High Speed Forming Press Using Electromagnetic Pulse Force

C. G. Park, Y. Choi, J. Y. Shim, B. Y. Kang

Convergence Components & Agricultural Machinery Application Center, Kitech, Jeonju, Jeonbuk, Korea

Abstract

In this paper, the finite element analysis for the design of a high speed forming press using electromagnetic pulse force has been performed. The punch of the press has been fixed on a aluminium plate, which is driven by the electromagnetic pulse force. The force is the repulsive force between aluminium plate and the coil. The coil has been supplied with a high voltage AC current impulse from the capacitors and then the magnetized aluminium plate has been forced to move upward with high speed. For the analysis of the pressing, the coupled analysis of electromagnetic field and rigid-body dynamic of the aluminium plate has been performed with a commercial FE-software, ANSYS and the rigid-body dynamics theory.

Keywords

High Speed Forming, Electromagnetic Force, Press, FE-analysis

1 Introduction

To overcome the lower formability of high strength material, high speed forming is widely investigated [1]. The papers related to electromagnetic forming(EMF) and magnetic pulse welding(MPW) are 79% in the field of high speed forming, ICHSF2012. In general, the punch is not required in EMF process because the electromagnetic forming force is applied to the workpiece directly. However, some high speed forming technology have been developed for the forming processes with need of the punch, such as high speed blanking and stamping with a small radius [2~4].

In this paper, the finite element analysis for the design of a high speed forming press using electromagnetic pulse force has been performed. The punch of the press has been fixed on a aluminium plate, which is driven by the electromagnetic pulse force. The force is the repulsive force between aluminium plate and the coil. The coil has been supplied with a high voltage AC current impulse from the capacitors and then the magnetized

aluminium plate has been forced to move upward with high speed. The forming press is an energy limit machine. The forming is limit to the kinematic energy of the aluminium plate. The kinematic energy is determined with the mass and velocity of the plate.
To evaluate the velocity of the plate, the analysis of the pressing, the coupled analysis of electromagnetic field and rigid-body dynamic of the aluminium plate has been performed with a commercial FE-software, ANSYS [5] and the rigid-body dynamics theory [6].

2 High Speed Press using Electromagnetic Pulse Force

2.1 Press system

As shown in Figure 1, the high speed press system which consists of an aluminium plate with the punch, a steel fixture, a spacer, an upper die and a coil. When charged electrical energy was discharged from magnetic pulse power source to the coil, electromagnetic force is generated between the aluminum plate and the coil. The aluminum plate has been moved high speed by this electromagnetic pulse force.
The coil shape is one of important factor for achieving successful forming because electromagnetic force value and distributions on the aluminium plate is changed according to the shape of the coil. The bar-type coil was employed for getting high electromagnetic force during forming process as shown Figure 2 in this study. The bar-type coil has high speed current flow than others shape, and generates the high electromagnetic field the between the coil and the aluminium plate instantaneously.

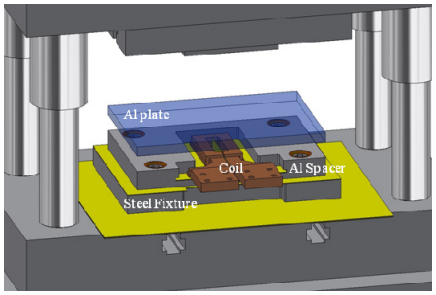

***Figure 1**: Schematic diagram*

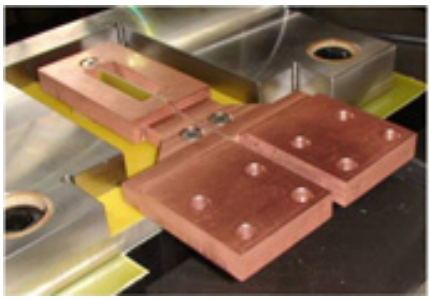

***Figure 2**: Bar-type coil*

2.2 Electromagnetic pulse power source

As shown in Figure 3, electromagnetic pulse forming system which manufactured by Welmate Co.,Ltd. for this study includes a magnetic pulse power source which consists of a capacitor bank with a maximum charging energy of 42kJ as shown Table 1. Additionally, in order to observe a discharge waveform and peak current, Rogowski coil was installed around the magnetic pulse power source and the coil.

Parameters	Specification
System capacitance	840uF
Charge voltages	1kV – 10kV
Inductance	0.4uH
Energy levels	0.4kJ – 42kJ

***Table 1**: Specification of magnetic pulse forming system*

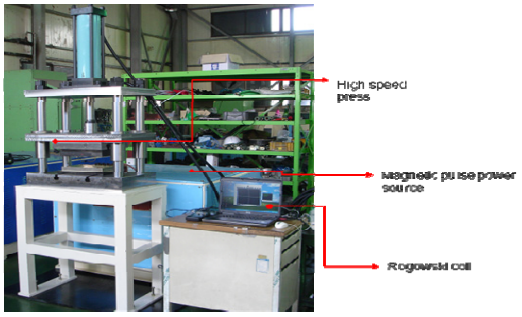

***Figure 3**: Electromagnetic forming system*

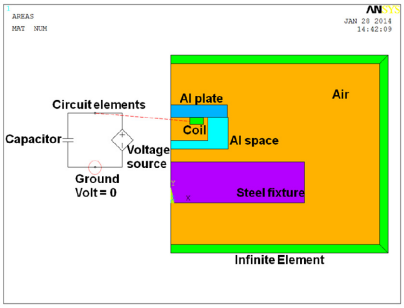

***Figure 4**: FE-model for the electromagnetic analysis*

3 Coupled Analysis

3.1 Electromagnetic field analysis

Using ANSYS [5], the electromagnetic force has been performed. For simplification of modeling, the coil and the aluminium plate have been assumed to be axisymmetric. Figure 4 shows the FE-model for the analysis. Firstly, the electric circuit has been evaluated. FE-model was constructed using the element PLANE53. nodes and elements of each area have been shown in table 2.

Part	Number of node	Number of element
Coil(Copper)	371	98
Al plate	2,153	741
Steel fixture	16,873	5,494
Air	24,706	8,303
Infinite Air	1,202	360

***Table 2**: Finite element model*

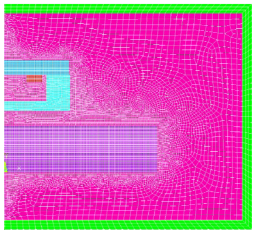

***Figure 5**: Finite element meshed*

In the model, the capacitance is 840uF. The charged energy is 10.5kJ and 15.12kJ with the initial capacitor voltage is 5kV and 6kV, respectively. The magnetic fields have been analysed with the obtained circuit on the coil. Table 2 shows the material properties and the dimensions of coil and plate.

Part	Electric resistivity (Ω·m)	Relative Permeability	Model dimension (mm)	Real dimension (mm)
Coil(Copper)	1.70e-8	1	ID : 90, OD : 156, T : 15	140X105X15 Hole : 90X22
Al plate	2.82e-8	1.000021	OD : 270, T : 30	195X295X30
Steel fixture	2.18e-8	200		
Air		1		
Infinite Air		1		

***Table 3**: Material properties and the dimensions of the FE-model*

3.2 Rigid-body dynamic analysis

The motion of the aluminium plate assumed to be a particle with the plate weight can be evaluated with rigid-body dynamics.

$$a = \frac{m_{al}}{F} \tag{1}$$

where, the force, F, is the z-directional total force obtained from the electromagnetic analysis. Adams-Bashforth two step method [6] is applied to solve the equation (1). The z-directional displacement of the aluminium plate can be calculated with the velocity.

$$v_1 = v_0 + \frac{\Delta t}{2}(3a_1 - a_0) \tag{2}$$

3.3 Coupled analysis

To solve the coupled fields, the electromagnetic force is obtained with electromagnetic analysis. The force is applied to the aluminium plate and the displacement of the plate can be calculated with the dynamics. The FE-model of the plate is changed with new position and the electromagnetic analysis has been repeated. Figure 5 shows the coupled analysis method.

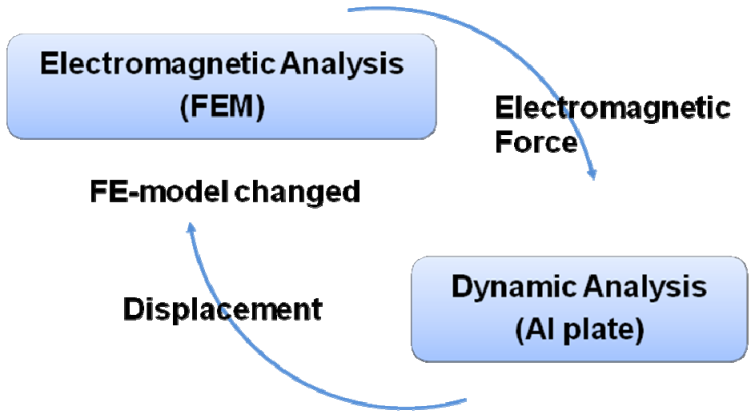

***Figure 6**: The coupled analysis method*

4 Results and Discussion

4.1 Electromagnetic force

Figure 6 shows the electromagnetic force applied to the aluminium plate. The force varied with the discharged electrical current. First peak force increased with the high initial

capacitor voltage, 6kV and the lighter plate. Because the displacement of the plate increased with the same conditions. Figure 7 shows the distribution of the electromagnetic force at the first peak with 6kV and 2.0kg. The force has been generated at the small region closed the coil.

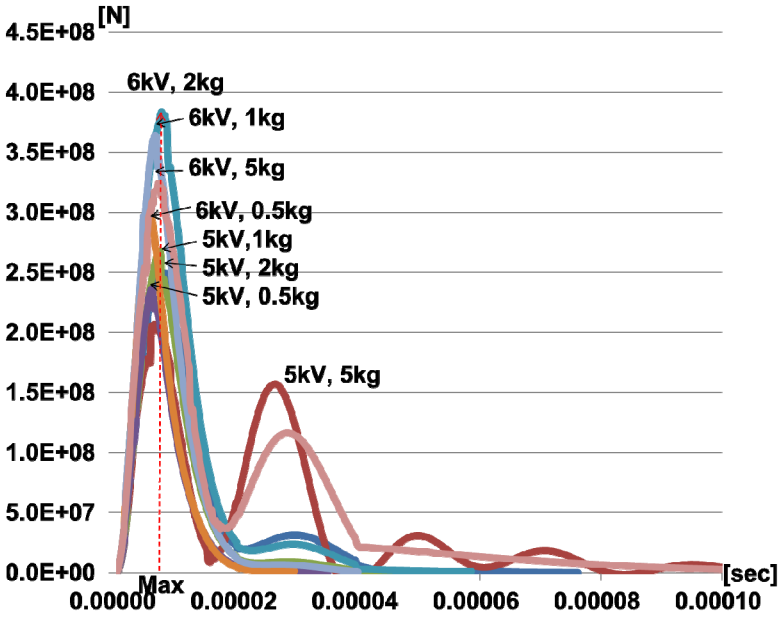

***Figure 7**: The electromagnetic force with various conditions*

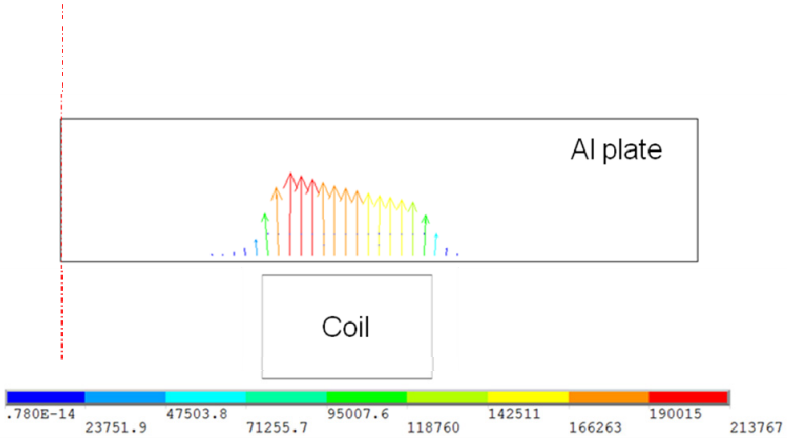

***Figure 8**: The electromagnetic force distribution on the plate*

4.2 Forming speed

Because the punch is fixed on the aluminium plate, forming speed is same as the velocity of the aluminium plate. Figure 8 shows the forming speed. With 6kV and 0.5kg plate, 4.3m/s can be obtained. On the design of the press, the mass of the aluminium plate must

be considered to obtain the certain velocity. The capacity of the magnetic pulse power source is important for the forming speed. The kinematic energy of the aluminium plate is shown in Table 3.

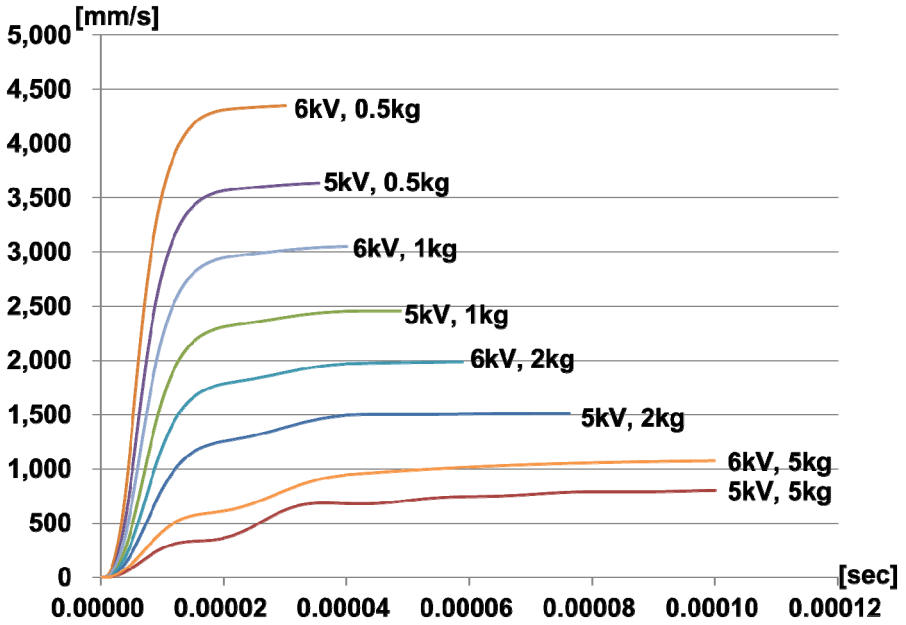

***Figure 9**: Forming speed of the press*

The initial capacitor voltage (kV)	Mass of the Al plate (kg)	Forming Speed (m/s)	The kinematic energy (J)
5	0.5	3.635	3.303
	1.0	2.456	3.016
	2.0	1.508	2.274
	5.0	0.801	1.604
6	0.5	4.348	4.726
	1.0	3.051	4.654
	2.0	1.987	3.948
	5.0	1.073	2.878

***Table 4**: Forming speed and kinematic energy of the moving aluminium plate*

5 Conclusion

In this paper, the coupled analysis of the high speed forming press has been performed using the electromagnetic pulse force. Some conclusions have been obtained. The obtained electromagnetic force are distributed very closed region with the coil. The forming speed depends on the mass of the aluminium plate and the capacity of the magnetic pulse power source(the initial capacitor voltage).

References

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