AmirKabir University of Technology
(Tehran Polytechnic)

AmirKabir Jounrnal of Science & Research
Mechanical Engineering
(ASJR-ME)
Vol. 48, No. 2, Summer 2016, pp. 77-79

Numerical and Experimental Investigation of Electromagnetic Tube Compression Forming in Coupled Method

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(Received 11 May, 2015, Accepted 15 February, 2016)

ABSTRACT

Coupling of electromagnetic field and mechanical structure field is one of the main problems in theoretical study of Electromagnetic Forming (EMF). In this study, two possible approaches for simulation of the electromagnetic tube compression forming process were implemented and compared: A loose-coupled and a sequential-coupled algorithm. In the loose-coupled the electromagnetic field and mechanical structure field were solved separately, but in the sequential-coupled algorithm, the electromagnetic simulation and the mechanical structure simulation were iteratively performed by using the Maxwell equations and the Finite Difference Method (FDM) as subroutine VDLOAD in ABAQUS software. A deformation of the tube and consequently a change in inductance of tube during the process in the sequential-coupled algorithm was considered. The depth of bead in loose-coupled algorithm compared to experimental result had a 35% error, but in a sequential-coupled algorithm this error has been reduced to 5%. To predict tearing in this process Johnson-Cook damage criterion was used. Increasing of discharge voltage and tube thickness respectively, had maximum effect on Johnson-Cook damage. Amount of damage less than 0.8 is conservatively suitable for the safe area without fracture.

KEYWORDS:

Electromagnetic Forming, Electromagnetic Tube Compression Forming, Sequential-coupled, Loose-coupled

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1- Introduction

Electromagnetic forming is an impulse or high-speed forming technology, which uses pulsed magnetic fields to apply forces to tubular or sheet metal work pieces. The electric circuit consists of a power supply and a capacitor bank. By charging capacitor and discharging it at once, a strong current in the coil occurs. According to Lenz law also an induced current in the tube occurs and disagree with its underlying cause and thus the tube gets away from the die. The force exerted on the tube which comes from the mutual disposal known as the Lorentz force [1].

This paper represents two methods, sequential-coupled and loose-coupled, for simulation of electromagnetic tube compression process. The Johnson-Cook damage criterion is used for predicting the tearing in this process. After that, the important parameters that influencing the depth of bead and Johnson-cook damage in compression tube forming of aluminum are discussed.

2- Estimation of Pressure Acting on Tube

Consider a tube with radius R, length l and thickness h that located in coil, the discharged current flowing in the flat spiral coil is approximately described by the Eq. (1) [1].

$$I(t) = I_0\, e^{-t/\tau} \sin \omega t \tag{1}$$

Where I_0 represents the maximum intensity of the discharge current, τ the damping coefficient of the circuit and ω the angular frequency.

The magnetic field density B possesses a radial component and axial component is given by Eqs. (2) and (3) [1].

$$-\frac{1}{\mu_0 \sigma_w}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2} - \frac{1}{r^2}\right) B_r + \frac{\partial B_r}{\partial t} = 0 \tag{2}$$

$$-\frac{1}{\mu_0 \sigma_w}\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial z^2}\right) B_z + \frac{\partial B_z}{\partial t} = 0 \tag{3}$$

The radial and axial components of the magnetic field density are obtained by following Eqs. (4) and (5).

$$B_r = \frac{\mu_0}{2\pi} j(r_0, z_0) s_0 \frac{z}{r} \frac{1}{r[(r_0 + r)^2 + z^2]^{1/2}} \tag{4}$$

$$B_z = \frac{\mu_0}{2\pi} j(r_0, z_0) s_0 \frac{1}{[(r_0 + r)^2 + z^2]^{1/2}} \tag{5}$$

2.1. Finite Difference Method for Solving Magnetic Equation

The metal tube is then discretized into cells of size $\Delta r * \Delta h$ where a grid point (i,j) can be defined by the Eq. (6).

$$(r_j, z_i) = (a + j\Delta r, i\Delta h) \; with \; 0 \le i \le \acute{n} \; and \; 0 \le j \le \acute{m} \tag{6}$$

Where

$$\Delta r = \frac{h_w}{\acute{m}} \; and \; \Delta h = \frac{l_w}{\acute{n}} \tag{7}$$

3- Simulation

Simulation of electromagnetic forming process of the tube compression consists of two fields, magnetic and mechanical structure. Hence, both the magnetic and mechanical part of process must be simulated. In loose-coupled method, the magnetic and mechanical structure field was simulated separately, but in sequential-coupled method the magnetic and mechanical structure field was simulated simultaneously step by step at each time step.

4- Tearing

One of the most important topics in the electromagnetic tube compression forming is tearing. Usually by increasing the depth of bead, risk of tearing will increase too. There is a different criteria such as a Wilkins fracture model, Johnson-Cook damage criterion, Maximum shear stress fracture criterion, Cockcroft–Latham fracture criterion, Constant fracture strain criterion, Bao–Wierzbicki fracture criterion for high strain rate [2]. But Johnson-Cook Damage criteria is a better match to the experimental work and it is also easy to obtain constants and is available for various metals [3].

5- Experimental Test

Figure 1 shows the structure of the electromagnetic forming device consists of part 1- die 2- coil 3- switch 4- the power supply 5- capacitor banks and 6- Control part. For recording of the peak flow and its time, Rogowski coil and the oscilloscope were used.

6- Results and Discussion

In the Figure 2 the effect of increasing of discharge voltage in two different simulation methods in 0.5 mm tube thickness and 0.1 mm clearance between the

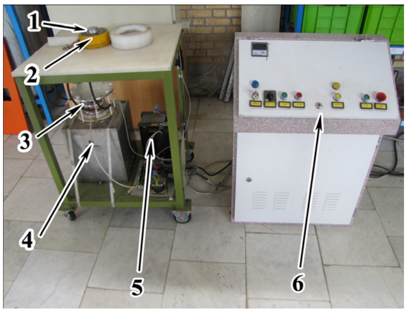

Figure 1. Structure of the electromagnetic forming device

die and tube is shown.

Figure 2 shows that by increasing the discharge voltage the depth of bead increased. The depth of bead in sequential-coupled simulation and loose-coupled simulation have maximum 5% and 35% error in 5000V respectively. The sequential-coupled results are close to the experimental data. The reason is that in the case of sequential-coupled simulation, deformation of the tube during the process, and consequently, the inductance of the tube will be considered and the error rate decreased.

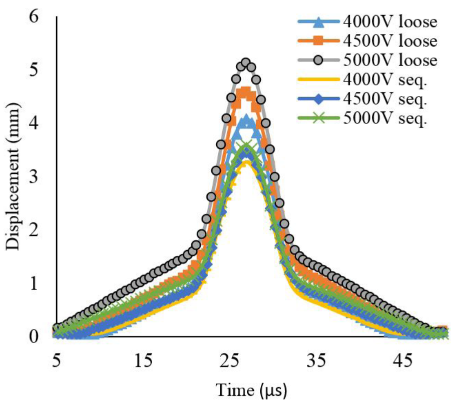

Figure 2. The effect of discharge voltage on displacement of tube in sequential and loose coupled simulation

Figure 3 shows the variation of amount of Johnson-Cook damage in whole simulation's time for the tip of bead in 4000V discharge voltage, 0.5 mm tube thickness and 0.1 mm clearance between the die and tube. The maximum amount of Johnson-Cook damage reaches to 0.45 and no tearing was observed in experimental test. To see tearing in experimental result, the discharge voltage selected as 6200V and tube thickness as 0.6 mm and clearance between die and tube as 0.1 mm. As can be seen in Figure 4 the tube completely fractures and in simulation result the amount of Johnson-Cook damage reaches to 0.85. Amount of damage less than 0.8 is conservatively suitable for the safe area without fracture.

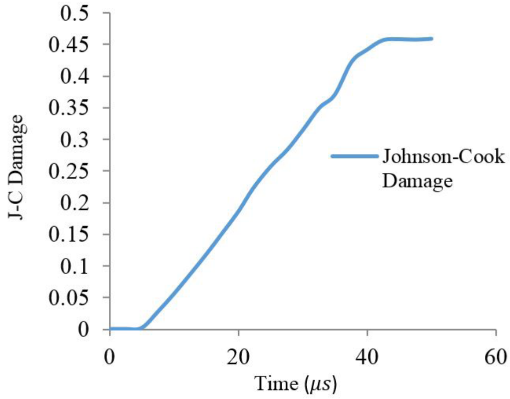

Figure 3. The variation of amount of Johnson-Cook damage for tip of bead in the simulation time

Figure 4. The final formed tube in the experimental test with 6200V, 0.6 mm thickness and 0.1mm clearance

7- Conclusions

By using sequential and loose-coupled simulation of tube compression forming and experimental test the following results were obtained:

1- Using sequential-coupled simulation method cause decreasing of simulation error about 5% for the maximum depth of bead.

2- Using Johnson-Cook damage to predict tearing has a good agreement with the results of experimental tests.

8- References

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