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Numerical analysis of friction welded titanium joints

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ABSTRACT

Purpose: Friction welding is found to be a suitable candidate for joining the dissimilar materials. Numerical model would be helpful for proper selection of processing conditions. In the present work, a thermo-mechanical model has been developed using finite element method based software.

Design/methodology/approach: Friction welding process is characterized of thermo-mechanical phenomenon, which is highly complex in nature. Thermo-mechanical model is considered as highly nonlinear due to the interaction between the temperature fields and time dependent on the material properties. The numerical model is subject to certain assumptions and boundary conditions.

Findings: The numerical investigation was carried out to predict the temperature distribution, heat flux, the axial shortening and stress on the friction welded titanium joints.

Research limitations/implications: Leading aerospace manufacturers are exploring the joining of titanium to titanium for aerospace applications. The approach is time saving and it is supposed to have a promising future in automotive and nuclear fields.

Keywords: Deformation; Heat flux; Friction welding; Stress and strain

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ANALYSIS AND MODELLING

1. Introduction

The joining of titanium plays a vital role in advanced manufacturing technology. Since diverse properties are required for the particular application, the properties of corrosion resistance and the highest strength to weight ratio of any metallic element. Depending on the manufacturing and operating conditions, different materials are used in the individual elements of a machined component or structure to achieve optimum economical and mechanical properties [1]. Friction welding is a solid state joining process that uses the rotational motion and high axial pressure to convert rotational energy into frictional heat a circular interface. The basic principle of friction welding is one of the components being welded is rotated while the other is kept stationary. The two components are then brought together by an axially applied force [2]. Rubbing the two surfaces together produces sufficient heat in such a way that local plastic zones are formed and axially applied force causes the plasticized metal to be extruded from the joint, carrying with contaminants, oxides etc. Generally, thermo-mechanical cycles, the process can be separated into two general stages: a welding stage or heating stage and a cooling stage.

2. Literature survey

Akbari Mousavi et al [1] performed numerical analysis of friction welding of 4340 steel/Mild steel combinations. Hazman Seli et al [2] predicted the burn off length, temperature distribution and stress during the joining operation of fully coupled thermo-mechanical model. Wenya Li et al [3] modelled the two-dimensional friction welding of dissimilar joints at various conditions using ABAQUS software. In order to achieve the better results three-dimensional model were developed using Finite element software. Hazman Seli et al [4] performed numerical analysis of friction welding of Mild steel/Al 6061 T6 alloy combinations. All the experiments performed were modelled using ABAQUS software Livan Fratini et al [5] developed the three dimensional lagrangian thermo-mechanical model using DEFORM 3D modelling environment.

During the simulation process the temperature distribution and the axial shortenings are predicted. B. Grant et al [6] performed numerical analysis of inertia friction welding of a sequentially coupled thermal mechanical finite element model which has been developed using the Deform package finite element software tool. L.W. Zhang et al [7] developed a combination of thermomechanical finite element model to simulate the temperature distribution of dissimilar joints (GH4169 alloy) during inertia friction welding process. Rajesh et al [8] carried out the transient thermal analysis to understand the joining of ceramics with metals and to predict the temperature distribution at the joint interface. Rajesh et al [9] developed a Finite element based three-dimensional nonlinear model for joining the dissimilar metals (Aluminium/Mild steel) to predict the temperature distribution and heat flux at the joint interface. Rajesh et al [10] presented a finite element based numerical model has been developed to understand the thermo mechanical phenomenon involved in the process of friction welding. Mohammed Asif et al [11] using ANSYS software to developed the three-dimensional nonlinear model to foresee the thermal history and axial shortening of the dissimilar metals during joining process.

3. Numerical analysis

Friction welding is a complicated metallurgical process that is accompanied by the frictional heat generation and plastic deformation. Friction welding of Titanium and Titanium was numerically developed by ABAQUS 6.14 Software. In the present work, the numerical simulation is carried out to predict the temperature distribution, stress, strain, deformation and heat flux vector of the dissimilar joints.

3.1. Assumptions

- The heat loss due to radiation was compared to the convection and conduction of the losses. [1]
- 100% of dissipated energy caused during the friction between parts was converted to heat and distributed evenly between two interfacing surfaces.
- The cylindrical rods were assumed to experience frictional contact described by Coulombs frictional law with temperature dependent friction coefficient μ.

3.2. Boundary conditions

The boundary condition is applied as convection mode of heat transfer for the external surfaces and conduction at inner surfaces of both Titanium sides (Fig 1). Initial temperature of the room is assumed to be 29°C.

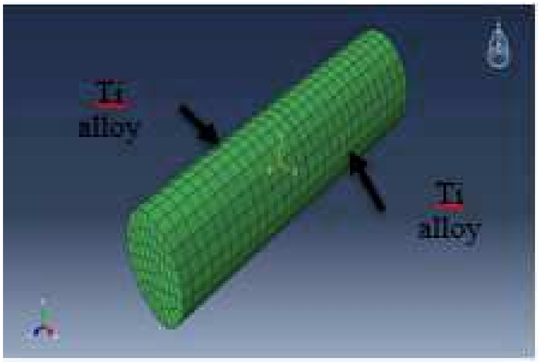

Fig. 1. Meshed Model

3.3. Mesh and geometry

The titanium alloy rods were modelled individually with 10 mm diameter and 20 mm length by using ABAQUS software. The element type of the dissimilar material C3D8RT which has an 8 node thermally coupled brick structure with tri linear displacement (Fig. 2).

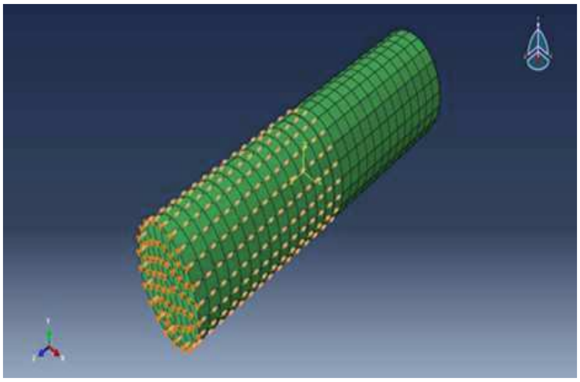

Fig. 2. Loading and boundary conditions

The numerical simulation of the friction welding was carried out using ABAQUS Software. The titanium alloy rod was rotating at an angular velocity of 108.3 rad/sec. The predicted heat flux 3.7 e6 W/m^2 was applied at the joint interface of the both dissimilar joints. The axial pressure and velocity were applied on the titanium rod at 10 bars and 20.3 m/s respectively. The simulation results predicted the temperature distribution, stress, strain and deformation of the titanium joints.

3.4. Coupled field analysis

The thermal model was sequentially coupled to mechanical model. The mechanical loading of stationary rod is taken into account while retaining the load step size used in the thermal model. The temperature history of the rod was considered in each load step with mechanical loading to predict the stress developed in the work pieces. In the present work, the direct method analysis could be used to predict the factors for the friction welding process. The direct method usually involves just one analysis that uses a coupled-field element type containing all necessary degrees of freedom. Coupling is handled by calculating element matrices or element load vectors that contain all necessary terms.

The temperature is very high at the joint interface of the dissimilar materials and the gradient of the temperature gradually decreases in the axial direction of the dissimilar joints. Peak temperature reaches 906.2°C at a friction time of 3 seconds (Fig. 3). The heating temperature reaches above 60% of the melting point of the material.

The rate of heat transfer on both the sides are same because the end of both material has the equal thermal properties of the titanium joints (Fig. 4).

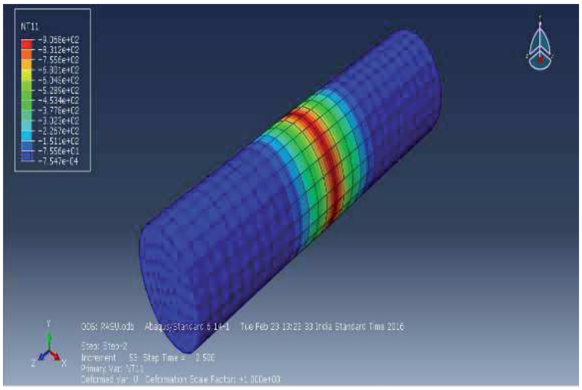

Fig. 3. Temperature distribution of titanium joints

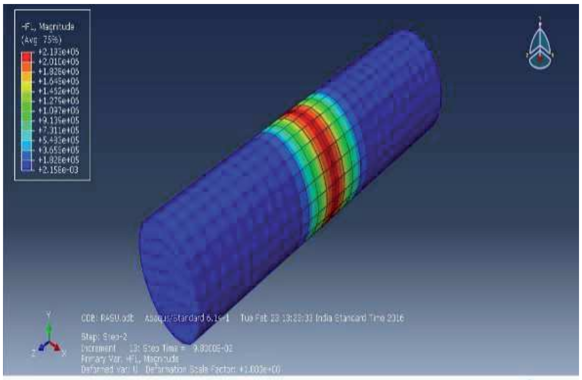

Fig. 4. Heat flux vector of titanium joints

The maximum principal stress occur 1.5 mm away from the centreline of the joint interface during friction welding process (Fig. 5).

During friction welding process deformation occurs at the joint interface of the titanium joint at 3 seconds (Fig. 6).

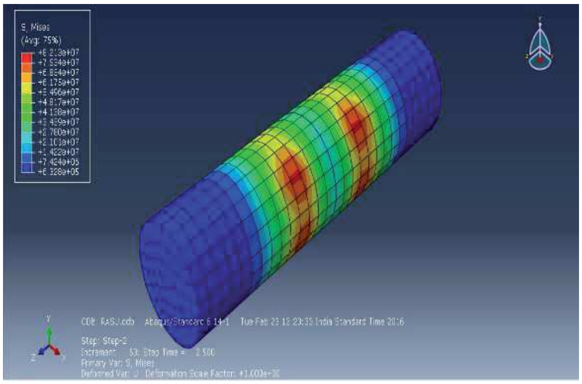

Fig. 5. Maximum principal stress

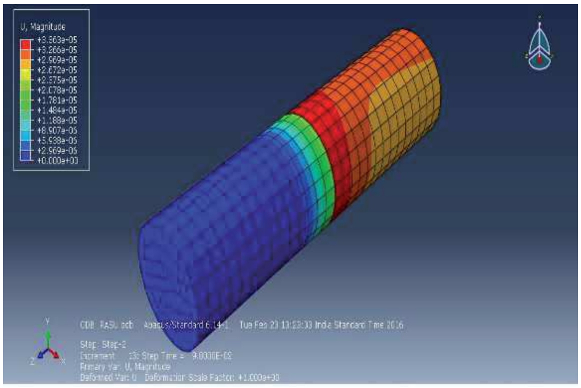

Fig. 6. Displacement of the joints

4. Conclusions

Numerical simulation was carried out to characterize the friction welding process that involves the deformation, temperature distribution and time dependent operations. The developed model is able to predict the temperature distribution, Heat flux vector, deformation and stress developed.

The following conclusions are drawn from this study:

- The peak temperature 956.2°C is obtained at the joint interface, during the friction welding process at the friction time of 3 seconds. The temperature gradually decreases axially away from the centreline.
- During joining of Titanium with Titanium alloy, the temperature distribution is found to be uniform on both the sides due to similar thermal properties.
- The maximum principal stress is produced at 1.5 mm away from the centreline of the joint interface on the titanium material joints.

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