COMPARISON BETWEEN RIVETED JOINTS AND FRICTION STIR WELDED JOINTS OF AA2014 ALUMINUM ALLOY

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Abstract: *AA2014 aluminum alloy has been widely used in aircraft and automotive industries as structural members. Conventionally, these structures were fabricated using rivets, as it is difficult to join this alloy by fusion welding processes. Friction Stir Welding (FSW) can be successfully applied to replace the riveted construction of aluminum alloy (AA2014) in aircraft structures. Hence, an attempt has been made to evaluate and compare the load carrying capabilities of FSW joints and riveted joints of AA2014 aluminum alloy. FSW joints were fabricated using optimized process parameters, and riveted joints were fabricated using standard shop floor practice in butt and lap configurations. FSW joints exhibited 75% higher tensile and shear fracture load compared to the riveted joints.*

Key words: *Aluminum Alloys, Friction Stir Welding, Riveting, Butt and Lap Joint*

1. INTRODUCTION

The high strength aluminum alloys such as 2xxx and 7xxx series are suitable for parts and structures requiring high strength to weight ratio and are commonly used in aircraft fuselage and wing skins. The structures are conventionally joined by rivets, because it is difficult to weld by fusion welding processes, due to the difference in melting point of the metal and oxide [1]. It is essential to remove and disperse this oxide film before and during welding in order to achieve the required weld quality. Moreover, there are many problems that occur during fusion welding of copper containing aluminum alloys and they are: solidification cracking, porosity, alloy segregation, partially melted zone [2]. Due to these problems, fusion welding of copper containing aluminum alloys such as 2000 and 7000 series is not preferred in the fabrication of critical structural components. In the aircraft industries, dissimilar riveted joints are used for structural fabrication to overcome the above problems. However, galvanic corrosion takes place in the riveted joints during the service period and also increases the weight of the aircraft.

In order to overcome the above problems, Friction stir welding (FSW) [3, 4], a solid state welding process can be applied to weld these grades of aluminum alloys without much difficulty in commercial applications. Since most aircraft and aerospace sheet metal structures involve both lap and butt joint configuration, use of FSW in place of riveted joints. [5, 6], can help to realize significant weight and cost saving with improved mechanical performance and reduced manufacturing complexity. It is generally known that the issues and considerations involved in butt and lap welds are different. Because, removal of surface oxide layers at the sheet interface is more difficult to accomplish in lap welding than in butt welding [7].

FSW can be used as a replacement for traditional rivet fastening in launch vehicle dry bay construction; Lockheed-Martin Space Systems as part of NASA investigation have designed and fabricated a large-scale friction stir welded 2090-T83 aluminum-lithium (Al-Li) alloy skin-stiffener panel [8]. The authors have pointed out several factors to explain this behavior including distortion, geometric imperfections, and reduced weldment properties. It was observed that distortion played a significant role in the FSW panel performance. Due to the welding imperfections the FSW panel failure load was 5% less than the predicted value, whereas the riveted panel ultimate load strength has attained higher value than the predicted one (the welded panel had a 20% lower failure load than the equivalent riveted panel). Letora et.al [9] used AA2024 to make overlap joint between flat panel and stiffeners, as to

Table 1: Chemical Composition (wt. %) of Base Metal

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
0.83	0.201	4.103	0.713	0.558	0.16	0.004	0.013	93.32

Table 2: Mechanical Properties of Base Metal

0.2 % Yield strength (MPa)	Ultimate tensile strength (MPa)	Percentage of elongation in 50 mm gauge length	Vickers Hardness 0.5kg, 15 sec (Hv)
433	461	8	154

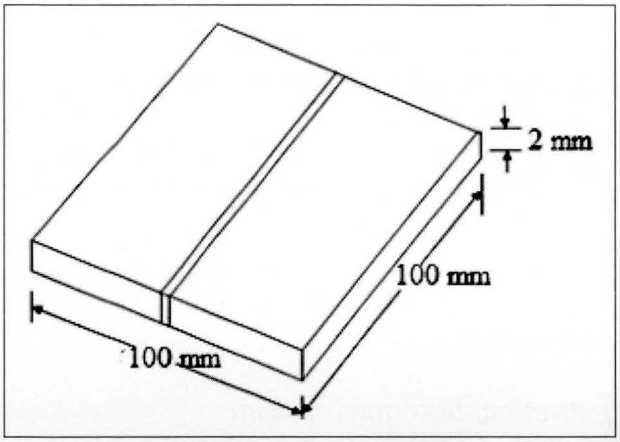


Fig 1. Butt Joint Configuration

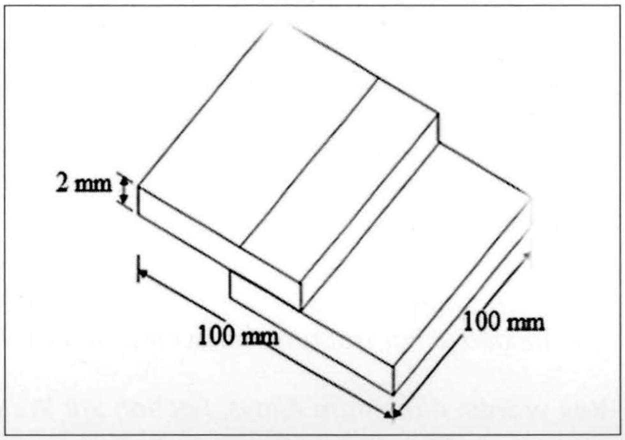


Fig 2. Lap Joint Configuration

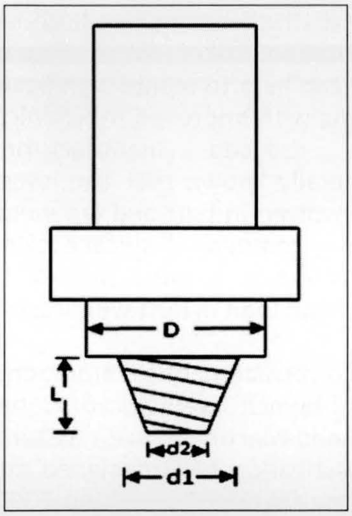


Fig 3. Schematic Diagram of FSW Tool

realize a typical structure of the aeronautical sector and to compare, by pressurization tests, the resistance of such panels with similar riveted joints. It was reported that the tensile strength of FSW joints was higher than that of the riveted joints (50% excess of the breaking load of riveted one). Babu et al [10] compared the mechanical and metallurgical properties of friction stir welded lap and riveted joints of the AA2014 aluminum alloy and they found that the lap joints made by FSW process exhibited higher breaking load than the riveted joints.

From the literature review, it is understood that the friction stir welding process has capable of replacing riveted joints in many applications, especially, in aircraft structures. However, very few investigations have been carried out to prove the superiority of FSW joints over the riveted joints. Moreover, most of the investigations carried out so far focused on lap joint configuration only. Hence, in this investigation, an attempt has been made to compare the load carrying capabilities of both butt and lap joints made by riveting and friction stir welding techniques.

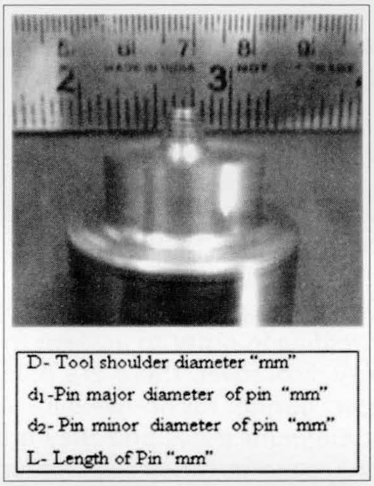


Fig 4. Photograph of FSW Tool

2. EXPERIMENTAL

Rolled aluminum alloy sheets of AA2014-T6 were used as the parent metal in this investigation. The chemical composition of AA2014 aluminum alloy is presented in Table 1. The mechanical properties of the parent metal are presented in Table 2. The 2 mm thick sheets were cut into 100 mm x 100 mm size and then rigidly clamped to achieve a square butt and lap joint configurations

Table 3: FSW Parameters used to Fabricate Butt and Lap Joints

Process parameters	Butt joint	Lap joint
Tool rotational speed "rpm"	900	1600
Welding speed "mm/min"	110	50
Tool shoulder diameter "mm"	10	7
Tool tilt angle "Q"	1.5	1.5
Pin major diameter "mm"	2	4
Pin minor diameter "mm"	1.5	3
Pin type	Taper threaded	Taper threaded
Shoulder concavity "deg."	1°	1°

(Fig. 1-2) for FSW and riveted joints. Non-consumable rotating tools as shown in Fig. 3 and Fig. 4 made of super high speed steel (SHSS) were used to fabricate the joints using a computer numerically controlled FSW machine. The optimized parameters used for the fabrication of the butt and lap joints are presented in Table 3. Riveted butt and lap joints were fabricated as per the standard shop-floor practices (cold heading with a pneumatic hammer). The rivets made of a commercial Al–Cu–Mg alloy V-65 were 4 mm in diameter and 12 mm in length. Fig. 5 shows the photographs of the riveted and FSW joints. The butt joint made by FSW process is referred as FBJ, and the lap joint is referred as FLJ. Similarly, the butt joint made by riveting process referred as RBJ, and lap joint made by riveting is referred as RLJ. These notations are used in the following sections. Tensile tests was carried out to evaluate the load carrying capabilities of the joints using electromechanical controlled universal testing machine with a cross head velocity of 1.5 mm/min.

3. RESULTS AND DISCUSSION

Tensile test results of the FSW joints and riveted joints are presented in Table 4. Fig. 6 shows the load elongation curve for the FSW and riveted joints. The average breaking load of riveted and welded specimen's exhibited different values depending on the joint configurations. The maximum load carried by FBJ and FLJ before fractures are 51.50 kN and 50.20 kN respectively. The FBJ exhibited 75% higher load carrying capability than the riveted butt joint. Similarly, FLJ exhibited 70% higher load carrying capability than the riveted lap joint (RLJ). Babu et al. reported that the friction stir lap welded joint exhibits higher breaking load than the riveted joints. The results obtained in this investigation in good agreement with the results of Babu et.al [11].

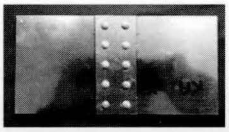
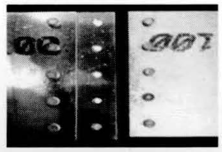
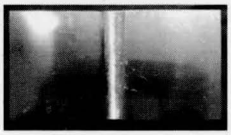
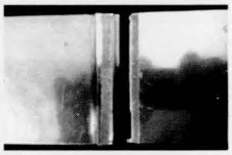
Type of joint	Before testing	After testing
Riveted butt joint (RBJ)		
Riveted lap joint (RLJ)		
FSW butt joint (FBJ)		
FSW lap joint (FLJ)		

Fig 5. Photograph of Riveted and FSW Joints (Before and After Testing)

Table 4: Tensile Test Results

Sl. No	Joint configuration	Maximum load before fracture "kN"	Fracture location
1	Riveted butt joint (RBJ)	28.80	Along riveted joints
2	Riveted lap joint (RLJ)	29.80	Along riveted joints
3	FSW butt joint (FBJ)	51.50	TMAZ/SZ
4	FSW lap joint (FLJ)	50.20	TMAZ/SZ

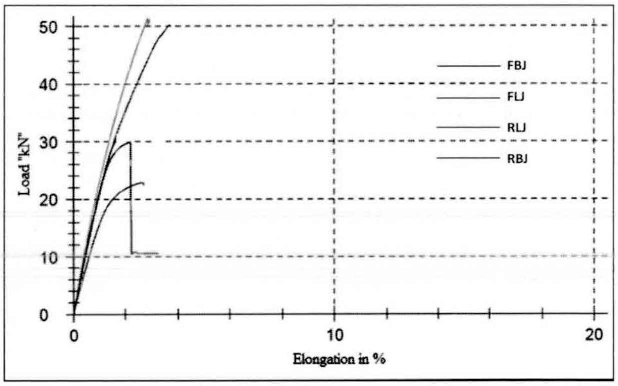
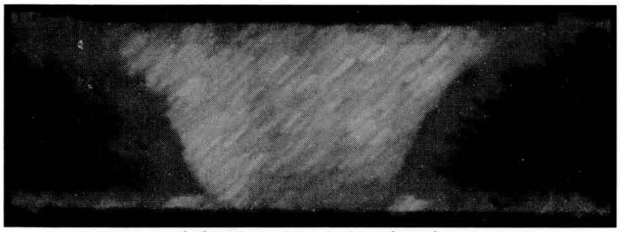


Fig 6. Comparison of Load vs. Elongation Graph of FSW and Riveted Joints



(a) FSW Butt Joint (FBJ)

(b) FSW Lap joint(FLJ)

Fig 7. Macrostructure of FSW Joints

Fig. 7 shows the macroscopic appearance of the FSW joint. No welding defects could be observed in the joint produced by FSW process.

In the FSW process the joint quality depends on the following factors: pin profile, material flow, and peak temperature in the stir zone, stir zone formation and hook formation in the lap joint. All the FSW joints are fabricated by the utilization of frictional heat between the tool shoulder and work piece. Due to the localized heat generation and forging force resulted in good consolidation with the plasticized material in solid state, and the phase transformations that occur during the cool down of the weld are of solid state [12]. Moreover, pin profile (Taper threaded pin) plays an important role in material flow around the pin, because a large amount of the material in FSW is extruded around the pin except near the top surface, where the deformation is more complex owing to the interaction with the tool shoulder. This implies that strain rate in the stir zone is largely controlled by the tool pin profile in addition to the process parameters such as rotational speed, welding speed, shoulder diameter and tilt angle. Hence, the pin geometry (Taper threaded) is one of the most important parameter that influences the deformation mechanism of the FSW process. Here the pin used was taper threaded and when the thread rotates in favorable direction it can accelerate a strong downward metal flow [13] resulted in full bonding over the entire width of stir zone.

The peak temperature and cooling rate, experienced at any location in the joint during FSW are the most important factor that determines the microstructural and tensile properties of the weld. Because recrystallization of AA2014 aluminum alloy takes place between 200° C to 350° C. Very fine, recrystallized grains were observed in the stir zones of both the welds, due to the thermo-mechanical action of tool shoulder and forging force. During the FSW cycle, the entire needle like precipitate (Al_2Cu) and rod shaped precipitates are dissolved due to the peak temperature [14]. Also, solid solution strengthening occurred in the stir zone because of higher precipitate dissolution and the nature of metallurgical bonding, superior mechanical properties was achieved. The bonding width in FSW weld is higher than that of the riveted joints. The riveted joints showed lower load carrying capabilities in both joint configurations and this is mainly due to the absences of either mechanical bonding or metallurgical bonding between the sheets. The rivets are used to lock the sheets mechanically and there is no bonding between the sheets. This may be reason for lower load carrying capabilities of riveted joints.

4. CONCLUSIONS

From this investigation, following conclusions are derived.

1. Friction stir butt joints (FBJ) exhibited 75% higher load carrying capability than riveted butt joints (RBJ);
2. Friction stir welded lap joints (FLJ) showed 70% higher load carrying capability than riveted lap joints(RJL);
3. Friction stir welded joints are stronger than the riveted joints in both configurations. This is mainly due to the existence of metallurgical bond in FSW joints.

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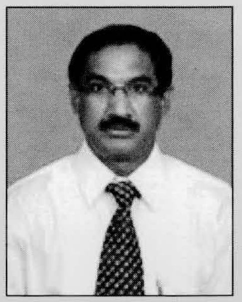

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