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A REVIEW ON PROCESS PARAMETERS AND THEIR EFFECT ON MECHANICAL PROPERTIES OF SIMILAR AND DISSIMILAR FRICTION STIR WELDED JOINTS

Mohit Saini[1], Ashish Goyal[2], Manjeet Bohat[3],Ravinder Chalia[4]

M.Tech Scholar, Mechanical deptt., UIET /Kurukshetra university, Kurukshetra, Haryana, India, mohitsaini8448@gmail.com [1]

M.Tech Scholar, Mechanical deptt., UIET /Kurukshetra university, Kurukshetra, Haryana, India, ashishgoyal016@gmail.com[2]

Assistant Professor, Mechanical deptt., UIET /Kurukshetra university, Kurukshetra, Haryana, msbohat2015@kuk.ac.in [3]

Assistant Professor, Mechanical deptt., UIET /Kurukshetra university, Kurukshetra, Haryana, India, ravinder_chalia@rediffmail.com [4]

Abstract: **TWI in 1991 came up with FSW, a new revolution in the field of welding for joining materials. It is a solid state welding process which can also weld light and soft materials (like Al, Mg etc.) which are nearly impossible to weld with conventional fusion welding process. Butt, lap, fillet, T and hollow work pieces like pipes tanks etc. can be welded by FSW. In this review different input process parameters and their effect on mechanical properties are studied and concluded that different process parameters (welding speed, tool rotation speed, tilt angle, plunge depth, tool shape etc.) affect the mechanical properties and microstructure of joint made by FSW. FS welded material shows high strength and hardness then fusion welded material. Advantages, disadvantages, application and future scope are also discussed in this study.**

Keywords: Friction Stir Welding, Process Parameters, Tensile strength, Hardness, Microstructure

INTRODUCTION

Friction Stir Welding (FSW) is a solid state welding technique, originated in The Welding Institute of UK in 1991, in which similar and dissimilar materials can be welded without melting and without any change in chemical composition of material. It can be applied to weld light and soft materials which are very hard to weld using other traditional fusion welding methods due to their low melting temperatures. The material welded by FSW shows improved Mechanical properties such as ductility, Ultimate Tensile Strength (UTS) and hardness then the joint made by fusion welding.

Process: Friction Stir Welding consists of a non-consumable tool which should be harder than the material to be weld. FSW tool have a shoulder and a pin. The shoulder diameter is larger than the diameter of the pin. During joining process (welding), the rotating tool pressed against the work piece placed together in clamp. The pin is plunged into the plates and the shoulder just touches the surface of the work piece. The pin length is shorter than the thickness of the work piece. Now the rotating tool is traversed along the centerline of the two plates which are to be welded**.** The friction between work piece and rotating tool causes heat generation. The temperature is around 70-80% of the melting temperature of the work piece. Now as the tool moves forward it forces the material from leading side to the rear side, due to this force joint is produced**.** The tool has two side, one is advancing side (AS) and other is retreating side (RS). The side where tool rotation and tool feed direction is same is termed as Advancing side, and the side where tool rotation and tool feed direction is different is termed as Retreating side as shown in figure 1.

Process parameters: The quality of Friction Stir Welded material can be influenced by the number of process parameters. The process parameters are:-

1. Tool geometry
2. Tool material
3. Tool rotation & traverse speed
4. Tool tilt angle
5. Tool plunge depth

6. Tool offset
7. Axial force
8. Advancing and retreating side

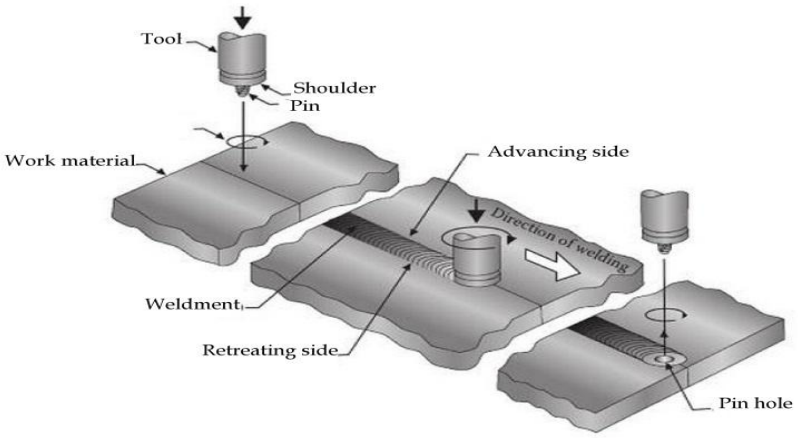

Figure 1 Friction Stir Welding process

Advantages of FSW

FSW have advantages as follows:-

1. FSW can weld materials which are hard to join by traditional fusion welding (Ex. 2XXX & 7XXX aluminium alloy).
2. Shrinkage of material welded by FSW is very less.
3. Tool used in FSW is non-consumable, so having very long life.
4. No filler material is used in process.
5. More safety due to absence of toxic fumes & material spatters.
6. Environmental friendly.
7.

Disadvantaged of FSW

FSW have disadvantages as follows:-

1. When welding is completed a hole is left when tool is removed.
2. More down forces required.
3. Slow welding speed then other welding methods.
4. Less flexible process then manual welding.

Applications of FSW

The FSW have application in:-

1. Aerospace
2. Automobile
3. Fabrication industry
4. Heat exchangers
5. Nuclear waste container
6. Railways
7. Robotics
8. Shipbuilding

Mechanical properties

The characteristics of material which describe its behavior under the action of applied external forces are called Mechanical properties. The investigation suggested that mechanical properties can be a function of process parameters like tool rotation speed, welding speed, material thickness, tool material, tool design, tool tilt angle etc. The mechanical properties of material which are influenced by FSW process parameter are:-

1. Ultimate tensile strength
2. Hardness
3. Fatigue
4. Elongation
5. Fracture toughness

LITERATURE SURVEY

P. Cavaliere, R.Nobile, F.W. Panella, A.squillace [2005] have compared the fatigue & UTS of joint made by FSW with the parent material i.e. 2024 & 7075AA. The sheets used were 2.5 mm thick. The tool traverse speed was set to 2.67mm/sec. The tool with 6mm nib dia 2.5 mm long & 20mm Shoulder dia. The tool was set at an angle of 3°. The hardness test was performed on Vickers indenter with 200gf load for 15s. The tensile test was performed on MTS 810 servo hyduallic machine with 100KN capacity & cross head speed was set to 0.1 mm/min. the experiment concluded that the UTS, Elongation & yield Strength of the joint of 2024 – 7075AA is lower than both the parent material. The value are as follow

	Sigma(MPa)	UTS	Elongation(%)
AA2024	380	490	17
AA7075	503	572	11
Joint	325	424	6

Thaiping Chen [2009] Investigated the mechanical properties of FSW Aluminum AA6061 – T651 & Steel pates SS400 plates of 6mm thickness. The work piece is taken 160mm* 40mm* 6mm. the input parameter are tool rotation speed (550 – 800rpm), transverse speed (0.9 – 1.5mm/s), tool tilt angle (1° – 3°) and tool pin dia. (6 – 8mm). The experiment concluded that the combination of 0.9mm/s transverse speed, 550rpm rotation speed have best impact and tensile strength value (225MPa).

Y.M. Hwang, P.L.Fan, C.H.Lin [2010] investigated the mechanical properties of C11000 copper welded by FSW. The plates were taken with 60mm length 20mm width and 3.1mm thickness. The tool was made of SKH9 High Speed Steel. The tool had 3mm pin diameter, 12 mm shoulder diameter & 2.8mm pin length. The tool set on 1° angle. Two welded conditions were taken 1) Tool rotation Speed 800rpm & 900rpm. 2) Welding Speed 30mm/min & 50mm/min. The Experiment concluded that the hardness of the joint with a) rotation speed = 800rpm & welding speed = 30mm/min. b) rotation speed = 900rpm & welding speed = 50mm/min were found 55% & 70% of base metal respectively & the TS of weld was approx.. 60% & 70% of base metal respectively. The approximate temp. for FSW of C11000 was between 460-530°C. Advancing side have higher temp. than retreating side. Hardness, Tensile Strength decreases offer FSW but elongation increases about 3 times.

P. Xue, D.R.Ni, D.warg, B.L. Xiao, Z.Y. Ma [2011] studied the mechanical properties of FSW Al 1060 & pure copper (11000) pales of 5mm thickness with tool made of tool steel with 20mm shoulder diameter, 6mm pin dia. and 4.8mm pin length. The input parameter taken was tool rotation speed (400-1000rpm) and tool pin offset (0 – 3mm) & transverse speed taken constant at 100mm/min. The tensile & bending test was carried out. The experiment concluded that the maximum tensile Strength & and sound bending properties obtained at 600rpm rotational speed & 2mm offset & sound weld was obtained when Cu is kept at advancing side.

Beytullah gungor[a,b], Erdinc Kaluc[b,c], emel Taban[b,c], Aydin Sik[d] [2013] investigated the mechanical properties of similar & dissimilar joint of 6mm 5083-H111 & 6082 – T651 Aluminum alloy plates made by FSW. The joints were made using three combination 1) F55 (5083 + 5083) 2) F56(6082 + 6082) 3) f66 (5083 + 6082). The H13 steel with taper cylindrical pin of 5-7 mm length & 20mm shoulder dia. was used as FSW tool. The welding done by using parameters as 1250 rpm tool rotation speed (counter clockwise) 64 mm/min welding speed & 2° tilt angle. The experiment concluded that F55 have high value of yield & tensile strength as 198.5 & 285 N/mm^2 respectively. For F56 yield & tensile strength were 193 & 212 N/mm^2 & F66 have min value of yield & tensile strength as 189.9 & 203 N/mm^2 respectively. Weld performance for welded joints were 86%, 65% & 62% for F55 , F56 & F66 respectively. The fatigue limit of all the joints were close to each other. The experiment also concluded that low FSW speed for similar & dissimilar joint of 5083 & 6082 have high fatigue limit & tensile strength according to previous studies.

R.Palanivel, p.koshy Mathews, Dinaharan, N. Murugan [2013] studied the mechanical properties of FSW AA5083 – H111 & AA6351 – T6 joint. High Carbon & high Chromium Steel (HCHCR) with 18mm shoulder dia., 6mm pin dia. & 5.7mm length was used for tool material. The work piece taken with dimension of 100mm*50mm*6mm. three joints were prepared using 3 welding speed of 36, 63 & 90 mm/min and the tool rotation speed was fixed to 950rpm. The experiment concluded that with increase in welding speed tensile strength increases upto a level and then decreases.

M.ilangovan, S. Rajendra Boopathy, V.Balasobramani [2014] conducted a test to compare the mechanical properties of Similar & dissimilar joint of AA6061 & AA 5086. The test was conducted by making three combinations 1) S66 (AA6061 with AA 6061) 2) S55 (5086 with AA5086) 3) D65 (AA6061 with AA5086). The work piece Size taken was 150mm*100mm*6mm

	AA6061 & AA6061	AA5086 & AA5086	AA6061 & AA5086
Tool rotation speed (rpm)	1300	500	500
Traverse speed	35	5	10
Axial Force (KN)	6.0	4.3	4.9
Tool pin profile	cylindrical taper threaded	cylindrical plain taper	cylindrical plain taper

High speed steel was used as tool material with 18mm shoulder diameter, 5-6mm tool pin diameter 5.7 tool pin length.

A.Azizi[1], R.vatankhah, Barenji[2], A.vatankhah, Barenji[1], M.hashemipour[1] [2015] investigated the joint made by friction stir welding of thick pure copper plate of 10mm. The rotation speed is taken constant 700rpm with discrete traverse speed of 50, 100, 150 & 200 mm/min. The tool was made of H13 steel with square pin profile. The tensile & hardness test were conducted. The experiment shows that with increase in traverse speed, ultimate tensile strength and hardness increases to a maximum value then decreases. The value was maximum at traverse speed of 150 mm/min but the elongation decreases with increase in traverse speed.

Vinayak D. Yadav[1], S.G Bhatwadekar[2] [2015] investigated the tensile strength of joint made by friction Stir Welding of material AA1100 & AA6101-T6. The plates were cylindrical tool of H-13 steel with shoulder diameter 18mm & pin diameter 6mm was used. The experiment was done with 1500 rpm spindle speed, 3mm/min feed rate. The experiment was carried out on vertical milling machining center. The experiment shows that the tensile strength of the dissimilar joint is less than both base metals. AA1100- 165.60N/mm^2 , AA6101-T6 – 284.4N/mm^2 & dissimilar joint – 153.33 N/mm^2 . studies shows that tunnel like defect are present on the surface of joint.

K.K. Ramachandran, N. Murugan & S. Shashi kumar [2015] investigated the joint made by friction stir welding of dissimilar material AA5052 & HSLA Steel. The 100×50×3mm work pieces were taken. The tool rotation speed was taken in range from 400-600rpm. The welding speed & axial forces were taken constant as 45mm/min. and 7KN respectively. The tool tilt angle taken as 0.5, 1.0, 1.5, 2.0 & 2.5 with different tool rotation speeds. The experiment shows that the joint have UTS 80% of UTS of base metal Al alloy when the tool rotation speed is in between 400-500rpm. The maximum UTS (196 MPa about 94% of base metal Al. Alloy) was found at tool rotation speed of 450rpm with constant welding speed 45mm/min. & axial load 7KN & tool tilt angle 1.5°.

M.R.M. Aliha, M. Shahheidari, M.Bisadi, M.Akbari, S.Hossain [2016] investigated the Mechanical properties of dissimilar AA7277-T6 & AA6061-T6 joint with Friction stir Welding. The work piece taken was of 200mm X 100mm X 5mm. H13 steel was used as tool material with 20mm shoulder dia. and a conical pin of 4.7 mm length. The process parameters taken were traverse speed (32 & 60mm/min) & tool rotation speed(600,825,1115,1500 rpm). 3^o tool tilt angle was used for all experiments. The experiment concluded that better hardness and tensile properties achieved when harder material(AA7277-T6) places on advancing side.

H.B.Cui, G.M.Xie, Z.A. Luo, J.Ma, G.D.Wang, R.D.K. Misra [2016] presented a test result after conducting an experimental investigation on Mechanical properties and microstructure of friction stir welded AISI 201 SS. W-Re stirring used as tool material with 20mm shoulder diameter & 3 mm pin diameter. Traverse speed, rotation speed and tool tilt angle of 3° were taken as input parameters. The experiment concluded that tensile strength decreases with increase in rotation speed.

Alireza yazdipour[1], Akbar Heidrzadeh[2] [2016] investigated the Mechanical properties of the joint made by friction Stir Welding of material AL5083-H321 & 316L SS of 5mm thick plate. H13 Steel with 20mm shoulder diameter & 5mm simple Cylindrical pin which is 4.7mm long was used as tool material. The tool was set at an angle of 2.5°. The rotation speed were ranging from 100-1400rpm. Tool traverse speed ranging from 160 – 315 mm/min. & tool offset was taken constant at 0.4 mm & the tool rotates clockwise. The experiment concluded that the sound joint can be attained at rotation speed from 180-550 rpm & traverse speed from 160-200mm/min. The speed instead of this range can produce defects on the joint surface.

A yazdipour, A Heidarzadeh [2016] investigated the mechanical properties of dissimilar metals AL5083-H321 & 316 L Stainless steel 5mm thick plates joined by FSW. The rotation speed of tool was taken fixed by 280 rpm. The different traverse speed taken as 160, 200, 250 & 315 mm/min. different pin offset were taken from -0.4 to 1 with clockwise and anticlockwise rotation of the tool. The tilt angle of tool was taken 2.5° and plunge depth was 0.3 mm. The Vickers hardness test was done using 0.98N for 105 and tensile test at cross head speed of 1mm/min. the experiment conclude that with increase in traverse speed from 160-200 mm/min and further more will increase in sectional defects like steel large fragments formation of tunnel and void defects which decrease the tensile strength. Value of pin offset gives better or increased tensile strength to a maximum level than decrease when increase from negative. The counterclockwise rotation of the tool was not able to complete the joint.

Hamed pashazadeh, Jamal Teimournezhad & Abolfazl Masoumi [2016] investigated the mechanical properties of FSW copper sheets. The input parameters taken was rotation speed (ranging from 500 – 710rpm), translational speed (ranging from 20 – 63mm/min) plunged depth (0.3 – 0.4mm) & tool tilt angle taken constant as 1.5°. The maximum tensile strength was found 368MPa with 500rpm, 20 mm/min & 0.4mm plunged depth. The experiment concluded that decreasing rotation speed have more effect on mechanical properties than increase translational speed.

CONCLUSION

This paper concluded that:-

1. FSW can be used to weld similar and dissimilar materials (Al, Mg, copper, brass etc.) successfully.
2. No filler material required, no spatter and no fumes occur so it is a safe and environment friendly technique.
3. With increase in rotation speed and welding speed tensile strength increases upto a certain limit. Further increase in both speeds will reduce the tensile strength.

4. With increase in tool rotation speed, heat input increases.

FUTURE SCOPE

This paper identifies, some areas on which further study can be done. :-
Tool wear and tool life can be investigated for different tool shape and different work piece materials.
Further different ferrous materials can be used as work piece with different tool material.
From literature survey we noticed that much research has been done on different materials, but a very few research is done on AL 6082 with different material. This material can be investigated using different process parameters and with different optimization methods.

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