Numerical Simulation of Aluminum Alloy Forming Using Underwater Shock Wave

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Abstract

In recent years, on automobile industry, the car has body using aluminum alloy. As for this material, #5000's, 6000's and 7000's aluminum alloy is used well. However, the sheet metal forming of these materials by the static method, such as the hydro bulge forming and general punching, is very difficult, because these are little elongation compared with major steel. We considered application of the explosive forming. Therefore, we have tried free forming of aluminum alloy as the basic study. We compared the elongation of aluminum alloy by the explosive forming with punching. Consequently, it was larger for the amount of deformation of aluminum alloy by the explosive forming. In addition, we have done a theoretical elucidation. It is important the investigation of deformation process of aluminum plate by the explosive forming. Therefore, we solve using the numerical simulation by LS-DYNA. In this simulation, it carried out detonation process of the explosive, propagation process and deformation process of aluminum alloy.

Introduction

In recent years, automobile development is performed briskly for the improvement in mpg. The cars, which used the aluminum alloy instead of steel material as the measure, have increased. However, an aluminum alloy has a limit in a forming performance compared with the conventional steel material. We have tried improvement in the forming limit of an aluminum alloy by the explosive forming method. In order to realize this method, it is necessary to clarify the deformation mechanism of aluminum plate in high-speed forming. Therefore, in this research, the numerical simulation was performed about the deformation process of the aluminum plate by the explosive forming.

Simulation Method

Figure. 1 shows a simulation model of explosive forming. Each size is determined based on the equipment used in the experiment. This analysis area was divided by many quadrilateral elements. Aluminum was a disk and the diameter and thickness was 230mm and 1mm, each. The material of aluminum was annealing material, A7039. There is water on the aluminum plate, which diameter was 130mm and the height was 50mm. Although the vessel of paper was used in the experiment, the vessel is not taken into consideration in numerical simulation. The highly explosive SEP was arranged in underwater. SEP explosive was provided by Asahi Kasei Corp., Japan. The density of SEP explosive is 1.31kg/m^3 and detonation pressure is 15.9 GPa. The distance from the top of the explosive and aluminum plate was 30mm. The curvature radius of the die shoulder was 15mm, and an opening diameter of die was 100mm. As the boundary conditions, the die was a rigid body. And then, since blank holder presses the perimeter part of water down, the aluminum plate surface was restrained in the direction of z. The vessel was disregarded and the surface of outside of water was free surface.

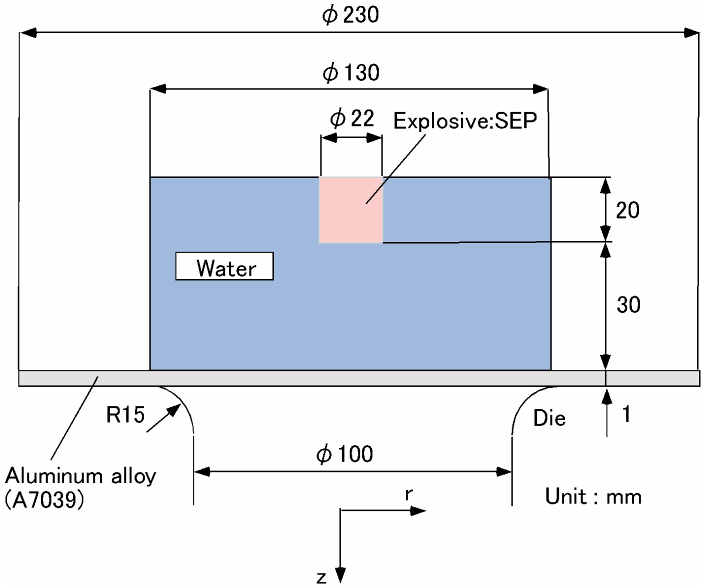

Figure 1 Simulation model

The pressure calculation of water was solved by the following Mie-Grümeisen equation of state1),

$$P = \frac{\rho_0 c_0^2 \eta}{(1 - s\eta)^2}\left[1 - \frac{\Gamma_0 \eta}{2}\right] + \Gamma_0 \rho_0 E \tag{1}$$

where, ρ_0 is initial density. E is internal energy, Γ_0 is Grüneisen parameter, $\eta = 1 - \rho_0/\rho$, c_0 and s are material constants. For the related materials, the values of those constants are given in Table 1.

Table 1. Parameter of Mie-Grümeisen EOS.

	ρ_0 (kg/m^3)	C_0(m/s)	S	Γ_0
Water	1000	1490	1.79	1.65

The pressure in detonation products of explosive is calculated by using the JWL (Jones-Wilkins-Lee) equation of state2). The equation has the following expression,

$$P = A\left[1 - \frac{\omega}{VR_1}\right]\exp(-R_1V) + B\left[1 - \frac{\omega}{VR_2}\right]\exp(-R_2V) + \frac{\omega E}{V} \tag{2}$$

where, A, B, R_1, R_2, C and ω are JWL parameters. V is the ratio of the volume of the product gases to initial volume of the undetonated explosive. For the explosive SEP, those constants were obtained from cylindrical expansion test and are given in Table 2.

Table 2. JWL parameters for SEP.

A(Gpa)	B(GPa)	R_1	R_2	ω
365	2.31	4.30	1.10	0.28

For the calculation of detonation of the explosive, the C-J volume burn method $^{3)}$ was used. When the volume of the cell of the original explosive in the calculation becomes equal to the volume of the detonation products at Chapman-Jouguet (C-J) state, the solid explosive is assumed to be completely decomposed into the gaseous products. Let V_0 represent the initial volume of explosive (the reciprocal of the initial density), V_{CJ} be the volume of the detonation products at the C-J state, the reaction rate of the explosive is simply expressed as,

$$W = 1 - \frac{V_0 - V}{V_0 - V_{cj}} \tag{3}$$

$$P = (1 - W)P_g \tag{4}$$

where, W stands for the mass fraction of the unreacted explosive, thus, before and after reaction, W=1 or 0, respectively, P_g is the pressure of the detonation products. The pressure, P, correspondingly, is assumed to be equal to that of the detonation products of the partly reacted explosive over the whole cell. The pressure, volume and energy of the reacted explosive are correlated by the JWL equation of state already described above.

The constitutive equation of the aluminum plate is described in the following. This equation is Johnson-Cook's equation$^{4)}$.

$$\sigma_y = \left(A + B\varepsilon^n\right)\left(1 + C\ln\dot{\varepsilon}\right)\left[1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m\right] \tag{5}$$

where, σ_y is the equivalent stress, ε is the equivalent strain and $\dot{\varepsilon}$ is the equivalent strain rate.

And then, A, B, C , m and n are material constants. These constants of A7039 are shown in Table 3$^{4)}$.

Table 3. Material constant of Johnson-Cook' equation for A7039.

A(MPa)	B(MPa)	C	n	m
337	343	0.01	0.41	1.00

Simulation Results and Discussion

Figure 2 shows pressure contour in the element of water. Moreover, Figure 3 shows the pressure history of the element of the water which touches the aluminum plate surface in r= 0, 10, 20, 30, 40 and 50mm. At the calculation time, from 5 to 10μs, the underwater shock wave produced by underwater detonation of an explosive spreads spherically. And then, the central part of underwater shock wave reaches an aluminum plate in about 15 μs. A reflective wave occurs from an aluminum plate immediately. Although the shock front is spread to the both sides of an aluminum plate after 20 μs, because the circumference of the water of both sides is free surface, an underwater shock wave arrives at this surface; the pressure will be decreased soon. The pressure action to the aluminum plate by the underwater shock wave is produced from the central part of the aluminum plate, and the pressure of the direction of the perimeter rises gradually. Most of this early pressure action is produced less than 40 μs, and the slight pressure rise of how often will be seen in near die shoulder (r= 50mm) by 400 μs.

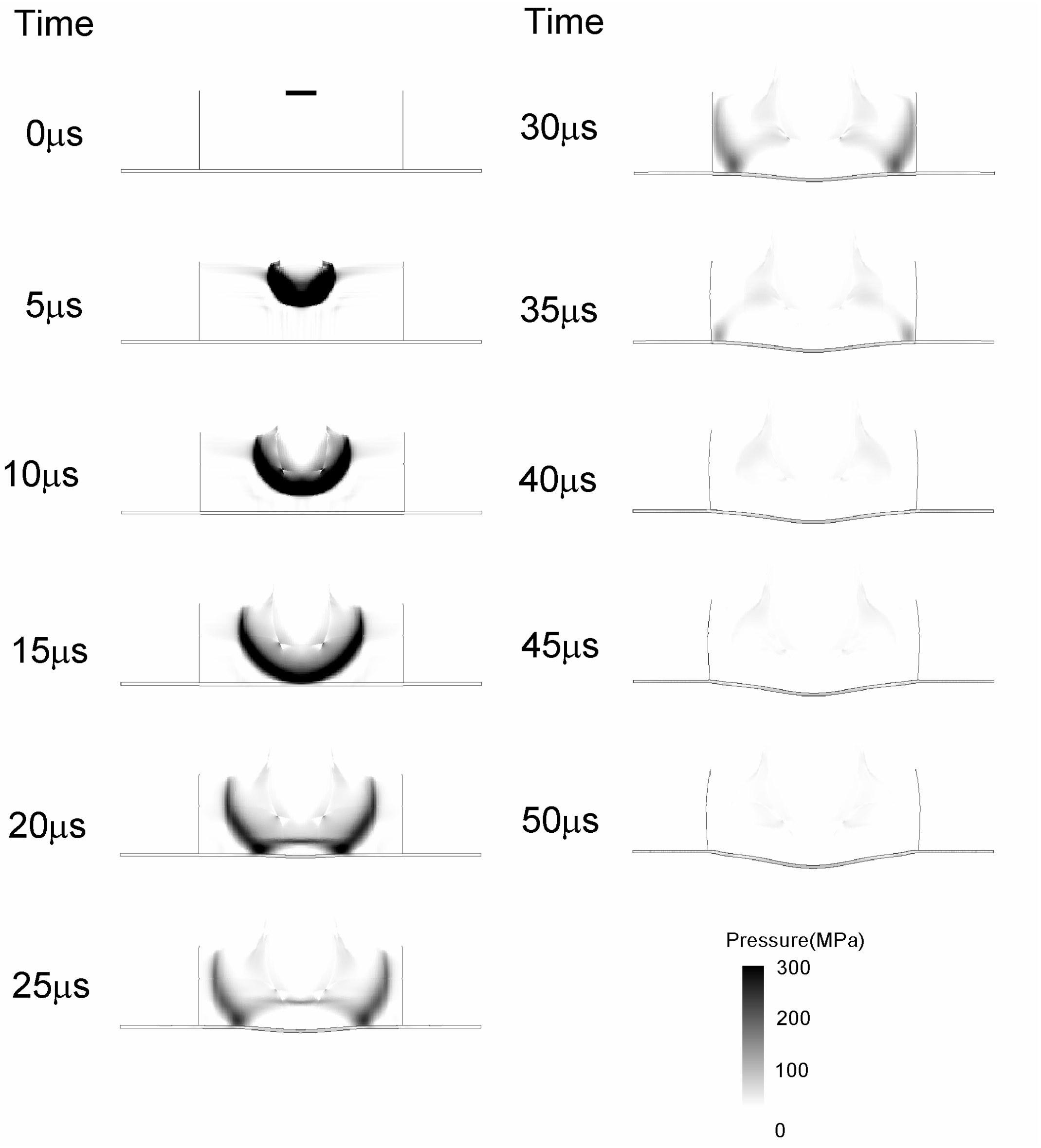

Figure 2 Pressure contour of water part.

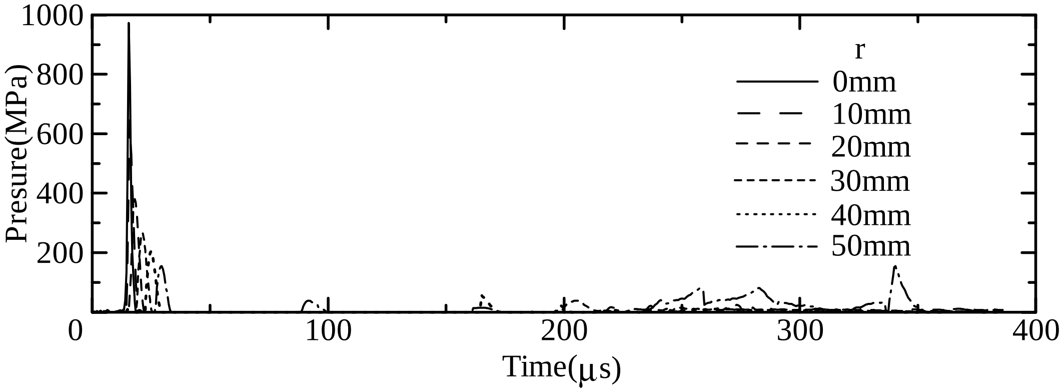

Figure 3 Pressure history in water cell on the aluminum plate at r=0,10, 20, 30, 40 and 50mm.

Figure 4 shows the deformation process of an aluminum disk. This Figure is shown every 20 μs till 300 μs. Because the deformation shape is hardly changing henceforth in 400 μs, the deformation was completed. In 20 to 40 μs, deformation arises from the central part of the aluminum plate on which an underwater shock wave begins to act first. Then, in 60 μs, it turns out that the underwater shock wave reached near the die shoulder, the board near opening both sides bent below a little, and the deformation has arisen. This bending deformation is moving in the direction of a center. The central part of the aluminum plate is projected greatly simultaneously, and the whole of the aluminum plate becomes a spherical shape in the last stage. The amount of deformation of the aluminum plate at 400 μs from top and bottom surface was approximately 43.8mm. Figure. 5 shows the deformation speed of the direction of z under r= 0, 10, 20, 30, 40 and 50mm. The shock wave, which acts on the central part of aluminum plate, was large. The deformation speed rises rapidly up to about 280 m/s. Then, a big pressure action does not take place but the deformation speed decreases gradually. Moreover, a speed rise takes place from the central part of aluminum plate gradually in the direction of the perimeter. The peak value decreases from the central part to a perimeter part.

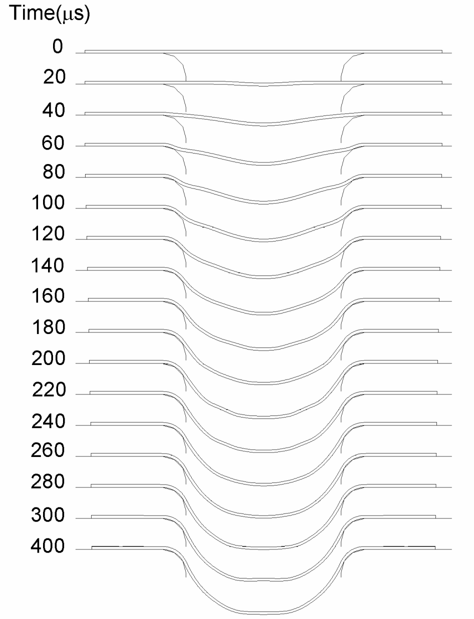

Fig.4 Deformation process of the aluminum plate.

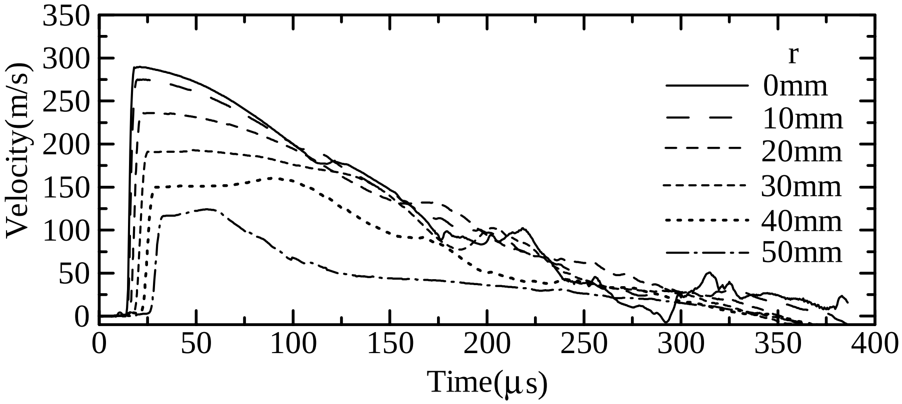

Figure 5 z directional velocity on the bottom surface of the aluminum plate at r=0, 10, 20, 30, 40 and 50mm.

Conclusion

In this research, the numerical simulation was performed about free forming of the aluminum disk by explosive forming method. The propagation process of an underwater shock wave and the deformation process of an aluminum disk were explained from the simulation result.

References

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