JOURNAL OF MATERIALS PROCESSING TECHNOLOGY 209 (2009) 2295–2301

journal homepage: www.elsevier.com/locate/jmatprotec

3D Simulation of magnetic field distribution in electromagnetic forming systems with field-shaper

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ARTICLE INFO

Article history:
Received 13 March 2007
Received in revised form 6 May 2008
Accepted 11 May 2008

Keywords:
Field-shaper
Electromagnetic forming
Magnetic pressure
Numerical simulation
IEMF

ABSTRACT

Impulse electromagnetic forming (IEMF) is an effective and powerful technique widely used for joining and shaping metals and field-shaper is a main part of the electromagnetic forming which has important effect on the distribution of magnetic field. In this technique, a metal work-piece is pushed to a die and formed by a pressure created using an intensive, transient magnetic field. This magnetic field is produced by passing a pulse of electric current through a forming coil in a pulsed power circuit. The produced transient magnetic field induces eddy currents in the surface of work-piece. Induced eddy currents in work-piece produce a magnetic field with reverse direction of initial magnetic field; this results in a mutual repulsion between coil and work-piece and in this way the work-piece is thrown toward the die. In this process created magnetic forces applied to work-piece are much like uniform, but in real applications, some regions of a work-piece have to be more deformed and therefore a much greater pressure has to be applied to these regions. The task of concentration of magnetic forces to some desired regions can be accomplished using field-shapers. Yu et al. [Yu, H., Li, C., Zhao, Z., Li, Z., 2005. Effects of field-shaper on magnetic pressure in electromagnetic forming. J. Mater. Process. Technol. 168, 245–249] have recently shown the effect of field-shaper on the distribution of the magnetic fields in electromagnetic forming, but because of the nature of 2D simulations some edge effects in real geometries could not be taken into consideration. In this paper, a 3D simulation using the FEA software MAXWELL has been applied to study the magnetic field distribution during an impulse electromagnetic forming process. Comparison of the 3D and 2D simulation results indicates that the maximum magnetic fields achieved in front of nodules of the field-shaper are about 15% stronger than those expected by 2D simulations.

By changing the geometry of the field-shaper, the influence of the shape of the field-shaper on the distribution of the applied forces on the work-piece has been studied. Based on these simulations, some simple guidelines to design the field-shaper have been derived.

1. Introduction

High-rate forming processes such as impulse electromagnetic forming (IEMF) can promote significant increases in strain to failure in low ductility materials due to strain rate and inertial stabilization of material failure modes. Impulse electromagnetic forming is a powerful and effective high-rate forming technique with a number of advantages such as high clean-

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0924-0136/$ – see front matter
doi:10.1016/j.jmatprotec.2008.05.024

ness, cost-efficiency, productivity. Applying this technique, the formability of some materials such as aluminum could be improved substantially. So the most critical limitation of the application of aluminum in a wide range of industrial applications like automotive industries; i.e. the low formability of this material using conventional forming methods with some undesirable side-effects like wrinkling, tearing and springing back as demonstrated (Oliveira, 2002; Oliveira and Warwick, 2003), could be solved.

In this technique, a metal work-piece is pushed to a die and formed by a pressure created using an intensive, transient magnetic field. This magnetic field is produced by passing a pulse of electric current through a forming coil in a pulsed power circuit. The produced transient magnetic field induces eddy currents in the surface of work-piece. Induced eddy currents in work-piece produce a magnetic field with reverse direction of initial magnetic field cause to a mutual repulsion between coil and work-piece result to throwing the work-piece toward the die. In this process created magnetic forces applied to work-piece are much like uniform, but in real applications, some regions of a work-piece have to be more deformed and therefore a much greater pressure has to be applied to these regions. A main part of an IEMF system is field-shaper that concentrates the magnetic fields in desired points of a metal work-piece during the forming process. A field-shaper transmits the energy produced by inductor system to the expected points. It must be noted that the efficiency of the system with field-shaper is reduced because of energy dissipation occurred in the field-shaper, but using this additional part it is possible to shape the force distributions in a much more economical way than using special coil systems for different applications (Batygin and Daehn, 1999). Although the field-shaper plays an important role in impulse electromagnetic forming systems, there is only very few studies on its influences on the magnetic field distribution.

In this paper, 3D simulations by FEA Software MAXWELL are used to calculate the magnetic force distribution applied on the work-piece during the impulse electromagnetic forming process. The results indicate a 15% increase in comparison to the 2D simulations in the maximum magnetic field using field-shapers. Comparison of the magnetic field distributions with different geometries of the field-shapers is used to derive simple guidelines for designing the electromagnetic forming systems.

2. Basic working principle

An impulse electromagnetic system is used in many different applications such as compression or expansion of metal tubes, forming of flat sheets; e.g. panels in automotive industries, welding and many other applications, however the main principle in all of the applications of this technique is the same. Depending on the geometry of the work-piece to be modified, the geometries of the coils and other parts of the impulse electromagnetic forming system could be different in shape. In Fig. 1, two different geometries of such systems adapted to the work-pieces with cylindrical symmetry or flat sheets are sketched schematically.

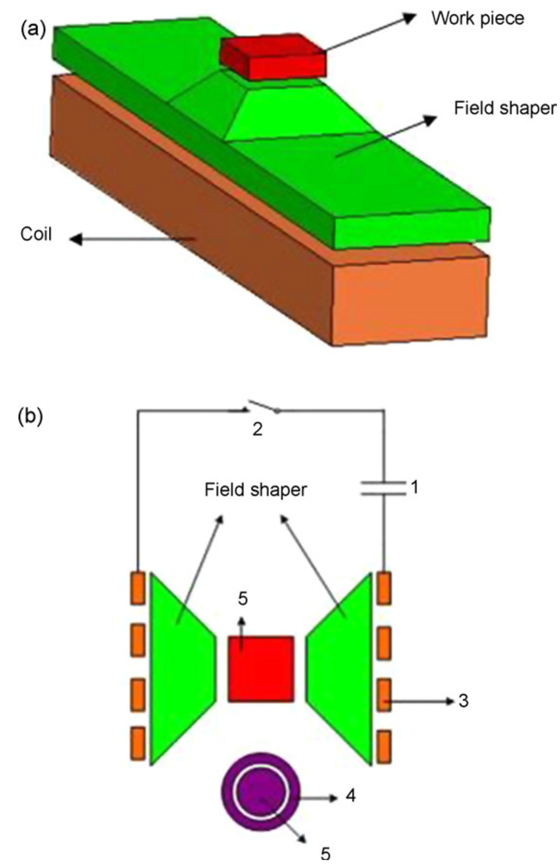

Fig. 1 – An IEMF system applied with a field-shaper (compression) for (a) flat model and (b) cylindrical symmetry model.

1. Capacitor bank for storing the electrical energy.
2. Fast switch for connecting capacitor banks to work coil and interrupting it.
3. Work coil for creating magnetic field in the work zone.
4. Work-piece.
5. Die or matrix.

It can be seen that an IEMF system consists of an electrical pulsed power circuit responsible for generation of the pulsed current flowing through the work coil, and some parts with pure mechanical functions like matrix, which is used to determine the desired shape of the final formed work-piece. Although field-shapers seem to be also a mechanical part, they play an important role in linking the electrical pulsed power system to the mechanical parts by modifying the magnetic field distribution generated on the work-piece. This specific role of the field-shapes is described in detail in the next parts of this paper.

2.1. *Physical description of an IEMF process*

In this process, a pulsed current with significant amplitude (up to some hundreds of kilo amperes) and high frequency (some tens of kilo Hertz) is produced by discharging an energized capacitor bank through a coil by closing a switch. This current