Review of Experimental Investigation in Friction Welding Process

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Abstract- *Industries are in huge demand of new materials essential for their requirements for different applications such as aerospace, automobile & chemical Industry. In this paper review of friction welding process for joining of various metals and thermoplastic and the effect of parameters (Burn off length, friction pressure and Rotational Speed) on the welding process has been discussed.*

Keywords – Friction Welding, Thermoplastic, CDFW, IFW

I. INTRODUCTION

Now a day's friction welding is one of the techniques that have been used extensively in recent times because of its advantages such as production time, ease of manufacture and environment friendliness. Friction welding principle as shown in fig. 1, one component is held Stationary in chuck while forced to rub against another component which is held in another chuck i.e., (rotating part) under some pressure. While rubbing each other interfaces, friction is generated. Due to formation of friction, heat is being produced. Where solid components interface started convert into softer material. Thus, when the pressure is applied the component formed a homogenous solution and gets welded together. There are two basic types of friction welding techniques; continuous drive friction welding and inertia friction welding. Here continuous drive friction welding (CDFW) is used in which two chucks are used to hold the work piece to be weld, one is fixed while the other one is rotating by the continuous drive motor. In inertia friction welding (IFW) 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.

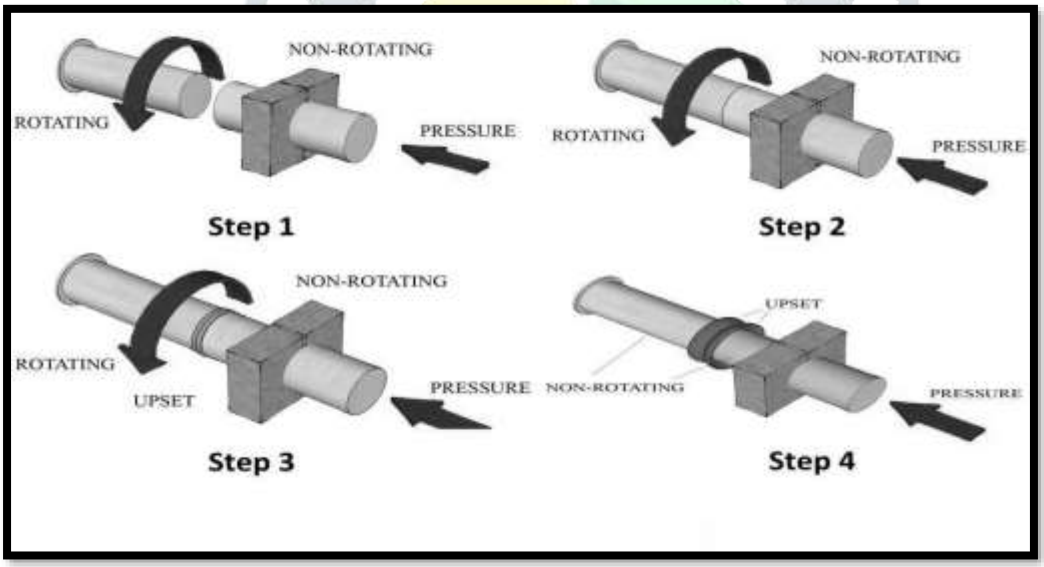

Fig 1. Diagram of Rotary friction welding

Thermoplastic Material

Nowadays, the engineering thermoplastics have potential to replace of metallic components by reducing weight and improving efficiencies. The automotive industry has traditionally produced a wide range of thermoplastic parts with the advantage of shorter processing type and fully automated equipments. Generally there are three types of polymer materials: Elastomers, Thermosets, and Thermoplastics. Out of these three polymeric materials, only thermoplastics are the weldable material. Thermoplastic molecules are held together by secondary chemical bonds, which can be broken by heating .This permits thermoplastic molecules to slide relative to each other and to diffuse across a weld interface thus, chemical and mechanical properties of polymers can be changed Thermoplastic composites have higher damage tolerance, fracture toughness, impact resistance, excellent corrosion and solvent resistance, good fatigue resistance, low storage cost and infinite shelf life. Thermoplastics are frequently joined by welding processes, after the application of localized heat at the interface which allows the polymer chains to interdiffuse.

Thermoplastic with Reinforcement of Metals Powder

Thermoplastic Material joins by using metal Powder Reinforcement by following different types of procedure. It leads to better efficiency with Friction Welding. Rheological properties (like: melt Flow Index (MFI) and glass transition temperature) play important role in properties of Thermoplastic. Thus to improve efficiency of joint in polymer reinforcement of metal powder is observed. Procedure for Reinforcement of metal powder in polymer and using in Friction Welding, Material selection according to application uses then checking MFI (Melt Flow Index) (it is a measure of the ease of flow of the melt of a thermoplastic polymer) reinforcement of metal powder in different proportions with these polymers results into similar MFI leads to contribute to better joint strength. Then DCS analysis means (Differential Scanning Calorimetry) is a thermal analysis technique in which the heat flows into or out of a sample is measured as a function of temperature or time, while the sample is exposed to a controlled temperature program. To prepare Filament, twin screw extruder setup is used. Filament will helpful in to prepare Cylinder shape specimen for experiment by using FDM (Fused Deposition Modeling) machine.
Different types of Rotary Friction Welding use for similar and dissimilar material. Basically Two types of (CDFW) Continuous drive friction welding and inertia friction welding (IFW).

Continuous drive friction welding (CDFW):

Continuous drive friction welding (CDFW) is a solid state joining process, in which one of the components to be welded is held stationary, while the other is rotated at a constant speed, and then the two parts are pushed against each other with an axial force. When sufficient temperature is reached at the friction surfaces, the rotating component is stopped rapidly and axial force is maintained at the same value or is increased for a short period of time. In this forging stage the hot metal cools under pressure and a weld is consolidated. During CDFW, temperature evolution and plastic deformation of joints are the dominant processes, which determine the removal of contaminants such as oxide debris from the weld region, and thus control the weld quality. In direct-drive friction welding (also called continuous drive friction welding) the drive motor and chuck are connected. The drive motor is continually driving the chuck during the heating stages. Usually, a clutch is used to disconnect the drive motor from the chuck, and a brake is then used to stop the chuck as shown in fig 2.

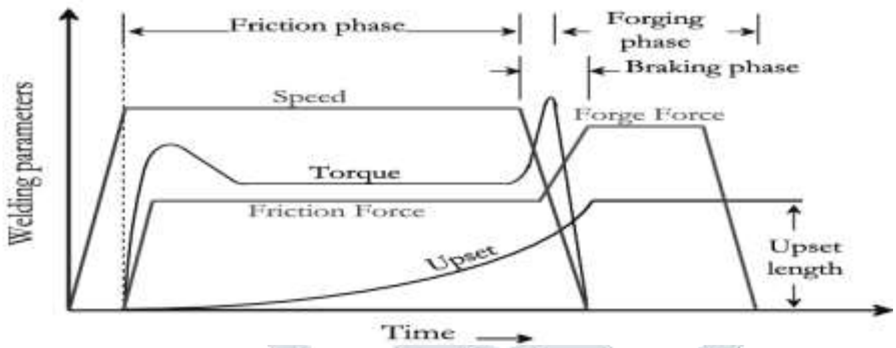

Fig. 2 typical time-load curve used during the friction welding process

Inertia Welding

In Inertia Welding (Fig. 3), one of the work pieces is placed 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.

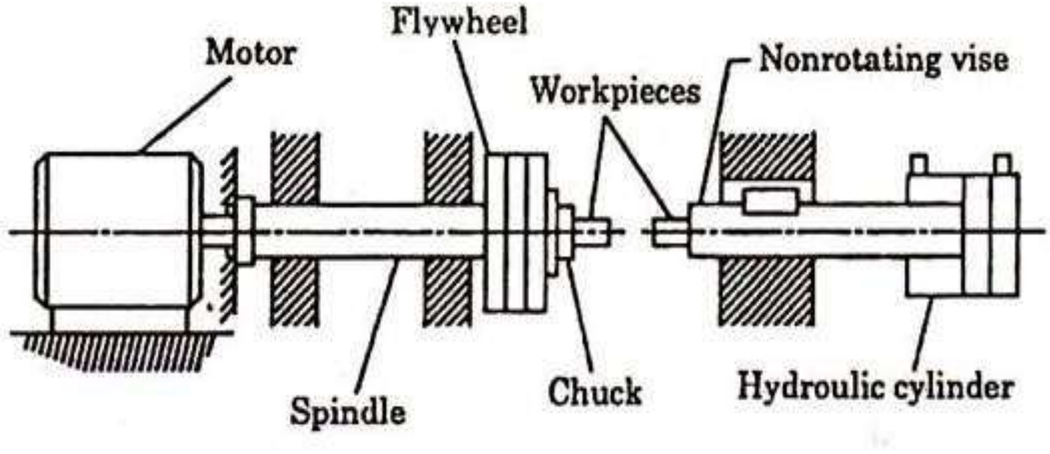

Fig. 3 Inertia Welding Schematic Diagram

Advantages of Friction Welding

- Enables joining of dissimilar materials normally not compatible for welding by other joining methods.
- Creates narrow, heat-affected zone
- Consistent and repetitive process
- Joint preparation is minimal – saw cut surface used most commonl
- Solid state process – no possibility of porosity or slag inclusions
- Reduces machining labor, thereby reducing perishable tooling costs while increasing capacity
- Reduces raw material costs in bi-metal applications. Expensive materials are only used where necessary in the blank
- Greatly increases design flexibility – choose appropriate material for each area of a blank

II. LITERATURE REVIEW

Bindal, T., Saxena, R. K., & Pandey, S. (2021) [(1)] investigated on welding of thermoplastic pipes under a shear joint configuration using friction spin welding. They evaluated the effects of welding pressure and rotational velocity on the joint overlap distance and joint strength between the parts of polypropylene plastic. The joint strength is tested by conducting the hydraulic pressure burst test. They conducted a burst test for welded specimens manufactured using different values of rotational velocity and welding pressure. It is observed that at the constant spin velocities, the welding pressure in the range 64.8 to 65.2 kPa produced better joint strength than the other values of welding pressure in the overall range 64–76 kPa. Further, they established that the user can control the joint overlap distance at 64.8 kPa welding pressure by selectively controlling the rotational velocity in the range of 700 to 2500 rpm.

Ramanujam, R. N., & Krishnamohan, S. (2020) [(2)] They have done experimentation on two dissimilar material and tested with Taguchi method is applied for optimizing the welding parameters to attain maximum tensile strength of the joint and hardness of the welded joint. It is widely used in aerospace and automotive industrial applications. The process parameters play a major role in determining the high tensile strength of the weld of dissimilar materials.1.Rotational speed, 2.Friction pressure, 3.Friction time, 4.Forge pressure. They concluded, A statistical approach namely is design experiments a Taguchi’s technique was utilized to plan and minimize the number of experiment, at the same time making reliable inference from the results. The influence of processing parameters foe the tensile property and fracture location where analyzed The optimum parameters where obtained for maximum weld strength .The welding strength is lower than base metal strength.

Kumar, M. D., & Palani, P. K. (2020) [(3)] has researched on weld strength of rotary friction welded austenitic stainless steel tubes. Austenitic stainless steel (SS304) tubes of outer diameter 19 mm, 2 mm thickness are joined together by rotary friction welding (RFW). The characterization studies are done by varying heating load, upset load, heating time, upset time and keeping constant spindle speed of 1100 rpm. The tensile and microhardness test were conducted for each fabricated joints to evaluate the mechanical properties of welded samples. The joint strength increased with increase in upset load and heating load. The maximum joint strength of 780 MPa and hardness of210HV achieved for weld parameter of upset load 143 MPa and upset time 4sec. The detailed fracture analysis reveals the weld sample joints had experienced a ductile mode of fracture at parent metal location. The microstructure analysis revealed coarse grain structure in the weld zone compared to base metal.

Alex Anandaraj, J., Rajakumar, S., Balasubramanian, V., & petley, V. (2020) [(4)] has studied mechanical and metallurgical properties of rotary friction welded In718/SS410 dissimilar materials. The optimized welding parameters are friction pressure 220 MPa, friction time 10 sec, forging pressure 220 MPa, forging time 8 sec, rotational speed 1300 rpm. The transverse tensile test has been assessed in room temperature with aid of universal testing machine and recorded the maximum fracture strength of 652 MPa. The hardness survey carried out in micro scale along the weld cross section, which records the lower hardness in TMAZ region. The macrostructure was used to study the flow behavior of rotary friction welding in lower magnification. The microstructure analysis carried out in weld and adjacent region to impose the characteristics of dissimilar joints. Finally, the results were concluded the most of the failure has been observed in the steel side thermo mechanical affected region (TMAZ). Although the ultimate aim of this research work to emphasis the dissimilar weld joint characteristics for aerospace and defence application

Sheng, J., Sohail, A., Wang, M., & Wang, Z. (2020) [(5)] they researched and develop the plastic clutch pump body based on the friction welding was carried out in order to realize the need for lightweight automobiles through replacing steel with plastics,. For the clutch pump body connected by friction welding process between the upper pump body and the lower pump body, the technical requirements of pressure 14 MPa and durability (high temperature 7.0×10^4 times, room temperature 7.0×10^5) are required. The structure type of the upper and lower pump bodies of the end face welding type was proposed. Through the static analysis of the pump body and weld and the mechanical analysis under the working condition, the structure of the clutch pump body (upper and lower pump body) was determined. According to the established welding process, the pressure of the clutch pump body is more than 15 MPa, and the number of high-temperature durable circulation and the number of room temperature durable circulation also reached 7.2×10^4 and 7.3×10^5 times respectively. The results show that the structural design of a clutch pump body meets the design requirements.

Xie, M., Shang, X., Li, Y., Zhang, Z., Zhu, M., & Xiong, J. (2020) [(6)] they studied RFW tests without upset forging on Mo in the atmospheric environment and investigated the effects of welding time on joint morphology, axial shortening, microstructures, micro hardness, tensile strength, and tensile fracture morphology. It found that the excessive and abrupt burning and a lot of smoke were generated around the weld zone during welding and spiral flashes were observed after welding. Under welding pressure of 80 MPa and spindle speed of 2000 r/min, the minimum average grain size and maximum tensile strength can be obtained in 4 s when the welding time is between 2–5 s. Scanning electron microscope (SEM) results show that there were morphologies of a large number of intergranular fractures and a small number of transgranular fractures in the fracture.

Nu, H. T. M., Le, T. T., Minh, L. P., & Loc, N. H. (2019) [(7)] they studied on selection of high-strength titanium alloys has an important role in increasing the performance of aerospace structures. Fabricated structures have a specific role in reducing the cost of these structures. However, conventional fusion welding of high- strength titanium alloys is generally conducive to poor mechanical properties. Friction welding is a potential method for intensifying the mechanical properties of suitable geometry components. In this paper, the rotary friction welding (RFW) method is used to study the feasibility of producing similar metal joints of high-strength titanium alloys. To predict the upset and temperature and identify the safe and suitable range of parameters, a thermo mechanical model was developed. The upset predicted by the finite element simulations was compared with the upset obtained by the experimental results. The numerical results are consistent with the experimental results. Particularly, high upset rates due to generated power density and forging pressure overload that occurred during the welding process were investigated. The performances of the welded joints are evaluated by conducting microstructure studies and Vickers hardness at the joints. The titanium rotary friction welds achieve a higher tensile strength than the base material.

Cheepu, M., & Che, W. S. (2019) [(8)] They studied on process Effect of Burn-off Length on the Properties of Friction Welded Dissimilar Steel Bars parameters such as burn-off length is one of the significant welding condition to govern the heat generation and coefficient of friction during welding. Burn-off length of 1 mm to 6 mm were selected to investigate its effect on mechanical properties and weld interface characteristics. An optical, scanning electron microscope and electron backscattered diffraction analyses were used to characterize the weld interface properties. The mechanical properties of the joints were evaluated by using hardness, tensile and fatigue tests. It is observed that, strength of the joints were increased with increasing of burn-off length up to optimum value of 4 mm and starts to decrease on further increasing of burn-off length.

Hamade, R. F., Andari, T. R., Ammouri, A. H., & Jawahir, I. S. (2019) [(9)] they Presented a study is a feasibility and energy study between the conventional method for joining HDPE pipes (Fusion Butt Welding) and rotary friction welding. Fusion butt welding is classed as a heat transfer model involving three phases, i) heating from room temperature, ii) steady state convection (maintaining the heat for any given period) and iii) conduction (contact between pipes and heating plate). they calculated total of the energy consumption of each of the phases is determined using a popular welding machine specification. Active control is carried out by real-time control on the process input variables, this allowed for data acquisition of thrust forces, torques and temperatures. Temperature profiles showed that the meting temperature is achieved in under 10 seconds and indicates that further analysis on heat generation is required to better understand the effect of the process input parameters on the weld quality.

Bindal, T., Saxena, R. K., & Pandey, S. (2019) (10) The material used for the present work is Polypropylene (PP) thermoplastic, used widely for industrial applications. The compo- nent manufactured using the process are generally used in making pipes and therefore, optimization of the parameters is an important requirement. The two parts of the component are fabricated using plastic injection molding. The two axisymmetric parts are successfully welded in a shear joint configuration using friction spin welding. The study is performed to analyze the effect of welding pressure and rotational velocity. The design of experiments is applied for the analysis. The minimum value of the joint overlap distance i.e., 14.2 mm is 64.1 kPa and 1100 rpm whereas the corresponding maximum values the response parameter i.e., 27.5 mm is 64.5 kPa and 1500 rpm.

Profile, S. E. E. (2019) (11) has researched on plastic vehicle fuel filler pipes have been welded on spin welding machine process. All parameters that identified and used on process control were tested with various types of experiments for analyze the effect of these parameters to the welding characterization. With the analyses pull-of tests of the samples; leakage test, hardness test, visual and optic microscope controls of samples are examined. Because of all detailed analyses; special appropriate parameters for machine were defined.

Michał, P., Krzysztof, W., Jan, G., & Maciej, B. (2019) (12) This article applies to the glue-free bonding of the components made of thermoplastics, specific techniques that use friction heat to plasticize and then join two surfaces. The featured technique is a friction (spin) welding process. Welding parameters were investigated and presented. Spin welding is known to consist of four phases. Analytical calculations were made for the first step. They are focused on the changeability of welding parameters depending on weld velocity. In the next part of this article, calculations including the finite element method were performed. This provided additional data and visualization of the process, which were not available in analytical calculations. Final results of both methods were compared.

Stütz, M., Pixner, F., Wagner, J., Reheis, N., Raiser, E., Kestler, H., & Enzinger, N. (2018) (13) has focused on Rotary friction welding of molybdenum components. Joining of TZM components by inertia rotary friction (IFW) welding is an established industrial process for welding cross-sections up to 1500 mm2. Up-scaling to medium-size components up to 5000 mm2 in a direct drive friction welding process requires a better understanding of the influencing factors of the weld procedure, e.g. machine parameters, weld preforms, and the clamping system. Based on the existing IFW process for TZM tubes, welding parameters were transferred to tubular components of pure molybdenum (OD: 150 mm, ID: 130 mm, 4400 mm2). Successful welds were produced showing a fine-grained, defect-free microstructure. However, molybdenum proved to be more challenging than TZM. Particularly high upset rates and motor overload occurred during the friction phase. Therefore, a study was carried out to reveal the underlying mechanisms with small-size samples under laboratory conditions. It was shown that extensive plastic deformation of the entire weld zone occurred due to higher thermal diffusivity and lower strength of molybdenum compared to TZM.

Wang, M.-L., Chang, R.-Y., Hsu, C.-H. (David), Wang, M.-L., Chang, R.-Y., & Hsu, C.-H. (David) (2018) (14) has investigate the effect of energy-input on the mechanical properties of a 304 stainless-steel joint welded by continuous-drive rotary friction-welding (RFW). RFW experiments were conducted over a wide range of welding parameters (welding pressure: 25–200 MPa, rotation speed: 500–2300 rpm, welding time: 4–20 s, and forging pressure: 100–200 MPa). The results show that the energy-input has a significant effect on the tensile strength of RFW joints. With the increase of energy-input, the tensile strength rapidly increases until reaching the maximum value and then slightly decreases.To verify the accuracy of the model, the optimal energy-input of a 170 MPa forging pressure was calculated. Three RFW experiments in which energy-input was equal to the calculated value were made. The joints' tensile strength coefficients were 90%, 93%, and 96% respectively, which proved that the model is accurate.

Singh, R., Kumar, R., Ahuja, I., & Grover, S. (2018) (15) has studied to perform process capability analysis for hardness obtained (for frictional welded specimens of ABS and PA6 at optimized process parameters). The work-pieces for welding of plastic based material of ABS and PA6 were prepared on FDM setup (by using feedstock filament prepared on twin screw extruder). It has been observed that the proposed process is statistically controlled with sigma value 5.74 at optimized process parametric settings.

Kumar, R., Singh, R., Ahuja, I. P. S., Amendola, A., & Penna, R. (2018) (16) Has studied on PA6 matrix reinforced with metal powder (Fe) has been joined by friction welding with ABS matrix reinforced with Fe powder for structural applications (like: joining of pavement sheets, assembly of pipe lines etc. The melt flow index (MFI) of PA6+Fe powder was put approximately equivalent to MFI of ABS + Fe powder by varying the proportion of Fe powder in PA6 and ABS matrix. After fixing proportion of Fe powder in PA6 and ABS material, these materials were used for preparation of feed stock filament of fused deposition modelling filament (FDM) by screw extrusion process. These geometrical shapes of two dissimilar plastic/polymer materials were used on friction welding setup. Finally under best parametric conditions of feed, rpm etc. these reinforced polymer materials were successfully joined.

P B Arun, Nithin Raj K, Yadhu V, & Sanalkumar C S. (2017) (17) has studied present similar joints of aluminum alloys (AA6061) were welded successfully. The welding process was investigated by tensile testing, SEM fractography analysis, micro structure analysis and Rockwell hardness test From Taguchi optimization, it is understood that S/N Ratio is maximum for experimental run 06 with a tensile strength of 210.2 MPa, working parameters of speed 1000 RPM, forging pressure 140 MPa and friction time 8 seconds.

Shanjeevi, C., Arputhabalan, J. J., Dutta, R., & Pradeep. (2017) [18] has reserached on dissimilar material combination of ferritic stainless steel and copper material are friction welded and its toughness of the weld interface were evaluated. Friction welding has been successfully joined with ferritic stainless steel and copper material. The impact toughness values obtained on joints were varied with one another. The lowest impact toughness obtained in friction welded joint was 14 J/cm2 and highest impact toughness shows with 46 J/cm2. Due to temperature rise at the weld interface and presence of intermetallic layers, accumulation of alloying elements results with poor impact toughness of the welded joint. Fracture analysis was made in the impact tested sample with different magnifications result in ductile mode of fracture with dimple formation.

Boparai, K. S., Singh, R., & Singh, H. (2016) [19] has researched development of filament for FDM system in terms of both academic research and industrial applications. The study demonstrates the high potential of alternative material for FDM process with its compatibility with FDM system and tailor made feature for RT and RM. This novel methodology helps to produce parts having complex geometry with customized properties through FDM process. A comparative study of flow rate under similar processing conditions was done by MFI and limits the reinforcement of filler content in polymer. Loading up to 40% by weight of Al+Al2O3 in Nylon 6 matrix is possible for uninterrupted processing in FDM system. The tensile strength, tensile modulus of composition A, B and C are 64%, 53%, 28% and 2.7%, 2.1%, 1.5% respectively lower than ABS material. The elongation at break increases with filler content and particle size.

Singh, R., Kumar, R., Feo, L., & Fraternali, F. (2016) [20] has presented work attempt has been made to perform friction welding of dissimilar plastic based materials by controlling the melt flow index (MFI) after reinforcement with metal powders. The present studies of friction welding for dissimilar plastic were performed on Lathe by considering three input parameters (namely: rotational speed, feed rate, and time taken to perform welding). Investigations were made to check the influence of process parameters on mechanical and metallurgical properties (like: tensile strength, Shore D hardness and porosity at joint). The process parameters were optimized using Minitab software based on Taguchi L9 orthogonal array and results are supported by photomicrographs.

Pal, K., Panwar, V., Friedrich, S., & Gehde, M. (2016) [21] has studied changes in tensile properties of polymers due to welding of semicrystalline and amorphous polymers, and its possible causes. Tensile testing proved that the welding of a semicrystalline polymer with any amorphous polymer results in poor tensile properties and thus the fracture occurs from weld zone itself. This may be considered due to the difference in glass transition temperatures of the two different types of polymers. The study opens a new trail in vibration welding of polymers to vary the properties of the polymers to be welded in such a way that their glass transition temperatures approach each other for impro- vement in morphology of weld zones.

Alves, E. P., Neto, F. P., An, C. Y., & da Silva, E. C. (2012) [22] has describes a method of temperature monitoring in bonding interface during the rotary friction welding of dissimilar materials. As it is directly related to the mechanical strength of the junction, its experimental determination in real time is of fundamental importance for understanding and characterizing the main process steps, and the definition and optimization of parameters. The temperature gradients were obtained using a system called Thermocouple Data-Logger, which allowed monitoring and recording data in real-time operation. In the graph temperature versus time obtained were analyzed the heating rates, cooling, determined the maximum temperature occurred during welding, and characterized every phases ofthe process. The system efficiency demonstrated by experimental tests and the knowledge of the temperature at the bonding interface open new lines of research to understand the process of friction welding

Costa, A. P., Botelho, E. C., Costa, M. L., Narita, N. E., & Tarpani, J. R. (2012) [23] These present work Reinforced thermoplastic structural detail parts and assemblies are being developed to be included in current aeronautic programs. Thermoplastic composite technology intends to achieve improved properties and low cost processes. Welding of detail parts permits to obtain assemblies with weight reduction and cost saving. Currently, joining composite materials is a matter of intense research because traditional joining technologies are not directly transfer- able to composite structures. Fusion bonding and the use of thermoplastic as hot melt adhesives offer an alternative to mechanical fastening and thermosetting adhesive bonding. Fusion bonding technology, which originated from the thermoplastic polymer industry, has gained a new interest with the introduction of thermoplastic matrix composites, which are currently regarded as candidate for primary aircraft structures. This paper reviewed the state of the art of the welding technologies devised to aerospace industry.

Summary of literatures Review

From the literature review following research findings are observed,

- Weld quality can be checked by tensile test, fatigue test, impact test, hardness test leakage test, visual and optic microscope controls.
- Taguchi methods use which combine the experiment design theory and the quality loss function concept have been used in developing robust designs of products and processes and in solving some taxing problems of manufacturing.
- Advantages of replacing Metal with Thermoplastic material which Reduced part weight, Simplified manufacturing

processes, with higher repeatability and less scrap, Higher tensile strength with proper part design, Increased part lifetime in corrosive and/or abrasive environments.

Optimization of weld parameters in friction welding**,**

- Use of metal powder in thermoplastic material can give high joint strength.
- Changing geometric shape can help to join both dissimilar materials.

Friction welding parameter play important role for performing experiment by taguchi approach. For inputting such parameter likes,

- Friction pressure,
- Friction time,
- Upset pressure,
- Upset time,
- Rotational speed,
- Burn off Length,
- Forge pressure.

III. CONCLUSION

Friction welding is solid state welding process in which they require heat will generate due to friction between the metals by relative motion, the faying surfaces are in plastic zone which temperature is below the melting temperature of the base metals, and the joint are sufficiently made successful by applying optimum forge/axial force for the determined weld time. Friction welding has immensely high potential in the field of thermo mechanical processing of various alloys. The mechanical properties and the resultant microstructure for friction weld were presented for different combinations of axial force, rotational and translational speeds. In this review paper the effect of various parameters on the friction welding of similar or dissimilar metals/thermoplastics are discussed. From the observation summarized that the friction pressure, friction time, forging pressure, forging time, rotational speed and burn off length are the most effective parameters for the friction welding process. Improper selection leads to the defects in the joint like porosity, non-joined area in weld zone, failure of joint.

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