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STATE OF ART: FRICTION STIR WELDING

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Abstract: Friction Stir Welding (FSW) is a solid state welding process. It is different from fusion welding process and also different from other old solid welding process. It is a way of joining materials without melting them. This joining method has advantages such as the shape of the sections to be joined changes little after joining. No melting occurs during friction stir welding. There is no solidification shrinkage when the joined sections solidify. The temperature is lower than fusion welding. The strength of the joint is high. It is relatively a new joining process. Friction stir welding (FSW) produces no fumes; uses no filler material; and can join aluminum alloys, copper, magnesium, zinc, steels, and titanium. FSW sometimes produces a weld that is stronger than the base material. No light is radiated as in fusion welding, no sparks fly, and no smoke is emitted in FSW. FSW is considerably more environmentally friendly than conventional "fusion" welding. In this paper, history, working principle, machine and tool and its materials, work piece material applications etc are presented.

I. INTRODUCTION

Friction Stir Welding (FSW) is a new joining process. It is a solid state welding process. It overcomes many of the problems associated with traditional joining techniques. The basic concept of friction stir welding is simple. Friction Stir Welding (FSW) is a solid-state joining process that creates extremely high-quality, high-strength joints with low distortion. A non consumable rotating tool with special pin and shoulder is inserted into abutting edges of sheets or plates. FSW produces welds of high quality in difficult-to- weld materials such as aluminum, and is fast becoming the process of choice for manufacturing lightweight transport structures such as automobiles, boats, trains and aeroplanes. Friction stir welding (FSW) is a relatively new solid-state welding process [1]. This joining technique is energy efficient, environmental friendly, and versatile. In particular, it can be used to join high-strength aerospace aluminum alloys and other metallic alloys that are hard to weld by conventional fusion welding. FSW is considered to be the most significant development in metal joining in a decade. Recently, friction stir processing (FSP) was developed for micro structural modification of metallic materials. A non-consumable spinning tool bit is inserted into a work piece. The rotation of the tool creates friction that heats the material to a plastic state. As the tool traverses the weld joint, it extrudes material in a distinctive flow pattern and forges the material in its wake. The resulting solid phase bond joins the two pieces into one.

II. HISTORY

In 1991 a novel welding method was conceived. Friction Stir Welding (FSW) is invented by Wayne Thomas at The Welding Institute (TWI)Ltd at England and patented in 1991[2]. TWI filed successfully for patents in Europe, the U.S., Japan, and Australia. TWI then established TWI Group-Sponsored Project. It is further developed New Friction Stir Technique for Welding Aluminum," in 1992 to study this technique.

The development project was conducted in three phases. Phase I proved FSW to be a realistic and practical welding technique, while at the same time addressing the welding of 6000 series aluminum alloys. Phase II successfully examined the welding of aerospace and ship building aluminum alloys such as 2000 and 5000 series, respectively. Process parameter tolerances, metallurgical characteristics, and mechanical properties for these materials were established. Phase III developed pertinent data for further industrialization of FSW.

Since its invention, the process has received world-wide attention, and today FSW is used in research and production in many sectors, including aerospace, automotive, railway, shipbuilding, electronic housings, coolers, heat exchangers, and nuclear waste containers.

FSW has been proven to be an effective process for welding aluminum, brass, copper, and other low-melting-temperature materials. The latest phase in FSW research has been aimed at expanding the usefulness of this procedure in high-melting-temperature materials, such as carbon and stainless steels and nickel-based alloys, by developing tools that can withstand the high temperatures and pressures needed to effectively join these materials.

III. WORKING OF FSW

In FSW, a cylindrical, shouldered tool with a profiled probe is rotated and slowly plunged into the weld joint between two pieces of sheet or plate material that are to be welded together (**Figure 1**). The parts must be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart or in any other way moved out of position.

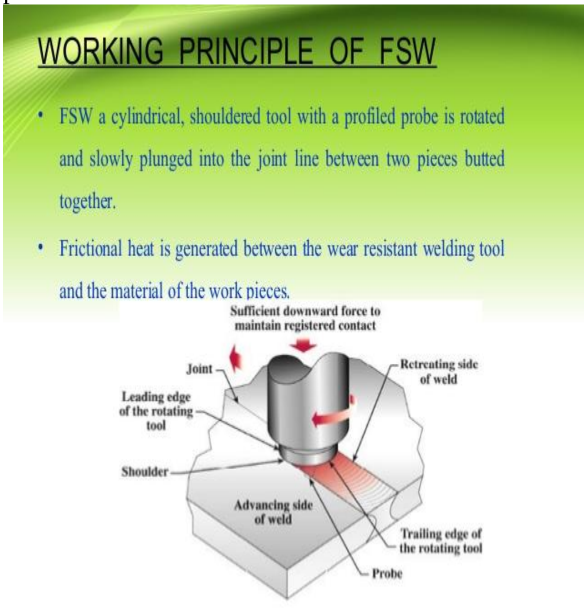

Figure -1.

Frictional heat is generated between the wear-resistant welding tool and the material of the work pieces. This heat causes the work pieces to soften without reaching the melting point and allows the tool to traverse along the weld line. The resultant plasticized material is transferred from the leading edge of the tool to the trailing edge of the tool probe and is forged together by the intimate contact of the tool shoulder and the pin profile. This leaves a solid-phase bond between the two pieces.

The process can be regarded as a solid-phase keyhole welding technique since a hole to accommodate the probe is generated, then moved along the weld during the welding sequence.

The process originally was limited to low-melting-temperature materials because initial tool materials could not hold up to the stress of "stirring" higher-temperature materials such as steels and other high-strength materials. This problem was solved recently with the introduction of new tool material technologies such as polycrystalline cubic boron nitride (PCBN), tungsten rhenium, and ceramics. The use of a liquid-cooled tool holder and telemetry system has further refined the process and capability. Tool materials required for FSW of high-melting-temperature materials need high "hot" hardness for abrasion resistance, along with chemical stability and adequate toughness at high temperature. Material developments are advancing rapidly in different tool materials, each material offering specific advantages for different applications.

Fabricators are under increasing pressure to produce stronger and lighter products whilst using less energy, less environmentally harmful materials, at lower cost and more quickly than ever before. FSW, being a solid-state, low-energy-input, repeatable mechanical process capable of producing very high-strength welds in a wide range of materials, offers a potentially lower-cost, environmentally benign solution to these challenges.

The process uses no outside (filler) material, no shielding gases, and requires low energy input when compared to other welding processes. The solid phase bond between the two pieces is made solely of parent material. The grain structure in the weld zone is finer than that of the parent material and has similar strength, bending, and fatigue characteristics.

Equipment used for Friction Stir Welding: Vertical Milling Machine, Heavy clamping system, and Tool.

Vertical Milling Machine: The milling machine should have good foundation. It should be free from vibrations. It is used for clamping milling vice for holding the work pieces are to be welded. The work pieces are held by good clamping devices or by a milling vice.

IV. CLAMPING DEVICES

These may be milling vices or clamps. These are used to hold work pieces to be butt weld or lap weld.

Tool and its material: The tool is fixed in the spindle of milling machine. It can be a cylindrical with slight taper at the one end or conical. It should have good High-temperature strength, Wear Resistance, Low Reactivity, Manufacturability, and Toughness.

Tool materials may be **Refractory Metal Alloys** (Tungsten, Molybdenum,Tungsten-Rhenium) and **Super abrasives** (Polycrystalline Diamond (PCD), Polycrystalline Cubic Boron Nitride (PCBN)).

Tungsten-Rhenium Tools: Higher room-temperature toughness (no preheat), Improved densification (less wear), some indications of chemical reaction with base plate

PCBN Tools: Excellent high-temperature strength, Abrasion resistant, Chemically inert, Limited in size, Relatively low toughness, Polycrystalline Cubic Boron Nitride (PCBN), Second in hardness only to diamond, Diamond crystal structure, with C and B occupying , alternate lattice sites.

Weldable Materials: The compatibility range extends to welding the following materials.
1. Aluminum (all alloys), 2. Copper, 3. Brass, 4. Magnesium, 5. Titanium, 6. Steel Alloys, 7. Stainless Steel, 8. Tool Steel, 9. Nickel and 10. Lead

Advantages & Benefits of Friction Stir Welding: Friction Stir Welding (FSW) from MTI is making a dramatic impact across a number of industries, including aerospace, defense, transportation, marine and electronics. In the automotive industry alone, for example, FSW is used to create everything from drive shafts and fuel tanks to hood panels and suspension links.
The process advantages result from the fact that the FSW process takes place in the solid phase below the melting point of the materials to be joined. The benefits include the ability to join materials that are difficult to fusion weld, for example, 2XXX and 7XXX aluminium alloys [3]. Magnesium and copper can be welded by friction stir welding very easily. Friction stir welding can use purpose-designed equipment or modified existing machine tool technology. The process is also suitable for automation and is adaptable for robot use.

- **Provides opportunities for new solutions to old joining problems:** Friction Stir Welding (FSW) is a leading-edge technology, meaning that MTI is continually identifying new applications for the process and, therefore, new solutions for its customers.
- **Virtually defect-free welding:** Easily controlled process parameters - such as pin tool geometry, pin tool force, rotational speed and traversing speed - are easy to monitor, allowing for easy avoidance of errors.
- **Versatile applications by welding all joint geometries including complex contours:** Friction Stir Welding (FSW) can weld almost any shape of contoured parts, including seam welding of cylinders. Some of the other joint geometries usual to the FSW process include butt, T-butt, lap, butt laminate, butt both sides, T-butt dual pass, lap laminate, L-outside, flange, multi-thickness, T-single weld, and L-inside (which requires special joint preparation).
- **Limitless panel length and width:** The process flexibility of Friction Stir Welding (FSW) accommodates the welding of large parts. Our standard models may be modified to expand axes as needed for your application. Our in-house FSW equipment can produce welds up to 55-feet long - one of the longest, continuous Friction Stir Welds in the world.
- **Superior mechanical characteristics:** This joining technology offers a weld with high weld strength and toughness. The weld has a fine grain structure that resists fatigue stress. Due to the low heat and small heat-affected zone, there is minimal distortion of the joined parts, reducing the costs associated with preparing the part for subsequent use.
- **Join dissimilar alloys:** Friction Stir Welding (FSW) may be used to weld dissimilar alloys, even combinations that are not compatible with other welding processes. See the **Weldable Materials** list above.
- **"Green"process:** Low energy input and lack of fumes, gases, etc., resulting from the process, makes FSW friendly to our environment.

Other advantages are as follows:

- Low distortion and shrinkage, even in long welds
- Excellent mechanical properties in fatigue, tensile and bend tests
- No arc or fumes
- No porosity
- No spatter
- Can operate in all positions
- Energy efficient
- One tool can typically be used for up to 1000m of weld length in 6XXX series aluminium alloys
- No filler wire required
- No gas shielding for welding aluminium
- Some tolerance to imperfect weld preparations - thin oxide layers can be accepted
- No grinding, brushing or pickling required in mass production
- Can weld aluminium and copper of >75mm thickness in one pass.

Weld Quality: **FSW produces excellent weld quality with these features:**

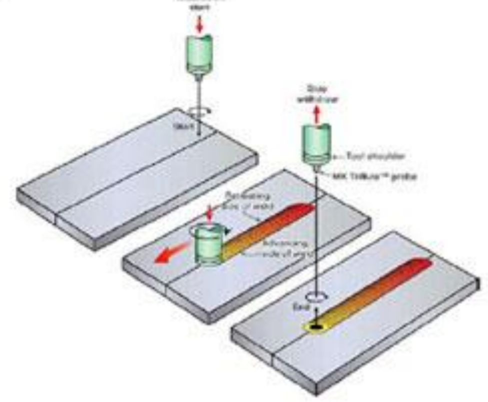

Figure -2

- **Low distortion.** In butt welding aluminum, for example, from 2.8 mm and thicker, the plate distortion in a properly built FSW machine is more or less zero. Tests on 12-m lengths have been carried out (**Figure 2**) in which sideway bends smaller than 0.25 mm (0.01inch) were achieved, and no twist was seen with material thicker than 2.8 mm. In thinner materials, a slight upward bend occurred, but no twist or side bends were seen.
- **Low shrinkage.** FSW produces the same predictable amount of shrinkage each time, normally found lower than 2 mm on 6-m-wide aluminum panel application.
- **No porosity.** Because the base material does not melt, there is no porosity.
- **No lack of fusion.** Because this is an extruding and forging joining method with a more accurate control of the heat, no lack of fusion is seen.
- **No change in material.** When joining aluminum, material properties change little from the parent material as the maximum temperature during the joining process is approximately 450 degrees C, and no filler material or anything other than heat is added to the joint (**Figure 2**). Due to the resultant finer grain structure in the weld nugget, the weld sometimes is stronger than the base material. In steels, most of these same advantages apply.

Disadvantages: Work piece must be rigidly clamped, slower transverse rate than fusion welding

Applications of Friction Stir Welding: The shipbuilding and marine industries are two of the first sectors that have adopted the process for commercial applications. The process is suitable for the following applications:

- Panels for decks, sides, bulkheads and floors
- Hulls and superstructures
- Helicopter landing platforms
- Marine and transport structures
- Masts and booms, e.g. for sailing boats
- Refrigeration plant

V. APPLICATION OF FSW

Aerospace Industry: At present the aerospace industry is welding prototype and production parts by friction stir welding. Opportunities exist to weld skins to spars, ribs, and stringers for use in military and civilian aircraft. This offers significant advantages compared to riveting and machining from solid, such as reduced manufacturing costs and weight savings. Longitudinal butt welds in Al alloy fuel tanks for space vehicles have been friction stir welded and successfully used. The process could also be used to increase the size of commercially available sheets by welding them before forming. The friction stir welding process can be considered for:

- Wings, fuselages, empennages
- Cryogenic fuel tanks for space vehicles
- Aviation fuel tanks
- External throw away tanks for military aircraft
- Military and scientific rockets
- Repair of faulty MIG welds
- Locomotive train and carriage panels (aluminium)
- Aircraft fuselage and avionics development
- Truck bodies, caravans and space frames
- Heat sinks and electronics enclosures
- Boat and ship panel sections
- Flat and cylindrical fuel tanks and bulk liquid containers
- Aluminium bridge sections, architectural structures and frames
- Pipelines and heat exchangers
- Electrical motor housings

Railway Industry: The commercial production of high speed trains made from aluminium extrusions, which may be joined by friction stir welding, has been established. Applications include:

- High speed trains
- Rolling stock of railways, underground carriages, trams
- Railway tankers and goods wagons
- Container bodies

Land Transportation : The friction stir welding process is currently being used commercially and is also being assessed by several automotive companies and suppliers. Existing and potential applications include: 1. Engine and chassis cradles 2. Wheel rims 3. Attachments to hydro formed tubes 4. Space frames, e.g. welding extruded tubes to cast nodes 5. Truck bodies & tail lifts for lorries 6. Mobile cranes 7. Armour plate vehicles 8. Fuel tankers 9. Caravans 10. Buses and airfield transportation vehicles

VI. MTI'S ADVANCED TECHNOLOGY FRICTION STIR WELDERS

MTI has pioneered the manufacture of robust, rigid, yet cost-effective, machines for general use in any production environment. MTI offers a wide range of machine choices for FSW applications, such as:

Model RM-1 - High force/low spindle run-out welder for small to medium sized components.
Model RM-2 - High stiffness welder for larger components
Model PM-0 - Small, cost effective welder for high volume production
Model LS-1 - Robust welder for linear welds, configurations up to 100m welds
Model GG-1 - Multi-axis welder for complex contours

Friction Stir Welders (FSW) from MTI also offer these value-added features:

- Turn-key Installation
- Preloaded, Zero-Backlash Linear Drives
- Balanced Actuator Loads
- Precision Spindle
- Multiple process control modes
- Data Acquisition System for all critical process parameters

Available optional features include:

- Water-cooled tool holder
- Retractable pin-tool
- Custom work-holding fixtures
- Automation
- Manufacturing Cell Integration, including Material Handling, Automatic Loading and Unloading, Robot Integration, Bar Coding, Quality Control, and Part Destruction
- Custom Design Machine Diagnostics and Maintenance Schedule for Full Preventive Maintenance

VII. CONCLUSIONS &

1. FSW opens new welding areas.
2. W successfully applied to wide variety of iron and nickel alloys.
3. Properties look good in most cases.
4. Low distortion, no spatter, no fumes
5. Welding will be done below the melting point of metals and alloys.
6. Good strength is possible.
7. Reasonable elongation.
8. Tool life is high enough for high-value applications, and increasing.
9. Good forging action by tool.
10. Creates high strength welds in hard to weld metals.
11. It is an alternative to fusion weld.

VIII. FUTURE SCOPE OF FSW

Forces acting on the tool can be computed for various welding and rotational speeds. The mechanical properties such as residual stress, fracture, fatigue and corrosion have good scope in future on FSW joint. Laser assisted friction stir welding, and possible use of induction coil and other mechanism.

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