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Materials Today: Proceedings 2 (2015) 5324 – 5328

International Conference on Solid State Physics 2013 (ICSSP'13)

Effect of field intensity on electromagnetic flat sheet forming

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Abstract

Electromagnetic forming (EMF) is a dynamic, high strain-rate forming method. In this paper modeling and calculation procedure are presented for the electromagnetic forming of thin aluminum sheets. Flat spiral coil was used as actuator in this scheme. The prime focuses of the study are: calculation of the electromagnetic field generated by coil using the software FEMM 3.4 and shape analysis of the formed workpiece. Electromagnetic field intensity has a principal role in forming of sheets. Concentric circles winding flat coil constructed and the pulsed current taken by discharge from the capacitor bank is the source of high intensity magnetic field. Two different energy levels of Capacitor bank were used (4 kJ and8 kJ) to get the field intensity 1.4 and 2.5 Tesla. The method is based on the Biot-Savart law, and solution of magnetic induction integral equations is performed by numerical methods specifically with the use of commercial software. Optimum results are presented at the end. Approach of this work was initially analysis of method and then development of durable actuator (coil).

Selection and Peer-review under responsibility of the Committee Members of International Conference on Solid State Physics 2013 (ICSSP'13)

Keywords: Modeling; Electromagnetic forming; Durable actuator; Spiral coil

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2214-7853 © 2015 Published by Elsevier Ltd.
Selection and Peer-review under responsibility of the Committee Members of International Conference on Solid State Physics 2013 (ICSSP'13)
doi:10.1016/j.matpr.2015.11.044

1. Introduction

Electromagnetic forming (EMF) systems consist of two major parts one is capacitor bank and second is an electromagnetic coil termed as actuator. This technique works on the principle of mutual induction between an actuator coil and a conductive work piece [1] In the EMF process, a transient electrical pulse of high magnitude is sent through a specially designed forming coil by a low-inductance electric circuit. During the current pulse, the coil is surrounded by a strong transient magnetic field. The transient nature of the magnetic field induces current in a nearby conductive work piece that flows opposite to the current in the coil. The coil and the work piece act as parallel currents through two conductors to repel one another. The force of repulsion can be very high, equivalent to surface pressures on the order of tens of thousands of pounds per square inch. Thin sheets of material can be accelerated to high velocity in a fraction of a millisecond [2, 3]. The high work piece velocities achievable using this forming method enhances the formability of materials such as aluminum. Also, the dynamics of contact with the forming die can help reduce or mitigate spring back, an undesired effect that cannot be avoided in other forming techniques such as stamping [4].

The commercial application of this process has existed since the 1960s. A recent interest in understanding the EMF of metals has been stimulated by the desire to use more aluminum in automobiles. The large majority of applications have involved either the expansion or compression of cylinders (tubes). The forming of sheet materials is considerably more complex and has received relatively little attention. The objective of this work is to develop an in house EMF facility that will enable the economic manufacture of automotive parts made from aluminum sheet.

2. Work Descriptions

The current work describes the EMF system for the deformation of circular metal sheets by using a flat spiral coil. The magnetic field produced can be calculated by applying the Biot-Savart law. The system to be represented by a set of differential equations (eq. 1-5) where the electrical problem is a circuit with mutual inductances and the electromagnetic problem is formulated in terms of the magnetic field. Experimental results are also presented for different thicknesses of aluminum plates.

A schematic model of the system is shown in Fig. 1(a), which shows a circular metal sheet is placed above a flat spiral coil connected to a charged capacitor bank. The transient electromagnetic problem can be separated in a RLC primary circuit coupled with secondary RL circuit [5, 6]. The discharge of the capacitor in the primary circuit can be written in differential equation:

$$\frac{d}{dt}(L_a.I_a + M.I_1) + R_a.I_a + V_c = 0 \tag{1}$$

Where L_a, R_a and V_c are the self-inductance, resistance of actuator coil and electric potential in capacitor bank. M is the mutual inductance between the actuator coil and work piece. I_a and I_1 is the discharge current in actuator coil and the induced current in work piece. For secondary RL circuit the differential equation is obtained:

$$\frac{d}{dt}(L_1.I_1 + M.I_a) + R_1.I_1 = 0 \tag{2}$$

Where, L_1 and R_1 are the self-inductance and resistance of work piece.