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A Review on Fracture Mechanics of AA2024 Aluminium Alloy Friction Stir Welding

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Abstract: In recent papers on the fracture mechanics of Aluminum welds have a lack of guidance on the assessment of structures containing joints made by friction stir welding (FSW). In this research we have investigated the crack initiation and propagation in butt joint configuration. fracture mechanics based crack analysis is carried out for the different types of failure in welded joints. Failure may happen due to mode-I, mode-II, mode-III or mixed of these modes. A probabilistic fracture mechanics analysis of FSW joints is then presented and result used to identify parameter for which additional data collection would be beneficial for improving our understanding of the fracture mechanics of FSW joints.
Keywords: Friction stir weld joints, Energy release rate (ERR), Mode I, Mode II, Mode III, Mixed Mode.

I. INTRODUCTION

A friction stir welding is a relatively new joining technique developed by TWI located in Cambridge (UK) in 1991. This process takes place in the solid state and offers number of advantage over conventional fusion welding technique, such as in automation and good mechanical properties of the resultant joint. Friction stir welding can join aluminum alloy which are not recommended to weld by fusion welding process.

Aluminum alloy AA2024 are used in fabrication of aircraft structures and other structure application due to their high strength to weight ratio and good ductility, they are difficult to join by the fusion welding process. Because of induced defects such as cracks and porosity can form easily in the weld during solidification of the molten metal as gases such as hydrogen are highly soluble in the weld pool. The problems in the conventional fusion welding of aluminum alloy AA2024 can be overcome by using the new innovative joining process friction stir welding.

Aluminum alloys with good heat transfer, high strength, good formability and weight saving being considered for aerospace structure, shipbuilding, railways cars, etc. Recently joints technology development of Al-alloys has been investigated for ultrasonic welding, explosive bonding, electric discharge bonding, friction welding on the other hand friction stir welding is one of the most popular technique for joining dissimilar materials. FSW is a solid state process which is capable of generating reproducible high quality welds in dissimilar materials. FSW has several advantages over the commonly used fusion welding method such as low energy input, short welding time, low distortion and relatively low welding temperature therefore FSW has been developed for aerospace, automotive, marine and nuclear assemblies.

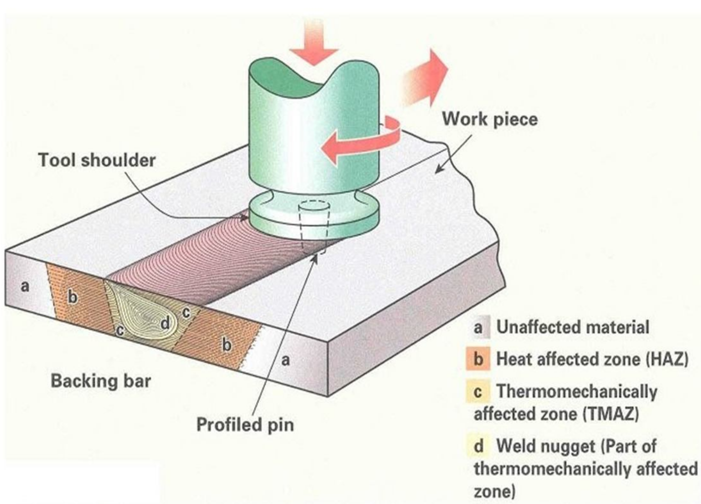

Fig 1.Working of Friction Stir Welding

Friction stir welding works on same principle of friction welding. In this process, friction is used to generate heat at interface surface. This heat starts diffusion process at the mating surface. A high pressure force applied at these mating surfaces which accelerate metal diffusion process and form a metal to metal joint. This is basic principle of friction welding. In friction stir welding, a rotating tool is used to applied friction and pressure force at the plates. This tool rotates at its own axis and move longitudinally at the plates interface which generates heat by friction between rotating tool and work piece. This heat deformed the interface surface and diffuses the two piece of work piece into one another by applying a high pressure force. This joint is created due to thermo mechanical treatment at the interface surface. One big advantage which makes it versatile welding process is that, it can be easily automated and gives higher metal joining rate. It is mostly used to join aluminum alloy.

The working process of friction stir welding as follow:

1) *STEP 1:* Tool rotates about its axis.
2) *STEP 2:* Tool pin plunges into the abutting edges of the material to be joined due to the frictional heat between the tool pin and material.
3) *STEP 3:* Tool shoulder contacts the material and plasticizes the material due to frictional heat between the shoulder and material.
4) *STEP 4:* Moving of rotating tool in a line which is to be weld s
5) *STEP 5:* Welding is made on the material.
6) *STEP 6:* Retracting of tool from welded material.

Fracture mechanics use a continuum mechanics approach to solve complicated problems. In fracture mechanics, material is considered as continuum body. But fracture mechanics assumes material is not continuous in all directions that means it has defects at the manufacturing stage or later service stage. Fracture has various approaches to define the failure of the material. Such as calculation of stress intensity factor, using strain energy release rate (G). If the size of defects is greater than the critical fracture size this method evaluates the structural failure. Hence fracture mechanics relies on two basic criteria, both implemented to study the materials with crack. One is on the stress intensity factor and the other is on energy-based concepts. The stress intensity factor (K), represents a kind of scale parameter that defines the change in the stress state in the neighbourhood of the crack tip, originated by infinite stress intensity. The energy criteria are based on the comparison between the strain energy release rate and the energy release rate.

Hence three different loading modes leading fracture to occur. Mode I is an opening mode, mode 2, and mode 3 are shearing and tearing mode respectively. In mode 2 crack surface move to perpendicular to crack tip, in mode 2 crack surface move parallel to crack tip. Considering a mode I loading, the stress intensity factor is-

$$K_{\mathrm{I}} = Y\sigma_r\sqrt{\pi a}$$

Y is a non-dimensional function that depends on geometry, load distribution, and is given, graphically for many practical cases σ_r the stress applied perpendicular to the crack length, a. the stress intensity factor characterizes the stress at the crack tip and measures the propagation capability. Crack will occur if $K_{\mathrm{I}} = K_{1c}$ where K_{I} and are K_{1c} calculated stress intensity factor.

II. OBJECTIVES OF STUDY

A. To work on the friction stir welding of aluminum alloy AA2024 for butt joint configuration.
B. To study crack initiation criterion for welded joints.
C. To study the direction of crack propagation in case of welded joints.
D. Calculation of ERR vs crack length for various conditions.
E. To study numerical simulation in ABACUS software

III. LITERATURE REVIEW

Dhanesh G Mohan S Gopi, In current scenario, FSW is widely applied for several industries such as aerospace, automobile, reactors etc. FSW has an ability to weld dissimilar metals having different melting points. The main advantages of FSW process are very eco-friendly and produces less waste. Friction stir welded region have high strength, low distortion, no melt related defects. The absence of filler materials and air eliminates filler induced defect, and porosity. FSW technique is uses to produce T, lap and butt shaped welding and also used in hollow pipes, pressure vessels etc. [1]

Antonio Carlos de Oliveira Miranda , Adrian Gerlich, Scott Walbridge, In this paper fatigue design of aluminium welds have highlighted a lack of guidance on the assessment of structure containing joints made by friction stir welding. With this scenario current paper presents a review of existing fatigue life data for FSW joints and reported measurement of key geometric and material parameter for which additional data collection would be beneficial for improving our understanding of the fatigue behaviour of FSW joints.[2]

Hongjun Li and Jian Gao and Qinchuan Li, In this work provides an overview of the fatigue mechanism, influencing factors, crack growth rate, and fatigue life assessment. It is found that the fatigue performance of friction stir welded joints can be affected by welding process parameters, test environment, stress ratio, residual stress, and weld defect. The optimized process parameters can produce high quality weld and increase the weld fatigue life. Laser peening is an effective post weld treatment to decrease fatigue crack growth rate and improve material fatigue life.[3]

Vinay Raghuram, In this work butt joint specimens of Al-2195 and Al-2219 are fatigue tested according to ASTM-E647. The effects of: (i) Stress ratios, (ii) Corrosion Preventive Compound (CPC), and (iii) Periodic Overloading on fatigue life are investigated. Scanning electron microscopy (SEM) is used to examine the failure surface, and examine the different modes of crack propagation i.e. tensile, shear, and brittle modes. It is found that fatigue life increases with increase in stress ratio; the fatigue life increases from 30-38% with the use of CPC, the fatigue life increases 8-12 times with periodic overloading, , and crack closure phenomenon predominates the fatigue facture. Numerical Analysis in FEA has been used to model a fatigue life prediction scheme for these structures, the interface element technique with critical bonding strength criterion for formation of new surface has been used to model crack propagation[4]

Comninou M, In this interface crack is given by comninou.in many cases fracture at interface leads to the failure of whole mechanical structure. Early solutions to such problem lead to unacceptable behaviour of crack abruptly changing oscillation in stress and displacement fields suggesting that the impossible phenomenon for interpretation. Two major modifications are given by Atkinson and Comninou. Atkinson study proposed that interface between two materials is not sharp and is The Atkinson modification recognizes that the interface between two different materials is almost never sharp and changing gradually. The Comninou approach allowing for partial closure at the tips. Both solutions are very helpful for determining the failure of the materials. Both scientist receives the praise due to the findings. Mainly concentrated numerical models of elastoplastic behaviour of interface cracks.[5]

Knésl, Z., Klusák, J. and Náhlík L, In This research proposed the criterion for crack initiation. The general approach in determining the stability of singular stress concentrations are developed in part first. this study is applied to the bimetallic materials. From this study tangential stress and strain energy density factor distribution in the near field of crack tip is developed. the critical stress is calculated as a function of geometry and material properties of biomaterial notch. this paper is trying to reveal the conditions when the crack initiates at the crack tip of bi-material. Bi-material notches takes in consideration while calculating the geometrical and material discontinuities. special case of singular stress concentrator is bi-material notch.[6]

Herr, A.F. and Nied, H.F, In this Both of this scientist studied the numerical simulation of 3D mixed mode. Simulation of arbitrary shape is tedious and time consuming.it becomes more tedious when analysis for true 3D crack at the interface of weld joint of two dissimilar materials. Simulating 3D crack requires creation of solid model and crack front definition. calculating stress intensity factors along crack front and remeshing in the vicinity of crack tip after each increment in crack length. this technique uses ANSYS software for simulation. ANSYS easily calculates the mode I, mode II, and mode III stress intensity factors. When this element is subjected to thermal loading mode II and mode III are dominant.[7]

Thakre, A.A. and Singh, A.K, In this paper Thakre and Singh have done the analysis of interface crack when shear force is applied.in this paper they have experimentally calculated the energy release rate. They have done the experiment on glass surface and gelatine hydrogels using slide-hold-slide experiment. Crack length and forces are used to calculate the ERR of sliding surface. static, dynamic and residual strengths are physically correlated. Work of rupture and work of steady sliding linearly increases with pulling velocity. Work of adhesion is independent of pulling velocity. Present study is correlated with fracture mechanics.[8]

IV. CONCLUSION

From the literature survey as mentioned above it is known that various research has been performed on the fracture mechanics of FSW joints and it is still being studied. In fracture mechanics mainly consider as crack initiation and in which direction crack is to be propagated. Fracture mechanics analysis investigated all the three modes and mixed mode to identify parameter for which additional data collection would be beneficial for improving our understanding of the fracture mechanics of FSW joints.

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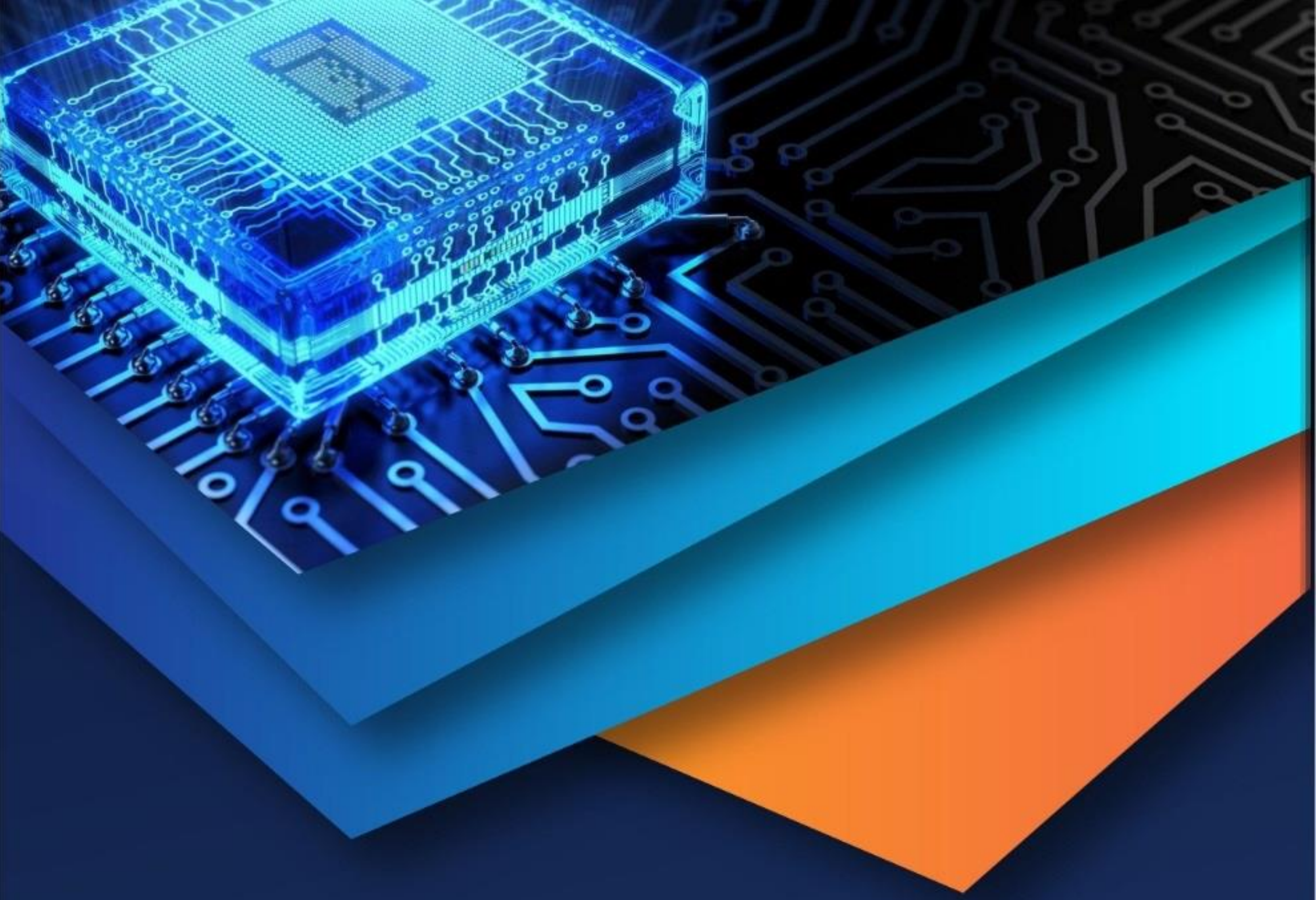

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