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Deep drawing of cylindrical cup using incremental electromagnetic assisted stamping with radial magnetic pressure

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Abstract

A new forming method named incremental electromagnetic assisted stamping with radial magnetic pressure is proposed to draw a deep cylindrical cup. The method combines with traditional stamping, electromagnetic sheet forming and electromagnetic launch technology. Three types of discharge coils are imbedded in die and blank holder, respectively. The 3D finite element model is set up to predict the complex deformation process. The forming process and principle of the new method are discussed. The values of material flow, stress and thickness in different forming processes are compared. In comparison with traditional stamping, incremental electromagnetic assisted stamping with radial magnetic pressure can significantly increase the value of material at sheet end flow inward, decrease the tensile stress and thickness reduction at the easily broken position, and obtain uniform stress distribution. Therefore, deeper cylindrical cup could be manufactured by incremental electromagnetic assisted stamping with radial magnetic pressure.

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Keywords: Electromagneitc assisted stamping; Deep drawing with radial pressure; Inverse bulging; Multi–physics field couping simulaiton

1. Introduction

Large tensile stress, which is larger than breaking strength, acting on the part sidewall is the main reason for workpiece broken during the traditional cylindrical deep drawing process. In order to increase the forming depth, it is needed to decrease the value of tensile stress. Therefore, two approaches have been adopted: (1) the friction

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force between the blank flange area and die should be reduced; (2) a large force is acted on sheet metal to push material flow toward the die hole.

Hydrodynamic deep drawing is a type of advanced flexible sheet metal forming method, which is the use of liquid as the force transmission medium instead of rigid die forming load (Siegert et al., 2000). During the forming process, the liquid will flow between sheet metal and die to produce liquid lubrication, which can reduce the friction on the blank flange area. Nakamura et al. (1987) proposed the hydraulic counter-pressure deep drawing assisted by radial pressure. The liquid in the liquid pool is brought to the edge of the sheet blank through certain bypass, which can apply the radial pressure on blank edge to increase the material flow property and significantly improve the ability of the sheet resistance to rupture. However, there are some disadvantages in hydrodynamic deep drawing in comparison with traditional stamping: (1) a lager drawing force and blank holder force are required, which can increase the cost of equipment; (2) it is difficult to seal in high liquid pressure.

Electromagnetic forming is a high velocity forming method, which has several advantages in comparison to conventional quasi-static forming process, such as increased forming limits, reduced spring-back, low cost tooling and high repeatability (Psyk et al., 2011). However, the coil stays in a fixed position and the sheet metal is deformed in an electric discharge, which can only manufacture small and shallow parts in conventional electromagnetic sheet forming process.

Aimed to produce deep and large parts for industrial application, Multi-step electromagnetic forming technology may be needed. Shang et al. (2011) proposed an electromagnetic assisted stamping method. In the forming process, the coil was embedded in a punch bottom to repeatedly-incrementally stretch the bottom of metal part. Then, the punch incrementally advanced downward between electromagnetic pulses to pull the bottom area flat. In comparison with traditional stamping, electromagnetic assisted stamping can dramatically improve the draw depth without the reliance on the lubrication. Recently, based on the principle of single point incremental forming, Cui et al. (2014) proposed a new technology named electromagnetic incremental forming. It is proved that the method is feasible to form a larger aluminium alloy sheet using small working coil and small discharge energy. However, it is difficult to increase the forming depth due to the sheet bottom become thinning by electromagnetic pulses force and the material in flange area cannot flow in the above forming methods.

In this paper, a new forming method named incremental electromagnetic assisted stamping with radial magnetic pressure is proposed to draw deep cylindrical cup. The 3D finite element model is established to predict the complex deformation process. The forming process and principle of the new method are discussed. The values of material flow, stress and thickness in different forming processes are compared to verify that the new method is feasible to manufacture parts with a greater proportion of depth to diameter.

2. Forming process of incremental electromagnetic assisted stamping with radial magnetic pressure

Fig. 1 describes the forming process of incremental electromagnetic assisted stamping with radial magnetic pressure. The forming system includes three types of discharge coils, which names Coil_1, Coil_2 and Coil_3. Those coils are imbedded in die and blank holder, respectively.The magnetic force generated by the coils can cause the blank corresponding to the die corner inverse bulging and push the flange area flow to the die hole. After three coils discharge termination, the punch moves down to straighten the deformed sheet. Repeat the forming process showed in Fig. 1 until the sheet rupture. Due to the material on flange area is pushed inward the die hole, deeper cylindrical cup could be manufactured by incremental electromagnetic assisted stamping with radial magnetic pressure.

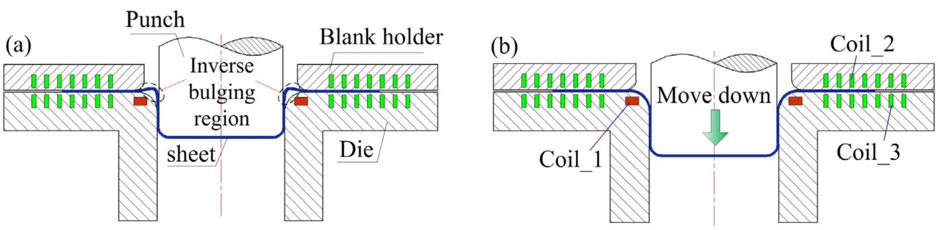

Fig. 1. Forming process of incremental electromagnetic assisted stamping with radial pressure: (a) sheet inverse bulging; (b) sheet straightened by punch.

3. Sequential simulation of incremental electromagnetic assisted stamping with radial magnetic pressure

3.1. Numerical scheme for incremental electromagnetic assisted stamping with radial magnetic pressure

In this work, the finite element software ANSYS is used. Fig. 2 shows the flowchart of numerical scheme for incremental electromagnetic assisted stamping with radial magnetic pressure. The magnetic forces on the workpiece are calculated using ANSYS/EMAG finite element code. Then the forces are imported into ANSYS/LSDYNA finite element code to predict workpiece deformation. According to the deformation result, the sheet geometry is updated in ANSYS/EMAG code to calculate the magnetic force again. This analysis process can be regarded as one step for electromagnetic-mechanical coupling process. If the sheet deforms termination by magnetic force, restarted technology in ANSYS/LSDYNA code is used to predict the traditional stamping process. Whereafter, the deformed sheet is imported into ANSYS/EMAG for the next step coupling analysis. In following simulation, the one-time step for electromagnetic – mechanical coupling analysis is 0.001s and one-time step for the quasi-static stamping is 0.05s.

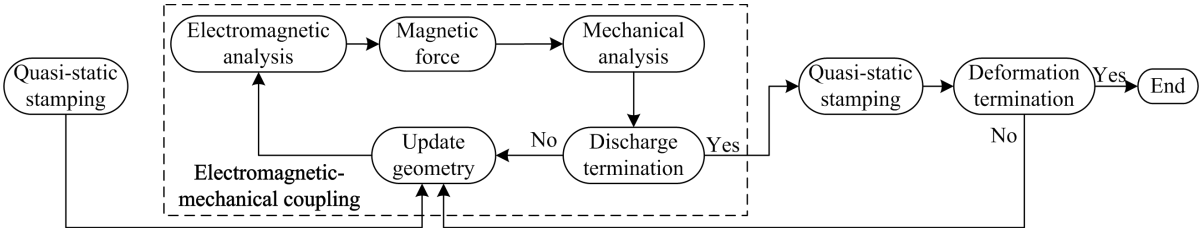

Fig. 2. Flowchart of numerical scheme for the incremental electromagnetic assisted stamping with radial magnetic pressure.

3.2. Modeling

Fig. 3 (a) shows the schematic diagram of the cylindrical cup deep drawing by incremental electromagnetic assisted stamping with radial magnetic pressure. The radius of the punch and its corner are 48.7mm and 8mm, respectively. The radius of the die and its corner are 50mm and 10mm, respectively. A three-turn flat spiral coil with section area of 1mm×4mm (Coil_1) is imbedded in the die to make sheet inverse bulging. Two one-turn flat spiral coils with section area of 3mm×10mm (Coil_2 and Coil_3) are imbedded in blank holder and die, respectively. The distance between the Coil_2 or Coil_3 and the sheet is 2mm. The main parameters includes: capacitance-213μF, rated voltage -30KV.

The material used in this experiment is the aluminum alloy AA3003 sheet with 1.0mm in thickness. The circular plates of 200mm diameter specimens were utilized. The Poisson's ratio is 0.3. The Elastic modulus is 68.4GPa and the density of the sheet is 2.75×103 Kg/m3. The initial yield stress is 50MPa. In order to benefit follow-up analysis, A, B and C points on sheet bottom surface are chosen. The position of three special points can be seen in Fig. 3 (a). Fig. 3 (b) shows the deformed result if the punch moves down 15mm using ANSYS/LSDYNA software.

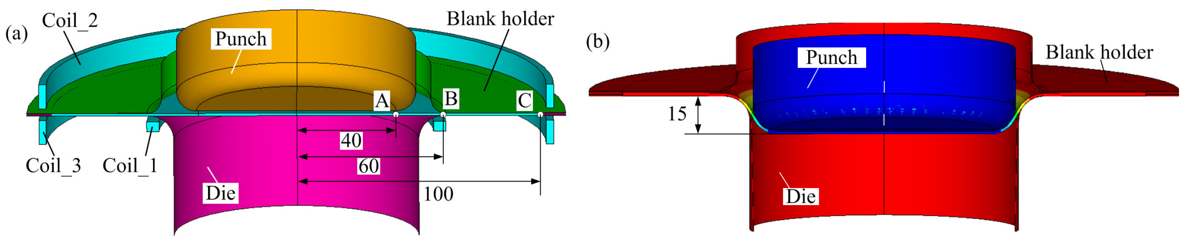

Fig. 3. Geometric and finite element model (unit: mm): (a) 3D model; (b) deformation results in the first stamping.

To prove the new forming method presented in this paper can be used to manufacture deep cylindrical cup, three kinds of forming processes are comparative analysis in the following:

Case 1: Three coils didn't discharge. This means the sheet deforms in quasi-static stamping process.

Case 2: The current is just loaded into Coil_1 to make sheet deformation at high speed.

Case 3: The current is loaded into the three coils to make sheet deformation at high speed.

4. Analysis and discussion

Based on the deformed sheet profile in Fig. 3(b), Fig. 4 shows electromagnetic field simulation results if the three coils discharge simultaneously. The magnetic forces generated by Coil_1 all can be broken up into F_{1z} and F_{1r}, which locate in the blank region corresponding to the die corner. The force F_{1z} will make the sheet inverse bulging and the force F_{1r} will pull the material inward sheet centre. In addition, the Coil_2 and Coil_3 will generate the force in the edge of the blank. Due to the same dimension of Coil_2 and Coil_3, the direction of the resultant force (F_{2r}) in the sheet edge points to die hole, which can push the edge of sheet toward die hole.

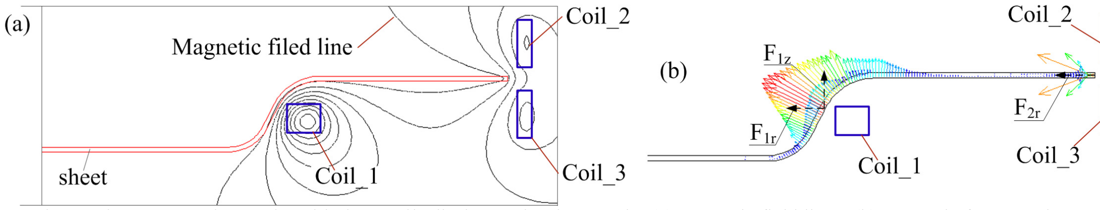

Fig. 4. Electromagnetic results with three coils discharge simultaneously: (a) magnetic field lines; (b) magnetic force on sheet.

Based on the deformation result presented in Fig. 3 (b), the sheet inverse bulging by magnetic force with discharge voltage 5000V is shown in Fig. 5. In comparison with the traditional stamping results, the values of the material flows from the sheet edge inward to die hole are increased if the coil discharge. The deflection of the inverse bulging height in axial direction in the condition of Case 3 is larger than the one of Case 2. This is because that the radial component of magnetic force (F_{1r}) caused by Coil_1 can pull the material in flange area into die hole. In comparison with Case 2, another radial magnetic force (F_{2r}) caused by Coil_2 and Coil_3 can also push the edge of sheet toward to die hole in Case 3. Therefore, it is feasible to improve the material flow property by setting the coil at the end of the sheet.

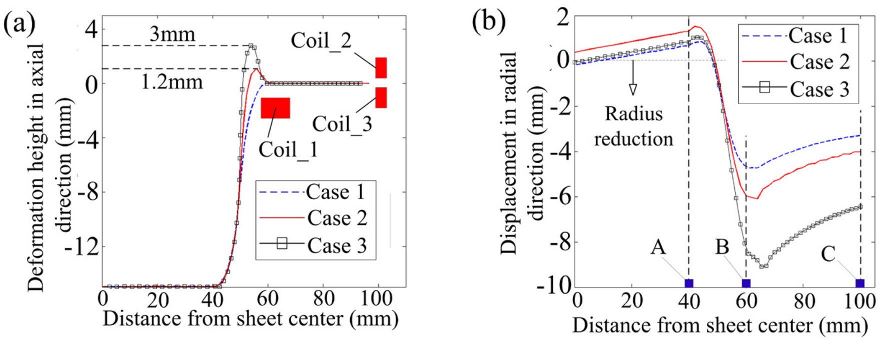

Fig. 5. Deformation results in first coil discharge (a) final sheet profiles (b) final displacement in radial direction.

Based on the inverse bulging results presented in Fig. 5, Fig. 6(a) shows the process of the sheet straightened by punch in the condition of Case 3. The initial time of the inverse bulging sheet straightened by punch is at 0.08s. Fig, 6 (b) shows the change of radial displacement with time at special points: (1) the radial displacement at C point flows inward to die hole with 3.2mm and radial displacement at A point almost no change from the time 0.05 to 0.051 s. The period corresponds to the time of coil discharges. (2) The radial displacement at A and B points is unchanged from the time 0.051 to 0.075 s. (3) The radial displacement at A and B points have very small change from the time 0.075 to 0.08 s. This shows the radial displacement at A point is almost no change from the time of sheet deforms by magnetic force to the initial time of the sheet straightened by punch.

In the condition of the deformation height is 25 mm, the incremental electromagnetic assisted stamping with radial magnetic pressure can increase the values of material flows inward at sheet end. Moreover, it can decrease the values of material flows outward at sheet corner in bottom surface, which will inhibit thickness reduction at this region. Therefore, the incremental electromagnetic assisted stamping with radial magnetic pressure will manufacture deeper cylindrical cup in comparison with the one produced by traditional stamping.

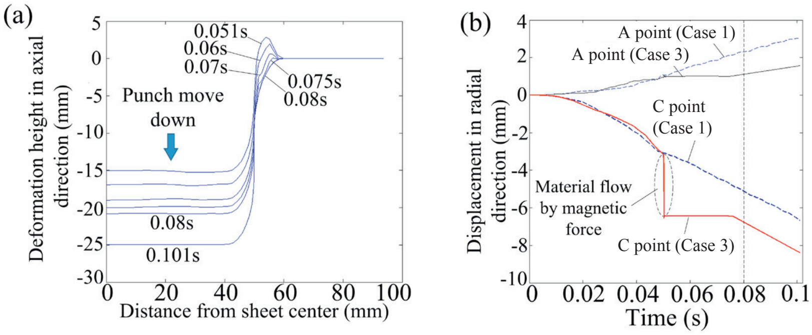

Fig.6. Sheet deformation results by punch move down 10mm after coil discharge: (a) sheet profiles at different time (b) displacement changes with time at special points

Figs. 7 and 8 show the changes of radial stress (σ_1), hoop stress (σ_2) and axial stress (σ_3) with time at the two special points in different forming processes. In the traditional stamping, there are three tensile stresses with high value in three directions at A point. While, there are two tensile stresses in radial and axial direction and one pressure stress in hoop direction acting at B point. The deformation results in Fig. 7 and Fig. 8 shows that the high tensile and pressure stress in hoop direction both exist at A and B points during the time of coil discharges. During the time from 0.051 to 0.8 s, the radial and axial stress at A and B points almost closes to zero. If the time exceeds 0.8s, the tensile stresses in three directions dramatically increase at A point. Therefore, in order to decrease the values of thickness reduction and tensile stresses in sheet radius regions, there exists optimum values corresponding to the sheet initial straightened for punch move down.

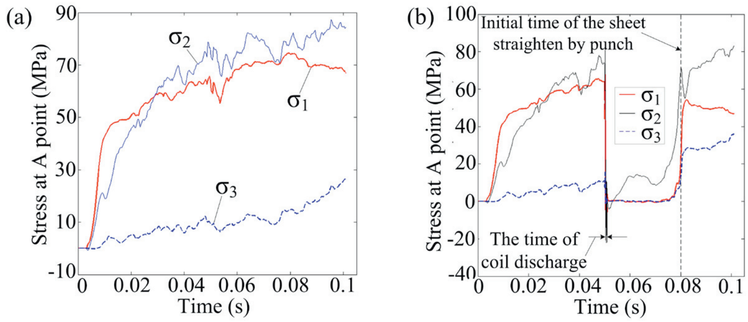

Fig. 7. Change of stress with time at A point; (a) traditional stamping; (b) incremental electromagnetic assisted stamping with radial magnetic pressure.

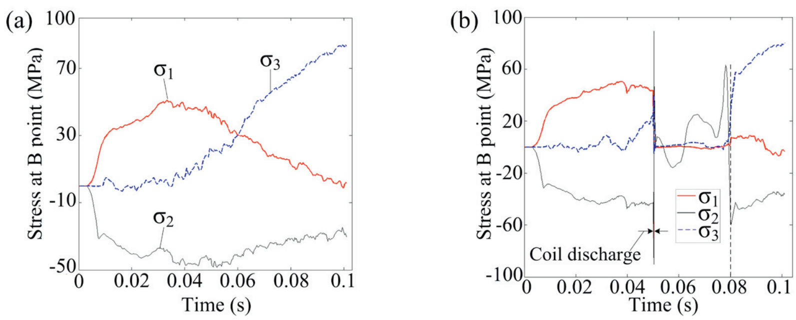

Fig. 8. Change of stress with time at B point; (a) traditional stamping; (b) incremental electromagnetic assisted stamping with radial magnetic pressure.

Fig. 9(a) shows the distribution of axial stress if the sheet deformation height is 35 mm in traditional stamping.

The maximum tensile stress is 100 MPa. The value of the material flow at sheet end is 9.4 mm.Maximum thickness reduction is 0.37 mm, which occurs at the sheet corner in bottom surface. Fig. 9(b) indicates the deformation height with 35 mm if the punch move down 15 mm, 10 mm and 10 mm in three times. The discharge voltage is 5000V between punch moves down. The maximum tensile stress is 90 MPa. The value of the material flow at sheet end is 14.3mm. Maximum thickness reduction is 0.08 mm, which occurs at the sheet corner in bottom surface. In comparison with traditional stamping, incremental electromagnetic assisted stamping with radial magnetic pressure can significantly increase the value of material flow inward from sheet end, decrease the tensile stress and thickness reduction at the easily broken position, and obtain uniform stress distribution.

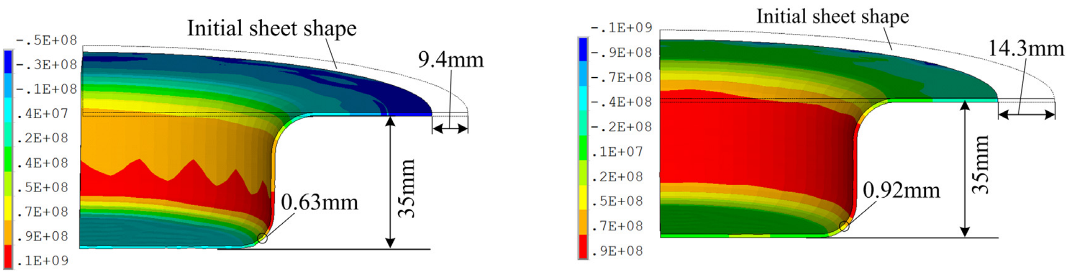

Fig. 9. Distribution of sheet thickness and stress: (a) traditional stamping; (b) incremental electromagnetic assisted stamping with radial magnetic pressure.

4. Conclusion

(1) A new deep drawing method, named incremental electromagnetic assisted stamping with radial magnetic pressure, is proposed. Radial magnetic force, which locates in sheet end, pointed to die centre can be generated by setting the coil at the end of the sheet.

(2) If the three coils discharge simultaneously, the high tensile and pressure stress in hoop direction both exist at the sheet deformation region. The radial displacement at sheet region corresponding to punch corner is almost no change from the time of sheet deforms by magnetic force to the initial time of the sheet straightened by punch. There exists optimum values for punch move down, which corresponds to the sheet initial straightened, to decrease the values of thickness reduction and tensile stress on sheet,

(3) In comparison with traditional stamping, incremental electromagnetic assisted stamping with radial magnetic pressure can significantly increase the value of material flow inward from sheet end, decrease the tensile stress and thickness reduction at the easily broken position, and obtain uniform stress distribution. Therefore, incremental electromagnetic assisted stamping with radial magnetic pressure can manufacture deeper cylindrical cup.

Acknowledgements

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References

Siegert, K., Häussermann, M., Lösch, B., Rieger, R., 2000. Recent developments in hydroforming technology. Journal of Materials Processing Technology, 98, 251-258.

Nakamura, K., Nakagawa, T., 1987. Sheet Metal Forming with Hydraulic Counter Pressure in Japan. CIRP Annals- Manufacturing Technology, 36(1), 191-194.

Psyk, V., Risch, D., Kinsey, B.L., Tekkaya, A.E., Kleiner, M., 2011. Electromagnetic forming - A review. Journal of Materials Processing Technology, 211, 787-829.

Shang, J.H., Daehn. G.S., 2011. Electromagnetically assisted sheet metal stamping. Journal of Materials Processing Technology, 211, 868-874.

Cui, X.H., Mo, J.H., Li, J.J., Zhao, J., Zhu, Y., Huang, L., Li, Z.W., Zhong, K., 2014. Electromagnetic incremental forming (EMIF): a novel aluminum alloy sheet and tube forming technolo gy. Journal of Materials Processing Technology, 214, 409-427.