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Friction welding of similar and dissimilar materials: A review

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ABSTRACT

In recent decades, the requirements for higher eco-friendliness in the car segment have persuaded the expanded utilization of design in lightweight mixes of multi-material. It has unavoidably prompted difficulties in joining base materials (for example, low, medium, and ultrahigh quality) where magnesium combinations, steels, and aluminium compounds are joined. Simultaneously, every one of these materials recommends fluctuating execution and superior properties for different segments in various areas of novel design. Accordingly, these base material blends will unavoidably be welded, which presents significant difficulties because of their contradiction during friction welding techniques utilized in vehicle fabricate. This paper discussed current advancement in friction welding procedures for joining the various parent materials and explains welding parameters controlling the joint quality. Be that as it may, financially savvy and dependable joints of lightweight amalgams (for example, aluminium) and steel will need significant advancement and contemplation. The reason for the current survey paper is to evaluate the status of friction welding of different base materials of vehicle manufacturing alloys, with explicit thoughtfulness regarding the future development, vehicle manufacturing sector, impediments, and difficulties.

Selection and peer-review under responsibility of the scientific committee of the International Virtual Conference on Sustainable Materials (IVCSM-2k20).

1. Introduction

The utilization of friction welding (FW) presents the potential for similar and dissimilar joining parts where expenses restrict the utilization of latches, self-piercing bolts, or glues. The primary test comes from the various properties (mechanical and physical), structure, and chemical composition, leading to harmful weld properties. The FW does not include mass liquefying of the parts; it is among the most helpful welding procedures for joining similar and dissimilar materials. Specified the numerous favorable circumstances, including improved mechanical properties like fatigue and tensile, improved cycle power, no consumables, diminished health and ecological issues, and lower working expenses, FW has increased critical enthusiasm for the car ventures and fabricates [1]. In-car enterprises, the consideration, and utilization of FW has been in three common zones. These incorporate the joining of expelled parts to shape "bigger expulsions", the fusion of tailor welded blanks joining, and spot welding for different gathering applications. The FW offers various preferences and potential for rate (Price) decreases in all these cases. Nonetheless, practical and solid joints between light-weight supplies (materials) will request a huge turn of events and further thought [2]. The Friction Welding has no need of consumables, eco friendly and easily welded.

Rotational friction welding is a strong state joining method, where the necessary warmth is created by rubbing between the joining materials. At the point, while the shear quality is attained, plastic deformation happens and the quality of the weld begins to form the shape. In commonly, two types are present: direct drive and inertia friction welding. The rotational welding portion driven by the motor through the entire cycle of the process and finally the

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pivot is slowing down, the hub pressure is expanded whereby the spark is fully produced and the cycle is finished soon after the shaft end is called as direct drive friction welding. The rotational part (metal) and a connected flywheel are quickened at that point the drive is disengaged and the welding accomplices are acquired contact. During the entire welding method, speed of the parts continuously slowdowns. The speed of the parts decelerates. Towards the rotating end, the pivotal power is expanded. It is called inertia welding [3,4]. The mix of aluminum (Al) compound/steel as a half and half construction shows incredible potential in decreasing all out weight and expanding processability, considering powerful energy saving and outflow decrease, which is considered to fill in as a magnificent up-and-comer as elite underlying parts for different mechanical applications [5].

The Al amalgam/steel structure by metallurgical welding display clear benefits in enormous creation with high proficiency and simplicity to fix, which can adequately relieve the issues happened in the half breed joint made by mechanical joining strategy. For what it's worth realized that Al compound and steel have fundamentally unique warm actual properties, i.e, dissolving temperature, warm development coefficient, explicit warmth, thickness, and so forth, which can cause particular compound arrangement through-the-thickness heading in the weld pool, just as temperature and stress field contrasts during welding [6,7].

This current article reviews a few of the overall develops that has developed in friction welding for similar and dissimilar joints in current applications. The primary benefit position general to virtually all the methods is that strong state preparing limits the temperature ascends inside the weld zone. This precludes the arrangement or development of unwanted and fragile intermetallic mixes inside the weld which crumble quality of the joints. The lower peak temperatures additionally limit residual stresses and thermal twisting, which can frequently prompt the break of the joint quickly after cooling of the weld for the situation while intermetallic are available and cracks are framed in the joint. A portion of the rest of the difficulties will likewise be featured regarding future applications for friction welding.

2. Literature review

Kimura et al. [8] stated that the impact of the tensile strength of copper and stainless steel was joined by friction welding. In this investigation, different friction welding parameters were studied for joints characteristics of tensile strength. They found a maximum temperature of 90 MPa, and a minimum temperature of 30 MPa frictional pressures was obtained in the welded joint. The middle portion of the welded joint interface was not joined properly when maximum friction pressure applied. They concluded that the copper base metal portion was welded completely through the low friction force condition of 30 MPa.

Abdul Khadeer et al. [9]. studied complete evaluation of the friction welding between the carbon steel and low alloy steel pipes. They conducted quenching and tempering method in welded joints material and received material and after that stress relief annealing was applied on that same welded metal. The low alloy steel has produced recrystallized grain structure by SEM and OM. The mixing of two dissimilar base metal microstructure was not revealed properly. Finally they concluded that the maximum hardness value achieved in quenched condition when compared with received condition. The carbon steel pipes composed higher tensile properties than low alloy steel pipes material.

Arivazhagan et al. [10] described mechanical characteristics between low alloy steel and austenitic stainless steel material by friction welding. Due to the maximum temperature and relocation of carbon at the welding interface side, the toughness was decreased. The minimum hardness was achieved between the two dissimilar alloys due to the impact of tempering in low alloy steel material.

Marta Orłowska et al. [11] investigated that the linear friction welding was conducted on the aluminium alloy 1070 to enhance the mechanical behavior that was capable of forming the excellent superplastic formation and resist of corrosion. They mainly focused on the growth of grain boundaries at the maximum temperature in the welded region. The researchers successfully joined the rectangular bars aluminium alloy in the linear friction welding. The small grain size in the welded region is a major aspect of enhancing the tensile strength of welded base material.

PeihaoGeng et al. [12] developed the finite element model on a nickel-based rectangular bar's friction welded material. This investigation mainly focused on estimating thermoelastic deformation's impacts, which is composed of a 3D finite model. They compared plastic to rigid friction couple and plastic to plastic friction couple at different friction welding process parameters. The pair of plastic friction produced a better model in the linear friction welding.

XuanxiXu et al. [13] investigated the dissimilar friction welding between the medium carbon steel and high strength low alloy steel. They analyzed the mechanical characteristics of welded joints with their impacts on spinning speed. When the spinning speed increased, the tensile strength also increased during the process. Due to the maximum spinning speeds like 2200–2800 rpm, specimens attained poor joints in the heat-affected zone region. Especially, the 2200 rpm of rotational speed gives better mechanical strength when compared to other parameters. The welded joints provide higher hardness when compared to the base metal with 2200 rpm of spinning speed.

Xinyu Wang et al. [14] conducted the friction welding effectively on titanium alloy with significant parameters. They studied the welded region's microstructure and mechanical characteristics to elucidate the joints for analyzing the strength and grains, respectively. The researchers investigated the output related to the parent metal, thermomechanically affected zone, and weld center region of varying dimensions. The transformation of phase and plastic deformation occurred in the friction welded joints compared to the unaffected parent metal. The hardness of welded regions produces higher values than the base metal.

Deepak Kumar et al. [15] examined the characterization of rotary friction welding on SS304 stainless steel. These studies were completed through the significant parameters, namely, 1100 rpm constant spinning speed, heating and upset load, heating, and upset time. The welded strength was improved at a maximum of heating and upset load. Similarly, maximum joint strength and hardness were attained at 143 MPa of upset load and 4 sec of upset time. Finally, the poor grain structure has occurred in the welded region.

Vyas et al. [16] investigated the friction welded joints of SS 304L and AA6063 pipe materials. The welded joints were analyzed by scanning electron microscope, optical microscope, leak test, pressure test, thermal test, hardness test, XRD, XR-Spectroscopy, XR-elemental mapping, and tensile test. The outcomes showed that the welded materials persistent with vacuum and leak finding difficulties. The maximum joint strength with welded efficiency is 72% than the base metal. Microstructure deviations were measured significant to parent metal (AA 6063) nearer to the combined SS 304L and AA 6063 joints.

Alex Anandaraj et al. [17] reported that the friction welded between the materials of SS410 and Inconel 718 for the mechanical characteristics. In the present studies, optimal friction welded process parameters are 1300 rpm spinning speed, 220 MPa forging and friction pressure, 8 s forging time, 10 s friction time. The welded joint of fracture strength was attained at 652 MPa. The microhardness was studied on the various welded samples region, particularly the lower values achieved in TMAZ. The microstructure studied was carried out in all the welded specimens. Lastly, the majority of the failures were measured in the SS410 in TMAZ.

Andrade et al. [18] produced the lap joints on the galvanized steel material using friction and friction stir welding. They studied macro and microstructural examinations on welded specimens with different tool traverse speeds, tool dimensions, and tool spinning speeds. The maximum strength was attained in welded models with the foremost tool spinning speed and traverse speed. The shear strength of lap joints has more strength than the other welded specimens but similar to the parent metal.

Buzzatti et al. [19] studied the friction welding on the API grade pipes. They investigated a comparison between fusion based welding and the solid-state welding method. The following tests, namely tensile, bending, microhardness, and metallography, were conducted on the welded specimen. Microstructure analysis was carried out on all the samples designed by the Box Behnken method. Most of the models give good joints with suitable processing ways. Bending and tensile test proves the better mechanical characteristics with their welded specimens.

DeepeshVimalan et al. [20] introduced a novel method of friction welding to produce the joints (AA1060 tube and AA6061 plate) with an external FSW tool. This study performed with tool spinning speed and tool plunge on welded parts. The numerical model was utilized to identify with total welding rotation limits to produce faulty joints. This model performed well with base materials. The faulty joints were identified with phased array ultrasonic and digital radiography testing with total welding rotation values.

Jedrasiak et al. [21] presented a finite element thermal model (FETM) for friction welded titanium alloy material. They measured the machine's cyclic load and transverse velocity on the welded interface region for identifying the power. The sequential based stepwise method, input lateral heat distribution due to the geometry variations, and heat loss with the spark's ejection were analyzed to eliminate the interface elements at isolated time intervals. Finally, there is improbability in data displacement, approximated power values from the force value, and accuracy of shifting the thermocouples. Due to that, 20% of variations were exhibited between the experimental and predicted power. So these models produce efficient, precise methods for developing the thermo-mechanical model.

Deepak Kumar et al. [22] investigated the friction welding between the ferrous and nonferrous metals. In this study, rotary friction welding is used to join the dissimilar materials. using the Taguchi method; the process was framed and conducted. The heating time and upset load were the significant parameters for FW. The welded strength was influenced by the heating time. The maximum welded strength attains increased by heating time and upset load. The 610 MPa welded strength was attained at 20 sec and 1200 kg of heating time and upset load. The microstructure uncovered the fractures for higher and lower weld strength.

Bingwang Lei et al. [23] analyzed the thermal process of rotary friction welded D50Re (Steel) material engaged with the finite element technique. The researchers mainly studied the dynamic growth process of interface region while minimum pressure rotary friction welding for evaluating the thermal-mechanical development. The three simulation cases, namely equivalent, real, and no thermal expansions, were considered for performing the finite element technique. The investigational and simulation outputs are influenced by the equivalent thermal expansion to enhance the welding torque and axial shortening. This article is beneficial for considering the physical condition during the friction welding process.

Peng Li et al. [24] studied that the dissimilar friction welded between the stainless steel and titanium alloy. They examined the mechanical behavior and interface of the inhomogeneous configuration of welded materials with post-weld treatment conditions. An interface welded region showed concave and convex shaped on stainless steel and titanium alloy. Few of the tensile specimens were an interface of inhomogeneous configuration in the mechanical characteristics. They conducted before and after post-weld heat treatment on overall tensile joints. Some of the tensile specimens have internal faults during post-weld heat treatment due to the cracks while preparing for machining; moreover, after post-weld heat-treated specimens were a homogeneous structure in the welded joints.

Liu et al. [25] reported the allocation of grain size, double boundaries, and low position grain boundaries on the 718 alloy welded joints. The following parameters, namely, weld temperature, axial force, and the weld's power, were maintained during the friction welding. The structure of grain growths and dynamic recrystallization on the welded materials were explained clearly. The rotation speeds were diminished from higher to lower rpm for composing the better grains in the welded region. Therefore, the lower force revealed that the grain boundaries are enabled on the welded region's interface.

Liu et al. [26] analyzed the boundary's misorientation in friction welded 718 alloys by grain enhancement mechanism. These models were improved to clarify the intergranular twin formation mechanism. The saved energy was reduced by initiated of plastic deformation in the interior of the grain. Moreover, inactive boundary development was attributed to intergranular twin boundaries. During the inactive boundary, development is attained to form the twin boundaries and modified the boundary orientation. Due to that, migration of boundary was processed for leaving the lonely twin boundary in the rear side.

Liu et al. [27] measured the compression and shear textures ($\alpha + \beta$) on friction welded titanium alloy utilizing the electron backscattered diffraction (EBSD). The significant texture was remained β in the TMAZ exhibits h-100i texture of the fiber. Similarly, the dynamic recrystallization region occurred in the h-111i texture of the fiber. The homogeneous dynamic recrystallization attained to holds the deformation texture. Finally, they summarized the significant deformation, leading to the compression in TMAZ and shear in the dynamic recrystallization region.

Ma et al. [28] joined the nickel-based alloy by friction welding with various process parameters conditions. During the process, the presence of oxide content at the corner of the welded material with suitable parameters produces a good joint between the materials. Therefore, the refined microstructure showed in the weld and thermo-mechanically affected region. Due to the relocation of the carbide in the weld and thermo-mechanically affected region, mechanical characteristics were improved. While linear friction welding, non-homogeneous dynamic recrystallization occurred, this directly increases the low angle grain boundaries and diminishes the twin boundaries in the weld and thermo-mechanically affected region.

Karadge et al. [29] stated that the friction welding on nickel super alloy for finding the single crystal to polycrystalline orientation with the welding's low-pressure condition is only based on the orientation in single crystal lattice for the primary slip technique. Therefore the mechanical strength was slightly enhanced with maximum temperature, which was simply solved with phase strengthening.

Marimuthu et al. [30] studied the dissimilar joints on copper material by friction welding. This study focused on rotary friction welding with the significant parameter of rotation speed in boiler based uses. The following parameters, namely, maintained feed rates, upset and frictional pressure, were applied in this process. Most of the welded joints were evaluated successfully in mechanical tests. The interfacial bonding structure was maintained in a few joints.

Nagasankar et al. [31]developed the optimization of dissimilar friction welding between the two different grade steel materials. They chose the following process parameters like soft, friction, and upset forces utilized for this process. This process was mainly used as a primary factor for this pressure-based application. The L8 array was framed by Minitab to manipulate parameters for this process. The regression model and ANOVA were successfully employed for the entire welded specimen.

Rohit Singh et al. [32] developed the molecular dynamics simulation from a single crystal model of tungsten for friction and cold-welded methods. This study is mainly used to clarify the thickness of various layers covered the welded area for structural analysis by the radial distribution function. During the process, some dislocations of atoms were generated for increasing the layer thickness. The different strain rate was examined the welded joint specimen of tensile samples. The friction welding method achieved better mechanical strength with lesser processing time compared to the cold welding method.

Yu Su et al. [33] studied the friction welded between the alpha-based titanium alloys. Mechanical and Microstructure tests were employed to estimate the welded joints. Due to the thermo-mechanical impacts, dynamic recrystallization has fully occurred in the welded region. So that, grains and substructure of grains were observed in the welded area. Finally, they summarized toughness was improved 19.1 percentage to the parent metal.

3. Conclusion

The fabrication of composite structure and multiple materials is essential for joining similar and dissimilar materials. These structures were used to present a superior performance, strength, design, and strength to weight ratio. Above the mentioned features are significant in various applications like vehicle, aircraft, and ship productions for marketing, fabricating, and design. It's a complicated method to join similar and dissimilar metals through the traditional fusion technique. This manuscript gives a extensive review of the art state that investigates friction welding between the different base materials for vehicle-based uses. In this research, friction welding methods are thoroughly reviewed in the entire manuscript. Based on the presented literature, mechanical and physical behavior of similar and dissimilar friction welding necessitates understanding. Also, interaction layers of welded zones, grain boundaries, optimization of processing, textures, post-weld treatment, parameters are reviewed in detail. Very few review articles are published in the area of similar and dissimilar friction welding. This current summary may useful to fabricators, researchers, fabrication of multiple materials composite structures, engineering, design field of fabrication by friction welding technique for present and future applications of the industrial sector.

CRediT authorship contribution statement

G.B. Sathishkumar: Writing - original draft. **P. Sethuraman:** Writing - original draft. **C. Chanakyan:** Methodology. **S. Sundaraselvan:** Methodology. **A. Joseph Arockiam:** Writing - review & editing. **S.V. Alagarsamy:** Writing - review & editing. **A. Elmariung:** Writing - review & editing. **M. Meignanamoorthy:** Validation. **M. Ravichandran:** Supervision. **S. Jayasathyakawin:** Validation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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