REVIEW PAPER ON FRICTION STIR WELDING AND ITS IMPACT ON ENVIRONMENT

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Abstract: *The comprehensive essay of knowledge that has been documented with respect to the friction stir welding(FSW) of different alloys since the technique was invented in 1991 is reviewed on this paper. The friction stir welding is a rapidly growing welding technique in the manufacturing industries.A proper tool design with a process parameters is welded on work material can result in high quality welding. The materials that are suitable for friction stir welding are aluminium and its alloys, Magnesium alloys, Titanium and its alloys, copper alloys, Mild steel, Stainless steel, etc. Response Surface Methodology (RSM) is an important area of research in an optimization of the process parameters. The design of tool pin profile and tool shoulder diameter creates considerable variations on welded microstructure.Different process parameters are considered for the variations in the outcome of the weld materials to optimize the welding techniques. There are many areas where friction stir welding have its application like shipping and marine industries, Aerospace Industries, and land transport. It has established a large advantage over conventional welding method like arc welding process. . The Friction stir welding has many benefits as it gives high-quality welds; it is environment-friendly and can be operated at low operational cost, etc.*

Key Words: Friction stir welding,Methodology,Process parameters

1. Introduction

Friction stir welding (FSW) is a solid-state process of joining two objects below its critical temperature.FSW has expanded rapidly since technology was first invented & developed by TWI, The Welding Institute in the year 1991. The characteristic feature of the FSW is to join materials without reaching their fusion temperature of the materials [1]. Initially, FSW was applied on aluminium alloys as it welds easily due to the relatively low softening temperatures of the alloys. Magnesium alloys have unique properties such as low density and high strength to weight ratio have more significant potential to replace aluminium alloys in much structural application [2]. Further metals and alloys which were also suitable for the FSW process like aluminium and its alloy, copper and its alloys, lead, titanium and its alloys, magnesium alloys, zinc, plastics, mild steel, stainless steel, nickel alloys, etc. Researches have been carried out on many other similar and dissimilar metal alloys of aluminium, steel, magnesium and titanium plates of various grades for further implications in manufacturing technology. This process is carried out with many considerations of process parameters and tool design for the better output.

This technique has exhibited a greater advantage over traditional arc welding process. It has found application in many industries such as aerospace, automotive, railway, maritime, etc.FSW is most environmental friendly than traditional welding techniques like arc welding, fume welding etc

2. Principle of friction stir welding

The basic principal of Friction stir welding is heating the metal to a temperature below re-crystallization temperature using Friction generated by the cylindrical shouldered tool on metal. This tool having characteristic profile pin, which is rotated and plunged into the joint area between two pieces of sheet or plate material. The parts have to be securely clamped using fixtures to prevent the joint faces from being forced apart[3]. The Frictional heat is produced between the wear-resistant welding tool and the workpieces, which causes the metals or alloys to soften without reaching the melting point.

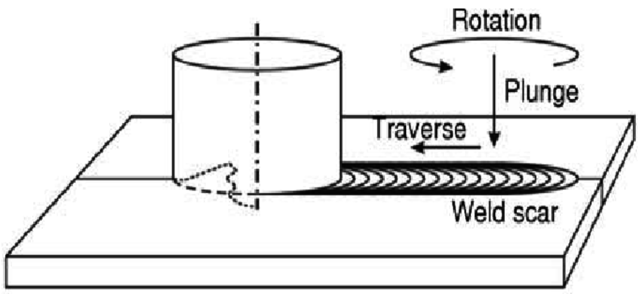

Fig. 1 Schematic of principle of Friction stir weld

The tool moves along the joint line[4] of the work materials as shown in fig. 1.The plasticized material gets transferred to the trailing edge of the tool pin and forged through intimate contact with the tool shoulder and pin profile. The cooling of the material leads to the creation of a solid phase bond between the clamped workpieces.

3. Significance of friction stir welding

The friction stir welding process has demonstrated many advantages over competing and established conventional fusion welding processes. The FSW have the advantage of Solid phase process, so there is no problem with hot cracking, porosity, Good mechanical properties, etc. Also, it produces. Low distortion, no filler wire or shielding gas requirement compare to conventional arc welding processes. No fume, no spatter, no UV radiation, Energy efficient make it more environmentally friendly. It is easy to automate as it Uses machine tool technology and reduces need for skilled welders. These can help in working at the different position.

The Friction stir welding process involves joint formation below melting temperature of the material. The heat generated in the process at the joint area is around 80-90% of the melting temperature. While calculating heat input in FSW, the calculation gets simplified with no current and voltage as compared to arc welding method. Several research studies have been conducted in FSW to identify the way heat generated and transferred to the weld joint. The following equation describes a simplified model:

$$Q = \mu\omega FK \quad \text{Eq.}(1)$$

Where the heat (Q) is directly proportional to tool rotation speed (ω), down force (F) and a tool geometry constant (K) where (μ) is the coefficient of friction

4. Welding Tool

The welding tool of FSW plays a prominent role welding process which has an impact in the mechanical properties and quality of microstructure of the material. Therefore the tool is designed carefully which may alter the weld quality. The tool should have idealistic and higher mechanical properties than weld materials .The difficulty associated are mainly with finding proper tool material;

- The material that can withstand the high temperatures that experience during the process. The high-temperature tool materials are suitable FSW.
- The resistance to wear (durability) is one of the important factors; which causes because of lack of tool hardening or due to process parameters.

The Rai et al.[46] reviewed and examined carefully several important aspects of FSW tools such as tool material selection, geometry and load bearing ability, mechanisms of tool degradation and process economics. The geometrical parameter of FSW is tool designed with D/d ratio(shoulder/pin ratio).The shoulder diameter(D) is decided with pin diameter(d), so that the ratio of D/d should be 3. The tool shoulder applies a pressure to the material to constrain the plasticized material around the pin and generates heat through friction and plastic deformation in a relatively thin layer under the shoulder surfaces. Elangovan and Balasubramanian[5] studied the influence of five different tool pin profiles on the formation of friction stir processing zone. The five-tool pin profiles, i.e., straight cylindrical, tapered cylindrical, threaded cylindrical, triangular and square pins to fabricate the joints as shown in fig. 2,

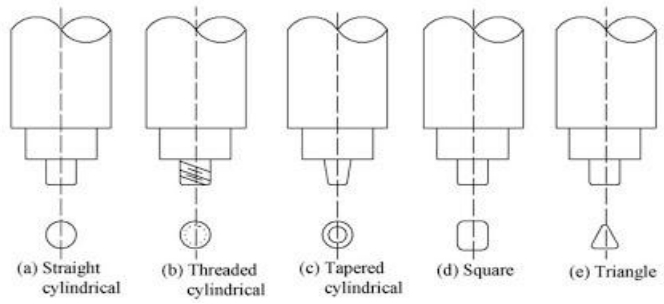

Fig. 2 Schematic diagram of different types of FSW pin profile (a) Straight cylindrical,(b) threaded cylindrical, (c) tapered cylindrical, (d) square and (e) triangle [5].

There are three types of Friction stir welding or processing tools. They can be named as fixed, adjustable and self-retracting. The fixed FSW tool corresponds to a single piece of the device comprising of shoulder and probe[6–8]. This tool is applied only to weld a workpiece having a constant thickness as it has fix probe length. The flexible FSW tool consist of two independent pieces of the separate shoulder and probe so as to make an adjustment of probe length during welding [9,10]. It uses for welding of variable and multiple gauge thickness workpieces. Also, Implementation of filling the exit hole left at the end of the friction stir weld performed with this type of tool. Both the fixed and the flexible tool often require a backing anvil. The self-reacting FSW tool consists of three independent pieces, top shoulder, probe and bottom shoulder[11,12]. It can have multiple gauge thickness joints due to the flexible probe length between the top and bottom shoulders[13,14]. The self-reacting tool can only work perpendicularly to the workpiece surface while the fixed and adjustable tools can be tilted longitudinally and laterally.

The different material used for the tool can be given as tool steel, AISI H13, SKD61, AISI 4340, O1 tool steel, High carbon high chromium steel, Refractory metals, Carbides and MMCs, PCBN, etc.[15]. These materials apply to only a specific type of workpiece materials. This tool material is decided based on the mechanical properties of the workpiece material. Tool steel has an advantage of low cost while it produces visible tool wear after welding for certain distance. Refractory metals are used when there is high melting temperature material. It is used in FSW of high melting material such as Cu, Ti, Ni alloys, and steel. Carbides and MMCs have advantages of reasonable fracture toughness at ambient temperature, and also it applies to optimize probe shape that is thread free probes. PCBN tool material is applicable for welding of a wide range of the material. It has excellent wear resistant at elevated temperature. It is a super abrasive synthetic material, and also it is second in hardness after diamond. It is very expensive with limited welding depth (less than 12mm) used for high strength and wears resistant material such as Cu, Ti and Ni alloys, Steel and Al-MMC.

5. Experimental setup and procedure

The experimental setup of friction stir welding consists of a conventional vertical milling machine or standard milling machine with specially designed rotating cylindrical tool, two discrete metal workpieces, fixtures(to clamp the workpieces on the dynamometer vice). Dynamometer and thermocouple are used to get the working data. The cylindrical tool with profiled probe fed into the joint between the two discrete metal workpieces. The profiled probe on the tool is slightly shorter design than the required probe depth so as tool shoulder can ride on top of the working surface[16]. The dynamometer along with dynamometer's vice and thermocouple are attached with a vertical milling machine. The dynamometer's vice is tightly clamped on the milling table as shown in figure 3. The dissimilar metals and alloys are fixed rigidly on the milling dynamometer's vice. 2 thermocouples are placed on the workpiece at 25 mm distance from each other and 15mm apart from weld line.

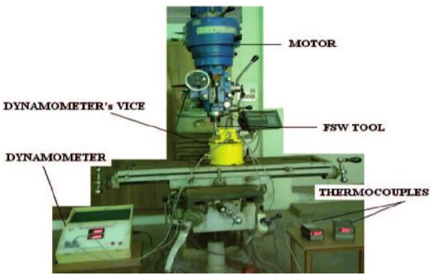

Fig. 3:FSW Experimental setup

The experimental procedure is followed with keeping all constraints in mind. Response Surface Methodology (RSM) is statistical and mathematical techniques used for designing, developing, improving and optimization of the process. It is widely used for FSW study purpose to examine the yield or output of a system as it varies in response to changing levels of the input applied factors[17].

The similar and dissimilar metals and alloys of the materials like aluminium, titanium, magnesium, etc. are welded using the FSW. The workpieces are cut to the dimension of 100mm x 100mm x 5mm for experimental purpose. A clamping arrangement is made to arrest all degrees of freedom. The pin profile tip is brought at the offset of the material before starting the welding. The material is then welded by penetrating the tool along the joint line with the plunge depth. The tool at this time as it rotates along with the contact with the surfaces it softens the material due to the frictional heating. This time is called preheat time or dwell period. The material motion occurs in two ways, i.e. one is by advancing side of a weld enters into a zone that rotates advances with the profiled probe. Other is the lighter material came from the retreating side in front of the pin and is drag around to the rear of the tool and filled into the created gaps between the arcs of advancing side material. From the operational viewpoint, a friction stir welding run can be divided into three sub-procedures or phases, i.e. Plunge and dwell, Traverse and Retract.

The sub-procedures is explained with the start of the plunge phase; both the tool and the workpiece are at ambient temperature. During penetration of the rotating friction stir tool into the workpiece, the material is too cold to flow and thus rubbing action creates chipping as in any machining process. The rate of penetration of tool determines the rate of temperature rise and extent of plasticity. It continues till the tool shoulder is in intimate contact with the base material surface. At this stage, the whole tool shoulder and pin surface produce the frictional heating and lead to dropping of the forces as the metallic workpiece reaches critical temperature for plastic flow. The higher melting point metals having the rotating tool is retained at this position for a short time so as to reach the desired temperature required for producing plastic flow. This phase is known as the dwell phase and a fraction of the time is required for dwell phase. It is programmed for controlled plunge rate that is vertical position controlled FSW, but it can also be done by controlling the force applied to the tool along its rotation axis that is force controlled FSW. Any combination of displacement and force controlled approach is possible. The vertical force reaches a maximum value in this part of a typical FSW run, and this tends to be a critical phase for the tool. It is important to control the rate of heat build-up in this phase. Metals with the higher melting point such as steel, titanium, etc., the plunge rate is particularly low so as to generate sufficient heat to plasticize the metal[18].

6. Process Parameters

The study of the variation of the process parameter input to the output effects and causes play a vital role in RSM. Using the FSW, there is four major process parameter that should be controlled; they are down force, welding speed, the rotation speed of the welding tool and tilting angle. This four parameter need to be mastered for making FSW ideal for mechanized welding.

Different parameters must be studied for the variations in the outcome of the weld. The process parameter like down force, welding speed, the rotation speed of the welding tool and tilting angle play a major role in the Mechanical Properties and hardness of the welded material. The different parameter produces the different effect on welded material. The effect of this parameter are rotation speed produce effects like frictional heat, stirring, mixing of material and oxide layer breaking, tilting angle produce the effect of the appearance of the weld and thinning, welding speed produce Appearance and heat control and downforce produce frictional heat and maintaining contact conditions.

Manish P. Meshram et al.[19] in 2014 studied the welding parameters for joining 4mm thick Austenitic 316 stainless steel plates and find the best parameters. Plates of dimension (120mm x 80mm x 4mm) were used for experiment with PCBN tool. Nine different experiments were conducted with different tool rotation speeds of 1100, 1000, 900rpm and welding speed of 8, 12, 16 mm/min. Each tool rotation speed gives three welding speed given above. The experiment concluded by a defect free weld with parameters of 1100rpm, and transverse speed of 8mm/min showed the similar tensile strength that of the base material with 37% elongation while 49% elongation of the base material.

Prakash Kumar Sahu et al[20] in 2016 conducted a study on the influence of plate position, tool offset and tool rotation speed on mechanical properties of dissimilar Al/Cu friction stir welding joints. They took base materials of 1050Al alloy and pure Cu plates with dimension (150mm x 100mm 4mm) for the butt joint. They took a single pass through the joint line. The H13 tool steel with shoulder diameter of 25mm, pin diameter of 6mm, pin length of 3.5mm and cylindrical pin profile were used for the experiment in a CNC FSW machine. Four process parameter were considered as tool rotation speed, welding speed, tool offset and plunge depth. The base materials were changed with the advancing side and retreating side of tool rotation to investigate the process. Total 12 experiment were done and 40% experiment they repeated two times to examine the repeatability of the process. The different rotational speed of 600, 120020, 30 and 40 mm/min, Plunge depth of 0.05, 0.10, 0.2mm were studied in the experiment. The welded material was then taken of microstructure study and for mechanical testing with standard dimension. The result that they inferred were offsetting the pin towards softer material(Al plate) and keeping the harder material(Cu plate) on advancing side produce an appreciable quality of the weld. At tool rotation rate of 1200 rev/min, welding speed of 30mm/min, 0.1mm plunging depth and 1.5mm offset towards Al alloy highest Ultimate tensile strength of 126MPa and yield strength of 119.3MPa which constitute 95% and 100% respectively of 1050 Al base metal. The. Highest achieved compressive strength and bending angle was 7.8MPa and 65°, respectively for specimens with highest tensile strength.

7. The forces and torque generated during friction stir welding and its simulation details

Force study is a critical aspect of friction stir welding as it is influenced by the pin diameter, welding parameters. FSW process is complex due to highly non-linear contact interaction between workpiece and tool, which causes deformation of workpiece leading to higher strains and strain rates. Experimental investigation reveals the generation of higher forces in the plunging stage as compared to the welding stage[21].Different methodologies have been implemented to measure the axial force[22] experimentally, three component rotating type piezoelectric dynamometer to measure forces and torque generated during the process[23], responses of the electrical motor(like power, current, etc.).To measure the forces and torque[24,25].

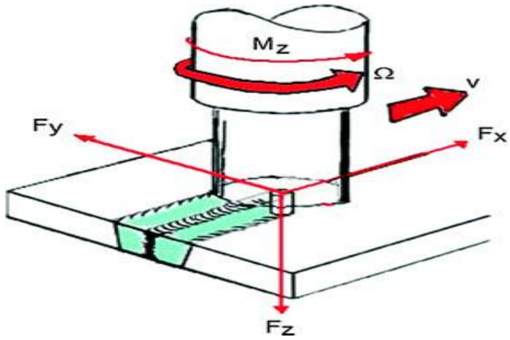

Fig. 4: Forces applied by the FSW tool into the workpieces.

Measurement of forces and torque is a quite difficult task as it requires expensive equipment and additional fixtures. One of the alternative ways of estimating forces is through the numerical modeling of the process. Though modeling of FSW has been done by a lot of researchers but only a few [23,26,27], have predicted the forces generated during the process. FSW process is feed within the range of input process parameters (rotational speed, welding velocity, plunge depth, tilting angle, time is taken to weld, etc.) and has various output responses viz. temperature, forces, torque, etc.

FSW modeling is divided into three stages i.e. plunging, dwelling and welding stages. For clear explanation during assembly of workpiece and tool. The tool is slightly tilted by say 2.5° toward its trailing edge. During the plunging stage, tool moves in negative z direction at defined rotational speed(600,800 and 1000 rpm) with the free velocity of 8mm/min. After dwell time of 10s in defined, in which tool rotates at the same rpm in its position to further increase the temperature, which makes the material beneath the material softer, and at last with welding speed define to the tool to simulate the welding stage till steady stage is achieved. The time required for plunging is 4s to achieve as plunge depth of 0.1mm.

All simulations are performed with the similar procedure explained above with tilt angle of 2.5°, plunge velocity 8mm/min, plunge depth of 0.1mm and welding velocity of 80mm/min. Now the above process is repeated at different speeds(600rpm, 800rpm, and 1000rpm) to investigate on output responses. All the above input parameters and dimensions are taken from experimental data of Su et at.[23]

8. Microstructure

The purpose of the metallographic analysis is to understand the microstructure changes due to the FSW process. The transition between the zone affected by the welding process and the base material is identified by microstructure. This microstructure of the work material is broadly classified into three main zones:

A. Nugget or stirred Zone,

B. Thermo- Mechanically Affected Zone (TMAZ)

C. Heat Affected Zone (HAZ)

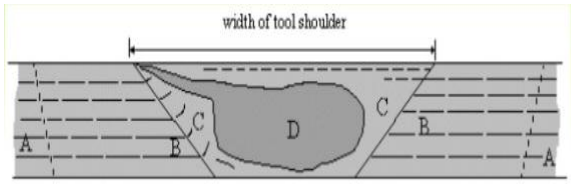

Fig. 5 A. Unaffected material ,B. Heat affected zone(HAZ), C. Thermo-mechanically affected zone (TMAZ),D. Weld nugget

1. *Nugget or stirred Zone*

The microstructure within the weld nugget shows dynamically recrystallized grains much smaller and equiaxed when compared to the elongated base metal microstructure, or already shown in Liu et al. (1997).

2. Thermo- Mechanically Affected Zone (TMAZ)

In the friction stir welded zone very fine recrystallized grains are present due to the high deformation and high temperature during the process. Hardness drastically decreases in the weld TMAZ.

3. Heat Affected Zone (HAZ)

The material affected by the welding process presently a fine stirred grain structure, and the material near the heat affected zone (HAZ) presents regular grains.

As suggested in the Harris and Normen[28] in 2003 this hardness variation was due to the different microstructure of the base material (BM) and welded material(WM). A hardness decrease of 27% and 32% was found in the top surface and side surface, respectively. Joshua says it is the stir zone temperature distribution along with the deformation history that determines the microstructure changes that the material undergoes. The microstructure is related to the weld strength, ductility, and toughness. Therefore, the weld properties are related to the temperatures in the weld zone.

9. Mechanical properties evolution

Once the metallographic analysis is performed the work material is subjected to various tests to calibrate the mechanical properties of the weld materials. The work material is cut into specific dimensions for the particular test performs. The tests performed are

i. Tensile test

The tensile properties of a welded joint are considerably the first tests performed to check the joint quality and its 'joint efficiency', which defines the tensile strength ratio of the weld to the parent plate. The tensile tests are carried out at the room temperature using an MTS 810 testing machine capacity of 250MPa with the initial strain rate of 10^{-3}/s. The ASTM E8M specifications are followed as shown in fig. 6, for tensile test. The specimens are sectioned in the particular direction to the weld line by employing an electrical discharge machine(EDM). The tensile specimens measured 12mm width, 80mm length for a gauge length of 25mm. Now, the tensile test is calibrated and correlated at different stress.

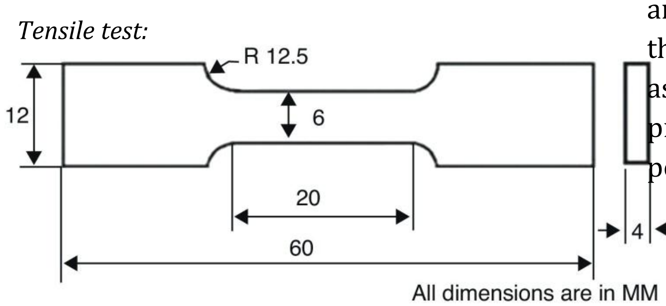

Fig. 6 Schematic of tensile specimen

ii. Fatigue test

The Fatigue test is carried out in servo-hydraulic MTS testing machine. The specimen dimension is taken according to the ASTM standard E466 as shown in fig. 7. The weld is kept at a perpendicular to load direction in the S-N tests. Maximum stress level is chosen as a function of yield stress for each type of joint. Also, the stress ratio and no. of cycles to failure are decided for the test. Then the specimens are tested on the machine with the input. The S-N fatigue curve is drawn with the data.

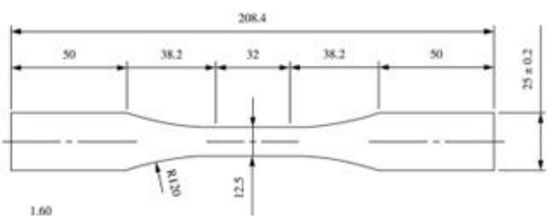

Fig. 7 Specimen of Fatigue test

iii. Hardness test

Hardness test of the weld material is carried out by Brinell hardness testing machine. The weld material is placed over the anvil, which can be adjusted by elevating screw. The weld area is placed exactly below the indenter. The lever is pushed down so that indenter with pointed edge penetrates into the weld material and hardness is tested. The hardness at nugget zone generally harder than the TMAZ and HAZ zones of the weld material and an area located at the center of the weld, hardness reduces at TMAZ and HAZ zones, and rises sharply at the base plates[47]. The simulated temperature profiles and the kinetics of natural aging were correlated to predict the hardness profiles in the FSW plate. The predicted minimum hardness locations are consistent with the measured hardness profiles in that the hardness moves away from the weld centerline as the aging time increases. More interestingly, the predicted minimum hardness is located at a similar position of failure in cross-weld tensile samples.

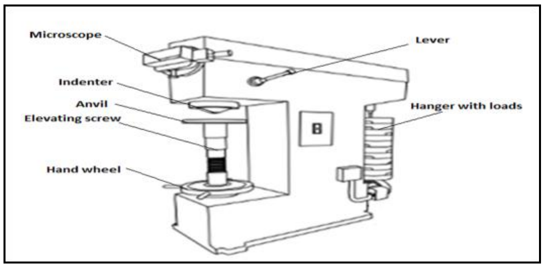

Fig.8: Brinell hardness Machine

10. Impact of Friction Stir Welding on Environment and Pollution

Friction Stir Welding is more environment-friendly compared to other conventional welding technique. FSW greater advantage as it has no arc, fumes or spotter while the procession of welding is done. It neither requires shielding gas to continue the operations nor does it require surface cleaning after the welding process. It eliminates grinding wastes. It can consume materials like rugs, wire, and any other gasses. It offers excellent physical and corrosion properties. Alloys of aluminum have produced an emission of microparticles during FSW due to tool wear. However, the research is in progress on biological relevance and toxic manifestations of the emitted microparticles from the tool. Studied have found that conventional welding technique has a higher incidence of respiratory illness in welders. There has been an estimation of about 10 million workers worldwide, who are currently employed as full-time welders. Also, the higher number of workers performs a welding intermittently as part of their job. The respiratory illness found are bronchitis, airway irritation, metal fume fever, chemical pneumonitis, lung infection changes, the incidence of lung cancer and small opacities on chest radiographs of asymptomatic welders. Sustainability and green construction continue to gain ground as being considered necessary advancements in steel construction, so knowledge on construction techniques such as FSW that have reduced environmental impact will be beneficial to the industry as a whole.

No large traces of pollution have occurred due to FSW. In fact, it reduces noise pollution in the workspace as well. Also, there are no harmful emissions due to it. It requires only 2.5% of the energy needed for a laser weld. It has an advantage of decreasing fuel consumption in lightweight aircraft, automotive, and ship applications. Therefore FSW is also safe with no UV or electromagnetic radiation hazards.

11. Benefits of FSW:

The benefits of FSW are large in the field of the welding process. FSW does not require joint preparation between two plates only degreasing is needed. It offers the high quality of welding with increased tensile strength, outstanding fatigue properties and corrosion resistance from the oxidation and chemical action. It is an economical method of welding with low operation cost, which has no consumable with less energy cost unlike consumption of electrode in arc welding process. Friction stir welding has no post heat treatment with low distortion and shrinkage of material [29].

FSW is one of the most environment-friendly compared to arc welding (or) gas welding, which has no arc, fumes or spotter during the procession. It neither requires shielding gas to continue the operations nor does it require surface cleaning after the welding process. It eliminates grinding wastes. It can consume materials like rugs, wire, and any other gasses.

The metallurgical benefits of friction stir welding are that this process is carried over solid phase. It has low distortion of the workpiece under external stress during machining. This welding is the constraint to the specified path, which gives good dimensional stability and repeatability with fine microstructure. There is no loss of alloying elements. There is absence of cracking due to hardenability of the material

The energy benefits of friction stir welding are as follows; the improved materials use (e.g., joining of different thickness) allows the reduction in weight. It has decreased fuel consumption in lightweight aircraft automation and ship applications.

12. Applications:

I. Aerospace

One of the first implementations of FSW was in the aerospace industries in the year 1998, when NASA began the process for use on the space shuttle external tank(ET).The repeatability and reliability of FSW, coupled with its ability to join lightweight alloys, makes the process efficient in the aerospace application. The technical maturation of this process for aerospace production at Marshall Space Flight Centre led to several noteworthy developments among them the implementation of a retractable pin tool(RPT) and friction stir plug welding[30].The development of non-destructive evaluation(NDE) techniques for FSW was also driven by the process's use on space vehicles[30,32].

In recent years, private aerospace companies have adopted the technology for their space applications.FSW is also rapidly gaining acceptance as a rivet replacement technology in the manufacture of aviation structure[33,34].In addition to weight savings, the use of FSW leads to a reduction in parts, reduced cycle times, greater joint strength, and lower manufacturing costs. In the private aviation sector, Eclipse Aerospace, developed an FSW process to join its 500 VLJ finding that FSW enabled joining speeds six times faster than automated riveting and 60 times faster than manual riveting[31,35].The Eclipse 500 has a total of 263 friction stir welds that total 136m in length and replace 7378 conventional fasteners. The fatigue life of the FSW joints equals or exceeds the fatigue life of the FSW joints equals or exceeds the fatigue life of comparable riveted joints, easily exceeding the eight-lifetime cycle requirement[31,35]

Many commercial aerospace manufacturers have also implemented the use of FSW has replaced rivets on longitudinal fuselage skin joints and wingspans for the A340, A350 and A380 aircraft[36].

II. *Automotive*:

FSW as well as variants like FSSW. The earliest investigation into applying FSW to automotive manufacturing FSW is also widely implemented a method of joining in the automotive industry. FSW implies to both conventional began in 1998 when TWI partnered with many of the automotive industries to explore FSW concepts applied to aluminium tailored blanks for door panels, drive shafts, and space frames[37].Since then, a lot of progress have been made, and, and FSW is now being used to manufacture automobiles and aftermarket components worldwide.

Several manufacturers have applied FSW to the joining of the center tunnel and floor structures. The fuel tank is housed in the central tunnel, a location that was found to be optimum based on reducing risk in collisions and maintaining weight distribution and center of gravity at different fuel levels[38].The use FSW also led to the improved dimensional accuracy of the assembly and an increase in strength of 30% when compared to fusion welded assemblies[38].The application of FSW to the center tunneled to a reduction in parts, an elimination of post-welding network, and economical.

Perhaps the latest application of FSW in the automotive industry is in the manufacture of a lightweight engine cradle for the 2013 Honda Accord. The cradle is a dissimilar aluminium and steel subframe assembly joined with continues FSW lap welds. Additionally utilizing of FSW has dropped electricity consumption by 50% and redesign of subframe and suspension mounting point was enabled, resulting in 20%greater rigidity and improved dynamic performance.

III. Maritime:

FSW has been utilized in maritime applications as well. In current Navy applications, FSW is used as a replacement for conventional gas metal arc welding(GMAW).Current applications are in material joining(friction stir welding), forming(friction stir processing and forming) and materials processing(friction stir processing) operations are being investigated for applications on future vessels. This process is prominent because of its low heat input about the arc welding process. An advantage of reduced heat input is the reduced dimensional distortion and residual stress which is induced in the part or component by the Process[39,40-48]. Using FSW, fabrications can provide large components for Navy vessel construction which have a reduced dimensional distortion, a reduced requirement for straightening operations post-process, and a reduced need for distortion mitigation techniques in sub-assembly and assembly(e.g. clamping, fixturing, flame straightening).This results in a reduction of total cost in manufacturing of component without the reduction in quality.

13. Future Research Of Friction Stir Welding

Future research will continue to advance the science of FSW, deepening the understanding of the complex physical interactions which underlie a process that emerged first as a technology. One area of much interest recently is thermal management, which is being attempted with both thermal boundary condition modification and closed-loop temperature control. Recent applications of FSW that have been reported span a range of areas. These include the welding of spacecraft cryogenic fuel tanks, military vehicles, rolling stock, and cold plates for thermal management in high power electronic devices (refer the proceedings of the 9th international symposium on FSW, TWI, CAMBRIDGE, UK, MAY 2012).It is the potential for these types of innovations that will continue to drive manufacturers to implement FSW and continue the future research.

Conclusion:

In the study of FSW, it is a process that can be applied for joining components of two similar or dissimilar components with properly placed on a fixture and correctly selected welding parameters making it possible to obtain good quality joints – without any defects and of the required mechanical properties. The process parameters selected are mainly Tool rotational speed, Welding speed, tool tilt angle, plunge depth, etc. Numerous factors must be considered for designing the tool of friction stir welding because the tool has a significant load, designers must pay attention to material, surface quality and geometry of tools. There is a growing demand for weld materials with high melting temperature, high strength, and hardening, and the key is the tool design and the tool itself. Further research areas that will continue to expand the applications of FSW to a wider range of engineering materials, advancing control techniques for continues welding and developing novel FSW variants. Hence we can conclude that FSW is the economical and environment friendly welding process for the industrial applications.

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