

3D Magneto-Structural Analysis of Magnetic Pulse Welding

A. Amardas¹ & B. R. Doshi¹

1. Institute for Plasma Research, Bhat, Gandhinagar 382428, INDIA

INTRODUCTION: Magnetic pulse welding (MPW) is a novel technique which uses Lorentz force generated in a short pulse to pinch an outer workpiece, called 'flyer' onto an inner parent work piece to realize a high quality, fast joint with high precision and without using any filler material. In this method, energy stored in a capacitor bank is discharged through a forming coil using a spark gap, which creates a damped sinusoidal current (\sim MA) for a few microseconds time. The schematic diagram of MPW system is shown in the fig.-1. It is necessary to optimize the gap (s) between inner & outer work piece and the impact velocity (v_i) to obtain best joint.

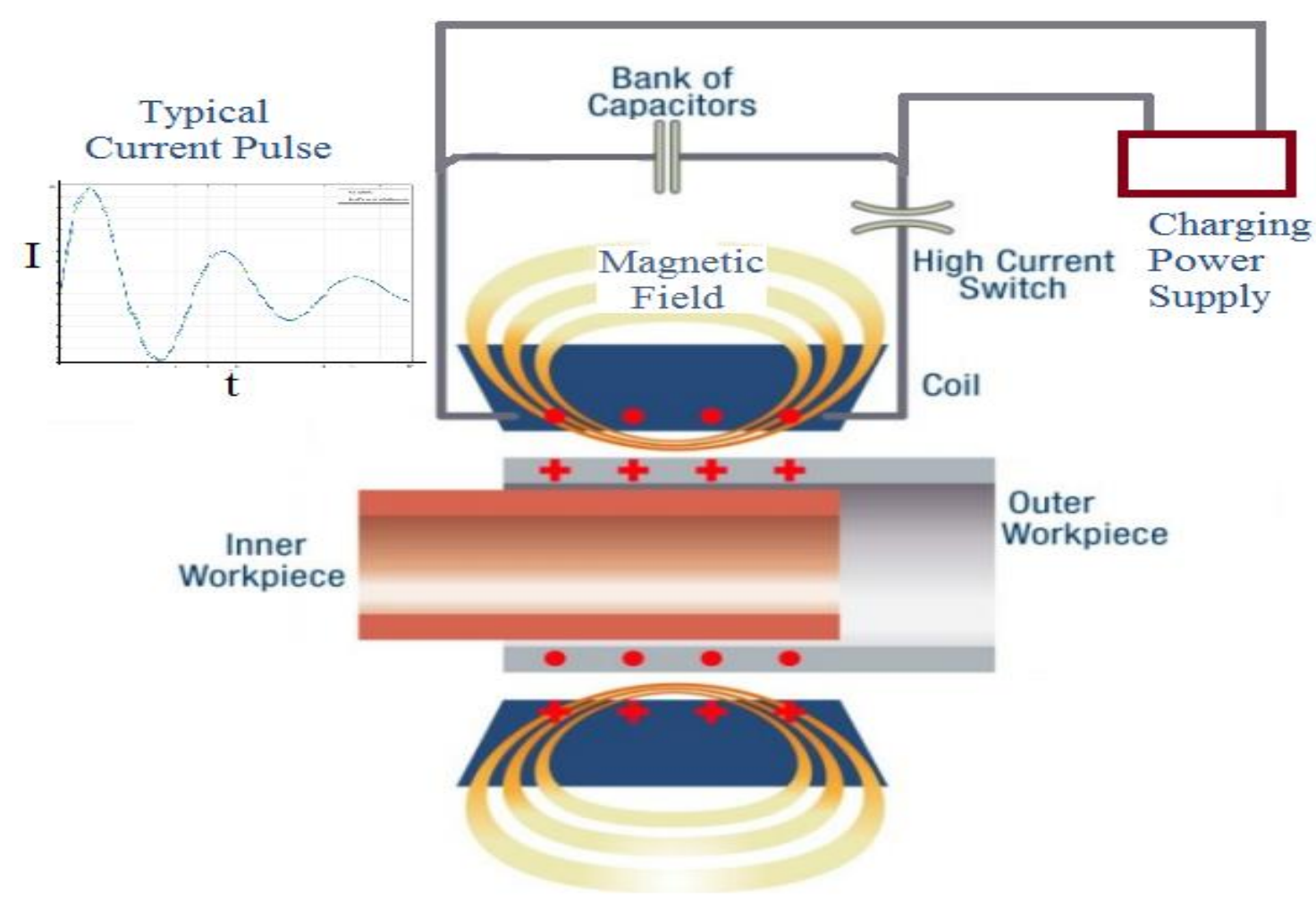


Figure 1. Schematic diagram of Magnetic Pulse Welding System

COMPUTATIONAL METHOD: When a transient current is passed through a conductor, the magnetic field produced, can well be described by Maxwell's equations that result in a diffusion like equation in vector potential formulation

$$\sigma \frac{\partial \mathbf{A}}{\partial t} + \nabla \times (\mu_0^{-1} \nabla \times \mathbf{A}) = \mathbf{J}_e$$

For the given external current density \mathbf{J}_e , to obtain the unique solution of \mathbf{A} and thereby magnetic field \mathbf{B} , the above equation is solved along with the Coulomb gauge constraint equation

$$\nabla \cdot \mathbf{A} = 0$$

Then the Lorentz force can be calculated by

$$\mathbf{f}_V = \mathbf{J} \times \mathbf{B} = \frac{1}{\mu} (\nabla \times (\nabla \times \mathbf{A})) \times (\nabla \times \mathbf{A})$$

The above equations are solved using the **Magnetic Fields interface** of **AC/DC module** in COMSOL Multiphysics®.

Now, the Newton's second law in material frame formulation (which is used in COMSOL Multiphysics®) can be written as

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} = \nabla_X(FS) + \mathbf{f}_V$$

where S is the second Piola-Kirchhoff stress tensor and F is the deformation gradient.

Using "Principle of Virtual work", this equation of motion is reformulated and solved with the **Structural Mechanics module** in COMSOL Multiphysics® to find deformation, stresses in the model. "Linear Elastic Material" node is used along with "Damping" and "Plasticity" sub-nodes to account for inertia and elastoplastic properties of the material. "Body loads" are called from the Lorentz forces by coupling both AC/DC & Structural Mechanics modules.

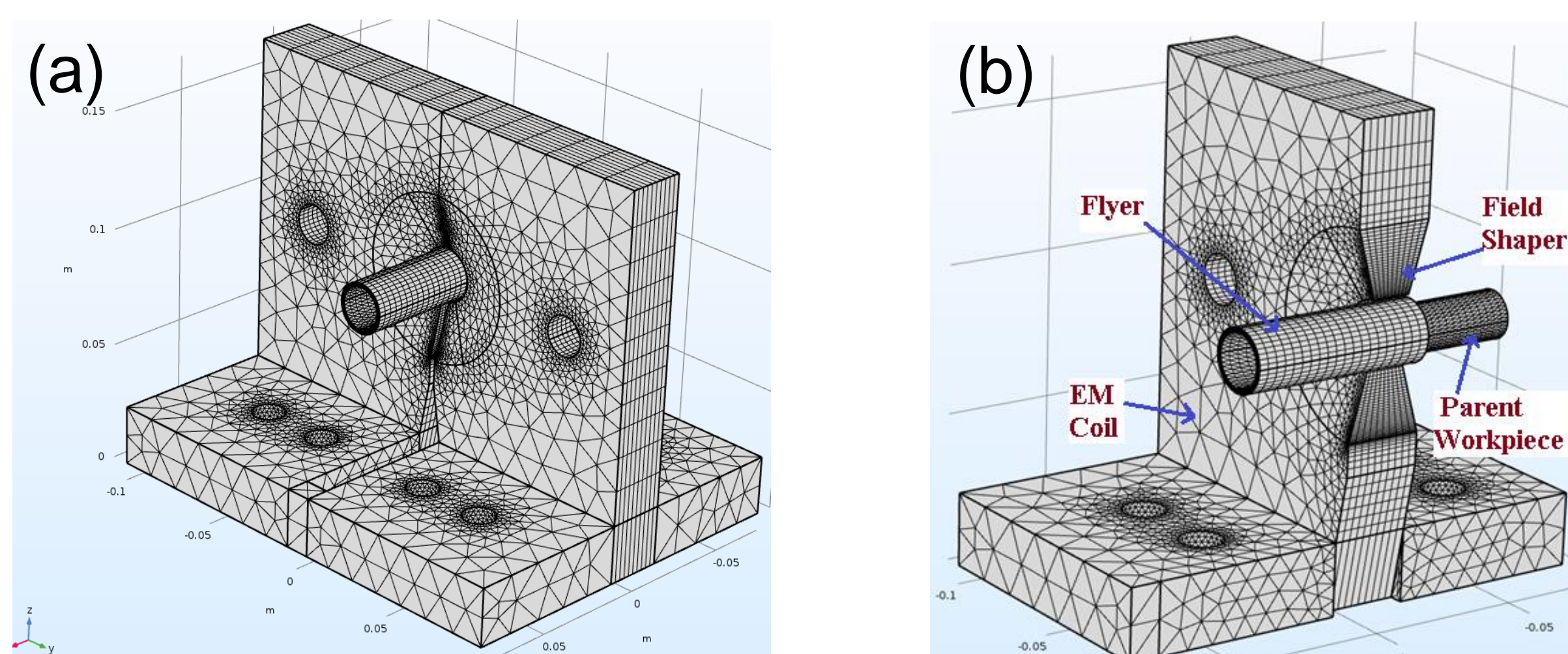


Figure 2.(a)Finite Element Model of Magnetic Pulse Welding (MPW) system, (b) Cut view of the same showing flyer & parent workpiece. The outer vacuum sphere around the model is not shown

The Finite Element model of the problem is built as shown in the fig.-2 with 314607 elements. To capture the elastoplastic deformation accurately and to have good convergence in the solution, the flyer tube of thickness 1.5 mm is meshed in 10 layers and the transient solver steps are taken as small as 0.01 ms.

RESULTS:

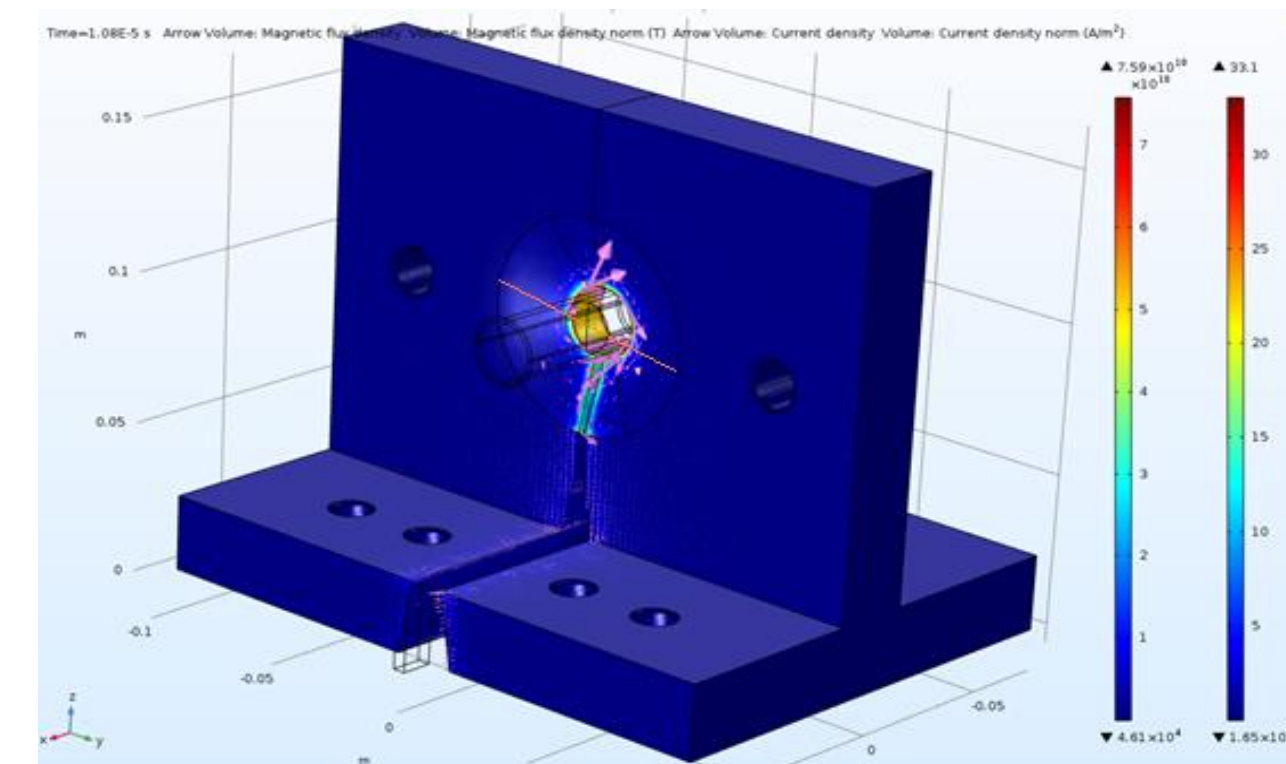


Figure 3. External current density and magnetic field produced in the system

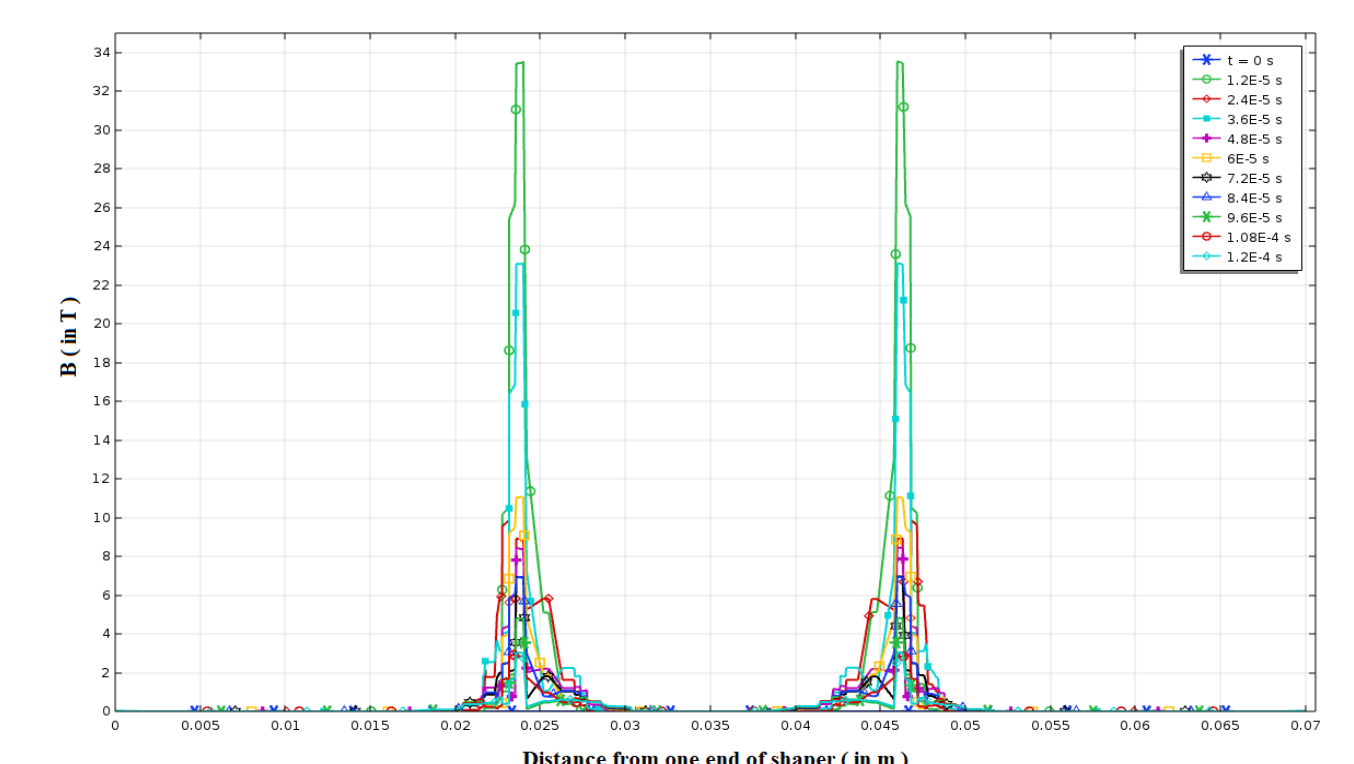


Figure 4. Fast transient field profile along the mid horizontal line shown in Fig.-2

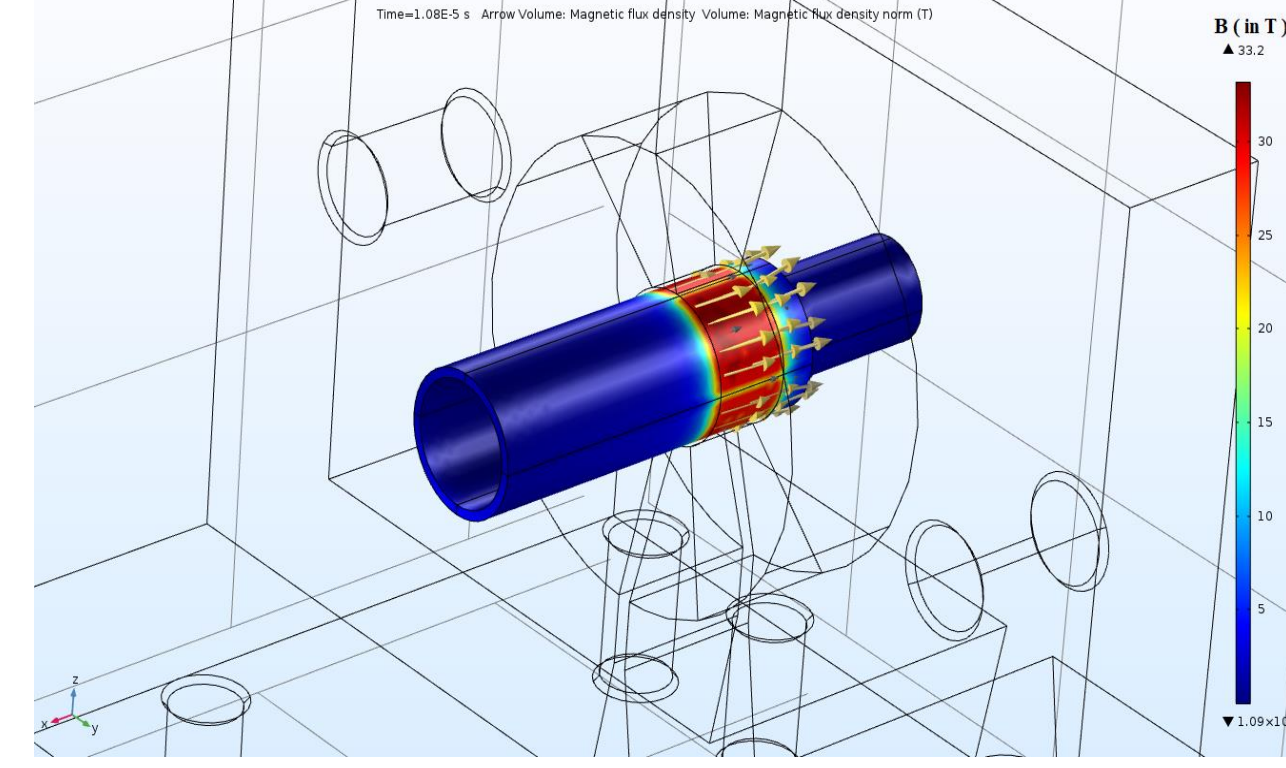


Figure 5. B at peak current on pipe and rod inserted in the system for joining

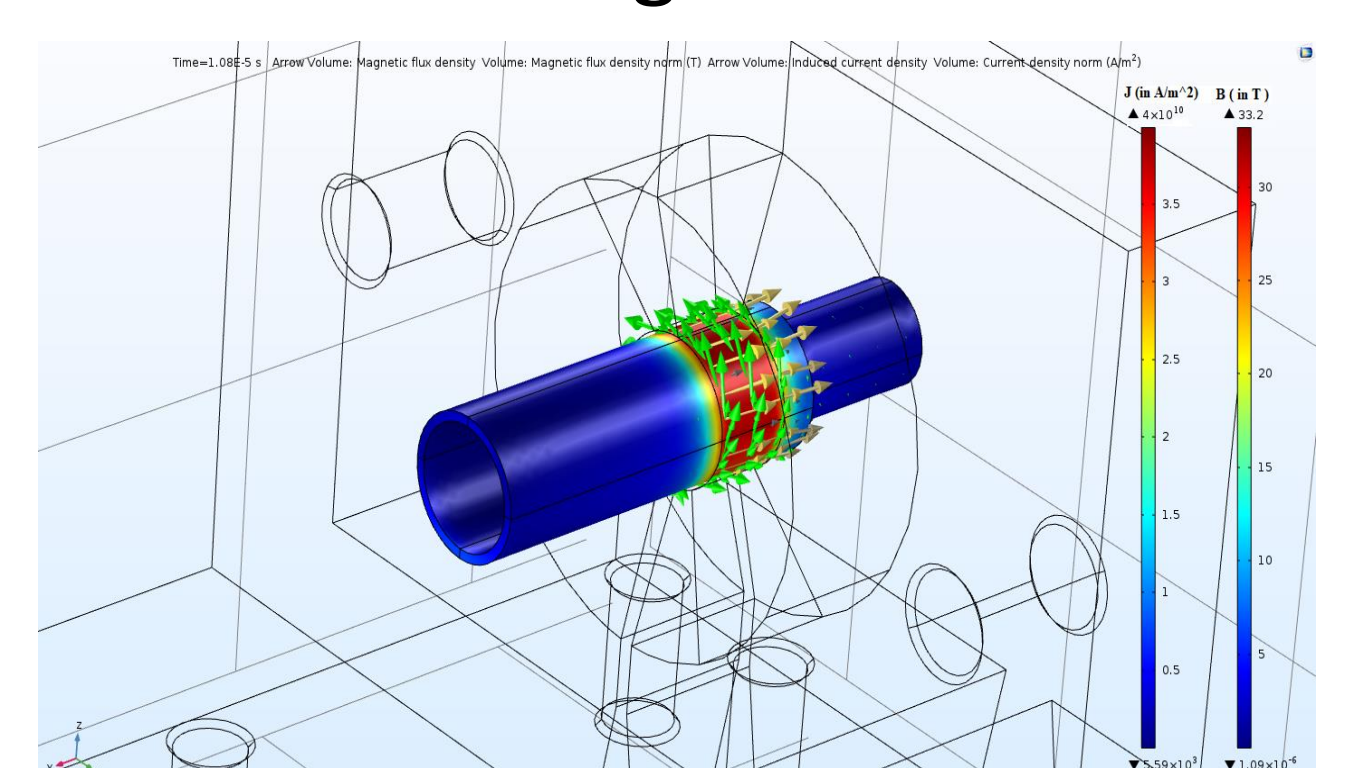


Figure 6. Induced current (J) and Magnetic field (B) on the pipe & rod

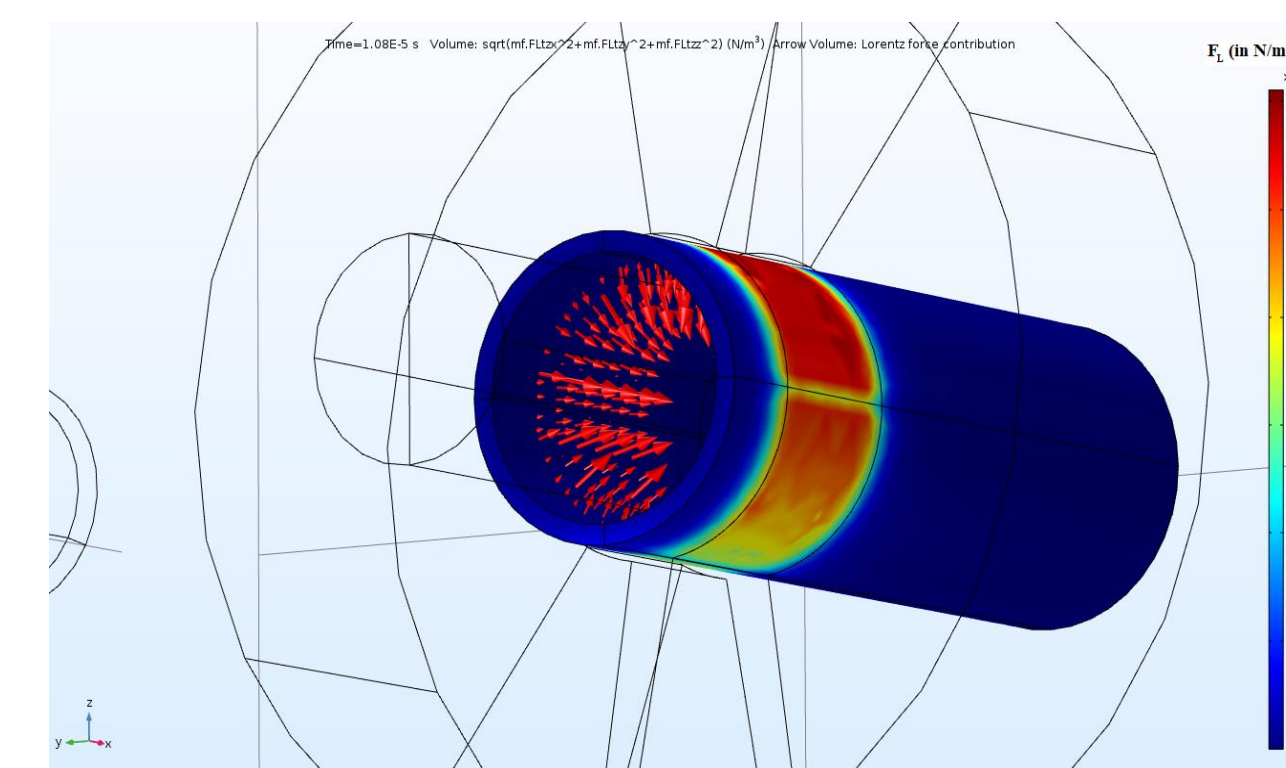


Figure 7. Lorentz force that pinching the outer workpiece

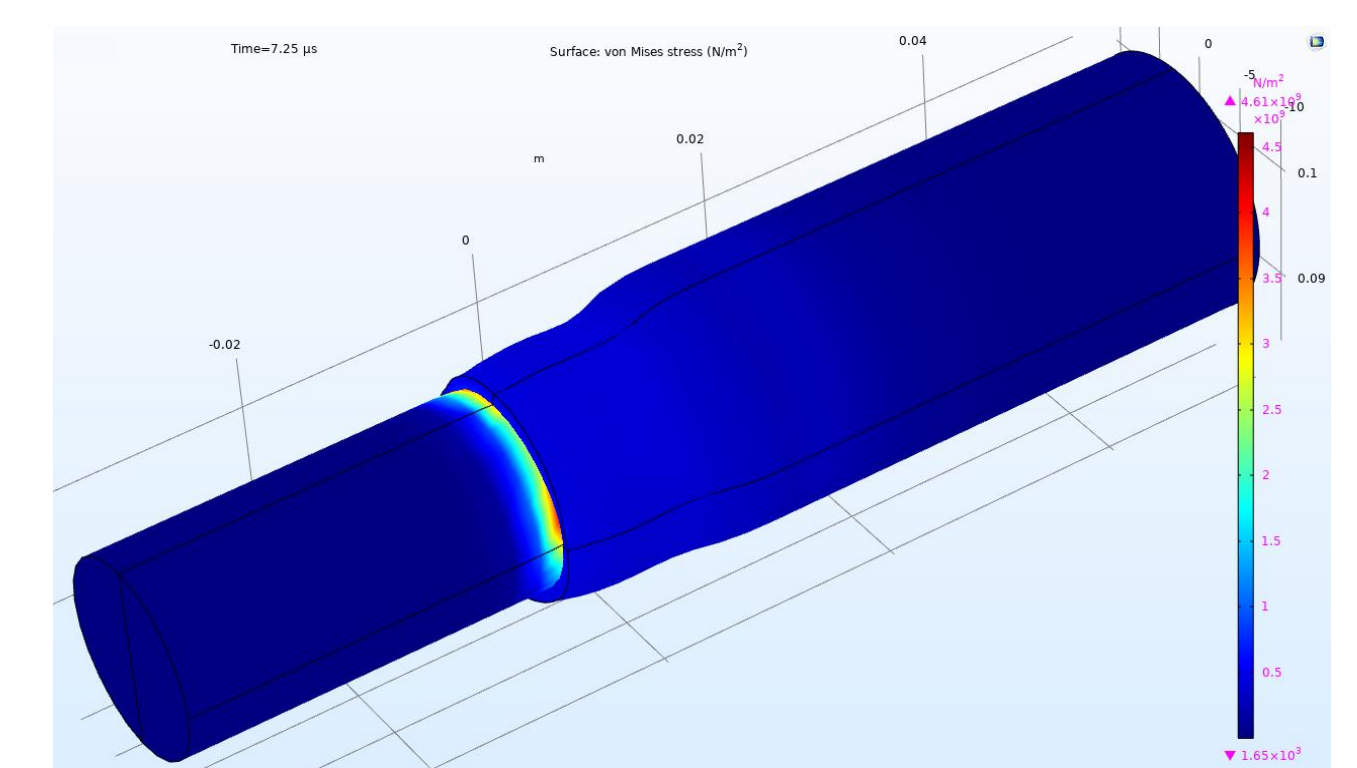


Figure 8. Stress profile in the joint

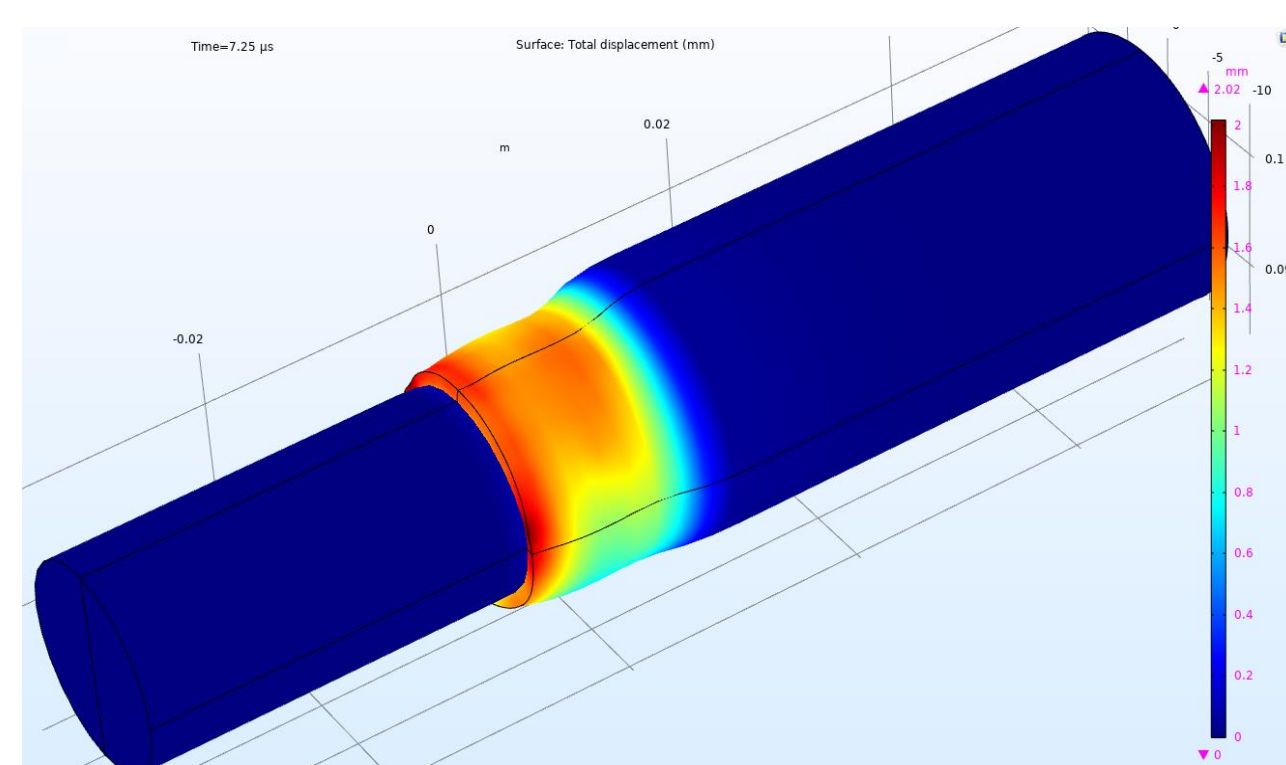


Figure 9. Deformation in the good joint

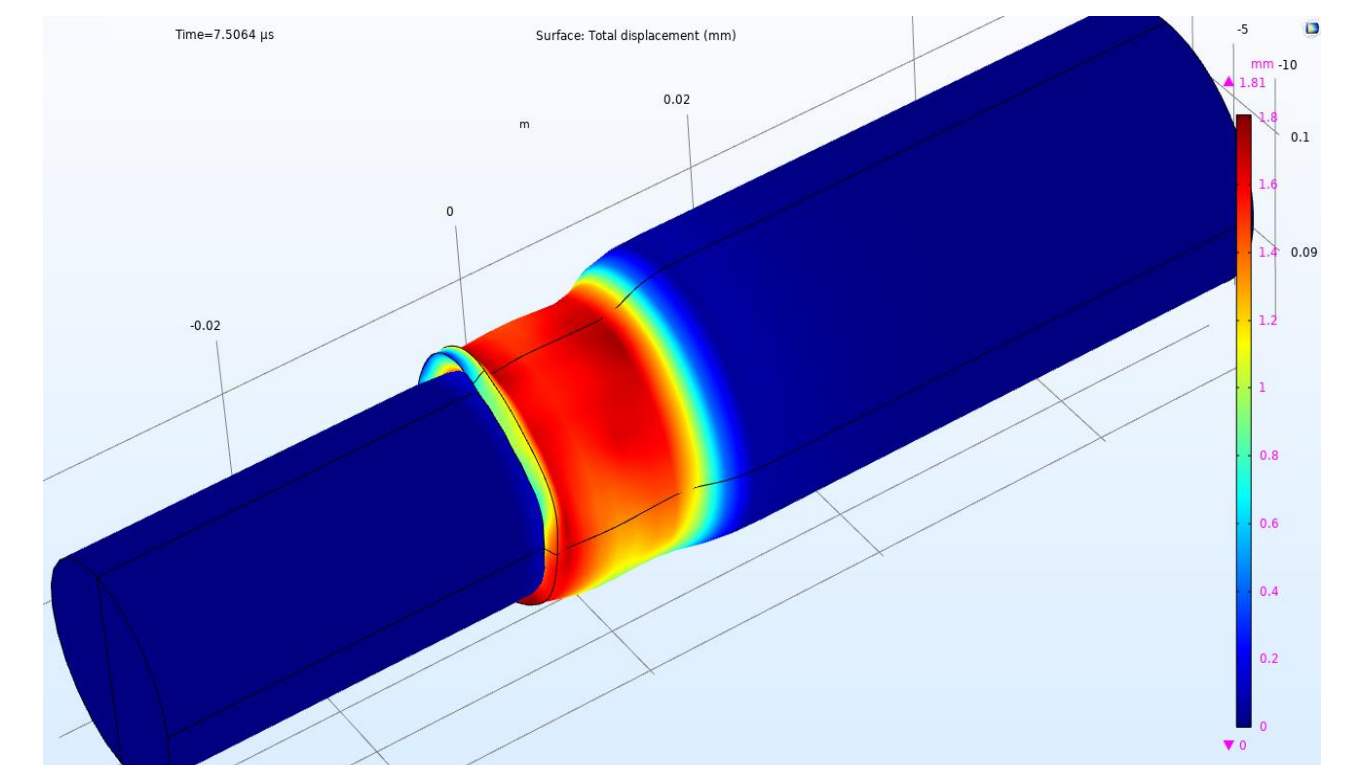


Figure 10. Deformation in the bad joint

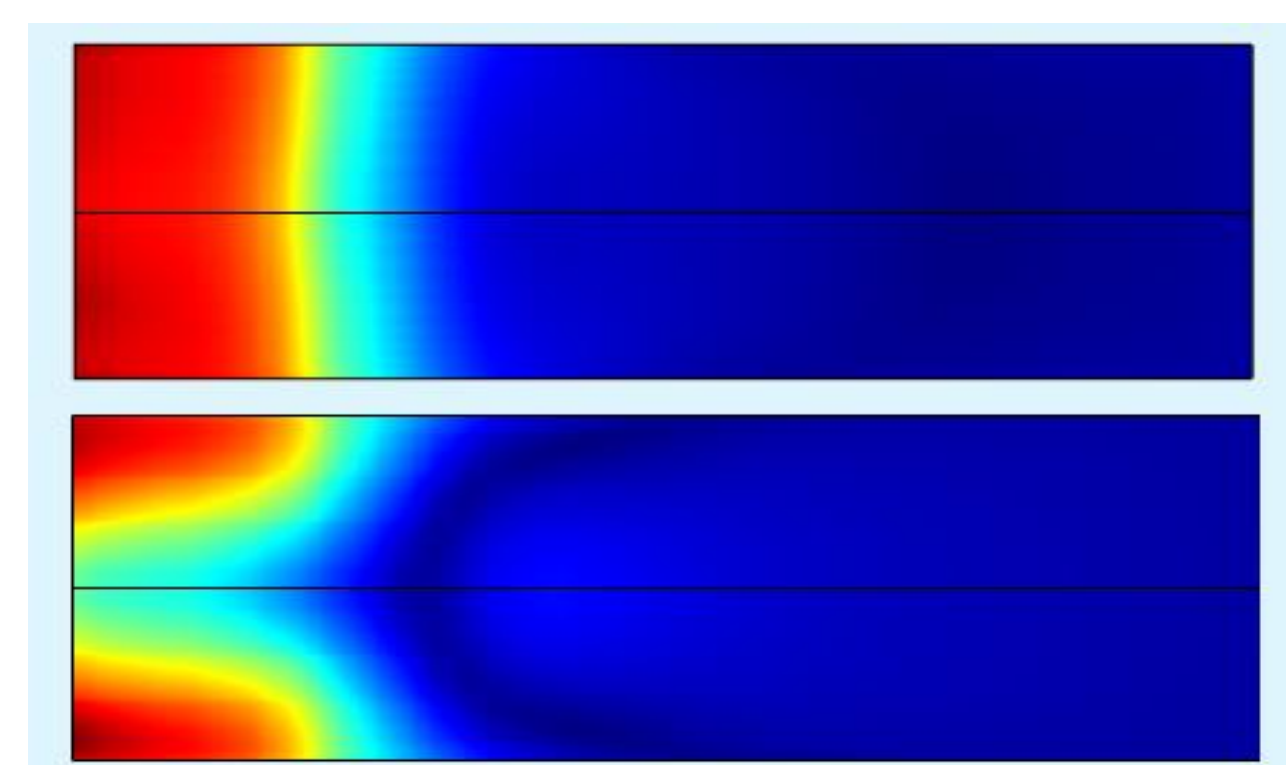


Figure 11. Comparison of stress profile in upper & lower half of outer work piece

CONCLUSIONS: 3D FEM model of "magnetic pulse welding process" is developed to investigate the 'asymmetric' deformations in the joint (due to narrow gap in EM coil) and to optimize the various parameters of the process to obtain the best joint for any give work pieces to be joined.

REFERENCES:

1. A. Stern, V. Shribman, et.al., Interface Phenomena and Bonding Mechanism in Magnetic Pulse Welding, J. of Mat. Eng. and Performance, V.ol.23(10),p.3449,(2014).