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Stress Analysis of Field Shaper in Electro-Magnetic Welding

Engineering

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ABSTRACT

Field shaper is a practical tool used in electromagnetic welding for influencing the magnetic field and pressure distribution. Magnetic pressure acting on the field shapers induces structural stresses which may lead to its failure. Two types of field shapers, one without radial slit and the other with radial slit are analyzed for static loading condition by classical thick cylinder theory and the results are compared with the numerical solution. Finite element simulation results indicated non uniform stress distribution around the circumference of the field shaper with radial slit.

INTRODUCTION

Sustainable development calls for environmental friendly innovative methods for joining of dissimilar metals. Nowadays, Electromagnetic welding (EMW) is considered to be a cost effective, fast and reliable process ideally suitable for joining of multi-material or tubular overlap parts. The feasibility of EMW is studied for a large variety of material combination with differing melting temperatures [1-4].

The bonding principle is to create a solid state weld by the impact (Lorenz) force at the interface of the two materials to be joined. Impact force is generated by the repelling interactions of magnetic flux produced by the discharge current running through the coil, and the eddy current induced at the work surface.

The basic EMW process includes a capacitor bank to store and release energy, a coil to create the magnetic field, and a work pieces to be joined or formed. Auxiliary parts are often used for a wide variety of purposes, including safety, additional control of the magnetic field, or to transmit the forces to a non-conductive material. Field shaper is an auxiliary tool which influences the distribution of magnetic field.

FIELD SHAPER

Field shapers are designed with different geometrical cross section mainly for tubular structures and are placed in between the coil and work piece. It is more economical to manufacture a field shaper than a special electromagnetic coil. Field shapers can prolong the service life of the coil, control the shape magnetic flux distribution, and exert the magnetic pressure at the specified region of the work piece. Field shaper transfers magnetic energy in the air gap between the coil and the field shaper into the air gap between the structure and the field shaper. Process efficiency improves considerably with the use of a field shaper made of higher conductivity material. From the structural point, field shaper is also subjected to deformation pressure, as a result of the interaction of its current and the magnetic field. Therefore, it should be made of material which meets desired electrical as well as mechanical properties.

The majority of high-conductivity metals, like copper or aluminum, do not have good mechanical strength. Some of the earlier works have suggested that copper-beryllium would be a good choice for use as a field shaper [5].Bimetallic designs were also considered with the field shaper layer closer to work piece made of high conductivity metal that is responsible for transferring the magnetic energy into the desired area while the second layer made of a metal with more mechanical strength to ensure the mechanical strength of the tool. However, due to practical constraints, such as joining two different layers, implementing this construction seems very cumbersome.

Field shapers are subjected to enormous magnetic pressure which may induce structural stresses leading to its failure. Little information is available on the stress distribution for a field shaper. In the present study, we have analyzed stresses in two types of field shapers one without radial slit and the other with radial slit for static loading conditions. The field shapers are assumed to have open ends with rectangular cross sections. Subsequently axial component of stress is considered to be zero. Aluminum material is selected for the finite element analysis purpose.

ANALYTICAL SOLUTION

Classical theory of thick cylinder, with open end concept is applied for the analysis of stress distribution in a field shaper. In practice field shaper is assumed to be subjected to differential internal pressure and external pressure. For simplicity, of the analysis only internal pressure (Pi) is considered and the external pressure (Po) is considered zero. The inner radius and outer radius are considered to be ri and ro respectively. Generally internal pressure causes radial and circumferential stress distributions across the thickness.

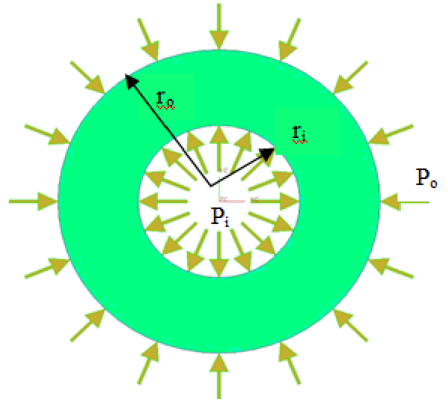

Figure 1a)

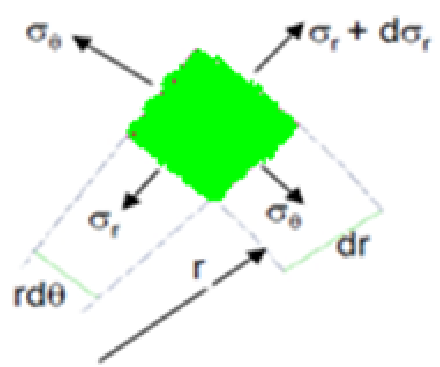

Figure 1b)

Figure1: a). Cross section of field shaper with pressure distribution b). Elemental area

Considering a small elemental area of field shaper, for a plain stress state, has the following equations for stress distributions across the thickness are derived from lame's equations:

$$\frac{\partial \sigma_r}{\partial r} + \frac{\sigma_r - \sigma_\theta}{r} = 0$$

where σr and σθ are taken as radial stress and circumferential stress respectively.

$$\sigma_r = \frac{P_i r_i^2}{r_0^2 - r_i^2}\left[1 - \frac{r_0^2}{r^2}\right] \qquad \sigma_\theta = \frac{P_i r_i^2}{r_0^2 - r_i^2}\left[1 + \frac{r_0^2}{r^2}\right]$$

At the inside surface, r= ri

$$\sigma_\theta = Pi\,\frac{r_0^2 + r_i^2}{r_0^2 - r_i^2} \qquad \sigma_r = -P_i$$

At the outside surface, r=r0

$$\sigma_\theta = \frac{2 P_i r_i^2}{r_0^2 - r_i^2} \qquad \sigma_r = 0$$

Maximum distortion energy or VonMises failure criteria is chosen for failure analysis. It says that the material will fail when the equivalent stress exceeds the yield point limit. Von Mises stress is given by the following equation.

$$\sigma_i = (\sigma_r^2 + \sigma_\theta^2 - \sigma_r \sigma_\theta)^{1/2}$$

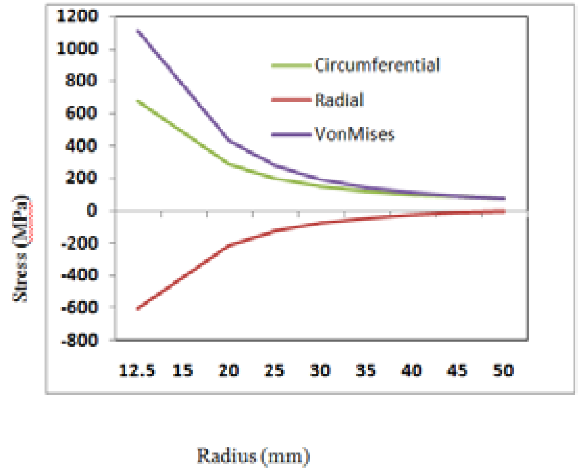

Figure 2: Graph of stress distribution along the radial direction.

From the graph in the figure 2, it is very clear that radial stress being negative is compressive in nature and the circumferential stress, with positive value is tensile. We can conclude that inner fiber of the material experiences maximum stress.

NUMERICAL ANALYSIS

Field shaper is numerically analyzed by finite element method and the results were compared with the analytical solution. The commercially available ANSYS 10, finite element software is used for this purpose. Three dimensional finite element analyses (FEA) is conducted using quad element under plane -strain , axi-symmetric conditions.

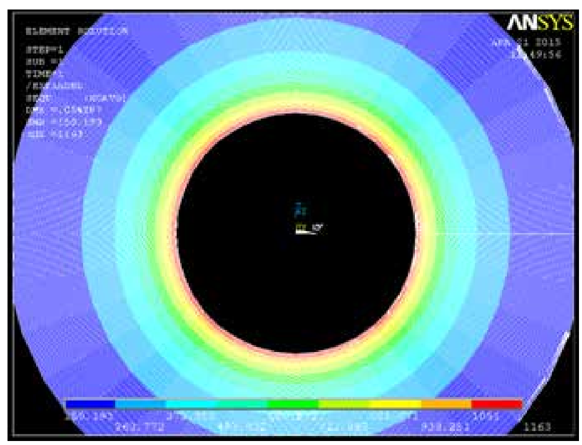

Figure 3: Stress distribution of Field shaper without radial slit

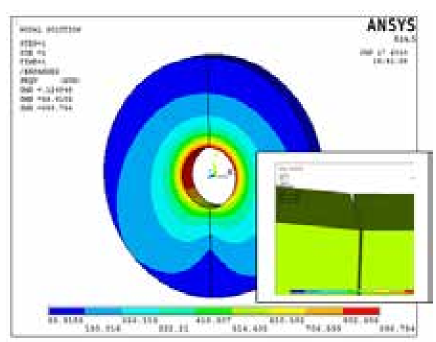

Figure 4: Stress distribution of Field shaper with the radial slit (insight: slit of field shaper)

Numerical simulation on the field shaper without radial slit does show constant stress distribution for a particular radius over the entire circumference. However the stress distribution does not seem to be uniform at a radius over the entire circumference for a field shaper with the radial slit. This is due to the fact that the field shaper is not axially symmetrical due to the presence of slit. Simulation result shows that magnitude of stress around the slit region is significantly low than at the rest of the circumference. The region around the circumference diametrically opposite of slit shows highest stress distribution. When the result is correlated with magnetic field, in an electromagnetic welding setup, current will not flow in the slit region. Thus the magnetic pressure will be lower in the slit region when compared to the rest of the circumference. Accuracy of simulation is limited to the accuracy of the parameters introduced into the model. Simulation results are validated with the theoretically obtained values for the field shapers without radial slit.

CONCLUSIONS

Field shapers were analyzed for static load condition both analytically as well as by finite element method and the following conclusions are drawn.

1. Stress distribution is uniform for a field shaper without the radial slit around its circumference. Finite element results are validated using classical thick cylinder theory.

2. Finite element simulation results showed non uniform stress distribution around the circumference of the field shaper with radial slit. The stress at the slit region is significantly low with the diametrical opposite region experiencing maximum stress.

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