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OPTIMISATION OF FRICTION STIR WELDING TOOLS

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ABSTRACT

Friction-stir welding (FSW) is a solid-state joining process (the metal is not melted) that uses a third body tool to join two facing surfaces. Heat is generated between the tool and material which leads to a very soft region near the FSW tool. It then mechanically intermixes the two pieces of metal at the place of the joint, then the softened metal (due to the elevated temperature) can be joined using mechanical pressure (which is applied by the tool), much like joining clay, or dough.

In this project we have designed circular tool by using solid works and then applied static (tool rotational velocity 900 rpm) and thermal (temperatures' and convection on plates and tool also) boundaries conditions And calculated results like deformation stress and heat flux etc.

Here we also designed 3 more tools (pentagon and tapered and truncated) and applied same boundary condition with same material properties and calculated all results from all these results which tool can be used in the place of circular tool

Software's were used:

CAD software: solid works

CAE software: Ansys workbench

1. Introduction

Friction stir welding

Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing workpieces without melting the workpiece material. Heat is generated by friction between the rotating tool and the workpiece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough, it was primarily used on wrought or extruded aluminum and particularly for structures which need very high weld strength. FSW is capable of joining aluminum alloys, copper alloys, titanium alloys, mild steel, stainless steel and magnesium alloys. More recently, it was successfully used in welding of polymers. In addition, joining of dissimilar metals such as aluminum to magnesium alloys has been recently achieved by FSW. Application of FSW can be found in modern shipbuilding, trains, and aerospace applications.

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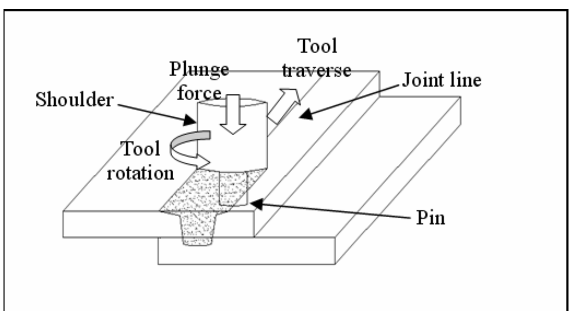
It was invented and experimentally proven at The Welding Institute (TWI) in the UK in December 1991. TWI held patents on the process, the first being the most descriptive

Main operation principle condition

A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped workpieces, until the shoulder, which has a larger diameter than the pin, touches the surface of the workpieces. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. After a short dwell time, the tool is moved forward along the joint line at the pre-set welding speed.

Frictional heat is generated between the wear-resistant tool and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the tool is moved forward, a special profile on the probe forces plasticized material from the leading face to the rear, where the high forces assist in a forged consolidation of the weld.

This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid-state deformation involving dynamic recrystallization of the base material



Advantages and limitations

The solid-state nature of FSW leads to several advantages over fusion welding methods, as problems associated with cooling from the liquid phase are avoided. Issues such as porosity, solute redistribution, solidification cracking and liquation cracking do not arise during FSW. In general, FSW has been found to produce a low concentration of defects and is very tolerant to variations in parameters and materials.

Nevertheless, FSW is associated with a number of unique defects if it isn't done properly. Insufficient weld temperatures, due to low rotational speeds or high traverse speeds, for example, mean that the weld material is unable to accommodate the extensive deformation during welding. This may result in long, tunnel-like defects running along the weld, which may occur on the surface or subsurface. Low temperatures may also limit the forging action of the tool and so reduce the continuity of the bond between the materials from each side of the weld. The light contact between the materials has given rise to the name "kissing bond". This defect is particularly worrying, since it is very difficult to detect using nondestructive methods such as X-ray or ultrasonic testing. If the pin is not long enough or the tool rises out of the plate, then the interface at the bottom of the weld may not be disrupted and forged by the tool, resulting in a lack-of-penetration defect. This is essentially a notch in the material, which can be a potential source of fatigue cracks.

A number of potential advantages of FSW over conventional fusion-welding processes have been identified

- Good mechanical properties in the as-welded condition.
- Improved safety due to the absence of toxic fumes or the spatter of molten material.
- No consumables — a threaded pin made of conventional tool steel, e.g., hardened H13, can weld over 1 km (0.62 mi) of aluminum, and no filler or gas shield is required for aluminum.
- Easily automated on simple milling machines — lower setup costs and less training.
- Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
- Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
- Can use thinner materials with same joint strength.
- Low environmental impact.
- General performance and cost benefits from switching from fusion to friction.

However, some disadvantages of the process have been identified:

- Exit hole left when tool is withdrawn.
- Large down forces required with heavy-duty clamping necessary to hold the plates together.
- Less flexible than manual and arc processes (difficulties with thickness variations and non-linear welds).
- Often slower traverse rate than some fusion welding techniques, although this may be offset if fewer welding passes are required.

Important welding parameters

Tool design

The design of the tool is a critical factor, as a good tool can improve both the quality of the weld and the maximal possible welding speed.

It is desirable that the tool material be sufficiently strong, tough, and hard wearing at the welding temperature. Further, it should have a 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 thickness ranges 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 penetration depth and thus increasing the plate thicknesses that can be successfully welded. An example is the "whorl" design that uses a tapered pin with re-entrant features or a variable-pitch thread to improve the downwards flow of material. Additional designs include the Triflute and Trivex series. The Triflute design has a complex system of three tapering, threaded re-entrant flutes that appear to increase material movement around the tool. The Trivex tools use a simpler, non-cylindrical, pin and have been found to reduce the forces acting on the tool during welding.

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. The Triflute tool uses an alternative system with a series of concentric grooves machined into the surface, which are intended to produce additional movement of material in the upper layers of the weld.

Widespread commercial applications of friction stir welding process for steels and other hard alloys such as titanium alloys will require the development of cost-effective and durable tools. Material selection, design and cost are important considerations in the search for commercially useful tools for the welding of hard materials. Work is continuing to better understand the effects of tool material's composition, structure, properties and geometry on their performance, durability and cost

Tool rotation and traverse speeds

There are two tool speeds to be considered in friction-stir welding; how fast the tool rotates and how quickly it traverses along the interface. These two parameters have considerable importance and must be chosen with care to ensure a successful and efficient welding cycle. The relationship between the rotation speed, the welding speed and the heat input during welding is complex, but in general, it can be said that increasing the rotation speed or decreasing the traverse speed will result in a hotter weld. In order to produce a successful weld, it is necessary that the material surrounding the tool is hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool. If the material is too cold, then voids or other flaws may be present in the stir zone and in extreme cases the tool may break.

Excessively high heat input, on the other hand, may be detrimental to the final properties of the weld. Theoretically, this could even result in defects due to the liquation of low-melting-point phases (similar to liquation cracking in fusion welds). These competing demands lead onto the concept of a "processing window": the range of processing parameters viz. tool rotation and traverse speed that will produce a good quality weld. Within this window the resulting weld will have a sufficiently high heat input to ensure adequate material plasticity but not so high that the weld properties are excessively deteriorated.

Literature review

Acerra.F et al (2010) attempted to weld the combination of two dissimilar aluminum alloy in T-configuration of AA7075-AA2024. It was to be investigated that higher the shoulder diameter of tool higher the heat to be generated by the FSW process on the weld zone. It was done to fulfill the forging requirement. Sometimes coating blank elements was obtained causes major defect was analyzed. [1]

Buffa et al (2006b) studied the model simulation in which he investigated how the tool geometry affect the weld zone. He tried with conical as well as cylindrical geometry of the tool and advancing speed of FSW on rigid visco-plastic three dimensional finite element model of 7075 aluminium alloy. In this model he studied how material flow takes place over the weld to be done as well as microstructural behavior like grain size variation. This result was used further to find the optimum tool geometry as well as speed to be advance. [2]

Aim of the project

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In this thesis friction stir welding tools were designed with the help of solid works tools and here 4 different types of friction stir welding tools were designed those are circular tool, pentagon tool, tapered tool, truncated tool, among all these tools circular tool is consider to be existing tool and the main aim of the thesis is to choose a better friction welding tools for real time boundary conditions

Results to be calculated: deformation, stress, strain, safety factor, total temperature distribution, heat flux

Designing process step by step

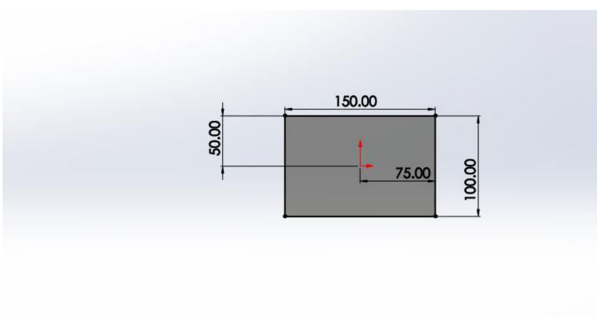
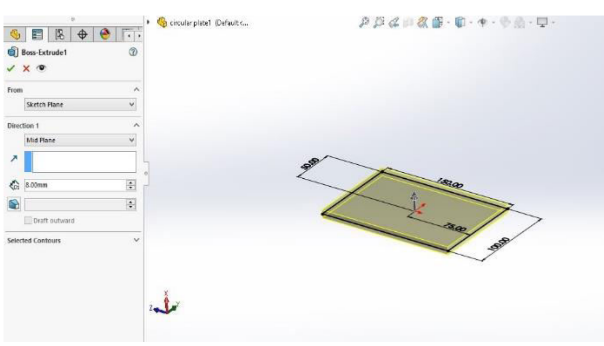
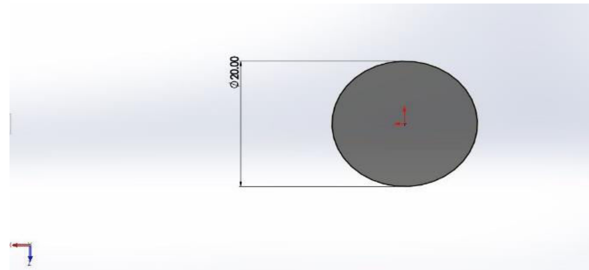
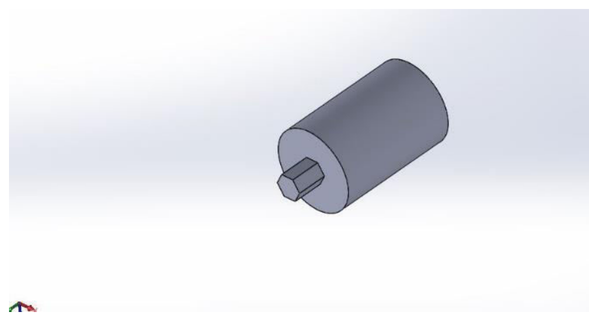


Plate dimensions

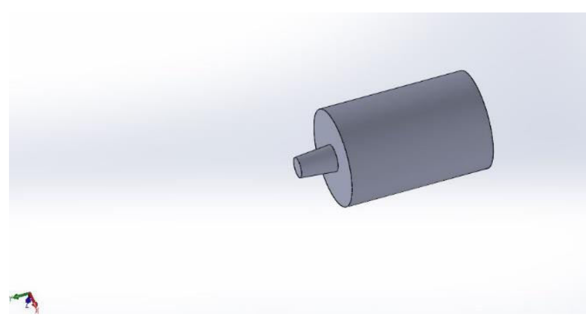




Tool 2d sketcher



Pentagon tool



Tapered tool

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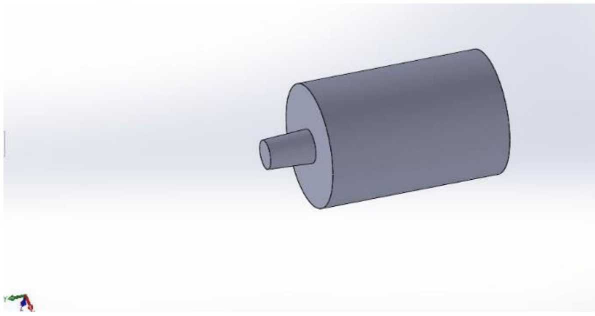
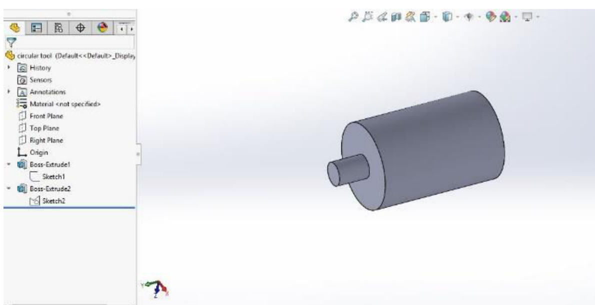
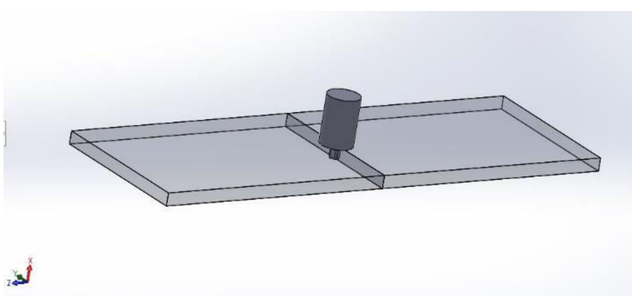


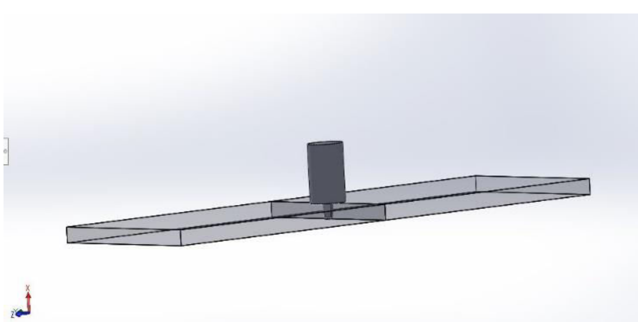
Truncated tool



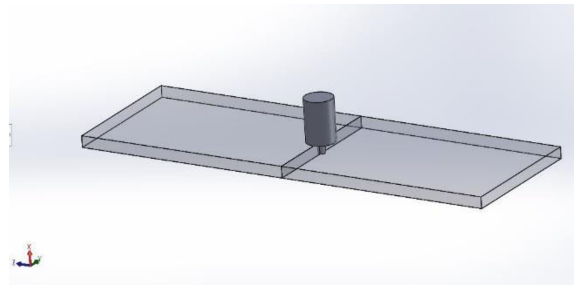
Circular tool



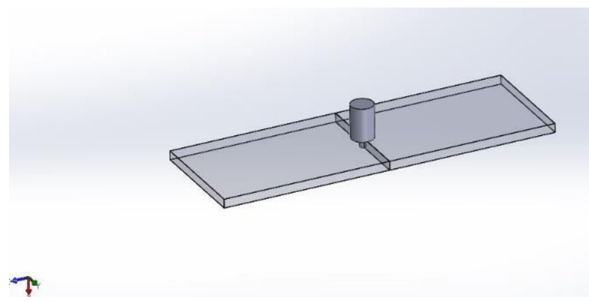
Circular tool assembly



Tapered tool assembly



Truncated tool assembly



Pentagon tool assembly

Material selection

Introduction

Aluminum 2048 alloy is a heat treatable wrought alloy type with good corrosion resistance.

The following datasheet will provide more details about aluminum 2048.

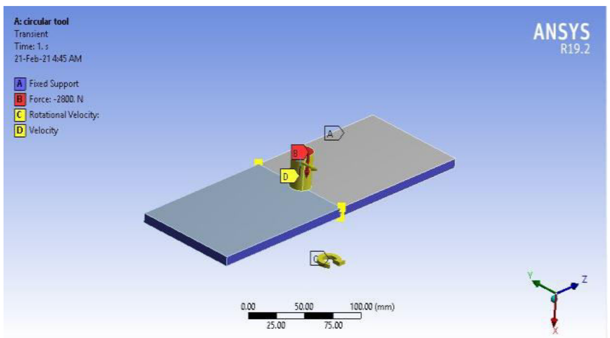
S45c

C45 grade steel is a medium carbon steel offering moderate tensile strengths. The material is capable of through hardening by quenching and tempering on limited sections but can also be flame or induction hardened to Hrc 55.

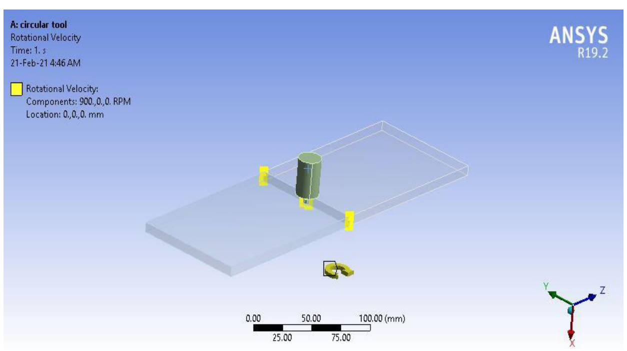
C45 round bar steel is equivalent to EN8 or 080M40. Steel C45 bar or plate is suitable for the manufacture of parts such as gears, bolts, general-purpose axles and shafts, keys and studs

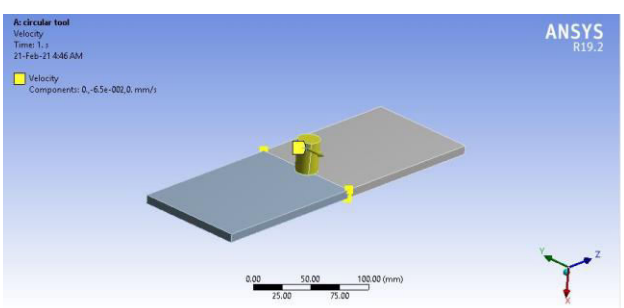
Ansys process

Boundary conditions



Here boundary conditions applied with an RPM of 900 and the force of spindle assume to be 2800N and required axial velocity

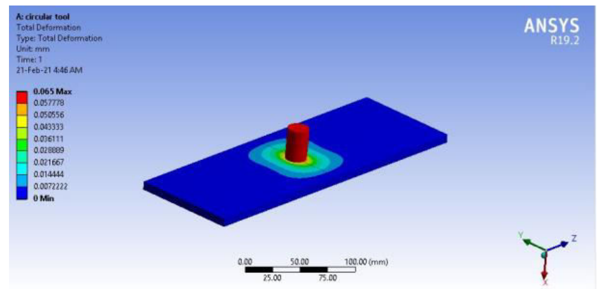




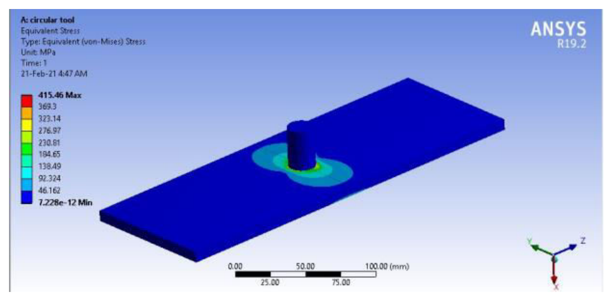
Static analysis

Circular tool

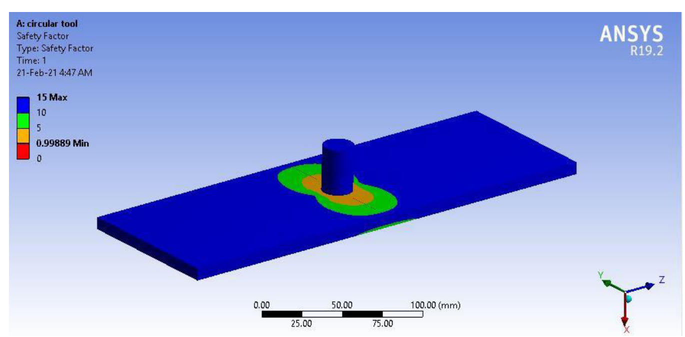
Deformation



Stress



Safety factor



Tables

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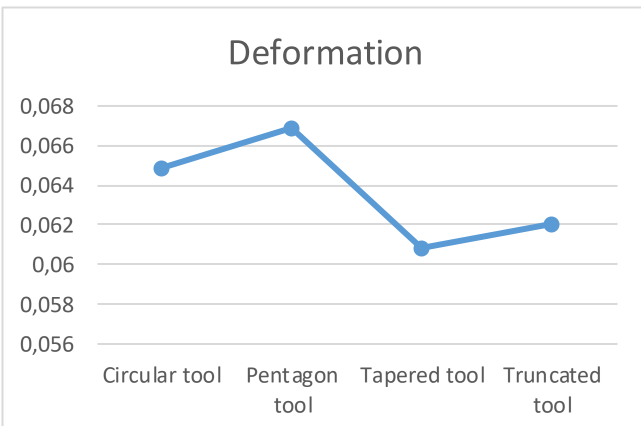
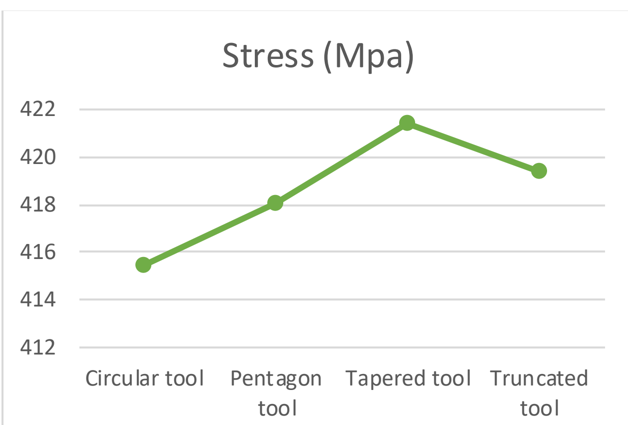
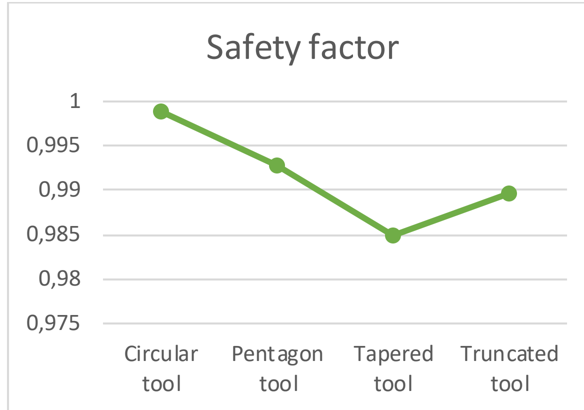
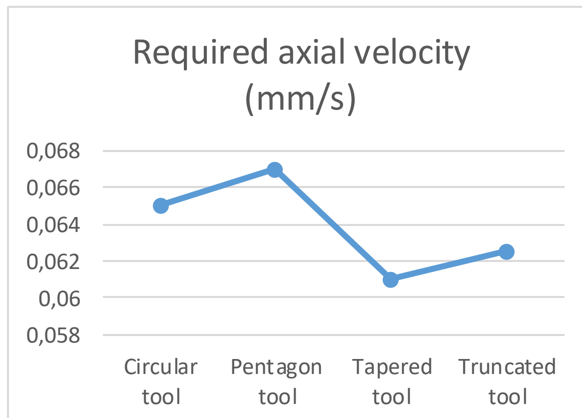
	Deformation (mm)	Stress (Mpa)	strain	Safety factor	Required axial velocity
Circular tool	0.0649	415.46	0.0059521	0.99889	0.065m
Pentagon tool	0.0669	418.04	0.0060768	0.99273	0.067m
Tapered tool	0.0608	421.39	0.0060371	0.98484	0.061m
Truncated tool	0.062	419.36	0.0060081	0.98959	0.0625m

Graphs





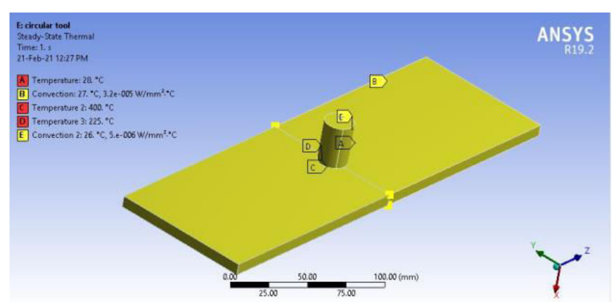




Thermal analysis

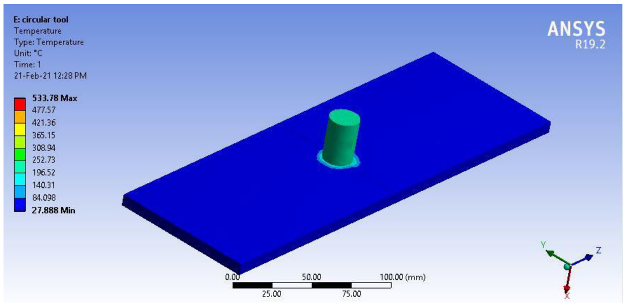
Circular tool

Thermal boundary conditions

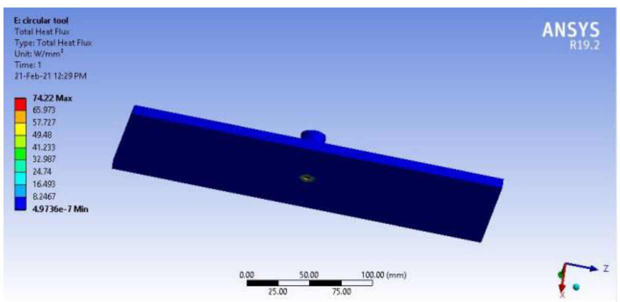


Above image represent the thermal boundary conditions of the object

Total temperature



Heat flux



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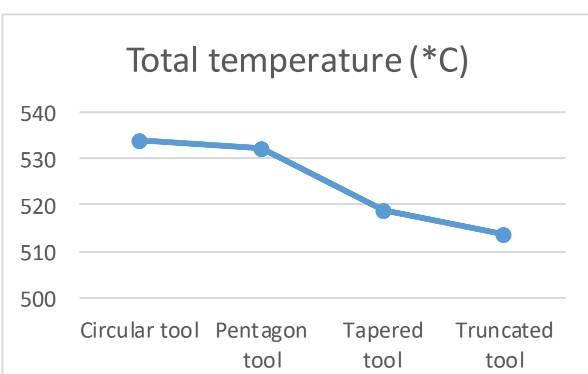
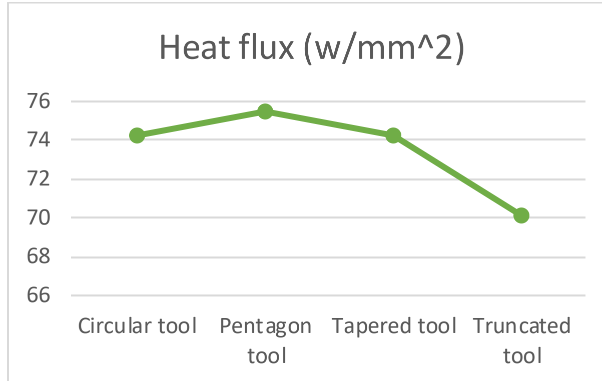
	Total temperature (*C)	Heat flux (w/mm^2)
Circular tool	533.78	74.22
Pentagon tool	532.41	75.489
Tapered tool	518.69	74.202
Truncated tool	513.91	70.137

Graphs





Conclusion

In this thesis friction stir welding tools were designed with the help of solid works tools and here 4 different types of friction stir welding tools were designed those are circular tool, pentagon tool, tapered tool, truncated tool, among all these tools circular tool is consider to be existing tool and the main aim of the thesis is to choose a better friction welding tools for real time boundary conditions

In this process al-2048 material were chosen for plates and then s45c material were chosen for friction welding tool, with the help of Ansys workbench transient boundary conditions, here calculating required axial velocity values to perform friction stir welding process, In this process each tool required different axial velocity values to perform the process in real time, among all tapered tool and truncated tools were required less amount of axial velocity values compare to other 2 tools, to know more accurate values of the process, here thermal analysis also performed on it, by knowing thermal analysis results it is clear that tapered tool is having optimum heat transfer rate values, and also it distribute the total temperature to plates, finally thesis concluded with tapered friction welding tool, and this tool perform friction stir welding process in low axial velocity, low axial velocity requires less time with less power consumption.

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