An Extensive Review Study On Friction Stir Welding And Specifications.

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Abstract — *Year 1991, revolution emerged in world of welding as solid process Fiction Stir Welding replaced Fusion Technology, for alloys, high strength materials (Aluminium, Magnesium, Steel, Brass, Polymers and dissimilar materials. As green technology, less energy consuming with no flux, no filler materials and smokeless. High strength good fatigue strength, high quality weld joint and good surface finish. Design of Equipment, tensile properties attained with different process parameter, defects morphologies, hardness, mechanical and designed microstructure properties are discussed. Non consuming rotating welding tools, generated heat , plastic deformation, process parameter, percentage elongation, effect on tensile strength at 1400rpm and 22 mm/rev. FSW, conventional welding process, a potential to revolutionise the aerospace, automobile, ships and marine, electrical and construction industry as versatile commercial application dramatic production cost reduction.*

Key words: *FSW Working, Mechanical Properties, Dissimilar Material, Quality Welding, Process Parameter, Tool Geometry, Mechanical Characterization.*

1. INTRODUCTION

Year 1991, The Institute of Welding, Cambridge England, in meticulous research emerged with a patent technology by W. Thomas, a solid phase welding technology i.e. Friction Stir Welding, a mature welding technology for light metal structure, titanium alloys, aluminium alloys, magnesium alloys, steel, titanium alloys, dissimilar materials. Welding with high quality, high tensile strength, no defects process, good surface finish, and non-consumable rotating tools, no filler materials, smokeless, and fast welding which has versatile application in many industries add evolution to technology.

Numerous advantages and application of welding in aerospace technology, railways industry, pipeline industry, automobile industry, and many other industries add advantages to time saving and fast production. Process employs forging and stirring of non- consumable rotating tool, with pin indulge into adjacent mating edge, produce frictional heat on solidification transfer to a solid weld.

- HAZ is near weld centre.
- Material region since thermal c ycle.
- Frictional force makes plastic deformation of metal when tool opposes traversing direction as a rotating side, intense plastic deformation by plastic atomic diffusion elevated temperature.

Friction Stir Welding results in dynamically recrystallized grain structure in welding nugget.

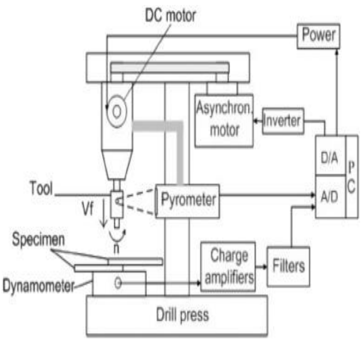

Fig.1. Schematic diagram of abrasive flow finishing set-up
Fig.2. Friction Welding Machine.

2. LITERATURE REVIEW

The literature review sate that studies about the effects of various process parameters on Frictional Stir Welding and surface roughness have been done by many researchers of Friction Stir Welding application.

2.1 PROCESS PARAMETER AND THEIR CONSEQU-ENCES.

The aspects which dominate on FSW Factor Stir Welding are as follows:

a) **Rotational Speed** which create frictional heat, material steering, form oxide layer, material breakdown and mixing for joint.
b) **Welding Speed** consecution appearance and heat control.

c) **Pressure on tools** (downward force) affect in frictional heat, maintaining.

d) **Tilting angles** for stirring material, appearance of weld thinning.

2.2 MATERIAL FLOW

No material or slight material draws in front of probe when tool rotate but material part in front of pin and passes down either side. As material passed probe, die side pressure forces material back together to consolidation join, as the tool shoulder passes overhead and the down force forges the material.

Recently, an alternative advanced theory that state considerable material movement in certain locations, holds that some material does rotate around the probe, for at least one rotation, and this material movement that produces the "onion-ring" structure in the stir zone. The researchers used a combination of thin copper strip inserts and a "frozen pin" technique, where the tool is rapidly stopped in place.

They suggested that material motion occurs by two processes:

1. Material on the advancing side of a weld enters into a zone that rotates and advances with the profiled probe. This material was very highly deformed and sloughs off behind the pin to form arc-shaped features when viewed from above (i.e. down the tool axis). It was noted that the copper entered the rotational zone around the pin, where it was broken up into fragments. These fragments were only found in the arc-shaped features of material behind the tool.
2. The lighter material came from the retreating side in front of the pin and was dragged around to the rear of the tool and filled in the gaps between the arcs of advancing side material. This material did not rotate around the pin, and the lower level of deformation resulted in a larger grain size.

Heat engenderment at same time friction-stir welding begins has two main sources: Friction at tool's surface and material deformation around tools.

Heat generation occur principally under the shoulder, due to its greater surface area, tools and work piece contact with pressure forces sliding friction, sticking friction, based on the interfacial shear strength at an appropriate temperature and strain rate.

The welding cycle can be split into several stages, during which the heat flow and thermal profile will be different.

- Preheating of material by a stationary, rotating tool to achieve a sufficient temperature ahead of the tool to allow the traverse. This period may also include the plunge of the tool into the work piece.
- As tool begins to move, there will be a transient period where the heat production and temperature around the tool will alter in a complex manner until an essentially steady state is reached.
- Thermal field around the tool remains effectively constant, at least on macroscopic scale even though there are fluctuations in heat generation.
- Near the end of the weld, heat reflects from the end of the plate, leading to additional heating around the tool.

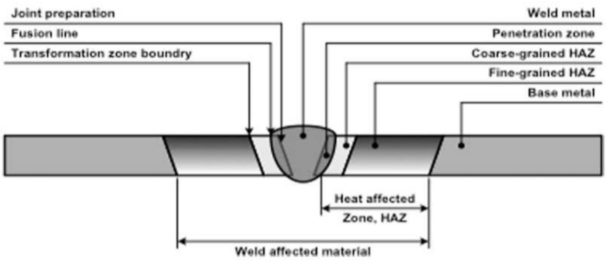

Fig:-3 Material Flow

2.3 HEAT FLOW GENERATION

- Heat input gets minimized and accelerate desiring travel speed as it will enhance productivity and gives a reducing impact on mechanical properties of weld.
  For sufficient material flow and anticipate sufficient material flow and anticipate prevention of flows, tools dilapidation it is mandatory to assure that the temperature around tool is high and acceptable.

- Ahead of tool there is always lack of time to conduct thermal gradients, possible only if transverse speed is increased for desirable heat input.
  Material ahead of tool will be too cold at some point when flaws stress is too high, permits sufficient material stirring flows result in tools damage, flaws, and fracture.

- Transverse speed can be accelerated higher in large "hot zone" which increases productivity.

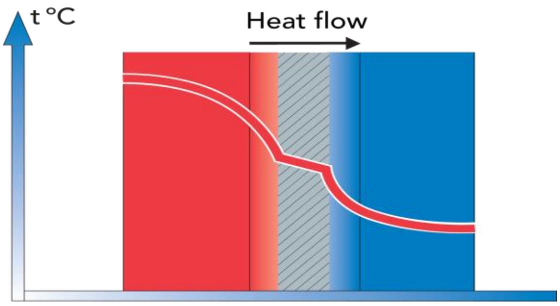

Fig: -4 Flow Diagram

3 TOOL:

3.1 Technological factors and its content

Tool Shape – *Pin Length* - approximately equal to the base metal thickness, *Pin shape* – to fit different material and thickness, *Angle of tool* – a certain inclination.

Tool Position - *Insertion depth of the pin*: about the work piece thickness, *Position of the center line*: just in the weld center line *Shoulder*: contact degree

Accuracy in Joint - The joint gap is recommended for 0 mm gap Material extrusion processing accuracy, joint processing accuracy are important factors to avoid defects.

Speed of Spindle - According to the work piece thickness, the shape of the tool Output power of the motor, stiffness Spindle speed is generally hundreds - thousands of revolutions per minute.

Speed of Welding - Welding speed is selected according to the spindle speed Welding speed of 60~150 mm/min, the same as the arc welding.

Fixation of work piece - In order to ensure the joint accuracy, dedicated fixture design is very important.

3.2 SHOULDER DESIGN

Diameter of Shoulder - Shoulder generates maximum heat, Heat generate by sliding and striking upon work piece, Plasticized material flow due to sticking, Material get adequately plasticized and flow, Tool should have adequate grip on the plasticized material, Total torque and traverse force should not be excessive.

Surface of shoulder - Tool shoulders surface is flat, Convex, concave, Shoulder may be stationary or moving, depends upon the friction stir welding machine design, The amount of material deformation produced by the shoulder, increase work piece mixing and higher-quality friction stir welding.

Pin (Probe) Geometry - Pin or probe shape influences flow of plasticized material and determine weld properties, Welding tool design is critical and important, Tool geometry influence the amount of frictional heat yield, Tool design efficient stirring, higher welding speeds, enhanced quality of joining.

Complex Motion Probe tool - Enhance tool travel speed, Boost the volume of material swept by pin-to-pin volume ratio, Develop the weld symmetry, Complex motion tools require specialized- Skew-Stir Tool, Com-Stirring of tool, Dual-Rotation of tool, Re-Stirring tool.

3.3 TOOL'S MATERIAL AND SPECIFICATION CHARACTERSTICTS

Tool steel - common tool material, good for aluminum, easy machine ability, economical.

Nickel- and Cobalt-Base Alloys - high strength, creep resistance, ductility, and corrosion resistance,

Carbides and Metal-Matrix Composites - Machining tools, superior wear resistance, tough reasonable fracture, work at high temperature, Tungsten carbide have smooth and uniform thread surface.

Cubic Boron Nitride - Polycrystalline cubic boron nitride, the turning and machining of tool steels, cast irons, and super alloys.

3.4 ALLOYS RESPECTIVE TO FORGING MATERIALS AND FORGING TEMPRATURE IN DEGREE C.

Copper alloys –Nickel, Tungsten alloys, Tool steel -1350-1700 C
Aluminum alloys - Tool steel, WC-Co, 370-480
Titanium alloys – Tool Tungsten alloys - 790-1065 C
Magnesium alloys - Tool steel, WC - 350-400 C
Stainless steels – Tool Tungsten alloys - 1095-1150 C
Carbon steels – Tool High strength - 1200-1300 C

3.5 TOOL DESIGN

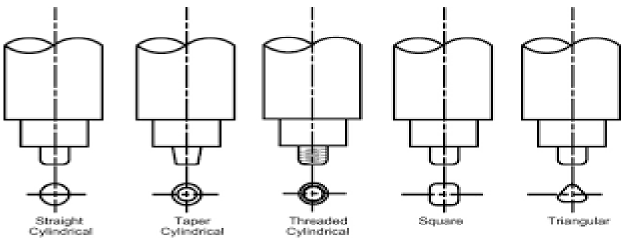

Fig: 5 Tool Shape and Size.

3.5.1 FRICTION WELDING TOOLS PROCESS:

Tool pin is the part which indulge in to material or work piece and stir midway edges of work piece to weld.

The stir friction welding pin starting at a zero penetration and extending to depth needed to repair a weld or to make a weld.

Then withdrawing the pin at zero penetration as the work is translated.

The weld path is thus ramped into and out of work piece leaving no holes which need to be repaired

Circumferential welds can be made keeping the pin extended to the welding path for at least one complete revolution of weld.

There are three major steps in friction stir welding as,

Plunging – Plunging is operation of localized indulging into the work piece and making a hole in work piece. it is done in two stages as a hole is pierced in the work at required position by tool pin, the pierced hole in work piece is shape of pin of tool.

Bonding – The tool pin stir edges of work piece and plasticize material and these discharge plasticized metal back to mix together in the groove and make a bonding on solidification of the materials. This process is known as bonding.

Drawing out – The tool pin is inserted into work piece is drawn out leaving a hole of pin size. The pin hole is the drawback of friction stir welding.

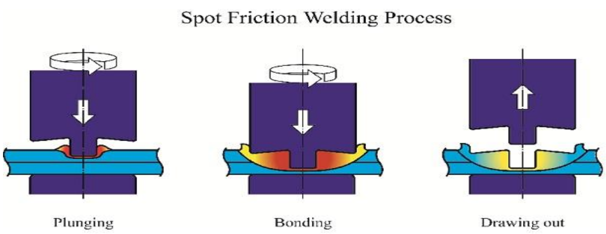

Fig.8 Friction Welding Process Spot.

3.5.2 PROCESS PARAMETER FRAMEWORK

Tool Design

- Weld Quality ,
- Securing maximal accessible welding speed,
- Pre-strong, tough and hard wearing,
- High welding temperature.

Tool Rotational Speed

- Solid state joining process
- Process between tool pin profile and plate.
- Friction generation depends on Rotational speed.
- Rotational speed increase or decrease weld quality will likely to increase or decrease accordingly.

Welding Feed Speed

- Temperature decreases when an increase in welding speed the temperature at local position.
- When there is slow feed speed the temperature increases.

Axial Force-

Material thickness increased enhances axial force. FSW practice for base metal or work piece metal are-

- Lead, Copper and its alloys, Titanium and its alloys, Magnesium alloys, Zinc, Plastics, Mild steel, Stainless Steel, Nickel Alloys.

Consideration of material specification before selecting tool materials:

- Wear resistance and tool resistivity.
- Coefficient of Thermal Expansion.
- Ambient and elevated temperature Strength
- Elevated temperature stability, easy material availability.
- Fracture toughness, Easy Machine ability.
- Uniform at microstructure and density,

3.6 Microstructure Studies

Super plasticity in friction stir processing parts is limited at elevated temperatures due to the evolution of a very coarse-grained microstructure. When downward force is applied on tool, too tip is inserted to metal work piece material, the fractional heat is generated as stirring tools contain pin which probe and shoulder. Work piece and pin contact generate frictional and deformational heating and plasticizing and moderates the work piece material, contain the deformed material.

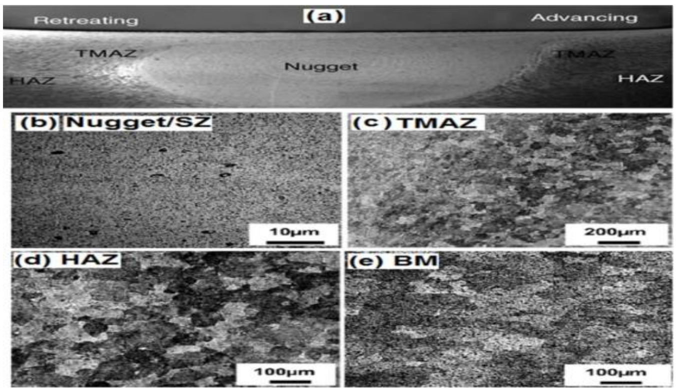

Fig. 6 Shows Microstructure Studies.

Microstructure in friction stir welding is composed of grains and different structure as there are mainly two phases confliction is produced.

- HAZ- Heat Affected Zone
- Thermo-Mechanically Affected Zone (TMAZ).

HAZ transfer to TMAZ. The plasticized material flow in HAZ and TMAZ is result of thermal effect and plastic shear stress caused by plastic material flow HAZ. The grains are appreciably elongated along direction of maximum shear stress. HAZ affected by sub-size concave shoulder and rotating tool pin.

Microstructure is HAZ are characterized by fine and equal - size grains, formed accordingly to dynamic recrystallization mechanism. As it experience high temperature and intense plastic deformation. Intense Stirring effects of rotating tool pin HAZ experience high temperature and plastic deformation, and microstructure in their zone are characterized by fine and equal size grain structure owning to dynamic recrystallization mechanism which is usual phenomenon when affected high temperature intense plastic deformation.

Welding parameters (e.g., tools rotation rotate and welding speed) dictate, for given tool geometry and thermal boundary conditions, the temperature and strain history of material being welded.

3.6.2 DETAILLING MICRO STRUCTURAL ANALYSIS

Different zones in a weld specimen

- Unaffected material
- Heat affected zone (HAZ)
- Thermo-mechanically affected zone (TMAZ)
- Weld nugget (Part of thermo-mechanically affected zone)

UNAFFECTED MATEIAL OR PARENT METAL

This is material remote from the weld, which has not been deformed, it may have experienced a thermal cycle from the weld is not affected by the heat in terms of microstructure or mechanical properties.

HEAT AFFECTED ZONE (HAZ)

The region of the parent metal which has undergone a metallurgies change as a research of the thermal cycle is called heat affected zone or thermally affected zone.

THERMO-MECHANICALLY AFFECTED ZONE (TMAZ)

In this region, the material has been plastically deformed by the friction stir welding tool, and the heat from the process will also have exerted some influence on the material. In the case of aluminum, it is possible to get significant plastic strain without recrystallization in this region.

WELD NUGGET

The recrystallized area in the TMAZ in aluminum alloys has traditionally been called the nugget. The microstructure analysis is carried out to determine the flow of the material and change in the microstructure and grain size of the material. The second microstructure photo shows the heat affected zone with the parent material. This photo helps in the comparison of the two. Cracks are found in the heat affected zone. The third picture shows the structure of weld nugget .Formation of small cracks due to improper fusion can be seen. The metal flow is seen clearly. Incomplete metal flow resulting in incomplete convergence and void formation. The fourth photo shows the flow pattern of metal.

BASE METAL

Base metal is the material in original form. Micro structure test of material before welding. In this situation base metal is in its real form without any change in micro structure of material.

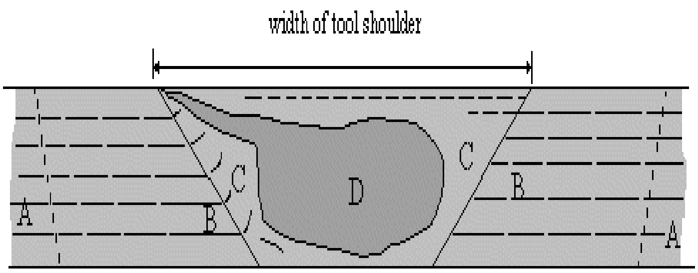

Fig.7. Microstructure of Material.

3.6.3 MECHANICAL PROPERTIES

It is now known that properties following FSW are a function of both controlled and uncontrolled variables as well as external boundary conditions. For example, investigators have now illustrated that post weld properties can be a function of:

Tool travel speed , Tool rotation rate , Tool design , Tool tilt, Material thickness, Alloy composition , Initial material temper, Cooling rate, Heat sink , Test sample size, location, and orientation , Surface oxides , Joint design., Post welds heat, FSW test system.

The different mechanical properties are found from the above functional requirement of FSW processes.

Hardness, Yield Strength, Elongation, Fracture Toughness Fatigue Crack Growth Rate.

3.6.4 TEMPERATURE DISTRIBUTION

Combination of friction and plastic dissipation during deformation of the metal generate heat. The weld parameters, thermal conductivities of the work piece, pin tool and backing anvil, and the weld tool geometry and the contact conditions between the two surfaces influence heat generation. Thermocouples (TCs) have been used to find out the temperature of field and Interpretation of measurements is affected by the coupled thermal conductivity of the work piece, the backing anvil, and the weld tool Depending on the TC location, embedded TCs near pin tool generally consumed in the weld process.

The welding tool geometric features of the pin and the shoulder encourage whether the two surfaces slide, stick, or alternate between the two modes.

Fatigue strength of blades, disks, hubs and shafts with uniform

Polishing on its edges. The adjustment of air flow resistance in blades, vanes, combustion liners, nozzles and diffusers, finishing of fuel spray nozzles, fuel control bodies, bears components, reworking the components to remove coke and carbon deposits and to improve its surface integrity.

3.7 TENSILE TEST

The tensile test of specimen has a dumb bell, Tensile strength specifies the point when a material goes from elastic to plastic deformation, expressed as the minimum tensile stress (force per unit area) needed to split the material apart. The necking phenomenon has been used to determine the tensile strength of the specimen. The specimen for tensile test was conducted using Ultimate Testing machine.

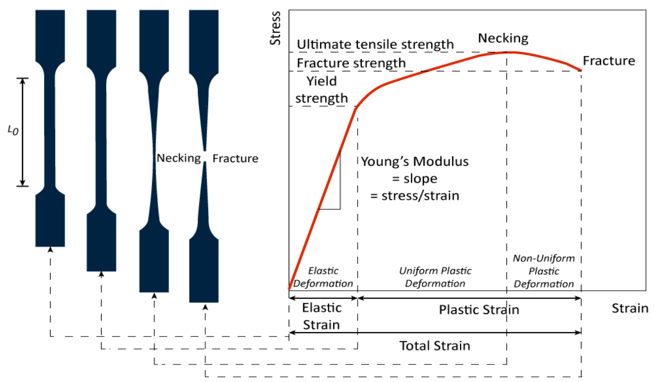

Fig.9 – Tensile test specimen.

CALCULATION OF PERTENTAGE ELONGATION

Original length = 80mm, Final length = 83mm % Elongation (L f - L 0 /L o) x100 = (83-80 / 80) x 100 % Elongation = 3.75

The maximum tensile strength obtained from the two specimens was approximately 75% of the parent material.

TENSILE TEST RESULT

Specimen	Operating Conditions		Tensile strength (N/mm2)
	Speed (rpm)	Feed(mm/ min)	
Specimen A	1400	30	75
Specimen B	1400	22	95

3.7.2APPLICATION, BENIFITS AND LIMITATIONS:

APPLICATIONS

Shipbuilding, Aerospace, Automobile, Construction Industry, Aluminum Industry, Train and Metro Industry, Refrigeration Industry, Piping and Pipeline industry , oil and gas industries, Metal forming industry, etc.

ADVANTAGES

High quality welding, no filler materials, no smoke, low energy consumption, high tensile strength, high welding strength

DISADVANTAGES

High machine cost, Work pieces must be rigidly clamped, Can't do welding for fillet work piece, Left hole when tool withdrawn.

4.1 RESULT AND DISCUSSION

FSW has achieved worldwide accomplishment and progress has established itself as a viable joining option for automotive industries, aerospace industries, ships and marine industries, space technology.

However more research required in future to analyses and optimize process and applications.

Tool Design another very important input which reduces cost and tool wear rates. Tool geometry and process parameters would provide desired weld quality.

Proper mechanical selection for tool is very important aspect.

Although ability of FSW to weld light weld, high strength, dissimilar material, from high melting temperature to low melting temperature (plasticizing)of material has its own benefits success rate of practice FSW.

Review demonstrate extensive study and research effort that continues to progress and update the understand FSW.

It enhances the microstructure and mechanical properties. It identifies a number of areas that are worth wile for further study.

For engineering and application perspective a numerous of uses practiced in many industries and has many advantages, and disadvantages and limitation process are being reduced by intensive research and development.

It influence tool design on flow occurrence and development of testing techniques to identify flow in both lap and butt weld would be beneficial.

Metal for molding capture aspect of thermos-mechanical behavior for significant challenges.

Tensile strength also provides a better weld joint. The hardness of weld region is higher than that of parent material. This revels that the welding is proper.

A lot of advantages and benefits added to strength in evolution of FSW. Some of benefits are- welding process id economical, low energy consuming, non-consuming tool, no fillet material, environment friendly, no smoke, high welding strength, high tensile strength, high welding quality, dissimilar material welding, clean welding process.

4.2 CONCLUSION

FSW is best for long lengths and high quality welding process. Much effort made for higher temperature welding material many alloys as aluminum alloys, magnesium alloys, titanium and steel alloys and dissimilar materials. Low HAZ, free spatter and free porosity defects is an emerging and alternative of fusion welding. For Friction Stir Welding number of process parameter affects welds mechanical properties, which are tool rotational speeds, welding speed, axial force, and tool geometry and tool angle. Metal flow carves thermo-mechanical behavior remains a significant challenge. It helps in explaining the various zones parts, and details microstructure of welding area.

Rotational speed of tools produce the frictional heat, plasticize the material. The low speed has fine mechanical properties than the weld produced at higher speed. The mechanical properties increase with rotational speed. Increase in axial length, increase in tensile load. Welding process by forging effects and no metal melts, increase its application in many industries and higher advantages as green welding technique, non-consumable tools, low power intake and high strength, high tensile strength, high quality of welding, economical and resistance free process.

The tensile strength of weld region is higher than that of parent's material, tensile test prove a better weld joint.

FSW gives a wide range of area for research work and scientific study of metal joining which leads in work standardization of engineer and researcher and will emerge higher extensive when FSW technology continues to move forward.

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- **Friction Stir welding Technology**

[2] Sivakumar1*, Vignesh Bose**2,** D.Raguraman3, D. Muruganandam4 -

- **Review Paper on Friction Stir Welding of various Aluminium Alloys**

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- **"Review paper on optimization of friction stirs welding process parameters"**

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- **Review paper on friction stir welding**