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Effect of tool pin profiles on surface roughness of friction stir welded 2050-T84 Al-Cu-Li alloys

The third generation of Al-Li alloy is a significant material, primarily applicable in the aerospace sector due to its low density, high strength, and increased fatigue crack growth resistance properties. In this study, three tools with different pin geometries, such as triangular, threaded taper, and hybrid tool pins (coupled triangular and threaded taper), are used to join Al-Li alloy at a specific set of process parameters to assess the tool design affects the joint's surface roughness (SR) and tensile strength. The surface roughness values of the friction stir welded samples were measured on different sides [advancing side (AS), retreating side (RS), AS to RS, and the weld centre (WC)]. At the same rotational speed (1400 rpm), welding speed (180 mm/min), and tilt angle (2°), the experimental results revealed that the HTP weld has a lower surface roughness value than other tools while having higher joint efficiency (78.44%) and tensile strength (418.98MPa).

Keywords : 2050-T84Al-Cu-Li alloy; friction stir welding; tool pin profile; surface roughness; tensile properties.

1.0 Introduction

Amidst the presence of Al alloy, the third generation of Al-Li alloy shows its utility in the structural components of aerospace, automotive, shipbuilding, and defence industries due to its lightweight and improved material properties over the 2×××, 6×××, 7××× series of aluminium alloy [1,2]. The aerospace-grade Al-Cu-Li alloy exhibits reduced density, higher stiffness to density ratio, improved strength, higher corrosion resistance, better fatigue, high toughness, and crack growth resistance with improved damage tolerance [3-5]. The presence of Li in Al-Cu-Li alloy improves the alloy's properties compared to Al alloy. Joining Al-Cu-Li alloys through conventional welding produces numerous defects like loss of the Li element, porosity, lack of fusion, stress corrosion, low penetration, oxide layer formation, cracks, etc. To solve this issue, the FSW process was used to join the material at solidus temperature and eliminate all defects associated with conventional welding [6]. A non-consumable friction stir rotating tool generates frictional heat by the relative motion between the stir tool and the base material to join the base metal plates during the FSW process. The generated heat during FSW softened the material by plastic deformation, resulting in minimal roughness in the weld bead appearance compared to traditional welding. [7]. The morphology of surface integrity is attributed to the SR, which causes the deterioration of the surface quality of welded workpiece, ultimately leading to the failure of the component. The reduced SR of the weld bead specimen helps enhance the welded sample's mechanical properties. The surface quality of the weld bead structure may affect the material's performance in industrial applications.

Several researchers have observed the effect of different tool pin profiles on SR and tensile properties of friction stir welded (FSW) 2050-T84 Al-Li alloy. However, the area of natural frequencies remains unexplored. Zuo et al. [8] discussed the effect of threaded taper tool on surface topography and SR at varying TRS (600-1400 rpm) and TTS (80-160 mm/min) of FSWed AA7075 alloy plates. The SR value and space of arc texture were lowest at TRS-1400 rpm and TTS- 120 mm/min. Boulahem et al. [9] observed that the lower SR (3.61 μm) was observed at higher TRS, lower TTS and small er shoulder dia. Sicilan et al. [10] reported a methodology to analyze the surface features and roughness with different process parameters (TTS and TRS) in FSW. The lower SR value (4.09 μm) is observed at TRS-1000 rpm and TTS-56 mm/min. Dawood et al. [11] used a straight cylinder tool to join AA6061 alloy plates and found the highest mechanical properties (tensile strength and microhardness) at low SR (37nm). Kumar et al. [12] investigated the SR of an abrasive water jet machined workpiece (AA6061-T6 alloy), joined by FSW and observed the better joint quality and minimum SR at TRS-500 rpm and TTS-40 mm/min. Budin et al.[13] observed that the straight cylinder tool provides the best surface finishing and extremely lower values of SR

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TABLE 1: CHEMICAL COMPOSITION OF THE MAIN CONSTITUENT ELEMENTS (WT%) OF BASE MATERIAL 2050-T84 Al-Cu-Li ALLOY

Cu	Li	Ag	Mg	Mn	Zn	Zr	Ti	Al
3.6	0.98	0.48	0.38	0.32	0.12	0.08	0.03	Bal

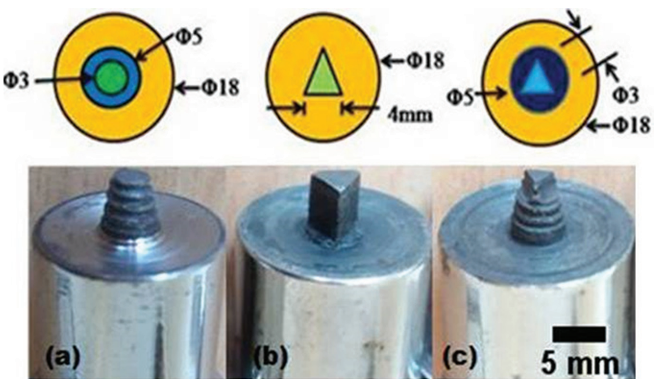

Fig.1:. Different friction stir tools were used for the experiment; (a) a taper threaded tool (b) a triangular tool and (c) The hybrid tool pin (HTP)

(1.85μm) among other tool pin profiles (straight cylinder, triangular, and tapered). Bhusan et al. [14] used simple cylindrical pin profile to joining the material and achieved higher tensile strength at low SR (6.84 μm).

The above discussion significantly reports the influence of tool pin profiles on the SR of FSW specimens. However, there is still a need for a comparative study on HTP and different conventional tools (triangular and taper threaded) on the SR and tensile strength of the FSW Al-Li alloy. The motivation for studying the effects of different tool pin profiles on the welded samples. This study aims to assess the effect of different tool pin profiles (HTP over other conventional tool pin profiles) on surface roughness (SR) and tensile properties of 5 mm thick FSW of third generation Al-Li alloys at constant process parameter conditions.

2.0 Experimental procedure

The base plate material (AA2050-T84), whose dimensions are 75 mm × 60 mm × 5 mm, is joined parallel to the rolling direction by friction stir welding (3T, Model-WS005) in a butt joint configuration. The chemical composition of each element percentage weight in the base material is enlisted in Table 1. The welding tool used in the current work is made of H13 steel with a hardness of 56 HRC. The selection of process parameters and tool pin geometries are based on previous published papers [15-17]. The different tool pin geometries, i.e., taper threaded tool, triangular tool, and hybrid tool, as shown in Fig.1, were used to join the base material at a constant tool rotational speed (TRS) of 1400 rpm, a welding speed (TTS)of 180 mm/min, and a 2° tilt angle (TTA).

The base plates of alloys were cleaned properly before welding using acetone and fixed on the machine bed for joining the material. Samples were sliced perpendicular to the welded direction from the welded samples to explore the SR and tensile strength of the welded specimen. The SR testing apparatus (Matsuzawa, model: MMT-X7B) measured the SR in AS, RS, WC, and in the direction from AS to RS. A 10 mm width sample was extracted from the welded sample to measure the surface roughness value of welded samples. The SR measurement was performed opposite to the traverse speed of 8.1 mm shown in Fig.2(a) and Fig.2(b). Using surface

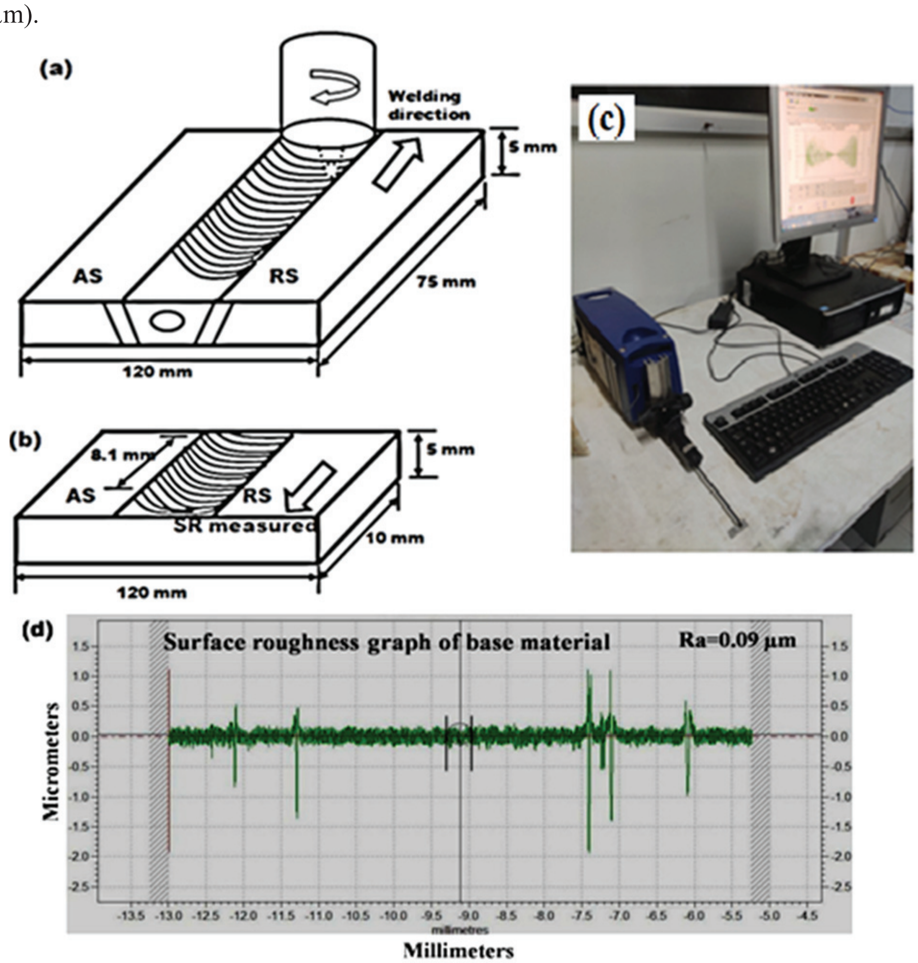

Fig.2: (a) Friction stir welded specimen (b) direction of measurement of surface roughness (c) set up of surface roughness tester machine (d) roughness of the base material.

tester equipment is also shown in Fig.2(c). The surface roughness value of base material is measured 0.09 ìm is depicted in Fig.2(d). For precision, three dog bone-shaped tensile samples were generated from each welded specimen according to the ASTM-E8 guideline, and tensile tests were performed at room temperature with a strain rate of $0.008s^{-1}$, and an experiment was conducted on Instron-1195.

3. Results and discussion

This section describes the influence of different tool-pin geometries (HTP and conventional tool pin) on surface roughness and tensile properties of FSW sample joints. All-welded specimens' surface roughness (at WC, AS, RS, from AS to RS) is measured in the opposite direction of the welding for better results.

4.0 Surface roughness analysis of weldment

Fig.3 shows the average surface roughness of the various region of the weld bead such as weld centre (WC), AS, RS and AS to RS formed by the different tool geometry under the same conditions (i.e., constant TRS, TTS, TTA, plunge depth). The surface roughness when observed on the arc texture is different due to the different texture of the welded surface, and it may be due to the use of different tool geometries. The middle portion of the joint is called the weld centre; it is smoother and more homogeneous than other region due to stirring action of the tool and generally has less surface roughness. But while performing experiment with a different tool, a lot of Al alloy gathered on the weld bead centre and provided a higher surface roughness value in NZ than AS and RS. Guerra et al. and Shah et al. [18,19] also reported that the plasticized material shifted from AS to RS, which affects the material's consolidation during FSW. A relative figure of surface roughness value (AS, RS, the weld centre (WC) and AS to RS) of all-welded samples at the zone and different sides have been enlisted in Table 2.

The unique HTP identified the lowest surface roughness value, whereas the triangular tool found the maximum. It could be related to the pin profile's geometry, which plays a crucial role in material deformation, softening, and movement. The weld bead surface texture is affected by the tool pin shape. Different tool pins generated different amounts of heat-induced and flow ability of softening material generated during FSW, which influences the surface roughness. Because it has a more significant sweeping volume [20], the triangle pin profile exerts more effort to distort the material, generating more frictional heat. The softening materials have less cooling time to consolidate the plasticized material due to higher TRS and TTS. However, the case is similar to HTP, but due to the presence of a threaded taper tool, the groove of the threaded taper tool provides better mixing and movement of the softening material after deformation, and an adequate amount of heat is generated during the interaction between tool pin and workpiece. The surface roughness values of AS are better than the weld centre and TMAZ (RS) because of high torque and higher frictional temperature generated in AS, which provide better material distribution during FSW. However, better surface roughness value is achieved in AS to RS direction as compared to another zone. It may be due to the softening material movement in the same direction i.e., AS to RS, providing better surface roughness.

TABLE 2: THE SURFACE ROUGHNESS VALUE OF WELDED SAMPLES AT DIFFERENT REGION

Tool pin profile	AS (μm)	WC (μm)	RS (μm)	AS to RS (μm)
Triangular	3.39	5.79	5.02	2.59
Taper Threaded	3.04	4.24	3.44	2.21
Hybrid	2.75	3.15	2.90	1.97

5.0 Tensile strength analysis

Fig.4 shows the effect of different tool geometries on the tensile properties (tensile strength, percentage elongation, and joint efficiency) of welded Al-Li alloy at constant parameters [TTS-180 mm/min, TRS-1400 rpm, and TTA-2°]. Due to changing temperature gradation and material deformation during FSW, the tensile qualities of welded samples created with different tool pin profiles have different tensile values. It has been observed that the HTP achieved a higher tensile strength (418.978MPa), % elongation (10), and joint efficiency (78.44%) of the welded joint. The maximum tensile strength was 27.44% lower than the base material which is 7-9% more (tensile strength by HTP) with respect to data reported by Wajidi et al. [21]. They applied the minimum quantity of lubrication during the FSW process to achieve higher strength. Li et al. [22] found 73.7% strength from the base material by using a novel FSW process (reverse dual rotation process). The HTP improved the stirring power and provided adequate frictional heat generated by the novel tool pin geometries. However, the value of the tensile properties obtained by the triangular tool-pin was lowest. The triangular type of tool pin restricted the lower heat generation and deformation of metal during FSW due to the less interface contact between the tool probe and workpiece; results provided the lowest tensile characteristics of the welded joints [23]. The SR values of the triangular pin profile are higher and affect the formation of grain size, which lowers the welded specimen's tensile strength. The threaded taper tool facilitated enhancement in stirring action due to its thread. The material moves quickly and is mixed up properly at this welding parameter and produced higher strength than the triangular tool [24]. The surface roughness value of HTP is less and has the smallest grain size in NZ because of which the tensile strength of the welded sample by HTP provides more strength than other tools.

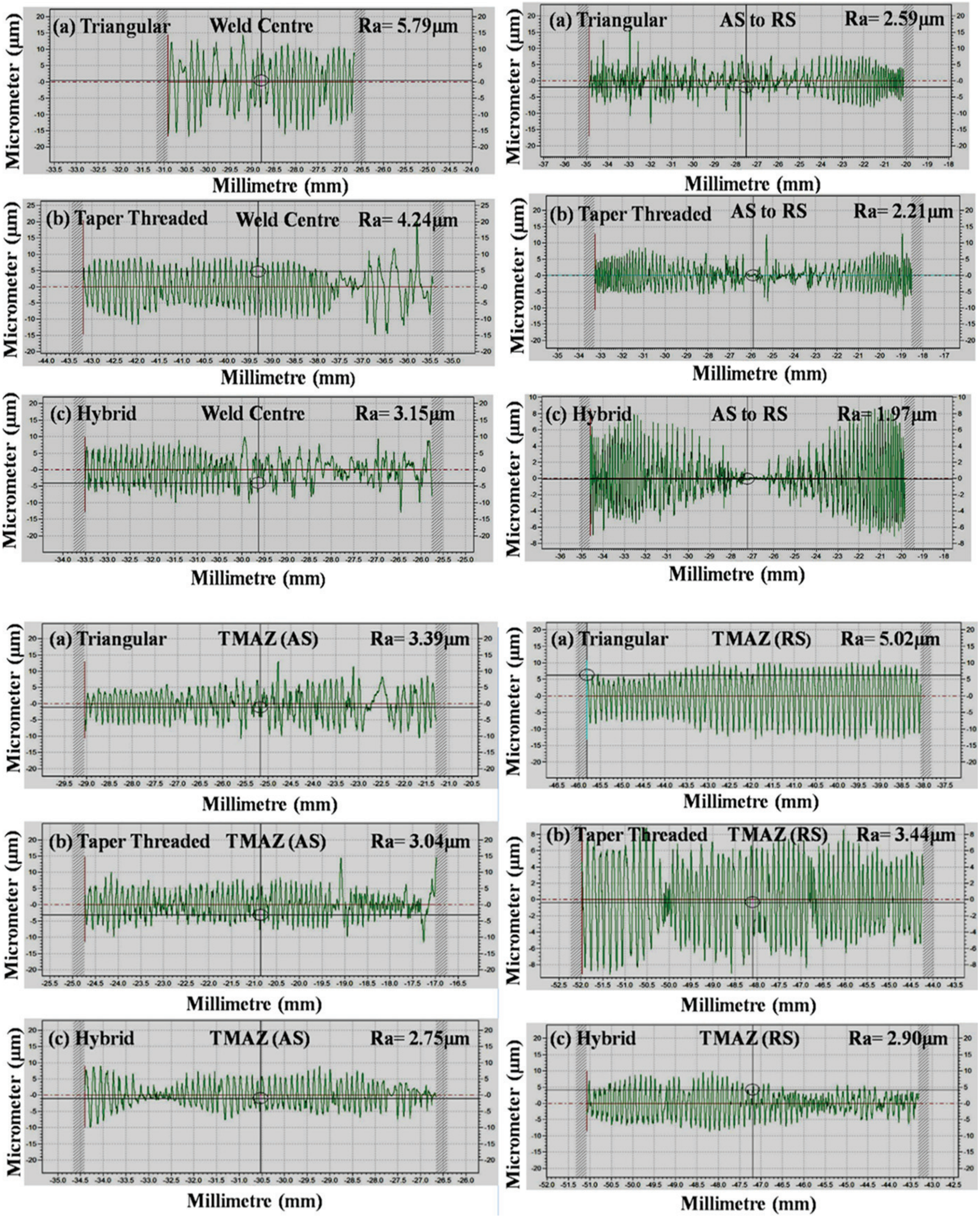

Fig.3: Surface roughness graph of friction stir welded samples using different tool geometry (a) Triangular, (b) Taper threaded and (c) Hybrid at the different portion of welded samples (weld centre, AS and RS of TMAZ and AS to RS)

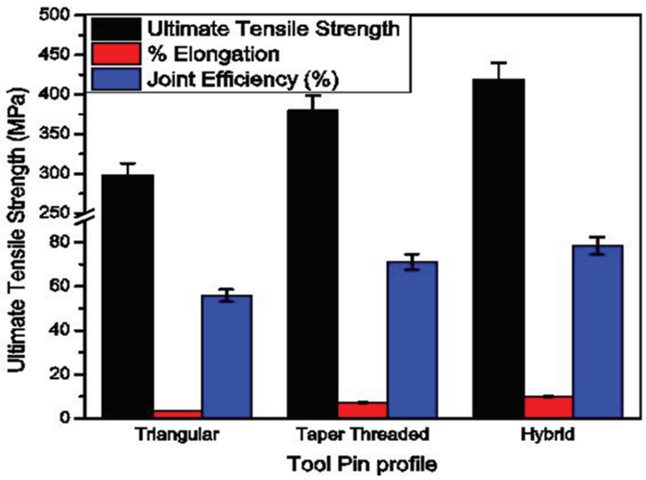

Fig.4: The tensile properties of the joints by using the different tool pin profile

6.0 Conclusions

The present study used different tool pin profiles to fabricate the third generation of Al-Li alloy (2050-T84 Al-Cu-Li) using FSW. The effect of the hybrid and conventional tool pin profiles (taper threaded and triangular) on the welded surface's surface roughness and tensile properties is analysed. On a comparative study, the following conclusion was as follows:

- In FSW, the triangular, taper threaded, and hybrid tool pin profiles were used to fabricate the third generation of Al-Li alloys at constant TRS, TTS, and TTA.
- The HTP provides better surface roughness among all tools (conventional tool) due to its geometric structure, which provides an adequate amount of frictional heat generated during FSW for better mixing of the softening material. An advanced side of friction welded specimen has less surface roughness than the RS and weld centre for all tool geometries. It may be due to the generation of more heat in AS.
- The HTP tool bears 40% higher strength than the triangular tool pin profile. The hybrid tool pin provides a higher joint efficiency (78.44%) and higher ultimate tensile strength (418.978 MPa) than the conventional tool pin profiles.

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