THEORETICAL APPROACH AND METHODS OF ROTARY FRICTION WELDING AND THEIR APPLICATIONS IN AUTOMOBILE INDUSTRY

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Abstract
Friction welding is a solid state welding process that generates heat through mechanical friction between a rotating or moving component and a stationary component. The principal advantage of frictional welding, being a solid state process is low distortion, absence of melt-related defects and high joint strength, even in those alloys that are that considered non-weldable by conventional welding techniques. Friction welding is further divided into as per type of drive, relative motion between work pieces. Numerous experiments have been performed using different materials and parameters and studied their effect on join strength. Friction welding obtained by frictional heat & it's a commercial process, which has found several applications in different manufacturing processes with the advancement in technology. Friction welding is one of the most widely used in the automobile industry after electron beam welding process. This paper presents a review of friction welding and various research done in this field.

Keywords: *Friction welding, Heat Affected Zone, Force, Temperature, thermal, inertia friction welding.*

I. INTRODUCTION

Friction welding is a type of solid state welding, where welding takes place by application of friction between two surfaces of metal having relative motion. Required heat is generated due to friction of two metals on each other and the temperature generated is evaluated to the level where the parts subjected to friction weld together. Friction welding is a collection of solid state welding processes, where heat is produced by means of mechanical friction between moving and stationary work pieces with the addition of an upsetting force to displace material plastically. It is a type of pressurized welding method, where no electric or other power sources are used, mechanical energy produced by friction in the interface of parts to be welded. Using heat in the welding region is efficiently distributing on surfaces, to which welding will be applied. Friction welding is a solid-state joining process that produces coalescence in materials, using the heat developed between surfaces through a combination of mechanically induced rubbing motion and applied load. The resulting joint is of forged quality. During the welding process, surfaces are under pressure and this period called the heating phase continues until plastic forming temperature is achieved.

The temperature in the welding region for steels is between 900ºC and 1300ºC. Heated metal at the interface accumulates by increasing pressure after heating phase. Thus, a type of thermo-mechanical treatment occurs in the welding region and this region has stable particle structure. Metals and alloys, which cannot be welded by other welding methods, can be welded using friction welding. In order to obtain welding connection between parts, untreated surfaces need to be contacted to one another. This contact is efficient because friction corrects contacting problems. The melting process does not normally occur on contacted surfaces. Even though, a small amount of melting may occur, accumulation caused by post-welding process makes it invisible. Fig 1. shows the stages of Rotary Friction Welding. One of the parts is stationary while the other one rotates. When the rotational speed rises to a certain value, axial pressure is applied and vocational heating occurs in parts at the interface. Then, rotation is stopped heated material at the interface accumulates.

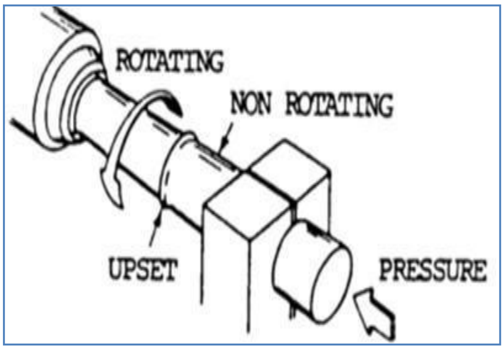

Fig 1: Rotary Friction Welding

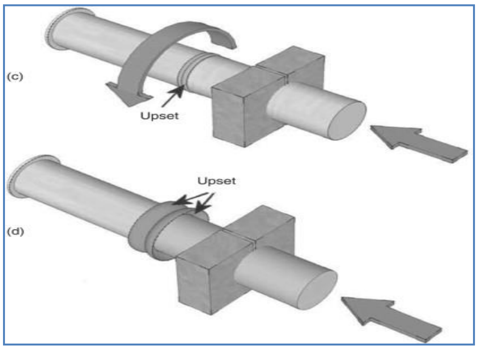

Fig 2: (HAZ) stages of friction welding.

Objective of the review

1. To study the basic methods and principle of welding technology and their automotive applications.
2. To study their Advantages, Disadvantages and limitations.
3. To identify the research issues and their challenges.

II. LITERATURE REVIEW

Friction welding is a commercial process which has developed through years with the advancement in technology. Preliminary trials were made using lathe machines for welding. However, they were considered impractical due to incorrect techniques. The first patent of friction welding process was granted to J.H. Belington. He applied friction welding to weld metal pipes. Studies on welding of plastic materials were carried out in the 1940s in USA and Germany. A Russian machinist named A. J. Chdikov has conducted experimental scientific studies and suggested the use of RFW as a commercial process. He patented this process in 1956. Researchers of American Machine and Foundry Corporation named Holland and Cheng have worked on thermal and parametrical analysis of friction welding. Studies of friction welding in England were carried out by The Welding Institute (TWI) in 1961.The Caterpillar Tractor Co. modified the friction welding to develop the method of inertia welding in 1962. After this study, conventional friction welding has been regarded as the Russian type process and inertia welding as the Caterpillar type process. With these advances, friction welding has found applications in different engineering fields. Friction welding is a widely used welding method in the industry after electron beam welding.

III. BASICS PRINCIPLES AND METHODS OF ROTARY FRICTION WELDING

Continuous Induced Friction Welding: An inducement driven spindle provides the necessary energy for rotation. Mechanical energy is converted to heat by applying pressure from rotating part to non-rotating part. One of the parts is connected to the engine inducement unit and rotates at a constant velocity; a constant axial force is applied to parts. Working parts interact with each other during welding or until axial shortening occurs. Then, braking system stops the process. Pressure applied during welding is increased and stays at a certain value until weld cools down. The essential welding parameters are rpm, friction force on the surface, and the length of friction joint, forging force and forging time. A schematic of continuous inducement friction welding machine is given in Figure 3 and process parameters in Figure 4.

1. Inducement engine
2. Brake
3 a. Spindle rotates
3 b. Spindle of stationary
4 a. Rotating working part
4 b. Stationary working part
5. Accumulation cylinder

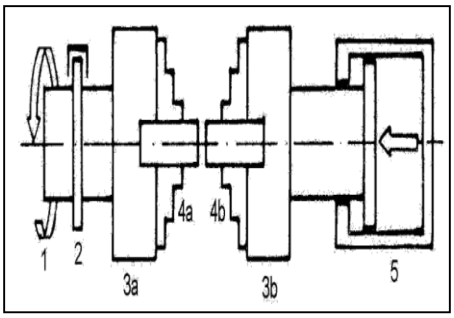

Fig.3: A continuous inducement friction welding

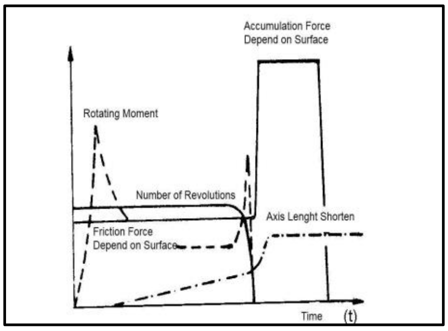

Fig 4: Process Parameters Vs time in FW.

Flywheel induced friction welding:

In this welding method, flywheel induced system constantly rotates and is joined to flywheel shaft system to achieve a certain speed. After reaching a certain speed, engine flywheel is separated from shaft flywheel. Shaft flywheel having a low moment of inertia stops without braking. Therefore, this welding method is known as welding of inertia. One of the parts is connected to the flywheel and accelerates at a certain speed and thus mechanical energy is stored in the flywheel. Then, the two parts are contacted and a certain welding pressure is applied. Parts under this pressure interact with each other and energy stored in the flywheel is spent for friction. The speed of flywheel decreases as welding region heats up. When pressure is increased before flywheel completely stop then the effect continues for some time. Flywheel induced friction welding has better seam, narrower HAZ, better serial production, lower power need and more simple apparatus than continuous induced friction welding. The essential welding parameters are rpm, forging force on the surface, the mass of flywheel, and forging time. A schematic of flywheel induced friction welding machine is given in fig: 5 & process parameters in Fig.6.

1. Inducement engine,
2. Changeable Flywheel,
3a.Spindle of rotating working part,
3b.Spindle of stationary working part,
4a.Rotating working part,
4b.Stationary working part,
5. Accumulation cylinder

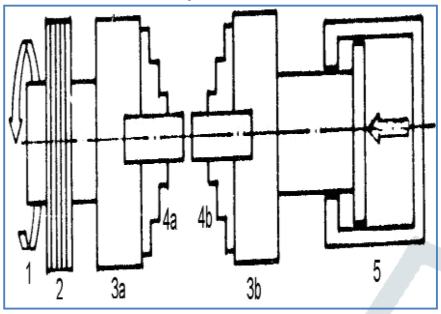

Fig 5: A flywheel induced friction welding.

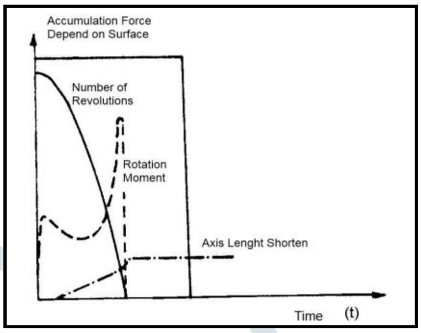

Fig 6: Process Parameters versus time.

Properties of Friction Welding Machine:

Phase 1: Low temp interface heat cycle by spinning one component against another stationary component.
Phase 2: Solid forging cycle showing displaced plastic state material when final axial forging force is applied.
Phase 3: Plastic state flashing is removed easily, even for harden able materials that would otherwise require grinding.

A friction welding machine has the main body, joining parts, rotate and accumulate mechanisms, brake system, power supply, control unit and control panel. Friction welding machines are all-mechanized machines. Joining and releasing of parts, turning of copular produced due to accumulation after welding are automatically accomplished. The main functions in friction welding are joining, compressing and releasing of parts, rotation and friction under pressure, braking, accumulation and precise adjustments of required processing times. Simple joining apparatus needs to have certain rigidity, must resist increased moments, and must eliminate vibrations and leaks. Especially, possible vibrations during welding process need to be taken into account while designing the friction welding machine. In addition to vibrations, other radial and axial forces have to be accounted for design consideration. Friction welding machines have certain particle size and material limitations. For example, a machine having 120KN compressed force and 15KW electric engine can be used in the welding of steels with cross sectional areas of 130-800 mm^2.All machines can be adjusted to meet certain specifications and can automatically be controlled. This process is sometimes done by just manually turning off the switch or protectors.

Rotary friction welding

Rotary friction welding (Fig.7) is a type of friction welding in which one component is rotated against the other, It is the most commonly used among the friction welding processes. Rotary friction welding (RFW) is a solid-state joining process which works by rotating one work piece relative to another while under a compressive axial force. The friction between the surfaces produces heat, causing the interface material to plasticize. The principle of friction welding is to change mechanical energy into heat energy. One of the work pieces is to be welded and rotated about its axis while the other work piece is stationary and does not rotate but it's moved axially to make contact with the rotating work piece. The rotation is stopped at the point of fusion and forging pressure is applied axially on to the stationary work piece. The forging force applied leads to coalescence, welding the two work pieces.

STEP 1: One work piece is held stationary. The second part is rotated in a spindle, which is then brought up to a pre-defined rotational speed. After the predetermined period of time, pre-defined axial force is applied.

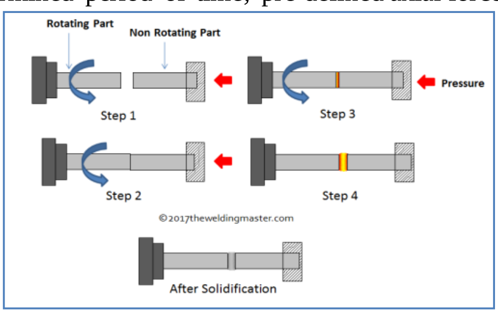

Fig.7. Steps of rotary friction welding

STEP 2: These conditions are maintained for a predetermined time. A second step of pressure is applied until the desired temperatures and material state exist. It's during this stage that the two materials are plasticized.
STEP 3: Rotational speed is stopped. Then increased axial force is applied to create "forge pressure" for another predetermined time completing the weld. This provides grain refinement and molecular bonding through the weld zone.

Inertia friction welding

In inertia friction welding the drive motor is disengaged, and the work pieces are forced together by a friction welding force. The kinetic energy stored in the rotating flywheel is dissipated as heat at the weld interface as the flywheel speed decreases. In Inertia Welding (Fig.8), one of the work pieces is connected to a flywheel and the other held stationary. The flywheel is rotated to a fixed rotational rpm, storing the required kinetic energy. The drive is then disconnected and the work pieces are forced together by the friction welding force. This causes the contacting surfaces to rub together under pressure. Due to which kinetic energy stored in the rotating flywheel generates heat through friction at the weld interface as the speed of flywheel decreases. Then force to generate friction welding may be applied before rotation stops. The force is retained for a fixed time after rotation stops.

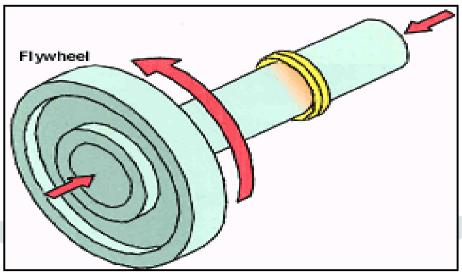

fig.8 Inertia welding

Friction stir welding

Friction stir welding also produces a required plasticized state of material, but in a different way. A non-consumable rotating tool is held under pressure against the materials to be welded. This tool is like a pin at the center, or probe, followed by the shoulder (Fig. 9).A plastic state material is generated due the heat resulted from friction between tool & materials it is in contact with. As the tool moves along the joint line, material from the front of the tool is cleaned around this plasticized circular region to the rear, so reducing the interface.

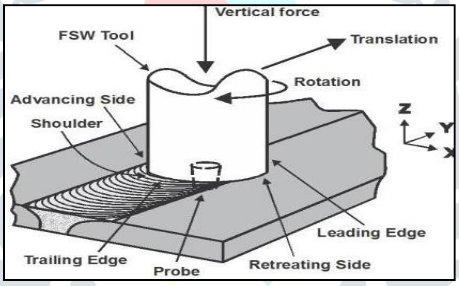

fig.9. Friction stir welding.

IV. ADVANTAGES, DISADVANTAGES AND LIMITATIONS

Dissimilar materials normally not compatible for welding can be welded. Heat-affected zone created is narrow. Minimal Joint preparation is required. Faster Turn-around Times - compared to the long lead time of forgings. No fluxes, filler material, or gases required. Environmentally friendly process – no fumes, gases, or smoke generated. Solid state processes no possibility of porosity or slag inclusions. Creates cast or forge-like blanks - without expensive tooling or minimum quantity requirements. Reduces machining labor, thereby reducing perishable tooling costs while increasing capacity. Full surface weld gives superior strength in critical areas. Reduces raw material costs in bi-metal applications.

In disadvantages, the process is restricted to joining round bars or tubes of same diameter (or bars tubes to flat surfaces), i.e. capable of being rotated about the axis. Dry bearing and non-forgeable materials cannot be welded, i.e. one of the component must be ductile when hot, to permit deformations. Preparation and alignment of the work pieces may be critical for developing uniform rubbing and heating, particularly for pieces having diameters larger than 50 mm. Capital equipment and tooling costs are high and free-machining alloys are difficult to weld.

V. APPLICATIONS

Applications of friction welding are generally used in the welding of pipes and circular rods. The basic movement in this kind of application is the rotational movement causing friction. Rotary friction welding is a type of friction welding in which one component is rotated against the other, is the most commonly used among the friction welding processes. It is mostly used in aerospace, automobile, marine and oil industries. Gears, axle tube, valves, driveline etc. components are friction welded. Hydraulic piston rod, truck rollers bushes etc. are join by friction welding. Used in electrical industries for welding copper and aluminum equipment's. Welding pump shaft (stainless steel to carbon steels). Gear levers, drill bits, connecting rod etc. are welded by friction welding.

RFW method is especially useful for the production of relatively smaller parts in the industry; Friction welding can generally be applied in the following applications listed below

Machine production and spare part industry: cogwheels, piston rods, hydraulic cylinders, radial pump Pistons, shaft with worm screw, crankshafts, drill bits, valves.

Automotive industry: valves, drive shafts, gear levers, axle fasteners, break spindles, transmission Mechanisms, preheat rooms, pipe spindles, banjo axles, Mono steel piston, Brake calipers, Transmission shafts & gears.
Aviation and space industry: repulsion jets, combustion chambers, spindles, turbines, rotors, pipes, flanges.
Work set industry: Spiral drills, milling cutters, borers, Reamers, cutting tools.
Electrical, electronics, and chemical industry: receiver camera for gas analysis, swing Contacts segregation columns for chromatograph, Electrical connectors, continuous solder top, pipe fittings.

Pump shafts Piston rods Drive shafts Airbag Drill Bits Engine valves

Fig. 10 Applications of RFW

VI. RFW TECHNOLOGY NECESSITY IN AUTOMOTIVE INDUSTRY

RFW is solid state, forged quality bonded joint offered by friction welding has made it an ideal manufacturing process for the automotive industry. With the ability to create highly durable, customized components for everything from commercial to personal use vehicles, friction welding helps to design flexible solutions to ever-changing challenges of the automotive industry. Because friction welding is highly adaptable to diverse applications, automotive manufacturers have used it to save money and improving quality of parts. Rotary Friction Welding in particular allows for high-volume production to manufacturing the parts more efficiently. From steering components to camshafts and U-joints, friction welding can accomplish. And because friction welding machines may be automated, the technology can be seamlessly integrated into a production cell. This further reduces the overall cycle time to produce the part. Parts are manufactured the same process in each time, so friction-welded parts are always produce the same high quality. And friction welding machines are more reliable than conventional welding techniques, and the automated nature of a friction welding machine takes individual operator skill out of the equation to deliver durable, defect-free parts. Compared to traditional methods, MTI’s recently developed advanced controls for friction welding allow the welded components to achieve better length control and/or radial orientation than ever before. This helps to reduce the welded tolerances that may drive the requirement for additional manufacturing operations in the production line ultimately reducing cost. When forging of two dissimilar metals together, you have the opportunity to reduce the weight of the final vehicle. The ability to combine aluminum, in particular, with other materials, has become a critical aspect of automotive production and friction welding makes it possible. So whether you’re joining aluminum with copper or steel with low-carbon alloys, the solid state bond quality you get is always strong and always consistent. The automotive industry runs on Just-in-Time inventory, where materials or parts are produced or acquired only as demand requires. Suppliers cannot afford the production disruption that comes from machine down time and must have a dependable technology in their production process. Rotary friction welding has been a part of vehicle production and it is a proven reliable process.

VII. FUTURE SCOPE AND RESEARCH ISSUES IDENTIFIED

From the literature review following research issues are identified and are summarized as: Weld quality can be checked by tensile test, fatigue test, impact test, microstructure test, hardness test. Weld quality can be improved by optimization of weld parameters, use of interlayer, changing geometric shape, pre and/or post processing. Variation in weld friction parameters like Friction pressure, friction time, upset pressure, upset time, and rotational speed. All forgeable varieties of engineering metals can be friction welded. It is necessary to optimize the friction welding process parameters to get good weld strength and weld geometry. Optimization of above parameters is highly material specific. Parameter optimization of aluminum and low carbon steel is not yet reported. Mathematical model can be developed to predict shear strength of friction welding. Finite element analysis of friction welding process can be done to optimize the weld strength. Study for checking the compatibility of various material and based on it development of mathematical model to predict compatibility

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VIII. CONCLUSION

A review study has been carried on rotary friction welding methods and their industrial applications, advantages limitations and research scope by the need of various industrial developments. RFW provides the manufacturing flexibility for manufacturing of the bimetallic parts. As the cost of tooling and machinery is quite high it is only used in mass production. The automotive application of permanent joining methods is discussed. The solid state welding method viz. the friction welding is also discussed. The technological advancement in the metal joining in the context of auto industry is presented.

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