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Comparative Studies on Influence of Tool Geometry on Heat Generation in Friction Stir Welding Process

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***Abstract:** Friction Stir (FS) welding offers a number of advantages over the conventional fusion welding process, and it is used to join aluminum alloys that are difficult to weld by fusion welding processes. It has compatibility to any alloy composition, and produces the welded joints by eliminating the defects with improved mechanical properties. The weld quality is mainly influenced by the heat generated and material flow pattern that takes place during the friction stir welding process which depends on the above mentioned parameters. The mechanical and micro structural properties are highly influenced by the heat generation and material flow patterns. The tool geometry plays a vital role in the heat generation and material flow. The aim of the research is to study the influence of tool geometry on heat generation and temperature during friction stir welding process. A comparative study has been done based on the results obtained from numerical analysis and experimentation. It was found that the dissimilar FS welded joints fabricated using hexagonal tool pin profile generates optimum heat generation and temperature required for formation of quality weld irrespective of other process parameter.*

***Keywords:** friction Stir Welding, Heat Generation, Tool Geometry, Thermography, Temperature.*

I. INTRODUCTION

Friction Stir Welding (FSW) is patented process developed by The Welding Institute (TWI). The uniqueness of this process is that it is eco-friendly unlike other welding processes. No electrodes or flux are used in this process. The important tool in this process is a tool which is non consumable. The tool consists of two parts shoulder and the pin. The uniqueness of this process is that change in each parameter gives rise to different material flow pattern which influences the quality of weld. This process is used for welding materials which cannot be welded with conventional welding processes. Seidel and Reynolds [1] studied the material flow in friction stir welds by marker insert technique and suggested a semi-quantitative method of the material transport that takes place in the weld zone. Few models were developed to explain flow around the tool pins using 2D models (Seidel T U, Reynolds A P.) [2].Colegrove and Shercliff [3] developed a model to illustrate the 3D metal flow around the tool. Nandan et al., [4] could develop models which illustrated 3D flow in the friction stir welding. Colegrove et al., [5] uses an advanced analytical model for estimation of the heat generation for tools with a threaded probe to estimate the heat generation distribution. According to H Schmidt et al., [6], the material flow and heat generation is as classified as sliding, sticking or partial sliding/sticking. Arora et al., [7], used computational methods to develop the optimum tool shoulder diameter for best weld strength. P. Sevvel and V. Jaiganesh [8], conducted studies to illustrate the influence of process parameters on Friction stir welding (FSW) of AZ31B magnesium alloy lap joints on the microstructure & mechanical properties. Zettler et al., [9], studied temperature distribution and the flow pattern by employing marker material in welding 4 mm thick 2024-T351aluminium alloy materials. Nandan et al., [10], conducted studies on 304 austenitic stainless steel using 3D viscoplastic flow and temperature field. In the present study we are concentrating on welding of dissimilar aluminum alloys of thickness of 8mm with different tool designs and study the heat generation and temperature evolution during the FSW process and impact on the quality of weld

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II. MATERIALS AND METHODS

2.1. Tools and Materials Used

Aluminum alloys AA6061 and 6082 are selected as work piece material.8mm thick plates each of dimension of 100mm X 200mm X 8mm are used. The tool material is HCHC steel. Properties of the material used are given in the Tables below.

Table 1. Chemical Composition of AA 6061

Chemical composition wt%								
Al	Si	Cu	Mg	Zn	Fe	Ti	Cr	Mn
Balance	0.40-80	0.15-40	0.6-1.2	0.20	0.7	0.1	0.25	0.40

Table.2. Chemical Composition of AA 6082

Chemical composition wt%								
Elements	Al	Si	Cu	Mg	Zn	Fe	Ti	Cr
Wt%	Balance	0.7-1..30	0.1	0.8-1..20	0.25	0.5	0.15	0.4

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Table 3. Chemical Composition and Hardened Tool Material

C	Si	Cr	Mo	V	Mn
1.5	0.3	12	0.8	0.9	0.6

2.2. Tool Design

Various types of tool profiles are employed which are triangular, square, pentagonal, and hexagonal. Table 4 &Fig.1 below describe the tools used.

Table 4. Details of the Tools used

Tool Designation	Tool Shape	Pin Length (mm)	Pin Diameter (Side of the polygon) (mm)	Shoulder Diameter (mm)
1	Triangular	7.8	8(6.93)	25
2	Square	7.8	8(5.66)	25
3	Pentagonal	7.8	8(6.09)	25
4	Hexagonal	7.8	8(4)	25

Fig.1. Tool Geometry

2.3. Experimental Setup

Experimental setup consists of the following (Fig.2)
Milling Machine(Modified to suit FSW)
Fixture
Thermocouples
Dynamometer

Fig.2. Experimental Setup

III. EXPERIMENTATION

3. Comparative Studies on Influence of Tool Geometry on Heat Generation,

Experiments are conducted with the experimental set up and the tools and work piece materials keeping the following process parameters constant and changing the tool geometry.
Tool Rotation (rpm) = 1000 rpm,
Tool Translation (mm/s) =25mm/min
Axial force (KN) = 6KN

Heat generation and temperature evolution during the FSW process using different tool geometries is measured and compared.

3.1. Heat Generation and Temperature Measurement during FSW with Different Tool Geometries

3.1.1. Temperature Measurement using Thermocouples

Temperatures were measured at selected locations, i.e., at different depths from top surface and offset weld axis, during the FSW process. In each experiment a total of four thermocouples at predicted locations were inserted into the work pieces from underneath as shown in Figure (Fig.3).

The grooves and seating arrangement for thermocouples is shown in the Figure (Fig.2). K- type thermocouples are used. Sensitivity = 41 µV/°C. The thermocouples are placed at a distance away from the weld centre line so that they cannot be melted and dissolved into the plates. The specifications of the K-type thermocouples are SS316, OD=1 mm and length=50mm with external cable length of 5 meters,

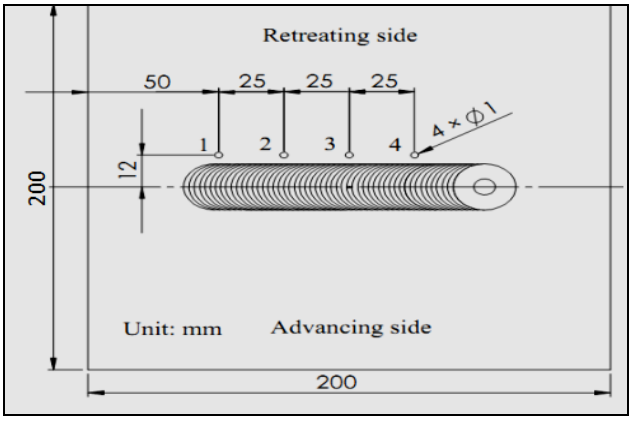

Fig.3. Arrangement of Thermocouples

Table.5. Temperatures measured using Thermocouples

S.No.	Tool Geometry	4	3	2	1
1	Triangular Tool	124^0C	220^0C	246^0C	280^0C
2	Square Tool	146^0C	272^0C	282^0C	296^0C
3	Pentagonal Tool	210^0C	320^0C	328^0C	364^0C
4	Hexagonal Tool	226^0C	420^0C	436^0C	454^0C

3.1.2.Temperature Measurement using Thermography

Thermography is used to measure temperatures and recorded during the welding process transiently. It is a NDT technique. The Thermal camera used has following specifications (Table 6.)

Table 6. Thermal Camera Specifications

Emissivity	0.95
Transmission	100%
Model	Fluke Ti32
IR Resolution	320x240
Manufacturer	Fluke thermography
Measurement range	-10°c to 600°c

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The maximum and minimum temparatures during the process as recorded using thermography are tabulated below.

Table 7. Temperatures obtained using Thermography with Different Tools

Tool	Maximum Temparature (°C)	Minimum Temparature (°C)
Triangular Tool	220.52	52.1
Square tool	297.41	71.4
Pentagonal tool	319.30	102.4
Hexagonal tool	452.24	108.3

IV. RESULTS AND DISCUSSION

4. Influence of Tool Geometry on Heat generation

4.1. Evolution of Heat during Friction Stir Welding

Generation of Heat and temperature are crucial in the formation of quality of weld as they influence the flow pattern of the material. There is a direct correlation between the temperature and quality of weld. But, the heat generation and rise and fall of temperature are dynamic in nature and their measurements during the experimentation are challenging tasks. Hence two methods are employed, one using thermocouples and second using the NDT technique, Thermography and both the recorded values are compared and correlated. Acceptable level of correlation is observed between the two methods which is evident from the graphs below

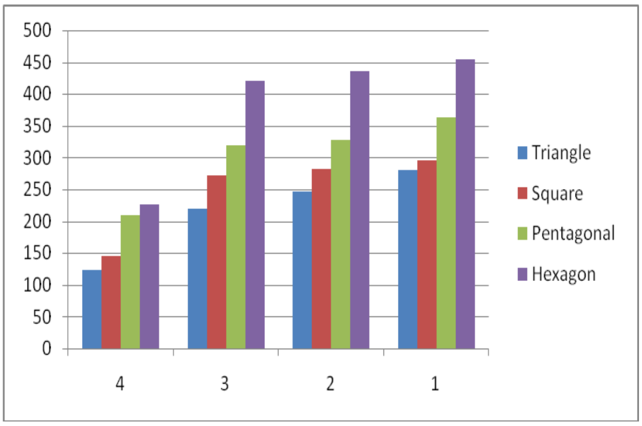


Fig.4. Variation of Temperature with Change in Tool Profile

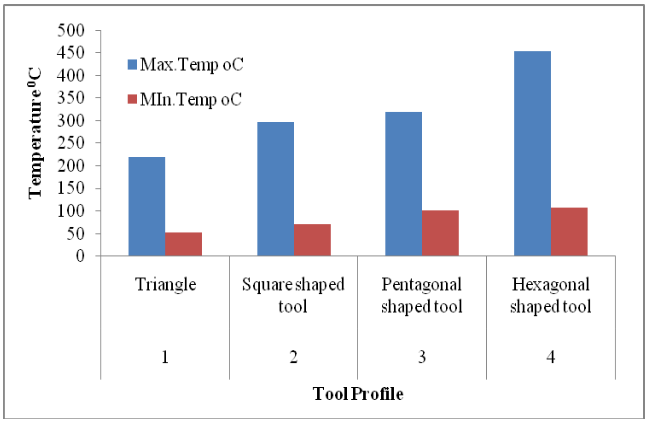
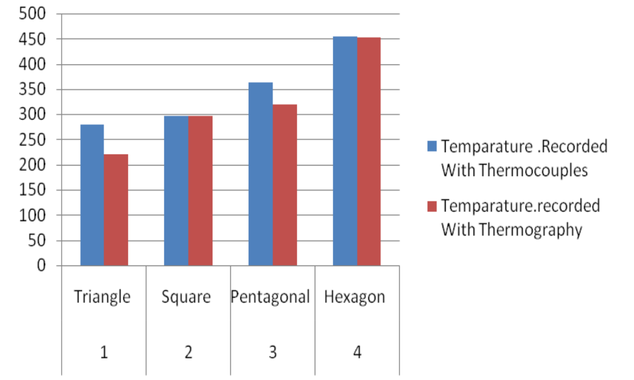


Fig.5. Maximum and Minimum Temperatures with Various Tool Profiles

4.2. Comparison between Temperatures recorded using Thermocouples and Thermography



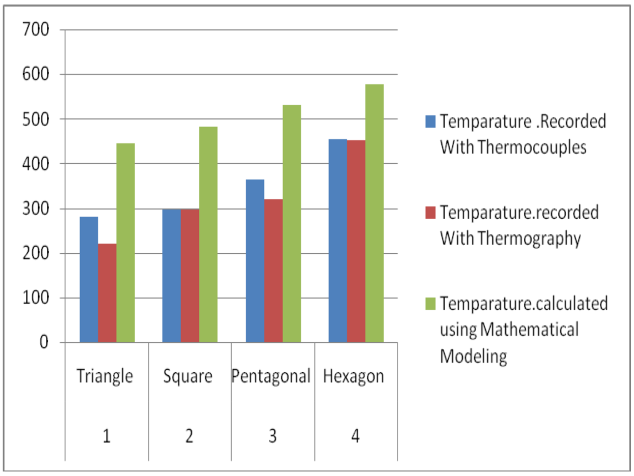


Fig. 6.Graphs Showing the Variation of Temperature with Tool Geometry

4.3. Variation of Heat Generation with Tool Geometry.

The Heat generated due to change in the probe radius, is estimated and graphs are drawn with giving the increment of the Probe radius, by an equal increment of 0.001m.and graphs show that change in the probe radius will increase the heat generated. Hence we can seen that shape as well as dimensions of the tool have impact on the heat generation

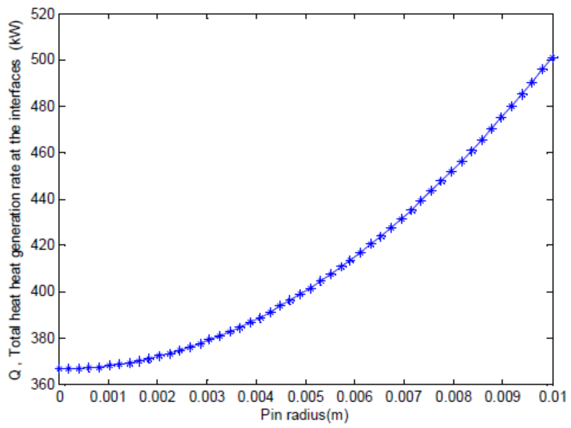


Fig.7.Graph showing the change of heat generated with Change in Pin radius

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4.4. Influence of Tool Geometry on Temperature during FSW

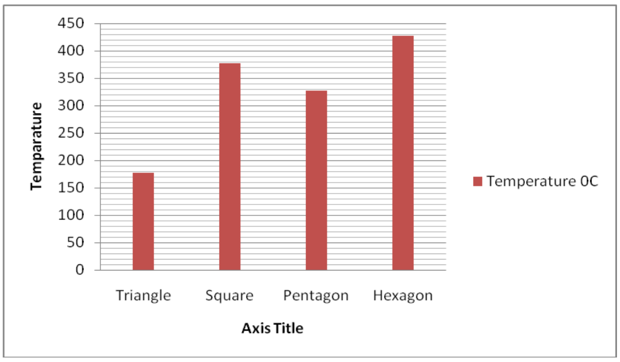

Fig.8.Influence of Tool Geometry on Temperature during FSW

The variation in temperature with different tool profiles is shown in the above graph. The hexagonal tool generates more temperature compared to other tools.

V. CONCLUSIONS

This Research aims at welding of AA6061 and AA6082 which have wide range of commercial applications. The study deals with the study of heat generation during the friction stir welding process using different tools. The change in the temperatures during the welding process is measured using thermocouples and thermography. Conclusions from the Experimental investigations are Heat generation during the FSW of AA 6061-AA 6082 is highest with the hexagonal tool which resulted in a temperature rise of 452 ^{0}C. The Best results are obtained using Hexagonal Tool profile in comparison with other tool profiles; this is due to more heat generation that is due to higher contact volume. From the results it can be concluded that proposed methodology will result in producing quality friction stir welds with less or zero defects. The outcome of the investigations results in welding of thick dissimilar aluminium alloys and can be extended to other materials for producing good quality welds with zero defects

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