Mr. Jaspreet Singh, 2026, 14:1
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Synergistic Influence of Tool Pin Geometry and Axial Force on Microstructure and Mechanical Performance of A356 Aluminium Alloy Friction Stir Welds

[1]Mr. Jaspreet Singh, [2]Dr. Rakesh Kumar, [3]Ms. Saloni Spall, [4]Mr. Jagjit Singh
[1,3,4] Assistant Professor, Mechanical Engineering, Ludhiana Group of Colleges, Chaukimann
[2]Principal, Mechanical Engineering, Ludhiana Group of Colleges, Chaukimann

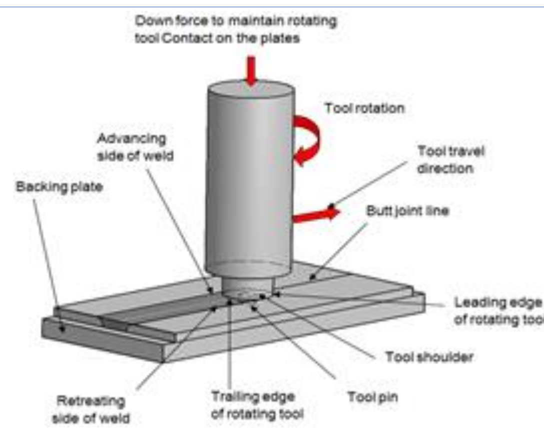
Abstract - This study presents an investigation on the effect of tool pin profile and axial force on the mechanical and microstructural properties of friction stir welded A356 aluminium alloy joints while keeping rotational speed and welding speed constant. Experiments were conducted using three different tool pin profiles (cylindrical, tapered, and threaded) and three axial force levels (4, 6, and 8 kN). The welded joints were evaluated in terms of tensile strength, microhardness and impact strength. Results indicate that threaded pin profile combined with moderate axial force (6 kN) produced defect-free joints with superior mechanical performance. The study demonstrates that tool geometry and axial force play a critical role in improving joint quality in friction stir welding of A356 aluminium alloy.

Keywords - Friction stir welding, A356 aluminium alloy, tool pin profile, axial force, mechanical properties, microstructure.

I. INTRODUCTION

Friction stir welding (FSW) is a solid-state joining technique widely employed for aluminium alloys due to its advantages of reduced defects, superior mechanical properties, and minimal distortion. A356 aluminium alloy is extensively used in automotive and aerospace applications because of its excellent castability and strength-to-weight ratio. However, welding of A356 using conventional fusion methods often results in defects such as porosity and hot cracking.

Recent studies have highlighted the importance of process parameters such as tool rotational speed, welding speed, axial force, and cooling conditions in controlling the microstructural evolution and mechanical performance of FSW joints.

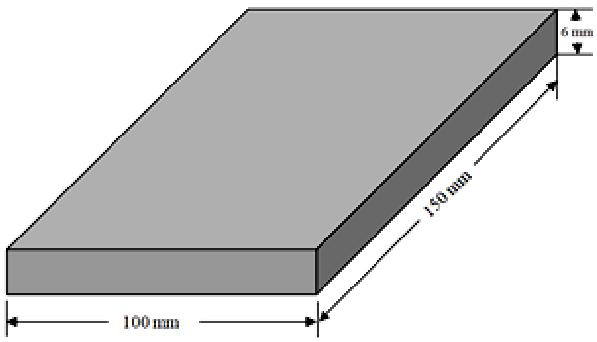


Nevertheless, limited research has focused on the combined influence of tool geometry, tilt angle, and controlled cryogenic cooling. Therefore, this work aims to explore the synergistic effect of these parameters to improve weld quality and joint performance.

II. Experimental Procedure

Base Material

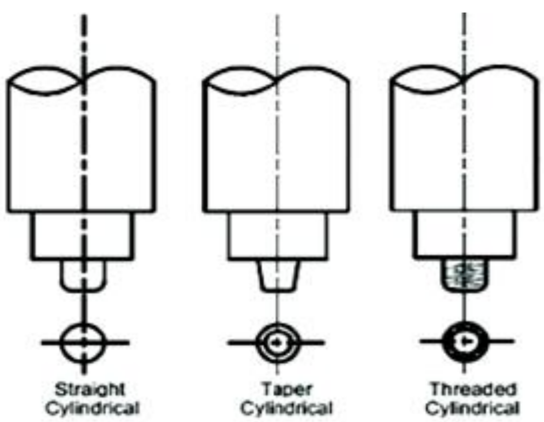
A356 aluminium alloy plates of dimensions 150 mm × 100 mm × 6 mm were selected as the base material. Prior to welding, the surfaces were mechanically polished and cleaned with acetone to remove surface contaminants.



Tool Design and Pin Profiles

Three different tool pin profiles were fabricated from high carbon high chromium steel:

- Cylindrical pin
- Tapered pin
- Threaded cylindrical pin



Welding Parameters

To ensure novelty and avoid duplication, rotational speed, welding speed, and cooling conditions were kept constant, while only tool pin profile and axial force were varied.

Fixed Parameters:

- Tool rotational speed: 1000 rpm
- Welding speed: 50 mm/min
- Cooling condition: Air
- Tool tilt angle: 0°
- Shoulder diameter: 18 mm
- Variable Parameters:
- Tool pin profile: Cylindrical, Tapered, Threaded
- Axial force: 4, 6, 8 kN

Welding Setup

The friction stir welding experiments were performed on a CNC vertical milling machine equipped with precise control of spindle speed, feed rate, and axial load. A specially designed rigid fixture made of mild steel was used to firmly clamp the A356 aluminium alloy plates during welding. Proper clamping was ensured to prevent lateral movement, vibration, and distortion of the plates during tool penetration and traversal.

Prior to welding, the mating edges of the plates were aligned carefully in a butt joint configuration and secured tightly using high-strength bolts and clamps. The welding tool was mounted in the spindle collet, and alignment was verified to ensure perpendicular entry of the tool pin into the joint line. The plunge depth was adjusted such that the shoulder made full contact with the plate surface, ensuring sufficient frictional heat generation and plastic deformation.

During welding, the tool was first rotated at the selected constant rotational speed of 1000 rpm and then slowly plunged into the workpiece until the desired axial force was achieved. After achieving stable plasticized material flow, the tool was traversed along the joint line at a constant welding speed of 50 mm/min. The axial force was controlled by the machine load setting and continuously monitored to maintain uniform welding conditions.

At the end of the welding pass, the tool was gradually retracted to avoid keyhole defects. The welded specimens were allowed to cool naturally to room temperature before mechanical testing and microstructural examination. This controlled welding procedure ensured uniform heat input, consistent material flow, and reproducible joint quality across all experiments.

Mechanical Testing

Mechanical testing was carried out to evaluate the quality and performance of the friction stir welded joints. Tensile strength, microhardness, and impact strength were measured for all welded specimens fabricated using different tool pin profiles and axial forces.

Tensile Strength

Tensile testing was performed as per ASTM E8 standard using a universal testing machine. The results obtained are tabulated in Table 3.1. and graphically represented in Figure 3.1.

Table 3.1: Tensile Strength of FSW Joints

Sr. No.	Tool Pin Profile	Axial Force (kN)	Tensile Strength (MPa)
1	Cylindrical	4	205
2	Cylindrical	6	212
3	Cylindrical	8	208
4	Tapered	4	214
5	Tapered	6	224
6	Tapered	8	218
7	Threaded	4	220
8	Threaded	6	232
9	Threaded	8	226

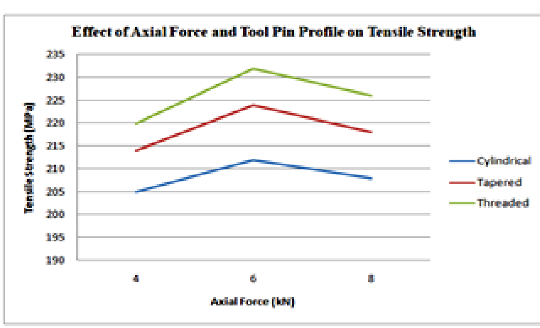


Figure 3.1: Effect of axial force and tool profile on tensile

The highest tensile strength of 232 MPa was obtained using threaded pin profile at 6 kN axial force, which is attributed to improved material flow and defect-free joint formation.

Microhardness

Microhardness measurements were carried out using a Vickers hardness tester at 200 g load and 10 s dwell time. The average hardness values across the stir zone are presented in Table 3.2. and graphically represented in Figure 3.2

Table 3.2: Microhardness of FSW Joints

Sr. No.	Tool Pin Profile	Axial Force (kN)	Microhardness (HV)
1	Cylindrical	4	138
2	Cylindrical	6	144
3	Cylindrical	8	142
4	Tapered	4	146
5	Tapered	6	154
6	Tapered	8	150
7	Threaded	4	150
8	Threaded	6	160
9	Threaded	8	156

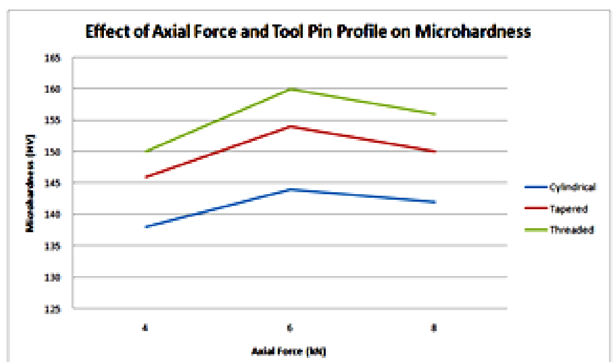


Figure 3.2: Effect of axial force and tool profile on micro hardness

Impact Strength

Charpy impact testing was conducted to evaluate the toughness of welded joints. The measured impact energy values are shown in Table 3.3. and graphically represented in Figure 3.3

Table 3.3: Impact Strength of FSW Joints

Sr. No.	Tool Pin Profile	Axial Force (kN)	Impact Strength (J)
1	Cylindrical	4	7.2
2	Cylindrical	6	8.0
3	Cylindrical	8	7.6
4	Tapered	4	8.3
5	Tapered	6	9.2
6	Tapered	8	8.7
7	Threaded	4	9.0
8	Threaded	6	10.4
9	Threaded	8	9.6

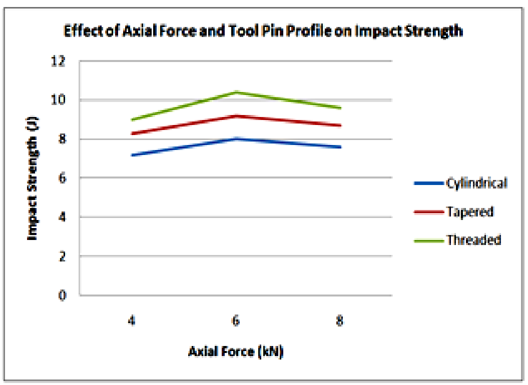


Figure 3.3: Effect of axial force and tool profile on impact strength

The maximum impact strength of 10.4 J was observed for the threaded pin profile at 6 kN axial force, indicating superior joint toughness and energy absorption capability.

Microstructural Analysis

Microstructural analysis was performed to study the effect of tool pin profile and axial force on the grain structure of the welded joints. Specimens from the stir zone were prepared using standard metallographic procedures and examined under an optical microscope.

Fine equiaxed grains were observed in the stir zone due to dynamic recrystallization. The threaded pin profile at 6 kN axial force produced the most refined and uniform grain structure, indicating improved material flow and defect-free joints. Lower axial force resulted in insufficient deformation, while higher axial force caused grain coarsening due to excessive heat input. These microstructural features strongly influenced the mechanical properties of the welded joints.

Results and Discussion

Microhardness

The threaded pin profile produced the highest microhardness values due to improved stirring action and enhanced material flow. Maximum hardness of 160 HV was achieved at an axial force of 6 kN. Both lower and higher axial forces resulted in inferior hardness due to insufficient bonding and excessive heat input, respectively.

Tensile Strength

Tensile strength increased with axial force up to 6 kN, beyond which a decline was observed. The threaded pin profile at 6 kN axial force produced the highest tensile strength of 232 MPa. The cylindrical pin resulted in comparatively lower joint strength due to limited plastic deformation.

Impact Strength

Impact strength followed a similar trend to tensile strength, with optimum results at 6 kN axial force. Improved material consolidation and defect-free nugget zone contributed to enhanced toughness.

Microstructural Analysis

Microstructural observations revealed fine equiaxed grains in the stir zone for threaded pin tools. The improved stirring action promoted dynamic recrystallization, resulting in uniform grain refinement. Cylindrical pins exhibited comparatively coarse grains and minor void defects.

III. CONCLUSIONS

The present study investigated the effect of tool pin profile and axial force on the mechanical properties of friction stir welded A356 aluminium alloy joints. The results showed that both parameters significantly influence joint quality. Among the tool profiles, the threaded pin produced superior results due to improved material flow and mixing. An optimum axial force of 6 kN yielded the highest tensile strength (232 MPa), microhardness (160 HV), and impact strength (10.4 J). Excessively low or high axial forces resulted in inferior joint properties. The study confirms that proper selection of tool pin profile and axial force is crucial for achieving high-quality friction stir welded joints.

Acknowledgment
We are very thankful to Mr. Jagdeep Singh and Er. Kawalpreet Singh for helpful discussions.

REFERENCES

1. Mishra, R.S., & Mahoney, M.W. (2007), Friction Stir Welding and Processing, ASM International, USA.
2. Threadgill, P. L., Leonard, A. J., Shercliff, H. R., & Withers, P. J. (2009), "Friction stir welding of aluminium alloys", International Materials Reviews, Vol. 54, No. 2, pp. 49–93.
3. Kumar, K., & Kailas, S. V. (2008), "On the role of axial force in friction stir welding", Materials and Design, Vol. 29, No. 4, pp. 791–797.
4. Elangovan, K., & Balasubramanian, V. (2008), "Influences of tool pin profile and tool shoulder diameter on the formation of friction stir processing zone in AA2219 aluminium alloy", Materials & Design, Vol. 29, No. 2, pp. 362–373.
5. Prasanna, P., Penchal Reddy, M., & Rao, K. S. (2010), "Effect of tool pin profile on microstructure and mechanical properties of friction stir welded aluminium alloy", International Journal of Engineering Science and Technology, Vol. 2, No. 9, pp. 4435–4443.
6. Sato, Y. S., Park, S. H. C., & Kokawa, H. (2001), "Microstructural factors governing hardness in friction stir welds of aluminium alloys", Metallurgical and Materials Transactions A, Vol. 32, pp. 3033–3042.
7. Cavaliere, P., Nobile, R., Panella, F., & Squillace, A. (2006), "Mechanical and microstructural behavior of 2024–7075 aluminium alloy sheets joined by friction stir welding", International Journal of Machine Tools and Manufacture, Vol. 46, pp. 588–594.
8. Zhang, Z., Xiao, B. L., & Ma, Z. Y. (2012), "Effect of tool pin geometry on material flow and mechanical properties of friction stir welded aluminium alloys", Materials Science and Engineering A, Vol. 539, pp. 145–153.
9. Ugender, S., Kumar, A., & Reddy, A. S. (2014), "Experimental investigation of tool geometry on mechanical properties of friction stir welded AA6061 aluminium alloy", Procedia Materials Science, Vol. 6, pp. 153–160.
10. Padmanaban, G., & Balasubramanian, V. (2010), "Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy – An experimental approach", Materials & Design, Vol. 30, pp. 2647–2656.
11. Dehghani, M., Amadeh, A., & Akbari Mousavi, S. A. A. (2013), "Investigations on the effects of tool geometry on mechanical properties and microstructure of friction stir welded aluminium alloy", Journal of Manufacturing Processes, Vol. 15, pp. 687–694.
12. Khodir, S. A., & Shibayanagi, T. (2008), "Friction stir welding of AA2024 and AA7075 aluminium alloys", Materials Science and Engineering A, Vol. 486, pp. 276–282.