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REVIEW ON FRICTION STIR WELDING

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ABSTRACT: *Friction stir welding is an important new non-fusion technique for joining sheet and plate material. A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped workpieces, until the shoulder, which has a larger diameter than the pin, touches the surface of the workpieces. Friction between the rotating tool and the plate material generates heat, and the high normal pressure from the tool causes a plasticized zone to form around the probe. The solid-state nature of FSW leads to several advantages over fusion welding methods, as problems associated with cooling from the liquid phase are avoided. Issues such as porosity, solute redistribution, solidification cracking and liquation cracking do not arise during FSW.*

Keywords: Welding, FSW

1. INTRODUCTION:

Friction stir welding is an important new non-fusion technique for joining sheet and plate material. FSW was invented by Thomos Wanyne in 1991, and is a TWI licensed technology. The basic form of the process uses a cylindrical (non-consumable) tool, consisting of a flat circular shoulder, with a smaller probe protruding from its centre. The tool is rotated and plunged into the joint line (between two rigidly clamped plates) so that the shoulder sits on the plate surface and the workpiece, as shown in Fig.1.1

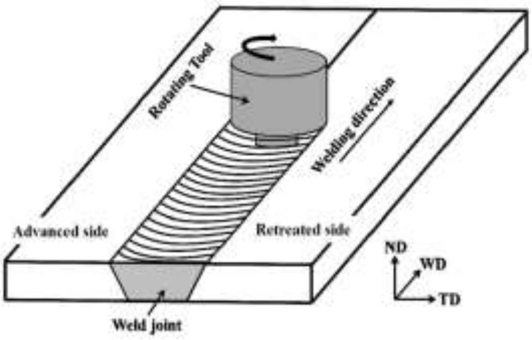

Fig1: Friction Stir Welding [1]

Friction between the rotating tool and the plate material generates heat, and the high normal pressure from the tool causes a plasticized zone to form around the probe. The tool is then traversed, frictionally heating and plasticizing new material as it moves along the joint line. As the tool traverses, the probe stirs the locally plasticized area and forms a solid-phase joint. [1]

2. LITERATURE REVIEW:

Gianluca Buffa, etal. conducted a study to predict the Mechanical and microstructural properties by artificial neural networks in FSW processes of dual phase titanium alloys. An artificial neural network was properly trained and linked to an existing 3D FEM model for the FSW of Ti–6Al–4V titanium alloy, with the aim to predict both the micro hardness values and the microstructure of the welded butt joints by varying main process parameters. A good agreement was found between experimental values and calculated results.[12]

ZhongweiMaa, Yueetal conducted a study to check the Fatigue properties of Ti-6Al-4V alloy friction stir welding joint obtained under rapid cooling condition. Friction stir welding joints of Ti-6Al-4V titanium alloy were obtained under air and rapid cooling conditions. After post welding heat treatment, the low-cycle fatigue properties of the joints were manly investigated.. The microstructures and mechanical properties of Ti-6Al-4V titanium alloy FSW joints under air and rapid cooling conditions were investigated .The effect of the rapid cooling on fatigue properties of joint has been mainly evaluated and the following conclusions can be drawn.[13]

Jian Wang, Xin Linetal conducted a study to check the Grain morphology evolution and texture characterization of wire and arc additive manufactured Ti-6Al-4V.In this study, four straight walls of Ti-6Al-4V titanium alloy were fabricated by wire and arc additive manufacturing to investigate the effect of deposition parameters on grain morphology evolution and texture characterization in the building direction. the preferred crystallographic orientations along the building direction formed gradually during the deposition process to a strong fiber texture in the building direction. In addition, there were also some equiaxed β grains at the top surface of the wall due to the occurrence of the columnar to equiaxed grain transition (CET) in the molten pool.[14]

A.F. Hasan, etal experimented on 3D-CFD model of the FSW process to compare the strain rate distribution. A validation process was carried out in this study in order to obtain robust results when using the model. Unstructured grids were also utilized to produce the best mesh quality for CFD modeling of the FSW process. The defect-free joint with the smooth surface finishing was acquired based on the stationary shoulder and the tapered thread pin with the triple facets. to the macro/micro-mechanical interlocking, the chemical bond and the partial infiltration of the carbon fiber into the Al alloy.[15]

Kapil Gangwar etal through a study highlighted that titanium is supreme when it comes to the higher strength to weight ratio, and higher corrosive resistance. Next generation of jet engines for aerospace industry clearly depends on the manufacturability and improved ability of titanium alloys that can withstand the high temperatures. However, the primary sheets, plates, billets, ingots, or rods are of limited sizes that need to be either machined or welded in order to produce a desired structure with optimal ratio. Through this study they summarized the research in the field of joining of titanium sheets with a direct focus on friction stir welding (FSW). The study potrayed the FSW of similar and dissimilar titanium alloys focusing on surface, and subsurface properties, such as microstructural, and mechanical properties, texture evolution.[16]

Farias et al. researched on the application of friction stir welding of titanium alloy Ti–6Al–4V., a major problem to overcome was the construction of tools that can withstand the extreme process environment. The possibilities approached were only few tungsten alloys. Early experiments with tools made of cemented carbide showed optimistic results. The metallographic analysis of the welds did not show primary defects of voids or similar internal defects due to processing, only defects related to tool wear which can cause loss of weld quality. The severe tool wear caused loss of surface quality and inclusions of fragments inside the joining, which was corrected or mitigated by means of coating techniques on tool, and by replacing cemented carbide with tungsten alloys.[17]

Aiping Wu et al. made dissimilar joints of Titanium alloy Ti6Al4V and Aluminum alloy 6061 with friction stir welding (FSW) method. The effects of welding parameters, including the stir pin position, the rotating rate and the travel speed of the tool, on the interface and the properties of the joints were investigated. The macrostructure of the joints and the fracture surfaces of the tensile test were observed with optical microscope and scanning electron microscope (SEM). The interface reaction layer was investigated with transmission electron microscopy (TEM). The factors affecting the mechanical properties of the joints were discussed. The results indicated that the tensile strength of the joints and the fracture location are mainly dependent on the rotating rate, and the interface and intermetallic compound (IMC) layer are the governing factor. [18]

Jian Wang etal. Conducted a study in which four straight walls of Ti6Al4Vtitanium alloy were fabricated by wireand arc additive manufacturing (WAAM) to investigate the effect of deposition parameters on grain morphology evolution and texture characterization in the building direction. A certain volume fraction of equiaxed β grain appeared at the bottom of the wall and can be controlled by deposition parameters, while the columnar β grain zone was on the equiaxed β grain zone. It is indicated that the formation of equiaxed β grains at the bottom of the wall initiated from the recrystallization. There were the large residual stress, strain, and high heating rate when depositing the first several layers near the substrate, which can induce the recrystallization of the already-deposited layers. However,the preferred crystallographic orientations along the building direction formed gradually during the deposition process, then the β grains began to grow epitaxially from the already-deposited layers, and changed to columnar β grains, which lead to a strong fiber texture in the building direction. In addition, there are also some equiaxed β grains at the top surface of the wall due to the occurrence of the columnar to equiaxed grain transition (CET) in the molten pool.[19]

Anthony R. McAndrew etal. researched regarding Linear Friction Welding (LFW).Linear friction welding (LFW) is a solid-state joining process that is an established technology for the fabrication of titanium alloy bladed disks in aero-engines. Owing to the economic benefits, LFW has been identified as a technology capable of manufacturing Ti-6Al-4V aircraft structural components. However, LFW of Ti-6Al-4V has seen limited industrial implementation outside of blisk manufacture, which is partly due to the knowledge and benefits of the process being widely unknown. By conducting this study they identified the ‘‘state-of-the-art”. First, the background, fundamentals, advantages and industrial applications of the process. through study they discussed the description of the microstructure, mechanical properties, flash morphology, interface contaminant removal, residual stresses and energy usage of Ti6Al4V linear friction welds.[20]

Hynes etal. Investigated on the effect of rotational speed on the quality of integrity of dissimilar Ti-6Al-4V/AA6061 joints. Effect of the most important process parameter, rotational speed on the mechanism of bonding at the interface was investi-gated by observing changes in microstructure of the welded specimen. It was observed that increase in rotational speed raises frictional heating at the interface and leads to dynamic recrystallization with recovery of recrystallized equiaxed grains which is highly favourable for enhancing joint strength. Increase in micro hardness at the weld line of the joint interface attributed to the formation of intermixed zone compound, which is brittle in nature. The rotational speed caused the formation of Ti3Al, TiAl at the joint interface. Experimental results of mechanical testing such as tensile strength and impact strength reveal that enhanced joint strength were achieved with 1000 rpm as rotational speed.[21]

A .F. Hasanetal. generated a validate model of the FSW process using the CFD software And was used to assess the detail of the differences in the flow behavior, mechanically affected zone (MAZ) size and strain rate distribution around the tool for both unworn and worn tool geometries. Comparisons were made at two different tool rotational speeds using a single weld traverse speed. The result showed that there were significant differences in the flow behaviour around and under the tool when the tool is worn. This modelling approach can therefore be used to improve understanding of the effective limits of tool life for welding, with a specific outcome of being able to predict and interpret the behavior when using specific weld parameters and component geometry.[22]

Kapil Gangwar1 etal. Conducted a study of joining of titanium sheets with Friction Stir Welding (FSW). Review of FSW of similar and dissimilar titanium alloys focusing on surface, and subsurface properties, such as micro structural, and mechanical properties, texture evolution, current challenges wasdone.summarizing a possible remedy for the recent development and research in the field.[23]

Fariasa,n, etal.conducted a study regarding the application of friction stir welding (FWS) of titanium alloy Ti6Al4V .Friction stir welding is a recent process and is being increasingly applied in many industries from basic materials, such as steel alloys, to high performance alloys, such as titanium. It is a processing great development and has its economic advantages when compared to conventional welding. For high performance alloys such as titanium, a major problem to overcome is the construction of tools that can with stand the extreme process environment. The metallographic analysis of the welds was done and it didn't show primary defects of voids (tunneling) or similar internal defects due to processing, only defects related to tool wear which can cause loss of weld quality. The severe tool wear caused loss of surface quality and inclusions off ragments inside the joining, which was corrected by means of coating techniques on tool, or the replacement of cemented carbide with tungsten alloys. [24

LivanFratinietal. Conducted a study to generate a cost savings and a time efficient design , an artificial neural network was properly trained and linked to an existing 3D FEM model for the FSW of Ti–6Al–4V titanium alloy, with the aim to predict both the microhardness values and the microstructure of the welded butt joints at the varying of the main process parameters. A good agreementwas found between experimental values and calculated results.[25]

Chunjie Huang etal.conducted a study regarding manufacturing of alloy by Selective Laser Melting (SLM) which adversely impacted the component performance in practical applications. A local post-treatment by Friction Stir Processing (FSP) was done which significantly reduced the porosity and homogeneity of the microstructure. This resulted in an increase in fracture strain from 0.21 after SLM to 0.65 following the FSP post-treatment. The porosity reduction was evidenced by 3D X-ray micro-computed tomography. A fully transformed β microstructure was formed after FSP. This microstructure involved α plates, α colonies, as well as equiaxed dynamically recrystallized α phases inside equiaxed prior-β grains. The deformed microstructure was observed during in-situ tensile test, using scanning electron microscopy, with the aim to unravel the damage mechanisms. In addition to the beneficial effect of initial porosity reduction, the transformed microstructure after FSP bears more damage before failure than the typical α' martensite laths in the as-built SLM samples.[26]

Shuhan Li1 etal. did evaluation regarding fabrication of defect-free butt welds of titanium alloy/steel viafriction stir welding. Joints were produced by employing rotation speed varied at 600 and 950 rpm with a constant travel speed of 47.5 mm/min. An increasing of rotation speed lead to thicken the nintermetallic compound layer, coarsen the grain size and thus decrease the joint micro hardness. Because of solid-state joining process, only a thin FeTi layer was formed at the interface even rotation speed increased to 950 rpm. As a result, all obtained joints fractured at the base steel material. The workcarried out clearly showed the good weldability of titanium alloy to steel via friction stir welding.[27]

Mingrun Yu etal. Conducted a study regarding production of Al/Ti lap joints under various welding conditions using FSW. More heat was generated when rotational rate increased or traversing rate decreased. Two types of Al/Ti interfaces – mixed interface and diffusive interface were formed under different welding conditions. The diffusive interface was formed with low heat input, and the mixed interface was formed more heat. The grains at the mixed interface were larger than those at the diffusive interface because of the higher heat input. Moreover, the microstructure of the mixed interface had a lower texture intensity compared with that of the diffusive interface, which was attributed to the enhanced continuous dynamic recrystallization (CDRX). TiAl3 was formed at the diffusive interface. When the interface was varied to the mixed interface as heat input increased, TiAl was fomed within the Al/Ti mixture following the formation of TiAl3. In addition, TiAl3 precipitates were observed in the diffusion layer. The hardness value of the mixed interface was higher than 350 HV, due to the larger amount of intermetallic compounds (IMCs). The lap shear strength reached a maximum value of 147 MPa with medium heat input and an interface that exits in a critical state between diffusive and mixed interfaces. All the specimens fractured at the interface, which was attributed to the presence of IMCs. [28]

ShuhanLiaetal.conducted study regarding linear friction stir welding. Linear friction stir butt-welding was used to join 2mm thick sheets of titanium alloy, Ti6Al4V to medium carbon steel, 30CrMnSiNi2A.Defect-free butt-welded joints were produced using travel speeds from 47.5–75 mm/min with a constant tool rotation speed of 750 RPM. With increasing travel speed, the thickness of the interfacial reaction layer gradually decreases. FeTi intermetallic compound was detected at the interface by micro-XRD testing. An optimal interfacial reaction layer approximately 1 μm thick was formed in the weld made at a travel speed of 75 mm/min. A reaction layer ranging from ~5 to 60μm thick was found at the interface with a travel speed of 47.5 mm/min. Such thick reaction layer is in contrast with the thinner layer formed in friction stir lap welds, which is believed to be related to the relatively higher welding temperature of friction stir butt welds. Welds formed at travel speeds ranging from 47.5–75 mm/min exhibit higher tensile strengths than the steel base material and were found to fracture from thermo-mechanically affected zone to heat affected zone on steel side or at the interfacial reaction layer on Ti-side. [29]

ZhongweiMaaetal. Conducted studies to obtain fatigue properties of Ti-6Al-4V titanium alloy under rapid cooling Friction stir welding joints of Ti-6Al-4V titanium alloy were obtained under air and rapid cooling conditions. After post welding heat treatment, the low-cycle fatigue properties of the joints were manly investigated. The results showed that the application of liquid nitrogen on the joint top surface decreases the peak welding temperature and the temperature gradient along the joint thickness, which resulted in a finer and more homogeneous microstructure. Consequently, the improved tensile properties and microhardness were obtained. [30]

Y.S. Satoetal briefly reviewed the current understanding and development of friction-stir welding and processing of Ti-6Al-4V alloy. The critical issues of theseprocesses were addressed, incl1uding welding tool materials and design, tool wear, processing temperature, material flow, processing window and residual stresses. A particular emphasis was given to microstructural aspects and microstructure-properties relationship. Potential engineering applications were highlighted.[31]

3. GAPS IN LITERATURE:

In reference to above studies we came to know that, there is not much work done in the field of Friction Stir Welding of Titanium 6Al 4V.Though we came across a few studies which are done on conventional machines but till date there is no work published in the field of FSW of Titanium 6Al 4V with the help of VMC. As we know that we can vary various parameters and configurations in VMC moreover it is very much economical as compared to other conventional or non conventional machines. That's why we decided to perform FSW with the help of VMC.

4. PRINCIPLE OF OPERATION:

A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped workpieces, until the shoulder, which has a larger diameter than the pin, touches the surface of the workpieces. The probe is slightly shorter than the weld depth required, with the tool shouldering at top of the work surface. After a short dwell time, the tool is moved forward along the joint line at the pre-set welding speed. [2]

Frictional heat is generated between the wear-resistant tool and the work pieces. This heat, along with that generated by the mechanical mixing process and the adiabatic heat within the material, cause the stirred materials to soften without melting. As the tool is moved forward, a special profile on the probe forces plasticized material from the leading face to the rear, where the high forces assist in a forged consolidation of the weld. [3]

This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in severe solid-state deformation involving dynamic recrystallization of the base metal.

5. ADVANTAGES AND LIMITATIONS:

The solid-state nature of FSW leads to several advantages over fusion welding methods, as problems associated with cooling from the liquid phase are avoided. Issues such as porosity, solute redistribution, solidification cracking and liquation cracking do not arise during FSW. In general, FSW has been found to produce a low concentration of defects and is very tolerant to variations in parameters and materials. [4]

Never the less, FSW is associated with a number of unique defects if it isn't done properly. Insufficient weld temperatures, due to low rotational speeds or high traverse speeds, for example, mean that the weld material is unable to accommodate the extensive deformation during welding. This may result in long, tunnel-like defects running along the weld, which may occur on the surface or subsurface. Low temperatures may also limit the forging action of the tool and so reduce the continuity of the bond between the material from each side of the weld. The light contact between the material has given rise to the name "kissing bond". This defect is particularly worrying, since it is very difficult to detect using nondestructive methods such as X-ray or ultrasonic testing. If the pin is not long enough or the tool rises out of the plate, then the interface at the bottom of the weld may not be disrupted and forged by the tool, resulting in a lack-of-penetration defect. This is essentially a notch in the material, which can be a potential source of fatigue cracks. [5]

A number of potential advantages of FSW over conventional fusion-welding processes have been identified:

Good mechanical properties in the as-welded condition.

1. Improved safety due to the absence of toxic fumes or the spatter of molten material.
2. Easily automated on simple milling machines — lower setup costs and less training.
3. Can operate in all positions (horizontal, vertical, etc.), as there is no weld pool.
4. Generally good weld appearance and minimal thickness under/over-matching, thus reducing the need for expensive machining after welding.
5. Can use thinner materials with same joint strength.
6. Low environmental impact.
7. General performance and cost benefits from switching from fusion to friction.[5]

6. APPLICATION:

The FSW process has initially been patented by TWI in most industrialised countries and licensed for over 183 users. Friction stir welding and its variants – friction stir spot welding and friction stir processing – are used for the following industrial applications: shipbuilding and offshore,[6] aerospace[7], automotive[8] ,railways[9], general fabrication, robotics [10], and computers.

6.1 Shipbuilding and offshore

One of the application of FSW is in Shipbuilding and off shore applications to make ship hulls[6]

6.2 Aerospace

The process is also used for the Space Shuttle external tank, for commercially produced aircraft parts, Floor panels for Airbus military aircraft Embracer uses FSW for Automation uses friction stir welding for gantry production machines developed for the aerospace sector, as well as other industrial applications.[7]

6.3 Automotive

Aluminum engine cradles and suspension struts are the automotive part that exploits the FSW process. FSW is applied to suspension struts for joining of aluminum sheets .Friction stir spot welding is used for the bonnet (hood) and rear doors of vehicles. Wheels are friction stir welded, Rear seats for Volvo are friction stir welded at Sapa, HVAC pistons at Halla Climate Control and exhaust gas recirculation coolers at Pierburg. Tailor welded blanks are friction stir welded for the Audi R8 at Riftec The B-column of the Audi R8 Spider is friction stir welded from two extrusions at Hammerer Aluminium Industries in Austria.[8]

6.4 Railways

Roof panels are made from aluminium extrusions using FSW machine, e.g. for DSB class SA-SD trains of Alstom LHB. Curved side and roof of rails are formed by Fsw. Innovative FSW floor panels are made by Hammerer Aluminium Industries in Austria for the Stadler KISS double decker rail cars, to obtain an internal height of both floors and for the new car bodies of the Wuppertal Suspension Railway.[9]

6.5 Robotics

KUKA Robot Group has adapted its KR500-3MT heavy-duty robot for friction stir welding via the DeltaN FS tool. The system made its first public appearance at the EuroBLECH show in November 2012. [10]

6.6 Personal Computers

Apple applied friction stir welding on the 2012 iMac to effectively join the bottom to the back of the device.

7. CNC VERTICAL MACHINING CENTER:

CNC vertical machining centers (VMCs) remain machine shop staples. These milling machines have vertically oriented spindles that approach work pieces mounted on their table from above and commonly perform 2.5- or 3-axis machining operations. They are less costly than horizontal machining centers (HMCs), which makes them attractive to small job shops as well as larger machining operations. In addition, the performance of these machines has increased over the years, leveraging technologies such as high-speed spindles and advanced CNC capabilities (including conversational control programming). Ancillary equipment is also available to increase the flexibility and capability of these machines, including spindle speeders, angle heads, tool- and part-probes, quick-change work holding devices, and rotary indexers to enable four- or five-axis machining work. [11]

7.1 COMPONENTS OF VMC:

7.1.1 Precision Linear Axis

Precision class l.m. guideways on all the 3-axis with exceptional static and dynamic stiffness for better rapid rates and accuracy. Preloaded ballscrews on each axis which is directly coupled with axis motor by integrated bracket. Complete linear system has been protected from dirt and dust by flexible telescopic covers. Automatic lubrication system available to maintain to necessary areas of movement for better performance and long life of machine.

7.1.2 High Performance Spindle

The spindle of the machine is designed and manufactured in-house at jyoti. Life time greased angular contact bearings are used for higher stability during heavy cutting load conditions. These spindles are manufactured in dedicated dust free, temperature controlled assembly shop where spindles are extensively tested for various performance criteria.

7.1.3 Fast Auto Tool Changer Px

Series machines are equipped with side mounted drum type with twin arm automatic tool changer. Mounting location of atc assures maximum working area without interference. Faster tool changing time with less maintenance is key feature of this design

7.1.4 Coolant Nozzle for Cutting Tool

The coolant nozzle around periphery of spindle face facilitates the manual adjustment for proper positioning of the coolant on the job while machining. [11]

Fig 2: CNC Vertical Machining Center [11]

8. SELECTIONOF MATERIAL:

Selection of friction stir welding/processing (FSW/P) tool material is an important task as it determines the quality of the weld produced. The tool material selection depends on the tool material operational characteristics such as operational temperature, wear resistance and fracture toughness which therefore determine the type of materials which can be joined. [16]

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