Studies on Effect of Tool Shoulder Geometry on Mechanical Properties of Friction Stir Welded 6082 T6 Aluminium Alloy

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Abstract—In **Friction stir welding tool, geometry plays a critical role in material flow and governs the transverse rate at which FSW can be conducted. 6082 T6 AA is a medium strength aluminium alloy with excellent corrosion resistance. It has the highest strength of 6XXX series alloys and it is most commonly used for machining. The tool serves three primary functions, i.e., (a) heating of the work piece, (b) movement of material to produce the joint, and (c) containment of the hot metal beneath the tool shoulder. Heating is created within the work piece by friction between both the rotating tool pin and shoulder and by severe plastic deformation of the work. The function of the tool shoulder is to provide heat by application of a large compressive force and tool rotation over the surface of the material being welded and to contain the softened, plasticized metal beneath it. Understanding the temperature generation around the tool shoulder contact is one of the important aspects of the friction stir welding process. In the present study, the effects of tool profile geometry as Taper cylindrical, Cylindrical Concave, Convex and Square tool on the and mechanical properties of the 6082 T6 aluminium alloy using FSW.**

***Index Terms*—AA 6082 T6, Friction Stir Welding, Pin Profile, Tool Shoulder Geometry.**

I. INTRODUCTION

The general requirements of a component in the mechanical, automobile and aerospace have given many challenging conditions. New materials can be modified and then can be fabricated as to a useful component. One such fabrication technique is solid phase joining process which is the traditional method. Many processes are generally termed as solid phase joining. Each and every process may vary based on time, pressure and temperature used and the application of heat. In a particular point, cold pressure welding can be done without any heating and several other metals or alloys can be integrated together. Processes such as magnetically impelled arc butt-welding, friction welding, explosive welding, etc., belong to another extreme, employing plastic deformation at higher temperature. The best strategy to overcome the problem is by solid state joining, where melting is not done and hence the defects are eliminated. The integration of immiscible or partially miscible alloy systems which is cumbersome in traditional fusion welding is also possible by this solid state joining. Many solid state joining techniques have been widely used on large scale for industrial processes.

A. Classification of Welding Processes

Welding processes can be divided into two main categories:

1. Liquid-phase welding, e.g. it includes all welding processes such as traditional arc welding, electron beam welding and laser welding.
2. Solid-state welding, e.g. it includes friction stir welding, forge welding, explosive welding and solid-state diffusion bonding.

B. Friction Stir Welding (FSW) Technology

The basic principles of FSW process are illustrated in Fig.1.The specially designed tool has two essential parts. The first part is the profiled pin extending along the rotating axis. The second part is the shoulder.

Rotating at high angular speeds, the pin plunges into the work piece until the shoulder makes full contact with work piece surfaces. The rotating tool then moves along the joint line with the shoulder fully in contact with the work piece surface under a relatively high axial forging force. The increase in temperature softens the material, and allows the rotating tool to mechanically stir the softened material flowing to the backside of the pin where it is consolidated to form a metallurgical bond.

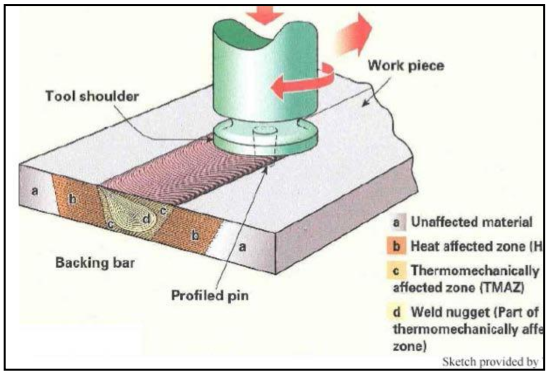

Fig.1 Principles of FSW Process

C. Aluminium and its Alloys

Aluminium is considered as the most important metal available in the earth‘s crust. This becomes a strong competitor for steel in various Engineering applications. Aluminium has many excellent properties and characteristics due to low density compared to steel. It is very cheap and flexible to use. It is also a consumer metal of great importance. For making of body panels and bumpers, aluminium alloys are generally used because they have high strength to weight ratio, corrosion resistance, formability and strength. However, its weldability is restricted by cracking which is occurring in the Heat Affected Zone (HAZ). Light weight construction materials have become one of the latest research focuses because of low level energy consumption. Many alloys and many grades of aluminium can be modified globally. Most of the aluminium alloys have resistance to oxidation and also resist corrosion by water, salt and other factors. The specialty of aluminium is that it is treated with heat to fairly high strength levels, and it is one of the more easily fabricated of the high performance materials, which usually results in lower costs.

D. Friction Stir Welding Tool

The pin and shoulder, two separate portions of the FSW, are shown in Fig.2. The key determinant of tool shape is the management of material flow, heat production and solders efficiency. The maximal temperature energy and torque are all influenced by the shoulder arrangement. The diameter of the tool shoulder is a critical parameter for work piece plastic deformation, and its optimal value is determined by the rate of rotation, the torque applied, and the ratio D / d. The data demonstrate that as the diameter of the deforming material grows, it moves from high flow pressure and low temperature to low flow stress and high temperature.

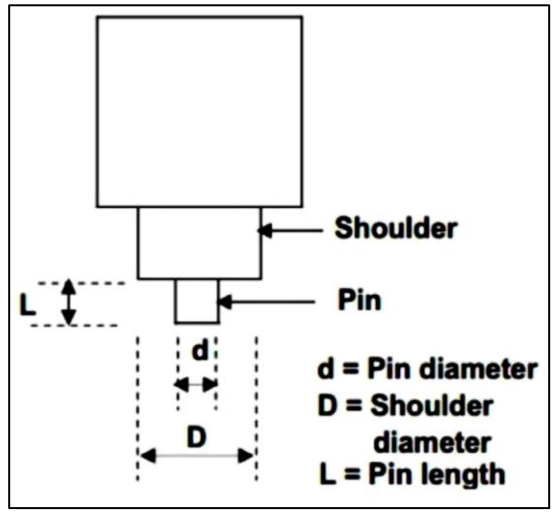

Fig.2 FSW Tool

II. LITERATURE REVIEW

K. RAMANJANEYULU et.al [1] have investigated, the influence of shoulder diameter on weld performance. Of the six joints fabricated using tools with different shoulder diameters at 1,000 rpm and 600 mm/min, the weld bead appearance is smooth without any surface defects in the welds produced with shoulder diameters from 12 to 15 mm. With a further increase in the shoulder diameter from 18 to 24 mm, surface defects were noticed. Peak temperatures measured below the shoulder, at the Nugget/TMAZ interface, increase with an increasing shoulder diameter. The temperature gradient also becomes less steep with increasing shoulder diameter, reaching a minimum for the 18 mm diameter shoulder. Beyond this, there is a moderate decrease in the temperature gradient up to 24 mm shoulder diameter.

KRISHNA KISHORE MUGADA et.al [2] presented that understanding the temperature generation around the tool shoulder contact is one of the important aspects of the friction stir welding process. In the present study, the effects of various tool shoulder end feature on the and mechanical properties of the 6082 aluminum alloy were investigated. The experimental results show that the axial force during the welding is considerably reduced by using tools with shoulder end features. The detailed observation revealed that around the tool shoulder contact, the amount of heat generation is higher between trialing edge (TE) to retreating side-leading edge corner (RS-LE) counter clockwise direction and lower between RS-LE to TE clockwise direction. Out of the four shoulder end featured tools, the welds produced with ridges shoulder tool resulted in superior properties with significantly lower axial force (approximately 32%) compared to plane shoulder tool.

NOOR ZAMAN KHAN et.al [3] investigated the effect of shoulder diameter to pin diameter (D/d) ratio on the joint strength during Friction stir welding (FSW) of 6063 aluminium alloy. 4.75 mm thick plates of AA6063-T6 were welded using FSW under varying levels of selected FSW parameters. A cylindrical pin profiled FSW tool of H13 tool steel was used. The welds were characterized using optical microscopy and mechanical testing. The findings of the study revealed that a D/d ratio of 2.6 gives the maximum tensile strength whereas a D/d ratio of 2.8 results in the minimum tensile strength.

J. STEPHEN LEON et.al [4] have developed to register thermal history in the parental metal during the process using a re-modified analytical heat input model applicable for different tool geometry. An experimental analysis is made and the numerically obtained results are validated for different tool designs. The obtained results conclude that the heat generation rate is directly proportional to the shoulder cone angle and inversely proportional to the pin taper angle irrespective to the tool pin shape. Regarding the geometrical shape of the tool pin, the intensity of heat generation is directly proportional to the number of sides in the tool pin. It can be concluded that tool with hexagonal pin can be designed with lesser shoulder cone angle and higher tool pin taper angle to control the amount of excess heat diffusion through the workpiece.

PRAKASH KUMAR SAHU et.al [5] identified the effect of shoulder diameter and plunging depth on mechanical properties and thermal history of the friction stir welded AM20 magnesium alloy. The results show that friction stir welding (FSW) can be utilized for joining AM20 and gives better mechanical properties, namely ultimate tensile strength, bending angle, and micro-hardness. The maximum tensile strength of the welded joint was 65%, to the base metal when the shoulder diameter was 24 mm. When shoulder diameter decreases, the contact surface area with the work piece also decreases which causes less frictional heat generation and as a result joint strength decreases. The bending performance of the welds was found to be satisfactory. The maximum bending angle of the welded joint is 45° whereas base metal bending angle is 90°. The hardness test was also done and it was found that the hardness of the upper zone is comparatively higher than the middle and bottom zone, irrespective of the process parameters setting. It is also found that the hardness is higher in the weld nugget zone compared to the heat affected zone and base metal.

III. TOOL TYPES AND FUNCTIONS

The friction stirring tool consists of a pin (probe) and a shoulder. The pin plunges into the mating place of the work piece creates frictional and deformational heating and softens the work piece material; contacting the shoulder to the work piece increases the work piece heating, expands the zone of softened material, and the deformed material. Naturally, there are important effects to the tool during welding: high temperature, abrasive wear and dynamic effects. Therefore, the good tool materials must satisfy some properties such as

1. Good wear resistance
2. High temperature strength, temper resistance
3. Good toughness

A. Tool Materials

Production of a quality friction stir weld requires the proper tool material selection for the desired application. Thus, it is undesirable to have a tool that losses dimensional stability, the designed features, or worse, fractures. There are several tool materials to use depending on the base material.

B. Tool Steels

The most commonly used material, easy availability and machinability, thermal fatigue resistance, wear resistance. Materials such as aluminum or magnesium alloys and aluminum matrix composites (AMCs) are commonly welded using steel tools. AISI H13, a chromium molybdenum hot worked air hardening steel, has been the most commonly used tool.

IV. MATERIALS AND METHODS

A. Aluminium Alloy-6082

AA 6082 is a heat-treatable aluminum alloy with magnesium as the primary alloying element. It is malleable when in the fully soft, annealed temper and can be heat-treated to high strength levels after forming. Due to its high strength to weight ratio, it is widely used in aerospace applications.

Table.1 AA 6082 Mechanical Properties

Density	2.70 g/cm^3
Modulus of Elasticity	70 GPa
Thermal conductivity	24x10^{-6} /K

B. Tool Profile Used

Aluminum alloy was used as base metal to perform friction stir welding in this study. The prepared samples were welded cylindrical pin but various tool shoulders are used to the welding process.

Fig.3 FSW Tool Shoulder Geometry

V. EXPERIMENTAL WORK

A. Various Tool Shoulders and its Parameter

AA 6082 was used as base metal in this study. The prepared samples were welded cylindrical pin but various tool shoulders will be used to the welding process.

Table.2 FSW Input Process Parameters

Shoulder Profile	Speed (rpm)	Tool-TR (mm/min)	AXFC (kN)
Cylindrical	1000	14	10
Taper Cylindrical	1000	14	10
Square	1000	14	10
Concave	1000	14	10
Convex	1000	14	10

Fig.4 AA 6082 Welded Strips

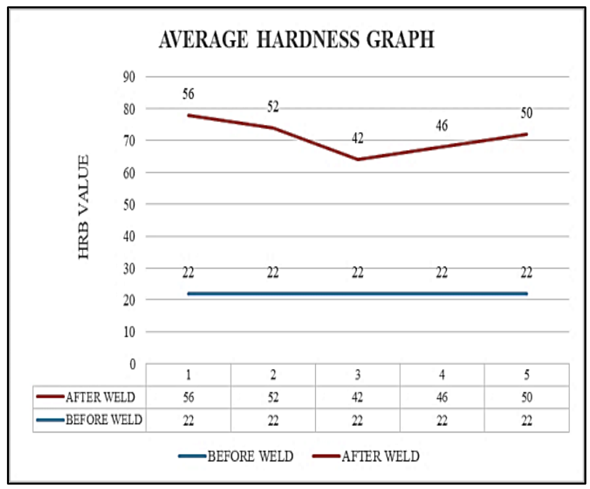

Fig.5 Hardness Survey Graph

B. Tensile Test and Elongation

Friction stir processed joints are evaluated for their mechanical characteristics through tensile testing. A tensile test helps determining tensile properties such as tensile strength, and percentage of reduction in area and modulus of elasticity. The welding parameters were chosen within the range available. The joints were made with parameters and evaluate tensile strength. Then the joints were made and evaluate the mechanical and metallurgical characteristics. The friction stir welded specimens were prepared as per the ASTM standard (E8). The test was carried out in a universal testing machine (UTM) 40 tones FIE make.

Fig.6 Tensile Test on Specimen

Table.3 Tensile Strength Values of the FSW Joints

Shoulder profile	Speed (rpm)	Tool-TR (mm/min)	AXFC (kN)	Tensile Strength (N/mm²)
Cylindrical	1000	14	10	85
Taper Cylindrical	1000	14	10	122
Square	1000	14	10	92
Concave	1000	14	10	88
Convex	1000	14	10	83

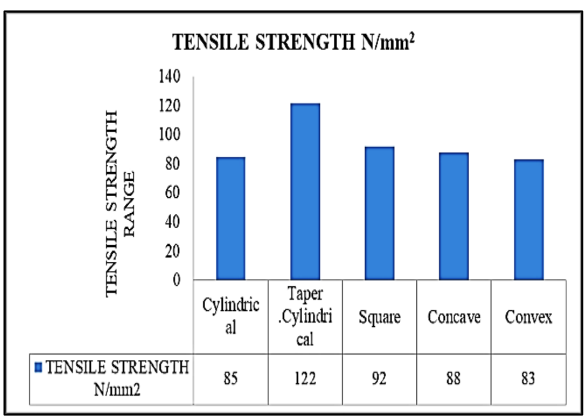

Fig.7 Tensile Strength Graph

C. Root Bend Test

Root and face bend tests are another simple low cost method of testing. It gives very simple to understand results and will show any signs of poor fusion or weaknesses such as porosity within the weld. There are numerous variations on this method; we will look at one of the simplest methods. Whether the sample piece is bent root up or root down decides whether it is a root or face bend test, with the root on the outside of the bend, in tension that would be a root bend test. Once a suitable section of the weld is selected, it is prepared for testing. The test piece is then put into a bending jig and force applied to it directly over the welded area. The piece should bend around without cracking. A crack would show a weakness of the weld. A neatly bent strip would show the weld is as strong as the parent metal.

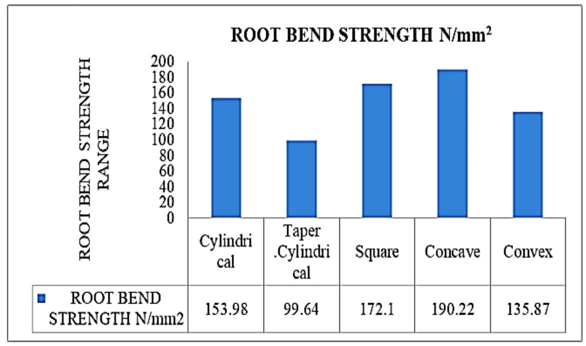

Fig.8 Root Bend Strength Graph

D. Root Bend Test

Fig.9 Angle Distortion of Taper Cylindrical Shoulder Tool

Fig.10 Angle Distortion of Square Shoulder Tool

Fig.11 Angle Distortion of Convex Shoulder Tool

Fig.12 Angle Distortion of Concave Shoulder Tool

Fig.13 Angle Distortion of Cylindrical Shoulder Tool

Table.6 Angle Distortion of Various Shoulders

Shoulder Profile	Angle Distortion (°)
Cylindrical	1.23
Taper Cylindrical	1.25
Square	1.25
Concave	1.04
Convex	1.04

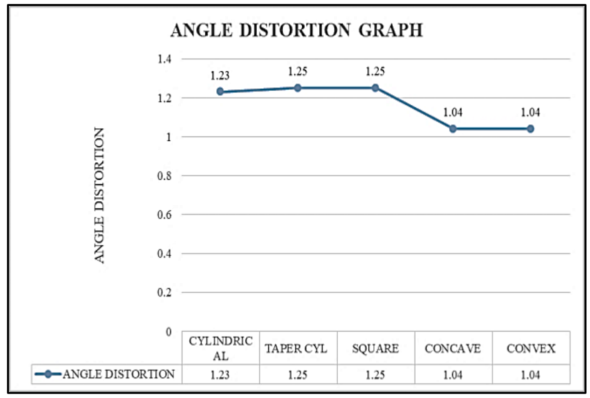

Fig.14 Angle Distortion Graph

D. Weld Appearance

Table.7 Weld Appearance

Shoulder Profile	Weld Appearance
Cylindrical	Fine weld texture at weld region
Taper Cylindrical	Very fine texture but crack occurs on the center of the weld.
Square	Rough texture at weld region some pin holes found middle of the weld
Concave	Rough texture at weld region it has no crack of the weld region
Convex	Very fine texture but mild porous effects formed at the initial weld

VI. CONCLUSION

The FSW constant process parameter was evaluated and compared different FSW tool shoulder profile. Generally, tool shoulder profile has also influenced the weld quality. For FSW process, we have been used cylindrical, wedge, square, convex & concave tool shoulder.

1. From this research work after FSW process weld bead observed concave tool shoulder profile tool execute without crack exhibit the good weld bead.
2. Low hardness value was obtained during the process welded with square shoulder tool pin (42HRB).
3. Based on the weld appearance cylindrical tool profile tool shoulder was executed very fine texture compare to other tool shoulders.
4. Maximum tensile strength 122 N/mm^2 was achieved in the sample welded with taper cylindrical tool shoulder.

5. Maximum bending strength (190.22 N/mm^2) achieved through concave tool shoulder compared to other shoulders.
6. Angle Distortion plate or Bead Straightness were analyzed through auto cad and found maximum deviation occurred in tool shoulders 2.5° at cylindrical, taper cylindrical and square. Minimum deviation occurred at concave and convex tool shoulders 1.04°

The taper cylindrical tool shoulder showed the highest tensile strength among the different kinds of tool shoulders, while the concave tool shoulder had the lowest angle distortion, the greatest depth of penetration, and the greatest strength in root bend. Finally concluded tapper cylindrical, concave tool shoulders were very better option for the FSW of AA6082.

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