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WELDING CHARACTERISTICS OF DISSIMILAR ALUMINIUM ALLOYS THROUGH FRICTION STIR WELDING

**NAVEENKUMAR. M[1], ABILASH. S[2], BALASUBRAMANIAN.A.R[2],
CHITHI GANAPATHY. S[2], GOKUL NISHANTH. B[2], Dr. M. SUBRAMANIAM[3],
Dr. T. PRAKASH[3], Dr. P. TAMIL SELVAM[4]**

Research Scholar, SNS College of Technology, Coimbatore – 641035[1]

UG Scholar, SNS College of Technology, Coimbatore – 641035[2]

Professor, SNS College of Technology, Coimbatore – 641035[3]

Dean, SNS College of Technology, Coimbatore – 641035[4]

Abstract: Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991. Initially, the process was regarded as a “laboratory” curiosity, but it soon became clear that FSW offers numerous benefits in the fabrication of Aluminium products. Friction Stir Welding is a solid-state process, which means that the objects are joined without reaching the melting point. This joining technique is energy efficient, environment friendly, and versatile. Friction stir welding has been proven to be an effective process for welding aluminium, brass, copper, and other low-melting materials. In FSW parameters play an important role like tool design and material, tool rotational speed, welding speed, and axial force.

In our project, we have used Aluminium material of 2025 and 7075 series with three different shaped tools and three different speeds, and three different feed rates.

The reason we choose aluminium for welding is because of its corrosion resistance and strength. Its weight advantage can also be used in the transport industry such as building Ships. Welding of these two aluminium materials can result in drastic improvement in strength and corrosion resistance. They can be also used in cold temperature applications, such as cryogenics and liquid natural gas transportation.

After welding, we sent the welded materials to go through some testing like Hardness Test, Tensile Test to check the properties like strength, ductility, resistance to corrosion, and others.

CHAPTER 1
FRICTION STIR WELDING

1.1 INTRODUCTION TO FRICTION STIR WELDING

Friction stir welding (FSW) was, invented and developed at The Welding Institute (TWI). It allows metals, including Aluminium, lead, magnesium, steel, titanium, zinc, copper, and metal matrix composites to be welded continuously. Many alloys, which are regarded as difficult to weld by fusion processes, may be welded by FSW. The process has already made a significant impact on the Aluminium producing and user industries.

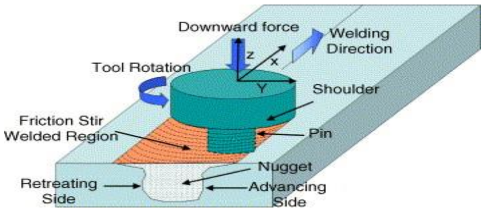

Fig 1.1 Schematic Diagram of Friction Stir Welding

A non-consumable rotating tool is employed of various designs, which is manufactured from materials with superior high-temperature properties to those of the materials to be joined. Essentially, the probe of the tool is applied to the abutting faces of the workpieces and rotated, thereby generating frictional heat, which creates a softened plasticized region (a third body) around the immersed probe and at the interface between the shoulder of the tool and the workpiece. The shoulder provides additional frictional treatment to the workpiece, as well as preventing plasticized material from being expelled from the weld. The strength of the metal at the interface between the rotating tool and the workpiece falls below the applied shear stress as the temperature rises, so that plasticized material is extruded from the leading side to the trailing side of the tool. The tool is then steadily moved along the joint line giving a continuous weld.

Although incipient melting during welding has been reported for some materials, FSW can be regarded as a solid-state, autogenous keyhole joining technique. The weld metal is thus free from defects typically found when fusion welding, e.g. porosity. Furthermore, and unlike fusion welding, no consumable filler material or profiled edge preparation is normally necessary. FSW is now a practical technique for welding Aluminium rolled and extruded products, ranging in thickness from 0.5 to 75 mm, and is used in commercial production worldwide. The present paper describes the current state of application of the process, together with future possible applications. It also covers recent developments in tool design, as this is the key to the successful application of the process.

Since it is discovered in 1991 FSW has evolved as a technique of choice in the routine joining of Aluminium components its applications for joining difficult metals and metals other than Aluminium are growing. There have been widespread benefits resulting from the applications of FSW in for example aerospace, shipbuilding, automotive, and railways industries.

Friction stir welding is considered to be the most significant development in metal joining in the past decades. It is an emergent green technology due to its energy efficiency (low heat input), sustainable utilization of natural resources (less material waste, reduced material lead time, part count reduction, high weld quality, and performance, longer life cycle), reduced environmental impact (no shielding gases required, no fumes/spattering/ ozone produced, part cleaning requirements reduced, filler material addition not necessary) and process versatility (adaptable welding orientations and different thicknesses, microstructures, and compositions). As a solid-state joining process, FSW is performed below the melting temperature of the material, which thus minimizes avoids some typical defects encountered in fusion welding such as cracking, porosity, and alloying element loss.

Nowadays FSW has become a practical joining technique for Al and other low strength alloys. However, for high-strength alloys such as Ti, Ni, and steel, cost-effective welding and long tool life remain as subjects for research development and processing technology optimization. The main roles of the FSW/P tools are to heat the workpiece, induce material flow and constrain the heated metal beneath the tool shoulder. Heating is created by the friction of the rotating tool shoulder and probe with the workpiece and by the severe plastic deformation of the metal in the workpiece.

The localized heating softens the material around the probe. The tool rotation and translation cause the movement of the material from the front to the back of the probe. The tool shoulder also restricts the metal flow under the bottom shoulder surface. Because of the various geometrical features of the tools, the material movement around the probe can be extremely complex and significantly different from one tool to the other.

A unique feature of the friction-stir welding process is that the transport of heat is aided by the plastic flow of the substrate close to the rotating tool. The heat and mass transfer depend on material properties as well as welding variables including the rotational and welding speeds of the tool and its geometry. In FSW, the joining takes place by extrusion and forging of the metal at high strain rates. Jata and Semiatin estimated a typical deformation strain rate of 10 s1 by measuring grain-size and using a correlation between grain-size and Zener–Holloman parameter which is temperature compensated strain rate. Kokawa et al. estimated effective strain rates in the range 2–3 s1. The plastic flow must feature in any theory for the process, and the behavior of the metal at high strain rates, its dynamic recrystallization behavior, and the effects of heating and cooling must also be considered.

The FSW (Friction stir welding) process is particularly applicable for Aluminium alloys but can be extended to other products such as stainless steel, copper and its alloys, Lead, Titanium, and its alloy, Magnesium and its alloys, Zinc, Plastics, and Mild steel. Plates, sheets, and hollow pipes can be welded by this method. The limitations of FSW are reduced by serious research and improvement. Cost-effectiveness and ability to weld dissimilar metals make it a commonly used welding process in recent times. However, the material of the tool depends upon the workpiece material. The influence of the tool rotation speed on microstructure, surface appearance, and mechanical properties of the friction stir welded plates were investigated and analyzed by various mathematical models and experimental techniques.

CHAPTER 2

FRICTION STIR WELDING PROCESS

2.1 HEAT GENERATION

During FSW, heat is generated by friction between the tool and the work-piece and via plastic deformation. A fraction of the plastic deformation energy is stored within the thermomechanical processed region in the form of increased defect densities. In the weld, a mixture of recovery and Fig. 2.1. Schematic cross-section of a typical FSW weld showing four distinct zones: base metal, heat-affected, thermomechanical affected, and stirred (nugget) zone.

Deformation not only increases the dislocation density but also the amount of grain surface and grain edge per unit volume and cutting precipitates may force them to dissolve. Heat is generated due to friction and plastic deformation at the tool–work–piece interface and due to plastic deformation in the TMAZ. The local interfacial heat generation due to friction is the product of frictional force and the sliding velocity. The interfacial deformation heat is the product of shear stress and the velocity of the work-piece material which sticks to the tool as it moves.

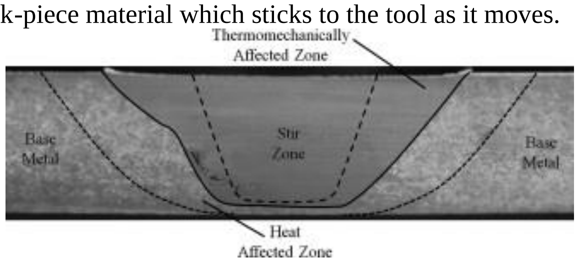

Fig 2.1 Schematic cross-section of FSW weld

In the context of heating resulting from plastic deformation, the decrease in the yield strength with increasing temperature leads to a reduction in the heat generation rate by this mechanism. Since strain rates depend on velocity gradients, which diminish rapidly away from the tool, most of the heat generation due to plasticity occurs close to the tool–work-piece interface.

2.2 MATERIAL FLOW AND MECHANISM OF JOINING

Three types of flow affect the overall transport of plasticized materials during FSW. First, near the tool, a slug of plasticized material rotates around the tool. This motion is driven by the rotation of the tool and the resulting friction between the tool and the work-piece. Second, the rotational motion of the threaded pin tends to push material downward close to the pin which drives an upward motion of an equivalent amount of material somewhat farther away. Finally, there is a relative motion between the tool and the work-piece. The overall motion of the plasticized material and the formation of the joint results from the simultaneous interaction of these three effects. The plastic flow models for FSW have been used to predict velocities around the tool pin. The velocities have also been estimated from strain rates which, in turn, were obtained from the correlation between grain-size and strain rate. Comparison of the shape of the TMAZ predicted by flow models with macrostructural observation has shown a satisfactory match. Good agreement between the torque values obtained using dynamometers and the computed values from the flow models for Al 2025 and Al 7075 alloy indicates the usefulness of the models to understand the FSW process. Since torque is a measure of the shear stress on the tool and since the shear stress on the work-piece is responsible for both heat generation and plastic flow, validation of the model predictions by experiments indicates that it is appropriate to use the models for the estimation of several important parameters. Through numerical modeling of plastic flow can aid tool design and the optimization of weld quality, there does not appear to have been an application of models towards the prediction of practical processing maps.

Welding variables the welding speed, the tool rotational speed, the vertical pressure on the tool, the tilt angle of the tool, and the tool design are the main independent variables that are used to control the FSW process. The heat generation rate, temperature field, cooling rate, x-direction force, torque, and power depend on these variables. The effects of several of the independent variables on the peak temperature have been discussed in the previous section. In short, peak temperature increases with increasing rotational speed and decreases slightly with welding speed. Peak temperature also increases with an increase in the axial pressure. During FSW, the torque depends on several variables such as the applied vertical pressure, tool design, the tilt angle, local shear stress at the tool material interface, the friction coefficient, and the extent of slip between the tool and the material.

Measured torque values can provide some idea about the average flow stress near the tool and the extent of slip between the tool and the work-piece for certain conditions of welding when other variables are kept constant. The torque decreases with an increase in the tool rotation speed due to an increase in the heat generation rate and temperature when other variables are kept constant. It becomes easier for the material to flow at high temperatures and strain rates. However, torque is not significantly affected by the change in welding speed.

The relative velocity between the tool and the material is influenced mainly by the rotational speed. Therefore, the heat generation rate is not significantly affected by the welding speed. High traverse speeds tend to reduce heat input and temperatures. The torque increases only slightly with the increase in traverse speed because material flow becomes somewhat more difficult at slightly lower temperatures. The torque on the tool can be used to calculate the power required from P ¼ x M, where M is the total torque on the tool. Excessive x-direction force can be an important indicator of the potential for tool erosion and in extreme cases, tool breakage. Axial pressure also affects the quality of the weld. Very high pressures lead to overheating and thinning of the joint while very low pressures lead to insufficient heating and voids. Power requirement also increases with the increase in axial pressure.

2.3 FSW PROCESS PARAMETERS

The Figure shows the Fish-bone diagram illustrating the FSW parameters which influence the weld strength properties are listed below.

- Tool rotational speed
- Welding speed
- Axial force
- Tool types
- Tool material
- Tool tilt angle

2.3.1 Tool Rotational Speed

The stirring and mixing of material in the region of the rotating pin were influenced by the tool rotation. The rotational speed is an important process variable given the fact that it tends to influence the translational velocity. More intense stirring and mixing of material took place due to higher tool rotation speed since it generates higher temperature because of high frictional heating. The formation of defects during the FSW process was determined by the stirring rate of the plasticized material. Too much stirring of plasticized material will cause the release of excessively stirred material to the upper surface which results in tunnel defects. Lower tool rotational speed generates less heat input which results in a lack of stirring will cause the lack of bonding. Stir zone temperature and the succeeding grain growth were influenced by the tool rotational speed.

2.3.2 Welding Speed

The stirred material during FSW was pushed by the translation of the tool due to the welding speed from the front to the back of the tool pin. The frictional heat was generated during FSW due to the rubbing of the tool shoulder and the tool pin with the workpiece. The frictional heat per unit length of the weld was determined by the welding speed which subsequently affects the growth of the grain. An increase in welding speed causes less frictional heat generation which in turn leads to inadequate stirring and mixing.

2.3.3 Axial force

The application of the axial force along with the rotating tool is responsible for the heat generation in the FSW, which is the primary source 9 for welding. The frictional heat generation during FSW between the rotating tool shoulder and the surface of the workpiece to be welded depends on the coefficient of friction which is decided by axial force apart from tool properties and workpiece material. The extrusion process influences the material flow in the weld zone where the applied axial force and the movement of the tool pin push the material once it has undergone plastic deformation. The plunge depth of the tool pin into the workpiece is influenced directly by the axial force because the temperature defining the amount of plasticized material during FSW is dependent on axial force. Hence in FSW process, axial force plays an important role in producing defect-free welds.

2.3.4 Tool Types

There are three types of FSW/P tool, i.e. (a)fixed, (b)adjustable, and (c)self-reacting as shown in fig 2.3. The fixed probe tool corresponds to a single piece comprising both the shoulder and probe. This tool can only weld a workpiece with a constant thickness due to the fixed probe length. If the probe wears significantly or breaks, the whole tool must be replaced. As an extreme example of the fixed tool for friction stir spot welding (FSSW), an FSSW tool consisting only of a single shoulder with no probe was reported. The adjustable tool consists of two independent pieces, i.e. separate shoulder and probe, to allow adjustment of the probe length during FSW. In this design, the shoulder and probe can be manufactured using different materials and the probe can be easily replaced when worn or damaged. Moreover, the adjustable probe length can allow welding of variable and multiple gauge thickness workpieces and implementation of strategies for filling the exit hole left at the end of the friction stir weld. Both the fixed and the adjustable tools often require a backing anvil. The bobbin type tool is made up of three pieces: top shoulder, probe, and bottom shoulder. This tool can accommodate multiple gauge thickness joints due to the adjustable probe length between the top and bottom shoulders. No backing anvil is needed but the bobbin type tool can only work perpendicularly to the workpiece surface. In contrast, the fixed and adjustable tools can be tilted longitudinally and laterally.

2.3.5 Tool Materials

Tool material characteristics can be critical for FSW. The candidate tool material depends on the workpiece material and the desired tool life as well as the user's own experiences and preferences. Ideally, the tool material should have the following properties:

(i) Higher compressive yield strength at elevated temperature than the expected forge forces onto the tool
(ii) Good strength, dimensional stability, and creep resistance
(iii) Good thermal fatigue strength to resist repeated heating and cooling cycles
(iv) No harmful reaction with the workpiece material
(v) Good fracture toughness to resist the damage during plunging and dwelling
(vi) Low coefficient of thermal expansion between the probe and the shoulder materials to reduce the thermal stresses
(vii) Good machinability to ease manufacture of complex features on the shoulder and probe
(viii) Low or affordable cost.

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CHAPTER 3
LITERATURE REVIEW

Ericsson and Sandstrom (2002) investigated that the fatigue strength of friction stir (FS) welds is influenced by the welding speed, and also compare the fatigue results with results for conventional arc-welding methods: MIG-pulse and TIG. The Al–Mg–Si alloy 6082 was FS welded in the T6 and T4 temper conditions, and MIG pulse and TIG welded in T6. The T4- welded material was subjected to a post-weld aging treatment. According to the results, welding speed in the tested range, representing low and high commercial welding speed, has no major influence on the mechanical and fatigue properties of the FS welds. At a significantly lower welding speed, however, the fatigue performance was improved possibly due to the increased amount of heat supplied to the weld per unit length.
Liu et al. (2003) in their research paper discussed the friction stir weldability of the 2017-T351 Aluminium alloy and determine optimum welding parameters, the relations between welding parameters, and tensile properties of the joints. Researchers found that the tensile properties and fracture locations of the joints are significantly affected by the welding process parameters. When the optimum revolutionary pitch is 0.07 mm/rev corresponding to the rotation speed of 1500 rpm and the welding speed of 100 mm/min, the maximum ultimate strength of the joints is equivalent to 82% that of the base material. Though the void-free joints are fractured near or at the interface between the weld nugget and the thermo-mechanically affected zone (TMAZ) on the advancing side, the fracture occurs at the weld center when the void defects exist in the joints.
Kovacevic (2003) In their research friction stir welding (FSW) is a relatively new welding process that may have significant advantages compared to the fusion processes as follow: joining of conventionally non-fusion weldable alloys, reduced distortion, and improved mechanical properties of weldable alloys joints due to the pure solid-state joining of metals. In this paper, a three-dimensional model based on finite element analysis is used to study the thermal history and thermomechanical process in the butt-welding of Aluminium alloy 6061T6.
Huseyin Uzun et al. (2004) investigated that the joining of dissimilar Al 6013-T4 alloy and X5CrNi18-10 stainless steel was carried out using the friction stir welding (FSR) technique. The microstructure, hardness, and fatigue properties of friction stir welded 6013 Aluminium alloy to stainless steel has been investigated. Optical microscopy was used to characterize the microstructures of the weld nugget, the heat-affected zone (HAZ), thermo-mechanical affected zone (TMAZ), and the base materials.
Cavaliere et al. (2005) investigated the mechanical and microstructural properties of dissimilar 2024 and 7075 Aluminium sheets joined by friction stir welding (FSW). The two sheets, aligned with perpendicular rolling directions, have been successfully welded; successively, the welded sheets have been tested under tension at room temperature to analyze the mechanical response concerning the parent materials.

Kovacevic (2005) In their research thermo-mechanical simulation of friction stir welding can predict the transient temperature field, active stresses developed, forces in all three dimensions, and may be extended to determine the residual stress. The thermal stresses constitute a major portion of the total stress developed during the process. Boundary conditions in the thermal modeling of the process play a vital role in the final temperature profile.
Driver a (2005) In the present paper, a three-dimensional thermomechanical model for Friction Stir Welding (FSW) is presented. Based on the velocity fields classically used in fluid mechanics and incorporating heat input from the tool shoulder and the plastic strain of the bulk material, the semi-analytical model can be used to obtain the strains, strain rates, and estimations of the temperatures and micro-hardness in the various weld zones. The calculated results are in good agreement with experimental measurements performed on a AA2024T351 alloy friction stir welded joint.
Marzol et al. (2006) established a friction stir welding (FSW) process parameters envelope for an AA 6061 alloy reinforced with 20% of Al2O3 particles, and determine properties of the obtained joints. After a brief description of the FSW technique, and the difficulties in joining MMCs, the experimental procedure is illustrated. The microstructure has been observed with an optical microscope, and images have been analyzed with image analysis software. Microhardness and tensile tests have been also carried out. The tool’s stirring effect has a substantial influence on the reinforcement particles' distribution and shape. Tensile testing revealed joint efficiencies over 80% for the Rp0, 2 and slightly more than 70% for the Rm, with failure outside the stir zone. The parameter envelope determined in the present study resulted in defect-free, high-strength welds.
Watanabe et al. (2006) tried to butt-weld and Aluminium alloy plate to a mild steel plate by friction stir welding and investigated the effects of a pin rotation speed, the position for the pin axis to be inserted on the tensile strength, and the microstructure of the joint. The behavior of the oxide film on the faying surface of the steel during welding also was examined. The main results obtained are as follows. Butt-welding of an Aluminium alloy plate to a steel plate was easily and successfully achieved by friction stir welding. The maximum tensile strength of the joint was about 86% of that of the Aluminium alloy base metal. A small number of intermetallic compounds was formed at the upper part of the steel/Aluminium interface, while no intermetallic compounds were observed in the middle and bottom parts of the interface. The regions where the intermetallic compounds formed seemed to be fracture paths in the joint. Many

fragments of the steel were scattered in the Aluminium alloy matrix and the oxide film removed from the faying surface of the steel by the rubbing motion of a rotating pin was observed at the interface between the steel fragments and the Aluminium alloy matrix.

Scialpi et al. (2006) studied the effect of different shoulder geometries on the mechanical and microstructural properties of a friction-stir welded joints have been studied in the present paper. The process was used on 6082 T6 Aluminium alloy in the thickness of 1.5 mm. The three studied tools differed from shoulders with scroll and fillet, cavity and fillet, and only fillet. The effect of the three shoulder geometries has been analyzed by visual inspection, macrograph, HV microhardness, bending test, and transverse and longitudinal room temperature tensile test. The investigation results showed that, for thin sheets, the best joint has been welded by a shoulder with fillet and cavity.

Ces-chini et al. (2006) investigated that the application of this solid-state welding technique to particles reinforced composites seems very attractive since it should eliminate some typical defects induced by the traditional fusion welding techniques, such as gas occlusion, undesired interfacial chemical reactions between the reinforcement and the molten matrix alloy, inhomogeneous reinforcement distribution after welding. The present work describes the effect of the FSW process on the microstructure and, consequently, on the tensile and low-cycle fatigue behavior, of an Aluminium matrix (AA7005) composite reinforced with 10 vol. % of Al2O3 particles (W7A10A).

Zhang et al. (2007) represent the 3D material flows and mechanical features under different process parameters by using the finite element method based on solid mechanics. Experimental results are also given to study the effect of process parameters on the joining properties of the friction stir welds. Numerical results indicate that the tangent flow constitutes the major part of the material flow. The shoulder can accelerate the material flow on the top half of the friction stir weld.

Villegas (2007) studied the macro cystitis integrifolia and Lessonia trabeculate form vast kelp beds providing a three-dimensional habitat for a diverse invertebrate and Wsh fauna oV northern chile. Habitat modifications caused by the El Niño Southern Oscillation (ENSO) are likely to alter the inhabiting communities. This study aimed to reveal relationships between distinct habitat structures of a M. integrifolia kelp bed, a dense L. trabeculata kelp bed, and L. Trabeculata patches colonizing a barren ground, and the associated dominant macrobenthic key species.

Amancio-Filhoa et al. (2007) described that aircraft Aluminium alloys generally present low weldability by the traditional fusion welding process. The development of friction stir welding has provided an alternative improved way of satisfactory producing Aluminium joints, in a faster and reliable manner.

Cavalierea et al. (2007) analyzed the effects of processing parameters on mechanical and microstructural properties of AA6082 joints produced by friction stir welding. Different welded specimens were produced by employing fixed rotating speeds of 1600rpm and by varying welding speeds from 40 to 460 mm/min. The SEM observations of the fatigue specimens, welded at 115 mm/min, showed that at higher stress amplitude levels the cracks initiate at the surface of the welds. By decreasing the stress amplitude the cracks initiate by the internal defects.

Elangovan et al. (2007) studied the influences of tool pin profile and welding speed on the formation of friction stir processing zone in AA2219 Aluminium alloy.AA2219 Aluminium alloy has gathered wide acceptance in the fabrication of lightweight structures requiring high strength to weight ratio. In this investigation, an attempt has been made to study the effect of tool pin profiles and welding speed on the formation of friction stir processing zone in AA2219 Aluminium alloy. From this investigation, the following important conclusions are derived.

Muthukumaran et al. (2008) state that Electromagnetic radiation is emitted during the transient stage of elastic to plastic deformation of metals and alloys. In the present work, Aluminium plates were welded by friction stir welding (FSW) at different process parameters, such as tool rotational speed, traverse speed, and rake angle. The EMR fundamental frequencies emitted during the tensile failure of the welds were measured and recorded. The variation in the fundamental frequency was analyzed by fuzzy modeling using MATLAB and it was observed that an increase in the first mode of metal transfer decreases the fundamental frequency. Further, the fundamental frequency of a weld was estimated from the obtained model and found to be closer to the experimental results. It will be more useful for metal flow analysis as well as online condition monitoring of the welds which are used in critical applications.

Chen et al. (2008) Al–Si alloy and pure titanium were lap joined using friction stir welding technology. The microstructure and tensile properties of joints were examined. The maximum failure load of joints reached 62% of Al–Si alloy base metal with the joints fractured at the interface. X-ray diffraction results showed that a new phase of TiAl3 formed at the interface. The microstructure evolution and the joining mechanism of Aluminium–titanium joints were systematically discussed.

Moreira et al. (2008) Studied that mechanical and metallurgical characterization of friction stir welded butt joints of Aluminium alloy 6061-T6 with 6082-T6 was carried out. For comparison, similar material joints made from each one of the two alloys were used. The work included microstructure examination, microhardness, tensile and bending tests of all joints. An approximate finite element model of the joint, taking into account the spatial dependence of the tensile strength properties, was made, modeling a bending test of the weldments. This study shows that the friction stir welded dissimilar joint present intermediate mechanical properties when compared with each base material. In tensile tests, the dissimilar joint displayed intermediate properties. For instance, in the hardness profile, the lowest values were obtained in the AA6082-T6 alloy plate side where the rupture occurred, and in the nugget, all types of joints present similar values.

Rodrigues a (2008) In this research paper present work friction stir welds produced in 1 mm thick plates of AA 6016-T4 Aluminium alloy, with two different tools, were analyzed and compared concerning the microstructure and mechanical properties. For each tool, the welding parameters were optimized to achieve non-defective welds. The differences in mechanical properties between the two types of welds are explained based on TEM microstructural analysis. Despite the under-matched characteristics of the ‘‘cold” welds relative to the base material, formability tests demonstrated that these welds improve the drawing performance of the welded sheets.

Jai KWON et al. (2009) experimented with Friction stir welding between 5052 Aluminium alloy plates with a thickness of 2 mm was performed. The tool for welding was rotated at speeds ranging from 500 to 3 000 r/min under a constant traverse speed of 100 mm/min. In all tool rotation speeds, the SZ exhibits higher average hardness than the base metal. Especially at 500 r/min, the average hardness of the SZ reaches a level about 33% greater than that of the base metal. At 500, 1 000, and 2 000 r/min, the tensile strength of the friction stir welded (Friction stir welded) plates is similar to that of the base metal (about 204 MPa). The elongation of the Friction stir welded plates is lower than that of the base metal (about 22%). However, it is noticeable that the maximum elongation of about 21% is obtained at 1 000 r/min.

Hwang (2010) This study aimed to experimentally explore the thermal history of a workpiece undergoing Friction Stir Welding (FSW) involving butt joining with pure copper C11000. In the FSW experiments, The appropriate temperatures for a successful FSW process were found to be between 460 ◦C and 530 ◦C. These experimental results and the process control of temperature histories can offer useful knowledge for an FSW-based process of copper butt joining.

Hattel a (2010) Studied that the post-welding stress state, strain history, and material conditions of friction-stir welded joints are often strongly idealized when used in subsequent modeling analyses, typically by neglecting one or more of the features above. But, it is obvious that the conditions after welding do influence the weld performance. The objective of this paper is to discuss some of the main conflicts that arise when taking both the post-welding material conditions and stress-strain state into account in a subsequent structural analysis

Kanwer S. Arora et al. (2010) in this research, successful friction stir welding of Aluminium alloy 2219 using an adapted milling machine is reported. The downward or forging force was found to be dependent upon shoulder diameter and rotational speed whereas longitudinal or welding force on welding speed and pin diameter. Tensile strength of welds was significantly affected by welding speed and shoulder diameter whereas welding speed strongly affected percentage elongation.

Hwang et al. (2010) experimentally explore the thermal history of a workpiece undergoing Friction Stir Welding (FSW) involving butt joining with pure copper C11000. In the FSW experiments, K-type thermocouples were used to record the temperature history at different locations on the workpiece. This data, combined with the preheating temperature, tool rotation speeds, and tool moving speeds allowed parameters for a successful weld to be determined.

Riahi (2010) In this research residual stress is lower in friction stir welding (FSW) compared with other melting weldment processes. This is due to being a solid-state process in its nature. There are several advantages in utilizing the stir welding process. Lower fluctuation and shrinkage in weldment metal enhanced mechanical characteristics, fewer defects, and the ability to weld certain metals otherwise impractical by other welding processes are to name just a few of these advantages. In the prediction of results of residual stress, only heat impact was studied. This was recognized as the main element causing a minor difference in results obtained for simulation in comparison with that of the actual experiment.

Tozak et al. (2010) newly developed tool for friction stir spot welding (FSSW) has been proposed, which has no probe, but a scroll groove on its shoulder surface (scroll tool). By use of this tool, FSSW has been performed on Aluminium alloy 6061-T4 sheets and the potential of the tool was discussed in terms of weld structure and static strength of welds. The experimental observations showed that the scroll tool had comparable or superior performance to a conventional probe tool. The shear fracture took place at smaller shoulder plunge depths or at shorter tool holding times, while the plug fracture occurred at larger shoulder plunge depths or at longer tool holding times. It was indicated that the tensile-shear strength and associated fracture modes were determined by two geometrical parameters in the weld zone.

S. Rajakumar et al. (2011) observed that AA6061 Aluminium alloy has gathered wide acceptance in the fabrication of lightweight structures requiring high strength-to-weight ratio and good corrosion resistance. 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. This process uses a non-consumable tool to generate frictional heat in the abutting surfaces. The FSW process and tool parameters play a major role in deciding the joint strength. Joint strength is influenced by grain size and hardness of the weld nugget region. Hence, in this investigation, an attempt was made to develop empirical relationships to predict grain size and hardness of weld nugget of friction-stir-welded AA6061 Aluminium alloy joints.

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The empirical relationships are developed by response surface methodology incorporating FSW tool and process parameters. A linear regression relationship was also established between grain size and hardness of the weld nugget of FSW joints.

CHAPTER 4
METHODOLOGY

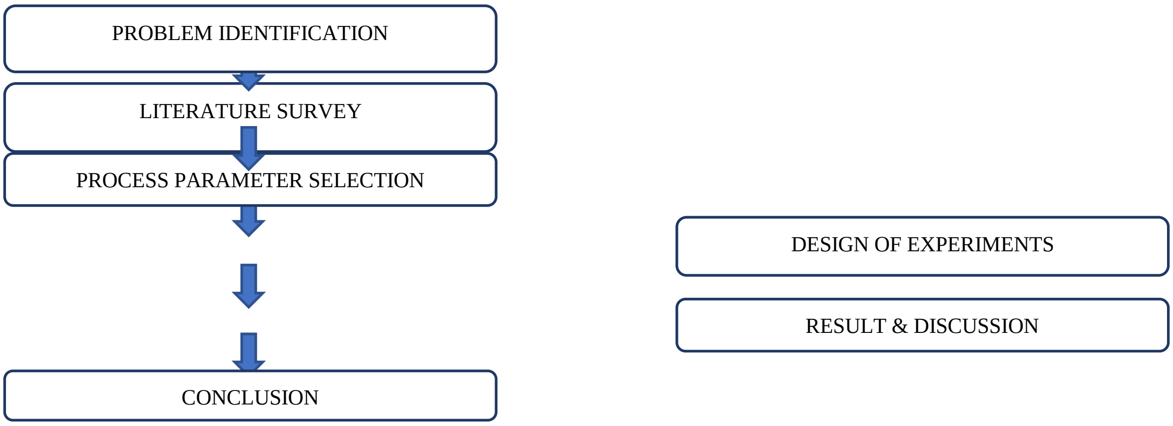


Fig 4.1 Methodology

4.1 WHY ALUMINIUM IS WELDED?

The most available metal in the earth's crust is Aluminium whereas, steel is the most used metal. In the majority of cases, Aluminium alloys are replacing steel in industrial applications. Aluminium alloys have low density i.e. nearly one-third when compared to steel. Some of these materials are allowing for a significant reduction of weight when compared with structural steels. Aluminium alloys are important for the fabrication of components and structures which require high strength, low weight, or electric current carrying capabilities to meet their service requirements. Aluminium alloys can resist the oxidation process, corrosion by water and salt, which steel cannot. The most desirable properties of Aluminium and its alloys are the lightweights, appearance, ability for fabrication, strength, and corrosion resistance and hence it is used for a wide variety of applications. When used in aerospace, rail, and road vehicles these attributes enable energy-efficient operation. In aerospace applications, materials with a high strength-to-weight ratio are required such as Aluminium alloys. The production of components of Aluminium alloys is not very complex, but the joining of these materials can sometimes cause serious problems. Among all Aluminium alloys, 2XXX and 7XXX play a major role in the marine industry. They are widely used in the ship applications because it has good formability, weldability, machinability, corrosion resistance, and good strength when compared to 6 other series of Aluminium alloys. Hence these alloys are chosen in this work for FSW process.

4.2 MATERIAL AND ITS PROPERTIES

4.2.1 Aluminium 2025

Aluminium 2000 series has copper as the key alloying element. When the alloys from this series are heat-treated, the mechanical properties are similar and better than those of medium steel. Aluminium 2025 alloy is a heat treatable wrought alloy. Aluminium 2025 material properties are taken from AZO Materials Website and then listed below.

Table 4.1 Physical Properties of Al 2025 Alloy

Properties	Metric	Imperial
Density	2.81 g/cm^3	0.102 lb/in^3
Melting Point	521-641ºc	970-1185ºF

Table 4.3 Mechanical Properties of Al 2025 Alloy

Properties	Metric	Imperial
Tensile Strength	400 MPa	5800 psi
Yield Strength	255 MPa	37000 psi
Elongation at break (@diameter 12.7mm/0.500 in)	19%	19%
Poisson's Ratio	0.33	0.33

Elastic Modulus	71.7 GPa	10400 ksi
Shear Modulus	241 MPa	35000 psi
Hardness, Brinell (@load 500kg; thickness 10.0 mm/1100 lb; 0.39 in)	110	110
Hardness, Knoop (converted from Brinell hardness value)	138	138
Hardness, Rockwell A (converted from Brinell hardness value)	44.4	44.2
Hardness, Rockwell B (converted from Brinell hardness value)	69	69
Hardness, Vickers (converted from Brinell hardness value)	124	124

Table 4.4 Thermal Properties of Al 2025 Alloy

Properties	Metric	Imperial
Thermal expansion coefficient (@20-100ºc/68-212ºF)	22.7µm/mºC	12.6µin/inºF
Thermal Conductivity	154 W/m k	1070 BTU in/hr.ft^2. ºF

4.2.2 APPLICATION

Aluminium 2025 is widely used in the following areas

- Aircraft Structures and Propellers
- Automobile Bodies
- Screw Fittings

4.2.3 Aluminium 7075

With zinc as its primary alloying element, it is exceptionally strong. A member of the 7000 series, it is one of the strongest alloys available and is comparable to many types of steel. Although it has high strength, it has lower corrosion resistance than other common Aluminium alloys and does not offer the same levels of machinability or weldability. Aluminium 7075 material properties are taken from the Aerospace Specification Metals Inc. Website and then listed below.

4.2.4 APPLICATION

Aluminium 7075 is widely used in following areas

- Aircraft Wing Spar
- Ground Support Equipment
- Gears and Shafts
- Missile Parts
- Worm Gears

4.3 SHOULDER SHAPE

Tool shoulders are designed to frictionally heat the surface regions of the workpiece, produce the downward forging action necessary for welding consolidation, and constrain the heated metal beneath the bottom shoulder surface summaries the typical shoulder outer surfaces, the bottom end surfaces, and the end features. The shoulder outer surface usually has a cylindrical shape, but occasionally, a conical surface is also used. Generally, it is expected that the shape of the shoulder outer surface (cylindrical or conical) has an insignificant influence on the welding quality because the shoulder plunge depth is typically small (i.e. 1–5% of the gauge thickness). It is noteworthy and Bakavos and Prangnell reported that sound welds can be obtained using a probe-free shoulder tool in which the bottom scrolled shoulder surface feature played a significant role in stirring the materials.

Fig 4.2 FSW Tool Nomenclature

4.4 PROBE SHAPES

The friction-stirring probe can produce deformational and frictional heating. Ideally, it is designed to disrupt the contacting surfaces of the workpiece, shear the material in front of the tool and move the material behind the tool. The depth of deformation and tool travel speed is mainly governed by the probe. summaries of the probe shapes and their main features. The end shape of the probe is either flat or domed. The flat bottom probe design that emphasizes ease of manufacture is currently the most commonly used form.

4.5 TOOL PICTURES

We have used three types of tools for welding.

- Square shaped
- Threaded and
- Pentagon shaped

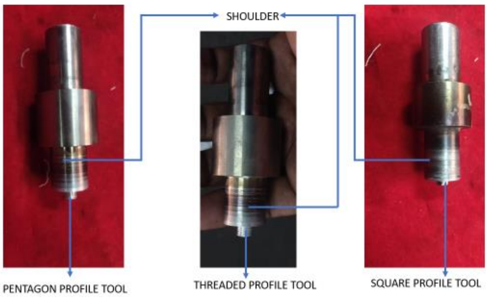


Fig 4.3 Types of Tool

4.6 MACHINE USED FOR WELDING

We used LMW KODI-40 for welding the metals. The machine KODI-40 we used for welding belongs to the brand LMW (Lakshmi Machine Works). This is also a type of CNC Machine (Siemens Sinumerik 808D).

4.6.1 Product Profile of Vertical Machining Centre [KODI 40]

Lakshmi machine works ltd offers a completely new product range comprising: high speed cnc lathes [4 machines in the platus range]; high power cnc lathes [3 machines in tfie rigi range]; vertical machining centres [2 machines in the kodi range]; the all new horizontal machining center [ooty 40]; and a mould making machine [kodi mould 50]. Its main specifications are: table size: 900 x 410 mm; axes traverse [x/y/z]: 560 x 410 x 460 mm; rapid feed: [x and y/z]: 20/12 m/min; spindle speed range: 150-4,000 rpm; maximum tool diameter / length: 125/250 mm; maximum tool weight: 8 kg; tools in atc: 20; and installation area: 3,560 x 2,115 mm.

Convert Specs to Imperial:

- X : 574 mm
- Y : 408.9 mm
- Z : 457.2 mm
- Power : 5.6 kW
- RPM : 8,000 RPM
- #ATC : 20
- Table-W: 429.3 mm
- Table-L : 896.6 mm
- Control : CNC (GE FANUC)

MAKE : INDIA
MACHINE MODEL : LMW LKODI 40
MANUFACTURER : LAKSHMI MACHINE WORK
SYSTEM MODE: FANUC – OI – MC

4.7 FSW SPECIMENS

Initially, the specimens were at a standard size of 100*100*6mm plate and we had cut the specimens to the required size of 100*50*6mm pieces by Power Hacksaw Machine. Fig 4.4 shows the Friction Stir Welding Specimens.

4.8 EXPERIMENTAL SETUP

The LMW KODI 40 VMC machine is used for our project which is owned by Vigshan Tools, Ganapathy, Coimbatore was used to carry out our FSW process. The experimental setup employed in this work for conducting the FSW on Al2025 and Al7075 was shown in Figure 4.5. Hydraulic controls are incorporated into the machine to make the FSW operation controllable. The variable-speed motor drive was used to vary the spindle speed in the wide range between 150 rpm to 4000 rpm, displayed on the digital indicator. The FSW tool was plunged into the workpiece using downward force which creates the frictional heat between the rotating welding tool and the workpieces. The axial downward force was exerted by the tool head along with the spindle can be varied in the range between 2.5 kN to 50 kN. A horizontal table (900 mm x 410 mm) was used to hold the workpieces, consists of two-axis movements, along lengthwise (X-axis) and crosswise (Y-axis). The specially designed fixture was attached to the top of the table to hold the workpieces firmly during the welding process.

4.9 PROCESS PARAMETER USING MINI TAB

By using the MINI TAB Software by Taguchi Method, we had made our design of experiments and they are illustrated in the table below.

Table 4.9 Process Parameters

S.No	Speed (rpm)	Feed(mm/min)
1	800	10
2	1000	20
3	1200	15
4	800	15
5	1000	10
6	1200	20
7	800	20
8	1000	15
9	1200	10

4.10 EXPERIMENTAL PROCEDURE

Before carrying out the FSW, Burrs were removed, and edges were made flat by using grinding and emery polishing. The specimens were cleaned to avoid any surface contaminations. To fabricate square FSW butt joints using single-pass FSW, the test plates were positioned and rigidly clamped to the backing plate using mechanical clamps which prevent the plates from lifting during welding as shown in Figure 4.6. The backing plate was clamped to the machine bed. A non-consumable square profiled tool, threaded tool, and pentagon tool were then rotated clockwise and slowly plunged into the surfaces of the positioned test plates until the welding tool shoulder contacts the upper surface of the plates. A short dwell time was allowed for the rotating tool to generate frictional heat for preheating and to initiating the plastic flow of the material along the joint line. After that, a vertical downward force was applied on the tool shoulder, and the weld traverse started. The direction of the welding was perpendicular to the rolling direction.

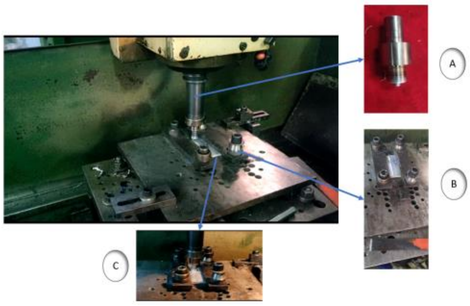


Fig 4.7 Experimental Procedure

A. Square Profile Tool B. Fixture Setup C. FSW Process

The plasticized material was transferred from the leading edge of the tool to the rear side and forged along with the applied force of the tool. The tool was traversed along the joint line until it reached the end of the weld. The rotating tool was retracted from the plate upon reaching the end of the weld, leaving a keyhole at the end of the weld. Figure 4.7 shows the geomatic diagram of the FSW specimen.

Again, the FSW process will be continued for the remaining specimens by using the MINI TAB Software by Taguchi method and the design of experiments was followed as shown in Tab 4.10. The Experimental procedure is the same for every specimen as said in the above paragraph.

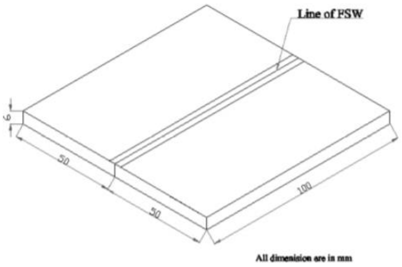


Fig 4.8 Geometric View of FSW

ADVANTAGES OF FSW

When compared to various fusion methods, FSW has several advantages. Based on the nature of the fusion welding process, a lot of process parameters such as purging gas, voltage, wire feed rate, travel speed, shielding gas, arc length, etc., must be controlled. On the other hand, in FSW a few of the process variables such as tool rotation speed, welding speed, axial force, etc., are effortlessly controllable. Given the fact that FSW is a solid-state process, the temperature of the metal does not attain its melting point. As a result, porosity, problems related as a result of the solidification of the metal like porosity, hot cracking, and solidification shrinkage are eliminated. Therefore, FSW emerges as a suitable method for welding Aluminium alloys with Cu, Mg, and Si content.

The workpiece undergoes plastic deformation during the solid-state process, which allows the resultant weld joint to retain a large part of its parent metal strength (Hattingh et al. 2004). In FSW, extensive thermomechanical deformation and forging action brings about dynamic recrystallization and recovery that makes the grain structure in the weld joint much finer when compared to that of its parental metal (Mahoney et al. 1998). As a result, welds prepared by FSW are exposed to have much better mechanical properties such as tensile strength and fatigue life when compared to the weld made by fusion welds (Sharma et al. 2004). FSW does not cause severe distortion and residual stresses compared to the traditional fusion welding processes (Jata et al. 2000, Bussu and Irving 2003, John et al. 2003). This process is mostly insensitive to contaminations, and for this reason, oxide removal before welding, which is a must for arc welding is not necessary (Cavaliere et al. 2005).

Overall, the FSW process is considered to be an evident advancement in metal joining since its origin in 1991 and soon turn out to be known as the ‘green technology' owing to its energy efficiency, environmental friendliness, and versatility (Arbegast 2003). In other welding processes, to protect the molten weld pool shielding gas is required, but in FSW it is not required. In FSW, no fumes are generated. As a result, the process is considered environment-friendly.

CHAPTER 5

RESULT AND DISCUSSION

Table 5.1 Mechanical Properties obtained after Welding

S.NO.	EXPERIMENT NUMBER	TENSILE STRESS (MPa)	HARDNESS VALUE (RHT)	IMPACT TEST (J)
1.	K1	264	75	1.4
2.	K2	242	71	1.7
3.	K3	258	71	1.3
4.	K4	262	75	0.7
5.	K5	255	67	1.2
6.	K6	269	72	1.1
7.	K7	277	65	1.6
8.	K8	296	74	1.2
9.	K9	244	66	0.9

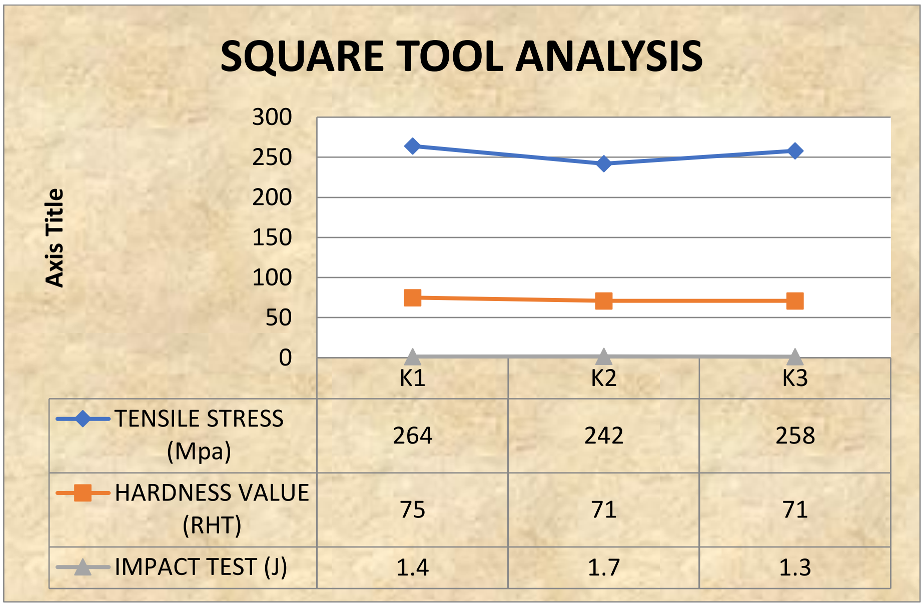
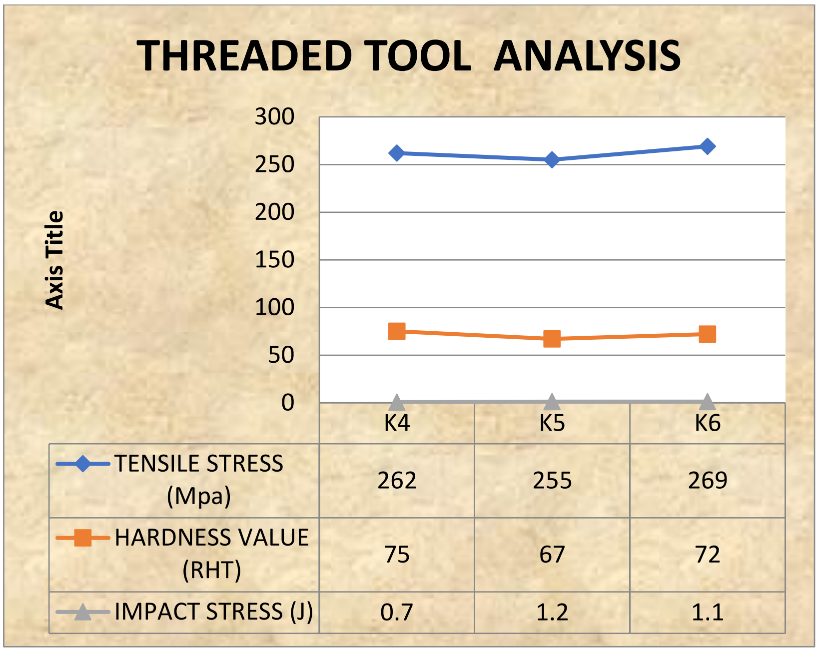
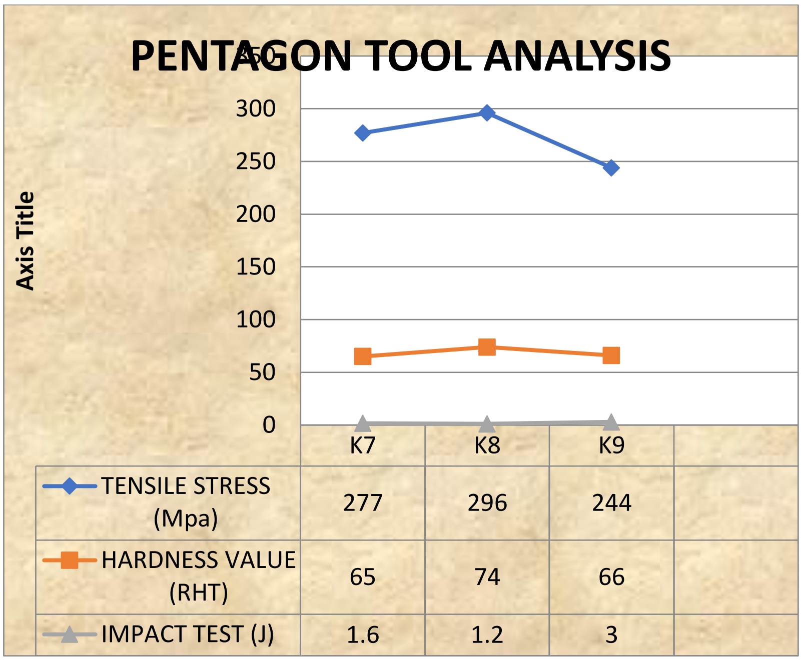


Fig. 5.1 Square Tool Analysis



	K4	K5	K6
TENSILE STRESS (Mpa)	262	255	269
HARDNESS VALUE (RHT)	75	67	72
IMPACT STRESS (J)	0.7	1.2	1.1

Fig. 5.2 Threaded Tool Analysis



	K7	K8	K9	
TENSILE STRESS (Mpa)	277	296	244	
HARDNESS VALUE (RHT)	65	74	66	
IMPACT TEST (J)	1.6	1.2	3	

Fig. 5.3 Pentagonal Tool Analysis

WEAR TEST RESULTS

sample		load (N)	speed (rpm)	time (s)	height wear (micron)	firctional force (N)	co-efficient of wear	wear rate (m/s)
k1	a	5	250	180	80	0.8	0.16	4.4x10^-6
	b	10			45	3.6	0.36	2.5x10^-6
	c	15			58	7.2	0.48	3.2x10^-6
k2	a	5	250	180	75	2.6	0.52	4.1x10^-

								6
	b	10			30	4.2	0.42	1.6x10^-6
	c	15			35	7.8	0.52	1.9x10^-6
k4	a	5	250	180	88	0.6	0.12	4.8x10^-6
	b	10			48	0.8	0.08	2.6x10^-6
	c	15			100	3.2	0.21	5.5x10^-6
k5	a	5	250	180	75	1.1	0.22	4.1x10^-6
	b	10			120	2.9	0.29	6.6x10^-6
	c	15			28	3.5	0.023	1.5x10^-6
k9	a	5	250	180	34	3	0.4	1.8x10^-6
	b	10			30	4.7	0.47	1.6x10^-6
	c	15			28	5.8	0.38	1.5x10^-6

CONCLUSION

In this work, the three different cross-sectional tools were used for finding the suitable tool that can be used for the dissimilar aluminium joints. For considering the Mechanical properties, the pentagonal tool has got the consistent values. The Ultimate Tensile strength with a higher value of 290 MPa and minimum value in the Square tool with 242 Mpa. In Hardness the pentagonal tool got its value with 74 in Rockwell hardness test as maximum and 75 in Square tool. For the Impact test, the Square tool the highest value of 1.7 J, and the pentagonal tool got the value of 1.6 J.

The quality of friction stir welded joint is determined by several criteria; hence it should be necessary to analyze all the criteria. The present work considered tensile strength, impact strength, and hardness for analysis. The conclusion has been made that the pentagonal tool has been recommended for joining of the aluminium Al2025 & Al7075 materials through Friction Stir Welding by considering Mechanical properties.

REFERENCES

[1] Bakavos . D and Prangnel . P. B: 'Effect of reduced or zero pin length and anvil insulation on friction stir spot welding thin gauge 6111 automotive sheet', Sci. Technol. Weld. Join., 2009, 14, 443– 456.
[2] Bakavos.D, Chen.Y. C: Babout.L and Prangnell P. B: 'Material interactions in a novel pinless tool approach to friction stir spot welding thin Aluminium sheet', Metall. Mater. Trans. A, 2011, 42A, 1266–1282.
[3] Ding R. J and. Oelgoetz P. A: 'Auto-adjustable probe tool for friction stir welding', US Patent no. 5893507, 1999.
[4] Dawes C and Thomas W.: 'Friction stir joining of Aluminium alloys', TWI Bull., 1995, 6, 124–127.
[5] Dubourg L. and Dacheux . P.: 'Design and properties of FSW tools: a literature review', Proc. 6th Int. Symp. on 'Friction stir welding', Vol. 52, No. 4, 62; 2006, Saint-Sauveur, PQ, TWI.
[6] Iordachescu M, Scutelnicu E. and. Iordachescu D: 'Fundamentals of the process and tools design: friction stir processing of materials', Weld. Equip. Technol., 2006, 17, 63–72.
[7] Mishra R. S and. Ma Z. Y: 'Friction stir welding and processing', Mater. Sci. Eng. R, 2005, 50R, 1–78.
[8] Mishra R. S. and Mahoney M. W.: 'Friction stir welding and processing'; 2007, Materials Park, OH, ASM International.
[9] Mishra R. S, Mahoney M. W, McFadden S. X. Mara, N. A and Mukherjee A. K.: 'High rate super plasticity in a friction stir processed 7075 Al alloy', Scr. Mater., 2000, 42, 163.
[10] Mishra R. S. and Mahoney M. W: 'Friction stir processing: a new grain refinement technique to achieve high strain rate super plasticity in commercial alloys', Mater. Sci. Forum, 2001, 357–359, 507–514.
[11] Thomas W. M.,Nicholas E. D, Needham J. C, Murch M. G, Temple-Smith . P and Dawes C. J. Patent . GB no. 91259788, 1991
[12] Tozaki .Y, Uematsu .Y and Tokaji . K: 'A newly developed tool without probe for friction stir spot welding and its performance',. Mater J. Process. Technol., 2010, 210, 844–851.