ADVANCEMENTS IN FRICTION STIR WELDING: A COMPREHENSIVE REVIEW OF PROCESS VARIABLES AND EMERGING DEVELOPMENTS

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Abstracte : Friction stir welding (FSW) is a solid-state welding technique widely employed to join materials such as Aluminum (Al), Copper (Cu), Magnesium (Mg), and their respective alloys. These materials find extensive use in industries like transportation, where lightweight materials with superior mechanical properties are in demand due to their reduced mass. Conventional fusion welding methods can adversely affect the mechanical properties of these welds.Over the last two decades, FSW has emerged as a specific and significant advancement in welding technology. Various parameters, including shoulder diameter, shoulder profile, pin length, pin diameter, tool angle, rotating speed, feed rate, and weld speed, play crucial roles in determining weld strength, quality, heat generation, and material mixing.The current research focuses on investigating the process variables that influence the characteristics of welded products. Furthermore, it includes an in-depth exploration of FSW fundamentals, recent advancements, and comprehensive literature reviews.

Keywords: Friction stir welding, process variables ,dissimilar materials

1. Introduction

FSW process is a solid-state welding to attach two surfaces in contact plates or components without burning the materials. Copper ,titanium and their alloys are the materials utilised for welding in this procedure. This method is likewise quite effective, does not release

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gases, but does not require additives to be used. The mechanical characteristics of the joints can be enhanced using this technique. It has become a sustainable compare to fusion welding techniques [1-3]. This technique, which joins surfaces of different metals by inserting a spinning pin tools into the metal pieces, is beneficial. Several studies have been conducted to enhance the tensile properties and other material performance of joint elements. Heat and friction are created by tool movement . In order to achieve the required heat and pressure for weld formation, various parameters were controlled, such as welding speed (WS), shoulder diameter (SD), tilt angle (TA), axial load (AL), rotating speed (RS), tool profile (TP), and axial pressure (AP). The microstructure of the joint comprises four distinct zones: Heat-Affected Zone (HAZ), Thermo-Mechanically Affected Zone (TMZ), and the weld nugget (WN).Friction stir welding (FSW) finds wide applications across multiple industries, including offshore, aerospace, automotive, railway, manufacturing, robotics, and personal computers.The direction of the weld is known as the advancing direction when the welding route is comparable to the tool revolving direction and the retreating way when the welding path is the opposite of the tool revolving direction [4].The FSW process is primarily influenced by three factors: (i) Tool Configuration,(ii) Welding variables, (iii) Joint shape. These parameters have a massive effect on the temperature variation and flow of material pattern. [5-7].This technique is strongly influenced by tool geometry. Previous studies claimed that the tool configuration has a significant role in the flow of raw materials and controls the traverse speed of the FSW process [8].The design of the tool is crucial since a good tool will improve the weld quality. How rapidly the tool turns and how fast it moves over the interface are the two tool speeds that need to be considered carefully. Although the link between RS ,WS and heat input while weld is complicated, it is generally true that hotter welding would come from either increasing rotational speed or reducing traversing speed. It has been discovered that a key parameter for ensuring weld quality is the depths of the fall, also called as the depth under the surface of the weld plate at the shoulder bottom point.

2. FSW procedure

To perform welding operations, a specific attachment for a machine tool is preferred. On both sheets, grooves are made at the ends before operation begins. A cylindrical instrument with a profiled probe is spun and slowly inserted between two sheets or plates of material that will be joined by welding. The components must be secured to a back bar by clamping them in a way that prevents the faces of the abutting joints from being wrenched apart or moved in any other way.The test specimens were carefully penetrated using a rotating tool until the shoulder reached a depth of 0.5 mm into the sample. This position was held steady for a duration of 50–90 seconds to make the essential heat for the welding process [9]. Subsequently, The tool moved in the direction of travel, and its movement, along with the heat generated at the weld site, induced mechanical stirring that brought the material to its plastic phase. Consequently, this enabled the amalgamation of the two metals. Once the welding process was completed, the machine setup was disengaged. Welding operations were conducted following the input parameters specified for the tool.

Table 1: Important terms in FSW tool

Items	Description
Tool material	H13 tool steel
Tool Geometry	Cylindrical truncated cone, square, triangle and threaded cylindrical pin,
Weld velocity	0-300mm/min and above

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Tool Rotational rate	Upto 3000 rpm. It may be increased depends on material selection
Shoulder Diameter	Up to 20mm
Pin Diameter	Range (1 to 8mm)
Pin length	Till 8mm
Tilt angle of tool	Depends on operation and application

Figure: 1 FSW setup

Figure:2 Plates joint process in FSW

3. Mechanical testing:

Tensile testing

This method is classified as a non-destructive testing technique, offering valuable insights into the tensile,yield strength of metallic materials [10, 11]. It quantifies the level of elongation or deformation that a composite or plastic object can endure before reaching its point of fracture.

Hardness test

This test is commonly employed to evaluate the properties and appropriateness of a material for a specific application. For this examination, a specially shaped indenter, typically in the form of a ball, is utilized on all test specimens [12,27]. The 1/16 ball indenter is pressed against the top surface of the specimen with a specific force. By measuring the width and depth of the resulting impression, the hardness value is determined.

Fracture toughness test

The objective of this test is to measure a material's resistance to the propagation of a fault by determining the load required to extend a fatigue pre-fracture into a brittle or ductile crack in a standardized specimen.

Creep test

Using a continuous tensile or compressive stress at a constant temperature, this test measures the amount of material deformation that occurs over time.

Nondestructive testing

It is a practise of observing for faults or differences in a material and assembly without destructive the part's capacity to purposeroutinely [13,26]. for example, optical testing, liquid penetrant testing [14], electromagnetic testing, magnetic particle testing, and radiographic testing are types of NDT.

4. Result and discussion

Various studies have been conducted to determine how to use friction stir welding to increase the tensile strength [15,32,33]and other mechanical properties of joint materials. In this part, a few literature reviews are discussed.In order to connect Al 6061 with 7075 alloys, Ravikumar et al. discussed the influence of input parameters on FSW. The usage of three types of pin tools in various forms, including cylinder, square, and taper square [16].Using various weld rates and distance adjustments between the sheets, aluminium alloy (2A70) was joined. When the weld speed was maintained at roughly 185 mm/min, the tensile strength increased up to 400Mpa [17,25].The use of an ultrasonic type shoulder as a tool for creating connections led to the development of optimum WS of 60 mm/min, RS of 915 rpm and ultrasonic power around 1500 W parameters that increased UTS by around 158MPa [18,24].In D. Maneiah used three input variables to determine the optimal TS. The results showed that the maximum elongation 10 percent and TS -190Mpa were achieved at a tool's rotating speed of 1400 rev / min, a 0 degree tilt angle, and a feed rate of 110 mm/min [19].Al6061/SiC/Alumina was created by using FSW, and it demonstrated excellent hardness when especially in comparison to base metal 6061. Additionally, SiC and Al2o3 particles increased avoidance distance of dislocation during deformation as well as decreased elongation [20].Research findings indicate that modifying the welding and rotating speeds leads to a reduction in BHN (Brinell hardness number) within the stir-zone at the junction of AA7075-O and AA2024-T4 alloys. This reduction is achieved by increasing the rotating speed while simultaneously decreasing the welding speed[21].the relationship between shoulder and pin diameters to achieve superior mechanical characteristics. The shoulder diameter of a pin strongly impacts the heat generated during the FSW process [22-24].The joint with shoulder diameter 15mm), rotating speed (900 rpm), and welding speed (100mm/min) provided the higher tensile strength when compared to other joints, according to Rajkumer et al's investigation on the impact of tool shoulder diameters on tensile strength of AA1100 joints [25]. Y. Zhang et al.[26]investigated the relationship between microstructure, welding conditions, and mechanical properties. The joints were produced using friction stir welding, with rotating speeds varying from 300 to 600 rpm. The experimental setup involved a 3 mm thick plate, a travel speed of 1 mm/s, and a welding tool plunger depth of 2 mm.Emel investigated the properties of the weld area for steel and Al elements and revealed that the strength is 170 MPa for mild upset pressure and 250 MPa for severe upset pressure [27].FSW done using on stainless steel and other materials was studied by Kumar et al. They verified that the composite carbides, which contain reinforced particles, may be employed as a tool material. They discovered that this tool material has to have excellent wear resistance and functional hardness [28].For friction stir welding, LI Xia et al. combined 3 mm thick Al /Cu sheets. They noticed that the majority of the pin diameter is on the aluminum side when rotating at 1000 rpm and moving at 80 mm per minute

5. Conclusion

It may be concluded from sources of literature reviews of publications about the friction stir welding process that the joint characteristics were considerably influenced by pin and shoulder diameter, profile, tool etc.. The primary cause of heat created in FSW is abrasion between the plate and tool shoulder. Depending on the melting temperature of the work items to be welded, several types of tools are employed. Material flow patterns are greatly affected by tool pin geometry, axial force and temperature. FSW is the ideal procedure to utilize if a high-quality weld is required to unite different alloys of aluminum that are lengthy in length. The FSW factors and conditions have a major effect on the mechanical characteristic of the composites after welding.

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