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Microstructure and Mechanical Property Changes during TIG Welding of 31000-H2 (IS-737) Aluminium Alloy

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Abstract: Welding, as one of the most effective joining methods for metals, has been extensively applied in engineering usage since a long time. The determination of microstructure and mechanical properties of welded structures is thus of paramount importance to implement a damage tolerant approach to structural life extension. In this study, structural and mechanical properties evaluation of 31000-H2 (IS-737) Aluminium Alloy after single pass Tungsten Inert Gas (TIG) welding were investigated to reveal the yield strength, ultimate strength, percentage elongation, impact strength and hardness of welded joints. The TIG Welding results of aluminium alloys 31000-H2 for 5 mm plate thickness using different filler materials during welding are presented in this paper. Effect of welding was studied on four different zones like base Metal, weld metal heat affected zone and combined zone of base Metal and heat affected zone.

Welded specimens were investigated using scanning electron microscopy (SEM), UTM and Rockwell micro-hardness tester. Scanning electron microscopy was used to characterize transition sites of welded zone, HAZ, base metal and combined zone of base Metal and heat affected zone. Tensile test was conducted to characterize weld strength by determining ultimate tensile strength and micro-hardness test was conducted to characterize the homogeneity of welding in terms of mechanical properties.

Key words: aluminium alloys, welding, hardness, tensile strength, yield strength, ultimate strength, impact strength and percentage elongation.

I. INTRODUCTION

Welding of Aluminium alloys is a major used application in the transportation, aviation, electronics and construction industry. The welding aluminium alloys requires a good understanding of the microstructures generated by the rapid temperature rise in the four different zones like base metal zone, weld metal zone, heat affected zone and combined zone of base metal and heat-affected zone. The major problem during welding of aluminium alloys includes the reduction of strength like grain growth, hardness reduction, and hot cracking. Many changes at microstructure level took place in the entire work piece during and immediately after welding [1].

During the welding, as the heat source or electric arc interacts with the material, the severity of thermal excursions experienced by the material varies from region to region, resulting in three distinct regions in the weldments. These are the fusion zone also known as the weld metal (W), the heat affected zone (HAZ), parent metal (PM) and combined zone of parent metal and heat affected zone (W+H). The W experiences melting and solidification, and its microstructural characteristics with rest of the zones are the focus of this article [2].

Various mechanical properties like yield strength, ultimate strength, impact strength, hardness and percentage elongation are considered for study to analyze the effect of TIG welding in all the four zones. Two filler materials are also used to see the effect on these mechanical properties, out of these fillers one is as the same composition as parent metal and other one is of different composition. This article presents a comparative study of the mechanical and microstructural properties of the welded 31000-H2 (IS-737) Aluminium Alloy with same filler material and different filler material.

Rolled plates of 5 mm thickness have been used as the base material for preparing single pass butt welded joints [3]. The filler metal used for joining the plates is IS-737 grade aluminium alloy as same filler and IS- 733 grade aluminium alloy is used as different filler. In the present work, tensile properties, micro hardness, impact strength microstructure morphology of the TIG welding joints have been evaluated, and the results are compared.

II. EXPERIMENTAL PROCEDURE

In the present study 31000-H2 (IS-737) Aluminium Alloy is used as the parent metal or base metal. Chemical compositions of the base metal is shown in Table 1 [4]. Two kinds of filler metals of Al-Mg-Si alloy were selected to investigate the influence of welding procedure on microstructure and mechanical properties of coarse-grained base metal and observe the cracking tendency of four different zones like parent Metal, weld metal, heat affected zone and combined zone of parent Metal and heat affected zone.

Therefore, 1.6 mm diameter filler wires were used. Welding was carried out by using a semi-automatic TIG welding machine (CEBORA 360, India). The following parameters were maintained during the welding:

(1) Electrode material: 2% thoriated tungsten electrode.
(2) Electrode size: 3.5 mm diameter.
(3) Shielding gas: a mixture of 98% argon and 2% oxygen.
(4) Arc length: 2.5 mm.
(5) Arc travel speed: 6.1 cm/min.
(6) Shielding gas flow rate: 12 L/min.

TABLE: 1- Chemical compositions of the base metal (wt. %)

Work Material	Mat. Grade	Cu	Mg	Si	Fe	Mn	Zn	Cr	Al	Condition
Parent Metal	31000	0.1	0.1	0.6	0.7	0.8-1.5	0.2	0.2	Remaining	H_2
Same Filler	IS-737	0.1	0.1	0.6	0.7	0.8-1.5	0.2	0.2	Remaining	H_2
Different Filler	IS-733	0.07	0.04	5.23	0.16	0.01	-	-	Remaining	
H2 = Strain hardened and then partially annealed.										

After welding the weldments were cut for the preparation of samples to study the microstructure, hardness and tensile strength. For microstructure, the specimens were collected from middle portion of the weldments to ensure a true representation of weld characteristics. The specimens were cut into suitable size [4]. The microstructure was studied using SEM for the purpose.

The mechanical properties of the weldments were studied by testing hardness and tensile strength (MPa) of the weld metal. The specimens for tensile strength were prepared after machining the top and root enforcement of the weld. The specimens were machined to size conforming to the relevant ASTM E8 (ISO 6892-1) standards. The tensile test specimens of both the weldments and base material conforming to ISO 6892-1 were obtained by machining.

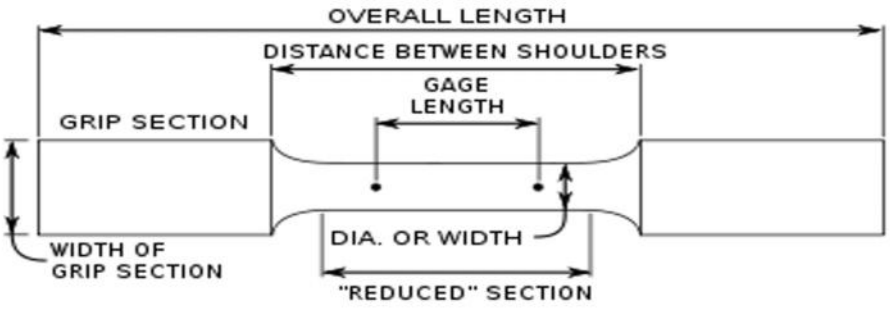

Fig.: 1 Schematic diagram of tensile specimen according to ASTM E8 obtained by machining

The tensile testing was carried out on a hydraulically operated tensile testing machine, having a maximum capacity of 100 KN under static load condition. Load was uni-axially applied on the specimen at two crosshead speeds of 1 mm/min and 0.1 mm/min. The ultimate tensile strength was determined from the ratio of maximum load and original cross-sectional area of the specimen.

Rockwell hardness measurement was carried out by using ball indenter on the metallographically polished section of the weld joint along the central line for the hardness of weld zone, at major load of 100 Kgf and minor load of 10 Kgf. Indentations were taken at five different locations at center of weld zone, heat affected zone and middle of these two. Hardness of the parent metal was also evaluated to find any variation in the property.

III. RESULTS AND DISCUSSION

A. Yield Strength

The transverse tensile properties such as yield strength, ultimate strength and percentage of elongation of 31000-H2 (IS-737) aluminium alloy joints were evaluated. In each condition, three specimens were tested, and the average of the three results for yield strength is presented in Fig. 1 and Fig. 2 for the samples welded with similar filler and different filler material.

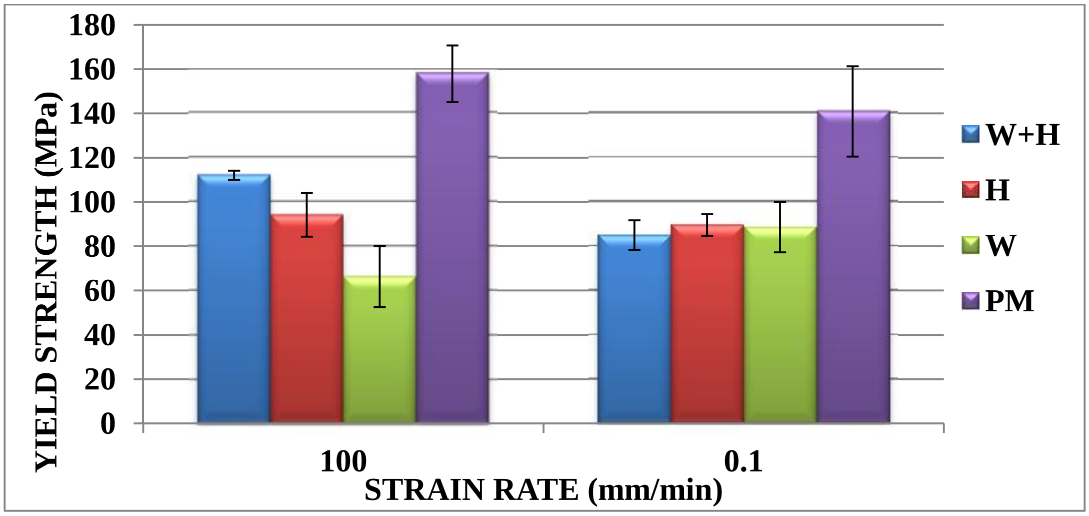

Fig. 1: Yield Strength of different zones for similar filler at different crosshead Speed

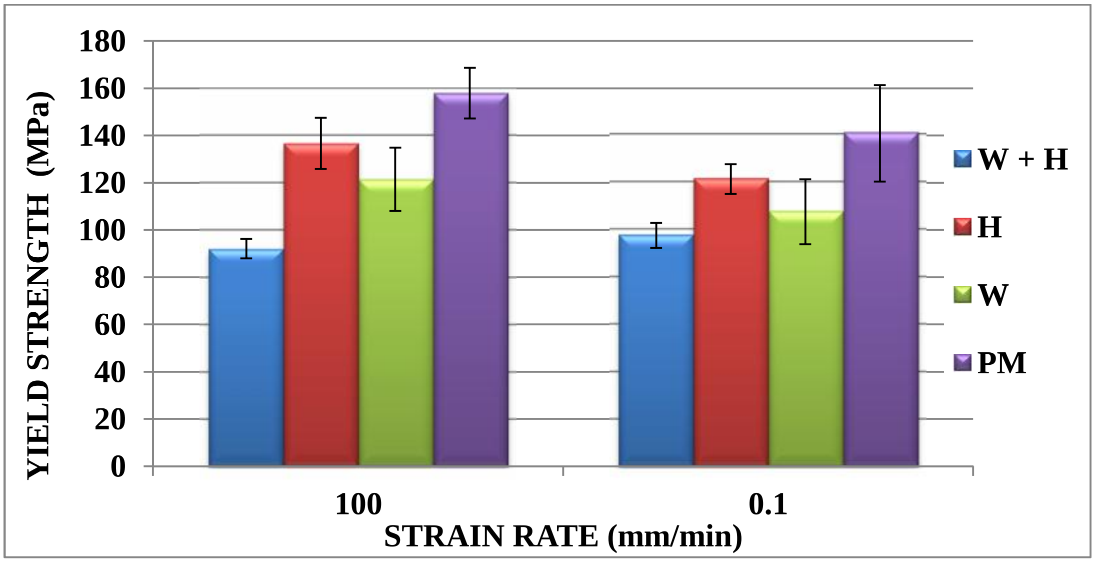

Fig. 2: Yield Strength of different zones for different filler at different crosshead Speed

On overall analysis the average values of yield strength for both crosshead speeds for all the zones, is grater in samples welded with different filler. The maximum values for yield strength is exhibits by the heat affected zone at crosshead speed 100 mm/min. However it is almost 7% less than the yield strength of parent material. For all the conditions the yield strength is more for crosshead speed 100 mm/min as compare to 0.1 mm/min. This trend is common for both similar and different filler materials. As compare to the parent material the yield strength is decreasing for all the zones.

Yield strength or yield point of a material is defined as the stress at which a material begins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. When designing a component since it generally represents an upper limit to the load that can be applied. Here we observe that the yield strength in all the conditions is decreasing, so it means the overall upper limit for the load that can be applied is reduced for both similar and different filler materials as compare to the parent material. It means the elastic deformation zone for similar filler and different filler welded samples is reduced while the yield strength is also decreased.

In GTAW, the filler rod is melted in the plasma region of the arc (midway between positive and negative polarity) and not in the positive polarity as in the case of GMAW. Due to this reason, heat input of GTAW is lower than for GMAW. Lower heat input and lower current density reduces the arc temperature and arc forces in GTAW [5]. Lower arc temperature reduces the peak temperature of the molten weld pool causing fast cooling. This fast cooling rate, in turn, causes relatively narrower dendritic spacing in the fusion zone [6]. These microstructures generally offer improved resistance to indentation and deformation and this may be one of the reasons for lower yield strength because due to the fast cooling there will be some strain hardening which reduce ductility, that’s why the yield strength is lower in all the zones as compared to the parent material.

B. Ultimate Strength

Ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. The effect of different zones on ultimate strength of material is shown in figure 3 and 4.

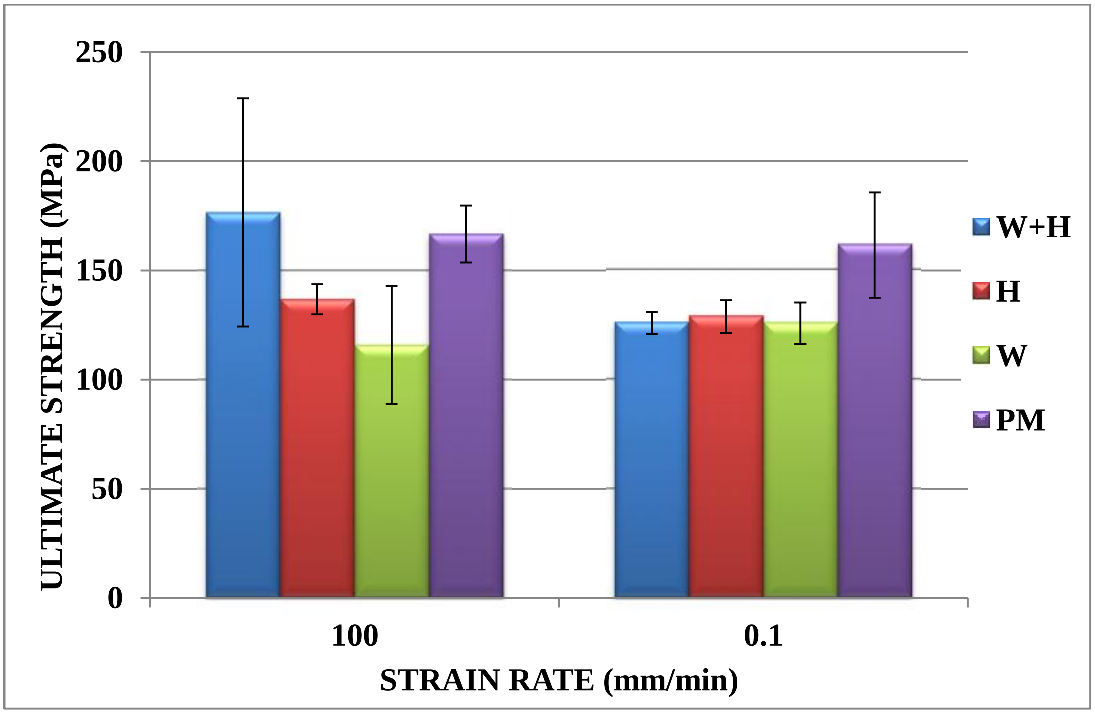

Fig. 3: Ultimate Strength of different zones for similar filler at different crosshead Speed

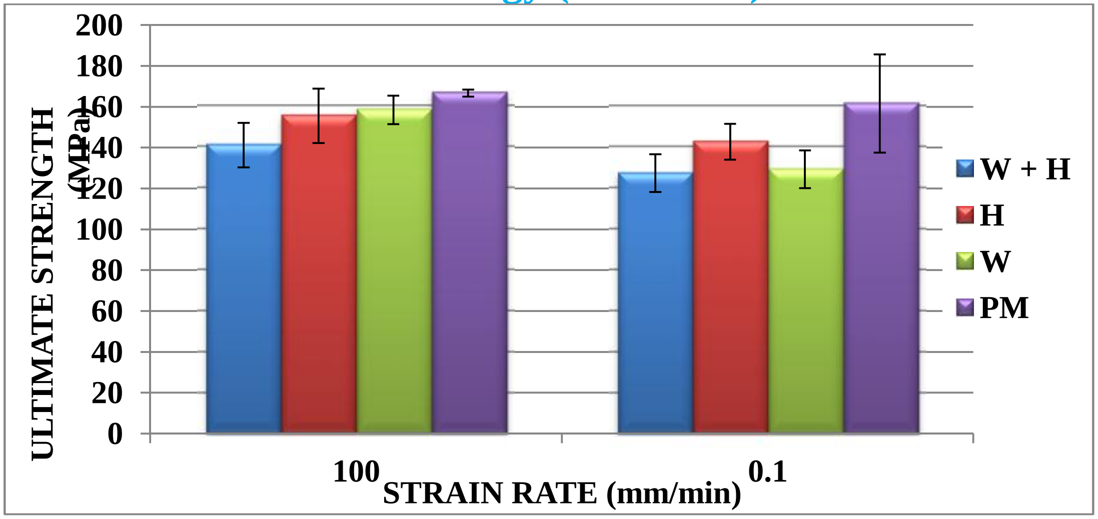

Fig. 4: Ultimate Strength of different zones for different filler at different crosshead Speed

From above we can find from fig. 3 that samples welded with similar filler of combined zone HAZ and Weld depicts higher ultimate strength at crosshead 100mm/ min. As compare to other zones and parent material. While in fig. 4 it is clear that in all the conditions the samples welded with different filler material reflects reduced ultimate strength as compare to the parent material for both the crosshead speeds.

So from above two figures it is clear that in combined zone of weld and HAZ (W+H) sample is showing improved ultimate strength compare to parent material at 100mm/ min. Crosshead speed for similar filler. Ultimate strength of the samples is improved by an increment of 5.9% while in all other conditions the reduction is recorded. The higher strength of the base metal is mainly attributed to the presence of alloying elements such as silicon and magnesium and these two elements combine and undergo precipitation reaction and forms a strengthening precipitate of Mg2Si. Fine and uniform distribution of these precipitates throughout the aluminium matrix provides higher strength and hardness to these alloys [7]. As the sample which is showing enhanced ultimate strength, welded with similar filler. It means the combined zones for weld and HAZ (W+H) has strengthening precipitate of Mg2Si because the filler is of same material as that of parent material. That’s why in this zone the sample is showing the enhanced ultimate strength.

C. Percentage Elongation

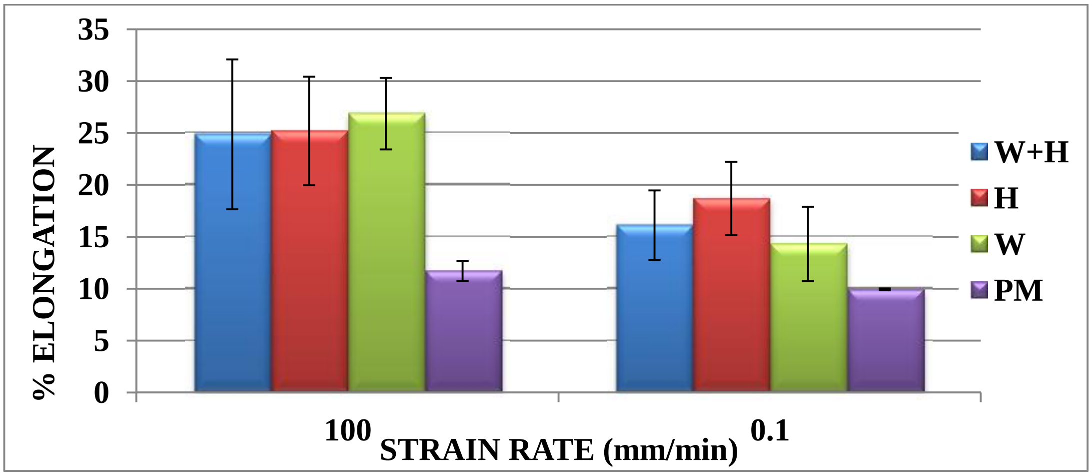

Fig. 5: Percentage Elongation of different zones for similar filler at different crosshead Speed

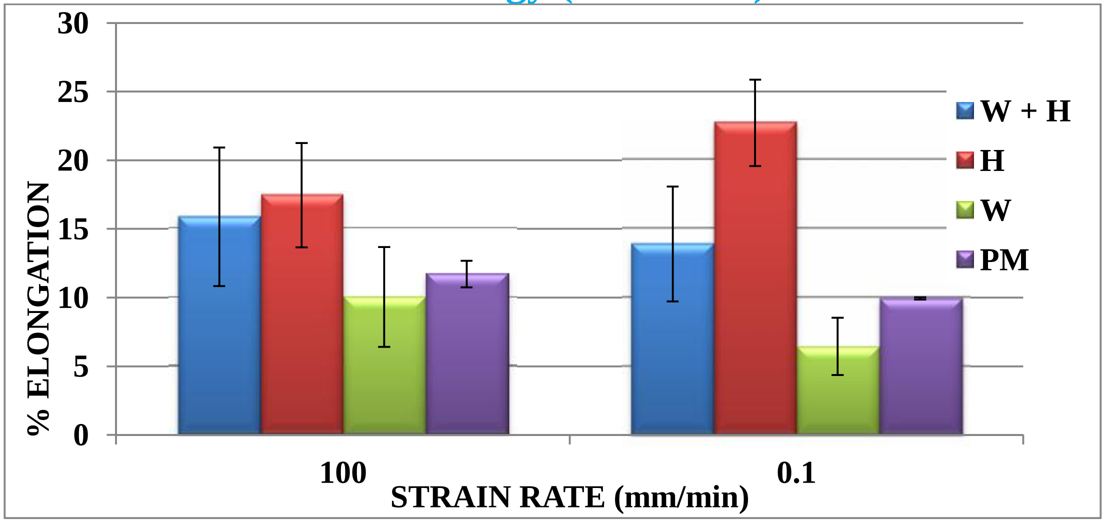

Fig. 6: Percentage Elongation of different zones for different filler at different crosshead Speed

It is clear from figure 5 and 6, that average percentage elongation is enhanced in all the conditions for both similar and different filler welded samples at all the crosshead speeds as compare to the parent material. The maximum enhancement of 129.43% at 100 mm/ min for weld zone (W) and 128.63% at 0.1 mm/ min for heat affected zone (H) is recorded for the samples welded with similar filler and different filler material respectively. Similarly an enhancement of 40% at 0.1 mm/ min. for combined HAZ and weld zone (W+H) and 48.98% for HAZ (H) and 35.58% for combined HAZ and weld zone (W+H) at 100 mm/ min are recorded for the samples welded with different filler material. While the samples of weld zone welded with different filler shows reduction in elongation by 35.14% for 0.1 mm/min crosshead speed and 14.27% for 100 mm/min crosshead speed.
The average percentage elongation is increasing for all the conditions for samples welded with similar filler. This is due to the fact that because of heat during the welding process the ductility of the different zones is increased as compare to parent material.

D. Hardness

The hardness across the weld cross section was measured using a Rockwell-hardness testing machine for weld zone and heat affected zone.

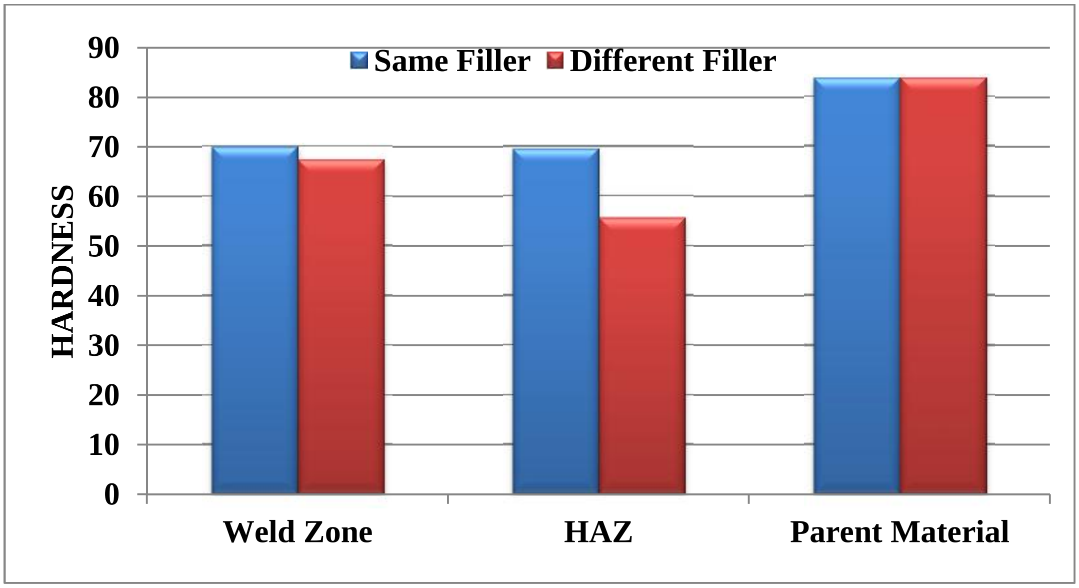

Figure 7: Hardness of weld zone, heat affected zone and parent material for specimen welded with similar filler and different filler.

The hardness of parent material (unwelded parent metal) in its initial H2 condition is 83.86 HRC. However, the hardness of the weld zone is 70 HRC for similar filler and 67.43 HRC for different filler material. Which means there is 16.52% and 19.52% reduction in hardness for the samples welded with similar filler and different filler material respectively. Similarly the hardness of TIG welded joints in the heat affected zone is 69.57 HRC and 55.71 HRC for similar and different filler material respectively. So a reduction of 17.04% for similar filler and 33.56% for different filler is recorded. This suggests that the hardness is reduced for both regions of GTAW joints, respectively due to welding heat, during the TIG, the temperature at molten pool is higher than 550 °C, and the alloy in this zone experiences meltage. The TIG welded seam exhibits cast structure, many Al3 (Sc, Zr) particles in this zone dissolve, and their precipitation strength effect becomes weaker. So The TIG welded joint experiences meltage, which results in its softening, the strain hardening disappears entirely and most of precipitation strengthening of second Al3(Sc, Zr) also disappears. Hence, the hardness of weld zone and heat affected zone is lower than that of parent material.

IV. CONCLUSIONS

After analyzing the above data and on the basis of discussion we can conclude this study as follows:

A. Narrower dendritic spacing in the fusion zone due to fast cooling, microstructures generally offer improved resistance to indentation and deformation and this may be one of the reasons for lower yield strength.

B. Combined zones for weld and HAZ (W+H) shows enhanced ultimate strength due to strengthening precipitation of Mg2Si for the samples welded with similar filler as compared to parent material.

C. The average percentage elongation is increasing for all the conditions for samples welded with similar filler. This is due to the fact that because of heat during the welding process the ductility of the different zones is increased as compare to parent material.

D. Comparison of all the conditions for both crosshead speeds between samples welded with similar filler material and different filler material indicates increasing of the length and the depth of the dimples. It indicates that the fracture in all conditions is ductile.

E. The hardness of weld zone and heat affected zone is lower than that of parent material.

In view of the above conclusions we can predict the suitable design criteria for the some productive purpose of the 31000H2 Al alloy using TIG welding with two kinds of filler material.

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