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Recent Trends in Friction Welding Process

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***Abstract*- The machine parts are produced by any one of the manufacturing methods such as forging, machining, casting, welding methods, etc. The selection of manufacturing methods purely based on the production cost and time. In general, the machine components are joined by welding process for higher dimensional accuracy. Welding is the one of the manufacturing technique to join similar or dissimilar combination of materials with or without application of filler rod. Friction welding is the one of the solid-state welding process for joining similar and dissimilar combination of materials without the use of filler rod. In friction welding process, heat is generated at the interface of joining the specimen under plastic deformation by converting the rotational energy into heat energy by means of pressure. Normally input process parameters considered for the experimental investigations are heating pressure, heating time, upset pressure, upset time, rotational speed and chemical composition of the test specimen and the output responses are axial shortening, hardness, tensile strength, impact strength and microstructure. The literature assessment on the friction welding process is crucial to study the effect of process parameters on the welding strength and quality of the welded specimen. Recently many researchers have dealt with the optimization of process parameters for various friction welding process. The specific objective of this paper is to review the collection of literature available on the friction welding process and optimization techniques by various research works. Recently, friction welding process is preferred in many industries to reduce the time and cost and increase the quality of the welded specimen. Based on the literature review, an investigation is essential to improve the quality of the welded specimen and reduce time and cost. The authors found that input process parameters play vital role in the quality and efficiency of the weld joint.**

***Keywords*-Friction Welding Process; Input process parameters; Output responses; Optimization techniques.**

I. INTRODUCTION

All the manufacturing industries are aimed to increase the productivity. The productivity of the industry directly depends on the machining time and quality of the product. At the same time, reducing the machining time affects the quality of the machined component. These unbalanced situations are solved by using the optimization process. Optimization is the act of obtaining the best result under the given circumstances. There are a number of statistical techniques available for engineering and scientific studies. Many researchers worked in this area with different directions and their research findings are listed below.

Chennakesava Reddy (2017) studied the evaluation of parametric significance in friction welding process of AA1100 and Zr705 Alloy using Finite Element Analysis. The main objective of this study is to evaluate the strength, Bulk deformation, Penetration and flame formation of the welded joint and the output responses are good penetration and mechanical bonding. It is concluded the welded parts must be stress relived using appropriate heat treatment process. Javed Akram et al. (2017) demonstrated the location of specific strain rates, temperatures and accumulated strains in the friction welds through Micro structure modeling. The main objective of this study is to predict the location specific strain rates, temperatures, grain evolution and accumulated strains in Inconel 718 friction welds by using the micro structural simulation method. The output responses considered are strain rates and different temperatures. The authors concluded that the strain rates predicted from simulation for both centers and edge location of weld formed to be increasing with increasing rotational speed. Kimmra et al. (2017) investigated the effect of friction welding condition of joining phenomena and mechanical properties of friction welded joints between 6063 aluminum alloy and AISI 304 Stainless steel. The main intention is to evaluate the effect of friction welding conditions on joining phenomena tensile strength and bending ductility of friction welded joints between test specimen by using the weld interface technique, mechanical and metallurgical test method and friction welding method. The output responses are joint efficiency and Vickers hardness. Thus, the authors concluded that the tensile strength, fractured point and hardness distribution not have difference between air and water cooling process. Meengam et al. (2017) demonstrated the friction welding of semi solid metal 7075 aluminium alloy. The main aim is to appraise the welding characteristic of friction welded similar joints of SSM7075 aluminium alloys by using the Microstructure test and Vickers hardness test. Meisnar et al. (2017) investigated the micro structural characteristics of rotary friction welded AA6082 and Ti-6Al-4V dissimilar joints. Thus, the authors concluded that the grain elongation near the weld interface on the Ti-side.

El-Oualid Bouarroudji et al. (2017) demonstrated about the thermal analysis during a rotational friction welding process. The investigation is to determine the optimal friction time. The output responses are Breaking limit, Temperature, Heating time, Optimal friction time. Thus, the authors concluded that the rupture has occurred outside of the welded joints for the majority of the conducted tests. Palanivel et al. (2017) investigated the microstructure and mechanical characteristics of continues drive friction welded grade 2 seamless titanium tubes at different rotational speeds. The authors concluded that, increase in rotational speed decreased the peak and equilibrium torque and increasing in rotational speed increases the weld time due to reduction in heating rate. Furkan Sarsilmaz et al. (2017) studied the microstructure and mechanical Properties of Armor 500/AISI2205 steel joint by using the friction welding process. The output responses are microstructural and mechanical properties and tensile strength. Thus, the authors concluded that the direct drive friction welding process without any defects. Radosslaw Winiezenko et al. (2017) investigated about the friction welding of tungsten alloys with aluminium alloy. The authors appraised that the friction welding of WHA to AA is successfully carried out without any interlayers and heat treatment. Rajesh et al. (2017) demonstrated about the joining of hybrid AA6063-6Sicp-3Grp Composite and AISI 1030 steel by friction welding. The objective is to evaluate the mechanical properties of the material by using the friction welding process. The output responses considered are axial shortening and impact strength. The authors concluded that the rotational speed and interlayer thickness contribute the about 39% and 36% respectively indicating the strength of welded joints.

Jeswin Alphy James and Sudhish (2016) investigated the effect of interlayer in friction welding process for dissimilar steels SS304 and AISI 1040. The investigation is to determine the properties of friction welded joint and compared the properties of weld with and without interlayer at different welding parameters by using Taguchi orthogonal array. The authors concluded that the FESEM images showed the microstructure of the weld and EDS spectrum indicated the composition of the weld part at the scan area. Tran Hung Tra and Motoki Sakaguchi. (2016) illustrated the optimization of high cycle fatigue behavior of the IN718 and M247 hybrid element fabricated by friction welding process at elevated temperature. The output responses are fatigue strength and FEM simulation. Thus, the authors observed that the element displays an excellent strength under HCF loadings at 500°C and 700°C and the IMHS is fractured on the M247 side outside the welded zone. Pandiarajan et al. (2016) studied the joining on SA213 tube to SA387 tube plate with backing black arrangement in friction welding process. The investigation is to obtain the maximum welding joint strength with output parameters of compressive strength by using the Taguchi orthogonal array and ANOVA method. Thus, the authors concluded that the microstructure proves the fine grain enhancement has been occurred in the welding interface which passes a high joint strength and hardness of the work piece. Hanish Anand et al. (2016) inspected the optimization of welding and analysis of aluminum 5083 alloy with mild steel by friction welding process. The authors concluded that the joint strength increased and then decreased after reaching a maximum value with increasing friction pressure and friction time. Berna Balta et al. (2016) studied the optimization of process parameters for friction welded steel tube joints. The output responses are good tensile strength, elongation and crack length. The authors concluded that, higher forging pressure and higher forging time application lead extrusion of the coarse grain towards the welding lips and less amount of soften material is left in interface, which leads to higher tensile strength.

Kimura et al. (2016) studied the optimization of joining phenomena and tensile strength of friction welded joint between Ti-6Al-4v titanium alloy and low carbon steel. The investigation is to determine the effect of friction pressure, friction time and forge pressure on the joint strength and the metallurgical characteristics of joints were observed and analyzed by using the continuous drive friction welding process. The output responses are good joint strength (joint efficiency 100%). The authors appraised that the temperature at the weld interface was decreases with increasing friction pressure. Xun li et al. (2016) illustrated the optimization of microstructure evolution and mechanical properties of rotary friction welded TC4/SUS321 joints at various rotation speeds. The output responses are profile of equilibrium interface temperature and V-curve based on rotation speed. The authors reported that, rotation speed increases from 400rpm to 1800rpm and the profile of equilibrium interface temperature depending on the rotation speed. Hong Ma Guoliang et al. (2016) studied the effect of post weld heat treatment on friction welded joint of carbon steel to stainless steel. The main objective of the investigation is to determine the 1045 carbon steel was joined to 304 stainless steel by friction welding and the joint was heat treated at different Post Weld Heat Treatment (PWHT) temperature by using the post weld heat treatment. Nada Ratkovic et al. (2016) examined the optimization of microstructure in the joint friction plane in friction welding of dissimilar steels. The study consists of friction welding process microstructure and mechanical characterization and fracture behavior by using the classical friction welding process. The authors reported that, friction on the side of the HS6-5-2-5 steel appears the carbide layer with maximum share of carbides of 20% but it decreases with increase of the friction time. Rupinder Singh et al. (2016) demonstrated the optimization of friction welding of dissimilar plastic/polymer materials with metal powder reinforcement for engineering applications. The main objective of the investigations is to perform friction welding of dissimilar plastic based material by controlling the melt flow index (rotational speed, feed rate and welding time) by using traditional joining technique. The output responses are high tensile strength, shore D hardness and porosity at joint. Thus, the authors suggested that dissimilar polymer materials with metal powder reinforcement can be joined together successfully by using the proposed methodology.

Raab et al. (2015) investigated the orbital friction welding as an alternative process for joining the specimen. The intention is to evaluate the influence of the different kinetics of heat generation on orbital friction welding by optimizing the input parameters such as force, displacement and frequency using the technique orbital friction welding. The authors concluded that, within the tested frequency range perform the shorter friction phases and also the central weld zone is larger in orbital friction welds due to the higher heat generation. Serdar merlan et al. (2015) studied the effect of welding parameters on the fatigue properties of dissimilar ALSI 2205-ALSL 1020 joined by the friction welding process. The main objective is to couple the ALSI 2205 steel with low carbon content through different operation parameters through friction welding process. The output responses are tensile strength and fatigue strength. The authors reported that, tensile and fatigue strength increased for the specimen connected with the 1300 rpm and 50Mpa friction pressure. Lorenzo donate et al. (2015) investigated the Finite Element Method analysis and experimental validation of friction welded process for prediction of welding quality. The authors concluded the numerical asserts were used for analysis of welding quality the critical ratio 1/44 has to be achieved. Lakshminarayanan et al. (2015) studied the characteristics of friction welded AZ31B magnesium and commercial pure titanium dissimilar joints. The objective is to exploring the properties of friction welded magnesium-titanium joints using tensile testing and image correlation method by varying the process parameters such as rotational speed, friction pressure, friction time, forging pressure and forging time. The output responses considered for this investigation are micro structure and macrostructure analysis and phase analysis and concluded that Mg-Ti friction weld failed in the Magnesium side in the vicinity of the intermetallic zone, this indicates that this was the weakest region of the Mg/Ti dissimilar friction welds. Lesnieski and Ambroziak (2015) investigated the friction welding of titanium and tungsten pseudo alloy. The main objective is to build the thermomechanical model using the Johnson cook equation to define the material properties using finite element analysis technique. It is done by varying the input parameters such as Time, Pressure and Revolution. The author concluded that changing the friction coefficient with temperature resulted in changes in the thermal field obtained in the particular models. The model results are validated the assumptions about the variation of the friction coefficient.

Zhidaliang et al. (2015) illustrated the microstructure characteristics and mechanical properties of the dissimilar friction welding of 1060 aluminum to AZ313 magnesium alloy. The author concluded that the maximum tensile strength of the welded joints 77% of the strength of the Al 1060 alloy base metal. Suresh D. Meshram and Madhusudhanreddy (2015) demonstrated the friction welding of AA6061 to AISI 4340 using silver interlayer to determine the tensile properties using the x-ray diffraction technique. The input process parameters considered are friction pressure and the distance from the weld centre. The author concluded that the pressure if Ag as interlayer reduces the Mg concentration at the weld interface. Prashanthi et al. (2015) studied the friction welding of mild steel and titanium and the optimization of process parameters in the friction welding process and evaluated the weld interface microstructure. The authors represented that, recrystallisation and grain growth in mild steel close to the interface was observed during diffusion annealing process due to the plastic strain. Ajith et al. (2015) investigated the multi objective optimization of friction welding of VNS S32205 duplex stainless steel. The main objective of this welding is to optimize the friction welding process of the duplex stainless steel by varying the input parameters using solid-state welding process. The input process parameters considered are friction pressure, upsetting pressure, speed and burn off length. The output response is tensile strength and micro hardness. The authors concluded that, austenite and ferrite phases are present in the weld zone and the tensile strength of the friction joint is higher than the base material strength and the fracture occurs in the ductile nature. Kumar and Balasubramanian (2015) investigated the application of response surface methodology to optimize the process parameters in friction welding of Ti-6Al-4V and SS 3041 rods. The authors concluded that, mechanical and metallurgical characteristics are observed that samples with an optimum parameter with low interlayer thickness produces better results.

Schmicker et al. (2014) demonstrated the implicit of geometry meshing for the simulation of rotary friction welding process. Input process parameters considered for the work is element size function and friction pressure. The output response is geometry of meshing. The problem revealed that, presented frame work is extremely robust and efficient in the handling of the self-contact of the flash. Selvamani and Palanikumar. (2014) illustrated the optimizing the friction welding parameter to attain maximum tensile strength in AlSi 1035 grade carbon steel rod. The ANOVA technique is used to determine the various strength of the steel rod by friction and changing the process parameters. The input process parameters are friction pressure, friction time, forging pressure, forging time and rotational speed. The output responses are tensile strength, notch tensile strength and % of elongation. The authors concluded that the rotational speed was found to have greater influence on tensile strength of the joints followed by forging pressure and friction pressure. Shailesh K. Singh et al. (2014) investigated the experimental and numerical studies on friction welding of thixocast A356 Aluminium alloy. The main goal is to analyze the globular microstructure on the weldability of semisolid processed aluminium alloy via high temperature flow behavior using the conventional fusion welding process. The input process parameters considered for this investigation are friction pressure, friction time, rotating speed and forging pressure. The output responses are stress distribution and tensile strength. The author revealed that the magnitude of the von mises stress distribution during welding for the thixocast A356 sample is found to be lower than the cast sample. Uday and Ahmad fausi (2014) investigated the joining process of friction welded 6261 Aluminium alloy/YSZ aluminium composite at low rotating speed. The investigation is to determine the joint properties of the friction welding by the low rotational speed using optical microscopy method. The input process parameters are friction force, friction time and rotational speed. The output responses are bending strength and micro hardness. The author concluded that the low frictional temperature results in the less intermetallic compound formation at the interface. WenyaLia et al. (2014) studied the abnormal microstructure in the weld zone of linear friction welded Ti–6.5Al–3.5Mo–1.5Zr–0.3Si titanium alloy joint and its impudence on the joint properties. The purpose of this research is to determine the compositions and phases near the weld line. The input process parameters are the Frequency, Amplitude, Friction pressure and Friction time. The output responses are tensile strength and fracture characteristics. The authors identified that, all the tensile strength test specimens fractured across the weld line with a quasi-cleavage fracture.

Damodharan et al. (2013) investigated the optimization of microstructure and mechanical properties of friction welded alloy 718. The main investigation is to determine the friction welded alloys are subjected to the heat treatment and the microstructure is analyzed by using Conventional Friction Welding Technique (CFWT). The output responses are hardness and tensile strength. Thus, the authors concluded that the friction weld zone of alloy 718 exhibited fire and dynamic recrystallized grains. Schmicker et al. (2013) studied the optimization of a robust simulation of direct drive friction welding with a modified carrear fluid constitutive model. The aim of this investigation is to determine the carrear fluid constitutive model is developed for the simulation of the direct drive friction welding process. The authors concluded that, summarizes a frame work for a stable friction welding and the experimental data describe the narrow stress and temperature ranges effectively. Shanjeevi et al. (2013) illustrated the evaluation of mechanical and metallurgical properties of dissimilar materials by the friction welding process. The main objective is to determine the tensile and hardness test by using Taguchi method. The authors described that the longer friction time excessive formation of the intermetallic layer and it has the poor strength depending on some alloying elements. Radoslaw et al. (2013) investigated the estimation of tensile strength of ductile iron friction welded joints by using the hybrid intelligent methods. The authors reported that the tensile strength is increased from 211Mpa to 255Mpa for the friction welded ZT-14 type. Radoslaw et al. (2013) studied the friction welding of ductile iron and stainless steel. The main investigation is to fracture morphology and

microstructure and phase transformation in the friction welding process. The authors concluded that the stainless-steel carbon enrichment result in the formation of chromium carbides that all distributed at the grain boundaries Cr-Ni combination should not exceed 50 µm.
JI shu-de et al. (2012) investigated about the 3D numerical analysis of material flow behavior and flash formation of steel in continuous drive friction welding process. The flow behavior and flash formation of ring component for steel in Continuous Drive Friction Welding (CDFW) process & 3D-Thermo mechanical couple finite element method are investigated. The output responses are the high peak temperature and axial pressure. The authors reported that the flow velocity of material in the middle region of friction surface is smaller than near the edge of friction surface. Ion Mitela et al. (2012) illustrated about the dissimilar friction welding of induction surface hardened steels and thermo chemically treated steels. The main intention of this investigation is to friction welding of surface hardened steels are analyzed based on the experiments using induction hardened steels as pivotal component by using carburization & nitriding technique. The authors revealed that the dissimilar joints with induction hardened steels used as pivotal component were successfully manufactured by friction welding with quench hardened steels. Paventhan et al. (2012) investigated the optimization of friction welding process parameters by joining the carbon steel and stainless steel. An attempt was made to develop as empirical relationship to predict the tensile strength of friction welded AISI 1040 Grade medium carbon steels and AISI 304 austenitic stainless steel by using the response surface methodology technique. The authors reported that the developed relationship can be effectively used to predict the tensile strength of friction welded dissimilar joints of MCS-ASS at a confidence level of 95%. Radoslaw et al. (2012) demonstrated the friction welding of ductile cast iron using inter layers. The authors concluded that the results of this study showed the process of ductile cast iron friction welding is accompanied by plastic deformation and diffusion process. Arivazhagan et al. (2012) investigated the hot corrosion behavior of friction welded AISI 4140 and AISI 304 in K_2SO - 60% NaCl Mixture using the thermo gravimetric technique. The authors observed that the scale thickness on low alloy steel side was higher than that on stainless steel side.

Madhusudhan Reddy and Venkata Ramana (2011) investigated the role of nickel as an interlayer in dissimilar metal friction welding of maraging steel to low alloy steel joints. The hardness, ductility and impact to toughness are determined by using post weld heat treatment, vickers micro hardness tester and Continuous Drive Friction Welding (CDFW) process. The authors concluded that the nickel can be employed barrier for diffusion of elements such as carbon and manganese to overcome the problem of carbon migration. Andrzej Ambroziak (2011) illustrated the optimization of friction welding of molybdenum to molybdenum and to other metals. The main objective of the investigation is to determine the produced joints were subjected to microscopic examination, micro-hardness test and strength test by using the conventional friction welding machine. The output responses are proper microstructure with no intermetallic phases. The author concluded that the parameters can be used for the direct welding of TZM to other metals and for the welding of interlayers. Celikyurek et al. (2011) studied the optimization of microstructure and strength of friction-welded Fe-28AL and 316L stainless steel. The main aim of the investigation is to determine the microstructures of the welds by scanning electron microscopy and optical microscopy and the welded samples were free of any pore or crack along the weld interface and also using Gas Tungsten Arc (GTA) welding and Electron Beam (EB) welding. The output responses are maximum shear strength. Thus, the authors reported that the best welding parameter combination was found to be at a friction pressure of 100 Mpa. Kimura et al. (2011) demonstrated the optimization of strength enhancement of autocompleting medium and high carbon steels friction welded joints. The main objective of the investigation is to determine the conditions to enhance the strength of the welded joint in an auto completing friction welding method. The output responses are good joint strength (joint efficiency 100%). The authors revealed that the MCS or HCS joint such as the base metal fracture with no crack was able to make by the autocompleting friction welding method when the CSF value nearly equaled. In-Duck PARK et al. (2011) examined the optimization of structural considerations in friction welding of hybrid Al_2O_3-reinforced aluminum composites. The main objective is to determine the comparative studies on the relationship between the welding parameters and joining efficiency in the friction welding of hybrid Al_2O_3-reinforced aluminum composites by using Scanning Electron Microscope (SEM) and tensile test. The author concluded that after micro-examination of the bonding interface, the base metal made some second particulate formed by condensed alumina particulate, however discoloration part distributed minute alumina particulate without second particulate.

Andozej Ambroziak (2010) investigated the hydrogen damage in friction welding copper joints. The main objective of this investigation is to study the effect of hydrogen from the decomposition of hydrocarbons from the mineral oil in the coper specimens using the resistance heating technique. The input process parameters considered are friction pressure, upset pressure, time of friction and friction contraction. The output parameters are the microstructure examination and tensile strength. The author concluded that after the sacking at a temperature the 600°C the strength of the elastic copper joints decreases to 30% of that of the native material and fracture occurs in the weld zone. Hazmanseli et al. (2010) studied the mechanical evaluation and thermal modelling of friction welding of mild steel and aluminium. The main objective is to investigate the mechanical properties and subjected to thermal effects and determination of cooling temperature distribution of joints using one dimensional finite element method. The authors concluded that the welded materials have lower hardness compared to their patent material due to the thermal effects of friction welding, thus the tensile strength are reduced.

Andozej Ambroziak (2010) investigated the friction welding of titanium and tungsten pseudoalloy joints. The main objective this research work is to determine the microstructure of the welded specimen and ensuring the brittle character in the joint using the diffusion welding technique. The input process parameters are friction pressure, upset pressure and contraction length. The output responses are tensile strength and interlayer formation. The author reported that the copper can be used for interlayer in titanium-tungsten pseudoalloy D18 joints but an additional vanadium layer is required. Khalidrafi et al. (2010) investigated the microstructure and tensile properties of friction welded aluminium alloy AA7075-T6. The intention is this investigation is to analyze the process parameters of the microstructure and tensile properties of friction welded joint by using the Taguchi method. The input process parameters considered for the investigations are spindle speed, friction pressure, upset pressure and burn off length and the output responses are microstructure and tensile strength. The authors reported that the sound joints in AA7075-T6 can be achieved by using the friction welding process with a joint efficiency of 89% in as welded conditions with proper selection of process parameters. Emel Taban et al. (2010) illustrated the dissimilar friction welding of 6061-T6 Aluminum and AISI 1018 steel: properties and microstructural characterization. The main objective is to determine the properties and microstructure characteristics. The process parameters are temperature, friction pressure and time. The authors concluded that the fracture surfaces from the mechanical test specimens indicate failure through the highly plasticized Aluminium adjacent to the joint interface.

The recent manufacturing industries used the friction welding process for better joining strength with high quality. Recently, the intention of the modern manufacturing industries is to achieve economical joining condition. The reduction of experimental time and cost plays crucial role for selecting the best input process parameters in the economical way. An investigation is crucial to progress the performance of the friction welding process and found that input process parameters plays essential features in the excellence and efficiency of the welded joint.

II. CONCLUSION

Welding operation is one of the most significant joining processes; it produces high efficiency joint, more economical and high speed of welded joint. During the friction welding process, heat is generated at the interface of the test specimen during the contact under pressure. Based on the review of various literature papers on the friction welding process, the following points are concluded.

- The welded parts must be the stress relived using appropriate heat treatment process.
- The strain rates predicted from simulation for both centers and edge location of weld formed to be increasing with increasing rotational speed.
- Increase in rotational speed decreased the peak and equilibrium torque. Increased in rotational speed increased the weld time due to reduction in heating rate.
- Microstructure proves the fine grain enhancement has been occurred in the welding interface which passes a high joint strength and hardness of the work piece.
- The temperature at the weld interface was able to estimate to decrease with increasing friction pressure.
- Mg-Ti friction weld failed in the Magnesium side in the vicinity of the intermetallic zone, this indicates that this was the weakest region of the Mg/Ti dissimilar friction welds.
- The recrystalisation and grain growth in mild steel close to the interface was observed during diffusion annealing due to the plastic strain.

- The friction weld zone of alloy 718 exhibited fire and dynamic recrystallized grain.
- The tensile strength of friction welded dissimilar joints of MCS-ASS at a confidence level of 95%.
- The dissimilar joints with induction hardened steels used as pivotal component were successfully manufactured by friction welding with quench hardened steels.

Based on the review work, the authors initiated that axial shortening, tensile strength, bending strength; hardness and impact strength are normally considered for the output responses. The authors identified that, there is a need of research in friction welding process to improve the quality of the output based on the input process parameters. This review work is very precious for the researchers to develop the ability of the friction welding of Teflon specimen is essential for the modern development in the engineering industry.

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