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A Productive Friction Stir-Welded Aa 6061 Joints Using Different Pin Tool Profiles Configuration to Grow Mechanical and Microstructural Characteristics

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ABSTRACT

There are six brand-new dual-pin FSW tools that are displayed, each with a unique combination of Dual Circle, Dual Triangle, Dual rectangle, and Triangle-Rectangle profiles. Combination pins in the shapes of circles, triangles and rectangles were developed. The samples with the welded joints underwent quasi-static testing, and information on stress-strain was gathered. The use of dual pin welding equipment resulted in expanded SZ and improved plastic flow, among other micro-structural changes. The highest tensile strength and ductility were found in the weld connections made using Dual Triangle and Rectangle-Triangle tools. This investigation looks at the effects of tool shapes on the tensile characteristics and micro-structural components in the stir zone and heat-affected zone of friction stir-welded Al 6061 joints.

INTRODUCTION

In order to create the weld connection, friction stir welding (FSW) employs a heat process and considerable plastic deformation [1]. There are several factors that affect heat generation and material flow, but tool form and process parameters are the most crucial ones [3]. It has been established that tool design is the most important factor in heat generation and material movement during the FSW process. The temperature of the materials being welded is never raised throughout this welding process. The essential elements of the friction stir welding process are heat generated by friction and material movement [2]. Two typical Friction stir welding tools are a shoulder and a pin. The weld quality, mechanical properties, and molecular structures of Friction stir welded are all improved with appropriately built welding equipment [4, 5]. A well-designed tool will increase plastic flow, reduce defects, and enhance the mechanical properties of the Welded joints and its surroundings.

There have been studies on the influence of tool shape on the mechanical characteristics of Al 6061-T6 Friction stir welded [6]. They used a range of tools, including straight cylindrical pins, square-shaped pins, triangle pins, tapered cylinder pins, and thread cylindrical pins. They discovered that samples with square- shaped pin welding had samples with better mechanical qualities. [7]. The mechanical characteristics of a number of Friction stir welded constructed of Al 2024 and Al 5083 were examined in relation to tool form. They came to the conclusion that the tapered hexagonal tool pin was what caused the highest tensile strength and elongation [8]. A variety of welding apparatus with pin geometries in the following shapes square, hexagonal, octahedral; cone, and square cone were inspect. The researchers discovered that joint samples welded using a square-shaped pin at 950 rev min^1 obtained the maximum mechanical strength of various Friction stir welded. [9]. The result demonstrated that a welding tool with a conic-shaped pin had greater ultimate tensile strength (UTS) and elongation when compared to a tool with a typical cylindrical pin [10]. The joint strength of tools with basic cylindrical pin shapes and threaded pin forms was examined. They claimed that a welding tool with flat surfaces and a cylindrical pin-like form had the best UTS [11]. Fused Al 6061 joint samples were created

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using an FSW technique and tools with square, triangular, and hexagonal geometries. They discovered that while the tool with a hexagonal pin form generated greater hardness values and more refined microstructures in the stirred zone, the tool with a square pin shape produced the greatest UTS in stir zone. Joints made of Al 6061friction stir welding looked at the effect of pin shape on plastic flow [12].

Using seven different pieces of welding equipment, they conducted experiments and found that circular welding tools offered more material flow than noncircular welding tools [13]. They discovered that the smaller area at the pin's cone-shaped tip did not agitate the material at the bottom of the work piece. studied how Al 2024-T4 alloy FSW joints' plastic flow was impacted by tool shape. Three tools with identical shoulders but various pin profiles were produced (rectangular, triangular, and round). The culprit was shown to be the triangular-shaped pin, which caused the most plastic flow in the work piece, altered the Stir Zone microstructures, and enhanced joint quality [14]. Researched the influence of tool geometry parameters on the mechanical properties and microstructures of two unique Al 6061 and Al 7075 FSW joints. They found that the highest mechanical strength was provided by rectangular pins, followed by circular and triangular pins. [15] Created an oddball dual-pin tool with a circular form for joining different materials. At all rotational speeds, they discovered that utilising a dual-pin tool improved mechanical characteristics and grain refit by increasing plastic flow and reducing defect density in the SZ.

The purpose of this research is to investigate the tensile properties of Al 6061 joint samples made using the FSW technique as well as how the design of the dual-pin tool affects joint strength. There were six different types of dual-pin tools utilised, each with a different combination of pin shapes, including dual circle, dual triangle, dual rectangle, circle triangle, circle rectangle, triangle rectangle. Investigated was how the geometry of the welding tool affected the micro-structural and mechanical features of FSW joints.
Despite the substantial research on the impacts of pin geometrical parameters on the mechanical properties and micro-structure of Friction stir welded, there are still approaches to enhance weld quality by using unique techniques. In comparison to single-pin tools, dual-pin tools make material deformation inside the SZ more visible, and connections produced with a dual pin tool could be able to withstand larger stresses. The pin tool profiles is essential for the development of tensile characteristics and grain refinement.

EXPERIMENTAL METHODS

The main components of the precipitation-hardened alloy of aluminium 6061-T6 are silicon and magnesium. Owing to its favourable weldability and corrosion resistance, this alloy is perfect for structural uses such as boats, pipelines, and leisure products. Al 6061-T6 has the following specifications: yield strength of 268 MPa, percentage of elongation of 70 GPa, UTS of 330 MPa, and elongation of 17%.

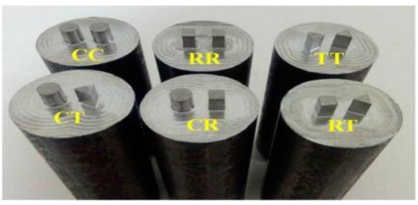

Figure 1. Dual-pin tools with different pin shapes.

Large Al 6061-T6 sheets measuring 100 x 10 x 5mm were sliced into smaller specimens. The plate samples were polished using a variety of sandpapers with grits ranging from 220 to 1200 to limit the danger of producing aluminium oxide and volume flaws in the SZ before the FSW operation [16]. To avoid distortions during the welding process, the samples were positioned next to one another in a predesigned fixture and firmly fastened. Using a tool tilt angle of 2°, a transverse speed of 60 mm min1, a rotational speed of 1180 rev min, and shoulder penetration of 0.1 mm, the FSW method was performed.

WELDING TOOLS

Hot-work tool steels with a 5% chromium content that could survive high temperatures were used to construct various eccentric dual-pin welding tools. There have been several designs and configurations made for two-pin tools, including dual circle, dual triangle, dual rectangle, dual circle-triangle, and dual triangle-rectangle pin combinations. Figure 1 depicts the FSW dual-pin instruments used in the current investigation.The triangular, octagonal, and round pins were all positioned in a circle with a 3.5 mm circumference. On each dual-pin tool, the space between the two circles was maintained at 6 mm. Figure 2 displays the size, shape, and tool nomenclature of each pin. In Figure 2, the dynamic volume is the area swept by the pins as the dual-pin tool rotates during the friction stir welding, and the static volume is the volume filled by each tool's pins. (d).

For a number of instruments, the ratios of dynamic volumes to static volumes are shown. The shoulder's diameter and pin's length on welding equipment were 18 and 4.7 mm, respectively. On a CNC milling machine, dual-pin tools were made, and their hardness was increased by heat treatment. Tools were warmed to 850 degrees Celsius and steel was austenitized at 1032 degrees Celsius and quenched in oil.

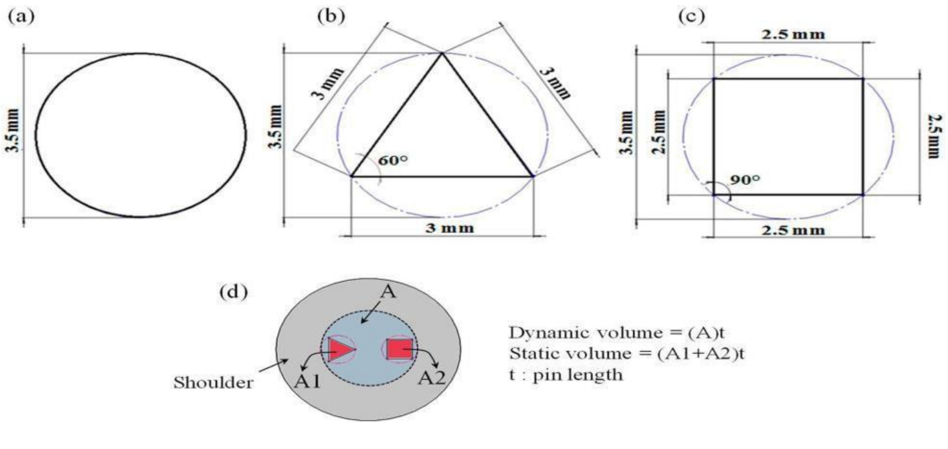

Fig 2. Geometric views and dimensions of (a) circular pin, (b) triangular pin, (c) square pin, and (d) terms used for a typical dual-pin tool.

TENSILE TEST AND MICROSTRUCTURE

The research findings are the average of three samples from each series of examined welded sheets. The schematic view of welded sheets and tensile test samples is shown in Figure 3. A 25 KN in ASTM machine was used to test the tensile strength of the joint sample. The hardness of the weld areas was then assessed using the Vickers testing instrument using a 50 g indentation force for 30 seconds.

The joint samples were subjected to metallographic tests to examine the macro- and microstructure of the weld areas. Using a Keller solution composed of 95% weight clean water, 1% weight HF acid, 1.5 weight hydrochloric acid, and 2.5 weight nitric acid, the joint sample was polished before being subjected to etching. The etching solution was left on the weld cross-section for 30 seconds. Hardness tests were carried out after the cross-sectional regions of the welded samples were polished with sandpaper. 16 measurements were taken in the weld section at 1.5 mm depth, perpendicular to the weld seam, at 1.5 mm intervals, to record the hardness distribution for each sample. The positions of the hardness test findings in the samples' cross-sectional area are visually represented in Figure 4.

RESULT AND DISCUSSION

The sample surfaces that were welded results Figure 5 displays top surface angle scanning electron microscope of joint samples produced using various dual-pin tools and FSW operation. Using the Dual Triangle, Dual Rectangle, CT, and RT techniques, it was discovered that the surfaces of welded samples were defect- and void-free. But there are certain problems with the samples made using the Dual Circle and CR tools, which are brought on by a lack of surface filling. When the plastic flow volume and temperature of the weld nugget are outside of the optimum parameters, wormhole flaws form [2].

The CC and CR tools have larger static volume than conventional tools, resulting in more friction between the pin walls and the material within the SZ. Larger material contacts, friction, and an increase in SZ temperature all contributed to material softening. [4]. the pins' form and eccentricity determine the dynamic volume or static volume values, and therefore, the dynamic volume to static volume ratio of the tools. The peak temperature of the welding process reduced as the dynamic to static volume ratio increased [17]. The dynamic volume to static volume ratios of joints created with Dual Circle and CR tools are smaller, and plastic flow is focused along the weld's centre-line, increasing the temperature at the weld's top surface.

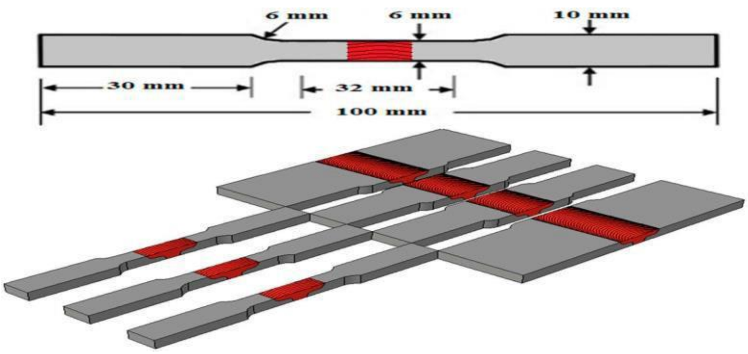

Fig 3. Schematic view of welded sheets and cut tensile test samples.

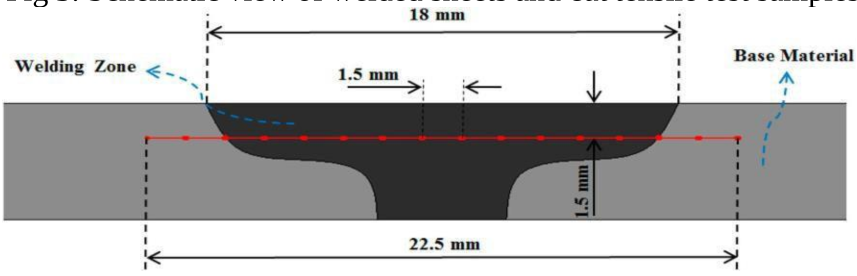

Fig 4. Schematic view of the locations of the hardness test measurements in the cross-sectional area of the joint sample.

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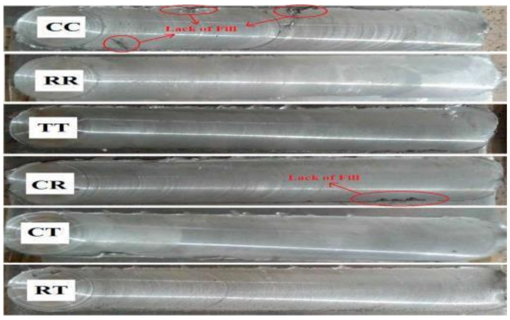

Fig 5. The top surface view of welded specimens with different dual-pin tools.

TENSILE TESTS RESULTS

The stress-strain curves of the FSW joint samples are contrasted with the stress-strain curve of the base metal Al 6061-T6 in Figure 6. The curves shown in this picture are the average outcomes of three test samples that were put through the paces of typical tensile testing. The design of dual-pin tools has a noticeable impact on stress- strain curves. The tensile strength and ductility of welded samples are greatly impacted by the dynamic volume to static volume of tool ratio, per the test findings. The dynamic volume to static volume ratio indicated in figure7 was found to be consistent with the tensile test outcomes for various welding devices.

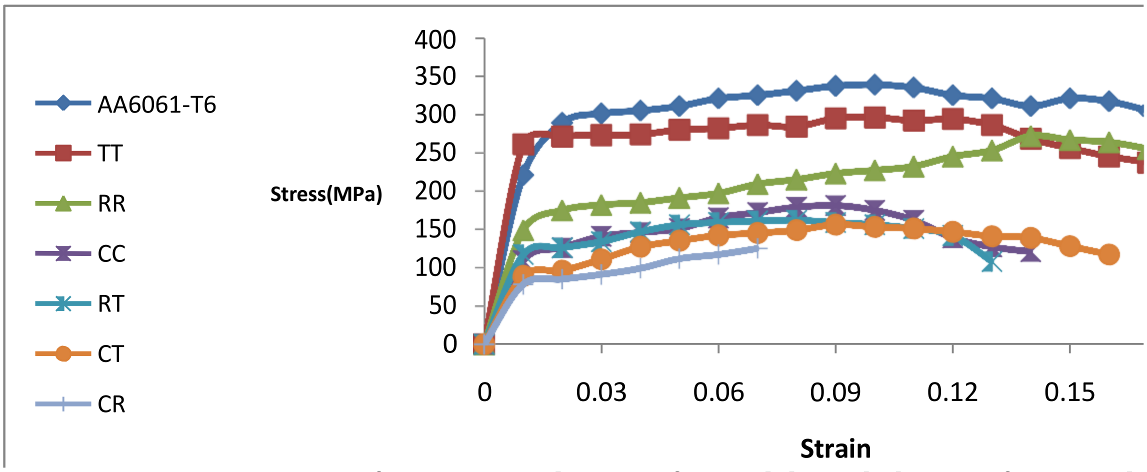

Fig 6. Stress–strain curves for FSW samples manufactured through the use of various dual-pin tools.

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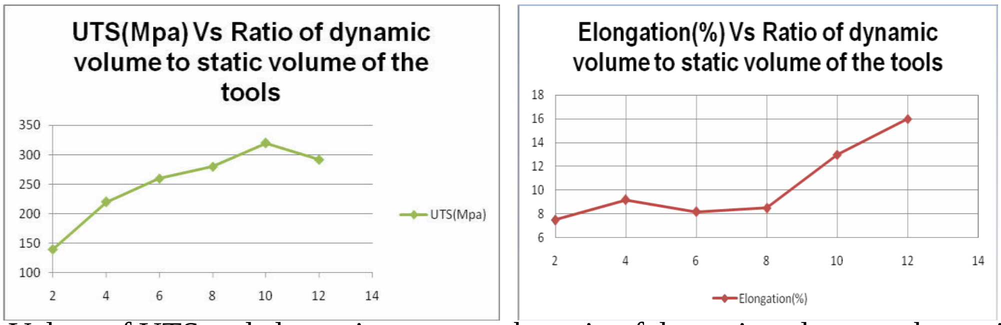

Fig 7. Values of UTS and elongations versus the ratio of dynamic volume to the static volume of the tools.

The changes in UTS and elongation in response to the dynamic volume to static volume ratio of the tools are shown in Figure 7. Overall, the UTS and elongation of welded joints both improved as this ratio grew. While the elongation magnitudes grew dramatically across the tool ratio range of 4–5, the UTS values remained essentially constant.

Tensile strength and ductility values were found to be highest in joint specimens produced by the TT and RT tools with the highest value of this ratio. On the other hand, joints that were welded using the CC and CR tools with the lowest ratio value had poorer strength and elongation. Similar results using tools with offset pins on the Welded joints of Al 5083-O alloy were reported in the literature [17]. The UTS and elongation values of joint samples that were tensile tested using various dual-pin instruments are shown in Figure 8. The TT and RT techniques were used to weld the joint samples in this figure, which led to greater UTS and elongation values, which suggest increased strain energy density. For joint samples welded with a CC tool, the product of UTS and elongation corresponds to the lowest strain energy density.

In contrast to the UTS values for the TT and RT specimens, which were 92 percent and 78 percent of the base metal, respectively, the elongation for the same specimens was 90 percent and 98 percent of the base metal. Ductility in welded samples manufactured using tools Dual Rectangle, CR, and CT had nearly the same strength, with 50-54 percent of the strength of base metal. The Dual Circle samples had the lowest static strength and ductility with 51 and 44 percent of the base metal, respectively. Figure 8 demonstrates that dual-pin tools with at least one triangular pin were used to weld the joint samples with the highest static strength and ductility.

During the FSW process, tools with non-circular pins caused impulses in the plastic flow in the SZ. This increased the SZ's plastic flow and strain rates. This effect has been used to refine the grains in the microstructure of aluminium alloys, leading to increased strength [18–20]. Joint samples welded with triangular or rectangular pins showed improved mechanical characteristics compared to equipment with circular pins because of their non-continuous pin form and longer impulses within the SZ. The joint samples under examination have a broken weld seam. The fracture pattern of the samples was unaffected by the use of different dual-pin tools.

MICRO-HARDNESS

It was found that the soil in the SZ was tougher than that in the HAZ. This is due to full dynamic recrystallization within SZ, which enhances the microstructure in this area. The HAZ showed the lowest hardness values for the materials under study, ranging from 60 to 80 HV. Distance affects how challenging anything is. Figures 9 and 10 depict, respectively, the range of hardness in joint samples welded by comparable and unique dual-pins. As shown in these data, the heat-affected zone (HAZ) and SZ suggest a consistent

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distribution of measured hardness values of joints samples welded by different dual-pin tools. This design is related to single-pin tool designs [2, 21].

For the materials under examination, the HAZ exhibited the lowest hardness values, ranging from 60 to 80 HV. The hardness values increased as they neared the region of the base metal. The Dual Circle tool produced the Stir Zone specimens with the lowest hardness values, whereas the Dual Triangle tool produced the greatest hardness values. The hardness values of joints welded by the Dual Circle tool pin in the Stir Zone were strikingly similar to those of HAZ, in contrast to joints welded by the Dual Triangle and Dual Rectangle tools. This is due to the tool's inability to build microstructure refits inside SZ. Within HAZ, the micro-hardness values of the specimens made by tools with different pins of CT, CR, and TR were relatively similar. There are different hardness levels on the forward and backward moving joint sample sides. Figure 11 displays the average hardness values of joint samples from both the retreating and advancing sides at different weld sites.

Joint samples inside HAZ have an average hardness that is greater on the retreating side than the advancing side. For FSW aluminium joints, similar hardness findings were discovered [22, 23]. It was found that joint samples manufactured with non-circular pins had micro-hardness that was greater than joint samples made with circular pins.

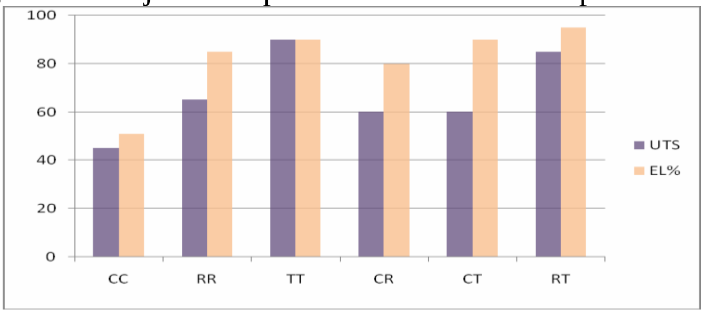

Fig 8. UTS and elongation of joint samples tested with different dual-pin tools.

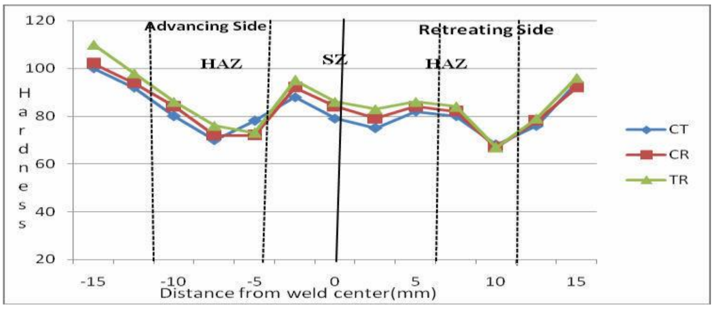

Fig 9. Micro-hardness distribution in the specimens fabricated by the tools with similar pins.

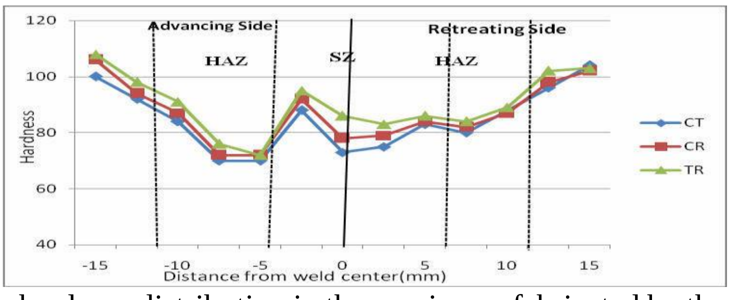

Fig 10. Micro-hardness distribution in the specimens fabricated by the tools with dissimilar pins.

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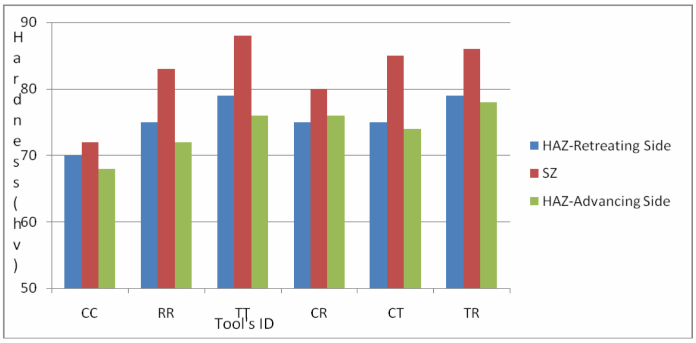

Fig 11. Average hardness values of joint samples in different weld regions in both advancing and retreating sides

MICROSTRUCTURES

The cross-sectional portions of the joint samples were macro graphed. Figure 12 illustrates the SZ and HAZ of welded samples utilising various dual-pin tools used in the current experiment. Investigations of various weld sites and flaws within these regions were extensive. The borders between SZ and HAZ are marked in this diagram by the red broken lines. The HAZ of the welded zone and the base metal are divided by a straight broken line.

From the top to the bottom surface of joint samples, the SZ area is essentially the same in this file. This results from the constant dynamic volume and shoulder diameter of the tools. On the bottom advancing side of the joint sample welded using the Dual Circle tool pin profile; a 200-meter-long wormhole fault could be seen. This defect results from inadequate material penetration in the bottom half of the SZ and insufficient vertical material flow. According to a joint sample welded using the CR tool, a gap of 150 m in diameter was created in the top retreating side of the SZ, which was related with the top surface fault of this joint. In contrast to Dual Circle and CR tool pin profiles

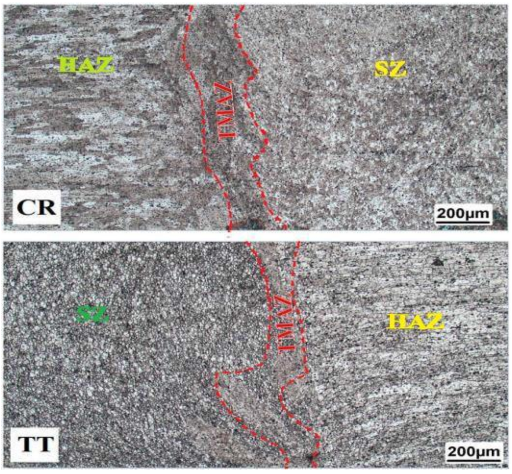

Fig 13. Microstructural features for different weld regions through CR and TT tools.

The TMAZ boundary region developed during the FSW operation at higher temperatures and as a result of consistent deformation. The main cause of the plastic deformation in this region is the current material flow caused by the tool's shoulder. FSW tools produced welded regions with uniform and constant zones and no volume defects. Figure 13 displays the boundaries of various weld regions produced by the CR and Dual Triangle toolsThis graphic shows how to identify between SZ, thermo-mechanically affected zone (TMAZ), and HAZ zones in welded connections using CR and Dual Triangle tools. In these connections, there is no sign of recrystallization in the weld HAZ. Contrarily, grains saw a little growth in this region.

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During FSW operation, the area of the TMAZ exposed to larger temperature gradient and plastic deformation was increased, leading to dynamic recrystallization and considerable microstructure alterations in this area.

The shoulder creates both horizontal and vertical movement in this region. Since the shoulder of every tool under investigation is the same, the pattern of deformation in this area is essentially the same and constant for all joint samples. Both a shift in grain size and a partial recrystallization occurred in this region. Both the CR and TT procedures improved the grain structure in SZ, which raised the joint sample strength. Using Image J software, Figure 14 displays the typical grain size in the SZ, TMAZ, and HAZ of joints welded with different dual-pin tools.

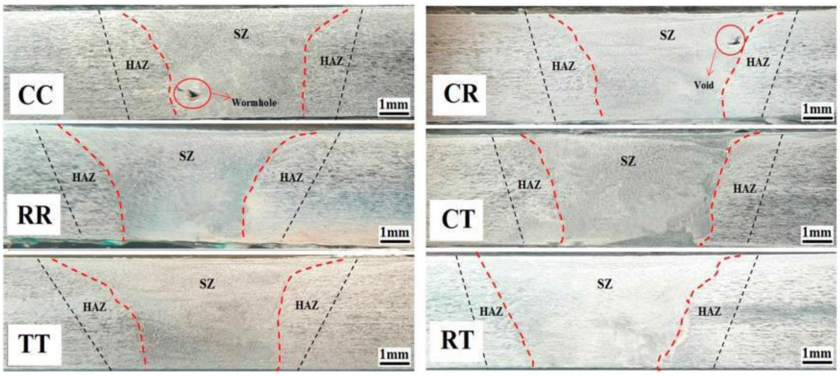

Figure 12. Macrographs of welded joints through the use of various dual-pin tools.

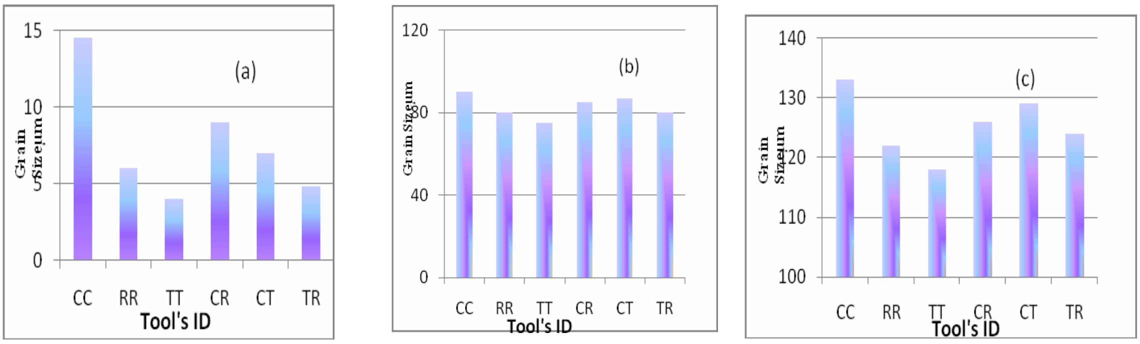

Fig 14. Average grain size for samples welded through use of various dual-pin tools within: (a) SZ, (b) TMAZ, and (c) HAZ.

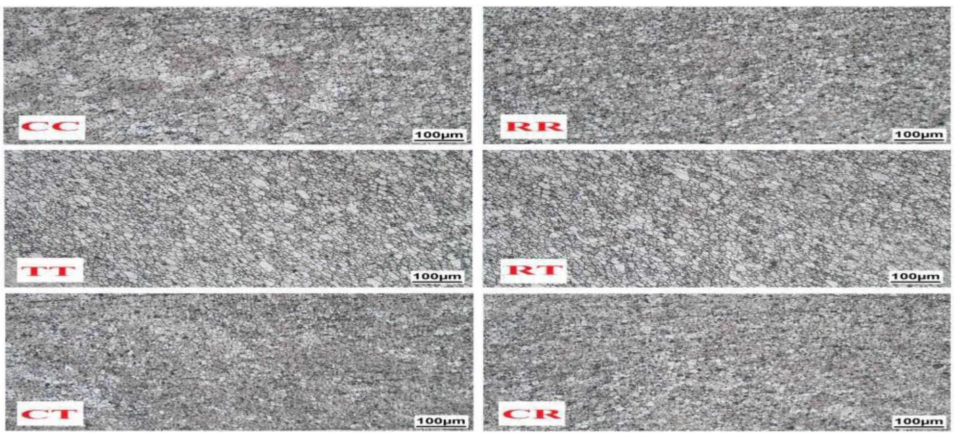

Fig 15. Microstructures of the SZ for joint samples welded by various dual-pin tools.

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According to Figure 14, the SZ had the smallest granules, whereas the TMAZ and HAZ had larger ones. The SZ, TMAZ, and HAZ of the welded samples had grain sizes of 4–12 m, 80–96 m, and 118–132 m, respectively. Due to the lack of considerable plastic deformation and micro-structural variations, the grain sizes in Heat Affected Zone were almost comparable to those in the parent metal. In joint samples that were welded utilising Dual Circle and Dual Triangle tools, respectively, the greatest and smallest grain sizes in weld zones were discovered. Joint samples welded using Dual Triangle tools demonstrated greater strength and hardness values inside the weld regions. Figure 15 depicts the growth of grains inside SZ in joint samples created using various welding techniques and FSW operations. The samples entirely recrystallized as a result of the tools Dual Triangle and TR, producing a consistent micro-structural pattern in their Stir Zone . It was discovered that the increased mechanical strength and hardness values closely matched the micro-structural reorganisation and uniform grain distributions depicted in Figure 15. The grain growth was not homogenous even though the recrystallization process occurred in the joint samples welded using different methods.

The variation in grain size between these samples Stir Zone s is clearly illustrated in Figure 15. One of the key factors in determining the mechanical properties of FSW joints, the formation of grains inside the Stir Zone, had a detrimental effect on the strength and hardness of the joints. This research main goal is to examine the weldability of Al 6061-T6 sheets using different-shaped dual-pin tools. Multi-pin tools have been utilised in several research to attempt and enhance the functionality of FSW joints [15, 24]. This work shows that micro- structural properties, recrystallization, and grain size development inside weld zones were significantly influenced by the shape and arrangement of dual-pin tools during FSW operation. These factors had an effect on the distribution of hardness and tensile properties throughout the weld zones. The authors feel there are more influencing factors to research in order to examine the mechanical features of joints welded employing different tool shapes in addition to the pertinent variables examined in this paper. More mechanical tests and the testing of alternative Friction stir welding tool shapes will be carried out as part of the next urgent research plan.

CONCLUSIONS

The strength, ductility, and micro-hardness of the welded samples were found to depend on the tools' dynamic volume to static volume ratio. The strength efficiency of these two joint samples was 92 and 78 percent, respectively, in comparison to base metal. The maximum elongation was seen in joint samples welded using equipment with at least one triangular pin. It was discovered that there was a constant distribution of hardness across the welded joints cross-sectional area. In Stir Zone, hardness levels were maximised, but in HAZ, hardness values were reduced to their absolute minimum. Narrative friction stir welding dual-pin tools were created and tested in order to evaluate the mechanical and tensile properties of welded seams made of aluminium 6061-T6. The micro-structural properties of welded samples, including as recrystallization, grain refit, and weld zone plastic expansion, are affected differently by different tool shapes. When the tools were used with two pins, the plastic flow in the Stir Zone increased noticeably, by selecting the appropriate welding tool pin profiles, it was possible to manage the mechanical characteristics and micro-structural components of welded connections as the Stir Zone region expanded and many weld locations underwent micro-structural refinement.

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