Mechanical Properties and Microstructural Characterization of Tungsten Inert Gas Welded AA5083 and AA5754 Aluminium Alloys with Scandium Added Modified Filler Rod

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Abstract

The refinement in weld metal grain size and shape results in both improved mechanical properties such as ductility and toughness as well as significant improvement in weldability. In the present study, the influence of scandium additions to the ER5356 fillers on the structure and mechanical properties of tungsten inert gas welded AA5083 and AA5754 weldments were investigated. A modified ER5356 filler rod with small quantity of scandium was prepared using stir casting. Tungsten inert gas welds were prepared using alternating current. The addition of scandium gives good grain refinement, which is mainly caused by Al_3SC particles. The observed grain refinement showed substantial increase in the hardness, yield strength and ultimate tensile strength of the fusion zone. The slow diffusion of SC in Al matrix and stability of Al_3SC precipitates at elevated temperature were suggested to be responsible for the improved high temperature yield strength of welds is made from SC modified fillers.

Keywords: *TIG welding, Scandium modified filler rod, AA5083, AA5754, Mechanical characterization.*

1. Introduction

The aluminium alloys AA5083-H111 and AA5754-H111 are non heat-treatable aluminium alloys with magnesium as the major alloying element. AA5083 and AA5754 are mainly used in marine applications. Few other applications of these alloys are in aircrafts, automobile components and cryogenic tanks [1-3]. The main properties of AA5083 and AA5754 aluminium alloys are its high ductility, high specific strength, good weldability and good formability [4,5]. For Tungsten inert gas welding usually filler rods with almost similar chemical composition as that of the base metals are used. Aluminium alloy AA5083-H111 and AA5754- H111 can be welded by using both friction stir welding and fusion welding methods. As we clearly know that friction stir welding gives better mechanical properties [6] buy yet TIG welding is used preferred by most of the industries because of the high cost of friction stir welding. Among the fusion welding process TIG welding is more reliable than the MIG welding process because the samples welded using TIG welding has high strength and ductility with less defects like porosity than MIG [7,8].

Scandium (Sc) is one of the promising alloying components in the periodic table which can be utilized to lessen grain growth and to increase recrystallization temperature

[9]. Scandium contributes in increasing the corrosion resistance and furthermore helps in diminishing the hot tearing vulnerability in the high quality aluminum alloys. Scandium addition to the aluminum combination helps in increasing its mechanical properties and weldability [10]. The addition of scandium to aluminum alloy controls grain development by 50% [11]. Since scandium is a rare earth metal, it is expensive and it is the fundamental explanation behind not utilizing it broadly. The addition of zirconium along with scandium additionally helps in improving the mechanical property and weldability of aluminum alloys [12]. The addition of zirconium along with a little amount of scandium assists with diminishing grain development and furthermore increases the thermal stability of the base metal.

In the present work microstructural and mechanical properties of TIG welded AA5083-H111 and AA5754-H111 with scandium added modified ER5356 filler rod was investigated. The microstructural and the mechanical properties are analyzed across the weld joint to find out the effect of scandium addition.

2. Experimental Procedure

The 5mm thick plates of the base metals AA5083-H111 and AA5754-H111 are cut into required dimensions of 150 mm x 55 mm using the power hack saw cutting machine. The chemical compositions of the base metals AA5083-H111 and AA5754-H111 are given in Table 1. The mechanical properties of the base metals AA5083-H111 and AA5754-H111 are given in Table 2. The modified scandium adder ER5356 filler rod is manufactured using the stir casting method. The filler rod ER5356 and the Al-2wt%Sc master alloy are melted at 650 ^{o}C at the electrically operated furnace and it poured into a cylindrical mould of 2.5 mm diameter. The molten metal is then allowed to cool in the atmospheric temperature and the cast filler rod is taken out of the mould. The process parameters that are used for the TIG welding of AA5083-H111 and AA5754-H111 are given in Table 3.

The tensile samples are extracted from the welded samples using the EDM wire cutting machine along the transverse direction of the weld according to ASTM-E8 standards. The tensile tests were carried out using the universal testing machine on the extracted samples. The microstructural study was carried out across the weld by using the optical and scanning electron microscope. The fractographic studies were done on the fractured surface of the tensile samples using the scanning electron microscope. The hardness across various zones of the weldments is found out utilizing the Vicker's Microhardness tester and is plotted.

Table 1. Chemical composition of the base metals (wt%)

Base Metal	Mg	Mn	Fe	Si	Cu	Cr	Zn	Ti	Al
AA5083-H111	4.25	0.53	0.26	0.98	0.35	0.11	0.10	0.019	93.31
AA5754-H111	3.60	0.50	0.40	0.40	0.10	0.30	0.20	0.15	94.35

Table 2. Base metal Mechanical properties

Base Metal	Yield strength(MPa)	UTS (Mpa)	Elongation (%)
AA5083	197.39	321.34	22.6
AA5754	95	224.67	33.67

Table 3. Process parameters of TIG welding

Process	TIG welding
Welding machine	Miller Synocroware
Tungsten electrode diameter(mm)	2.5
Voltage(V)	16
Current (A)	170
Welding speed (mm/min)	150
Shielding gas	Argon
Gas flow rate(L/min)	11
Filler material used	Scandium added modified ER5356

3. Results and Discussions

3.1 Weld Microstructure

The microstructural characterization of the weldments are done to find out the grain size, grain orientations and the precipitates shapes and precipitate sizes present on the various zones. TIG welded samples are divided into three major zones, they are the parent metal zone, heat affected zone, and the weld zone. The microstructural characterization is done on the various zones of the weldments using optical microscopy to find out the grain size and grain orientations. Scanning electron microscopy in done on the weldments to study about the precipitates structure and shape in various zones.

3.1.1 Optical Microscopy

The optical microscopy images are taken using optical microscope at 500X magnification and are given in Fig. 1. Fig. 1(a) shows the optical microstructure image of AA5083-H111 base metal. Fig. 1(b) shows the optical microstructure image of AA5754-H111 base metal. The heat affected zone of the AA5083-H111 and AA5757-H111 sides are shown in Fig. 1(c) and 1(d) respectively. The weld Zone of sample welded with scandium added modified ER5356 filler rod is shown in Fig. 1(e).

AA5083-H111 and AA5754-H111 are non heat-treatable aluminium alloys which have Mg as the major alloying elements. The base materials attain its strength mainly from solid solution strengthening and precipitate strengthening. Substitutional solid solution can be found to occur on the AA5083 and AA5754 aluminium alloys with Mg atoms replacing the Al atoms [13]. Some major precipitates that contribute to the strength of AA5083 and AA5754 aluminium alloys are $Al_6(Fe,Mn)$, Al_3Mg_2, Mg_2Si. The addition of scandium through the filler rod to the weld pool increases the strength of the weld zone, due to the formation of Al_3Sc precipitates in the weld zone. The formation of Al_3Sc particles in the weld zone is shown in Fig. 1(e).

The hardness and the yield strength of the weldments are increased due to the formation of the Al_3Sc precipitates in the weld zone [14]. From the Fig. 1(e) it can be clearly seen that the scandium interlayer is mixed properly to the dissimilar AA5083-H111 and AA5754-H111 aluminium alloys. The reduction of grain size can be observed because of the addition of scandium in the weld zone which makes the weld zone the strongest zone in the weld. Very large grains are observed on the HAZ of the welded samples because of the high heat flow at the HAZ region during the welding process. The increase in the grain size at the HAZ of the weldments makes it the soft region and the failure occurs in the HAZ of the weldments.

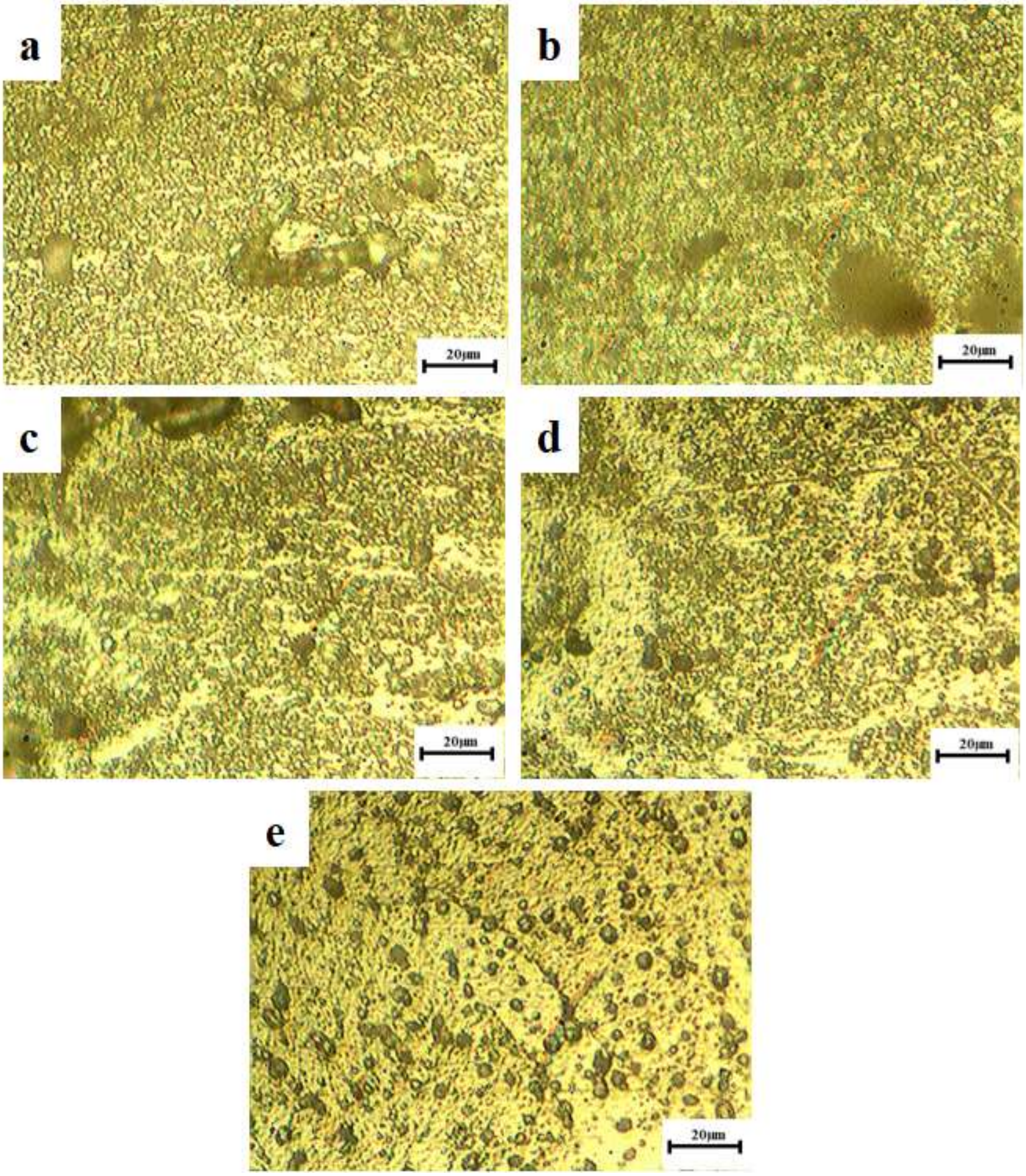

Fig. 1. Optical Microscopy (a) AA5083 Base Material (b) AA5754 Base Material (c) AA5083 HAZ (d) AA5754 HAZ (e) Weld Zone

3.1.2 Scanning Electron Microscopy (SEM)

The scanning electron microscopy images were taken using scanning electron microscope at 5000X magnification and are given in Fig. 2. Fig. 2(a) shows the SEM image of AA5083-H111 base metal. Fig. 2(b) shows the SEM image of AA5754-H111 base metal. The heat affected zone of the AA5083-H111 and AA5757-H111 are shown in Fig. 2(c) and 2(d) respectively. The weld zone of sample welded with scandium added modified ER5356 filler rod is shown in Fig. 2(e).

The SEM microstructure of the sample welded with scandium added modified filler rod shows five phases like $Al_6(Fe,Mn)$, Al_3Mg_2, Mg_2Si, Al_3Sc and the aluminium matrix. The Al_3Sc precipitates contribute to the increase in the yield strength of the weldments. The Al_3Sc particles also contribute to the grain refinement and hence it increases the hardness value of the weld zone.

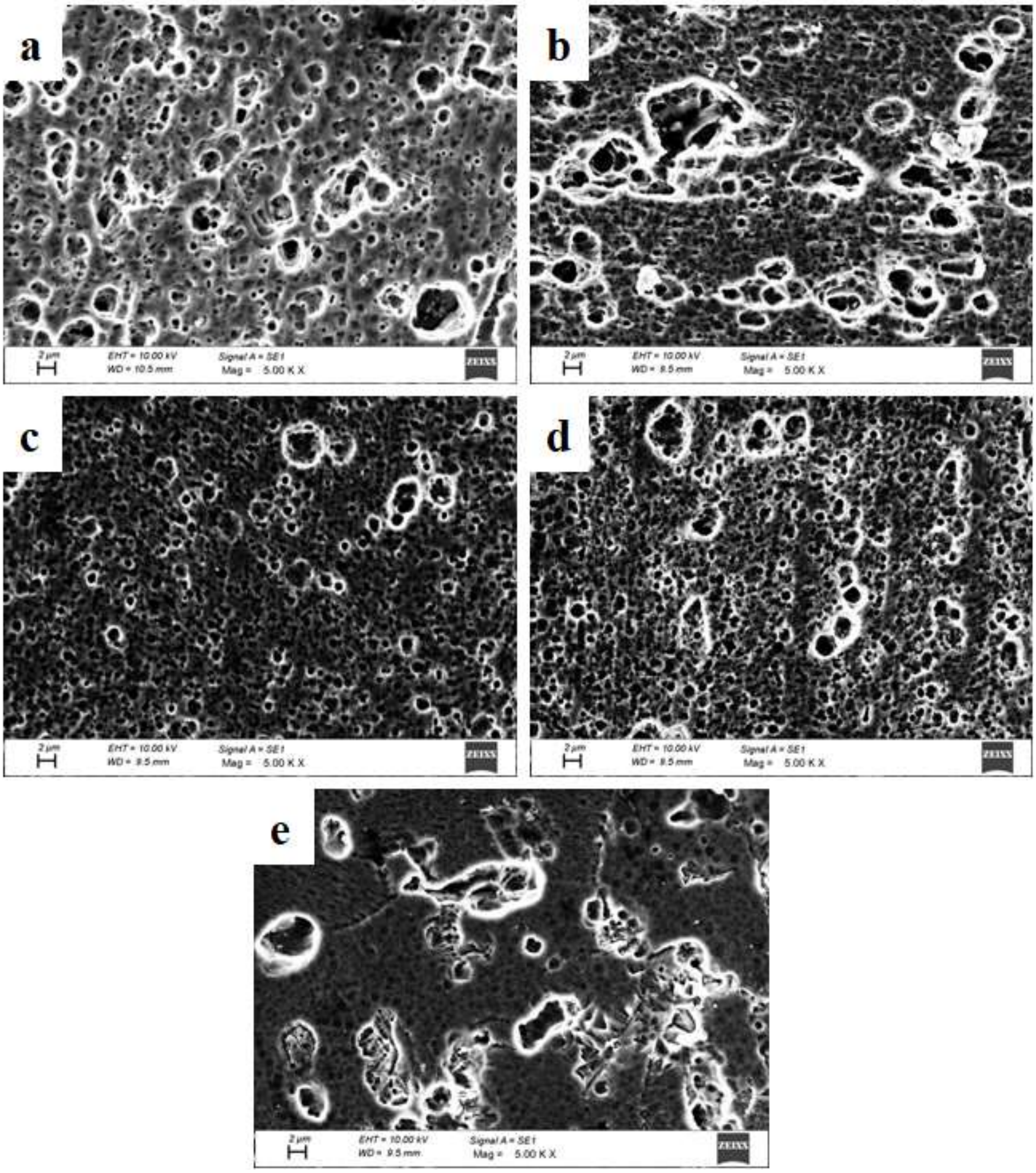

Fig. 2. Scanning Electron Microscopy (a) AA5083 Base Material (b) AA5754 Base Material (c) AA5083 HAZ (d) AA5754 HAZ (e) Weld Zone

3.2 Tensile Properties

The tensile samples are extracted from the welded samples along the transverse direction of the weld. The samples are extracted as per ASTM E8 standards. The tensile tests were carried out on the extracted samples using the universal testing machine and the values obtained are shown in Table 4.

Table 4. Tensile parameters of the sample welded with modified ER5356 filler rod

S. No	Type of Joint	Yield Strength (MPa)	UTS (MPa)	El (%)	Fracture Location
1	Sample 1	130	249	20	At AA5754 HAZ
2	Sample 2	125	236	18.50	At AA5754 HAZ
3	Sample 3	129	225	19.25	At AA5754 HAZ
Average Value		128	236.67	19.25	-------------

The UTS of the welded sample was 236.67 MPa which is 5% higher than the UTS of the weaker base metal (UTS of AA5754 – 224.67 MPa). The similar result was observed by a researcher during the TIG welding of AA5083-F aluminium alloy using scandium modified ER5356 filler rod [15]. The YS value of the welded sample was 128 MPa which is 25.78% higher than the YS of the weaker base metal (YS of AA5754 – 95 MPa). The percentage elongation of the welded sample was 19.25% which is very much lower than the weaker base metal percentage elongation (% El of AA5083 – 22.6%). From the above results it is proved that the addition of scandium has improved the ultimate tensile strength by a minor value and has improved the yield strength by a major value but it has decreased the ductility of the base metal to a great extent. The similar phenomenon was observed by few researchers [16-18]. The main strengthening mechanisms that contribute to the 5xxx series aluminium alloys is solid solution strengthening mechanism caused by the Al-Mg solid solution. The addition of scandium has increased the contribution of solid solution strengthening by the formation of Al-Sc solid solution. The addition of scandium has also induced both precipitate strengthening by the formation of Al_3Sc precipitates and orowan strengthening by reducing the grain growth during the welding process. The orowan strengthening mechanism in the weld is very small because of dissolution of the strengthening precipitate like Al_6Mn and Al_6FeMn.

3.3 Fractographic study

The fractographic analysis was studied using the scanning electron microscope on the fractured surface of the tensile samples welded with the scandium adder modified filler rod. Fig. 4(a) and 4(b) shows the fractography image of the base metals AA5083-H111 and AA5754-H111 respectively. Fig. 4(c) shows the fractography image of the sample welded with scandium added modified ER5356 filler rod.

It is observed from Fig. 4(a) and 4(b) that large quantities of dimples are present in the fractured surfaces of the tensile samples. The dimples in the fractured surface show high ductility. As AA5083 and AA5754 aluminium alloys are high ductile materials, large numbers of dimples are seen on the fractured surface of the base material. The study on the fractured surface of the welded sample with scandium added modified filler rod (Fig. 4(c)), very few dimples are seen. This shows that the addition of scandium reduces the ductility of the material to a large value. By comparing the quantity of dimples on the base materials (Fig. 4(a) and 4(b)) it can be concluded that the ductility of AA5754 is higher than compared to ductility of the AA5083 base metal. The fractographic study on the base metals and the welded samples proves that the addition of scandium reduces the ductility of the material to a large value.

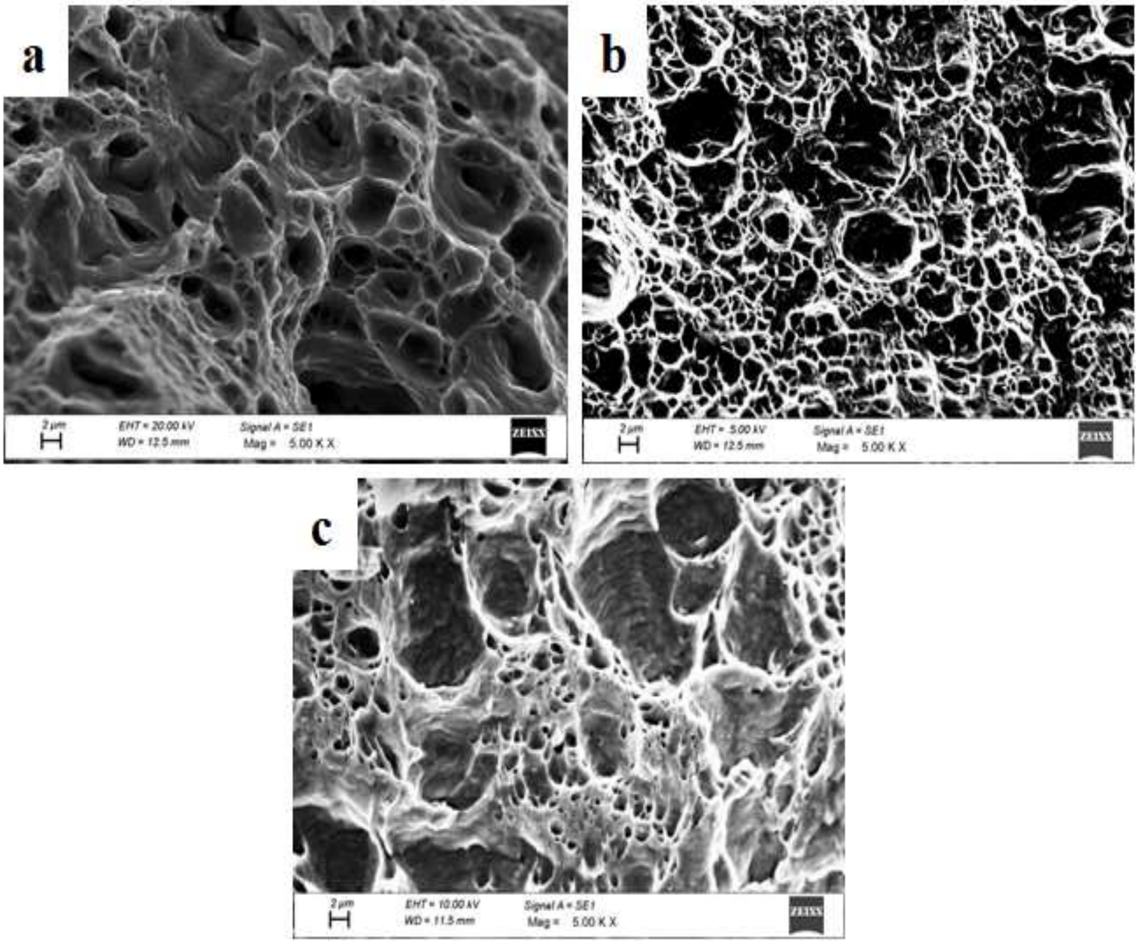

Fig. 3. Fractography (a) AA5083 Base Material (b) AA5754 Base Material (c) Welded sample

3.4 Hardness

The hardness distribution along the transverse cross section of the welded joint with scandium added ER5356 filler rod and base metals AA5083 and AA6061 are shown in Fig. 4. The hardness along the heat affected zone of AA5083 (Al-4.2Mg-0.7Mn) aluminium alloy side remains almost same as that of the base metal but the HAZ of AA5754 (Al-2.5Mg-0.4Fe) aluminium alloy side the hardness values have gone down than that of the AA5754 base metal because of the heat flow. The scandium containing ER5356 filler rod (Al-5.2Mg-0.5Sc), has reached a maximum of 105HV1 hardness in the welded zone.

The average hardness values of the base metals AA5083 and AA5754 are 80HV1 and 70HV1, respectively. The hardness values of the weld zone were approximately 25% greater than high magnesium content aluminium alloy (AA5083-H111). The increase in hardness along the Scandium added ER5356 filler zone or weld zone was because of the presence of scandium in the weld zone. The similar observations are made by few researchers during the addition of scandium [19-21]. The addition of scandium to ER 5356 filler rod increases the tensile strength and hardness of the welded sample using three different strengthening mechanisms, Solid solution strengthening, Grain boundary strengthening, and Orowan strengthening.

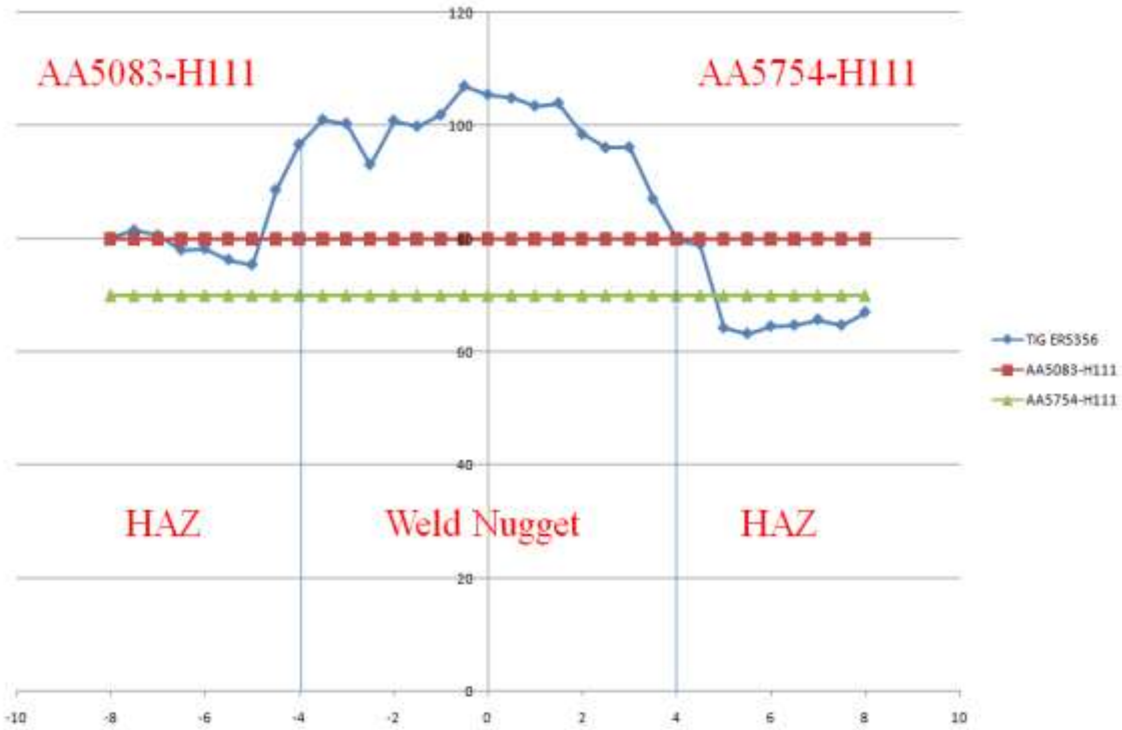

Fig. 4. Vickers Hardness Plot of the base metals and welded sample.

4. Conclusions

The aluminium alloys AA5083-H111 and AA5754-H111 are TIG welded successfully with scandium added modified ER5356 filler rod without any defects. The conclusions made in this study are given below:

1. The microstructural analysis on the weld zone showed good grain refinement because of the addition of scandium.
2. The tensile studies on the welded sample proves that the addition of scandium has increased the yield strength and the ultimate tensile strength than the weaker base metal AA5754-H111, but the addition of scandium has reduced the ductility of the aluminium alloy.
3. The fractographic studies on the fractured surface of the welded samples showed brittle nature. This proves that the addition of scandium reduces the ductility of the ductile materials.
4. The Vickers hardness comparison of the welded samples with the base metals shows no much difference in the values at the heat affected zone and the base metal zone whereas in the weld zone the hardness has been increased to a greater extent because of the addition of scandium to it.

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