REVIEW PAPER ON FRICTION STIR WELDING AND ITS VARIOUS PARAMETERS

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ABSTRACT

Friction Stir Welding is the sort of welding utilized as a strong state joining process for materials that are diverse amalgams of aluminium, magnesium and so forth and furthermore for hard materials like steels since it redirects the normal issues got in ordinary welding forms. The truth that joining of combinations could be typically confronted issues in numerous divisions that incorporates car, aviation, send building ventures, gadgets and so on where combination welding is unimaginable because of huge contrast in physical and compound properties of the segments to be joined. Troubles in traditional welding forms are porosity development, cementing breaking, and synthetic response may emerge amid welding of unique materials albeit sound welds might be acquired in some limited cases with uncommon guides to the joint structure and readiness, process elements and filler metals.

INTRODUCTION

FRICTION STIR WELDING (FSW) was envisioned in 1991 at The Welding Institute of the United Kingdom as a solid state material joining strategy and this was at first associated with aluminum mixes. The fundamental of contact mix welding working is essentially a non-consumable turning instrument with an exceptionally arranged stick and shoulder is installed into the bordering edges of two plates to be joined and thusly crossed along the joint line definitions for the gadget and workpiece as showed up in Fig.1. Most definitions are quite obvious, yet advancing and pulling back side definitions require a short elucidation. Advancing and pulling back side presentations require learning of the instrument turn and travel heading.

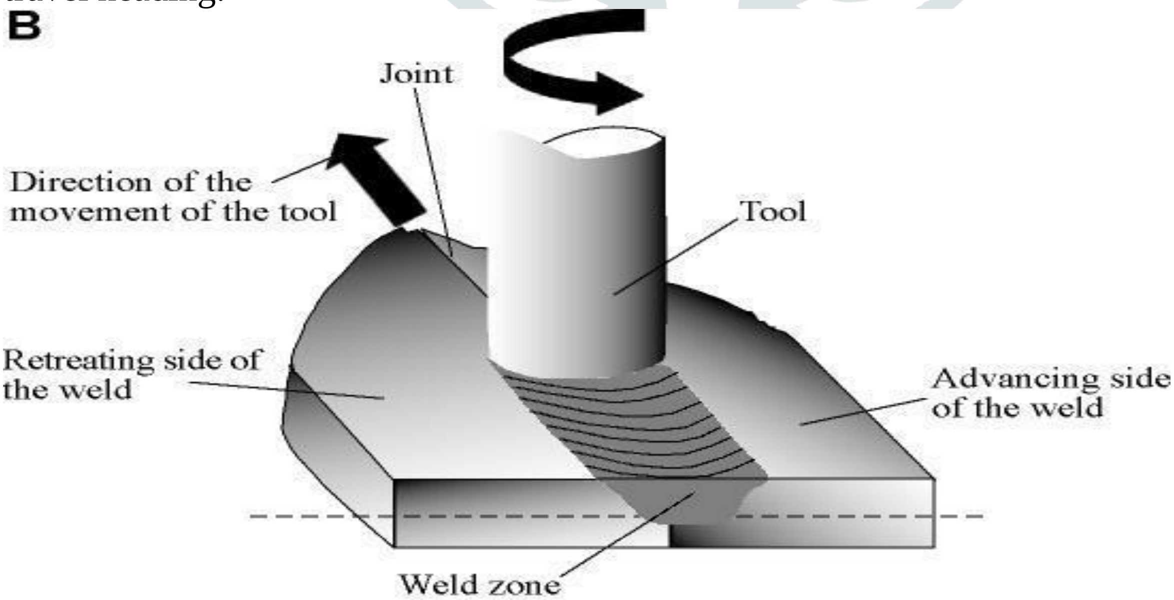

Fig.1 Frictions Stir Welding Process.

The factors which influence on the friction stir welding are as follows:

- Welding Speed
- Pressure on Tool (Down Force)
- Tilting Angle
- Rotational Speed
- Transverse Speed

Main and essential factor which effects in FSW process are:

- Mechanical Properties
- Temperature Distribution
- Tool Material
- Tool design
- Microstructure Development
- Workpiece Material

Materials for Welding

In the technique of friction stir welding, the material determination is a crucial bit from the base materials different confinements are sure similar to apparatus material, rotational speed, down power, translational speed. By utilizing FSW process fast and amazing welding of 2xxx and 7xxx arrangement of combinations, generally estimated un-weldable currently grow likely with this procedure. As far as high-temperature materials, FSW has been a fruitful of aluminium alloy and materials like.

- Copper (Cu) and its alloys
- Lead (Pb)
- Titanium (Ti) and its alloys
- Magnesium (Mg) alloys
- Zinc (Zn)
- Plastics
- Mild steel (M.S)
- Stainless steel (S.S)

2. MATERIAL FOR TOOL

A short time later the determination of base material additionally the crucial limitation in the FSW procedure is the choice of tool materials and state of hardware stick, bear. The apparatus delivers the thermo-mechanical distortion and workpiece frictional warming fundamental for friction welding. At the point when the down power is connected on apparatus then the instrument is presenting in the base materials. The friction stir tool contains a stick or test, and shoulder. Contact of the stick with the workpiece produces frictional and deformational warming and conservatives the workpiece material reaching the shoulder to the workpiece builds the workpiece warming, grows the zone of mollified material, and compels the twisted material.

2.1 Characteristics of material for tool

Choosing the right tool material requires knowing which material qualities are vital for every friction stir application. Various material attributes could be viewed as imperative to friction stir welding process.Wear Resistance, Coefficient of Thermal Expansion ,Ambient- and Elevated-Temperature Strength ,Elevated-Temperature Stability ,Tool Reactivity, Fracture Toughness ,Machinability ,Uniformity in Microstructure and Density ,Availability of Materials.

2.2 Materials

Apparatus materials booked for erosion blend welding and handling. The planned apparatus materials ought not be seen as a broad rundown, in light of the fact that numerous papers don't indicate the instrument material or right the device materials are restrictive.

1. Tool Steels

Apparatus steel is the most well-known device material utilized in FSW. This is on the grounds that a larger part of the distributed FSW writing is on aluminium composites, which are effectively rubbing mixed with instrument steels. The focal points to utilizing instrument steel as erosion mix tooling material incorporate simple accessibility and machinability, low cost, and established material characteristics.

2. Cobalt-Nickel Based Alloys

To have high quality, creep opposition, malleability, and consumption obstruction the high-temperature nickel and cobalt base amalgams were created. These amalgams get their quality from encourages, so the utilization temperature must be kept underneath the precipitation temperature (normally 600 to 810 °C) to anticipate accelerate over maturing and disintegration.

3. Metal-Matrix Composites (MMCs) and Carbides

Carbides are normally utilized as machining instruments because of predominant wear obstruction and sensible crack sturdiness at encompassing temperatures. Since they are made for machining apparatuses, carbides perform well at raised temperatures. Grinding blending devices produced using tungsten carbide are accounted for to have smooth and uniform string surfaces for the FSW.

4. CBN and PCBN

Polycrystalline cubic boron nitride was used for the turning and machining of tool steels, cast irons, and super alloys

3. DESIGN OF TOOL

Heat generation rate, cross power, torque and the thermo mechanical condition experienced by the apparatus geometry. The stream of plasticized material in the work piece is influenced by the apparatus geometry just as the straight and rotational movement of the instrument. Imperative variables are bear width, bear surface edge, stick geometry including its shape and measure and the idea of hardware surfaces.

1. Diameter of shoulder

The breadth of the instrument bear is imperative on the grounds that the shoulder creates the vast majority of the warmth, and its grasp on the plasticized materials generally builds up the material stream field. Both sliding and staying produce heat where as material stream is caused just from staying. For a decent FSW practice, the material ought to be satisfactorily diminished for stream, the apparatus ought to have sufficient grasp on the plasticized material and the absolute torque and cross power ought not be unnecessary.

2. Shape for shoulder

The idea of the device bear surface is a vital part of hardware plan. The concentrated level, curved and inward instrument shoulders, and tube shaped, decreased, backwards decreased and triangular stick geometries. They found that triangular pins with curved shoulders brought about high quality spot welds. Inspected the job of geometric parameters of raised shoulder step winding (CS4) instruments and distinguished the sweep of arch of the device shoulder and pitch of the progression winding as essential geometric parameters. Shoulder Features the FSW instrument shoulders can likewise contain highlights to expand the measure of material distortion created by the shoulder, bringing about expanded work piece blending and higher-quality rubbing mix welds these highlights can comprise of parchments, edges or knurling, grooves, and concentric circles and can be machined on to any apparatus bear profile (sunken, level, and curved).

3. Geometry for tool-tip

The state of the device stick (or test) impacts the stream of plasticized material and influences weld properties. Welding apparatus configuration is basic in FSW.

Streamlining instrument geometry to create more warmth or accomplish increasingly effective "blending" offers two primary advantages: improved breaking and blending of the oxide layer and progressively proficient warmth age, yielding higher welding speeds and, obviously, upgraded quality.

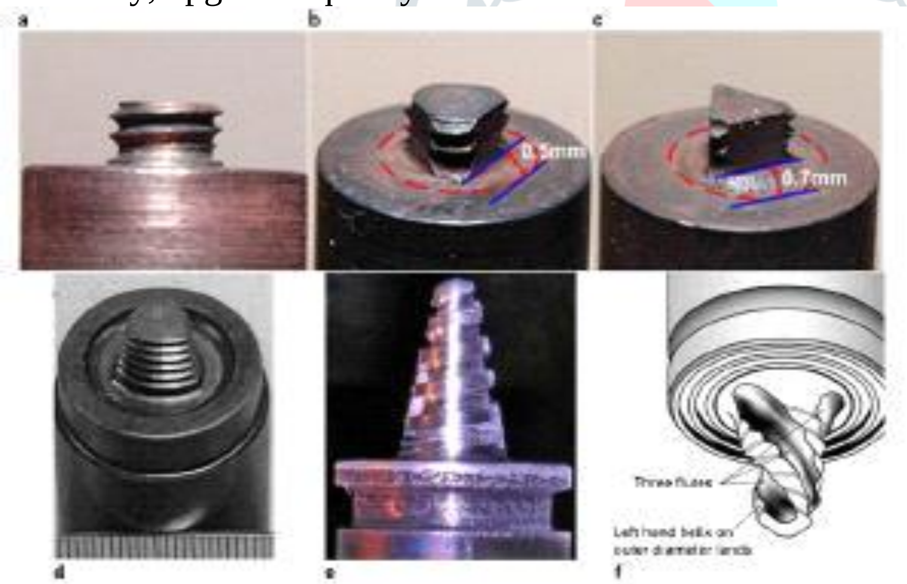

Fig.2- different shape of tool

4. Different Motions of Tool

The ongoing examination on FSW apparatus structure that builds the instrument travel speed, increment the volume of material cleared by stick to-stick volume proportion, and additionally expands the weld symmetry. A significant number of these instrument structures have concentrated on apparatus movement and not explicitly on the device stick plan, albeit each kind of complex movement can have an ideal device plan. Most unpredictable movement instruments require specific apparatus or exceptionally machined devices, making these devices inadmissible for fundamental applications.

1. Skew-Stir Tool
2. Com-Stir instruments
3. Dual-Rotation Tool
4. Re-Stir Tool

4. TEMPERATURE DISTRIBUTION

Warmth is produced by a blend of rubbing and plastic dispersal amid misshapening of the metal. The commanding warmth age system is affected by the weld parameters, warm conductivities of the work piece, stick apparatus and support blacksmith's iron, and the weld device geometry and furthermore rely upon the contact conditions between the two surfaces. The weld apparatus geometric highlights of both the stick and the shoulder impact whether the two surfaces slide, stick, or shift back and forth between the two modes.

For the Detailed temperature estimations with installed thermocouples (TCs) have been utilized to outline the temperature field Interpretation of these estimations is influenced by the coupled warm conductivity of the work piece, the sponsorship blacksmith's iron, and the weld device Depending on the TC area, inserted TCs near the pin tool are generally consumed in the weld process. The below Fig.3 shows the transverse section of a FSW welding process with zones on the material :

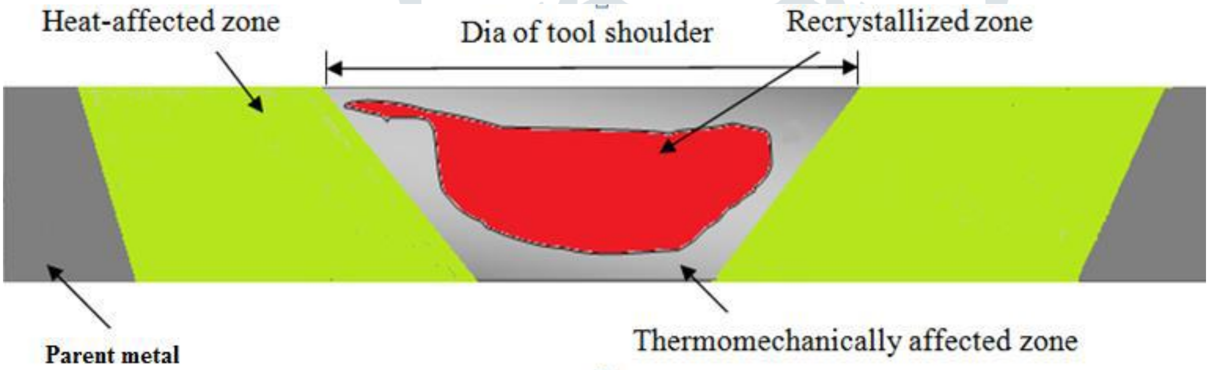

Fig.3- MICROSTRUCTURE OF THERMOMECHANICALLY AFFECTED ZONE

5. DEVELOPMENT OF MICROSTRUCTURE

The microstructure and resulting property conveyances created amid friction stir welding (FSW) of aluminium composites are subject to a few components. The contributing variables incorporate compound synthesis, composite temper, welding parameters, the gage of the welded plate, and other geometric elements. Amalgam piece decides the accessible fortifying systems and how the material will be influenced by the temperature and strain history related to FSW. The amalgam temper manages the beginning microstructure, which can importantly affect the combination reaction to FSW, especially in the warmth influenced zone (HAZ). Welding parameters (e.g., apparatus turn rate and welding speed) direct, for given instrument geometry and warm limit conditions, the temperature and strain history of the material being welded.

6. MECHANICAL PROPERTIES

It is currently realized that properties following FSW are an element of both controlled and uncontrolled factors just as outer limit conditions. For instance, agents have now delineated that post weld properties can be an element of:

1. Tool travel speed
2. Tool pivot rate
3. Tool tilt
4. Material thickness
5. Cooling rate
6. Heat sink
7. Surface oxides
8. Joint plan
9. Post weld heat
10. Tool plan

FSW is especially suitable for the welding of high quality combinations which are widely utilized in the aeroplane business. Mechanical affixing has for quite some time been favoured to join aviation structures since high quality aluminium composites are hard to join by regular combination welding systems (Pouget G. et al., 2007). Its primary trademark is to join material without achieving the combination temperature. It empowers to weld practically a wide range of aluminium compounds, even the one named non-weldable by combination welding because of hot breaking and poor hardening microstructure in the combination zone (Zimmer Sandra et al., 2009). FSW is viewed as the most noteworthy advancement in metal participating in 10 years and is a "green" innovation because of its vitality productivity, condition kind disposition, and adaptability. The key advantages of FSW are abridged in Table 1(Mishra R.S. et al., 2005).

FSW METHODOLOGY

The working standard of Friction Stir Welding process in which welding instrument included a shank, shoulder, and stick is fixed in a preparing machine heave and is turned about its longitudinal rotate. The work piece, with square mating edges, is fixed to a rigid help plate, and a snap or smithy's iron keeps the work piece from spreading or lifting in the midst of welding. The half-plate where the heading of upheaval is comparable to that of welding is known as the driving side, with the contrary side relegated like the pulling back side (Nandan R. et al., 2008). The transforming welding gadget is bit by bit infiltrate into the work piece until the shoulder of the welding gadget coercively contacts the upper surface of the material. By keeping the device turning and moving it along tahe wrinkle to be joined, the appeased material is really combined encircling a weld without dissolving (Rowe C.E.D. et al., 2005).The welding gadget is then pulled back, overall while the pole continues turning. After the mechanical assembly is pulled back, the stick of the welding gadget leaves an opening in the work piece close to the completion of the weld. These welds require low essentialness input and are without the usage of filler materials and mutilation.

literature review of fsw

Thomas [1996] concentrated on this investigation the generally new joining innovation, friction stir welding (FSW). friction stir welding could be utilized to join most aluminum compounds and surface oxide introduces no trouble to the procedure. Based on this investigation it was prescribe that number of lightweight materials reasonable for the car, rail, marine and aviation transportation enterprises can be created by FSW.

Lee et al (2003) made investigation dependent on the joint properties of unique cast A356 and fashioned AA6061 by changing the fixed area of materials. While doing the longitudinal elastic tests, and ingested that the blend zone quality for AA6061 is more noteworthy than A356 when put on the withdrawing side.

Peel et al (2003) use AA5083 aluminum composite for FSW by differing the welding conditions like device plan, pivot speed, and interpretation speed. The consequences of microstructural, mechanical property and leftover pressure examinations of four aluminum AA5083 uncovered that welding properties are impacted by the warm info as opposed to the mechanical distortion by the instrument.

R.S. Mishra and Z.Y. Maworks (2005) in this paper they worked fundamentally on the aluminum amalgam with some method parameters also gave the focal issues results that, the frameworks are accountable for the course of action of welds and microstructural refinement and moreover effect of methodology parameters on the microstructure of the base metals and joints. Similarly an incredible arrangement work had been done on the instrument structure parameters for FSW.

Lakshminarayanan and Balasubramanian (2008) applying Taguchi way to deal with decide the components influencing the elasticity of the joints of friction stir welded RDE-40 aluminum combination. Through this methodology, the ideal dimension of procedure parameters (instrument rotational speed, cross speed and hub constrain) is resolved. From the outcomes, it was discovered that the rigidity of the joint is generally affected by turning speed, welding speed and hub constrain.

Elangovan et al., [2009] developed a numerical model to predict unbending nature of the contact blend welded AA6061 aluminum composite by uniting FSW process parameters. Four factors, five dimensions central composite structure has been used to restrain number of test conditions. Response surface method (RSM) has been used to develop the model. The joints made using square stick profiled gadget with a rotational speed of 1200 rpm, welding pace of 1.25 mm/s what's increasingly, vital intensity of 7 kN indicated pervasive pliant properties diverged from various joints.

Yan and Reynolds (2009) contemplated the underlying temper impact of base metal (T7451, T62 and W) and furthermore examined the 4 mm thick AA7050 aluminum compound by differing process parameters alongside post weld heat treatment. The outcome which is to be gotten by beginning temper of the base metal increment the mechanical quality and furthermore extraordinary mechanical properties of 7075 aluminum compounds. Post weld maturing builds the joint quality and furthermore changes the break separation from warmth influenced zone to piece of weld.

Hassan et al (2010) examined the microstructure and mechanical qualities of disparate A319 and A356 cast Aluminum amalgams plates joined by utilizing FSW. He explored dependent on the impact of hardware rotational welding velocities and post-weld heat treatment. Post-weld heat treatment is done at a solutionizing temperature of 540°C for 12 hours pursued by maturing at 155°C for 6 hours. It is discovered that the hardness at the weld zone is found to increment by expanding the tool rotational speed or diminishing the welding speed. From their examination they closed saying that expanding in the instrument rotational speed, builds the pliability of the joint however its tractable and yield quality declines.

Acerra.F et al (2010) attempted to weld the blend of two disparate aluminum composite in T-design of AA7075-AA2024. he was to be locate that higher the shoulder distance across of hardware higher the warmth to be created by the FSW procedure on the weld zone. It was done to satisfy the producing necessity. Here and there covering clear components was acquired causes real deformity was investigated.

Da Silva et al (2011) considered progression of material, microstructural conduct, mechanical properties like malleable quality and hardness dependent on variety of procedure parameter and their impact on weld to be finished by friction stir welding joints of two different composites between AA2024-T3 also, AA7075-T6. Limit the between of base metal all around the mix zone was obviously seen just as no onion ring development to be watched.

Kumaran et al.(2011) In this examination different degrees of progress have been going on in the field of materials getting ready. rubbing mix welding is a basic solid state joining framework. In this investigation adventure, grating mix welding of cylinder to-tube plate using an outside instrument (FWTPET) has been performed, and the strategy parameters have been composed using Taguchi's L27 symmetrical group. Genetic figuring (GA) is used to propel the welding system parameters. The suitable criticalness of applying GA to FWTPET process has been endorsed by strategies for preparing the deviation among foreseen and likely procured welding process parameters.

Karthikeyan et al, [2011] led an investigation on connection between procedure parameters and mechanical properties of friction stir prepared AA6063-T6 aluminum composite with 200 mm X 50 mm X 10 mm as workpiece dimensions. The device utilized was HSS with round and hollow shoulder and right hand strung stick. Shoulder and stick distance across were 18 mm and 6 mm individually with 5.7 mm stick length, rotational speed of 800, 1000, 1400, 1600 rpm is taken for every one of 22.2, 40.2 and 75 mm/min device feed for every one of 8, 10 and 12 kN of pivotal power were weld parameters. They presumed that the weld had refined and homogenized grain structure in microstructure. The extraordinary mechanical properties can be got with feed of 40.2 mm/min, rotational speed in scope of 1200-1400 rpm and pivotal power of 10 kN. Imperfection free welds with great microstructure was gotten by these properties. The most extreme increment in UTS is 46.5%, malleability is 133%, smaller scale hardness is 33.4% of the parent metal. Examples in which welding is done at 8 kN feed rate yielded process deserts.

Singh et al (2011) talk about the effect of post weld heat treatment (T6) on the microstructure and mechanical properties of grating mix welding 7039 aluminum compound joints. FSW parameters were updated by making welds at the steady turning pace of 635 rpm and the welding rate of 8 and 12 mm/min. It was seen that the thermo-exactly impacted zone (TMAZ) show coarse grains than that of mix zone. The results revealed that PHWT cuts down the yield quality and outrageous flexibility anyway improves the rate prolongation of the joints.

Koilraj et al (2012) In improved FSW process as for the elasticity of the unique welds AA2219 and AA5083 utilizing five distinctive device profiles, for example, rotational speed, Transverse speed and D/d proportion where D= bear breadth and d= device stick width are the parameters considered for the examination.

R. Rai, A. De, H.K.D.H. Bhadeshia and T.DebRoyhad (2012) given the data about the achievability of the FSW for harder compounds, for example, titanium, steels and so forth. Likewise they clarified that the execution of the apparatuses are absolutely relies upon the determination of material and furthermore the structure of the procedure.

Y. N. Zhang, X. Cao, S. Larose and P. Wanjara, (2012) done the review of the tool friction stir welding and handling, in this survey the FSW/P devices are quickly abridged as far as the device types, shapes, measurements, materials and wear practices. Erosion blend preparing (FSP), a variation of FSW, has been created to produce composites, locally dispense with throwing deserts, refine microstructure and additionally improve the related mechanical and physical properties counting quality, flexibility, exhaustion, creep, formability and consumption resistance.

Rajakumar and Balasubramanian (2012) contemplated the erosion mix weld joint made by six unique sorts of aluminium amalgam in which out of these one of the two composites has a place with the 7xxx arrangement amalgam which was AA7075 also as AA7039. The examination of the microstructure was performed to acquire the scope of achievable procedure parameters around which the weld ought to be finished. Reaction surface system which has observational connection was utilized to get the ideal procedure parameters of welding to accomplish a most extreme conceivable quality.

Liu a (2013) In their examination, the 4 mm thick 6061-T6 aluminum alloy was self-reacting friction stir welding at a reliable instrument insurgency speed of 600 r/min. The remarkably arranged self-reacting instrument was portrayed by the two unmistakable shoulder widths. The effect of welding speed on microstructure and mechanical properties of the joints was analyzed. As the welding speed extended from 50 to 200 mm/min, the grain size of the mix piece zone extended, anyway the grain size of the glow impacted zone was about not changed. Assumed band structures from the driving side to the weld center were recognized in the mix piece zone. The strengthening meta-stable quickens were by and large decreased in the blend lump zone and the warm exactly impacted zone of the joints. In any case, great proportion of b0 stages, tending to reduce with growing welding speed, were held in the glow affected zone. The eventual outcomes of transverse pliable test exhibited that the expansion and pliable nature of joints extended with growing welding speed. The flaw free joints were gotten at lower welding speeds what's more, the bendable split was arranged at the glow affected zone adjoining the warm exactly impacted zone on the pushing side.

Manish P. Meshram et al. (2014) examined the welding parameters for joining 4mm thick Austenitic 316 treated steel plates and locate the best parameters. Plates of measurement (120mm x 80mm x 4mm) were utilized for try different things with PCBN device. Nine unique tests were led with various apparatus revolution velocities of 1100, 1000, 900rpm and welding pace of 8, 12, 16 mm/min. Each instrument pivot speed gives three welding speed given above. The examination finished up by an imperfection free weld with parameters of 1100rpm, and transverse speed of 8mm/min demonstrated the comparative elasticity that of the base material with 37% stretching while 49% extension of the base material.

Guo et al. (2014) coordinated a thorough preliminary examination of the effect of various FSW process parameters on material stream, microstructure, microhardness assignment and tractable properties of the one of a kind material joints including AA 6061 and AA 7075 aluminum mixes. The examination developed that the two aluminum mixes can be viably FSWed, and that the helper soundness and mechanical properties of the weld are truly sensitive components of the system parameters. Besides, it was shown that, in view of the as of late referenced asymmetry of the FSW joint, the course of action of a given amalgam on the advancing or pulling back side of the weld can altogether influence the material stream similarly as on the consequent weld microstructure and properties.

Bayazid et al.,[2015] showed up, the effect of rotational speed, travel speed and plates positions on quality of dissimilar 6063-7075 joint which was investigated by using Taguchi system and ANOVA examination. Delayed consequences of S/N examination demonstrates that the perfect condition for different 6063-7075 joint is cultivated when estimations of rotational speed, travel speed and plates' positions were 1600 rpm, 120 mm/min and AS-7075 independently. In such condition, unbending nature of joint was 143.59 MPa. The ANOVA examination demonstrated that feasibility of rotational speed, travel speed and plates' position parameters on versatility of joint were 59%, 30% and 7% independently.

Fu et al., [2015] performed FSW over unique 6061-T6aluminum composite to AZ31B magnesium mix using 800 rpm and 50 mm/min by H13 Quenched and Tempered to 50 HRC instrument. The setting of Mg on the driving side lead to removal of distortions and progressively homogeneous mixing. A little pit was seen when the gadget balance is zero in Mg-Al plan. In Mg-Al setup when the instrument was given counteracted Al the region betrays extended. Right when the gadget speed was changed (with gadget offset +0.3mm) from 600 to 800 rpm and cross speed was in the stretch out 30 to 60 mm/min, sound weld with no disfigurement is procured. The Energy Dispersive X-shaft examination of IMCs of model obtained at 700 rpm, 60 mm/min with Mg on AS and offset +0.3 mm revealed the closeness of the Al, Mg content, the assortment of substance suggested that layers of Al12Mg17& Al3Mg2 were accessible. Welding condition was impacted by two components heat information and measurement of warmth commitment to materials. The glow input was moved from turn rate and welding speed.

H. Mehdi, R.S. Mishra (2016) he studied intends to diagram the present taking a shot at friction stir welding with number of explicit issue including welding parameter, diverse aluminum alloy, full scale and microstructure, mechanical properties, tool wear and weariness assessment. friction stir welding have a potential advantages in cost decrease, joint proficiency improvement and high creation exactness make it progressively alluring for non weldable arrangement. The welding parameter, for example, navigate speed, apparatus pivot speed and hub constrain have a lot of warmth age and quality of rubbing blend welding joints.

Sharma et al. [2016] friction stir welding of round butt weld joint between Aluminum combination AA6061 and Magnesium combination AZ31 was examined and considered as AL 6061 and Mg AZ31 can be welded utilizing FSW by appropriate choice of hardware stick profile and welding parameters. Distinctive instrument plans and details influence the appearance just as properties of welded joint. As the apparatus rotational speed of 1200 rpm and welding pace of 10 mm/min were observed to be the most compelling parameters, influencing mechanical properties of roundabout butt weld joint somewhere in the range of AA6061 and AZ31 when welded by utilizing barrel shaped strung stick instrument of HCHCr material.

Akshay Sheoran et al. (2016) considered that The aluminum compound 6063 effectively welded by friction stir welding process the different mechanical properties like elasticity, smaller scale hardness and miniaturized scale structure were assessed. As the rotational speed of tool is expands the elasticity of the welded joint is additionally increments. what's more, the elasticity of the welded joint is higher when contrasted with the base metal. At the point when the feed rate builds the rigidity and smaller scale hardness of the weld joint is diminishes and it is additionally discovered that the elasticity and miniaturized scale hardness of the weld joint is lower when contrasted with the base metal when feed rate is increments. In this FSW procedure we explore miniaturized scale hardness by Vickers test and in this test we got normal hardness is 33Hv and we discovered that the hardness is more at FSW zone as contrast with the base metal.

8. CONCLUSIONS

FSW is the best method to welding of various combinations of aluminium for long lengths with an astounding quality. Impressive exertion is being made to weld higher temperature materials, for example, combinations of magnesium, titanium and steels by utilizing FSW. Take the procedure past its present utilization of primarily straightforward butt and lap joint arrangements and make it a considerably more adaptable manufacture process. In this literature survey we find the fact is that research has been observed to find the best procedure of machining parameters that gives best quality for welding of materials.We can conclude that process parameters of friction stir welding i.e. pin profile, rotating speed and translatory feed rate of tool, tool material, base material are higher influencing factors affecting on weld quality.In the literature review, it can be observed that friction stir welding process has been successfully applied for joining similar as well as dissimilar materials. Different optimisation techniques can be used to optimise welding process parameters.We can conclude that preheating of material can improve the quality of weld.The distinctive sorts of hardware are utilized for the welding according to base materials producing temperature. Friction stir welding attributable to its interesting qualities: low mutilation and shrinkage even in long welds, free of bend, filler metal, and protecting gas, low HAZ, free of splash and porosity imperfection is rising as an option in contrast to combination welding.

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