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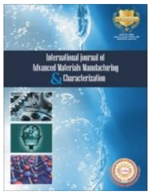

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Coupled 3D Finite Element Modeling of Electromagnetic Free Expansion of Al Tube

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ABSTRACT

In automotive industry there is a general trend of decreasing the vehicle weight which encourages the use light weight metals like aluminium. As EMF can enhance the formability of aluminium it is becoming popular in automotive industry. The limitations of conventional forming like low formability increased wrinkling and springback can be overcome by EMF. As the driving force in EMF is the pulsed magnetic field, it is a contactless forming process which is another advantage over conventional forming. As the EMF process takes place in few microseconds it's too hard to study it experimentally. EMF is simulated by EM module in LS-DYNA™ to predict deformation, current wave pattern, and electromagnetic field.

Introduction

Electro-magnetic force is the driving force in electromagnetic forming process. It has been used in the forming of light weight and difficult to form metals like aluminium and magnesium alloy etc. As the process involves high strain rate, it has all the advantages of high-velocity forming process like increased formability, reduced springback and reduced wrinkling [1, 2]. In this technique large amplitude electric current (100 kA to 200 kA) is passed through the coil for few microseconds. The strain rate achieved is of the order of 10^{-3}. Inertia force plays an important role in EMF reducing the wrinkling of the parts [3].

Electromagnetic forming involves thermal, mechanical and electromagnetic phenomenon. Conraux et al. [4] developed a formulation for a 3D magneto dynamic problem and presented constitutive equations that govern electromagnetism during electromagnetic forming. LSTC has developed EM module to numerically simulate electromagnetic forming [5]. Electromagnetic fields are solved by finite element method and surrounding air/insulators are taken care by boundary element method. M.A.Bahmani et al. [6] have carried out 3D simulations by FEA software MAXWELL and they are used to calculate the magnetic force distribution applied on the workpiece during the electromagnetic forming. G.Bartels et al. [7] has presented simulation approaches for the preliminary investigation of the electromagnetic metal forming process. He has compared an uncoupled simulation model to a more rigorous sequential-coupled approach. According to G.Bartels et al. the simple loose coupled approach can only be used for relatively fast deformation process. Otherwise the more accurate sequential-coupled model should be used. Jianhui Shang et al. [8] have assessed the predictive ability of EM module in LS DYNA through comparison between experimental and numerical results of electromagnetic tube expansion. Electromagnetic forming process is carried out in few microseconds and it is difficult to find out the strain behaviour, velocity of workpiece, and deformation pattern experimentally. Current work is focusing on estimating few of these parameters numerically. The simulation of electromagnetic free expansion of Al tube is carried out with the help of EM module available in LS-DYNA™.

Physics of EMF

Maxwell's Equations, form the basis of numerical computation in LS-DYNA software. The Maxwell's Equations are given as follows

$$\nabla \times \bar{E} = -\frac{d\bar{B}}{dt} \quad (1)$$

$$\nabla \times \bar{H} = \bar{J} \quad (2)$$

$$\nabla . \bar{B} = 0 \quad (3)$$

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$$\bar{B} = \mu \bar{H} \quad (4)$$

$$\nabla . \bar{J} = 0 \quad (5)$$

$$\bar{J} = \sigma[\bar{E} + V \times \bar{B}] \quad (6)$$

$$\bar{F} = \bar{J} \times \bar{B} \quad (7)$$

Where,

E-Electric field

B-Magnetic field density

μ- Permeability

J- Current density

F-Lorentz forceElectrical energy stored in capacitor bank is given by following Eq.

FE Analysis of EMF

Electromagnetic tube expansion involves two components tube and coil. Here the tube used is of Al alloy with dia. 63.5 mm and thickness 0.89 mm. The coil used is of Cu alloy with number of turns 3, pitch 9.9 mm and 61 mm dia. The energy for expansion is 1.2 kJ. The capacitance and voltage used are 426 μF and 2.373 kV respectively. EM forming is a high strain rate forming and the material model which takes care of strain rate hardening and softening due to temperature rise is Jhonson-Cook material model.

$$\sigma_y = \left(A + B \bar{\varepsilon}^{p^n} \right)\left(1 + c \ln \dot{\varepsilon}^*\right)\left(1 - \left(\frac{T - T_R}{T_m - T_R}\right)^m\right)$$

The values of A, B, c, n, m, Tm are taken from literature [8].

Arrangement of workpiece and coil is as shown in the Fig 1. The gap kept between tube and coil is 0.36 mm

Electrical energy stored in capacitor bank is given by following Eq.

$$EC(t) = \frac{1}{2} C V_{(t)}^2 \quad (8)$$

The resulting current I (t):

$$I(t) = V0 \; Sin(\omega t) e^{-\beta t} \quad (9)$$

Where, V (t) voltage across capacitor

C - Capacitance

ω - Frequency

β - Damping coefficient

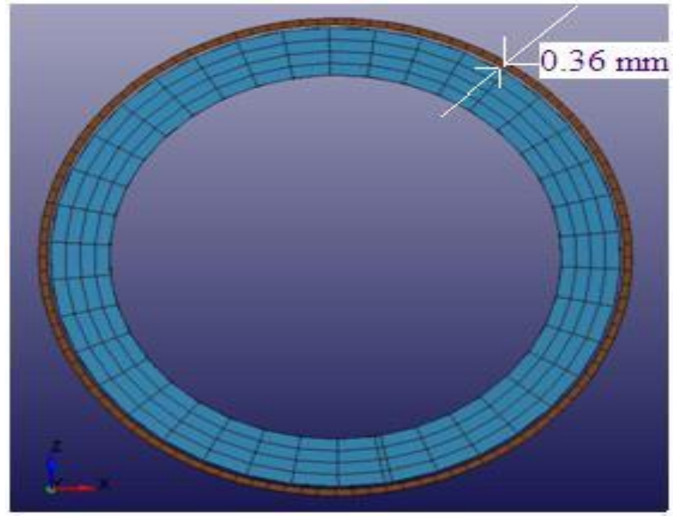

Fig.1.Arrangement of tube and coil

Simulation Results

The current wave form in simulation using LS DYNA, for the used electric configuration of EM forming set up is as shown in following Fig.2.

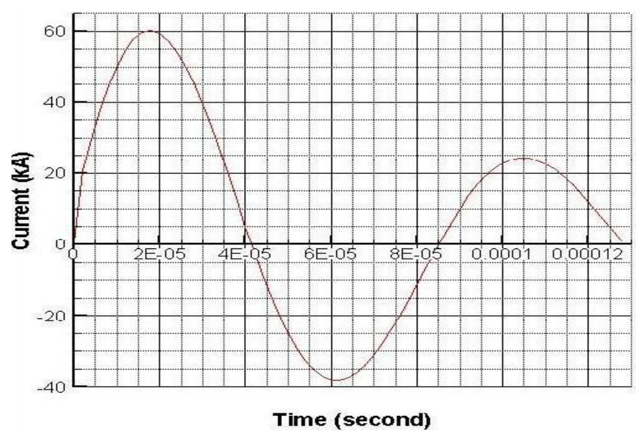

Fig. 2 current Vs time curve

Frequency of current is 11 kHz. The maximum current reaches at 18 μs and the total time period is 85 μs. It can be observed that the peak current is at ¼ th time of the total cycle.

The fringe pattern obtained for magnetic field is shown in the Fig. 3. The maximum value of magnetic field was found to be 0.1212 Tesla for the element which is located at middle of coil. At the ends of coil magnetic field is 0.00121 Tesla. Combined effect of magnetic fields of all turns of coil should give the maximum magnetic field at the centre of three turns of coil. Element A is at the middle of tube. E and F are at the two ends of tube. C and D are in between.

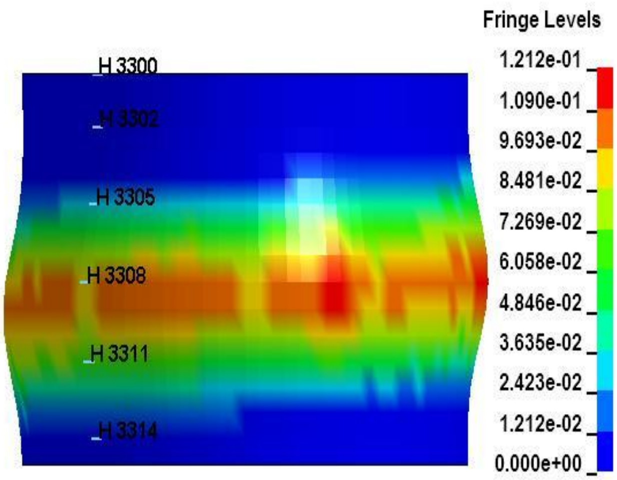

Fig. 3 Distribution of magnetic field on tube

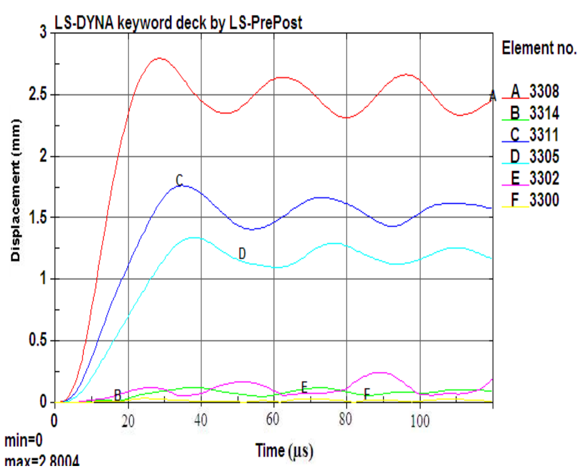

Fig. 4 Deformation pattern

The maximum displacement is for element A (H3308) which is at middle of the coil. The final deformation obtained for element H3308 is 2.5 mm. At both the ends magnetic field is minimum hence the deformation also. Maximum deformation obtained is at 20th µs. This fact supports the conclusion of A.G. Mamalis et al [10] that only the first half of the pulse is responsible for deformation rest of the pulse does not have sufficient energy to deform the workpiece.

Conclusion

Electromagnetic expansion of a tube is presented here to study the electromagnetic field and deformation pattern. From the simulation of EM expansion of Al tube using LS-DYNA it can be concluded that the maximum electromagnetic field is present at the middle of the coil. The first half of the pulse is responsible for deformation remaining pulses are not contributing t the deformation.

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