Technical Journal, University of Engineering and Technology (UET) Taxila, Pakistan Vol. 25 No. 1-2020
ISSN:1813-1786 (Print) 2313-7770 (Online)

The Effect of Filler Materials (Al 4047 and Al 5356) on Mechanical Properties of Aluminum Alloys (AA6061-O and Heat-Treated AA7075-T6) in Tungsten Inert Gas (TIG) Dissimilar Metal Welding

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Abstract- The purpose of the current work is to investigate the combined effect of thickness and the mechanical properties of dissimilar aluminum alloys annealed AA6061-O and heat-treated AA7075-T6 on the tensile strength of the joint. The joint is made by Tungsten Inert Gas (TIG) welding using suitable fillers Al 4047 and Al 5356. Different samples i.e. Welded Over-Nugget Sample (WOS), Welded Ground Sample (WGS) and Base Material (BM) were investigated under tensile loading. In order to avoid failure, the thickness of weak strength AA6061-O must be greater as compared to the thickness of AA7075 comprising high strength in order to balance stresses on both sides. In addition to, the effect of grounded and as-welded bead on the joint properties of the weld is explained in this research. The joint is also characterized by micro-structural attributes using electron microscopy and the grain size is observed as well. .

Keywords- Aluminum Alloys, TIG welding, Tensile loading, Microstructural attributes.

I. Introduction

Aerospace technology is dependent widely on the Strength-to-Density ratio of materials and aluminum Alloys (Usually Al-7075 T6). It plays a vital role in accomplishing these requirements. Al-7075 T6 is often utilized in transport applications, including marine, aviation and automotive, numerous automobiles due to its high tensile strength, superior fatigue strength, average machine-ability, significantly better corrosion resistance than the 2000 alloys. The 7075 Al-alloys are employed in brake pistons, air deflector parts, transport and marine, aerospace because of their great strength-to-density ratio, rock climbing equipment, airframes, mold tool manufacturing owing to these properties [1]. The joining of Al-7075 is of large concern and a lot of work has been done and research is going on a daily basis to attain maximum joint strength of Al-7075 with any other Alloy.

As compared to other alloys of aluminum, the 6061 series Al-alloys have been examined broadly due to their attributes like medium strength, better weld-ability, formability, good corrosion resistance and reduced cost of Aluminum alloy 6061 is one of the most utilized of the 6000 series aluminum alloys [2]. It is a versatile heat treatable alloy with intermediate to advanced strength capabilities [3]. The 6061 Aluminum alloys are extensively used in the fabrication of several Aircraft and aerospace components, transport and bicycle frames, marine fittings, camera lenses, electrical fittings drive shafts, and connectors, brake components, valves, pylons, couplings, and towers and tubes, boiler making and motorboats and Rivets [4].

While TIG welding is broadly used in the aerospace industry, the process is extensively used in the bulk of many other areas. There are several industries that employ TIG welding for thin workpieces, exclusively for non-ferrous metals. This welding is frequently employed in the fabrication of space vehicles, and for welding small-diameter, thin-walled tubing of bicycle components [5]. A circular welded joint of ring rigid cylindrical sandwich shells of the 7A05-T6/5A06-O aluminum dissimilar alloy has been used for Tungsten Inert Gas Welding (TIG) and single and double-sided welding form [6]. TIG welding is becoming increasingly critical for transportation industries such as vehicles ranging from cars and trucks to aircraft which are made lighter to minify fuel consumption and save on ever-higher costs of fuel [7].

Several studies are accessible and forthcoming concerning about the cognition used in joining Al alloy to other Al alloy, and a few of them are Friction Stir Welding (FSW) [8], Metal Inert Gas Welding (MIG) [9], Resistance Spot Welding (RSW), Tungsten Inert Gas welding (TIG) [10].

Dissimilar aluminum alloys of grades 2024 and 7075 were joined using FSW and their mechanical behavior

and microstructural attributes were studied [11]. Similar 6061-T6/7075-T651 and dissimilar RSW joints were treated under the aging process and examined the change in the properties[8]. Good match of mechanical properties and defect-free joints achieved of the dissimilar aluminum alloys .i.e. Al 6181 and Al 5754 alloys of different thickness using FSW [12]. The influences of welding parameters and tool geometry on the mechanical properties of the joint were taken into account[13].
Inspected the mechanical and micro-structural properties of Al tailored blank having different thickness combinations and observed a decrement in the properties with augmentation of thickness ratios [14]. The Mechanical properties of dissimilar thickness aluminum alloy weld by single/double pass FSW were investigated and reached to a conclusion that specimens get botched at the thinner side of the material instead of the welded region [15]. The endurance limit of AA2219-T87 in TIG welding was assessed using ABAQUS software [16]. Brinell Hardness Testing of Al7075 T6 was done in Abaqus [17]. Tungsten Inert Gas (TIG) welded Compact Tension (CT) specimens of Aluminum alloy temper AA2219-T87 were experimentally verified and numerically simulated [18]. Mechanical properties of dissimilar aluminum alloys (AA2024 and AA6063) using gas TIG welding was studied by S.Vijay [19]. Tensile tests were performed by Habib ur Rahman to investigate the deformation behavior of AA6082 and AA8011 using TIG welding[20].
Only a little work has been carried out on TIG welding and the combined effects of thickness and tensile properties of dissimilar joints on the failure of the specimens are not yet investigated.
In this research, it is investigated that the mechanical properties of the TIG welded specimens (AA6061 & AA7075-T6) depends upon the thickness and the tensile strength of materials. Welding is done using filler metals of aluminum alloys AA4047 and AA5356 with the joining line perpendicular to the rolling direction,
Tensile results reveal that if equal tensile forces are applied on dissimilar joints then the thickness of the plates has to be varied in order to avoid fracture from the side other than joints. However, a large difference in thickness of dissimilar joints is not possible. So suitable materials have to be selected in order to enhance the properties of the joints or heat treatment must be done. In addition to this, fine and controlled conditions of welding must be achieved. The effects of the grounded and as-welded specimens on the tensile behavior of specimen are reported and their microstructure is examined under the scanning electron microscope (SEM).

II. EXPERIMENTATION

A. Materials

In the study, annealed AA6061-O and heat-treated AA7075-T6 aluminum alloys are used. Through the vertical milling machine, AA7075 is cut to the final dimensions of 305×152×4mm and AA6061 is cut to the final dimensions of 305×152×5mm using a CNC machine.
The chemical composition of Al in AA6061 and AA7075 alloys is 95.85 % and 87.1% respectively and compositions of other elements in these materials are illustrated in table 2.

Table 1 Composition of AA6061-O and AA7075-T6 by wt%

	Zn	Mg	Cu	Fe	Si	Mn	Cr
AA6061	5.5	2.4	1.7	0.5	0.4	0.3	0.2
AA7075	0.1	0.9	0.2	0.2	0.5	0.7	0.1

The mechanical and thermal properties are given below in Table 2 Mechanical properties of plates

Materials	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)
AA7075-T6	575	462	6
AA6061-O	175	150	7

B. Welding conditions and joint preparation:

Specimens of the plates are TIG welded. Forthcoming the welding arc, an advanced frequency generator with the Power AC source of 0-130A provides an electric spark i.e. the conductive pathway for the welding current. The spark passes through the shielding gas i.e. argon (99% pure) and it permits an arc to initiate. The electrode of pure tungsten and the workpiece are totally isolated, about 1.5–3 mm apart. As soon as the arc is stricken, the torch nozzle is located in the form of the small circle for creating a pool in the flat vertical configuration of the butt joint. Flame temperature is kept up to 70-130°C.
While keeping a continuant distance between the electrode and workpiece, the torch is repositioned slenderly and is slanted about 10–15 degrees backward from the vertical.
To the front end of the weld pool, filler metals AA4047 and AA5356 are added manually as per requirement. Figure 1 shows the welded plates having an over-nugget area between them.

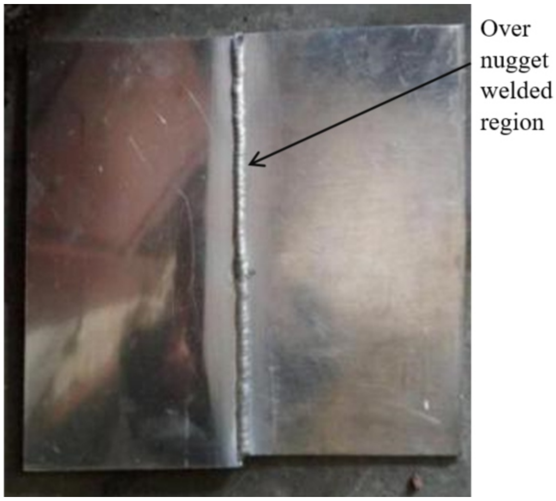

Figure 1 Over-Nugget Welded Plates

C. Specimen preparation

Tensile test samples of standard ASTM E8M as shown in figure 2. They are made by turret milling machine via end mill cutter. Three kinds of samples according to a given standard are made i.e. base metal, over-nugget and grounded.

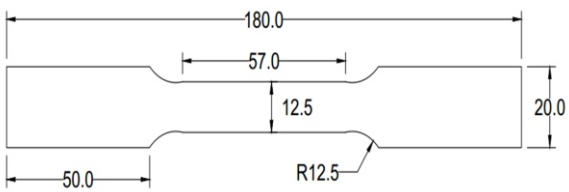

Figure 2 ASTM-E8M tensile test sample

The base metal is shown in figure 3.

Figure 3 Base Metal Specimen

Two types of samples similar to the base metal specimen are made after welding. One, over-nugget sample and the other grounded one. Figure 4 illustrate the grounded sample which is flattened from the overhead nugget weld part area to plane position corresponding to the plate's thickness using a grinder wheel. Then the samples are finished using the emery paper of grade 400.

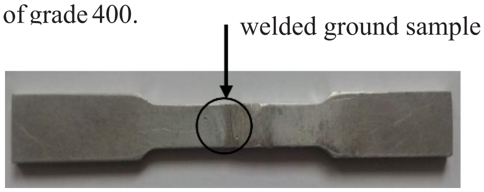

Figure 4 Grounded Sample

D. Tensile test

All the Samples i.e. over-weld nugget, grounded and base metal samples are tested under the Mechanical Testing Machine (MTS) 810 machine with a force of 5kN. The tensile behavior of dissimilar joints is studied; stresses on each of the sides of the joint are evaluated on the basis of their different cross-sectional areas and are compared with the ultimate tensile strengths of the base metals. The thickness is varied in order to avoid failure, and their stress-strain relationships are concluded. All the samples are then analyzed on the basis of their yield and ultimate tensile strength and their effect on the failure of the specimens is examined.

The figure 3 shows the failure of specimens. All the specimens are fractured from the 6061 side irrespective of the bead size.

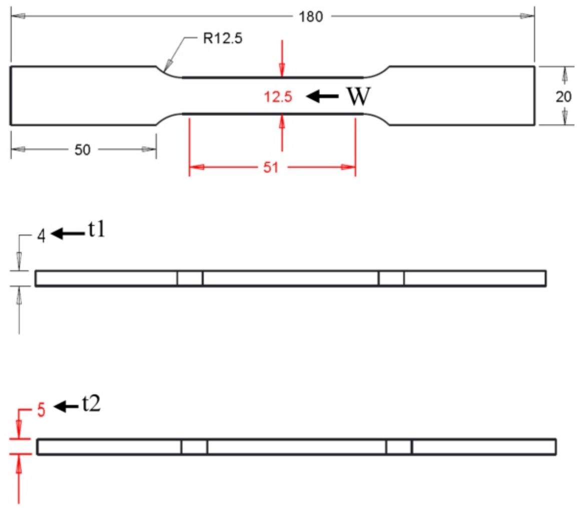

Figure 5 Dimensions of Tensile Specimen

This is because

Area of joint from 7075 side

$$A_1 = w_1 \times t_1 \quad (1)$$

$$A_1 = 12.5mm \times 4mm$$

$$A_1 = 50\ mm^2 \quad (2)$$

Area of joint from 6061 side

$$A_2 = w_2 \times t_2 \quad (3)$$

$$A_2 = 12.5mm \times 5mm$$

$$A_2 = 62.5\ mm^2 \quad (4)$$

Stress acting on the cross-section of 7075 side of joint

$$S_1 = F_1 / A_1 \quad (5)$$

$$S_1 = 5kN / 50mm^2$$

$$S_1 = 100MPa \quad (6)$$

Stress acting on the cross-section of 6061 side of joint

$$S_2 = F_2 / A_2 \quad (7)$$

$$S_2 = 5kN / 62.5mm^2$$

$$S_2 = 80\ MPa \quad (8)$$

In order to equalize the stresses on both the sides, comparable to their strengths, the thickness of 6061 side of the joint must be increased in proportion to the combined thickness and strength of 7075 side as follows:
If AA7075-T6 section having strength 400 MPa is acted upon by 100 MPa stress, than AA6061-O section having strength 105 MPa must be acted upon by

$$= (100/400) \times 105 \quad (9)$$

$$= 26.25\ MPa\ stress \quad (10)$$

Or more than this stress in order to avoid failure. Thickness proportional to this stress must be

$$t_2^* = F_2 / (S_2 \times w_2) \quad (11)$$

$$t_2^* = 5kN / (26.25MPa \times 12.5mm)$$

$$t_2^* = 15.23mm \quad (12)$$

E. Microstructural analysis

TESCAN SEM VEGA 3 is used for this experiment that produces images of a sample by scanning it with a focused beam of electrons having a resolution of 2.5 nm at 30 kV and it is utilized to study the surfaces of materials after the failure.

III. RESULTS DISCUSSIONS

A. Tensile strength analysis

Comparing these stresses with the ultimate tensile strengths of the dissimilar materials, it can be seen that as compared to AA7075-T6 side of the joint, very large stress is acting on AA6061-O side, therefore it fails abruptly. Though the stress on AA6061-O is less than its Ultimate Tensile Strength (UTS), but it still fractures the specimen from this region due to improper welding, less precise controlled conditions and improper mixing of filler metals. Both the over-nugget and grounded samples are fractured from AA6061 sides as shown in figure 5(a) and 5(b) respectively.
The thickness of the AA6061-O side of the joint must be 15.23mm or more than this to avoid failure from this side.

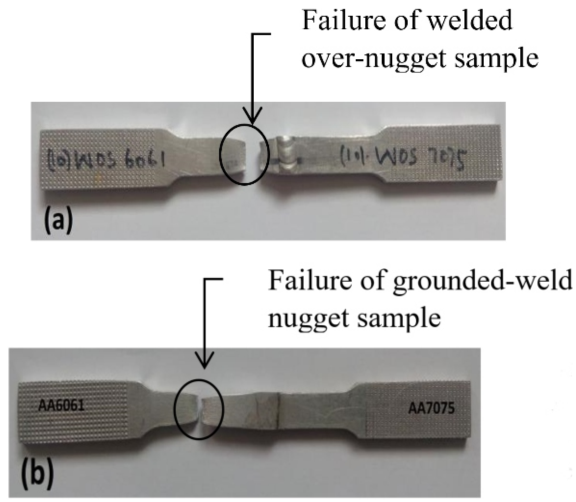

Figure 6 Failure of Samples (a); over-nugget specimen failure (b); grounded specimen failure

However, welding of the dissimilar joints having large differences in the thickness is not possible and it takes account of intense controlled conditions to weld through. Alternatively, the strength of AA6061-O can be enhanced by heat treatment and the aging process up to the tempers T6 or T651.
By doing this, the UTS of AA6061 arise up-to 385-400 MPa which is quite comparable with the strength of AA-7075. This joint will be strong enough to effectuate the requirements of aerospace, automotive and other industrial components. Or a new suitable metal conforming to the withstand the applied stresses having adjacent Ultimate Tensile Strength (UTS) with AA7075-T6 alloy must be employed to increment the mechanical strengths of the joint and may appreciably be used in aerospace.
Stress-strain results of different grounded, as welded and base metals specimens are illustrated in table 4.

Table 1: Tensile test results of different specimens

Sample	Stress (MPa) against 0.03 strain	Stress (MPa) against 0.06 strain
AA (7075)	348	377
AA (6061)	145	141
welded over-nug get sample	105	106
welded ground sample	96	100

It can be observed from the readings that base metal AA7075-T6 shows the highest stress among all the specimens and base metal AA6061-O undergoes a reduction in the stress when the strain is further increased beyond its ultimate tensile strength. This shows that failure will occur early from this sidelong of the sample.

Different samples, as welded and grounded samples do not show a significant difference in the tensile strengths of the joint. But the tensile strength of as-welded specimens is still more than the grounded one, because of greater weld thickness.

Figure 6 illustrate the strain curve and the comparison of different specimens. A bar graph of different tensile samples can be shown in figure 7.

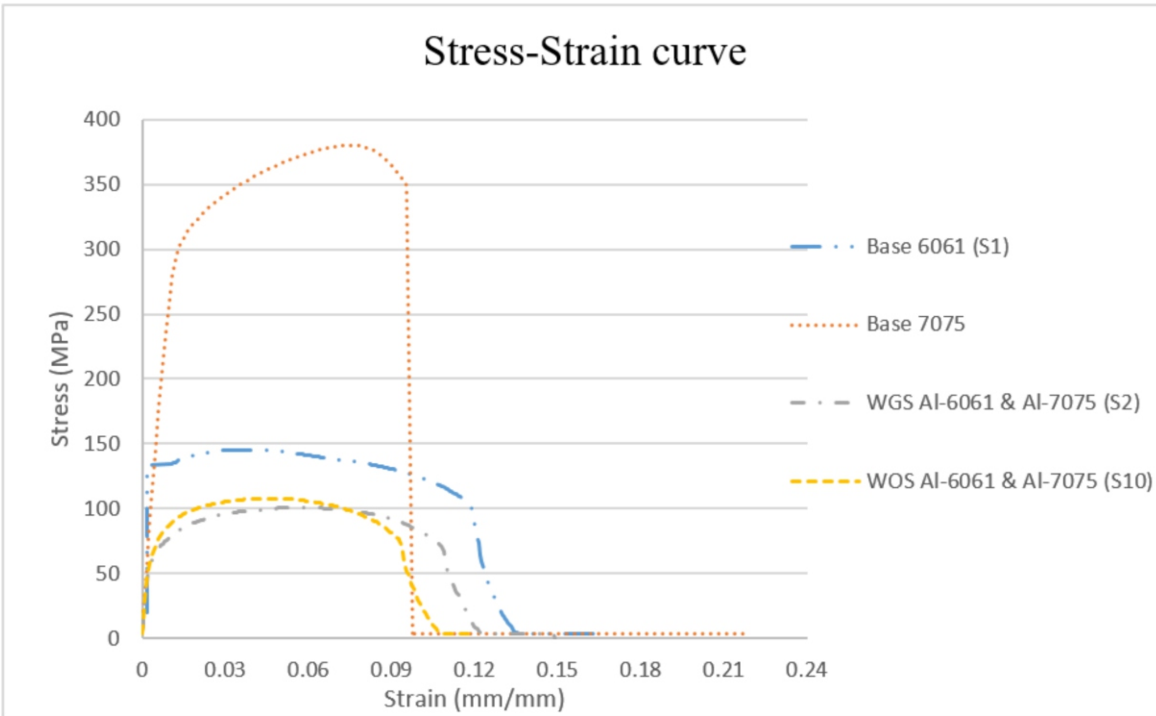

Figure 7 Stress-Strain Curve: Comparison Between Different Samples

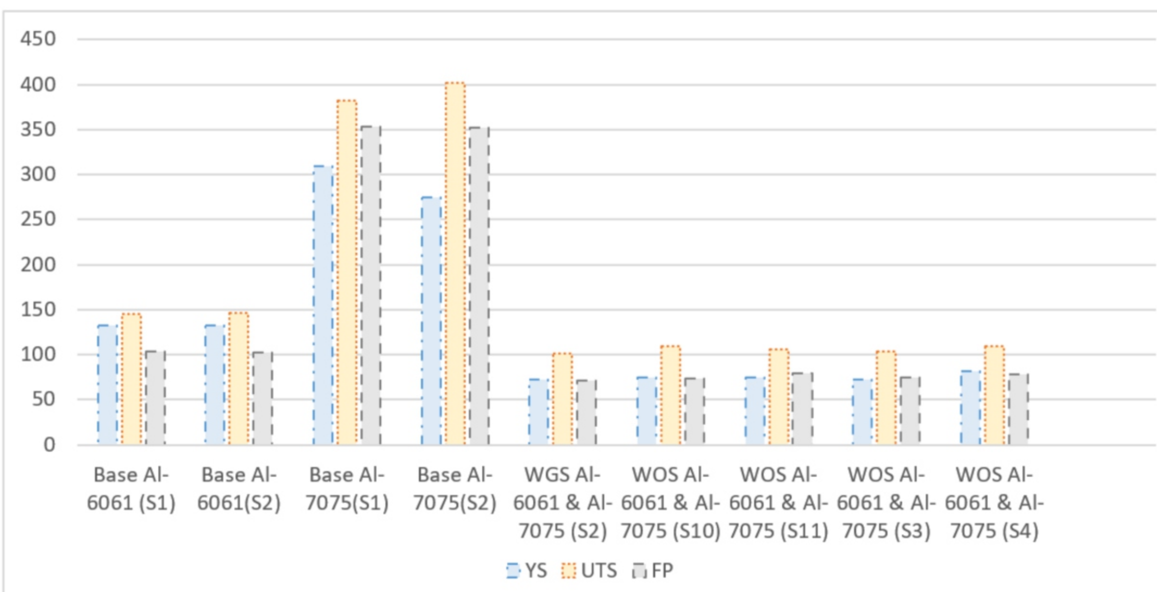

Figure 8 Bar graph of tensile samples

B. SEM analysis

The fractured portions for both welded over-nugget sample and welded ground sample, shown in figure 7, are observed under SEM.

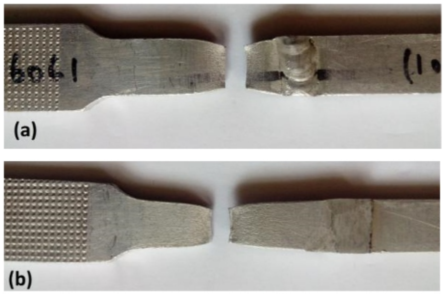

Figure 9 Fractured Portions (a): Welded over-nugget (b): Welded ground sample

Scanning Electron Microscope (SEM) analysis of fractured portions shows that both base metals are ductile as cup and cone structures are observed as in figure 7.

Scanning the welded samples, the nugget zone is ascertained to have correspondingly precise equiaxed grains. The grains in the nugget zone are quite minute than those in the other regions. The average grain size in the four zones follows the order of *Base metal > Heat affected zone > welded zone > nugget zone*

In the welded zone, side by side to the nugget zone, the strain and temperature are fewer than in the nugget zone and the effect of welding on the micro-structure is observed to be correspondingly less.

Unlike the nugget zone, the micro-structure is recognizably that of the parent material, although it is significantly malformed and rotated. The grain size of the Heat-Affected Zone (HAZ) is just like that of the base metal.

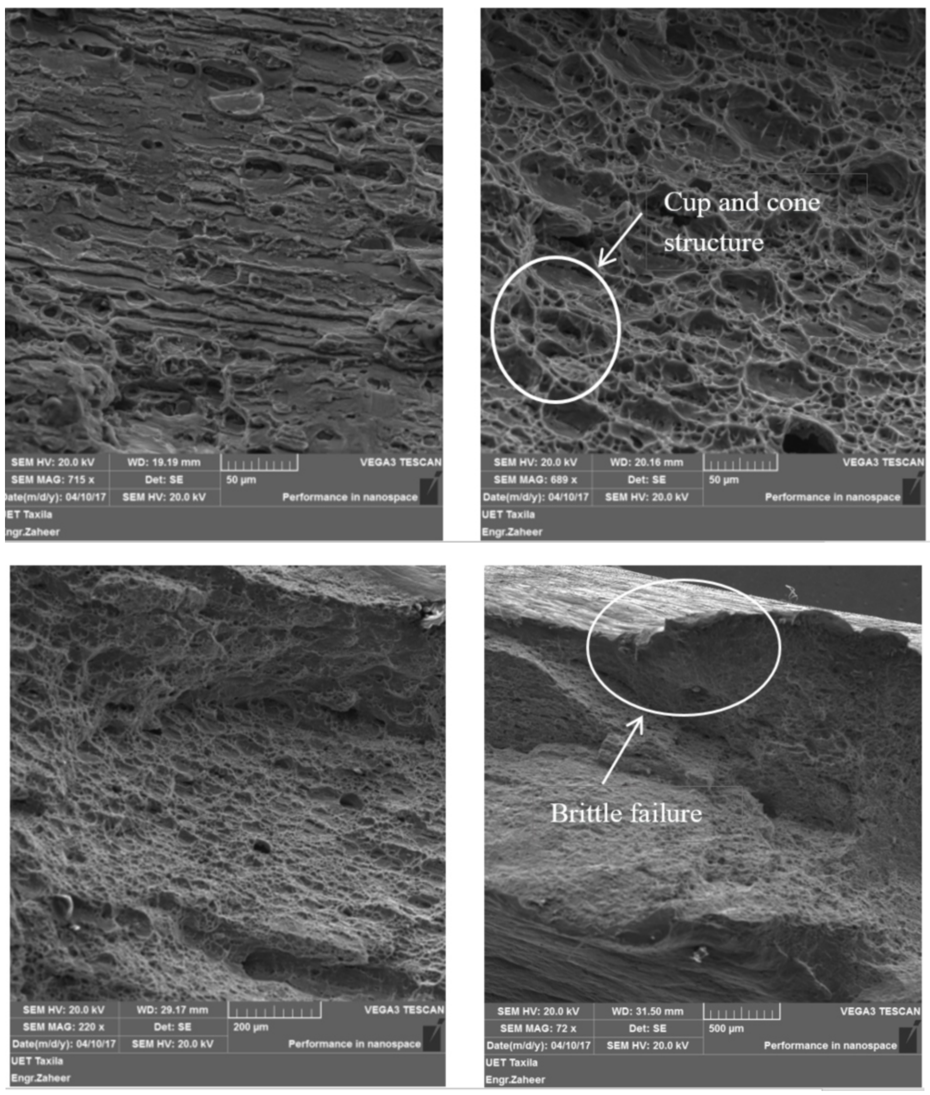

Figure 10 Cup and Cone Structures Using SEM

IV. Conclusions

- Different welded samples are tensile loaded using MTS and none of them failed at the welded portion because the weld nugget is thicker than each of the base plates which make the weld stronger.
- However they all are fractured from AA6061-O side of the sample because the tensile strength of Al-6061 is 175 MPA which is extremely lower than that of the welded portion and AA7075-T6 having 575MPA strength.
- In order to avoid failure, the thickness of AA6061-O must be increased to 15.23mm compared to the 4mm thickness of AA7075 in order to equalize stresses on both sides.
- However, this difference in thickness of dissimilar joints is quite impossible to weld through so heat treatment and aging must be accomplished to outgrow AA6061-O strength contiguous to AA7075 strength. Also precise welding technique, controlled conditions and suitable filler metals in their desired quantities need to be employed for sufficient strength.
- Different samples i.e. as welded and grounded samples do not show a significant difference in the tensile strengths of the joint i.e. 105MPA and 96MPa respectively, but by precise, controlled conditions and accurate grinding a difference in the strengths can be observed.
- Moreover, the SEM analysis of fractured portions shows that both base metals are ductile as cup and cone structures are observed.
- In the thermo-mechanically affected region, weld failure occurred during the tensile test.
- Scanning the welded samples, the nugget zone is observed to consist of fine equiaxed grains. Grains are so much smaller in the nugget area than in other areas.
- HAZ is similar in its grain size to the base metal.
- Also, the average grain size in the four zones follows the order of Base metal > Heat affected zone > welded zone > nugget zone

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