The Study of Microstructure and Mechanical Properties of Friction Stir Welded AA1200 Aluminium Alloy With and Without Scandium Master Alloy Insert

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Abstract

This work focus on improving the mechanical and the microstructural properties of friction stir welded, solid solution hardened AA1200-H14 aluminium alloys with and without Al-2%Sc Master Alloy insert. The microstructural characterization of both the welded samples is studied using optical microscope and scanning electron microscope. The elemental analysis is done using SEM-EDX to find out the intermetallic particles present in the weld nugget. The mechanical property is characterized using universal testing machine to find out the effect of scandium on tensile strength and % elongation of the welded samples. The fractured surface is analysed using scanning electron microscope to find out the type of failure that has occurred in the welded samples. The hardness analysis is done along the transverse direction of the weld to find out the hardness values at the various zones of the weld.

Keywords: *Friction Stir Welding, AA1200-H14, Optical microstructures, SEM microstructure, Fractography, Tensile properties and Hardness.*

1. Introduction

Aluminium alloy AA1200 is widely used in engineering structures because of its very high specific strength and low density. The above mentioned applications increase the demand for aluminium in various aerospace, automotive, marine and defence industries [1]. Selection of proper temper condition with required mechanical properties is very much important. The aluminium associates have made much effort to standardize the aluminium alloy designations. It is important for the engineers to stay acquainted with these standards before selecting the aluminium standard for their usage.

Friction stir welding is a solid state welding process that is used to overcome the various solidification and liquidification defects caused by conventional welding methods [2-4]. Friction stir welding is used to effectively join any combination of two dissimilar metals [5-7]. In friction stir welding the heat required to weld two materials is generated by the frictional force created between the non consumable rotating tool and the work piece. The welding occurs by plasticizing and transporting the material from one end to the other and makes a good welded joint as possible. The frictional heat produced by the rotating tool must be much less than the melting point of the alloys to be welded, so that no melting of metals takes place. The solid state welding eliminated many solidification related problems such as hot cracking, porosity, partially melting zone and alloy segregation.

Scandium (Sc) is one of the promising alloying elements in the periodic table which can be used to reduce grain growth and to increase recrystallization temperature [8]. Scandium contributes in increasing the corrosion resistance and also helps in reducing the hot tearing susceptibility in the high strength aluminium alloys. Scandium addition to the pure aluminium alloy helps in increasing its mechanical properties and weldability [9]. Addition of scandium to pure aluminium alloy controls grain growth by 50% [10]. Since scandium is a rare earth metal, it is very costly and it is the main reason for not using it widely. The addition of zirconium along with scandium also helps in enhancing the mechanical property and weldability of aluminium alloys [11]. The addition of zirconium along with a very small quantity of scandium helps to reduce grain growth and also increases the thermal stability of the base metal.

In the present work the effect of scandium addition on friction stir welding of AA1200 aluminium alloy is investigated. The microstructural and the mechanical properties are analyzed across the weld joint.

2. Experimental Procedure

The 5mm thick plates of the base metal (AA1200-H14) is cut into required dimensions of 150 mm x 55 mm using the power hack saw cutting machine. The cast Aluminium scandium master alloy of 5 mm thick plate is cut into dimension of 150 mm x 1.5 mm strip using wire EDM machine. The chemical compositions of the base metal AA1200-H14 and Aluminium-Scandium master alloy are given in Table. 1. The friction stir welding with and without scandium insert is done using the friction stir welding machine. The process parameters of the friction stir welding are given in Table. 2.

Table 1 Chemical Composition of the base metal and the Al-Sc Insert in Wt. percentage

	Fe	Si	Sc	Al
AA1200-H14	0.25	0.25	---	99.50
Al-Sc Master Alloy	---	---	2.00	98.00

Table 2 FSW Parameters

Tool material	H13 Tool Steel
Tool pin profile	Straight Square
Tool Rotational speed	1400 RPM
Tool Travel speed (mm/min)	20 mm/min
Tool Tilt Angle	0˚
Tool Shoulder diameter	15 mm
Tool Pin diameter	5 mm
Tool Pin length	4.8 mm

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

3. Results and Discussions

The microstructural characterization of the welded samples are done to have a detailed study on the grain size, grain orientations and the precipitates shapes and sizes present on the various zones. Friction stir welded samples are divided into four major zones, they are the parent metal zone, heat affected zone, thermo mechanically affected zone and the weld nugget zone. The microstructural study is done on the various zones of the welded samples using optical microscopy to find out the grain size and its orientations. Scanning electron microscopy in done on the weld nugget to study about the precipitates structure and shape.

3.1.1 Optical Microscopy

The optical microscopy images were taken using optical microscope at 100X magnification and are given in Fig. 1. Fig. 1(a) showed the optical microstructure image of AA1200-H14 base metal. The heat affected zone of the FSWed sample without and with scandium master alloy insert is shown in Fig. 1(b) and 1(c) respectively. The weld nuggets of samples welded without and with scandium insert are shown in Fig. 1(d) and 1(e) respectively.

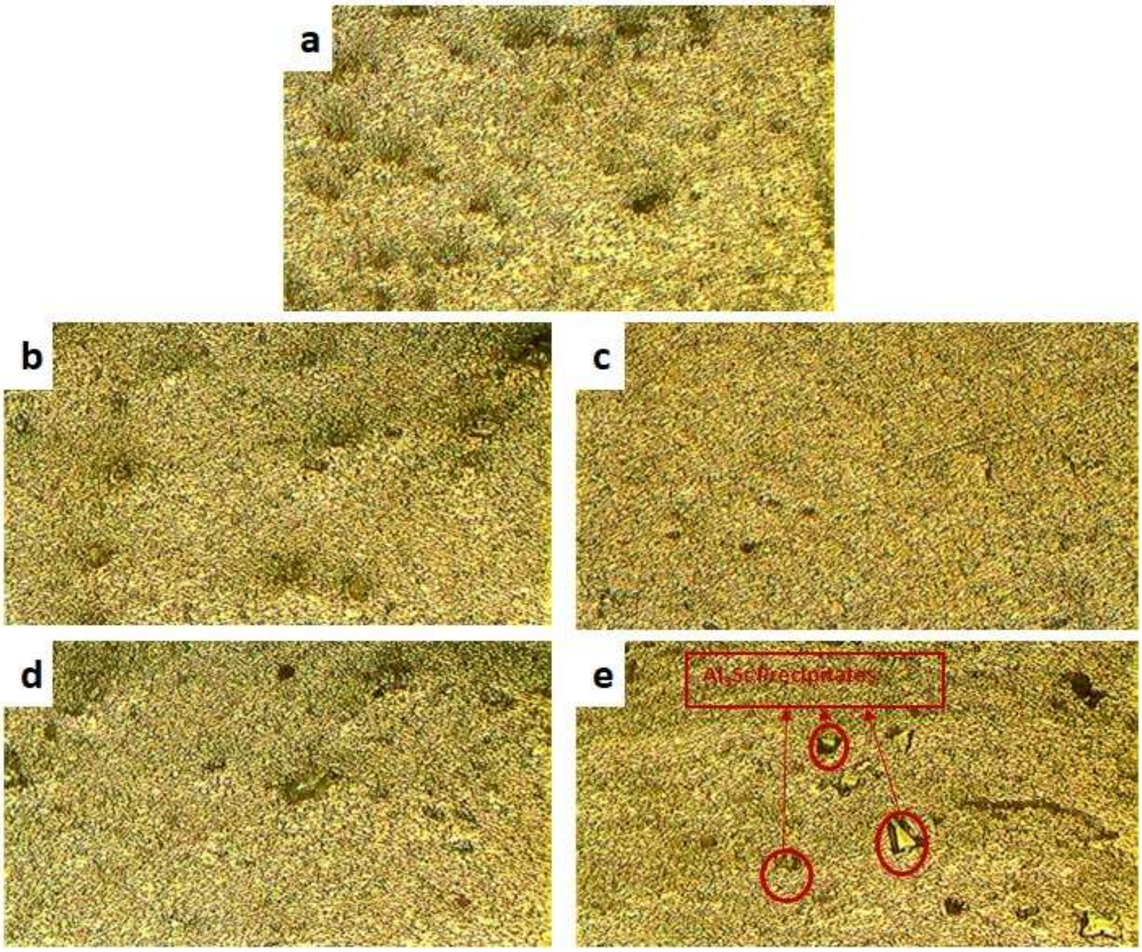

Fig. 1 Optical Microscopy (100 X Magnification) – (a) Base Metal, (b) HAZ of FSWed AA1200 without Sc insert, (c) HAZ of FSWed AA1200 with Sc insert, (d) Weld Nugget of FSWed AA1200 without Sc insert, (e) Weld Nugget of FSWed AA1200 with Sc insert.

AA1200 aluminium alloy is a pure aluminium alloy which has only Fe and Si to it as impurities. Some major precipitates that are formed inside the AA1200 aluminium alloys are AlFeSi and Al_3Fe. The addition of scandium master alloy strip to the middle of the weld, increases the strength of the weld nugget, because of the formation of Al_3Sc particles in the weld nugget zone. The formation of Al_3Sc particles in the weld nugget zone can be seen clearly in Fig. 1(e).

The Al_3Sc precipitates that are formed in the weld nugget zone helps in increasing the hardness and the yield strength of the welded samples[12]. From the Fig. 1 it is clear that the scandium interlayer is mixed properly to the AA1200 aluminium alloy. The addition of scandium has also reduced the grain growth in the weld nugget zone making the weld nugget the strongest region in the weld. Very large grains are found on the heat affected zone of both the friction stir welded samples. This has happened because of the high heat flow that has occurred at the HAZ region of the weld. The increase in the grain size makes the HAZ of the welded samples the soft region and the failure occurs in the HAZ in both the welding cases.

3.1.2 Scanning Electron Microscopy

The SEM images are obtained at the weld nugget of the welded samples using scanning electron microscope and are shown in Fig. 2. The weld nugget image of the sample welded without scandium insert is shown in Fig. 2(a) and the weld nugget of the sample welded with Al-2%Sc master alloy insert is shown in Fig. 2(b).

The SEM microstructure of the sample welded without scandium insert shows the presence of three phases including alpha AlFeSi, Al_3Fe and aluminium matrix. Whereas the sample welded with the Al-2%Sc master alloy insert shows four phases like AlFeSi, Al_3Fe, Al_3Sc and the aluminium matrix. The Al_3Sc precipitates contribute to the increase in the yield strength of the welded samples. The Al_3Sc particles also act as a grain refiner and increase the hardness value in the weld nugget zone.

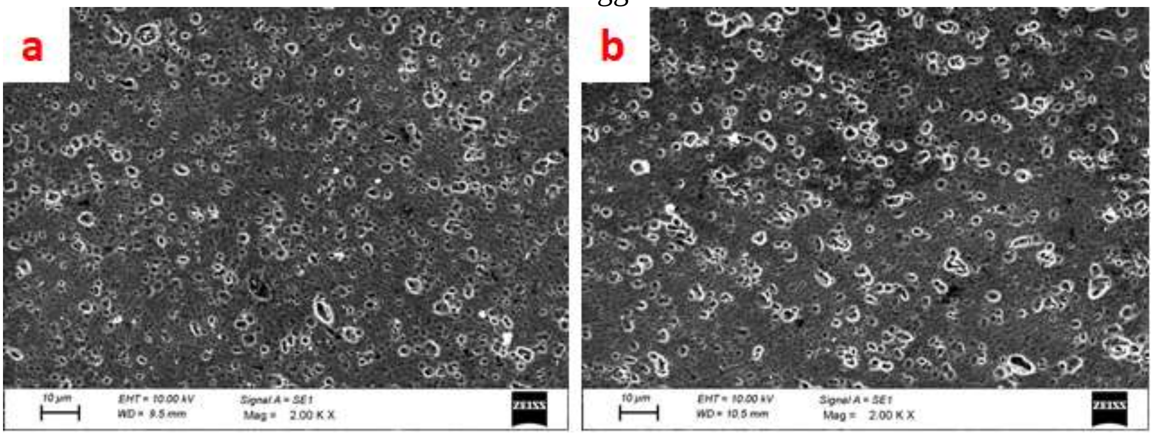

Fig. 2. SEM images of the weld nugget (a) Without scandium insert (b) with scandium insert

3.2 SEM – EDX

The energy dispersive x-ray (EDX) analysis was taken at 5 spots on the weld nugget of both the welded samples. The weld nugget image with EDX spots marked on it is shown in Fig. 3. The weight percentages of elements present in the samples welded without and with scandium insert are shown in Table 3 and Table 4 respectively. By observing the data from Table 3 it is clear that the weight percentage of iron (Fe) and silicon (Si) has reduced slightly. This has happened because of the dissolution of the intermetallic particles due to the high heat at the weld nugget.

Table 4 shows the EDX analysis results of the sample welded with Al-2% scandium master alloy insert. The EDX analysis confirms the presence of Al-Sc intermetallic phase presence in the weld nugget. The presence of Al_3Sc particles contributes to the increase in the yield strength of the aluminium alloys. An average of 0.55 weight percentage of scandium was only observed in the weld nugget zone, this shows that the scandium particles has dissolved due to the high heat gradients in the weld nugget zone. The addition of more quantities of scandium helps in increasing the yield strength and ultimate tensile strength of the welded samples.

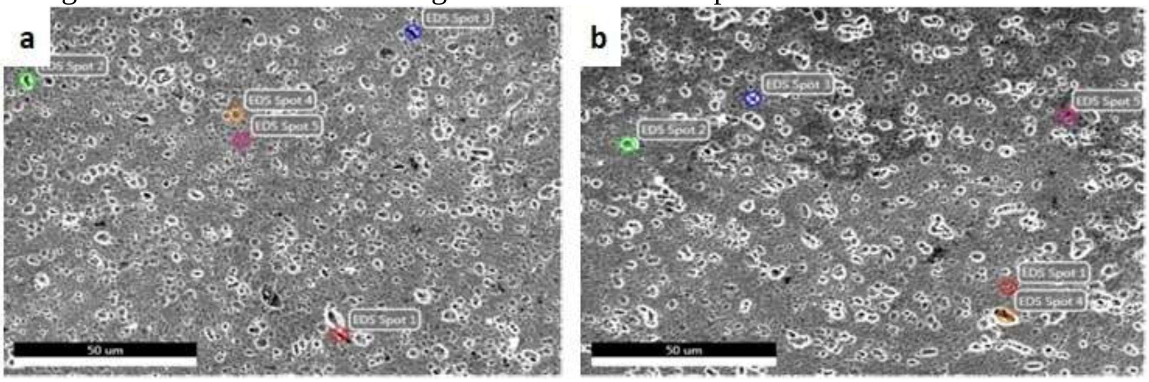

Fig. 3. SEM EDX images at the weld nugget (a) Without scandium insert (b) with scandium insert.

Table 3 Average wt% of elements for FSW AA1200 without Scandium insert

Spots	Al	Fe	Si
Spot 1	99.51	0.29	0.20
Spot 2	99.64	0.21	0.15
Spot 3	99.47	0.24	0.29
Spot 4	99.58	0.18	0.24
Spot 5	98.46	0.29	0.25

Table 4 Average wt% of elements for FSW AA1200 with Scandium insert

Spots	Al	Fe	Si	Sc
Spot 1	98.96	0.29	0.20	0.55
Spot 2	99.22	0.21	0.15	0.42
Spot 3	98.94	0.24	0.29	0.53
Spot 4	98.93	0.18	0.24	0.65
Spot 5	98.99	0.24	0.23	0.54

3.3 Tensile Properties

The tensile properties of the welded samples without and with Al-2% scandium master alloy insert is found out using the universal testing machine and the obtained results are given in Table 5. It can be clearly seen from the Table 5 that the addition of scandium has increased the yield stress of the welded sample compared to the sample welded without scandium insert. There is a small decrease in the ultimate tensile strength of the samples welded with scandium insert. The similar phenomenon was confirmed by some researchers [13-15]. It is also observed from Table 5 that the addition of scandium has reduced the percentage elongation of the weld drastically. This shoes that the addition of scandium reduces the ductility of the aluminium alloys.

Table 5 Tensile Properties of FSWed AA1200 alloy with and without Scandium insert.

FSW Type	Yield Stress, MPa	UTS, MPa	El, %
AA1200 – BM	47.5	78.5	54.25
Without Sc Insert	28	83	40.25
With Al-2Wt.%Sc	34.5	64.5	14.75

3.4 Fractographic study

The fractography analysis was carried out on the fractured surface of the tensile samples welded with and without Al-2%scandium master alloy insert using the Scanning Electron Microscope. Fig. 4(a) shows the fractography image of the base metal AA1200, Fig. 4(b) shows the fractography image of the sample welded without scandium insert and Fig. 4(c) shows the fractography image of the sample welded with Al-2%Sc master alloy insert.

It can be observed from Fig. 4(a) that a large number of dimples are present in the fractured surface. The dimples in the fractured surface show high ductility. As AA1200 aluminium alloy is a high ductile material, a large number of dimples are seen on the fractured surface of the base material. On analyzing the fractured surface of the sample welded without any insert (Fig. 4(b)), dimpled surface can be seen. This shows that the sample welded without scandium insert shows high ductility. By comparing the quantity of dimples on the Fig. 4(a) and 4(b) it can be concluded that the ductility is decreased slightly on the welded sample compared to the base metal sample. On the other hand, the analysis of the sample welded with Al-2% Sc master alloy (Fig. 4(c)) shows no dimples on the fractured surface. This shows that the addition of scandium reduces the ductility of the material to a large value.

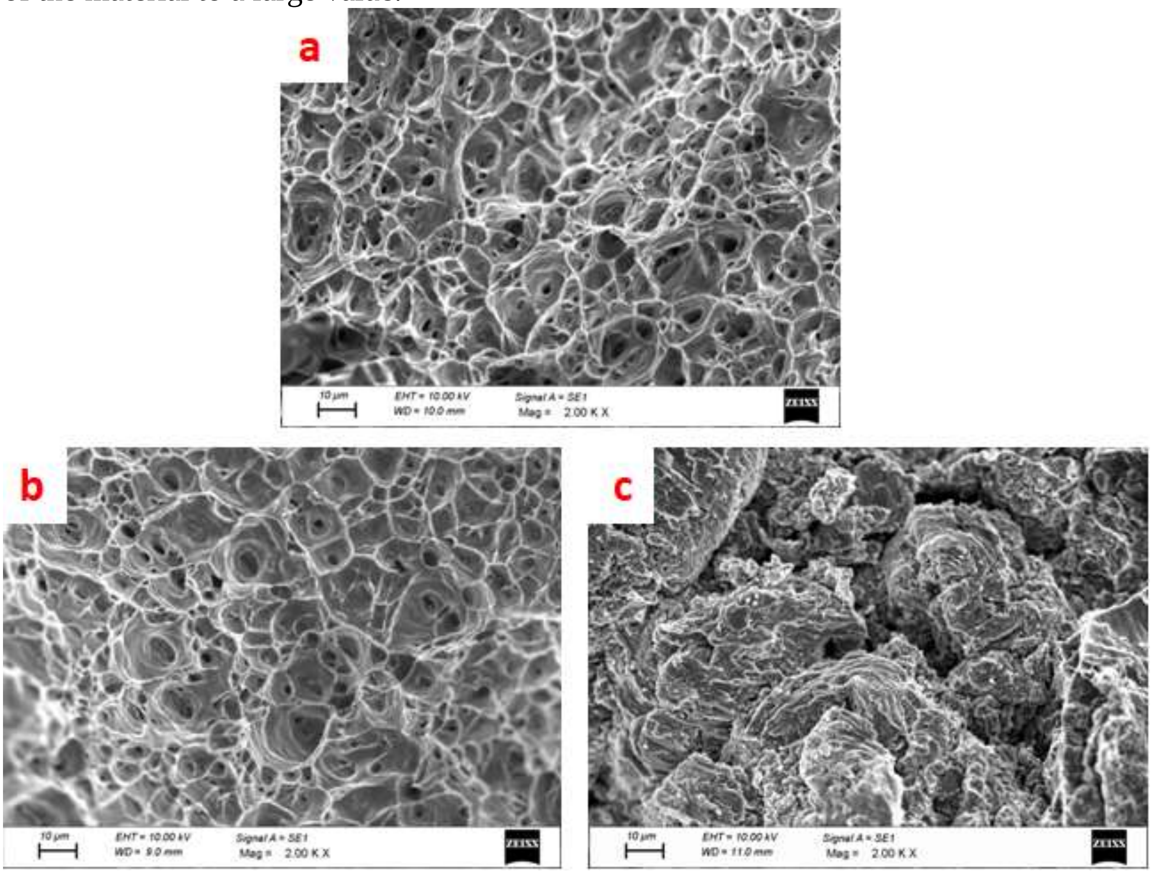

Fig. 4. Fractography images (a) Base metal AA1200 (b) without scandium insert (c) with scandium insert

3.5 Hardness

The hardness survey of the samples welded with and without Al-2%Sc master alloy insert is conducted using Vicker's microhardness tester and the graph obtained is given in Fig. 5. By analysing the graph obtained it can be seen that the hardness values are almost same in all the zones but it shoes a small peak at the weld nugget zone. By comparing the graph obtained it can be seen clearly that the addition on scandium has increased the hardness values by a small quantity. This is proved by few researchers [16-18]. The main reasons for the hardness increase due to the addition of scandium are, the formation of solid solution that causes strong hardening [17] and the Al_3Sc intermetallic formation that increases the hardness of the alloy [18].

Fig. 5. Hardness survey of the welded samples.

4. Conclusion

Friction stir welding trials are successfully conducted on the AA1200-H14 aluminium alloys with and without Al-2%Sc master alloy insert. The welded samples obtained were found to be defect free and the conclusions obtained from various tests are shown below:

1. The microstructural analysis using optical microscopy and the scanning electron microscopy shows the weakest zone as the heat affected zone of AA1200 alloy on the retreating side. This is because of the increase in grain size at the heat affected zone.
2. The elemental analysis carried out using EDX analysis on the weld nugget shown confirms the presence of Al_3Sc precipitates which acts as a grain refiner to increase the strength of the weld.
3. The tensile strength of both the welded samples which are characterized by the universal testing machine shows that the addition of scandium has increased the yield strength but it decreased the ultimate tensile strength. The addition of scandium has also decreased the ductility of the welded sample at a higher rate.

4. The hardness survey recorded on both the welded samples using the Vicker's microhardness tester shows high hardness values at the weld nugget zone and the lowest hardness values were recorded at the heat affected zones.

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