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COMPUTATIONAL ANALYSIS ON THE FRICTION STIR WELDING TOOLS WITH VARIOUS PIN PROFILES

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ABSTRACT

Friction Stir Welding (FSW) process is a solid state welding process, that uses a non consumable tool for joining the plates. The tool, its pin profile, shape and dimensions plays a vital role in making the weld joint. In FSW, the stress distribution of tool pin is affected by the thermo mechanical characteristics of the work piece. In this present paper, three tools with different pin shapes (Conical, Cylindrical and Frustum) are designed with and without threads in their profiles. Initially the tool dimensions are based on the base material plate thickness taken into consideration, the induced structural stresses are checked within the permissible stress limits. The tools are modeled in CATIA and analysis is performed in ANSYS software for exploring stress distributions and displacement vector sum in the pin, at different speeds and temperatures. The frictional force between the tool shoulder and work piece is considered for simulating the stress and displacement vector in the pin profiles. The tool pin profiles considered for structural and thermal analysis, used in this paper are cylindrical, conical, and frustum. The vonmises stress distributions in pin profiles, displacement vector sum of the pin profiles, are obtained from ANSYS software and the pin with optimum strength is determined.

Keywords: *Welding, Analysis, Stresses, Displacement, Tool Profiles.*

I. INTRODUCTION

Friction stir welding (FSW) was invented at The Welding Institute (TWI) of UK in 1991 as a Solid-state joining technique, and it is initially applied to aluminum alloys. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint.

The tool serves two primary functions, heating of work piece, and Movement of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of work piece. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process a joint is produced in 'solid state'. Because of various geometrical features of the tool, the material movement around the pin can be quite complex. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains. The fine microstructure in friction stir welds produces good mechanical properties.

II. TOOL DESIGN

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. 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.

Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminum alloys within the thickness range of 0.5 – 50 mm. But more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites or higher melting point materials such as steel or titanium.

Improvements in tool design have been shown to cause substantial improvements in productivity and quality. TWI has developed tools specifically designed to increase the depth of penetration and so increase the plate thickness that can be successfully welded. An example is the 'whorl' design that uses a frustum pin with re-entrant features or a variable pitch thread in order to improve the downwards flow of material.

The majority of tools have a concave shoulder profile which acts as an escape volume for the material displaced by the pin, prevents material from extruding out of the sides of the shoulder and maintains downwards pressure and hence good forging of the material behind the tool.

Where 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.

Design of FSW tool with cylindrical pin

When a member is loaded so that the stress state is uniaxial, then the stress induced and strength can be compared to know whether the member can function safely. The analysis is simple, because there will be only one value of stress and one value of strength-yield strength, ultimate strength or shear strength. The problem becomes more complicated when the stress state is biaxial or triaxial, i.e., when the member is subjected to multiple stresses, but still with only none significant strength. In such cases, it is essential to know which causes failure. The criterion of failure may be represented in the form of an equation involving certain constants, together with an experimentally determined stress. Many theories have been proposed to explain the test results. In fact, the problem is so complicated that a number of different theories have been formulated.

In this case we consider maximum shear stress theory (Guest's Theory / Tresca's Theory). According to this theory failure will occur if maximum shear stress exceeds the maximum shear caused by the direct stress at elastic limit. This theory gives good correlation with experimental results obtained with ductile materials.

As per this theory, $$(\tau_{\max}) \leq \frac{\sigma_{yc}}{2},$$

$$\frac{\sigma_{yc}}{2} = (1650/2) = 825$$

This indicates that at 7000 N, the FSW tool will not fail according to the theories of failure as the maximum shear stress is less than half of the yield stress value of the material. Hence, as per theories of failure, the FSW tool can sustain the stresses developed in it during the process at 7000N.

In the similar way, FSW Tools with Frustum pin and conical pin are designed according to the Theories of Failures.

Tool material

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. High hardenability, excellent wear resistance and hot toughness. H13 has good thermal shock resistance and will tolerate some water cooling in service.

Analysis

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.

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Analysis of FSW tool with cylindrical pin using ansys

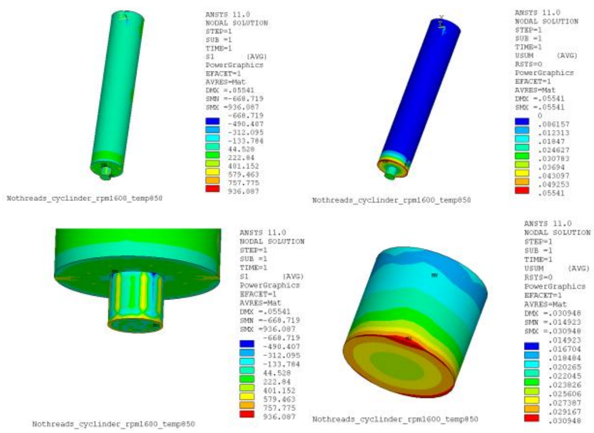

Fig.2. Schematic view of stress distribution and displacement vector sum at 850^{0}C

The fig that the rotational speed of the .4.6 displays tool is 1600rpm and the temperature generated because of the friction is 850^{0}C. The maximum stress distribution is at the bottom of the pin and is 936.087Mpa. The maximum displacement vector sum of the pin is 0.05541mm.

Analysis of FSW tool with frustum pin using ansys

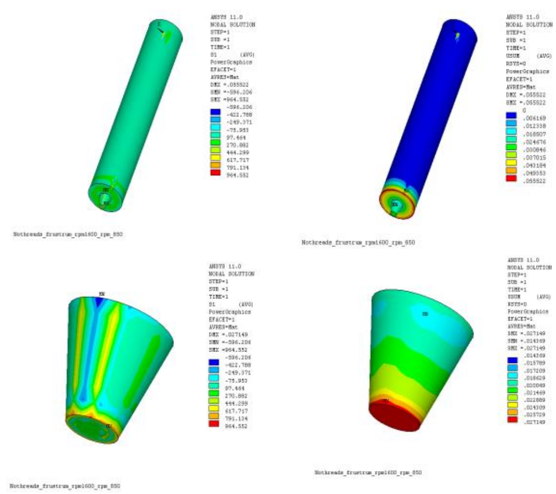

Fig.3. Schematic view of stress distribution and displacement vector sum at 850^{0}C

Fig.4.11 exhibits that the FSW tool with frustum pin is rotating with a speed of 1600rpm,temperature induced because of the friction between tool and work piece is 850^{0}C and maximum stress observed to be 964.552Mpa ,maximum displacement vector sum is 0.0555mm.

Analysis of FSW tool with conical pin using ansys

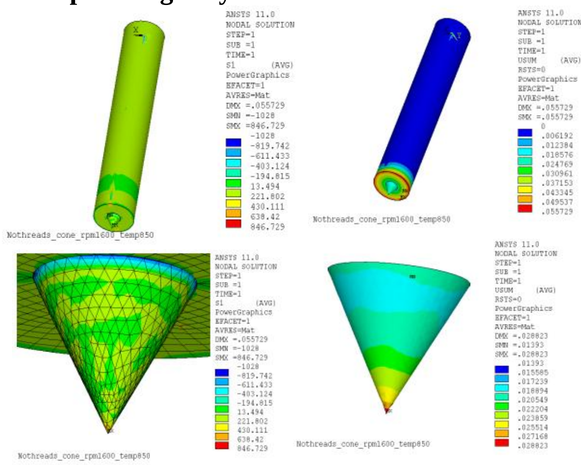

Fig.4 displays that the FSW tool with conical pin is rotating with a speed of 1600rpm, temperature induced because of the friction between tool and work piece is 850^{0}C and maximum stress observed to be 846.729Mpa; maximum displacement vector sum is 0.0557mm.

Consolidated results data

Table1. .Stress distribution and Displacement vector sum for various tool profiles

	Threaded Cylindrical pin		Threaded Frustum pin		Threaded Conical Pin	
Speed (rpm)	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)	Stress Distribution(N/mm^2)	Displacement Vector Sum (mm)
1200	544.8	0.0413	640.557	0.0413	710.21	0.0415
1300	544.9	0.0415	640.576	0.0415	710.24	0.0416
1600	545.15	0.042	640.64	0.0421	710.25	0.0423
Temp (^{0}C)						
650	545.15	0.042	640.64	0.0421	710.25	0.0423
750	634.35	0.0486	745.45	0.0487	782.31	0.0491
850	723.56	0.0552	801.29	0.0553	825.12	0.0554

Table2. Stress distribution and Displacement vector sum for various Threaded tool profiles

	Cylindrical pin		Frustum pin		Conical Pin	
Speed (rpm)	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)	Stress Distribution (N/mm^2)	Displacement Vector Sum (mm)
1200	704.847	0.0414	726.465	0.0415	784.217	0.0416
1300	704.86	0.0415	726.475	0.0416	784.216	0.0418
1600	704.922	0.0421	726.513	0.0422	784.212	0.0426
Temp (^{0}C)						
650	704.922	0.0421	726.513	0.0422	784.212	0.0426
750	820.541	0.047	845.517	0.048	815.341	0.049
850	936.08	0.0554	964.55	0.0555	846.721	0.0556

Graphs for FSW tools with unthreaded profiles

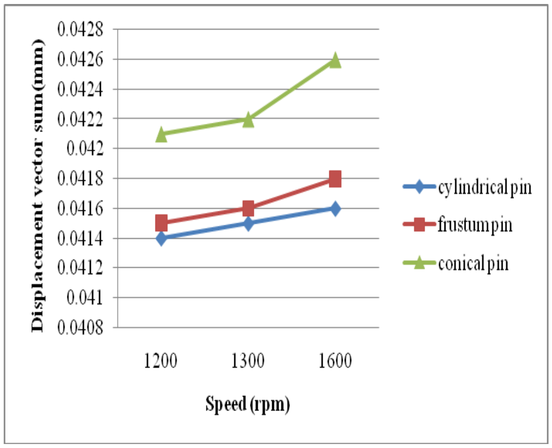

Fig.4.35 Variation of displacement vector sum with rotational speed in various tool profiles

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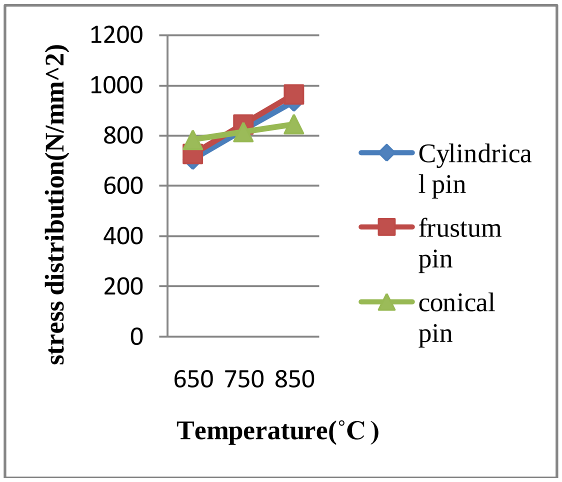

Fig.4.36 Variation of stress distribution with temperature in various tool profiles

Graphs for FSW tools with threaded profiles

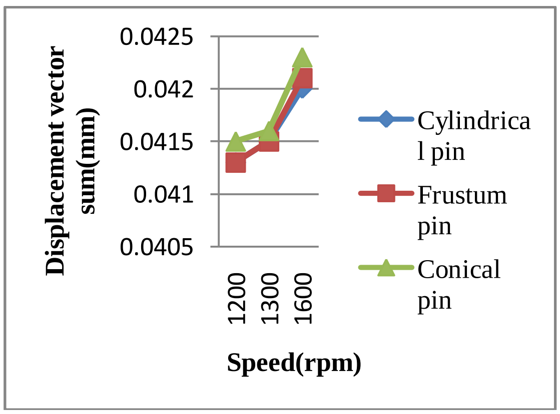

Fig.4.39 Variation of displacement vector sum with rotational speed in various tool profiles

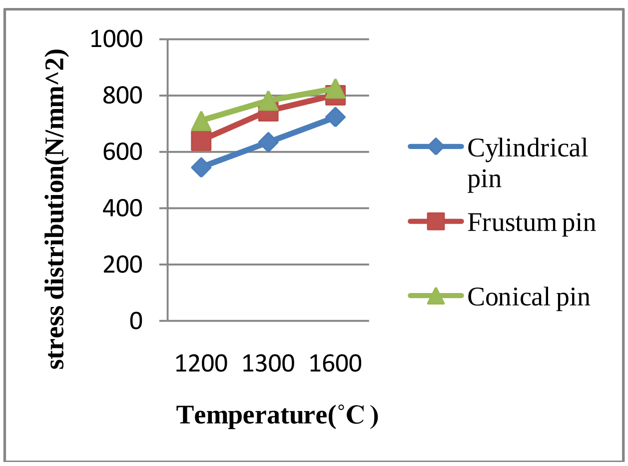

Fig.4.40Variation of stress distribution with temperature in various tool profiles

III. CONCLUSIONS

1) From the above results it can be concluded that among all profiles, the maximum stress distribution and displacement vector sum are very less in the tool with cylindrical profile with threads.
The stress distribution and displacement vector sum are observed to be increased as the temperature in the welding zone increases in the profiles with and without threads,. It is also maximum in the tool with conical profile.
2) Tthe stress distribution and displacement vector sum are observed to be maximum in the tool profiles without threads when the comparison of results is done in tools with and without threads.
3) Among all the profiles, the maximum stress distribution and displacement vector sum are maximum in the FSW tool with conical profile and is observed that by increasing the rotational speed there is not much change in the maximum stress distribution and displacement vector sum.

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