Effect of vibratory treatment for improving weldment properties of AA2014 aluminum alloy

Balasubramanian K[1], Balusamy V[2]
[1] Department of Mechanical Engineering
[2] Department of Metallurgical Engineering
[1] Sri Krishna College of Engineering and Technology,Coimbatore , Tamilnadu, India.
[2] PSG College of Technology, Coimbatore, Tamilnadu, India.

Abstract- *Formation of hot cracking is a major problem in welding of high strength aluminum alloys. Hot cracking can be reduced by different techniques like inoculation, magnetic stirring, arc oscillation and pulsing. In this present investigation, an attempt is made to reduce the hot cracking in aluminum alloy welding through vibratory treatment. The material used for the investigation is AA2014 aluminum alloy. Weld bead is made by using Gas Tungsten Arc Welding (GTAW) in the presence and absence of vibration. Vibratory treatment is carried out in the frequency range of 450 Hz. Weld metal made with and without vibratory treatment were compared using Houldcroft hot cracking tests and other characterization tests like microstructural analysis, cooling rate measurements and hardness measurements. The experimental results show that the hot cracking is controlled by applying vibratory treatment.*

Keywords- Hot cracking, Vibratory treatment, Cooling rate, Aluminum alloy, Microstructure

I. INTRODUCTION

Aluminum alloys are very high sensitive to hot cracking. It appears near the end of the solidification process in the fusion zone. It is normally believed that hot cracking is a complex phenomenon linked to the inadequate liquid and the accumulation of thermally induced stresses/strain during solidification contraction. Hot cracking is generally observed when the thermally induced stress exceeds the strength of the semi solid (mushy) and enough liquid metal is not available to fill the initial cracks. The most commonly used remedial method presently being used for controlling the hot cracking in welds of high strength aluminum alloys is appropriate choice of filler metals [1].

Formation of fine grained structure in the weld metal is another important method to control the hot cracking. Various methods are used to control the grain structure in the weld metal have been reported in literature, viz, inoculation, weld pool stirring, arc oscillation and arc pulsation. Inoculation involves the addition of nucleating agents or inoculants to the liquid metal to be solidified. Inoculants are added into the liquid weld metal to promote heterogeneous nucleation and the liquid metal solidifies with very fine equiaxed grains similar to casting. Ramanaiah N et al [2] observed significant grain refinement and increase in hardness by adding Ti + B. In their work, Ti and B elements are added directly to the weld pools either as filler rods cut from master alloy or by pre placing correct amounts of pieces of master alloys along with 4043 fillers in a groove cut in the base material. Weld pool stirring can be achieved by applying an alternating magnetic field parallel to the welding electrode. Stirring the weld pool tends to lower the weld pool temperature, thus helping heterogeneous nuclei survive (in cooperation with inoculants addition). Mousavi M G et al [3] achieved grain refinement in electromagnetically stirred AA7020 welds and proved that the grain refinement is due to the grain detachment. Arc oscillation can be produced by either magnetically oscillating the arc column using a single / multiple magnetic probes or mechanically vibrating the welding torch. In this technique, Grain refinement is achieved by dendrite fragmentation and heterogeneous nucleation. Kumar P et al [4] got improved mechanical properties of AA 5456 Aluminum alloy welds through magnetic arc oscillation process and also optimized the magnetic arc oscillation welding process parameters of non-heat treatable AA 5456 Aluminum alloy welds for increasing the mechanical properties by using Taguchi method. Ram G D J et al [5] studied the gas tungsten arc welds in two high strength, age hardenable aluminum alloys with and without an external magnetic field. Metallographic characterization revealed the degree of structural refinement produced by magnetic arc oscillation.Arc pulsation is obtained by pulsing the weld current (using peak and base current). Rajesh manti et al [6] observed that the pulse TIG welding of Al-0.8%Mg-0.5%Si (6061) alloys produced finer grain structure of weld metal than conventional TIG welding (without arc pulsation). Kishore Babu N et al [7] discussed the influence of direct current pulsing on the microstructure, room temperature hardness and tensile properties at four different temperatures of tungsten inert gas (TIG) weldments of Ti–6Al–4V. Autogenous full-penetration bead-on-plate TIG welds are made with and without direct current pulsing. Current pulsing resulted in slight refinement of prior β grains leading to higher hardness, tensile strength and ductility of weldments in the as-welded condition.

This work aims at forming fine grained structure in the weld metal by applying vibratory treatment during the welding process. Some of the works have been reported in the available literature relating the vibratory treatment on controlling hot cracking. Garland J G [8] studied the effect of torch vibration on the grain structure and solidification cracking susceptibility of Al- Mg (1.7 to 2.8%) alloy using autogeneous GTA (Gas Tungsten Arc) welding and found that fine equiaxed grains were formed and hot cracking was reduced. Takehiko Watanabe et al [9] investigated the effect of ultrasonic vibration on the solidification microstructure and mechanical properties of the weld metal of ferritic stainless steel by introducing ultrasonic vibration directly into the weld molten pool and found that the ultrasonic vibration enhanced more equiaxed grains to form in the central region of the weld metal and improved the tensile strength of the weld. Shijie Guo et al [10] conducted experiments both in the absence and presence of electromagnetic vibrating force to measure the microstructure of AZ80 billets. The experimental results show that the grains have been greatly refined by applying electromagnetic vibration.

II. EXPERIMENTAL METHODS

Material characterization tests, in terms of chemical composition and mechanical properties, particularly hardness measurements, were conducted. The Houldcroft test, which was used as the main weldability test to determine the hot cracking resistance. The vibration unit, which was used to generate vibration energy and which was applied during welding. The characterization tests like microstructural analysis, cooling rate measurement for grain size measurement were also conducted.

1. Materials

The material used for this investigation was AA2014 aluminum alloy and its chemical composition is presented in table.1

Table 1. Chemical composition of AA2014 Aluminum alloy investigated

Material	Composition (Wt. %)				
	Cu	Mg	Si	Mn	Al
AA2014 aluminum alloy	4.05	0.65	0.47	1.25	Bal

2. Welding

Welding was done using GTAW process. The main parameters used for welding are

Welding current - 250 amps
Travel speed - 6.5 mm/s
Electrode - EWTh-2, Φ3mm
Shielding gas - Argon
Polarity - Direct Current Electrode Negative (DCEN)

3. Houldcroft test

Various hot tearing tests have been developed in order to study the alloys hot crack sensitivity. It is classified in to two categories namely self restraint tests and external load test. In self restraint tests, the mechanical loading of the semi solid zone is produced by the thermal restrain. But in case of external load test, plastic strain is induced by a loading device during welding of the sample. Houldcroft cracking test was employed for assessing the specimens for resistance against hot cracking. This test was developed by Houldcroft P T [11] in 1955. This self restraint test was selected because it is very easy to incorporate the vibrating treatment. The specimen used for the present work is of size 76mm x 44mm x 4mm. The specimen contains grooves in two rows with nine grooves in each row, cut to different depths, as shown in Figure 1to provide thermal restraint.

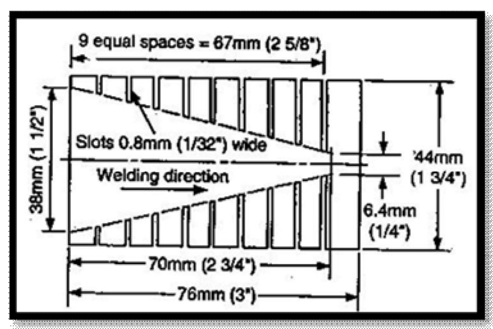


Figure 1. Houldcroft test specimen

In this test, a bead-on-plate is made autogenously from high restraint end to low restraint end as shown in fig.1. During welding, longitudinal crack is initiated from high restraint end and propagate along the centerline of the weld. Series of slot are cut to different depths on either side of the weld line provide gradual reduction of thermal strain along the length of the specimen. The crack length is used as the index of hot cracking susceptibility of the materials. Crack sensitivity is calculated as percentage of crack length with respect to the total weld length.

$$\text{Hot crack sensitivity} = \frac{\text{Crack length}}{\text{Specimen length}} \times 100\ \%$$

4. Vibratory treatment

The vibration generator cum analyzer used in this work consists of a piezo electric transducer capable of producing mechanical vibration in different frequency range. The transducer is made to transmit the vibratory energy to the weld plate through a welding fixture. The welding fixture and the specimen holding method are such that the energy loss during transmission from transducer to the weld plate is kept to the lowest value. The arrangement of this vibratory treatment unit is shown in figure 2.

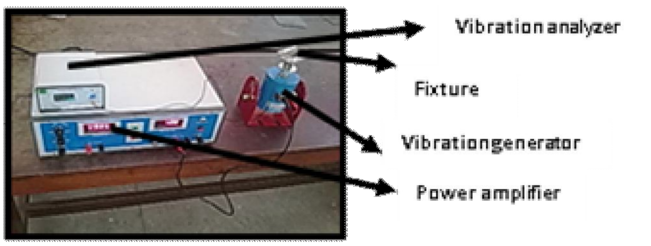


Figure 2. Vibratory treatment unit

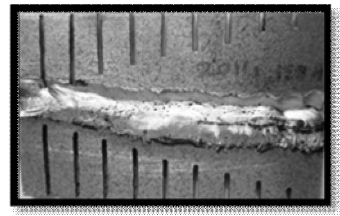
5. Characterization tests

The extent of grain refinement due to vibratory treatment was determined through microstructural analysis, cooling rate measurements and hardness measurement. The welded specimens, after sectioning and polishing, were etched with a solution containing 15ml HCl, 10 ml HF and 90 ml water, cleaned with water, cleaned with concentrated HNO3 and rinsed with water again. Microstructural analysis, Cooling rate measurements and hardness measurements on the sectioned specimens were carried out mainly to compare the grain size of specimen welded with vibration.

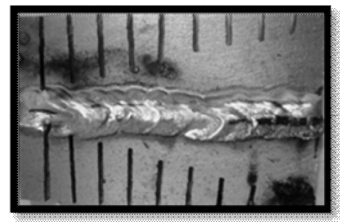
III. RESULTS AND DISCUSSIONS

1. Effect of vibration on hot cracking

Houldcroft test was conducted to determine the resistance of weld metals against hot cracking. Specimen welded with vibration was compared with the specimens welded without vibration. Vibratory treatment was carried out at a frequency of 450 Hz. Photographs (Fig.3) of the Houldcroft welded samples show the crack in the specimen welded at a frequency range of 450 Hz.



(a)



(b)

Figure 3. Houldcroft test results for AA2014 aluminum alloy (a) without vibration (b) with vibration of 450 Hz

The cracking sensitivity factor is related to the vibration frequency as shown in figure 4.

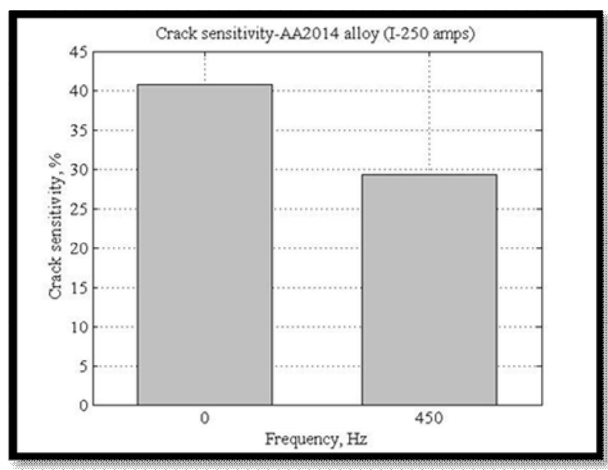
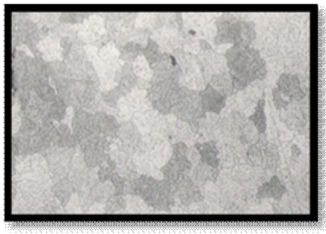


Figure 4. Crack sensitivity of AA2014 alloy with and without vibration

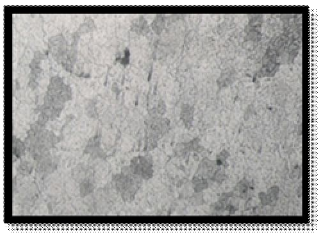
The crack sensitivity is around 40.7% when the specimen was welded without vibration. Then, the crack sensitivity is decreased to 29.3% when the specimen vibrated at a frequency range of 450 Hz. Hence, the hot cracking is reduced due to vibratory treatment

2. Effect of vibration on grain structure

Figure 5 shows a comparison between the microstructure of specimens welded without and with vibration. Coarse grains were observed in the specimens welded without vibration (Fig. 5a). On the other hand, the grains were disturbed due to vibration treatment and formed finer grains in the frequency range of 450 Hz (Fig. 5b). The finer sub-grain structure in the vibrated weld was due to higher cooling rate during solidification [12].



(a)



(b)

Figure 5. Microstructure of weld metal (a) without vibration (b) with vibration of 450 Hz

3. Effect of vibration on weld metal temperature

Vibrating the weld metal tends to lower the weld pool temperature by means of fast heat removal, thus helping the more the nuclei coming into play, resulting in finer the resulting sub grain structure.

Weld metal temperature curves are drawn for AA2014 aluminum alloy by recording the temperature of the weld centre as a function of time using infrared thermometer. After welding, the temperature fall for every 10 sec up to 1 min is recorded. Table 2 shows the recorded temperature for a frequency of 450 Hz with respect to time for a period of one minute.

Table 2. Temperature Vs Time for AA2014 aluminum alloy

Time in sec	**0**	**20**	**40**	**60**	**Weld metal temperature removal rate**	
Frequency in Hz	**Temperature in ˚C**				**˚C/sec**	**˚C/min**
0	253	229	213	201	0.866	52
450	250	224	204	192	0.966	58

Figure 6 shows the comparison of temperature removal rate for a weld metal of AA2014 aluminum alloy with and without vibration. The weld metal temperature removal rate was 52oC/min for the specimen without vibration whereas it was 58oC/min in the case of vibrated specimen at a frequency range of 450 Hz. Lu Qinghua et al [12] explained that the vibrated weld pool has two velocity components: one in the welding direction and the other perpendicular to the welding direction with the help of vibration. The resultant velocity is greater than the velocity of the non-vibrated weld pool. This significantly higher weld pool velocity apparently produced a higher cooling rate during solidification and it promotes finer sub grain structure in the vibratory weld.

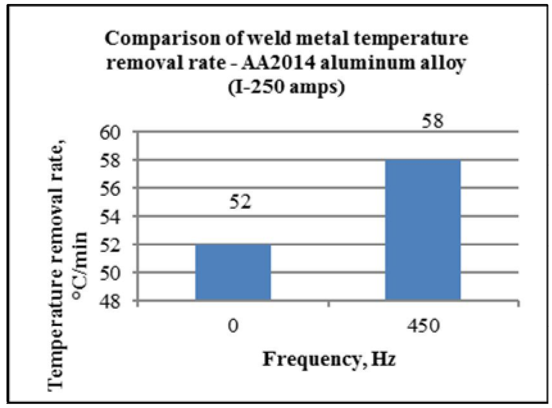


Figure 6. comparison of weld metal temperature removal rate with and without vibration for a weld metal AA2014 alloy

4. Effect of vibration on hardness

The Vickers hardness test was conducted on weld metal cross section of AA2014 aluminum alloy at regular intervals of distance. The average weld metal hardness values on weld metal cross-sections (Fig.7) reveal that the weld metal hardness increases from 98 VHN for non vibratory condition to 108 VHN for vibratory condition at a frequency of 450 Hz.

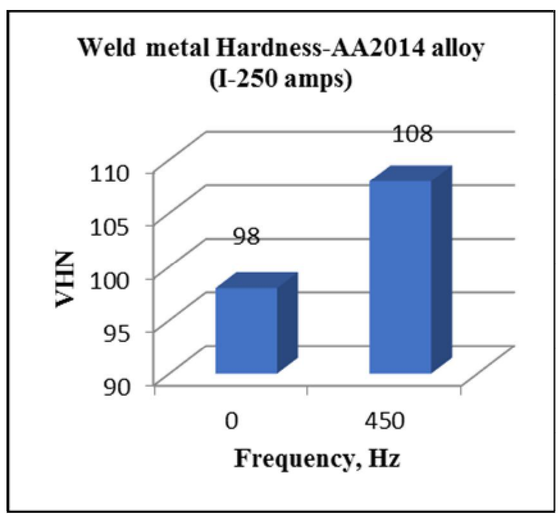


Figure 7. Weld metal hardness values

IV. CONCLUSION

The effect of vibratory treatment on weldment properties of AA2014 aluminum alloy has been investigated and found that:

- The vibratory treatment applied during GTA welding of high strength Aluminum alloy 2014 has resulted in reduction of hot cracking at weld metal.
- The crack sensitivity is 40.7% for the specimen is welded without vibration. Then, the crack sensitivity is decreased to 29.3% when the specimen vibrated at a frequency range of 450 Hz.
- The non-vibrated specimen was composed of coarse grains.
- Grains were disturbed and structural refinement of AA2014 alloy was achieved by the imposition of vibratory treatment during welding.
- The weld metal temperature removal rate is higher than the specimen welded without vibration.
- The weld metal hardness is also improved in the vibrated specimen.

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