International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Rotary Friction Welding of Dissimilar Materials

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***Abstract:** Friction welding (FW) is a solid state welding method invented in 1940s by the welding institute. Without genuine liquefying of the materials, a normally excellent weld joint is produced with this procedure. The method is quick, environment friendly and easy to carry out. The extent of the present examination is to assess the effect of welding variables on the tensile properties of friction welded of dissimilar metals. From this review study, posted research papers of different authors has been studied and it has been determined that the welding variables like revolution pace, rubbing time , friction stress, forge time, forge strain are have high impact on the mechanical properties of friction welded joints. Finally, the conclusions of the review study presented the practical applications for the manufacturing sector and proposals for further innovative work and advancements. The purpose for this article is to advise industry and the scholarly world regarding the advantages of rotary FW so the procedure might be used in better way.*

***Keywords :** Mechanical Properties, Forge Stress, Friction Welding (FW), Dissimilar Metals, Friction Stress , Rotational Speed, Tensile Strength.*

I. INTRODUCTION

Friction welding is a solid state welding process that permits joining of explicit materials which are viewed as un-weldable by ordinary systems. The principle of this technique is the changing of mechanical energy into thermal energy with friction between weld interfaces. So as to fabricate a friction weld, the two segments are compelled to pivot against one another (friction stage), in this way producing heat at the joint interface. When the idyllic upset length or process time has been achieved, the abrasion movement stops (braking stage), the stress rises (swelling time) and the parts are squeezed adjacent to one another (forging stage) until they are chilled down. [1-4]

Manuscript published on November 30, 2019.
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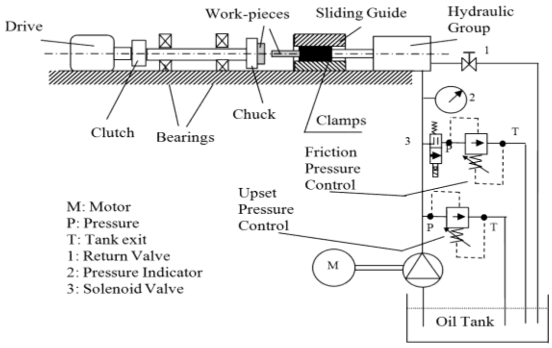

Fig No.1:- Rotary Friction Welding Set-Up [4].

It is done in four unique phases which can be recognized in the vibration welding process. [3,5,6,7]

1. Solid Friction Phase: In this phase heat is generated because of friction among two surfaces which makes the plastic state material heat, until the liquefying point begins. The heat generates with respect to applied speed as well as stress.

2. Transient Phase: In this phase a thin molten polymer is formed which develops as consequence of continuous heat generation. In this phase heat production done by thick dissemination. At first just a slight molten layer exists and subsequently the shear rate and thickness heating commitment are enormous. As much as the thickness of the molten layer expands the level of viscous heating decrease.

3. Steady Phase: In this phase the melting rate approaches the outward stream rate. When this phase has been achieved, then thickness of molten layer remains constant .This state is maintained till a certain melt down depth has been reached and the rotation is stopped at the point.

4. Cooling Phase: In this phase the polymer melt solidification begins, but the film waste still happens till the welding stress remains. After complete solidification of material, waste stops and join is fabricated.

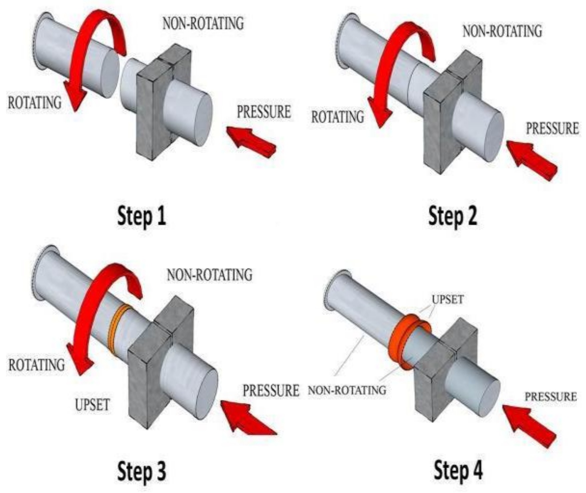

Fig No.2:-Phases of Friction Welding

There are six process variables used during rotary FW [2-3,6-8]

- Rubbing time
- Upset time
- Spindle Speed
- Upset stress
- Friction stress
- Temperature

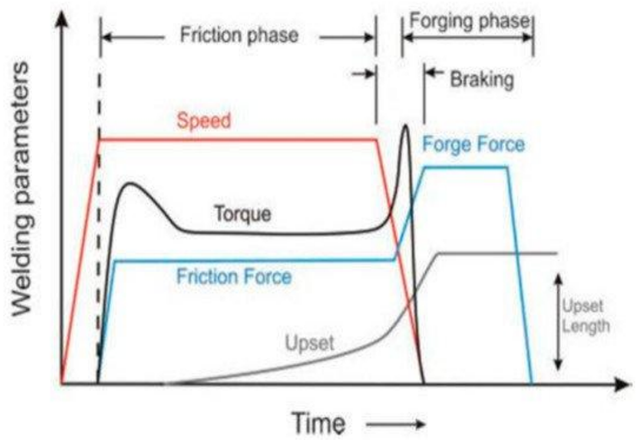

Fig No.3:-Variation of the welding variables with time in rotary friction welding [2]

Rotary friction welding process offers many advantages over competing manufacturing processes, for example: *[3,5,9]*

- Due to solid-state weld, the defects associated with melting and solidification as seen in fusion welding like pores and solidification cracks reduced.
- It can easily join dissimilar materials which are not well-suited for welding by other joining techniques.
- Create narrow heat affected zone.
- It is a consistent and repetitive process
- Joint preparation is minimal
- Faster turnaround times as compared to long lead time of forgings
- Greatly increases design flexibility as give freedom to choose appropriate materials for every area.
- No fluxes, filler materials, or gases used.
- Environmental friendly process as it does not produce harmful fumes, gases.
- Due to welding in solid state there is no chance of porosity or slag inclusions.
- No expensive tools are used in the process
- Full surface welded materials shows high strength in critical areas
- Reduces raw materials costs in bi-metal applications

The process does however have some limitations also, for example:

- High initial setup cost
- Not suitable for small production
- Finishing operation may be required
- Tight dimensions are difficult to achieve
- Tooling and setup may be required.

Rotary friction welds have several distinct zones:

- Heat Affected Zone (HAZ)
- Thermo-mechanically Affected Zone (TMAZ),
- Weld Centre Zone (WCZ)

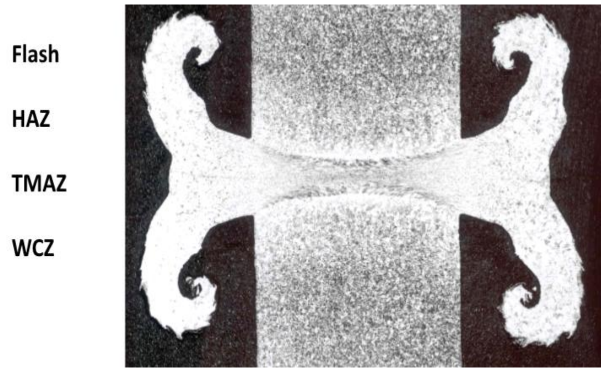

Fig No.4:-Several distinct zones of weld joint [9]

The scope and microstructure of these affected zones are fully dependent on the material composition and conditions in which procedure is done. The weld section is enclosed by a flash collar .With optimum friction welding process variables; RFW can fabricate weld joints which would show superior or similar strength as the parent material for any alike and divergent material combinations.

Wide range of parts can be produced by Rotary Friction Welding as it has capacity to create much different joint geometries as enlisted below: [10]

- Tube To Bar
- Tube To Disk
- Tube To Tube
- Tube To Plate
- Bar To Bar
- Bar To Plate

II. LITERATURE

Rombaut et al. [2] had developed a friction weld joint of steel to ceramic and Al to steel. The various challenges faced during the procedure of FW of ceramic to steel were like due to very big disparity in thermal expansion of both material which leads to induces of thermal stresses at the weld joints interface which could lead to cracking. The brittleness and porous character of ceramics makes it extremely hard to absorb manufacture defects. The strength of a ceramic is vastly dependent of its grain size and surface roughness.

Retrieval Number: D7456118419/2019©BEIESP
DOI:10.35940/ijrte.D7456.118419
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
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Similarly problems faced during welding procedure of Al to steel were like very higher melting points of steels as compared to Al alloys, disparity between the thermal expansion coefficients of both materials due to disparity in thermal conduction properties lead to formation of brittle inter-metallic compounds at welded interface. Bhate et al. [3] had reviewed various research papers related with FW techniques. In his study the type of FW techniques like liner FW, rotary FW, inertia FW, friction surfacing and friction stir welding are elaborated in details with its working principles, advantage, disadvantage, and effect of various variables on the welded materials with sketches. The study concluded that the FW of similar and dissimilar materials is much different than usual fusion welding process. It also concluded that less work has been done on continuous drive FW process. Shubhavardhan et al. [4] developed weld joints of AA6082 Al alloy AA6082 and SS AISI 304, by rotary FW technique and various tests were performed. The friction variables measured were friction stress (65, 104, 156 MPa) and rubbing time (3, 5, 7 second) were varied where as forge time (6 sec), Spindle Speed (1400 RPM), forge stress (210 Megapascal) remains constant. The most favorable rubbing time and stress to achieve high tensile value which was 188.40 Megapascal were at 5 second and 104Megapascal respectively. The strength of welded joints starts decreasing when it reaches at highest value, with increase in friction stress and rubbing time. Some welded samples had low strength due to the thickness of reaction layers when increased beyond a critical point then some samples had low joint strength, show brittle nature and got broken at the weld joint interface. The joint strength was good when there was no abundant area and a thin reaction layer produced along the complete weld interface. Abhijith et al. [5] study the effect of inter layer on penetration, sliding and sticking. In the works, ANSYS software code was used for the numerical simulation of rotary FW process to weld Inconel600 and SS304. The inter layer material was pure Al. The process variables for this welding were friction stress (40, 60, 80 Megapascal), rotating speed (1500, 1800, 2000 rpm), frictional time (4, 6, 8 sec) and forging stress was 1.5 time of frictional stress. The forging time was considered same as that of frictional time. A 3D model of inconel600 and SS304 alloys of 25.4mm diameter and 100mm length were made by ANSYS work bench. The size of inter layer was 1mm thick and 24.4mm diameter. First the transient thermal analysis was performed keeping inconel600 alloy rod stationary and SS 304 rod in rotation. The coefficient of friction 0.2 was enforced at the specimen interfaces. The convection heat transmit coefficient was enforced at interface of three materials to be welded. Temperature distribution was estimated. Thermal analysis was combined with static structure analysis. For structure analysis, the rotating rod was brought to stationary rod and forging stress is enforced along longitudinal axis of inconel 600. Contact analysis was also carried out to determine the depth of penetration and sliding of the material at interfaces. Penetration, sliding and sticking indicates flow of interlayer material along interface. High value of all of them leads to high value of equivalent stresses at interface. The optimum levels process variables in the present work were observed at friction stress 80Megapascal; rpm 1500 and rubbing time 8sec. Ozdemir. [6] had investigated the friction welded joints mechanical properties fabricated between standard ss304 and 4340 steel at different functional Spindle Speed. The FW process was performed using five Spindle Speeds (1500, 1700, 2000, 2300, 2500 rpm) and various constant variables like friction stress 40Megapascal , forging stress 60Megapascal , rubbing time 5 sec and forging time 10 sec. To evaluate the samples various test are performed like SEM for micro structural properties of heat affected zone (HAZ), micro hardness and ultimate tensile value test. A Spindle Speed of 2500 rpm gives highest hardness and ultimate tensile values i.e 700HV and 88N/mm^2. It decreases with further decrease in Spindle Speed. Alves et al. [7] developed the welded joints of dissimilar material Al AA1050 and SS 304 by using rotary FW technique (RFW). The process was carried out on a GATWIK brand rotary FW machine with constant speed of 3200 RPM, friction stress (2.1 Megapascal constant), rubbing time (7, 17, 27, 32 seconds), forge stress (0.7, 1.4, 2.1, 2.8Megapascal) and forge time (1, 2 seconds).The highest tensile value 80.08Megapascal was obtained at rubbing time 32 sec, forge time 2 sec and forge stress 1.4 Megapascal. The tensile values of friction welded joints elevated with increase in rubbing time and forge strain values until it reaches its essential restriction after which start lowering again because of increased plastic deformation. Handa et al. [8] had attempted to join austenitic SS AISI 304 with low alloy steel AISI 1021 at 1600rpm constant with varying parameter axial stress (75, 90, 105, 120, 135 Megapascal). The strength of the joint was evaluated by mean of various mechanical properties such as impact strength, tensile strength, torsion and micro hardness. The tensile tested samples were also subjected to SEM analysis to determine the failure pattern. The ultimate tensile value test reported that the specimens welded at axial stress 75MPa, 90Megapascal, 105Megapascal and 120Megapascal showed certain amount of displacement before failure, but the specimen welded at 135Megapascal axial stress failed without showing any displacement and took minimum time before failure. The highest ultimate tensile value (442.47Megapascal), torsion strength (26.71Nm and angle of twist was 14) and impact strength value was observed at 105Megapascal axial stress and then it start declining with further increase in axial stress . The SEM images depict very small size voids and brittle cleavage fractures in all specimens. The highest micro hardness obtained at the interface of welded joint and decreases gradually away from the welded interface. Seshagirirao et al. [11] had performed a experimental work to analyze tensile and hardness properties of weld materials. The welded joint samples were fabricated between Al (H-30) and mild steel (AISI-1040) by using Rotary FW technique with variation in spindle speeds on medium duty lath machine. The tests like tensile test and hardness test of specimens were analyzed and compared at diverse spindle speeds with 10mm, 12mm diameters of Al (H30) and 10mm, 12mm diameters of mild steel (AISI-1040) respectively. The specimens of combination of both as similar and dissimilar were produced. It was assessed by results that Al and AISI 1040 steel can produce sound weld by using FW procedure. Sahin et al. [12] has analyzed the welded joint interface characteristics of austenitic-SSs 304 fabricated by FW technique. During the experiments the upset time and upset stress had been kept consistent to reap right rubbing time and friction stress. Friction stress (60 Megapascal) was kept steady and rubbing time s were various and then rubbing time (9 sec) fixed and friction stress s were varied.

The tensile strengths value of the welded joints achieve high strength more than optimum values, parts heat and deform much more as rubbing time and stress are increased. Therefore, the weld strength start decreasing. The tensile stress ranges were varied between 150 Megapascal and 250 Megapascal. The fatigue strengths of welded joints are slightly lower than parent SS304 material. The notch impact toughness of welded joint is nearly twice as those of parent SS304 material. Hardness variations obtained by Vickers hardness testing. The hardness value decreased at interface of weld joints due to that SS 304 was not hardened by heat treatment. It is determined from the hardness value variations along interface and microstructures austenitic-chrome steel has no widespread hardening effect in the welding quarter. Ananthapadmanaban at el. [13] developed a weld joint of dissimilar materials low carbon-SS 304 and Al-Cu and has analyzed the mechanical properties with reference to the microstructure. The process variables measured for low carbon steel-SS were spindle speed (1000, 2000 rpm), forge stress (127.5, 180 MPa), friction stress (40,120 Megapascal), and burn off length (2, 6 mm) and for Al-Cu process variables were spindle speed (500, 750, 1000 rpm), burn off length (1, 2, 3 mm), forge stress (127.2, 159, 190.8 Megapascal) and friction stress (63.5, 82.2, 95.4 Megapascal). The results were analyzed as impact strength; bend tests, ultimate tensile value and hardness. The micro-structure and SEM has also been carried out to observe the consequence of process variables on type and nature of fracture. The optimum variables are friction stress 120 Megapascal, forge stress 127.5 Megapascal and Spindle Speed 1000rpm to obtain ultimate tensile value 632 Megapascal for low carbon and SS 304 and friction stress 63.5 Megapascal, forge stress 127.2Megapascal and Spindle Speed 750 rpm for Al and Cu. It is observed that the ultimate tensile value increases with respect to forge stress increase up to some optimum value and then it start decreasing, for both combinations and the weld strength totally dependent on Spindle Speed and forge stress. Handa et al. [14] had studied the mechanical properties of weld joints between AISI 304 and AISI 1021 steels fabricated with FW technique. The main variables considered were Spindle Speed (920 RPM) which remain constant and range of axial stress (75, 90, 105, 120, 135 Megapascal). To evaluate the welded joints, various tests like tensile strength, torsion strength, impact strength and hardness test were conducted. The fractography of tensile specimens were also conducted for failure analysis. It was seen that the most extreme ultimate tensile value of 432megapascal became carried out at 135megapascal axial stress. This turned into because of the transfusion of alloying additives from the AISI 304 toward low alloy steel side. The malleability marginally diminishes at 135megapascal axial stress. This might be due to flashing of the heated soft material from the interface on upset stress. Fractography investigation uncovered that bendable disappointments were seen at higher axial stress s. The torsion strength additionally increments with the ascent in axial stress. This was because of more exchange of the mass at higher axial stress s. It has been also seen that impact strength of the weldments pursues the turnaround pattern; it decreases as axial stress increments. The most extreme impact durability estimations of 25J and 20J both for charpy and izod were accessible at 75Megapascal and with the expansion in axial stress, the hardness at the focal point of weld cross-segment increments and most extreme hardness was seen at 135Megapascal. Sarsilmaz et al. [15] had investigated the properties of friction welded joint of Armor 500 steel and duplex steel AISI 2205 (ferritic/austenitic). The considered variable variables are rubbing time (4, 6, 8 sec), friction stress (60, 80 Megapascal) and fixed variables such as spindle speed (1800 rpm), forging time (6sec) and forging stress (120 Megapascal). The experimental results indicated that the armor 500 steel could be joined to AISI 2205 steel using the traditional FW technique. The strength and microstructure of fabricated joints were observed. The best ultimate tensile value that's 1020 megapascal is acquired while friction strain is 80megapascal and rubbing time is 8 sec, there are no cracks, micro voids and unbounded areas in the welded interface and a sound weld was found. Sathiya et al. [16] had investigated mechanical and metallurgical properties of friction welded AISI 304 austenitic steel. Prior to the experiment, the contacting surfaces were polished by means of emery papers and cleaned by means of acetone. The friction welded joint variables for the study were heating stress (1.5, 2.0, 2.0Megapascal), rubbing time (3, 5, 8sec), upsetting stress (4.0, 4.0, 4.5Megapascal), and upsetting time (5, 7, 3sec). The ultimate tensile value and microstructure of fabricated joints was observed. The highest ultimate tensile value which is 610 Megapascal is obtained in two combinations i.e when friction stress is 4.5 Megapascal and rubbing time is 3sec and second when friction stress is 4.0 Megapascal and rubbing time is 5sec. In microstructure its shows that at higher stress rates new sub grains are more nucleated resulting in a finer sub grain shape inside the deformed material. Handa et al. [17] had conducted the experimental study on weld joints of AISI 1021 steels fabricated with FW process to analyze the mechanical properties of weld joints. The main variables considered were Spindle Speed (800, 1000, 1250 RPM) and range of axial stress (60, 75, 90, 105, 120, 135 Megapascal). To evaluate the welded joints, various tests like tensile strength, charpy impact test and rockwell hardness test were conducted. It was seen that the ultimate tensile value increments with the expansion in axial stress up to 120 Megapascal as the most extreme ultimate tensile value of 472 Megapascal was accomplished at the axial stress of 120 Megapascal at the Spindle Speed of 1250 rpm and afterward further increment in axial stress , ultimate tensile value begin declining. It was same for every Spindle Speeds. It has been also seen that with the expansion in axial stress the impact strength diminishes, yet the impact strength increments with the expansion in Spindle Speeds. It is likewise apparent that most extreme charpy impact strength was observed to be 29 Joules which was acquired at 1250 rpm and least impact strength was seen at 135 MPa at all the three diverse rotational rates. Most extreme hardness was found at the weld interfaces, this may be attributed to the highest temperature which was generated at the rubbing faces. As we leave from the weld interface, the HRC continue diminishing demonstrating the low heat influenced zone. Ananthapadmanaban et al. [18] studied the mechanical property variation under different FW conditions for mild steel SS joint. The materials used in investigation were cylindrical rods of 75mm length and 12mm diameter. The various variable variables were burn off length (1, 2mm), friction stress (80, 160Megapascal), upset stress (160, 280Megapascal) and Spindle Speed remain constant (1500rpm).

Yield strength, ultimate tensile strength, percentage elongation of the welded joints and hardness variations across the weld interface has been reported. The hardness value of the specimens increased at the weld joint interface. A highest value of hardness was 450HV which has been found near the weld joint interface. The spindle speed 1500rpm, friction stress 80Megapascal, upset stress 160Megapascal and burn off length 1mm shows highest hardness, yield strength 531Megapascal, UTS 629Megapascal, 10 % elongation and broken location of weld was weld interface. James et al. [19] had discussed the properties of friction welded joint of cylindrical rods of austenitic SS 304 of length 55mm and diameter 10mm and medium carbon steel AISI 1040 rod of 75mm and diameter 10mm with holding side diameter 20mm compared the properties of weld joint without and with interlayer at diverse welding variables. The interlayer materials selected is nickel which was deposited by electroplating on SS 304 sub states with a range of 50+ 3micrometer or 50-3 micrometer on particular number of specimens after the careful finishing of face of material with grinding emery paper. The welding variables used were forging stress (1.884, 1.570, 1.256 ton), Spindle Speed (2500, 2300, 2100 rpm), rubbing time (8, 6, 4 sec) and friction stress was kept constant at 0.28ton. The process parameter combinations were chosen by applying taguchi orthogonal array method to optimize the process to obtain highest tensile strength. The highest value of ultimate tensile value without interlayer was 630Megapascal and with interlayer was 656Megapascal. The strength increase can be accounted mainly to the presence of nickel which reduces the creation of inter-metallic in the weld section. Handa et al. [20] had evaluated the fracture behavior and ultimate tensile value of welded joints between AISI 304 and AISI 1021 steels fabricated with FW procedure at Spindle Speeds (800, 1000, 1250, 1430, 1600 RPM) and range of axial stress (75, 90, 105, 120, 135 Megapascal). To evaluate the welded joints, various tests like tensile strength, fractography test and micro hardness test were conducted. The highest severe tensile value was seen at 1430 rpm and at 120megapascal axial stress and changed into 1.8 % higher than AISI 1021 discern steel, while the least tensile value determined to be 80% of the AISI 1021 parent metal was at a 1000 rpm and 75megapascal axial stress . The ultimate tensile value right off the bat expands arrives at the greatest worth and later on starts declining. At 1430 rpm and at 120 megapascal axial stress s, most intense strain estimation of 0.44 was watched and the specimen fails from the parent material and now not from the weld interface. The higher hardness value have been found to be at austenitic hardened steel side for every specimen, for each sample with the rise in either the axial strain or the spindle speed, the estimation of hardness increments. The most excessive hardness was located at 1600 rpm and at 135megapascal axial stress s wherein it crosses the 290 Hv value, this could be the purpose that the pattern fails at this parameter without giving any deformation. Kumar et al. [21] has proposed technique to decide close to superior settings of the procedure variables in FW. The achievement of the FW system is based totally on diverse input variables like friction stress, upset stress, rubbing time and upset time and output variables like hardness number, ultimate tensile value and material loss. Al and SS304L material had been welded with the aid of FW process using interlayer method. To decide the number of experiments to be achieved and discover the best system variables for acquiring higher joint strength, Box−Behnken design and response surface methodology (RSM) have been implemented. Joint strength of 523megapascal was obtained at a upset strain of 40 n/mm2, friction stress of 12 n/mm2, rubbing time of 1. 2 s and upset time of 7s.Handa et al. [22] has designed and fabricated experimental setup on the way to perform FW between austenitic SS and low-alloy steel. Samples had been welded beneath numerous axial stress s ranging from s75 to 135 megapascal, with constant rotational pace of 1250 rpm. The axial stress has been located to be an influential parameter for the FW as if axial stress expanded then the tensile value increase, the time taken before sample fracture will also increase with the same. The highest time was recorded at a 135 megapascal, which was 34 s. The ultimate tensile value was 466.83 megapascal, available at this axial strain. It's been determined that the impact toughness value declines as axial stress increase. The most impact toughness values of 23 and 17 j each for charpy and izod impact have been to be had at 75 mpa. It was seen that the hardness at the middle of weld cross-segment will increase with boom in axial stress. The ultimate hardness 248 Hv was available at a 135megapascal axial strain. Yilba et al. [23] studied the metallurgical and mechanical properties of friction welded Al-Cu and Al-steel. The considered variables were enforced load (5-12.74, 6.37 -17.83, 7.64-22.93 kg), Spindle Speed (2000, 2500, 2800 rpm) and duration of welding (4, 7, 10 second). The optimum variables to achieve high tensile value were axial load range (6.37 -17.83 kg) and spindle speed (2800 rpm) for Al-steel and Spindle Speed (2000 rpm) and axial load range (5-12.74 kg) for Al-Cu. Tensile properties get better for Al-steel welds when the inter-metallic thickness extends to critical level after that further increase in the thickness reduces the ultimate tensile value for both cases. Mercan et al [24] had welded AISI 2205 duplex treated steel which is most ordinarily utilized material in its group and AISI 1020 steel couple with low carbon content which extremely practical by utilizing diverse activity variables with FW. Tensile test and rotary bending fatigue test were conducted to the welded specimens, and the effect of the welding variables on exhaustion quality was inspected. The outcomes demonstrates that when the welding variables utilized in interfacing AISI 2205 and AISI 1020 steel through FW were chosen accurately, weariness quality of the association would expand contrasted with the principle material, and it would diminish with in-compliant variables .

Table.1. Literature Summary.

Authors	Work Materials	Welding Variables	Remark
Rombaut *et al*	Steel- Ceramic Al-steel	_	Disparity in thermal expansion of both material combinations which leads to induces of thermal stresses and formation of brittle inter-metallic compounds at welded interface which could lead to cracking and other welding defects.
Bhate *et al.*	_	_	Type of FW techniques like liner FW, rotary FW, inertia FW, friction surfacing and friction stir welding are elaborated in details with its working principles, advantage, disadvantage, and effect of various variables on the welded materials with sketches.
Shubhavardhan *et al.*	AA6082-AISI30 4	Rubbing time Friction stress Forge time Spindle Speed Axial stress	The strength of welded joint start lowering after attainment a highest value, with growing friction strain and rubbing time. A few welded samples had low strength as the thickness of reaction layers while extended over a critical point. A few samples had low joint energy, show brittle nature and broken at the weld joint interface. The strength of joint was good when there was no considerable region and a skinny reaction layer produced alongside the complete weld area.
Abhijith *et al.*	Inconel600-SS30 4	Spindle speed Friction stress Rubbing time Axial stress	A 3D model of 25.4mm diameter and 100mm length were made by ANSYS work bench. The size of inter layer was 1mm thick and 24.4mm diameter. First the transient thermal investigation was performed maintaining inconel 600 stationary and SS 304 rod in rotation. The coefficient of friction 0.2 was enforced at the specimen interfaces. Thermal analysis was combined with static structure analysis. For structure analysis, the rotating rod was brought to stationary rod and forging stress is enforced along longitudinal axis of inconel 600. Contact analysis was also carried out to determine the depth of penetration and sliding of the material at interfaces. Penetration, sliding and sticking indicates flow of interlayer material along interface. High value of all of them leads to high value of equivalent stresses at interface.
Ozdemir.	SS304-4340 Steel	Spindle speed Friction stress Rubbing time Forge Stress Forge time	A Spindle Speed of 2500 rpm gives highest hardness and ultimate tensile values i.e 700HV and 88N/mm^2. It decreases with further decrease in Spindle Speed.
Alves *et al*	AISI1050-SS304	Friction stress Forging stress Rubbing time Forge time Spindle speed	The ultimate tensile value of welded joints elevated with growth in rubbing time and forge stress values till it reaches its essential restrict and then begin decreasing again because of multiplied plastic deformation.
Handa *et al*	AISI304-AISI10 21	Axial Stress Spindle speed	The ultimate tensile value test reported that the specimens welded at axial stress 75MPa, 90MPa, 105MPa and 120MPa showed certain amount of displacement before failure, but the specimen welded at 135Megapascal axial stress failed without showing any displacement and took minimum time before failure. The highest ultimate tensile value (442.47MPa), torsion strength (26.71Nm and angle of twist was 14) and impact strength value was observed at 105MPa axial stress and then it start declining with further increase in axial stress. The SEM images depict very small size voids and brittle cleavage fractures in all specimens. The highest micro hardness obtained at the interface of welded joint and decreases gradually away from the welded interface.
Seshagirirao *et al.*	H30-AISI1040	Spindle Speed	The specimens of combination of both as similar and dissimilar were produced. It was assessed by results that Al and AISI 1040 steel can produce sound weld by using FW procedure.
Sahin *et al.*	Austenitic-ss304	Upset time Upset stress Rubbing time Friction Stress	The fatigue strengths of welded joints are slightly lower than parent SS304 material. The notch impact toughness of welded joint is nearly twice as those of parent SS304 material. Hardness variations obtained by Vickers hardness testing. The hardness value of the joints is decreased at interface due to the reason that SS 304 was not hardened by heat treatment. It is observed from the hardness value variations along interface and microstructures austenitic-SS has no significant hardening effect in the welding zone.

Ananthapadmanaban *at el.*	Low carbon-SS304 Al-Copper	Forge stress Friction stress Spindle speed Burn off length	It is observed that the ultimate tensile value increases with respect to forge stress increase up to some optimum value and then it start decreasing, for both combinations and the weld strength totally dependent on Spindle Speed and forge stress.
Handa *et al*	AISI304-AISI1021steels	Axial stress Spindle Speed	The highest ultimate tensile value of 432Mpa was observed at 135Megapascal axial stress. It shows that at better temperatures, good elemental diffusion takes place from the austenitic-SS in the direction of the low alloy metallic; therefore escalating the bond strength, ductility slightly decreases at 135Megapascal axial stress. This reduction might be because of flashing of soft material from the interface on upset stress. Fractography investigation discovered that ductile disasters had been found at higher axial stress. The torsion strength value additionally increases with upward thrust in axial stress due to greater mass transfer at higher axial stress. It has been determined that impact toughness of the weldments follows the opposite trends
Sarsilmaz *et al*	Armor Steel 500-AISI2205	Friction stress Rubbing time Forge stress Forge time	The investigational consequences indicate that the armor steel 500 might be welded to AISI 2205 steel with usage of the conventional FW method. The strength and microstructure of fabricated joints had been discovered. The best ultimate tensile value which is 1020 Megapascal is received when friction stress is 80 Megapascal and rubbing time 8 sec, there aren't any cracks, micro voids and unbounded regions within the welded area and a good weld was discovered
Sathiya *et al.*	Austenitic-AISI304	Friction stress Rubbing time Upset stress Upset time	The highest ultimate tensile value which is 610 Megapascal is obtained in two combinations i.e when friction stress is 4.5 Megapascal and rubbing time is 3sec and second when friction stress is 4.0 Megapascal and rubbing time is 5sec. In microstructure its shows that at higher stress rates new sub grains are more nucleated resulting in a finer sub grain shape inside the deformed material
Handa *et al.*	AISI1021 steel	Spindle Speed Axial Stress	A high value of tensile strength, in addition to, impact strength may be obtained at a spindle speed of 1250 rpm with an axial stress of one hundred twenty Megapascal. Rockwell hardness values were calculated at the centre point of weld interface throughout the sectional location and also away from the centre point at diverse points. It determined that variation of hardness value was located to be perfect for the welding produced at 1250 rpm and a hundred and twenty Megapascal axial stress.
Ananthapadmanaban *et al*	Mild steel-SS	Friction stress Upset stress Burn off length Spindle speed	The hardness value of the specimens increased at the weld joint interface. A highest value of hardness was 450HV which has been found near the weld joint interface. The spindle speed 1500rpm, friction stress 80Megapascal, upset stress 160Megapascal and burn off length 1mm shows highest hardness, yield strength 531Megapascal, UTS 629Megapascal, 10 % elongation and broken location of weld was weld interface.
James *et al*	SS304-AISI1040	Friction stress Forging stress Rubbing time Spindle speed	Properties of weld joint compared without and with interlayer at diverse welding variables. The interlayer materials selected is nickel which was deposited by electroplating on SS 304 sub states with a range of 50+ 3micrometer or 50-3 micrometer on particular number of specimens after the careful finishing of face of material with grinding emery paper. The process parameter combinations were chosen by applying taguchi orthogonal array method to optimize the process to obtain highest tensile strength. The highest value of ultimate tensile value without interlayer was 630Megapascal and with interlayer was 656Megapascal. The strength increase can be accounted mainly to the presence of nickel which reduces the creation of inter-metallic in the weld section.
Handa *et al.*	AISI304-AISI1021 steels	Spindle Speed Axial stress	The axial stress and Spindle Speeds are the principal variables that could impudence the strength of the fabricated weld joint. With boom in axial stress the joint power will increase, the joint power also increases with boom in the rotational pace as nicely. It also shows that with expansion in axial stress, impact strength value diminishes, but the strength value increments with the growth in Spindle Speeds.

Kumar *et al.*	Al-SS304L	Friction stress Upset stress Rubbing time Upset time	Al and SS304L (SS) materials were welded by FW procedure utilizing interlayer strategies. To choose the quantity of examinations to be performed and distinguish the ideal procedure variables for acquiring better joint quality, Box−Behnken structure and reaction surface philosophy (RSM) were enforced. Joint quality of 523 MPa strength was obtained at a upset stress of 40 N/mm2, friction stress of 12 N/mm2, Rubbing time of 1.2 s and upset time of 7s.
Handa *et al*	SS-Low alloy steel	Axial Stress Spindle speed	The axial stress has been observed to be a compelling parameter for the FW process. It was seen that in the event that axial stress expanded, at that point the ultimate tensile value increase, the time taken before test sample break additionally increments with the same, impact toughness decreases as axial stress expands, hardness at the focal point of weld cross-segment increments with increment in axial stress.
Yilba *et al.*	Al-Cu Al-Steel	Spindle Speed Applied load Forge time	The optimum variables to achieve high tensile value were Spindle Speed (2800 rpm) and axial load range (6.37 -17.83 kg) for Al-Steel and Spindle Speed (2000 rpm) and axial load range (5-12.74 kg) for Al-Cu. As ultimate tensile value get better for Al-steel weld joints till the inter-metallic thickness reaches to decisive level after that further increment in the thickness reduces the ultimate tensile value for both cases.
Mercan *et al*	AISI2205-AISI1020	_	The outcomes demonstrates that when the friction welding variables utilized within the interface of AISI 1020 and AISI 2205 steel through FW process were chosen accurately, weariness quality of the association would expand contrasted with the principle material, and it would diminish with in-compliant variables.

III. CONCLUSION

Following points can be sumarized from the above study.

- The ultimate tensile value of weld joints expanded among increment in rubbing time and forge stress values till it reaches at its critical point and further increment prompts decrease of tensile.
- FW procedure is the method which accomplishes 100% metal-to-metal welding with properties of parent metal.
- Fillers materials are requirement is nill for FW technique.
- The procedure is without emanations as no hurmful emmision discharge during the procedure.
- FW is essential apparatus for disimilar metals welding.
- The optimal variables for welding should be chosen appropriately in the FW process while welding.
- FW procedure is proficient to fabricate weld between materials which are considered not suitable to weld by other traditional welding processes

IV. FUTURE RESEARCH SCOPE

Less study is done on FW procedure which builds extent of investigates for the welding of dissimilar and similar materials. Optimization of welding variables like rubbing time, forge time, spindle speed, friction stress and forge stress can be done. FW procedure is a moderate procedure as compare too other traditional welding methods, the chance of performing FW at higher paces, with better properties of the weld joints, should be investigated.

Disclosures Statement

The authors proclaim that there is no clash of interest on the subject of the publication of this paper.

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