Thermal Parametric Study of Butt Joints Using Friction Stir Welding

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Abstract- The purpose of this study is to look at the mechanical and microstructural properties of dissimilar 2024 and 7075 aluminum sheets that have been welded together using friction stir welding (FSW). The two sheets, which were aligned with perpendicular rolling directions, were successfully fused; the welded sheets were then tested under strain at room temperature to determine the mechanical response to the materials for the parents Since the fatigue behavior of light metals is known, the fatigue endurance (S–N) curves of welded joints have been achieved. A resonant electro-mechanical testing machine load is the best performance indicator for a significant part of industrial applications; welded sheets is the best performance indicator for a big part of industrial applications. At a load frequency of around 75 Hz, a constant load ratio R = 0.1 was employed. The microstructure that formed as a result of the FSW Optical and scanning electron microscopy have been used to investigate the process, both on 'as welded' specimens and on tested specimens following a rupture

Keywords: Friction stir welding; Dissimilar materials; Microstructure analysis; Fatigue tests; Mechanical properties.

Introduction

The current aerospace and automotive industries are considering friction stir welding (FSW) technology for high-performance structural demanding applications [1]. When compared to typical welding procedures, such a joining process has been shown to minimize severe distortions and yield very low residual stresses [2–4]. The FS The weld nugget, the thermomechanical affected zone, and the external heat impacted zone are all produced by welded material. The weld nugget's microstructural grain structure is typically highly fine and equiaxed, ensuring high mechanical strength and ductility [5,6]. Indeed, several researchers have discovered that the microstructure in the weld nugget zone undergoes a continual dynamic recrystallization process [7], resulting in improved mechanical characteristics. In the FSW process, a specific tool mounted on a rotating probe moves down the length of the base metal plates in face-to-face contact, generating the plastically deformed zone through the associated stirring action. At the same time, the thermo-mechanical plasticized zone is created by friction between the tool shoulder and the top plate surface, as well as by material contact with the tool edges, resulting in plastic deformation [8]. The probe is somewhat shorter than the workpiece thickness, and its diameter is normally equal to the thickness of the workpiece [9]. This advanced method can weld aluminum alloys that are difficult to weld using typical fusion procedures (the 2XXX series alloys have limited weldability, and the 7XXX series, which is mostly used in aerospace applications, is also said to be difficult to weld. Due to traditional TIG and laser welding, dendrite structure forms in the fusion zone, resulting in a significant reduction in mechanical behavior [10]. Because the FSW method is a solid-state process, the welded metal lacks a solidification micro-structure and brittle inter-dendritic and eutectic phases are avoided [11]. Furthermore, such technology allows for the successful joining of aluminum-based metal matrix composites, as problems associated with reinforcing particle debonding are avoided, and the welded material results in a recrystallized microstructure with improved mechanical properties compared to the parent material [12]. Other important factors are the presence of brittle solidification phases and the production of porosity after fusion welding; the FSW technology often solves these issues. In more detail, the workpiece does not approach the melting point during FS Welding, and the mechanical properties of the welded zone in terms of ductility and strength are projected to increase when compared to traditional welding processes [13–15]. It's amazing how the FS works. Welded components have low distortion and misalignment effects, fewer residual stresses, and no defects caused by porosity; intergranular fissures and precipitate coalescences are easily avoided, resulting in dimensional and mechanical stability being maintained. Friction Stir Welding is currently mostly utilized to join similar materials; however, few systematic research have been conducted to examine the influence of material dissimilarity [16–19]. In fact, one of the most promising design challenges for the future is the requirement of the aircraft industry to replace traditional joining technologies with low-cost, high-efficiency procedures such as friction stir welding.

FSW is proving to be a valuable and promising method for dealing with structural joining issues in the automotive and aerospace industries. The need for welded aluminum structural sheets with high tensile and fatigue qualities, both in commercial and military applications, is critical. The actual demand for enhanced joining technologies for aluminum sheet alloys 2XXX and 7XXX is closely tied to the material choice for future modern aircraft. For large-scale production applications, friction stir welding technology is planned to be introduced to replace fastener, riveted, and arc welding joining methods.

Some aluminum alloys can be welded using electrical resistance techniques if the surface is thoroughly prepared and the oxide production is kept under control. FSW, on the other hand, can successfully weld most Al alloys since surface oxide production is not a deterrent to the process and no special cleaning activities are required prior to welding.

The purpose of this research is to look at the mechanical and microstructural aspects of different FS butts. Welded aluminum alloy sheets in 2024-T3 and 7075-T6 with a joining line perpendicular to the rolling direction.

METHEDOLOGY

Friction Stir Welding was used to create dissimilar 2024 and 7075 Al welded alloy sheets under the T3 and T6 conditions, respectively. Both sheets had a thickness of 3.5 mm. The longitudinal direction of the FSW line was perpendicular to the rolling direction of the 2024 alloy and parallel to the rolling direction of the 7075 alloy; this joint was chosen to simulate the most severe mechanical combination in comparison to the traditional reference welding trials found in literature, in which both sheets are welded with the same extrusion direction. The welding speed was set at 3.67 mm/s, based on previously determined optimised welding parameters; the welding tool was fixed to the revolving axle in a clockwise direction, while the backside portions were translated. The tool nib was 7 mm in diameter and 2.8 mm in length, with a 25 mm shoulder machined perpendicular to the tool axis and a 38-degree tilt angle.

A Vickers indenter with a 200 gf load was used to measure the Vickers hardness profile of the welded zone on the weld cross-section for 15 seconds. Mechanical testing were carried out on calibrated specimens measuring 40 mm in length and 16 mm in width. Electrical Discharge Machine was used to obtain all of the specimens (EDM). The applied axial load was parallel to the weld line. To assess the static characteristics of the welded connections, tensile tests were carried out. They were carried out at room temperature with an MTS 810 servo-hydraulic testing equipment with a load capacity of 100 kN, a cross-head speed of 0.15 mm/min, and an accurate extensometer of type MTS 634.12F-24, 25 mm base length, according to the ASTM-E8 standard code.

High cycle fatigue tests have been performed on a resonant electro-mechanical testing machine in order to accelerate the testing time up to 250 Hz wave loading control. The TEST-TRONIC 50G25 kN, produced by RUMUL has been used.

Axial stress amplitude control mode (R=0.1) was used for the fatigue tests. The working frequency was 75 Hz because to the specimen compliance installed in the flexible grips. All of the tests were completed to failure, and the specimen design complies with industry standards (the welded profile was not polished). To analyze the grain structure of the welded zones and allow optical microscope characterization, the important rupture surfaces were successively produced using standard metallographic procedures and etched with Keller's reagent. In addition, a scanning electron microscope equipped with a field emission gun (type JEOL-JSM 6500 F) was used to observe the specimens' fracture surfaces under monotonic and cyclic loads, as well as the microscopic morphology and defects of the welded joints, as well as the mechanics involved during tensile and fatigue failure.

RESULTS

The dissimilar materials 2024 and 7075 aluminum alloys were successfully connected using the FSW Process in this investigation, with no obvious superficial porosity or macroscopic flaws on both the top and rear welded surfaces.

On the welded specimen cross-sections, light microscopy observations revealed that the FSW Process applied to dissimilar 2024 and 7075 aluminum alloys revealed the classic formation of the elliptical 'onion' structure in the Centre weld, which is confirmed by the microstructure with fine recrystallized grains. Optical microscopy can also be used to identify the Thermomechanical Affected Zone (TMAZ). The micro hardness profile along the FS Weld, which reaches a value of 150 Hv at the Centre weld; the micro hardness profile grows on both the 2024 and 7075 sides, then begins to decrease after 2 mm from the Centre, until it reaches the hardness corresponding to the parent materials. In comparison to both the 2024 and 7075 parent material sides, the welded joint hardness in the HA Zone assumes lower values; this is in line with the typical behavior of aluminum alloys welded by FSW.

The 'nugget' zone, which comprises of fine and equiaxed grains, is depicted in Figure 3 at a distance of 2 mm from the weld Centre on the AA2024 side. According to all of the FSW literature data for aluminum alloys, greater temperatures and extreme plastic deformations result in noticeably smaller grains than the base metal; the parent materials' initial elongated grains are mechanically changed to a new equiaxed thin grain structure. The optical micrographs of the recrystallized zones at higher magnifications reveal exceedingly tiny and equiaxed grains. When the grain dimension is focused away from the weld Centre section on the AA7075 side, the grain dimension grows dramatically, and the orientation becomes less equiaxed. A considerable number of resident parent material grains begin to develop at a distance of 4 mm from the weld Centre. This area correlates to the Heat Affected Zone, which has a poor hardness compared to the base metal. In reality, as Jata et al. [4] point out, the precipitates in this location are coarsened. Because of the low temperature field created by the Friction Stir process, no recrystallization appears to occur in the region close to the nugget, i.e. TMAZ.

Figure 1 At a distance of 2 mm from the weld Centre of the examined joints on the AA2024 side, fine recrystallized grains were seen.

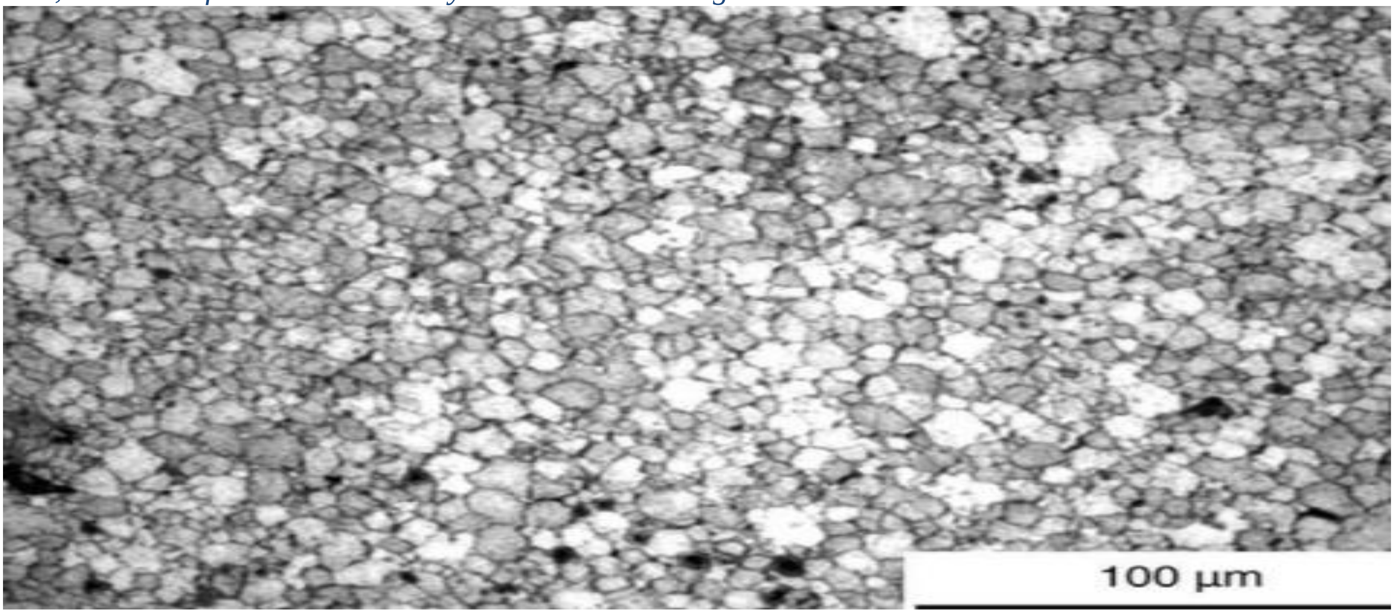

Figure 2(a) depicts the deformed grains in the TMAZ and its surrounding regions, whereas Figure 2(b) demonstrates that the grain size is identical to that of the base metal. In low ranges, however, the HAZ's hardness is limited. In the FSW zone of the 2024 alloy side of the weld, similar microstructural behaviour was found.

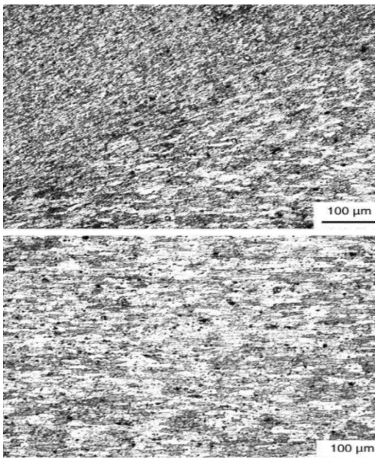

Figure 2 TMZ zone grains (a) and parent material grains (b) on the AA7075 side: the grains dimensions variation in the examined joints is readily visible.

After yielding, the joints have excellent ductile qualities, and the Ultimate Tensile Stress has stabilized at high values. Despite this, the FS The mechanical results are extremely good considering the extreme conditions to which the materials are subjected during the Friction Stirring process. Welded specimens show lower proof stress at 0.2 percent and limited total elongations with respect to the base metals; the mechanical results are extremely good considering the extreme conditions to which the materials are subjected during the Friction Stirring process.

All of the specimens fractured towards the 2024 material side, near the weld HAZ zones. This is consistent with the behavior of dissimilar welded sheets, in which, due to grain dimension variations and precipitates concentration at the interfaces, the mechanical response of the centre weld is higher than the parent material and the HAZ from a microstructural standpoint. The optical scans revealed that the mean grain equivalent diameter in the lateral zones was roughly 2.5 mm. The fatigue findings indicate the normal behavior for dissimilar aluminum sheets, with a trend of fatigue life decreasing with stress amplitude and an average slope that is particularly high even for a typical ductile alloy. Because aluminum alloys have fatigue limits at very high cycle counts (typically greater than 10^7 or even higher), but the main goal is to estimate fatigue behavior under high stress, the tests were conducted to produce rupture at relatively short times (around 10^6 cycles) rather than at a higher number of cycles. Given the small number of specimens evaluated, the fatigue curves indicate good and consistent findings, with a modest scatter band. In addition, when compared to typical alternate stress levels for the parent material at the same test frequency, the data appear to be positioned at a lower but acceptable and interesting level, given the severe and critical conditions exhibited by aluminum welded joints subjected to cyclic loading. Finally, heat treatments, re-precipitation, and hardening processes in the TMAZ can improve fatigue characteristics.

Because the influence of the microstructural morphology of the welded interfaces on the endurance time is crucial, a better knowledge of the mechanical fracture and defect nucleation properties is heavily reliant on purposed investigations of the rupture surfaces. A number of intriguing observations have been made.

At room temperature, the fracture surface of the welded 2024–7075 specimens tested under tension was covered with a large population of microscopic voids of various sizes and shapes. The material showed ductility to occur within the fracture progression, and FEGSEM observations confirmed the presence of locally ductile mechanisms.

With the rapid adoption of FSW technology in a variety of applications, investigating fatigue and fracture behavior in low and high cycle regimes is an important task for validating the process; additionally, fractography studies using high resolution instruments such as scanning electron microscopes equipped with field emission guns have been extremely useful in detecting the rupture mechanism and determining the typology and distributions of fractures.

Additional low magnification observations were made to analyze the macroscopic fracture mode; the regions of microscopic crack start and stable crack propagation, as well as the regions likely subjected to the final failure process or overloading effects, were determined.

Higher magnification observations were performed in the zones of early microscopic crack growth to identify the size, location, and number of microscopic cracks, as well as their progression in the material microstructure, to characterize the fine-scale topography and microscopic mechanisms governing fracture. However, the region of overload and eventual collapse has also been investigated in order to find fine-scale traits resembling local regulating systems.

CONCLUSION

Friction stir welding was used to successfully combine different 2024 and 7075 aluminum alloys in the form of 2.5 mm thick sheets. Optical microscopy has been used to examine the resultant microstructure, revealing the grain structure and precipitate distribution changes caused by the procedure. Finally, tensile and fatigue tests were used to evaluate the static and dynamic properties of the welded connections. Although the presence of the FSW line affects fatigue behavior, the comparison to the parent materials is acceptable, allowing the FSW to be considered as an alternative connecting technology for aluminum sheet alloys. Using a FEGSEM microscope, the fracture surfaces of the specimens were thoroughly examined after testing, revealing the defect type and position following the Friction Stirring process, as well as the microscopic mechanisms that happened during high stress deformations and final failure.

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