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Laser Beam and Friction Stir Welding of AA 5083-H321 Aluminum Alloy Plates

K. Subbaiah*

Department of Mechanical Engineering, SSN College of Engineering, Chennai - 603 110, Tamil Nadu, India.

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ABSTRACT

Aluminum-magnesium alloy AA5083-H321 is used extensively as a structural material in aerospace, automobile, and marine applications. Fusion welding processes such as metal inert gas welding, tungsten inert gas welding, and laser beam (LB) welding generally result in lower joint efficiencies mainly due to defects such as porosity, large columnar grain structure, loss of strain hardening effect in fusion zone and heat affected zone and loss of magnesium due to evaporation. Friction stir (FS) welding is a solid state welding process which has been proved to solve the above-mentioned problems. In this study, bead-on-plate welds were made on 5 mm thick plates of AA5083-H321 using both LB and FS welding processes. Studies using light microscopy revealed that FS welding results in fine recrystallized grains in the weld zone. Hardness values and tensile testing of the joints revealed that FS welding results in superior mechanical properties compared to LB welding process. It is concluded that FS Welding process resulted in significantly stronger joints and is more suitable to join AA5083-H321 aluminum alloys.

Key words: *Aluminum-magnesium alloys, Laser beam welding, Friction stir welding, Grain refinement, Evaporation.*

1. INTRODUCTION

Conventional fusion welding of aluminum alloys produces a weld prone to defects such as porosity, loss of strain-hardening in the fusion zone, as-cast coarse microstructure, hot cracking in fusion zone due to segregation of alloying elements during solidification, results in the decrease of mechanical properties [1-4]. Laser welding process is widely used in the industries due to its numerous advantages: A small heat affected zone (HAZ), deep penetration, high welding speed, and small distortion after welding.

Friction stir (FS) welding is a solid-state joining process that enables welding hard-to-weld metals such as high-strength aluminum alloys. FS welding was developed and patented by the welding institute in 1991 [5]. Since then the research efforts to understand the micro and macro mechanics of the process are continuous. During FS welding, no melting occurs, and as a result the process is performed at much lower temperatures than conventional welding processes.

Laser beam (LB) welding of automotive aluminum alloy 5456 (Mg - 5.25 wt.%) has produced on 12.7 mm plates, a weld joint efficiency based on yield stress of 77% [6]. Welding trails on AA5083 alloy using a 2.5 kW CO_2 laser source was conducted [7]. The weld quality studies on an AA5083 (annealed condition) aluminum alloy with thickness 3 mm for the maximum power (2.5 kW), the joint efficiency achieved was slightly more than 80% [8].

Though research work of comparative study of FS welding of AA5083-H321 with other welding techniques has been reported [9-11], it appears that systematic study and detailed comparison between FS and LB welding for AA5083-H321 aluminum alloy has not been reported yet.

2. EXPERIMENTAL PROCEDURES

In the present work, LB welding was applied to 5 mm thick plates of non-heat treatable aluminum alloy AA 5083-H321 plates using a CO_2 laser. A diffusion-cooled slab 3.5 kW CO_2 laser welding system was used. Bead-on-plate welds with full penetration were performed. The welds were made using a CO_2 laser on the aluminum plates at a speed of 3.5 m/min. Helium was used as shielding gas with a flow rate of 20 L/min. The experiments are conducted using LB incident power value of 3.5 kW.

The 5 mm plates have been FS welded using an indigenously designed and developed machine (30 KN; 3000 rpm; 15 HP). The tool was made in high-

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*Corresponding Author:
E-mail: subbaiahk@ssn.edu.in

speed steel, M2, quenched at 1020°C, characterized by a 50~55 HRc. The shoulder diameter is 15 mm, and the pin is a truncated cone (5 mm base and 4 mm head diameter) 4.7 mm height. The vertical plunge force was set at 9 kN. The tool speed and traverse speed was kept at 650 rpm and 158 mm/min respectively.

After welding, the joints were cross-sectioned perpendicular to the welding direction for metallographic analysis and tensile tests using an electrical discharge machining cutting machine. The mechanical properties of the joint were measured by tensile tests. The configuration and size of the transverse tensile specimens were prepared according to ASTM-E8 standard. The chemical compositions were calculated using vacuum optical emission spark spectrometer model: Spectro laboratory: 750 V, Germany. The chemical composition of the base metal AA5083 in H321 condition is given in Table 1. Before the tensile tests, the Vickers hardness profiles were measured under the load of 1 N for 15 s along the centerlines of the cross-section of the tensile specimens using an automatic micro-hardness tester.

The cross-sections of the metallographic specimens were polished with alumina suspension, etched with Keller's reagent for about 10 s, and observed by optical microscopy. Microstructural characterization of the weld was performed using conventional metallographic techniques, optical microscopy, and scanning electron microscopy (SEM).

3. RESULTS AND DISCUSSION

3.1. Compositional Analysis

The magnesium present in the base metal was subjected to evaporation during fusion welding processes of aluminum alloys [12-14]. The chemical compositional results of base metal, LB weld, and FS weld, were listed out in Table 2. The gain/loss of important volatile elements was presented in Table 3. In our study, we have got a loss of 13% magnesium in the fusion zone of the LB welded samples, whereas the percentage of magnesium present in the FS welded samples were higher than that of base metal by 9.7%.

3.2. Macro Structural Studies

The macrostructures of LB welded joint contained weld defects. The top of the weld shown in Figure 1 has maximum underfill defect of depth 900 μm. The reduction in weld cross-section due to the presence of underfill defect naturally affects the weld tensile properties. The defect-free macrostructure of the FS weld is shown in Figure 2.

3.3. Optical Microstructures

The microstructure of the base metal AA5083 in H321 condition is shown in Figure 3. The elongated grains were seen in this microscope were due to cold working of the alloy. The alloy contains β-phase precipitate Al_3Mg_2 and the intermetallic compound $Al_6(Fe, Mn)$. The SEM microstructure of AA5083-H321 is shown in Figure 4.

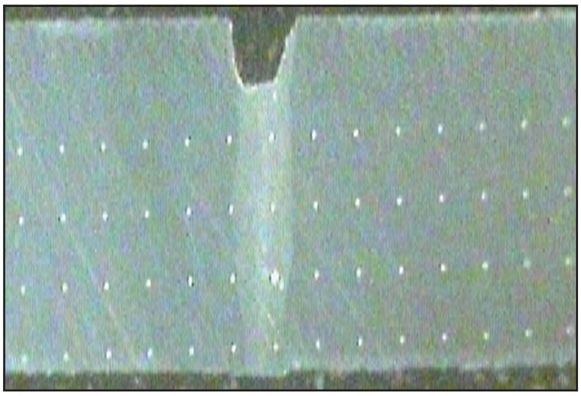

Figure 1: Macrostructure of laser beam weld.

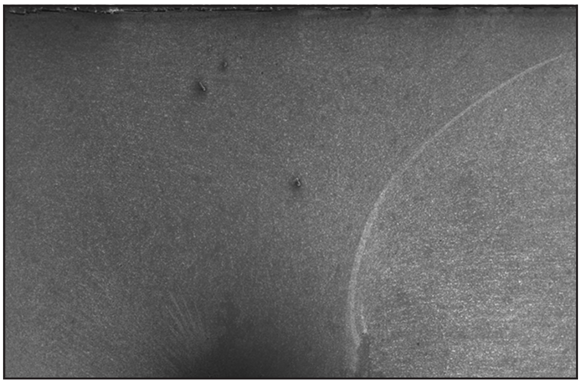

Figure 2: Macrostructure of friction stir weld.

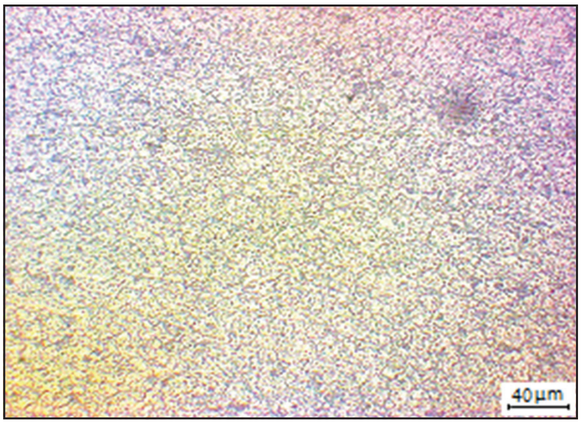

Figure 3: Optical microstructure of AA5083-H321.

Table 1: Chemical composition of AA 5083-H321plates used in this study.

Element	Mg	Mn	Fe	Si	Zn	Cu	Cr	Ti	Al
Wt.%	4.214	0.787	0.407	0.165	0.12	Maximum 0.025	Maximum 0.01	Maximum 0.01	Rest

The optical microstructure of LB weld at 3.5 kW laser incident power is shown in Figure 5. The microstructure of the FS weld zone is shown in Figure 6. These microstructures of the LB and FS welded zones were very fine compared to the base metal microstructure shown in Figure 3.

The SEM image of LB weld at 3.5 kW is shown in Figure 7. The dendrites shown in this figure are coarser. The absence of the intermetallic compounds Al_6(Fe, Mn) was observed in this SEM image [4]. Fine dendrites shown in LB welded joint were responsible for the reduction in mechanical properties. The SEM image of the FS welded joint weld zone is shown in Figure 8, and the grains were recrystallized. Fragmentation and nucleation of new Al_6(Fe, Mn) particles helped in retaining the mechanical properties of FS welded joints to very close to the base metal values.

3.4. Micro-hardness Values

The hardness across the weld cross-section was measured using a Vickers microhardness testing machine. The weld region hardness of the LB welded jointly is lesser than the HAZ and the base metal. In the case of FS welded joint, the weld metal region exhibited higher hardness than the thermomechanically affected zone/HAZ and base metal regions. The hardness of the base metal is 76 Hv1; however, the hardness of the LB welded joint at the weld region is 70 Hv1. This indicates that the hardness is decreased to 6 Hv1 in LB weld region due to grain growth. The hardness of the FS welded joint in the weld region is 100 Hv1, and it is 30 and 24 Hv1 higher compared to LB welded joint and base metal, respectively. This is mainly due to the formation of very fine grains in the stir zone caused by severe plastic deformation during friction stirring.

3.5. Tensile Tests

The average values of the tensile properties of AA5083-H321 base metal, LB and FS welded AA5083-H321 plates are shown in Table 3. On comparing the tensile properties of both LB and FS welded joints with the base metal values, the FS welded joint tensile properties are better than the LB welded joint tensile properties. The reduction in tensile properties in the case of LB welded joints are 13% in yield stress and 15% in tensile strength, whereas in the case of FS welded joints are 6% in yield stress and 5% in tensile strength, respectively. FS welding produced superior tensile properties compared to LB welding.

Table 2: Compositional analysis of Mg in AA5083-H321 alloy base metal, LB and FS welds.

Materials and Joints	Mg %	Loss/gain of Mg, %
Base metal	4.214	-
LB welding	3.678	−13
FS welding	4.622	+9.7

FS=Friction stir, LB=Laser beam

3.6. Fractographic Study

The fractograph of the LB weld shown in Figure 9 was taken by an SEM. The presence of micropores of size <20 µm has been observed in the LB weld fracture surface. The fracture occurred in LB weld is brittle in nature. The fracture surface of FS weld at 9 kN axial loads is captured with the help of an SEM and

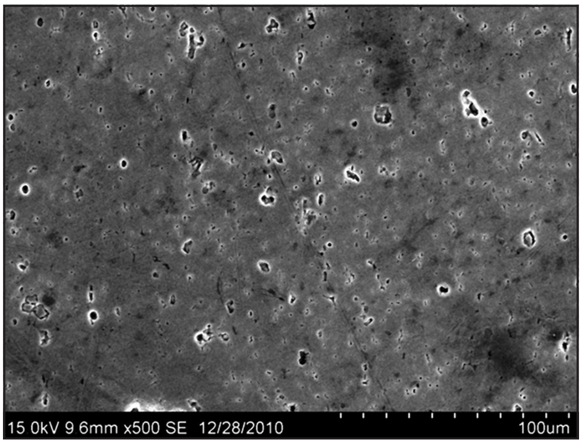

Figure 4: Scanning electron microscopy microstructure of AA5083-H321.

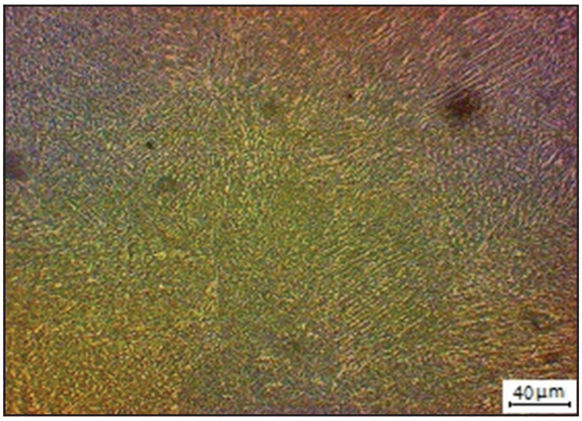

Figure 5: Microstructure of laser beam weld.

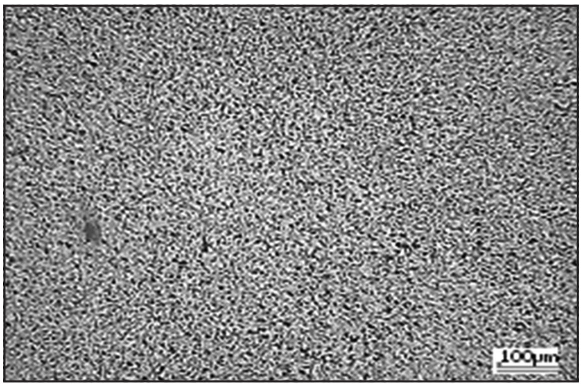

Figure 6: Microstructure of friction stir weld.

Table 3: Tensile properties of LB, FS welded joints and AA5083-H321 base metal.

Process	Yield stress, MPa	Tensile strength, MPa	Elongation, %	Joint efficiency, %
LB welding	226	248	13	85
FS welding	245	278	18.2	95
AA5083-H321	261	292	26.4	-

FS=Friction stir, LB=Laser beam

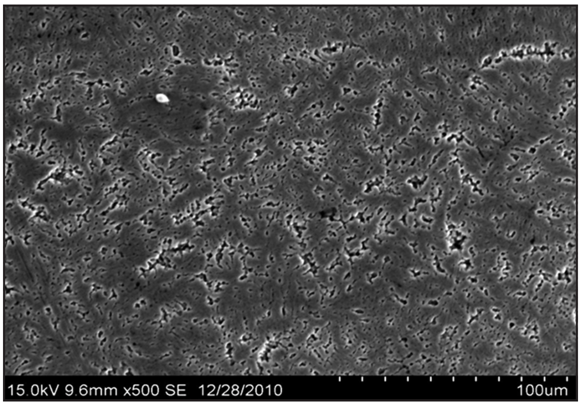

Figure 7: Scanning electron microscopy image of laser beam weld.

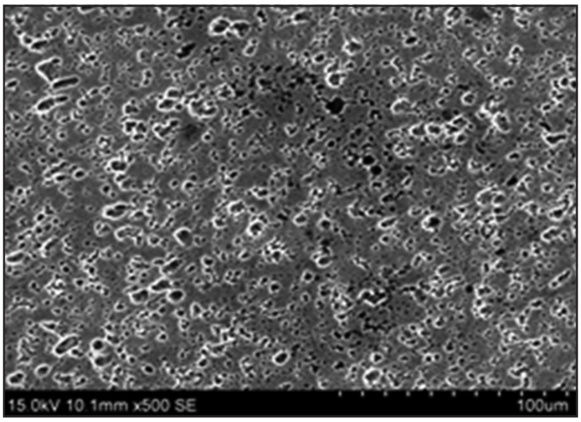

Figure 8: Scanning electron microscopy image of friction stir weld.

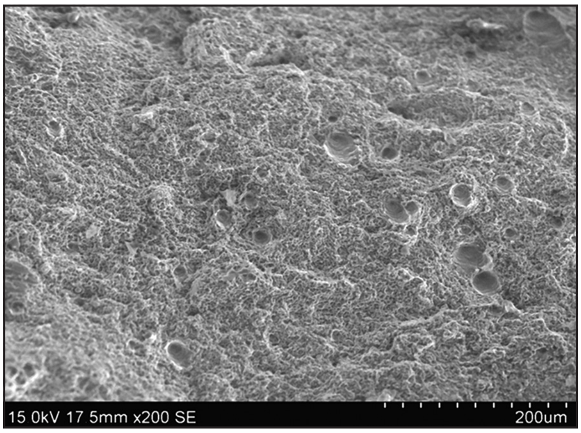

Figure 9: Fractograph of laser beam weld.

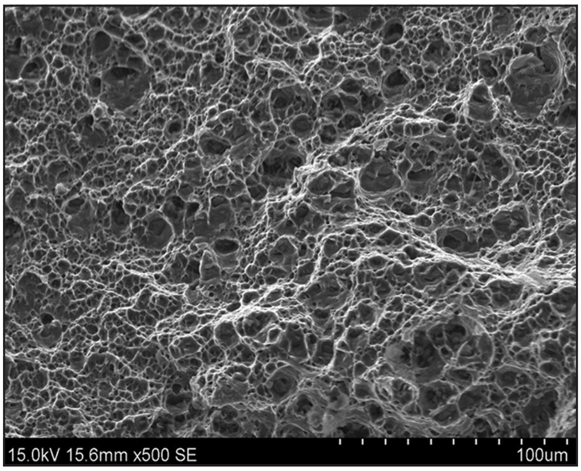

Figure 10: Fractograph of friction stir weld.

shown in Figure 10. The fracture surface contains fine dimples indication ductile fracture.

4. CONCLUSIONS

Sound welds have been obtained using LB and FS welding of 5 mm thick AA5083-H321 aluminum alloy plate. Evaporation of Magnesium is more in the case of LB welded joints, whereas no evaporation has occurred in the case of FS welded joints. The tensile properties of FS welded joints are better than the tensile properties of LB welded joints due to a reduction in the solidification defects and porosity. LB welded joint contains dendrites, micropores and loss of Mg lead to poor tensile properties. Fine and fragmented microstructure due to dynamic recrystallization in FS welding resulted in higher joint efficiency than LB welded joints. Lower hardness values in the LB weld induced due to dendritic structure compared to FS welded joints.

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***Bibliographical Sketch**

I have completed my B.E Degree in Mechanical Engineering during the year 1981 and M.E Degree in Aeronautical Engineering during the 1983. I have completed 32 years of Teaching in Engineering colleges. I started my research carrier during 2006 and have 10 years of research experience. I am currently guiding 12 Ph.D students in Anna University in TamilNadu at India.