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A Review Paper on Rotary Friction Welding

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ABSTRACT

Friction welding is solid state joining process. One of the factors that make friction welding popular among manufacturers is its unique ability to join dissimilar metals. There is limitation in conventional welding because most metal combinations are not compactible when using conventional method. Friction welding method is cost effectiveness to time saving and consistent quality to reduced waste, the benefits are many. It is applicable in Aerospace, earthmoving applications, Pump making industries, and other heavy duty industries. This paper presents a review of research papers related to friction welding is done.

Keywords – Rotary Friction Welding, Dissimilar metals, similar metals, Friction welding

I. GENERAL INTRODUCTION

Friction welding is a pressure welding process that produce high integrity and full contact joints. In this welding process, no filler material, flux or shielding gases are required. In friction welding, joint created between two materials by generating heat between two mating surface because of friction along with application of pressure. The friction welding components are forced to rub against each other, thereby generating heat at the interface. This softens the material on either side of the rubbing interface. The softened materials starts to flow together to initiate a weld. Once enough heat has been generated, the rubbing action is terminated and the contact pressure is maintained or increased for a period of time, to promote the solid-phase bond. Therefore, the friction welding process requires a machine which is designed to convert mechanical energy into heat at the joint interface using relative movement between work pieces. Friction welding is the welding process in which the heat required for welding is obtained by friction between the ends of the two parts to be joined .One of the parts to be joined is rotated at a high speed near and the other part is axially aligned with the second one and pressed tightly against it. The friction between the two parts raises the temperature of both the ends. Then the rotation of the part is stopped abruptly and the pressure on the fixed part is increased so that the joining takes place.

II. TYPES OF FRICTION WELDING PROCESSES

1. Linear friction welding

In linear friction welding as the relative motion between the work pieces is linear. In LFW process the parts to be welded are forced to come in direct contact of each other and then they are subjected to an overturned motion .This results in frictional heating of work pieces at the weld plane, thereby raising its temperature near to its Melting point. As time passes this thermo-plastic layer is extruded at the periphery of the weld-layer as undulated sheets of metal termed as flash. The formation of flash conforms the fact that any interfacial has been thrown out during the friction between the parts. The heat affected zone (HAZ) in LFW is small because the joining of parts takes place at a faster rate and the direct heat input to the weld-pool is just enough to create a small HAZ. So with proper selection of material and weld parameters, the material deformation at the weld surface can be controlled.

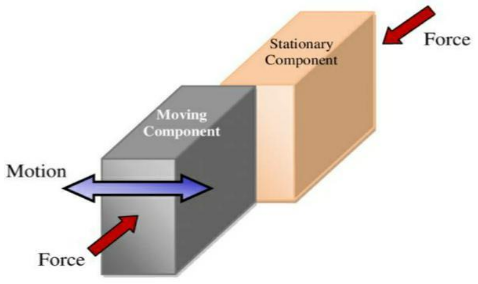


Fig. 1 Linear Friction Welding proces

2. Rotary friction welding

In RFW, one work piece is rotated against the other. It is the most commonly used friction welding process in automobile industry. The process has been used to manufacture suspension rods, steering columns, gear box forks and drive shafts and engine valves, in which there is requirement of welding of unalike materials of valve stem and head.

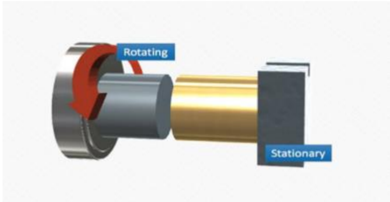


Fig. 2 Rotary friction welding process

3. Inertia Friction Welding

In this friction welding, the energy required to make the weld is harnessed from the rotational KE stored in a fly wheel of the welding set up. In Inertia Friction Welding, one part is connected to a flywheel and the other is constrained from rotating. The flywheel is accelerated to a specific rotational speed to store the required energy. Then the driving motor is withdrawn and the work pieces are forced together to interact directly. This drives the surfaces to rub against each other under pressure. The kinetic energy stored in the rotating flywheel forces the part attached to t to rotate and this rotation is opposed by the other constrained part which results in generation of heat. Due to the opposition by the constrained work piece the fly wheel get slowed down and its KE gets converted into heat. An increment axial force is applied before rotation stops. The axial force is kept for a specific time even after rotation stops.

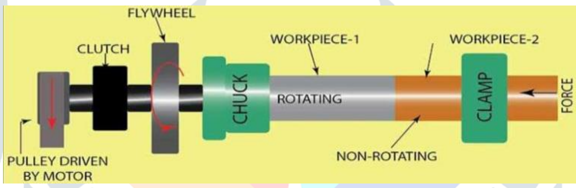


Fig. 3 Process of Inertia Friction Welding

4. Friction Stir Welding

Friction Stir Welding (FSW) is a recently developed friction welding process which was developed at The Welding Institute, Cambridge, UK. This method uses a rotating non-consumable welding tool. This technique uses a non- consumable rotating tool to create frictional heat and distortion at the welding position, thereby upsetting the development of a joint, while the material is in the solid state. The main benefits of FSW, being a solid-state procedure, are low alteration, absenteeism of melt-related flaws and great joint strong point, even in those alloys that are considered non-joinable by conventional practices. In addition, friction stir welded joints are regarded as the absence of filler-induced glitches or defects, since the method necessitates no filler. Also the hydrogen damage that occurs during welding of steel and other iron alloys has to be avoided by decreasing the hydrogen contents of the friction stir welded joints.

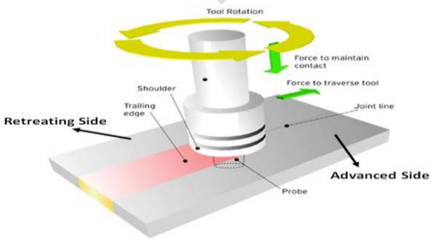


Fig. 4 Friction Stir Welding process

III. ADVANTAGES

Friction welding is economical in that it permits joining together different materials, one of which may be inexpensive and its quality control cost is minimal with a guarantee of high quality welds. Moreover, the weld cycle is extremely short, so that productivity is very attractive. Friction welding process is suitable for mass production.

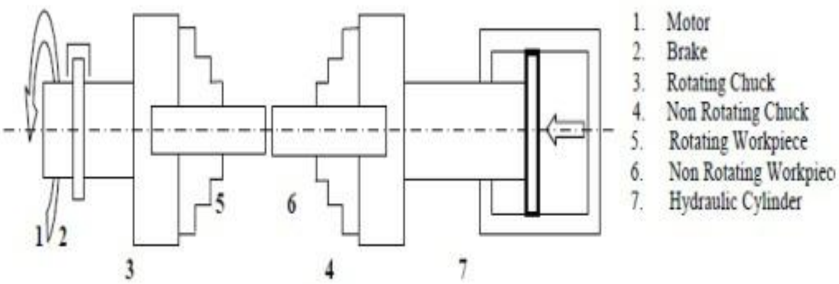
The friction welding process is suitable for non-homogeneous joints involving materials having quite different chemical, mechanical and thermal properties. The process is suitable for automation and adoptable for robot use. Other advantage as follows:

- Weld heat affected zone (HAZ) has a fine grain hot-worked structure, not a cast structure found with conventional welding
- Material and machining cost savings -100% Bond of full cross section
- High production rates
- Automatic repeatability
- Stronger than parent material, with excellent fatigue resistance
- Similar and dissimilar material joined with no added fluxes or filler metals
- Low distortion, even in long welds -excellent mechanical properties as proven by fatigue, tensile, bend tests -no fume is produced
- No porosity
- No spatter
- No filler wire is required for welding
- No welder certification is required
- It can operate in all positions
- More energy efficient than other welding technologies
- Environmentally friendly process minimizes energy consumption and generate no smoke, gasses or waste stream
- Joint strength equal or greater than that of parent material
- Join highly dissimilar metal combination to optimize your product's quality and properties
- Save labour, material and operations through near net size design
- Join less costly, lighter or tubular material to expensive material.

IV. WORKING PRINCIPLE

The principle of this method is the changing of kinetic energy (it may be rotational or translational) energy into heat energy through friction. One piece is obsessed and revolved about its axis while the other part to be joined to it is engrossed and is not revolved but can be relocated axially to create interaction with the spinning component. When fusion temperature is reached, then gyration is clogged and forging pressure is smeared. Heat is produced due to friction and is focused and contained at the edge, grain structure is polished by scorching exertion. Then the joint gets formed but there is no melting of material.

Fig. 5 Layout of continuous drive friction welding



V. SCHEMATIC EXPERIMENTAL SET-UP

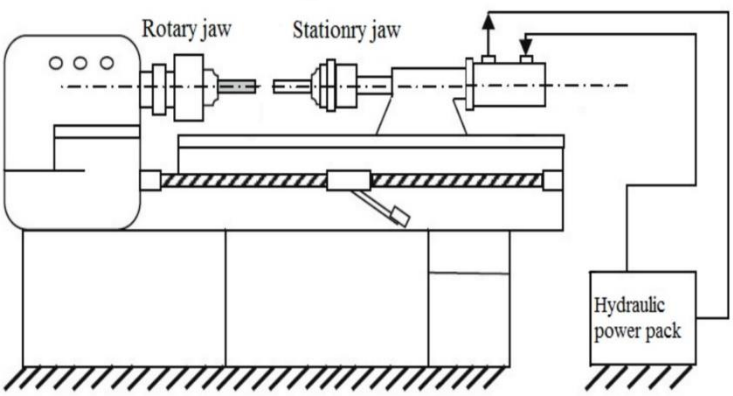


Fig. 6 schematic Experimental setup

Initially both materials are load in to fiction welding machine. From both materials one material held in chuck and another material is held in stationary fixture or chuck. After that input some parameters like friction time, upset time, friction pressure and forge pressure. Three steps of friction welding process which is listed below:

Step 1: In first step, one material held in spindle which is rotating and another material is stationary which is held in fixture. After that input the predefined parameters like rotational speed, axial force, and friction pressure and friction time.

Step 2: These all parameters applied for predefined time. These parameters applied till desired temperature obtained. During this stage the materials are deform and plasticized. Due to deformation here some length of both materials are reduced is called length loss and triggers the stopping point when the part reaches planned Overall Length.

Step 3: in this stage the rotational speed is stopped and axial force or forge force is applied for another pre-defined time. Finally the weld is created and specimen is removed from friction welding machine. This provides grain refinement and molecular bonding through the weld zone.

VI. OBJECTIVES OF THE REVIEW

Following are the objectives of the literature review.

1) To learning work finished in the area of friction welding by different researchers.

2) To study their outcomes.

3) To identify the research concerns.

VII. LITERATURE REVIEW

[1] R.kumar investigated the Ti-6Al-4V titanium alloy and 304 L stainless steel friction welded with copper interlayer. The weld joint was analysed for its mechanical strength, microstructural analysis and elemental analysis were carried out by EDS and formation of intermetallic compounds at the interface was identified by XRD analysis. The parent metal without interlayer welded but the joint was failed in drop test. This was due to the crack formation and the brittle intermetallic compounds with martensite phase resulted in lower strength. The addition of the copper interlayer has produced high tensile strength in order of 523.6Mpa as compared to joints without interlayer. In mechanical and metallurgical characterization of the weld samples with minimum thickness have produced better strength.

[2]M.dipak Kumar was investigated characterization studies on weld strength of rotary friction welded austenitic stainless steel tubes (SS304) tubes. The parameters used heating load, upset load, heating time, upset time and keep spindle speed 1100 rpm constant. SS304 tubes outer diameter 19 mm and thickness 2 mm. Weld strength obtained 780mpa at parameter upset load 143Mpa, and Upset time 4sec. Taguchi method is used for optimising parameters.by Annova method the significant factors is heating pressure and upset pressure. The optimised parameters is heating pressure 143mpa, upset pressure 143mpa heating time 22sec and upset time 4sec and from analysis it is observed that the tensile strength of joint increased with increase in upset pressure and heating pressure.

[3] Tanju teker did the examination of mechanical properties of high chromium white cast iron and AISI1030steel welded by friction welding with nickel interlayer. Thickness of interlayer is 2mm and length of H-cr-w-cl and AISI1030is 75mm.weld joints produced by following parameters rotation speed2000rpm, friction Pressure 80mpa, forging pressure 150Mpa, forging Time 8sec and variance in friction time is (8, 10 and 12sec).Nickel is higher in weld zone. The three specimen ns created and the maximum tensile test results of samples S1, S2, and s3 were measured 310,336and, 386mpa respectively. The conclusion of this study is tensile test value increases with increasing in friction time.

[4] Honggang Dong, Yanguang Li, Pengli did the investigation of mechanical properties and microstructure inhomogeneous behaviour in friction welding of 5052 aluminium alloy and 304 stainless steel. The intermetallic compound and mechanical properties were inhomogeneous due to the inhomogeneity of heat generation along the radius direction. Imcs formed in R/4, R/2, and 3R/4. The thickness of imcs maximum value in 3R/4 rather than edge location rotary friction welding own the inherent nature rotating around it's axis which results in homogeneity of heat generation along the radius direction, so the microstructure and mechanical properties of joints are inhomogeneous in different locations.

[5] M. Deepak kumar investigated effect of welding parameters of joint strength of rotary friction welded UNS S31803 tubes successfully. In this experiment they used duplex stainless steel. For this experiment they used parameters like heating load, upset load, heating time and upset time. Taguchi L9 orthogonal array used for optimization of parameters. The heating time is most influencing factor. The maximum tensile strength get 610Mpa at the welding condition of heating load 1200kg, upset load 1200kg , heating time 20sec, and upset time 4 sec.

[6] M.balasubramanian, rkumar and s.gopinath s. did the experiment for multi objective optimisation of friction welding parameters in joining titanium alloy and stainless steel with a novel interlayer geometry. In friction welding of titanium alloy and stainless steel they make a taper groove on SS304L surface for inserting the interlayer material copper. They used pure copper coin thickness 2.5mm. SS304L and Ti-6Al-4V dimensions is 20mm diameter and length 100mm. process parameters were friction

pressure, upset pressure, friction time, upset time, four parameters used. Taguchi L27 orthogonal array selected. In this experiment the maximum tensile strength get 364.29Mpa at friction pressure 20bar, upset pressure 40 bar, friction time 6 sec, upset time 7 sec. from analysis of variance of this experiment the friction pressure is highly significant factor. The optimal level of friction pressure, upset pressure, upset time and friction time is 20bar, 40bar, 1 sec and 6 sec respectively.

[7] Billel cheniti, Djamel miround, investigated microstructure and mechanical behaviour of dissimilar AISI304L and Wc-Co cermet rotary friction welds. Experiment is conducted using different friction times. The microstructural results showed that increase in friction time 4sec to 12sec than increase in grain size in both HAZ. Increase the friction time resulted in a decrease of hardness and increase of young modulus whereas the maximum bonding strength was obtained at 8 sec friction time. In friction welding of Wc-Co cermet to AISI304L stainless steel the microstructural and mechanical investigation conclude that for used parameters upset time, upset pressure, friction pressure, and rpm. 8 sec is optimum time. The parameters used upset time, upset pressure, friction pressure and rpm is 5sec, 5Mpa, 3Mpa and 3000rpm respectively.

[8] G.samuthiram did the experiment of rotary friction welding of EN24 steels cylindrical rods. They optimise the process parameters for maximize the tensile strength and hardness. The optimum parameters of high hardness value of EN-24 steel rods are 125Mpa of friction pressure and 3 sec friction time. The optimum parameters of high ultimate strength of EN-24 steel rods are 150Mpa of friction pressure, 220Mpa of forge pressure and 5 sec of friction time. EN-24 steel rods of welded joints provide good strength and better ultimate strength and improve toughness after friction welding process.

[9] k murali did the investigation of mechanical properties of dissimilar metals by friction welding. Joining of dissimilar metal is most essential need of the industries. Dissimilar metals used for this experiment is mild steel and copper. Dissimilar metal mild steel, copper both measuring 19mm diameter and length of mild steel 265mm. And length of copper 82mm used in this experimental work. The highest tensile strength obtained in weld joint was 149.571Mpa. the highest hardness obtained in the weld joint was 835 RHN. The hardness in the welded zone was higher than the heat affected zone. The friction pressure and forge pressure is plays an important role in making the strong diffusion with the surfaces of materials.

[10] Paulraj sathiya, optimization for friction welding parameters with multiple performance characteristics. This paper presents an investigation on the optimization and the effect of welding parameters on multiple performance characteristics tensile strength and metal loss obtained by friction weld joints. The output variables were the tensile strength and metal loss of the weld. These output variables were determined according to the input variables is heating pressure, heating time, upset pressure and upset time. From these parameters the tensile strength is maximize and minimize the metal loss. The metal loss tends to increase with increasing the friction time in all the base materials tested for the optimized input values by Taguchi method and joints exhibited higher quality.

[11] M.Vural scrutinized the friction stir welding competency of the EN AW 2024-0 and EN AW 5754-H22 Al alloys. These two Aluminium alloys are extensively used in the industry. The experiment presented that the hardness value of EN AW 2024-0 at the weld area is increased about 10-40 Hv. This may be the result of recrystallization and compact grain structure formation. But hardness of EN AW 5754-H22 got decreased due recrystallization and loose grain structure formation. Welding performance of EN AW 2024-0 is 96.6 and for EN AW 5754-H22 it is 57%. Welding performance of dissimilar Aluminium alloys EN AW 2024-0 and EN AW 5754-H22 is reached a value of 66.39%. Analysis of Welding zone using scanning electron microscope showed no change in the microstructure in the welding zone. Hardness distribution at the weld zones didn't show any significant change in hardness

[12] Yong-Jai Kwon et al. investigated the friction stir welding between 5052 aluminium alloy plates with a thickness of 2 mm. The tool rotation speeds were ranging from 500 to 3000 rpm under a constant traverse speed of 100 mm/min. Welded joints were obtained at tool rotation speed 1 000, 2000 and 3000 rpm. At 500, 1000, and 2 000 rpm onion ring structure was clearly observed in the friction-stir-welded zone (SZ). The effect of tool rotation speed on the onion rings was observed. Gain size in the SZ is smaller than that in the base metal and is decreased with a decrease of the tool rotation speed. The study showed that the strength, tensile strength of the joint is more than that of the parent metal. The investigation also demonstrated that the joint is less ductile than the parent alloy.

[13] Whitley Eder Paduan Alves, Institute of Aeronautics and Space São José dos Campos – Brazil The purpose of this work was to assess the development of solid state joints of dissimilar material AA1050 aluminium and AISI 304 stainless steel, which can be used in pipes of tanks of liquid propellants and other components of the Satellite Launch Vehicle. Tests were conducted with different welding process parameters and the results were analysed by means of tensile tests, Vickers micro hardness, metallographic tests and SEM-EDX. The strength of the joints varied with increasing friction time and the use of different pressure values.

[14] Emel Taban a, Jerry E. Gould b, John C. Lippold. Dissimilar friction welding of 6061-T6 aluminium and AISI 1018 steel. Specifically, the introduction of aluminium alloy parts into a steel car body requires the development of reliable, efficient and economic joining processes. Since aluminium and steel demonstrate different physical, mechanical and metallurgical properties, identification of proper welding processes and practices can be problematic. In this work, inertia friction welding has been used

to create joints between a 6061-T6 aluminium alloy and a AISI 1018 steel using various parameters. Optimum speed rpm related to bending strength (Mpa).

[15] J. Adamowski et al. analysed the mechanical properties and micro structural variations in Friction Stir Welds in the AA 6082-T6 with varying process parameters. Tensile test of the welds was done and relation among the process parameter was judged. Microstructure of the weld interface was observed under optical microscope. Also micro hardness of the resulting joint was measured. It was observed that test welds show resistance to increment of welding speed, Hardness reduction was observed in weld nugget and heat affected zone (HAZ). The reason for this occurrence was the kinetic and thermal asymmetry of the FSW process. The hardness was inferior to that of fusion welding. Tunnel defects were found in the nugget zone.

[16] Yeung, M.N. Ahmad Fauzi,M.B. Uday, H. Zuhailawati, A.B. Ismail are investigated Microstructure and mechanical properties of alumina-6061 aluminium alloy joined by friction welding alumina-6061 aluminium alloy joints were welded successfully by friction welding. Some interesting developments of microstructure and properties were observed in the welding area. The HAZ is very narrow, if not non-existent, in the case of 1250 rpm and the bending strength values obtained were greater in joint using rotational speed of 2500 rpm than with 1250 rpm. The use of higher rotational speed with constant friction time and pressure increases the bending strength of friction welded as a result of heat input, high plastic deformation and shearing of grains at the interface.

[17] Shyam Kumar Karna1, Dr. Ran Vijay Singh2, Dr. Rajeshwar Sahai was carried out Application of Taguchi Method in Indian Industry and he investigate Taguchi Parameter Design is a powerful and efficient method for optimizing the process, quality and performance output of manufacturing processes, thus a powerful tool for meeting this challenge. Off-line quality control is considered to be an effective approach to improve product quality at a relatively low cost.

[18] Wang, SHUBHAVARDHAN R.N & SURENDRAN S in investigated friction welding to join stainless steel 304 and aluminium 6082 materials via continuous drive friction welding process and study about austenitic stainless steel (AISI 304) and aluminium materials were welded successfully. The welding process was investigated by tensile testing, impact testing, Vickers micro hardness testing, fatigue testing, micro structural observation, and ED's measurements with the following results. The weld joint with optimum upset pressure and upset time absorbed valuable amount of energy representing the complete bonding and good weld strength at the interface, compared with the other two, lesser upset pressure and upset time, and higher upset pressure and upset time weld joint specimens.

[19] Radosław Winiczenko investigated Effect of friction welding parameters on the tensile strength and microstructural properties of dissimilar AISI 1020-ASTM A536 joints. Study of RFW parameters and microstructures of AISI 1020 -ASTM A536 materials are carried in this paper. RSM (Response surface methodology) and GA (Genetic Algorithm) technique are use to module, simulate and optimize parameters. Friction force and friction time is directly proportional to tensile strength. Maximum tensile strength of joint is 87% of base metal. Tensile properties, microstructure, Vickers hardness distribution, fracture morphology is studied. Metallography study conclude that diffusion of carbon atoms from ductile iron to steel takes place during welding which causes formation of carbon rich zone at interface and decarburization zone in ductile iron near to bond surface.

[20] Peng Lia,c, Honggang Donga, Yueqing Xiaa, Xiaohu Haoa, Shuai Wanga, Longwei Pana, Jun Zhoub studied about Inhomogeneous interface structure and mechanical properties of rotary friction welded TC4 titanium alloy/316L stainless steel joints. Study of structure and mechanical properties of friction welded (as welded and post welded heat treated conditions) joint of TC4 Titanium alloy and 316L SS. Interface side of TC4 is convex while that of SS 316L is concave. Initially tensile strength obtained is 117 MPa which increases to 419 MPa after heat treatment at 600 degree Celsius for 2hours. This is due to homogenization of aggregated atoms. Sliced samples are weak after treatment due to internal defects which results into cracks after machining which causes stress concentration at the interface. The X–ray diffraction patterns of TiC , $Cr_{23}C_6$, Fe_2Ti, FeTi, $FeNi_3$, $AlTi_3$, $CrTi_4$, NiTi and TiCr phases and the river like features on fracture surfaces indicate a brittle quasi-cleavage fracture mode. Carbon and chromium aggregates are found around interface after welding and before heat treatment.

[21]J. Alex Anandaraj a, S. Rajakumar a, V. Balasubramanian a, Vijay petley b had done Investigation on mechanical and metallurgical properties of rotary friction welded In718/SS410 dissimilar materials. In718 and SS410 are friction welded and their microstructural behaviour and mechanical properties are determined. Parameters: 220 MPa friction pressure, 10 s friction time, 220 forging pressure, forging time 8 s and 1300 rpm. Maximum strength of 652 MPa is obtained. Microstructure analysis says that mostly failure occurs in steel side thermomechanical affected region.

[22] Jeswin Alphy James, Sudhish. R had Study on Effect of Interlayer in Friction Welding for dissimilar Steels: SS 304 and AISI 1040. Comparison of properties of weld (microstructure, tensile strength, micro hardness and FESEM -EDS), with and without interlayer weld form between austenitic SS 304 and medium carbon steel AISI 1040 using different parameters. Nickel is used as an interlayer material. Taguchi Orthogonal Array is used for designing experiment.

[23] Hyogo Prefectural Institute of Industrial Research, Kobe-shi, Hyogo Semitsu Industries Co Ltd, Osaka-shi, Osaka Silverloy Co Ltd, Kasai-shi, Hyogo Chiukyo Co Ltd, Konan-shi, and Aichi had studied on Friction welding of cemented carbide alloy to tool steel. Tool steel is friction welded with cemented carbide alloy using interlayer. Interlayer was dispersion strengthen by

tungsten carbide with nickel as matrix. Tensile strength of joint is more than 730 MPa when forge pressure is less than 250MPa, but by increasing forge pressure more than 300 MPa tensile strength decreases. Tensile strength decreases for forge pressure more than 300 MPa due to formation of minor cracks in intermediate layer. These cracks are result of the difference in deformation rates of nickel matrix and WC particles due to compressive strength produced while providing forge pressure.

[24] Moat et al., have studied Microstructural variation across inertia friction welded SCMV (high strength low alloy Cr–Mo steel) and Aermet 100 (ultra-high strength secondary hardening steel). They carried out micro-hardness testing and hard X-ray diffraction mapping on inertia friction welded samples of SCMV steel and super high strength Aermet 100 steel in the as-welded post weld heat-treated condition.

[25] Dey et al. chose titanium (18 mm dia. & 100 mm length) and 304L stainless (14 mm dia. & 100 mm length) steel to weld by continuous drive friction welding. During this work they have investigated optimum friction welding parameters that produce joints that are stronger than the Ti base material as confirmed by tensile test, and tensile test failure occurred in the Ti base material. As-welded bend test samples failed with almost zero bend ductility. The bend ductility was improved to 5° PWHT (Post weld heat treatment). Corrosion test showed corrosion rate of 10 mpy (milli-inch per year) with boiling nitric acid.

[26] Seli et al., have studied mechanical properties of mild steel and aluminium welded rods to understand the thermal effects. They used an explicit one-dimensional finite difference method to approximate the heating and cooling temperature distribution of the joint. They observed thermal effects of the friction welding to have lowered the welded materials hardness compared to the parent materials.

[27] Mumin Sahin, have worked on computer program simulation of how weld flashes occur in welded joints of equal or different diameter of AISI 1040 (Medium carbon steel). He investigated that the optimum welding parameters obtained from equal diameter parts cannot be used in welding of parts that have different diameter and width. As a result, in welding of parts having different diameter and width, the optimum parameters of the joints should be ordinary selected in the experiments.

VIII. LITERATURE REVIEW CONCLUSIONS (SOLUTIONS FOR RESEARCH ISSUES)

Weld quality can be checked by tensile test, fatigue test, impact test, microstructure test, hardness test.

• Weld quality can be improved by

i. Optimization of weld parameters

ii. Use of interlayer,

iii. Changing geometric shape,

• Weld friction parameters:

Friction pressure, Friction time, Upset pressure, upset time, Rotational speed.

• All forgeable varieties of engineering metals can be friction welded.

From the literature review following research issues are identified and are summarized as below,

• It is necessary to optimize the friction welding process parameters to get good weld strength and weld geometry. (Welding parameters: Friction time, friction pressure, upset pressure, upset time, rotational speed)

• Optimization of above parameters is highly material specific.

• The optimum welding parameters that obtained from equal diameters parts could not be used in welding of different diameters parts.

IX. CONCLUSION

The friction welding quality is much higher than conventional fusion welding process. The variation in the friction welding parameters directly affect the weld strength. The optimization of friction welding parameter is required for getting higher strength. Weld geometry is also studied for getting higher bonding strength and high quality weld.

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