Development of Numerical Simulation Model and Formability Evaluation for Electrohydraulic Forming Process

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Abstract

In the automotive industry, the consumption of advanced high strength steels and aluminium alloys is increased to reduce the weight of automotive parts. However, because these materials have lower formability, it is not easy to deform these in the general forming process. Therefore, high speed forming processes are introduced such as electrohydraulic forming, electromagnetic forming and explosive forming. High speed forming is a process that deforms a material at a speed of more than 100 m/s. This paper describes the electrohydraulic forming (EHF) process. EHF is high strain rate forming process based on the electric discharge in the fluid. This process can improve the formability of the material due to the high strain rate of $10^3 \sim 10^4\ s^{-1}$ *and it can reduce the experimental cost by using only one-sided rigid tool. In this study, numerical model of EHF was developed in LS-DYNA commercial program and it showed that the material could be deformed by electric energy input inside the fluid. In addition, forming limit diagram (FLD) at high strain rate condition was obtained from M-K theory as criteria of formability evaluation and it was applied to the results of numerical simulation. As a result, it was predicted that the material has no cracks or wrinkles at a given energy input.*

Keywords

Electrohydraulic forming, high strain rate, Forming limit diagram

1 Introduction

In the automotive industry, reducing weight of vehicles is the most important factor for reducing fuel consumption. Among the many solutions to reduce the weight of vehicles, the use of aluminium alloys and advanced high strength steels as materials for car manufacture is considered. These materials, however, have lower formability as compared to mild steels, which is commonly used in the automotive industry. Hence another approach, electrohydraulic forming (EHF) process, that forms the material at very high velocity, has recently been developed.

EHF makes use of an electric discharge in a fluid. Two electrodes are submerged in a fluid-filled chamber and a high-voltage discharge takes place between the electrodes. A high-pressure shock wave is created, which propagates through the water towards blank placed in contact with the fluid as shown in Fig. 1.

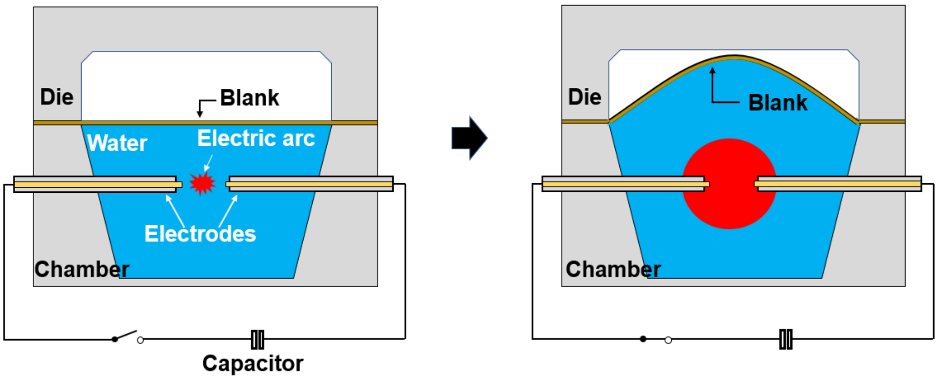

***Figure 1**: Schematic view of electrohydraulic forming*

According to T. Altan (2012) and S. Golowin (2007), the formability and the springback of the material can be improved at high-speed conditions because of the inertial effect and substantial increase of elongation in the range of strain rates 10^3~10^4 s^{-1}. In addition, EHF has no bouncing effect as compared to other high-speed forming process, so it allows a material to be deformed into complex shapes without any wrinkle (M. A. Woo, 2017).

This paper presents the feasibility study for application of EHF process. The object of this paper is to develop numerical model of EHF process in advance using LS-DYNA commercial software to predict the deformation shape of the blank. Lagrange-Eulerian method was applied to model the fluid parts and Lagrangian mesh was used for structural parts. In addition, to predict the fracture area of the deformed blank, forming limit diagram (FLD) at high strain rate condition was employed.

2 Numerical model of electrohydraulic forming

LS-DYNA commercial program was employed to develop the numerical model of electrohydraulic forming and a quarter model was used because the model is symmetric about y-z and x-z planes. As shown in Fig. 2, the numerical model was composed of the plasma, water, vacuum, blank, die and the chamber. Unlike Fig. 1, the electrodes were excluded from the analytical model for the efficiency of analysis.

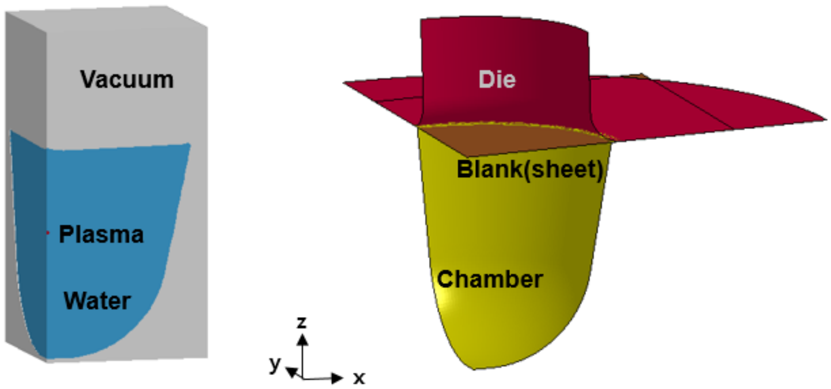

***Figure 2**: Numerical model of electrohydraulic forming*

Instead, electrical energy generated by the capacitor was applied to plasma part. The plasma was modelled as an adiabatically expanding gas and the energy in plasma was assumed to uniform through entire volume. Equation of State (EOS) was used to apply electric energy to the simulation and the pressure of the plasma part is calculated by Eq. (1).

$$P = (\gamma - 1)(\rho/\rho_0)\, E \tag{1}$$

Where γ is an adiabatic index, ρ is the density, ρ_0 is the initial density and E is the initial electric power per volume of the plasma. The parameter E is calculated as the product of the current and the voltage. The current and voltage curves applied to simulation were shown in Fig. 3. The current wave was obtained experimentally, and the voltage was assumed to decrease linearly from the input point (S. F. Golovashchenko, 2013).

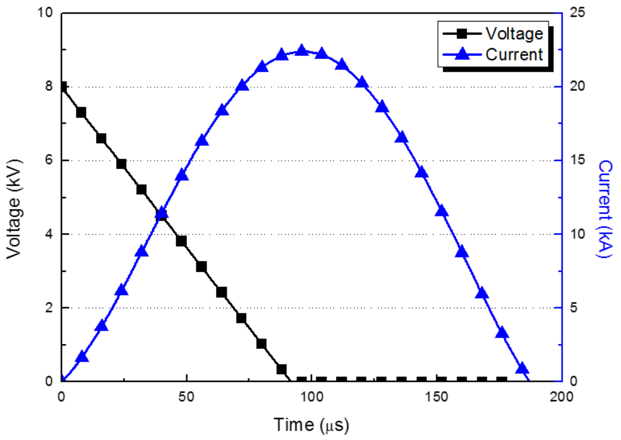

***Figure 3**: The current and voltage curves*

When modelling the fluid parts, such as plasma, water and vacuum parts, Arbitrary Lagrange-Eulerian (ALE) method was employed. ALE mesh allows relatively simple definition of the interaction between fluid parts and it has no mesh distortion unlike structural parts. Because fluid parts, especially water part, have a very large deformation, ALE mesh is reasonable choice for fluid to prevent mesh distortion problem.

Structural parts, chamber, blank and the die, were modelled using shell elements and chamber and the die were assumed to be a rigid body for efficiency of simulation. The material of the blank is Al 6061-T6 and has thickness of 1 mm. The size of the blank is 250 mm X 250 mm.

When the material was deformed under high-speed condition, the properties of the material are different when compared to quasi-static conditions. Therefore, material properties obtained at high-speed condition should be applied to the analysis. In this research, Split Hopkinson Pressure Bar (SHPB) test was carried out and the flow curves was obtained as shown in Fig. 4.

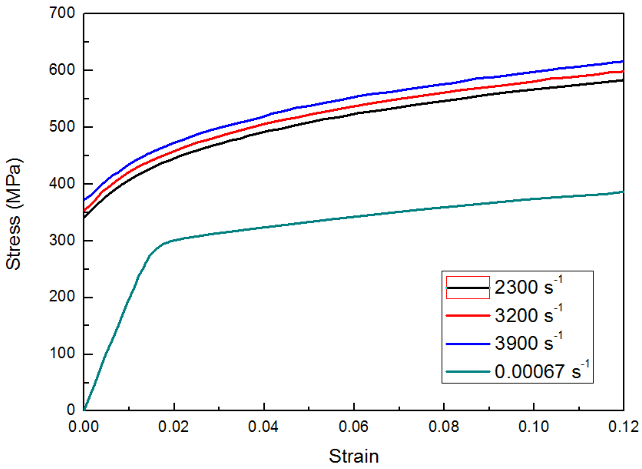

Figure 4: *Material properties of Al 6061-T6 under high-strain rate and quasi-static condition*

3 Results of numerical simulation

Fig. 5 shows results of the numerical simulation over time and Fig. 6 shows the pressure distribution of the fluid parts.

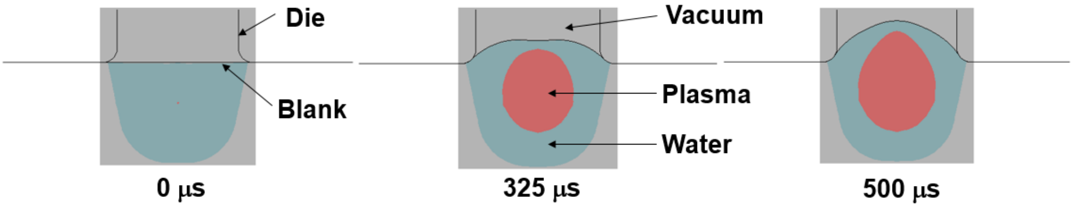

Figure 5: *Deformation behaviour of the numerical model*

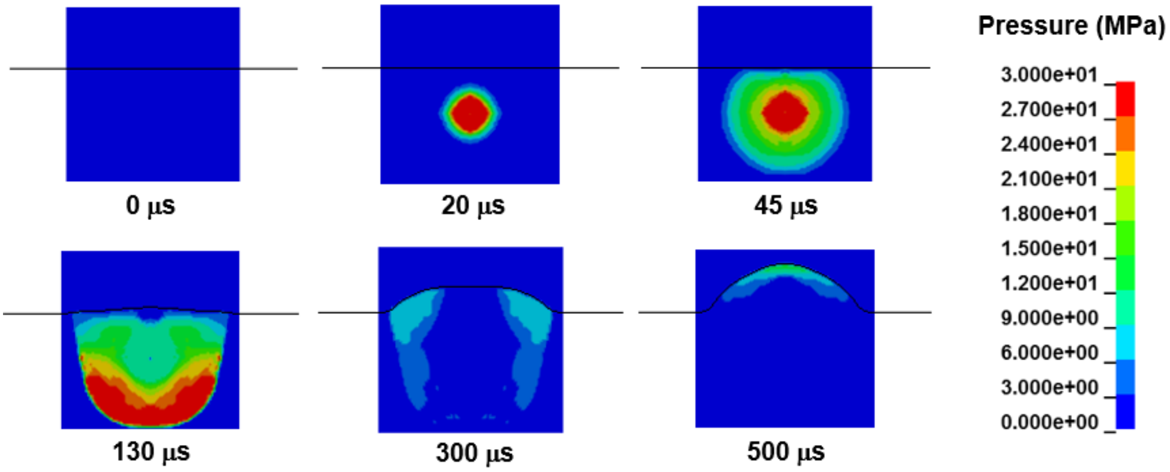

Figure 6: *Pressure distribution of the fluid parts*

The initial plasma was small, but it expands very quickly and at the same time the movement of the water, working fluid considered here, begins. The propagation of the pressure wave is clearly observed up to 130 µs and after that time, it shows more complex shapes by interference of reflected pressure waves on the chamber wall.

The deformation behaviour of the blank is demonstrated in Fig. 7. At 500 µs, the maximum bulge height is about 38 mm. The maximum effective strain is about 0.23 at the top area of the blank.

The final deformation shape of the material was compared with the experiment at the same energy input condition and it is shown in Fig. 8. As a result of comparing the two results, it can be concluded that the reliability of the finite element analysis is secured because less than 10% error occurs at the maximum forming height.

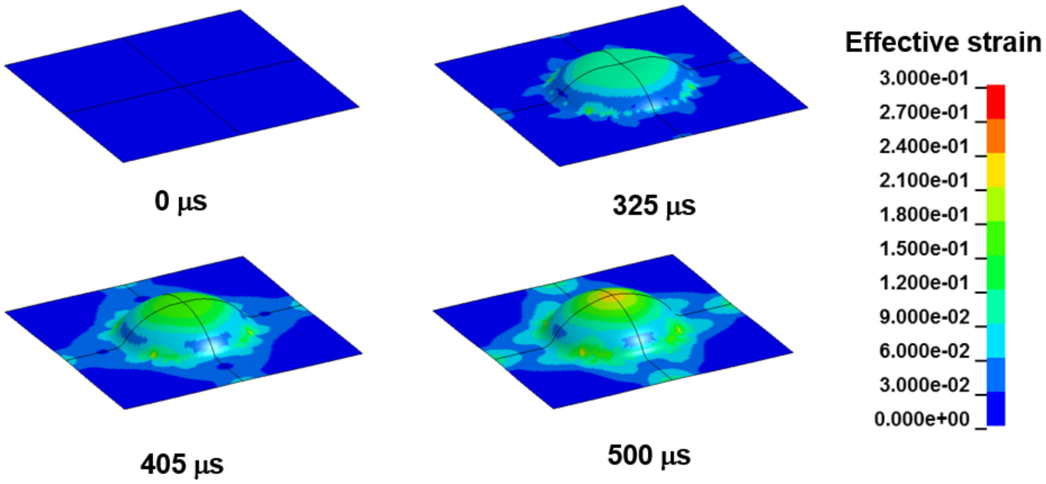

Figure 7: *The deformation behaviour of the blank*

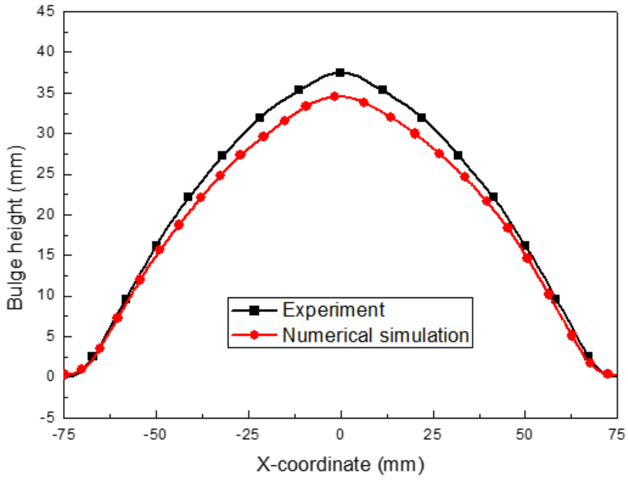

Figure 8: *Comparison of bulge height of the numerical simulation and experiment.*

4 Formability evaluation using forming limit diagram

To evaluate the formability of the deformed material, forming limit diagram (FLD) was applied. FLD is a curve for characterizing the formability of the material, which reflects the maximum and minimum principle strains prior to localized necking. In this paper, FLD was obtained theoretically by M-K model (Z. Marciniak and K. Kazimierz, 1967) and high-strain rate condition was considered.

Fig. 9 demonstrates the results of formability evaluation. As shown in Fig. 7, the area where fracture is expected is the top of the deformed blank with the highest effective strain value. Therefore, the strains at this area were obtained from the numerical simulation and is shown in Fig. 9.

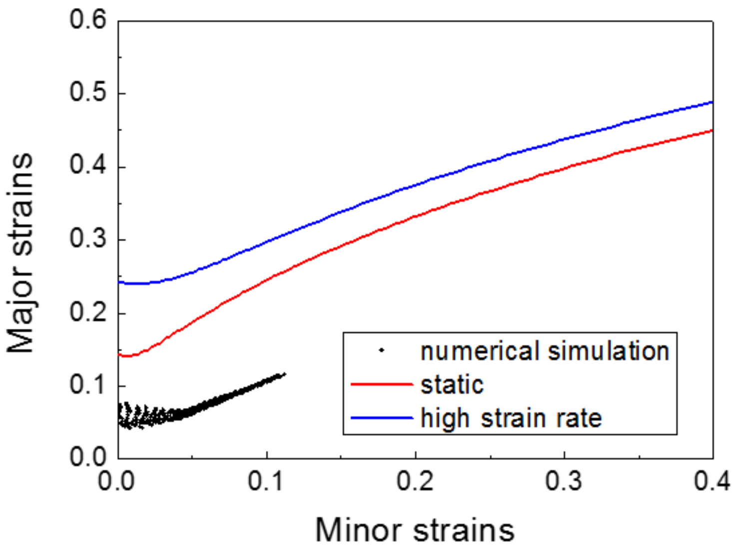

Figure 9: *Formability evaluation of Al 6061-T6 for electrohydraulic forming process*

Most elements near the top of the material were subjected to biaxial tensile loads, so major and minor strains show positive values. In addition, all of strains are located below the curve, which means that under the conditions inputted in the analysis, the material have no fracture and the forming was performed well without defects.

5 Conclusions

EHF is one of the high-speed forming process that uses electric energy discharge in fluid. In this study numerical model of Electrohydraulic forming (EHF) was developed using LS-DYNA commercial program. Arbitrary Lagrange-Eulerian method was employed to avoid the mesh distortion problem and to define the interaction between fluid parts simply. The results of the simulation showed that the analytical model was well developed so that the material could be deformed by the input electric energy. The maximum bulge height is about 38 mm and the maximum strain rate is about 0.23.

In addition, the formability of the material was evaluated by theoretically obtained forming limit diagram (FLD). As a result, at the energy level applied in this study, it was confirmed that the top area of the material didn't break and have any chance of wrinkles.

Acknowledgement

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