Analysis of friction stir welding with parameters tool profile and rotational speed on the aluminum 7475 alloy and copper weldments

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Abstract: **This research investigates the influence of tool profile and rotational speed on the structural and thermal behavior of dissimilar weldments of Aluminum 7475 and Copper using Friction Stir Welding (FSW). Three distinct tool profiles (Round, Hexagonal, and Taper Threaded) were evaluated at varying rotational speeds (700, 1000, and 1400 RPM). Finite Element Analysis (FEA) was performed to simulate static and thermal responses of the welds. Results reveal that the Taper Threaded profile, especially at lower speeds, offers optimal thermal regulation, minimizing deformation and residual stress. This study provides insights for enhancing weld quality in dissimilar material joints.**

Keywords: **Friction Stir Welding (FSW), Aluminum 7475, Copper, Tool Profile, Rotational Speed, Finite Element Analysis**

I. INTRODUCTION

Friction Stir Welding (FSW) is a state-of-the-art solid-state welding method that was developed by The Welding Institute (TWI) in 1991[3]. Unlike conventional welding techniques that rely on melting and fusion. FSW connects materials through plastic deformation by producing frictional heat that softens the metal without melting it. This process involves a rotating cylindrical tool that has a specially crafted probe, which is inserted into the materials along the joint line. As the tool moves across the joint, it blends the material and forges it together under pressure, resulting in a solid and defect-free weld[1].

Friction Stir Welding (FSW) is a solid-state joining process widely used in aerospace, automotive, and shipbuilding industries. When joining dissimilar materials such as Aluminum 7475 and Copper, challenges like different melting points, thermal conductivity, and material flow behavior arise. Tool geometry and rotational speed significantly affect weld quality, influencing heat generation, material mixing, and mechanical strength[2].

A significant advantage of FSW is its ability to create high-quality welds with minimal distortion and superior mechanical properties. The welds produced are recognized for their outstanding strength, fatigue resistance, and enhanced micro structural properties. It is particularly effective in welding aluminum alloys, which can be difficult to join using traditional fusion welding methods. The ability of FSW to produce solid and high-integrity joints makes it a popular choice for critical structural applications.This study aims to analyze these parameters using simulation techniques[4].

II. METHODOLOGY

Identify suitable candidate materials (e.g., Aluminum, Steel, Copper) conduct a thorough review of relevant literature and previous studies, and assess material properties (including thermal conductivity, hardness, ductility, etc.) Al7475 and Cu are selected as materials for the present study. Select the appropriate tool material work-piece material and design specification. Determine shape, speed, and material thickness parameters. Optimize parameters by material properties.

The experimental setup was modeled using CATIA, define tool geometry and boundary conditions. Conduct initial simulations to validate designs

The simulation for static and thermal analysis was conducted using FEA tools. Three tool profiles (Round, Hexagonal, Taper Threaded) were tested at 700, 1000, and 1400 RPM. The analysis measured deformation, stress, strain, temperature distribution, and heat flux to evaluate the performance of each tool profile.

Work piece Materials: Aluminum 7475 and Copper (5 mm thickness)
Tool Profiles: Round, Hexagonal, Taper Threaded
Rotational Speeds: 700, 1000, 1400 RPM
Software Used: CATIA for modeling, ANSYS R14.5 for analysis

III. MODELING

Computer-aided design (CAD) plays a crucial role in creating mechanical models by providing a digital platform for engineers to develop accurate and detailed representations of parts and assemblies. With CAD software, designers can visualize intricate geometries, simulate how designs will perform under different conditions, and effortlessly incorporate design changes before production begins. This approach improves precision, decreases reliance on physical prototypes, and optimizes the overall design process, facilitating the efficient development of high-quality mechanical systems[5]. The material models and tools models are designed in CATIA and further assembled and generated meshing and applied boundary conditions.

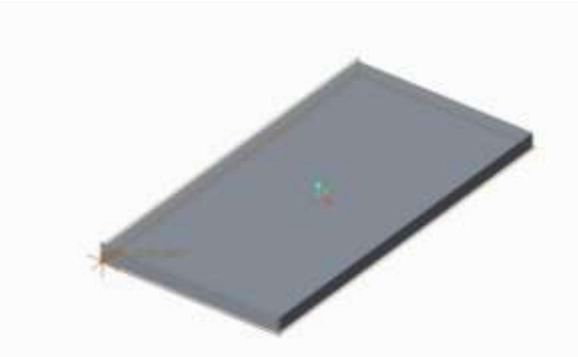

Fig.1: 3D Model of plate

Fig.2: 3D Model of the Tool

As shown in the figure1,2 the 3D model of plates are designed for both aluminum and copper with same dimensions. The 3D model of tool was designed with tool tip shaped in hexagonal, round, taper threaded shapes.

IV. ASSEMBLY AND BOUNDARY CONDITIONS

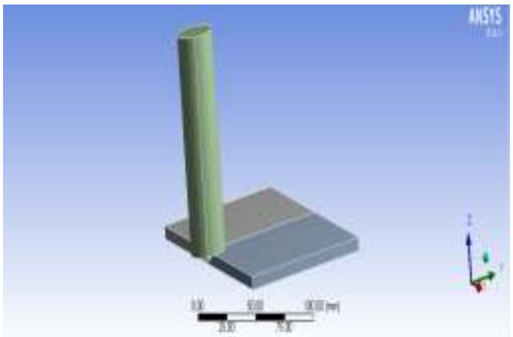

Fig.3: Imported model from CATIA

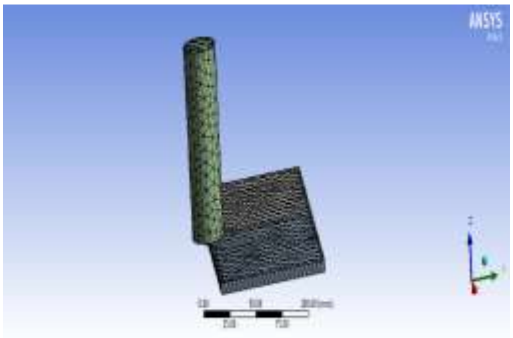

Fig.4: Meshing applied on the FSW model

The modeled material plates and tool are subsequently imported into ANSYS, where they are assembled for further analysis. Materials are assigned to all components, and meshing is performed on the FSW model as shown in the Fig 3,4 to enable the application of boundary conditions.

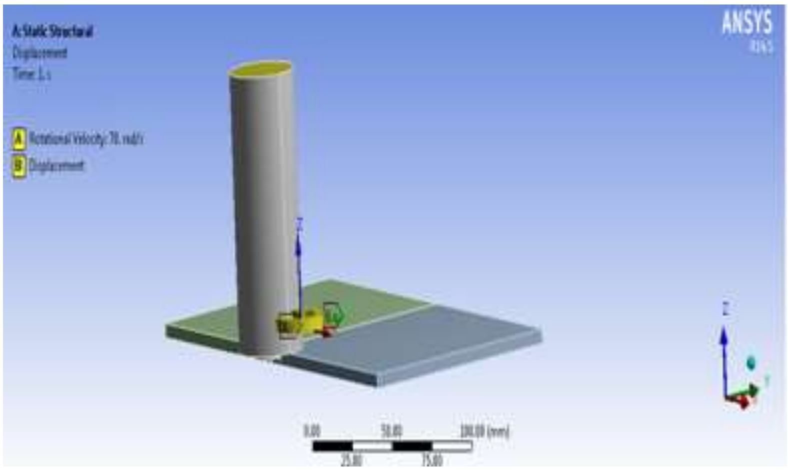

Fig.5: Boundary conditions applied on the FSW model

As shown in Fig:5 Boundary conditions like pressure, axial restrictions, rotational velocity, and tool speed are applied to the model in order to evaluate key parameters such as deformation, stress, strain, temperature distribution, and heat flux.

V. STATIC STRUCTURAL ANALYSIS

Static structural analysis in the Friction Stir Welding (FSW) of dissimilar materials, such as aluminum and copper, is essential to evaluate the strength and deformation behavior of the welded joint under load. Due to differing material properties, stress concentrations can arise at the interface, making analysis crucial for ensuring joint reliability. Using tools like FEA, engineers can predict performance, optimize process parameters, and improve weld quality for structural applications[6].

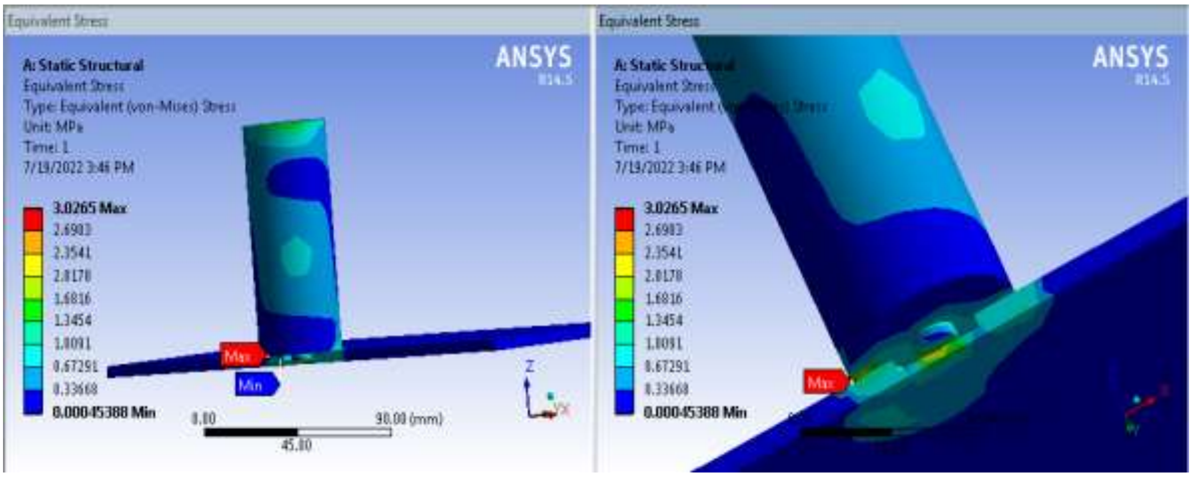

Fig.6: Total Equivalent stress of the round tool at 1000RPM

As shown in Fig:6 the equivalent stress observed from this analysis for a speed of 1000RPM and round shape was at a max of 3.0265N/mm^2. Likewise, the results obtained for tools with hexagonal and tapered threaded shapes are presented below.

Table 1: Static Analysis Results

Shape of Tool	Speed (RPM)	Deformation (mm)	Stress (N/mm2)	Strain
Round	700	0.00018356	1.6669	2.24E-5
	1000	0.00037829	3.0265	4.58E-5
	1400	0.00074144	6.6792	8.978E-5
Hexagonal	700	0.00015983	1.4398	1.9354E-5
	1000	0.0003414	3.0955	4.13E-5
	1400	0.00068943	6.2107	8.34E-5
Taper Threaded	700	0.00014076	1.268	1.7045E-5
	1000	0.00031326	2.822	3.79E-5
	1400	0.00064918	5.8481	7.81E-5

Discussion: Deformation, stress, and strain increase with RPM across all profiles. The round tool shows the highest values, suggesting better plastic flow but higher residual stress. The taper threaded tool exhibits minimal values, implying better heat dissipation and dimensional control.

VI. THERMAL ANALYSIS

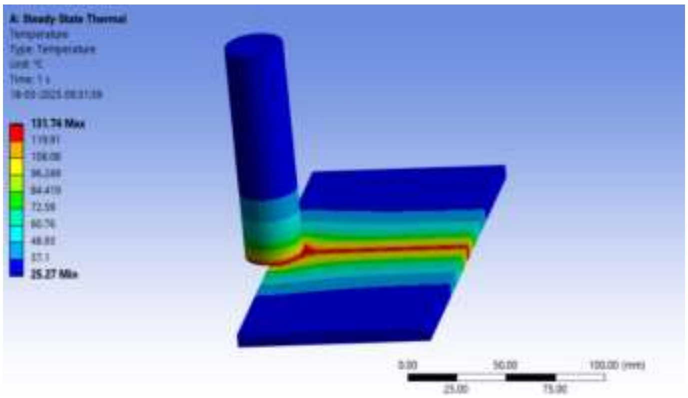

Fig.7: Temperature distribution of round tool at 700RPM

As shown in Fig:7 the equivalent stress observed from this analysis for a speed of 700RPM and round shape was at a max of 131.740C. Likewise, the results obtained for tools with hexagonal and tapered threaded shapes are presented below.

Thermal analysis in FSW of dissimilar materials helps study heat distribution during welding.Due to different thermal properties, materials like aluminum and copper heat unevenly. This affects weld quality,and micro-structure. Simulations help optimize parameters and reduce defects[7].

Table 2: Thermal Analysis Results

Shape of Tool	Speed (RPM)	Temperature (°C)	Heat Flux (W/mm2)
Round	700	131.74	1.5912
	1000	80.922	0.8141
	1400	58.588	0.4836
Hexagonal	700	126.66	1.513
	1000	75.839	0.7384
	1400	52.458	0.3945
Taper Threaded	700	121.57	1.4331
	1000	70.757	0.6630
	1400	52.458	0.3945

Discussion: Higher RPM reduces temperature and heat flux. The taper threaded tool consistently results in the lowest heat buildup, indicating efficient heat dissipation and reduced thermal distortion.

VII. GRAPHICAL ANALYSIS

Deformation graph:

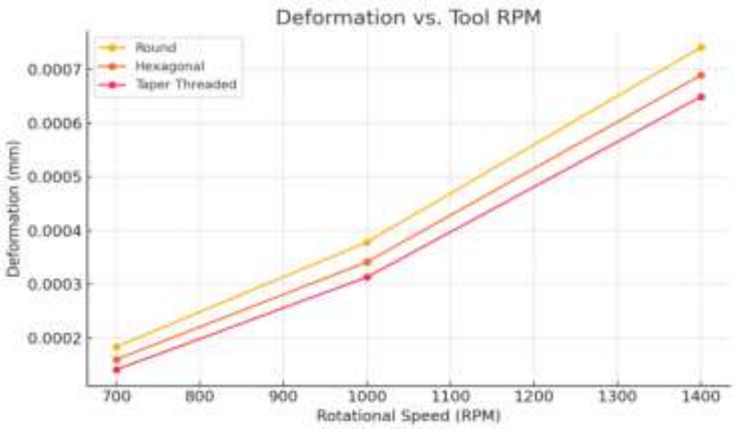

Fig.8: Deformation Vs Tool rotational speed Graph

From Fig:8, we can infer the data regarding deformation versus different tool rotational speeds and shapes. The minimum deformation is achieved at the tool profile of taper threaded and tool rotational speed of 700 RPM.

Stress graph:

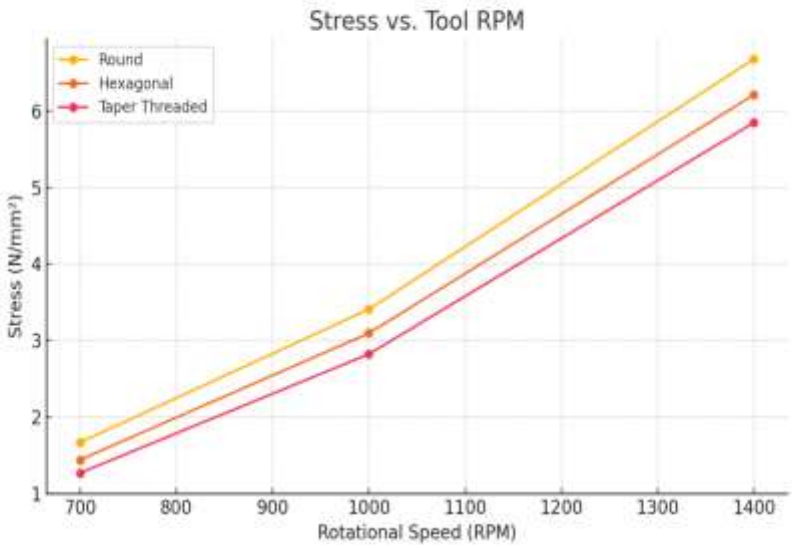

Fig.9 Stress Vs Tool Rotational Speed Graph

The impact of different tool rotational speeds and profiles on stress is depicted in Fig:9. The minimum stress is obtained with taper threaded tool and at rotational speed of 700 RPM in comparison with other tool geometries and profiles.

Strain graph:

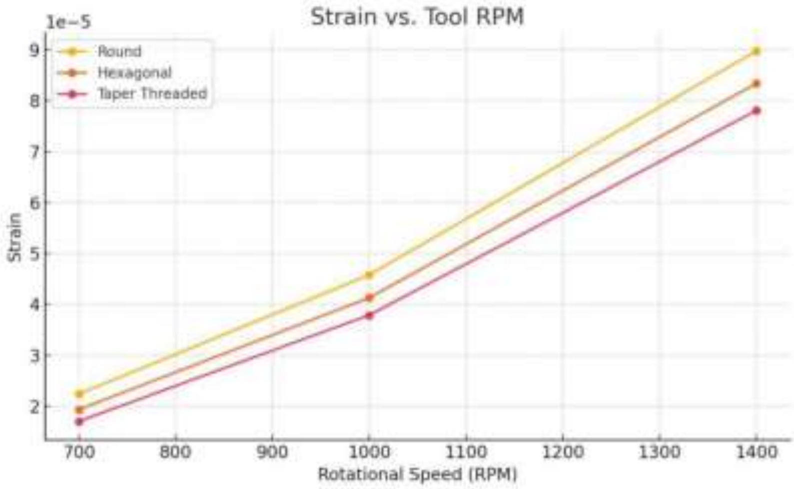

Fig.10: Strain Vs Tool rotational speed Graph

From Fig:10, the effect of different tool rotational speeds and profiles is visualized. The minimum temperature obtained for taper threaded tool with rotational speed of 700 RPM.

Temperature graph:

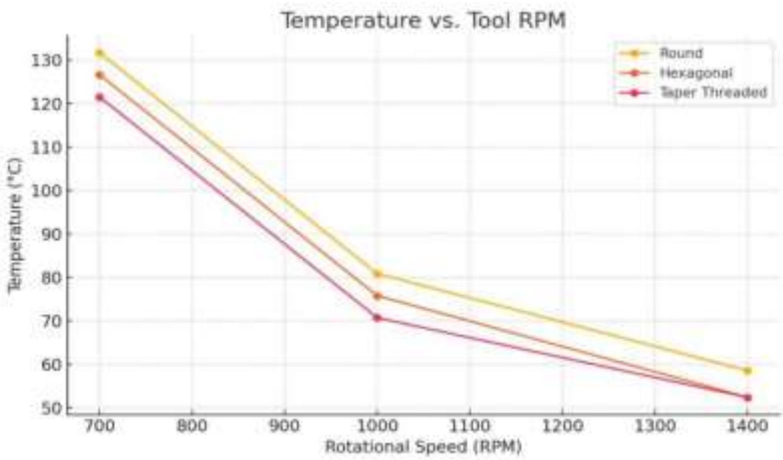

Fig.11: Temperature Vs Tool Rotational Speed Graph

The maximum temperature generated at different tool rotational speeds and profiles is represented in Fig:11. The minimum temperature is achieved for tool profile of taper taper-threaded tool and hexagonal shaped tool with rotational speed of 1400 RPM in comparison with other tool geometries and speeds.

Heat flux graph:

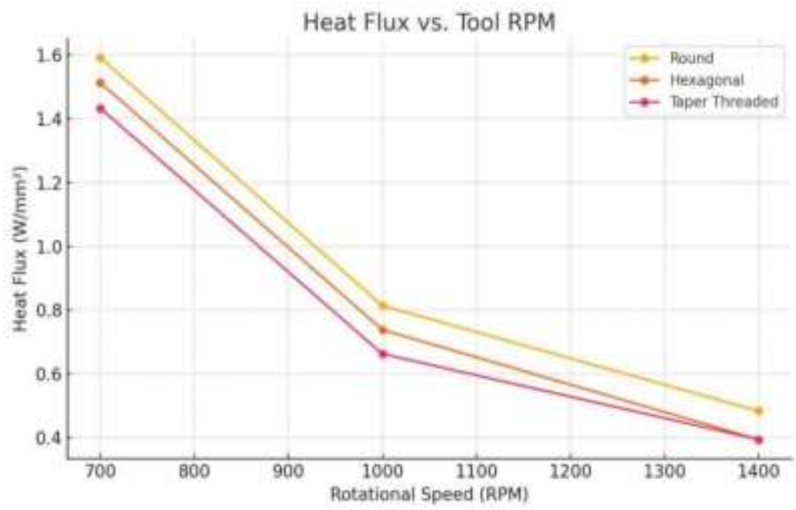

Fig.12: Heat flux Vs Tool rotational speed Graph

The fig:12 describes the influence of different tool rotational speeds and profiles on heat flux. The maximum heat flux is obtained at round tool with rotational speed of 700 RPM and minimum heat flux is obtained at tool profile of taper thread with tool rotational speed of 1400 RPM.

VIII. CONCLUSIONS

In this project, various cutting tool pin profiles are designed for Friction Stir Welding two dissimilar materials, Aluminum7475 and Copper of 5mm thickness running at speeds 700 rpm,1000 rpm, and 1400 rpm. Modeling is done in CATIA. Modeling of FSW setup is successfully carried out in CATIA.

Structural analysis is performed on the different tool pin profiles at different speeds to analyze the deformation, stress, and strain.

Thermal analysis is performed on the different tool pin profiles to study the temperature distribution and heat flux.

From the static analysis results, it is inferred that the deformation, stress and strain values are decreasing by decreasing the tool rotational speeds using taper threaded pin profile in comparison with other tool geometries and speeds.

From the thermal analysis results, the heat flux and temperature generated are minimal for the taper-threaded tool profile when compared to other tool profiles. Tool geometry and rotational speed are critical to weld quality. Round tools generate higher heat and deformation, suitable for high plastic flow but with risk of distortion.

Taper threaded tools offer optimal performance, minimizing stress and temperature. Lower rotational speeds generally yield better structural and thermal stability.

IX. SCOPE FOR FUTURE WORK

Further studies can explore micro structural analysis, hardness, corrosion resistance, and mechanical testing in friction stir welding. Experimental validation can support simulation results. Tool wear analysis and real-time temperature monitoring are also promising research areas. The scope for future work in this field is huge with numerous opportunities for further research and development. Advancements can focus on important factors such as joints, strength, hardness, and residual stresses. Additionally, thermal analysis can focus on understanding heat distribution during the welding process and its effects on the evolution of the micro structure.

This study can improve valuable insights into improving weld quality, increasing thermal stability, and enhancing the overall efficiency of FSW in dissimilar materials for the welding process.

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