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Research Article

Comparison of Threaded and Unthreaded Tool Pin Profiles in Friction Stir Welding using Ansys

Sucharitha V†, V.Thirumal Reddy‡ and Bhargavi Pokala†

†Mechanical Engineering Department, CVR College of Engineering, Hyderabad, Telangana ,India
‡Mechanical Engineering Department, Sreenidhi Institute of Science and Technology, Hyderabad, Telangana, India

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Abstract

In Friction Stir Welding, the design of the tool is a critical factor as a good tool can improve the quality of the weld at the maximum possible welding speed. In present work an attempt is made to compare the tool pin profiles which are used in friction stir welding. The tool pin profile is an important factor which influences the weld joint. Threaded pins are useful in specific FSW applications where thread features would not survive without fracture or severe wear. Most of the studies in literature used threaded pins since most industrial applications currently use threaded pins. In this study six tools with different pin shapes (Cylindrical, Threaded Cylindrical, Conical, Threaded Conical, Frustum and Threaded Frustum) were designed in CATIA and analysis is performed in ANSYS. The structural and thermal analysis has performed simultaneously. The results of pin profiles were compared and the pin with optimum strength is determined.

Keywords: *Friction stir welding, ANSYS, Tool pin profiles.*

1. Introduction

Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process in which the material that is being welded does not melt and recast. FSW process was developed by The Welding Institute (TWI) of Cambridge, England in 1991(W. Thomas, *et al*, 1991). In friction stir welding a nonconsumable rotating tool with a specially profiled threaded/unthreaded pin and shoulder is rotated at a constant speed. The tool plunges into the two pieces of sheet or plate material and through frictional heat it locally plasticized the joint region. The tool then allowed to stir the joint surface along the joining direction (C.Rhodes, *et al*, 1997).

Tool geometry is very important factor for producing sound welds. However, at the present stage, tool designs are generally proprietary to individual researchers and only limited information is available in open literature. From the open literature, it is known that a cylindrical threaded pin and concave shoulder are widely used welding tool features. Compared to the traditional fusion welding, friction stir welding exhibits a considerable improvement in strength, ductility and fatigue and fracture toughness. The material flow behavior is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters (Liu, *et al*, 2006). (Fujii, *et al,* 2006) investigated the effect of tool shape on mechanical properties and microstructure of friction stir welded aluminum alloys, effect of the tool shape on the mechanical properties and microstructures of 5mm thick welded aluminum plates. Threads are used to transport material from the shoulder down to the bottom of the pin. Tools operating under aggressive environments (high temperatures or high abrasive composite alloys) cannot retain threaded tool features without excessive pin wear. Tools used to friction stir weld thin sheet commonly have fine pins with little surface area for features. The addition of any threads would severely weaken the pin causing premature pin failure (Rajiv S. Mishra, *et al*, 2007).Initially threaded tools may become unthreaded because of the tool wear when used for high melting point alloys or reinforced aluminium alloys (O. Lorrain, *et al*, 2010).

It is desirable that the tool material is sufficiently strong, tough and hard wearing, at the welding temperature. Further it should have good oxidation resistance and a low thermal conductivity to minimize heat loss and thermal damage to the machinery further up the drive train. Welding is carried out around 70 – 90% of the material melting point so it is important that the tool material has sufficient strength at this temperature otherwise the tool can twist and break. With conventional aluminium alloys, tools made of tool steel give good results.

*Corresponding author **Sucharitha V, V.Thirumal Reddy and Bhargavi Pokala** are working as Assistant Professors

The tool material used for computational analysis is H13 Tool steel. This alloy is one of the Hot Worked, Chromium type tool steel. It also contains molybdenum and vanadium as strengthening agents. The chromium content assists this alloy to resist softening if used at higher temperatures. H13 has high hardenability, excellent wear resistance, toughness, good thermal shock resistance and will tolerate some water cooling in service.

2. Design of Fsw tool with different pin profiles

Here 'r_{o}' is the radius of the tool shoulder, 'r_{i1}' is the radius of the pin at the tool shoulder, 'r_{i2}' is the radius of the pin at the pin bottom and 'h' is the pin height.

2.1. Design of Fsw tool with cylindrical pin and Threaded cylindrical Pin

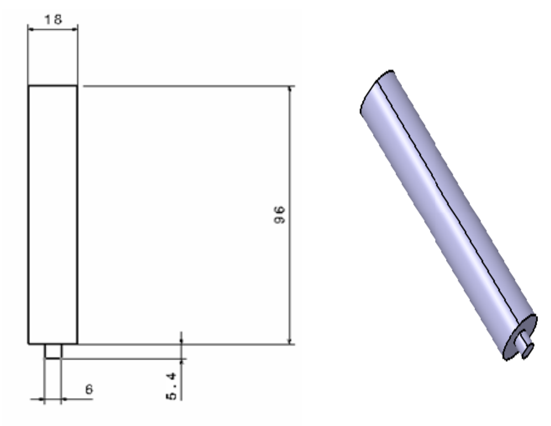

Fig.2.1.1.2D & 3D models of FSW tool with Cylindrical Pin

r_{i1} = 3mm
r_{i2} = 3mm
h = 5.4 mm
Downward force applied on the pin = 7000N

In the present work, the applied downward force is taken as 7000 N.As per theories of failure, the FSW tool can sustain the stresses developed in it during the process at 7000N.

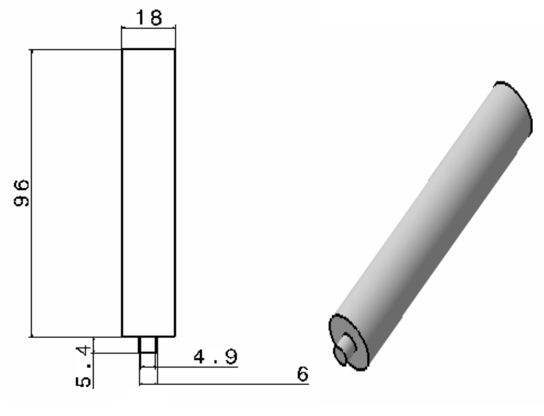

Fig.2.1.2.2D & 3D models of FSW tool with Threaded Cylindrical Tool Pin

2.2. Design of Fsw tool with Conical Pin and Threaded Conical Pin

r_{i1} = 3mm
r_{i2} = 0
h = 5.4 mm

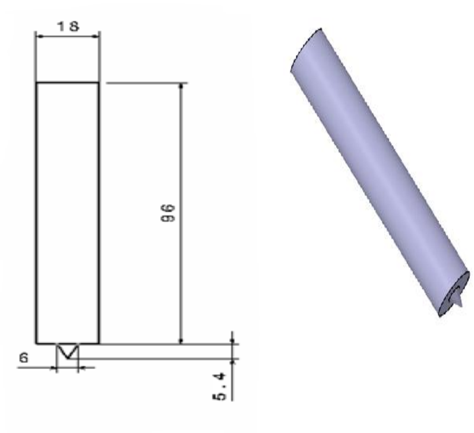

Fig.2.2.1. 2D & 3D models of FSW tool with Conical Pin

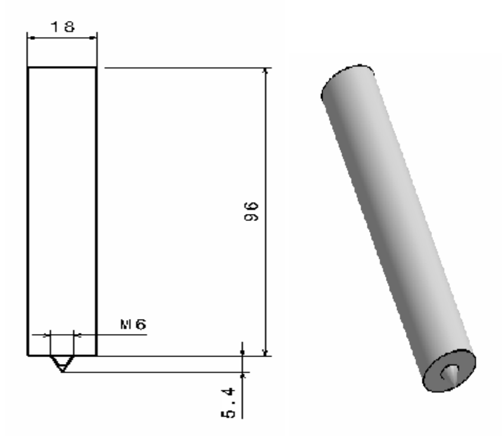

Fig.2.2.2.2D & 3D models of FSW tool with Threaded Conical Pin

2.3. Design of Fsw tool with Frustum Pin and Threaded Frustum Pin

r_{i1} = 3mm
r_{i2} = 1.5mm
h = 5.4 mm

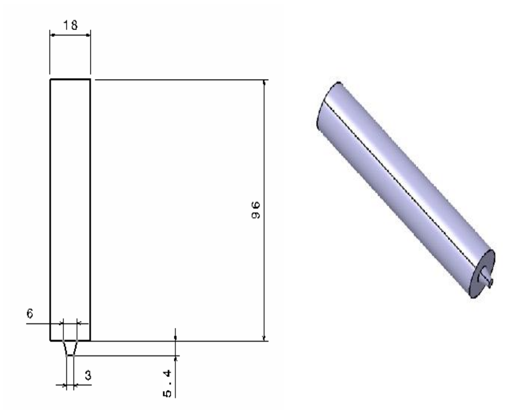

Fig.2.3.1. 2D &3D models of FSW tool with Frustum Pin

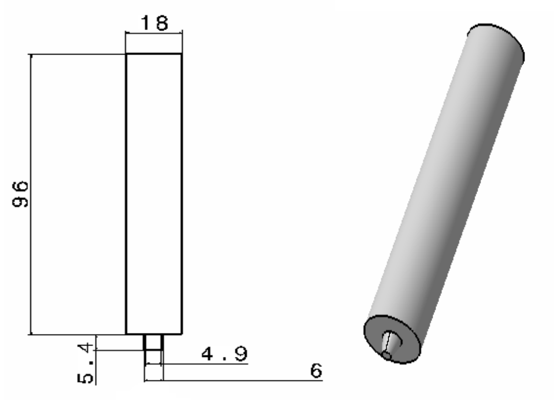

Fig.2.3.2 2D & 3D models of FSW tool with Threaded Frustum Pin

3. Computational analysis using ANSYS.

The present analysis is a coupled field analysis. The structural and thermal analysis has to be performed simultaneously. Due to this, the structural properties and thermal properties of the material are given as input to the ANSYS software at a time. First structural loads were applied and on the obtained results, the thermal loads are applied. The data common to the shapes of the three pin profiles under consideration is given as input in ANSYS.

The FSW tool with cylindrical pin is meshed with solid45 element because for meshing volumes solid elements are used. On the shoulder of the tool for few nodes all DOF are fixed except rotation in z direction(Rz), the tool is subjected to an axial load of 7000N, frictional force of 2100N applied tangentially on the tool pin,tool is rotated at a speed of 1200rpm and subjected to a temperature of 650^{0}C.

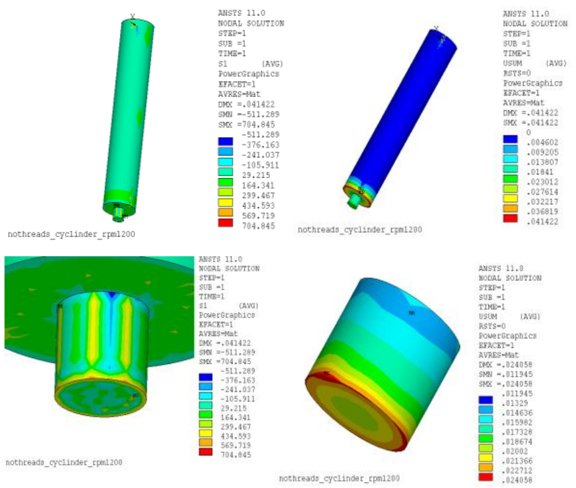

Fig.3.1. Schematic view of stress distribution and displacement vector sum at 1200rpm for Cylindrical Pin

The figure depicts that in the FSW tool with cylindrical pin maximum stress distribution is maximum at the bottom of the pin and the value is 704.845Mpa.Maximum displacement vector sum of the tool is 0.041422mm and if only pin is considered maximum displacement vector sum is 0.02405mm and is maximum at the bottom of pin.

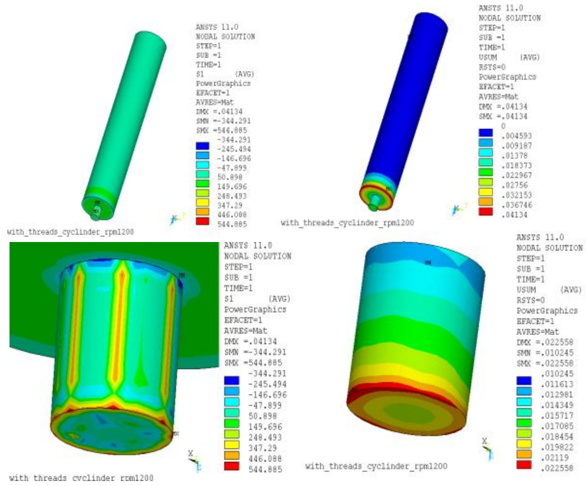

Fig.3.2. Schematic view of stress distribution and displacement vector sum at 1200rpm for Threaded Cylindrical Pin

As the resisting area of the pin increased the maximum stress distribution is decreased and displacement vector sum is also decreased.

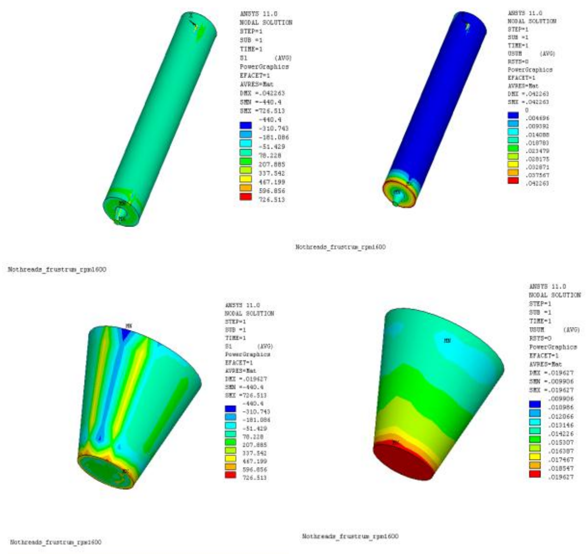

Fig.3.3. Schematic view of stress distribution and displacement vector sum at 1600rpm for Frustum Pin

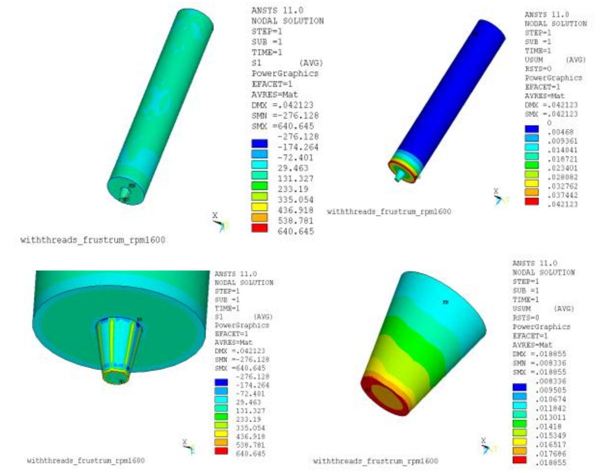

Fig.3.4. Schematic view of stress distribution and displacement vector sum at 1600rpm for Threaded Frustum Pin

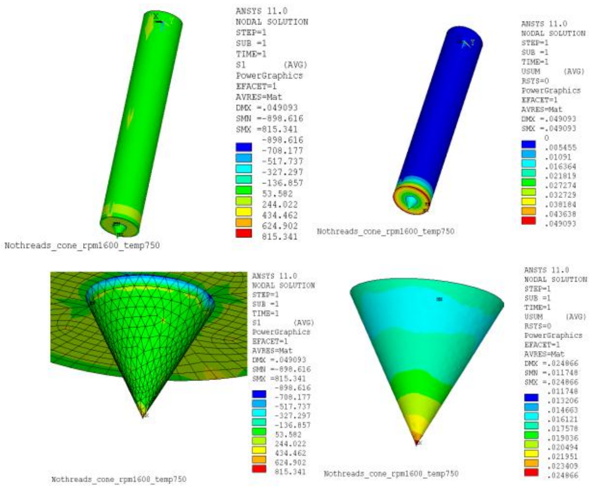

Fig.3.5. Schematic view of stress distribution and displacement vector sum at 750^{0}C for Conical Pin

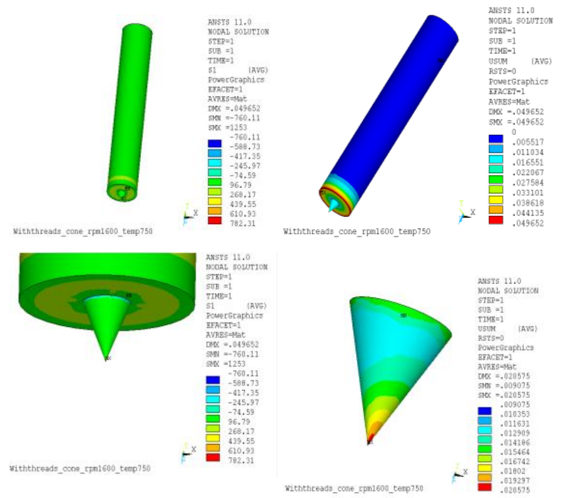

Fig.3.6. Schematic view of stress distribution and displacement vector sum at 750^{0}C for Threaded Conical Pin

4. Stress distribution and Displacement vector sum for various tool profiles.

Table 1 Cylindrical pin Vs Threaded Cylindrical pin

Speed (rpm)	Cylindrical pin	
	Stress Distribution (N/mm^2)	Displacement Vector sum (mm)
1200	704.847	0.0414
1300	704.86	0.0415
1600	704.922	0.0421
Temp (^{0}C)		
650	704.922	0.0421
750	820.541	0.047
850	936.08	0.0554
Speed (rpm)	Threaded Cylindrical pin	
	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)
1200	544.8	0.0413
1300	544.9	0.0415
1600	545.15	0.042
Temp (^{0}C)		
650	545.15	0.042
750	634.35	0.0486
850	723.56	0.0552

Table 2 Frustum pin Vs Threaded Frustum pin

Speed (rpm)	Frustum pin	
	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)
1200	726.465	0.0415
1300	726.475	0.0416
1600	726.513	0.0422
Temp (^{0}C)		
650	726.513	0.0422
750	845.517	0.048
850	964.55	0.0555
Speed (rpm)	Threaded Frustum pin	
	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)
1200	640.557	0.0413
1300	640.576	0.0415
1600	640.64	0.0421
Temp (^{0}C)		
650	640.64	0.0421
750	745.45	0.0487
850	801.29	0.0553

Table 3 Conical pin Vs Threaded Conical pin

Speed (rpm)	Conical Pin	
	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)
1200	784.217	0.0416
1300	784.216	0.0418
1600	784.212	0.0426
Temp (^0C)		
650	784.212	0.0426
750	815.341	0.049
850	846.721	0.0556
Speed (rpm)	Threaded Conical Pin	
	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)
1200	710.21	0.0415
1300	710.24	0.0416
1600	710.25	0.0423
Temp (^0C)		
650	710.25	0.0423
750	782.31	0.0491
850	825.12	0.0554

5. Graphs

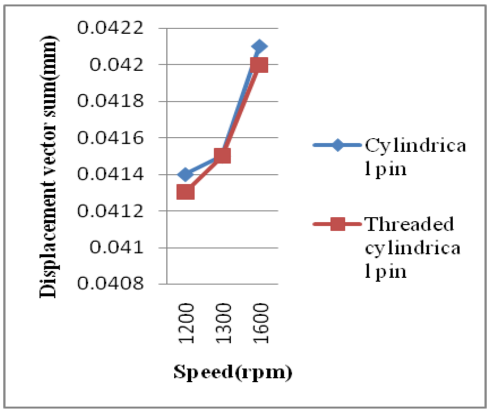

Fig.5.1. Variation of displacement vector sum with rotational speed in Cylindrical pin and Threaded Cylindrical pin

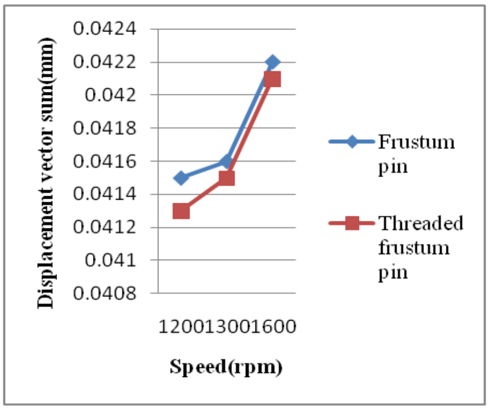

Fig.5.2. Variation of displacement vector sum with rotational speed in Frustum pin and Threaded Frustum pin

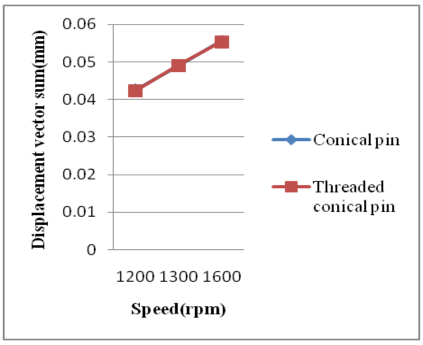

Fig.5.3. Variation of displacement vector sum with rotational speed in Conical Pin and Threaded Conical Pin

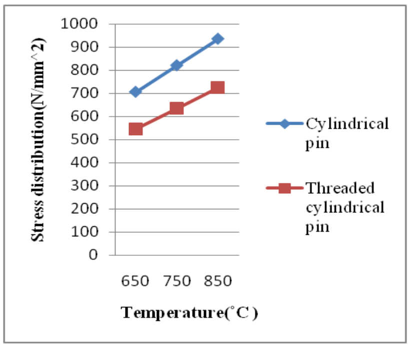

Fig.5.4. Variation of stress distribution with temperature in Cylindrical pin and Threaded Cylindrical pin

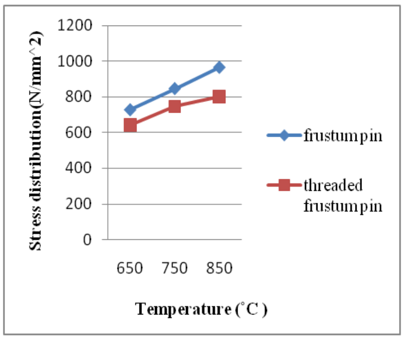

Fig.5.5. Variation of stress distribution with temperature in Frustum pin and Threaded Frustum pin

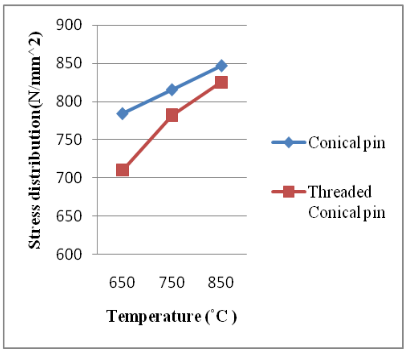

Fig.5.6. Variation of stress distribution with temperature in Conical Pin and Threaded Conical Pin

Conclusion

From the results it can be concluded that the tool geometry, rotating speed and temperature will affect the weld joint. As the resisting area of the pin increased the maximum stress distribution is decreased and displacement vector sum is also decreased for threaded profiles. If the results of profiles with and without threads are compared, the stress distribution and displacement vector sum are observed to be maximum in the tool profiles without threads. Among all the profiles, the maximum stress distribution and displacement vector sum are maximum in the FSW tool with conical profile and minimum in the FSW tool with threaded cylindrical profile.

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