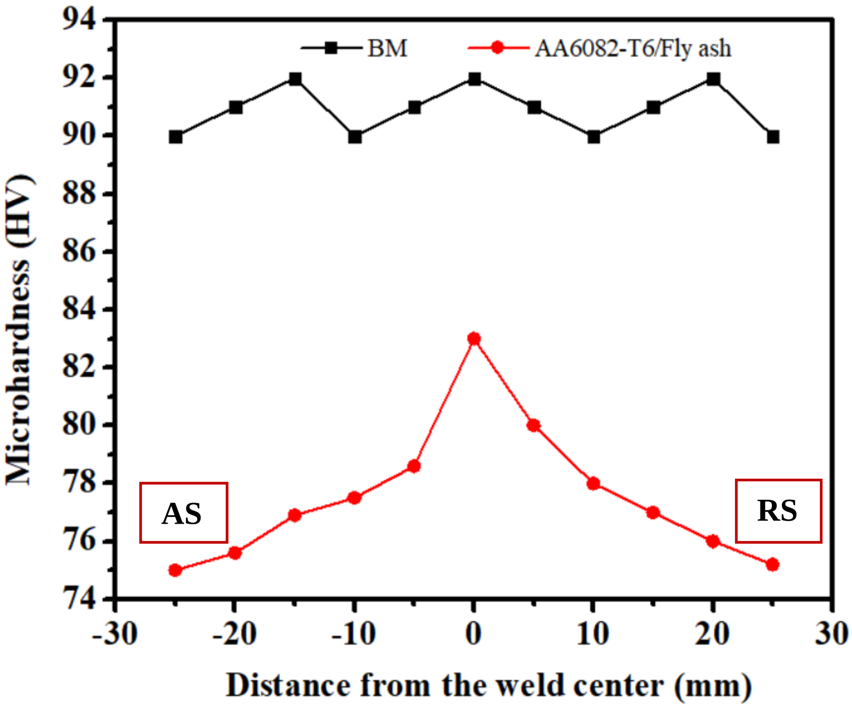


**Fig. 4 Variation of microhardness from the weld center.**

### 3.3 Tensile characteristics

Fig. 5 shows the engineering stress-strain curve for the base material and AA6082-T6/fly ash weld joint. Transverse tensile test specimens are made according to ASTM E08 specifications. However, the specimens are chosen from the center of the weld joint in perpendicular direction to the welding area. A tensile test is performed at room temperature. The base material exhibits UTS of 468 MPa and fly ash joints exhibit 152 MPa respectively. After FSW, the strength is reduced due to metallurgical transactions that occurred in between the welding region. The efficiency of fly ash weld joints is 32% obtained.

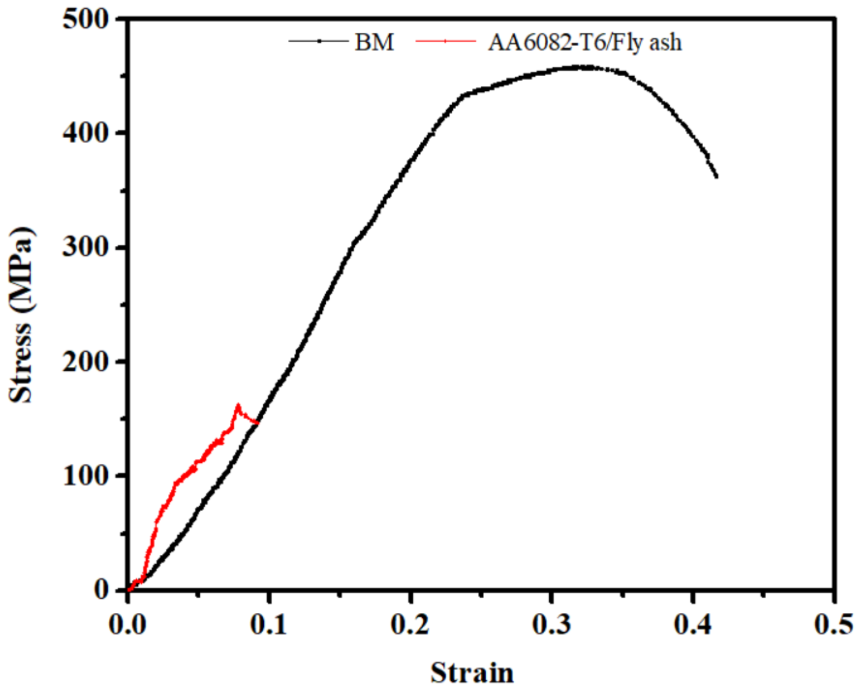


**Fig. 5. Engineering stress strain curve**

### 3.4 Wear resistance

Wear and frictional force of AA6082-T6 along with various reinforcements of fly ash were measured by using circular pin on disc testing set up. The wear and frictional force of the square specimen is having 10 mmdiameter and 30 mmheight are considered for testing. The wear track diameter of 120 mm and wear time of 10 min is taken for the test. The test is performed at a room temperature without any kind of lubrication. Fig. 6a shows the wear and tear of AA6082-T6/ fly ash for a stable speed of 300 rpm for a varing load such as 10, 20 and 30 N respectively.There is a significant decrease in wear rate of AA6082-T6/fly ash and base material from 38 to 25 µm, 51 to 20 µm respectively. It's because of softer material, therefore wear rate is continuously decreses. Fig. 6b shows frictional force versus load. Fig. 6c shows coefficient of friction versus load.

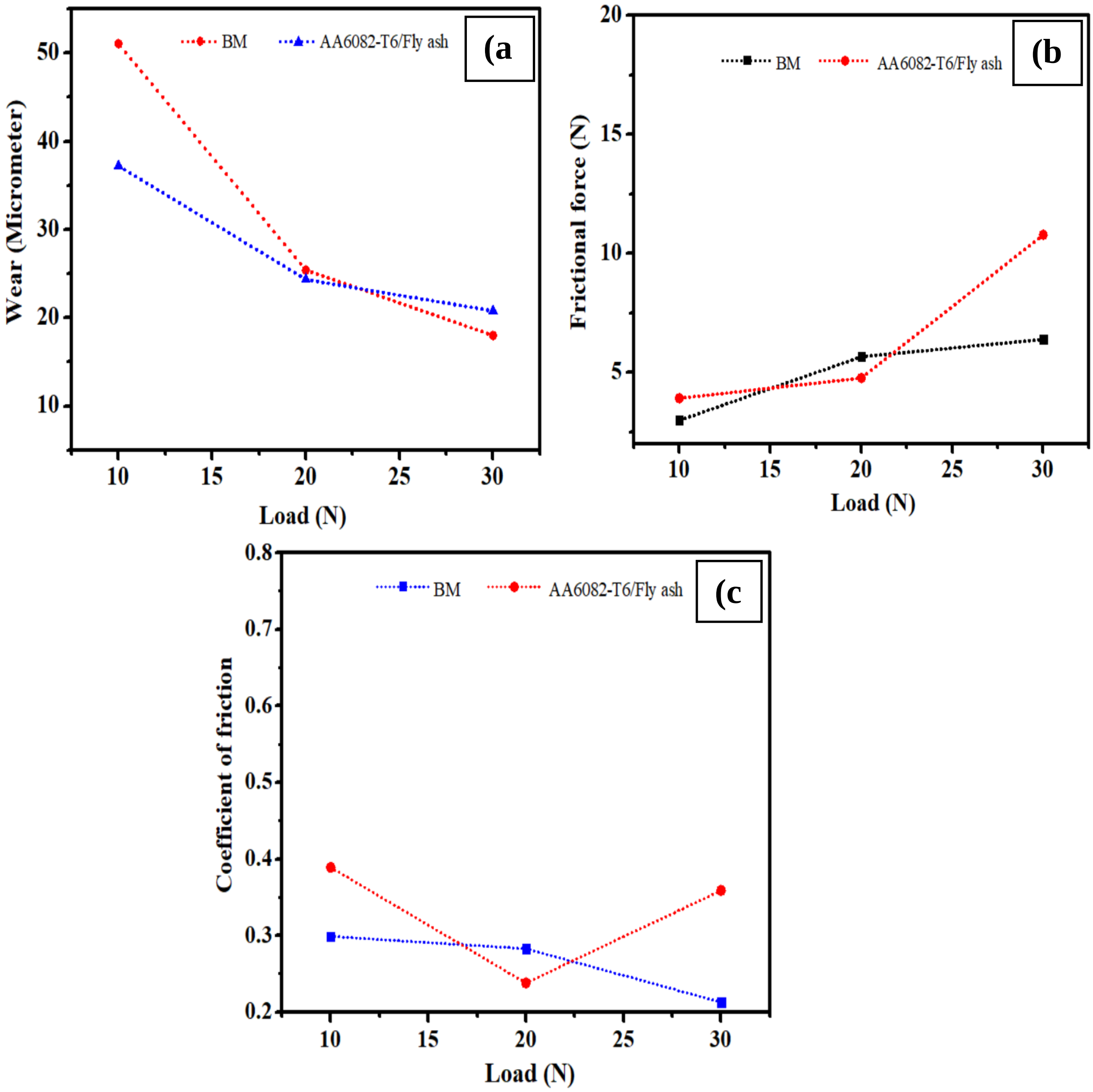


**Fig. 6. For a constant speed of 300 rpm(a) wear rate versus load, (b) frictional force versus load, and (c) coefficient of friction versus load.**

### 3.5 Fracture analysis

Fracture surface of base alloy 6082-T6 aluminum alloyand FSWed joint shown in Fig. 7(a and b). The dimples on the crack surface. It proves that ductile kind of failure occur. The wrinkles are identifiable by cup and cone structure. The dimples are smaller in weld joint than base material. During the AA6082-T6/fly ash weld joint, the grain size consistently decreases. It's because of uniform dispersion of reinforcement particles, significant material mixing, are observed. It's found that fracture of the weld joints are occurred at TMAZ and HAZ region respectively. It's due to coarser grain structure.

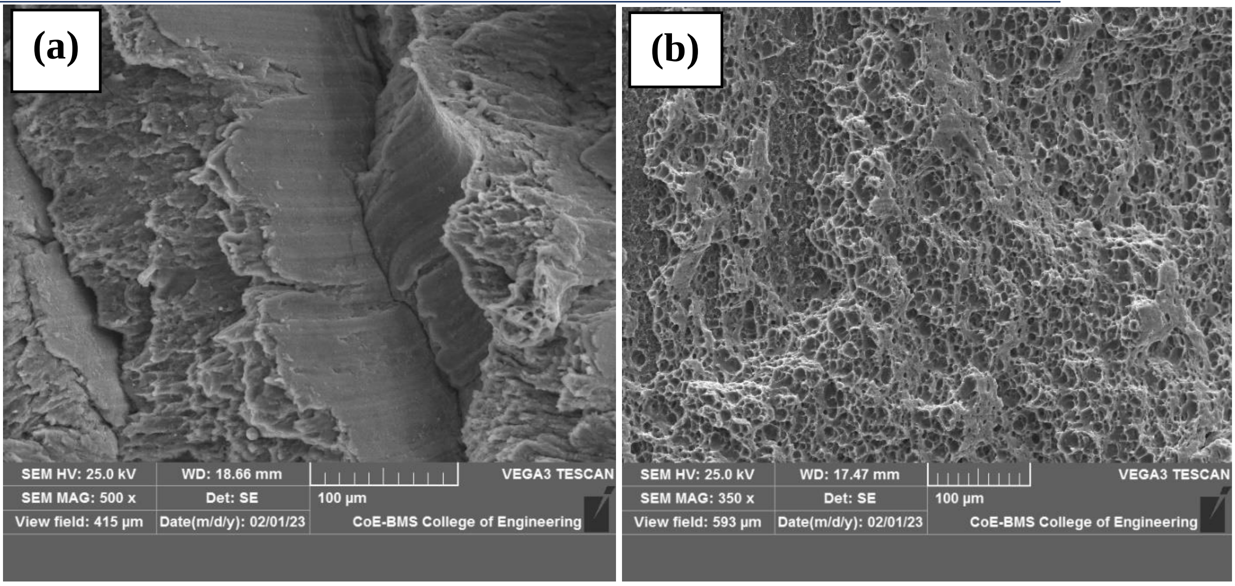


**Fig. 7Fracture analysis of (a) base material AA6082-T6 (b) FSW of AA6082-T6/fly ash.**

## 4. Conclusions

In this research, FSW of AA6082-T6/fly ash weld joints were successfully performed. In further mechanical, and microstructural characterization of the joints are investigated. The following points are the conclusions of research work,

- FSW of AA6082-T6/fly ash, resulted in the most affective grain refinement in the nugget region of the weld joints.
- Obtained the ultimate tensile strength of 464 MPa and yield strength of 380 MPa of the weld joints.
- Maximum all welded joints are fractured in TMAZ and HAZ region. It'sindicating that defect free in nugget region.
- Higher microhardness is obtained at nugget region its due to significant grain refinement.

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