Study on Explosive Forming of Aluminum Alloy

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ABSTRACT
Now, the aluminum alloy is often used as auto parts, for example, body, engine. For example, there are the body, a cylinder block, a piston, a connecting rod, interior, exterior parts, etc. These are practical used the characteristic of a light and strong aluminum alloy efficiently. However, although an aluminum alloy is lighter than steel, the elongation is smaller than that. Therefore, in press forming, some problems often occur. We have proposed use of explosive forming, in order to solve this problem. In the explosive forming, since a blank is formed at high speed, a strain rate effect becomes large and it can be made the elongation is larger. Then, in order to clarify this feature, we carried out experimental research and numerical analysis. In this paper, these contents will be discussed.

1. 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. Then, we have tried improvement in the forming limit of an aluminum alloy by the explosive forming (1). 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 method by the finite difference method used the Lagrange coordinate (2).

2. EXPLOSIVE FORMING

2.1. GENERAL METHOD

A general explosive forming method is shown in Fig. 1. A metal plate is held in place by a blank holder and a metal die is connected. After detonation, an underwater shock wave was generated and propagated towards the metal plate and then hit it. In this method, a bubble wave occurs after the shock wave and is also propagated towards the metal plate and hits it. This metal plate is deformed by these loading and collides with the metal die. In the end the deformed surface of the metal plate has come to match the shape of the metal die. The feature of explosive forming that allows the die to sufficiently transfer its shape onto the plate is that the spring-back effect is less than with ordinary forming methods, like punching and hydro bulging. So, we considered using this method for aluminum alloy forming.

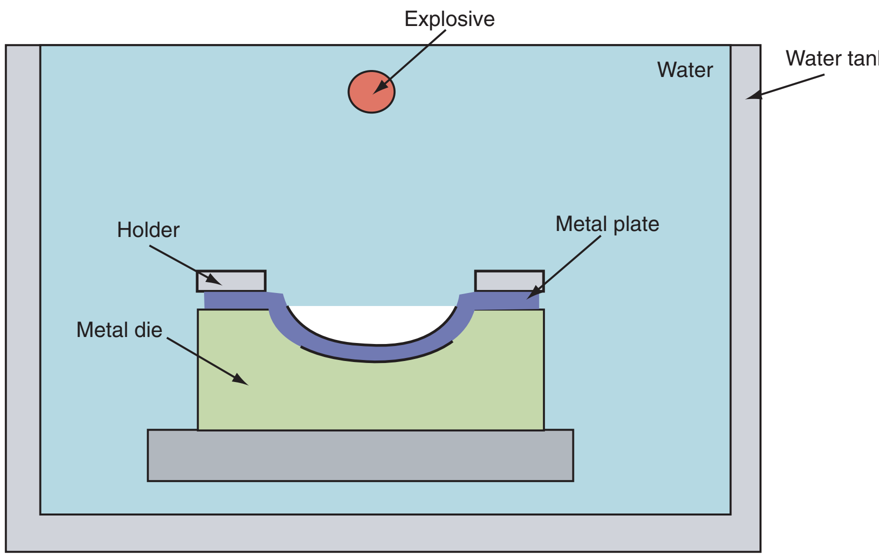


Figure 1 A schematic diagram of explosive forming.

However, the forming of these materials as sheet metal by static methods, such as hydro bulge forming or general punching, is difficult for the aluminum forming because the aluminum alloy allow little elongation compared to conventional steel. In order to examine the application of explosive forming, we tried free forming aluminum alloy as the basis of the study.

2.2. EXPERIMENTAL PROCEDURE

Fig. 2 shows an experimental equipment. The aluminum plate was installed between the metal die and the blank holder, and the explosive was connected to the tip of the electric detonator as seen here. However, in the results shown by this study's equipment, the bubble wave went off in an upper direction and there was good effect on the aluminum plate. The aluminum plate was A5052-O. The explosive, SEP is used, which was provided by Asahi Kasei Corp. in Japan. The detonation velocity was 6970 m/s, and the detonation pressure was 15.9 GPa.

2.3. EXPERIMENTAL RESULTS

Fig. 3 shows photographs of aluminum alloy plate after forming by explosive forming and static press forming. The left hand side is in the case of explosive forming, and the right hand side is in the case of press forming. In the experimental condition of static press forming, the radius of die shoulder was 4 mm, a clearance between punch and die was 2.5 mm and punching cycle was 35 cycle/min. Then, Fig. 4 shows the result of sectional shape measurement of each forming method.

The explosive forming limit, shown in Fig. 3, it can be attained at 10 g of explosive, and the bulge depth was 39 mm. The configuration obtained by static press forming is shown in Fig. 4. The maximum bulge depth was 28 mm. Comparison of the two configurations makes it clear that the amount of deformation by explosive forming is larger.

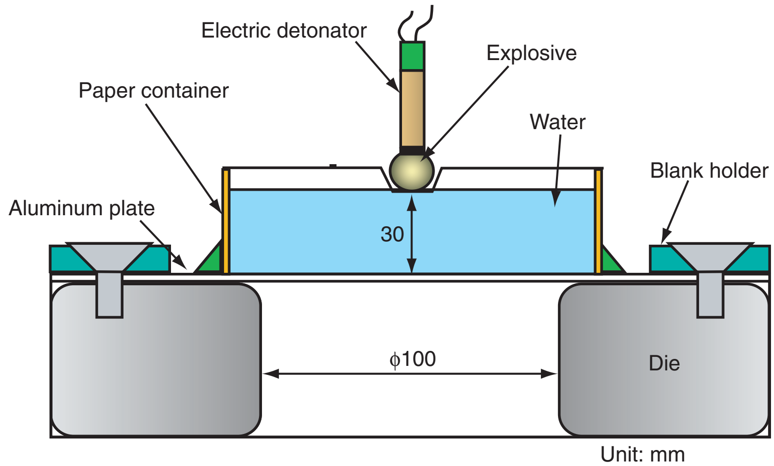
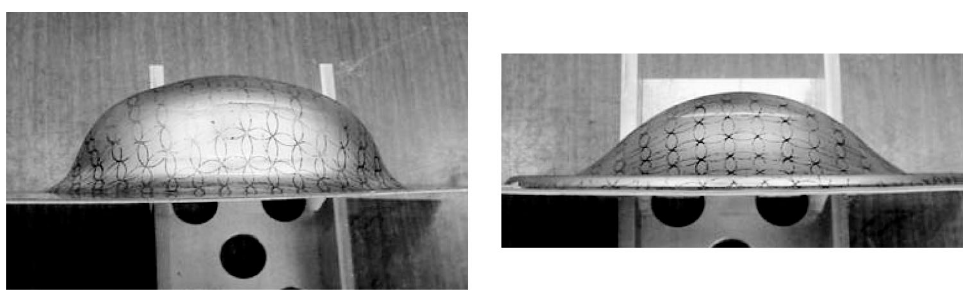


Figure 2 A schematic diagram of experimental equipment for aluminum alloy forming.



Explosive mass: 10 [g]
Bulge depth: 39 [mm]

Press forming
Bulge depth: 28 [mm]

Figure 3 Photographs of aluminum alloy plate after forming by explosive forming and static press forming.

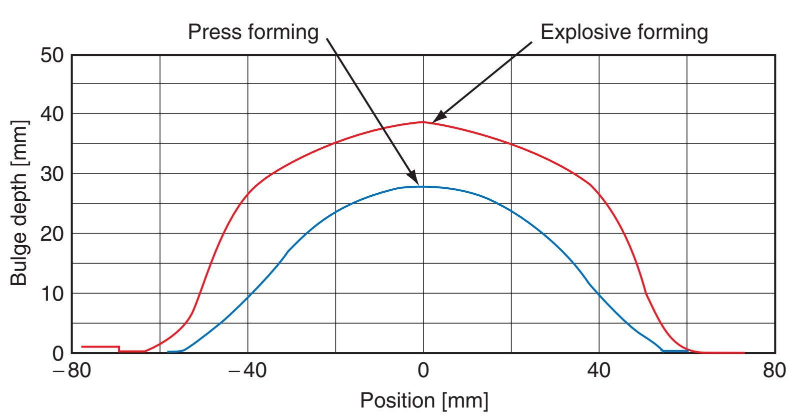


Figure 4 Sectional configuration of explosive forming and static press forming.

3. NUMERICAL ANALYSIS

3.1. ANALYSIS METHOD

Fig. 5 shows a simulation model for aluminum forming. We attempted an elucidation of the deformation mechanism of aluminum alloy forming using FDM (Finite Difference Method) (3). Each dimension was determined for the equipment used in the experiment. The aluminum was in the form of a disk with a diameter of 230 mm and thickness of 1 mm. So, water, the explosive, and the metal plate were divided into the mesh of a quadrilateral, and calculation was carried out. The aluminum was as A5052-O. A water column 130 mm in diameter and 50 mm in height rested in the center of the aluminum plate. Although a paper container was used in the experiment, it wasn't included in the numerical simulation. Highly explosive SEP was positioned in the water. The distance between the bottom of the explosive and the aluminum plate was 30 mm. The curvature radius of the die shoulder was 15 mm and the die opening diameter was 100 mm. As a boundary condition, the die was a rigid body. Because the blank holder presses down around the perimeter of the water, the aluminum plate's surface is restrained in the direction z. Since the paper vessel was disregarded in the model, the sides of the water column were considered a free surface. The surface contact between the water and the aluminum plate was the slide boundary.

3.2. PRESSURE CALCULATION

The pressure calculation for the water was solved by this Mie-Grüneisen equation of state (4). Where ρ_0 is the initial density, e is energy, Γ_0 is the Grüneisen parameter, and $\eta = 1 - \rho_0/\rho$, c_0 and s are material constants. The values of those constants are given in Table 1.

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

The pressure from the explosion is calculated by using the JWL (Jones-Wilkins-Lee) equation of state (5), where A, B, R1, R2 and ω are the JWL parameters. V is the ratio of the

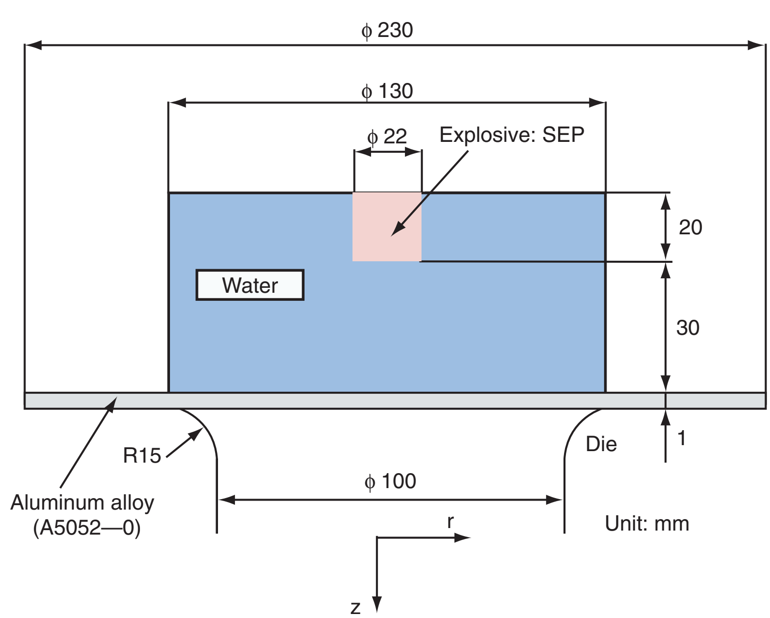


Figure 5 Simulation model.

Table 1. Material constants in Mie-Grüneisen EOS.

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

Table 2. JWL parameters for SEP explosive.

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

volume of the gases produced by the explosion to the initial volume of the undetonated explosive. The JWL parameter for the SEP are shown in this table.

$$P = A\left[1-\frac{\omega}{VR_1}\right]\exp(-R_1V) + B\left[1-\frac{\omega}{VR_2}\right]\exp(-R_2V) + \frac{\omega e\rho_0}{V} \quad (2)$$

3.3. CONSTITUTIVE EQUATION

The constitutive equation of the aluminum plate is described in the following. We computed uniquely this equation.

$$\sigma_y = 72 + 132\varepsilon^{0.28} + 12.8\varepsilon^{0.710}\ln\left\{\dot{\varepsilon}/(2.0\times10^{-10})\right\} \quad \text{(MPa)} \quad (3)$$

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

4. SIMULATION RESULTS

Fig. 6 shows a propagation of the underwater shock wave by the simulation result. Fig. 7 shows the pressure history of the element where the water touches the aluminum plate surface at r = 0, 10, 20, 30, 40 and 50 mm. With the detonation calibrated at 0 μs, during the time interval from 5 to 10 μs the underwater shock wave produced radiates spherically. The arc of the shock wave reaches the center of the aluminum plate at about 15 μs. A wave is then instantaneously reflected off the aluminum plate. Although the shock front has spread to the edges of the aluminum plate by 30 μs, because the circumference of the water is a free surface, the shock wave arriving at the edge is soon dissipated.

Fig. 8 shows the comparison of pressure values between the experimental and simulation results. The horizontal axis is the distance through the water from the bottom of the explosive. The experimental data was measured using a tungsten bar pasted two strain gages as shown in Fig. 9. When the shock wave through inside this tangsten bar, the shock velocity was measured by strain gages. And then, from the shock velocity, the puressure is calculated. From this figure, it can be seen that the values are almost same and the plausability of the calculations are validated.

Fig. 10 shows the deformation process on 20 μs time interval. Between 20 and 40 μs, the deformation appears in the central part of the plate. At 60 μs the wave has apparently approached the die shoulder, the plate shown as bending down a little around the opening as deformation progresses. This bulge at the die shoulder continues toward the center, whereupon the central part of the plate projects all at once in a great bulge, with the

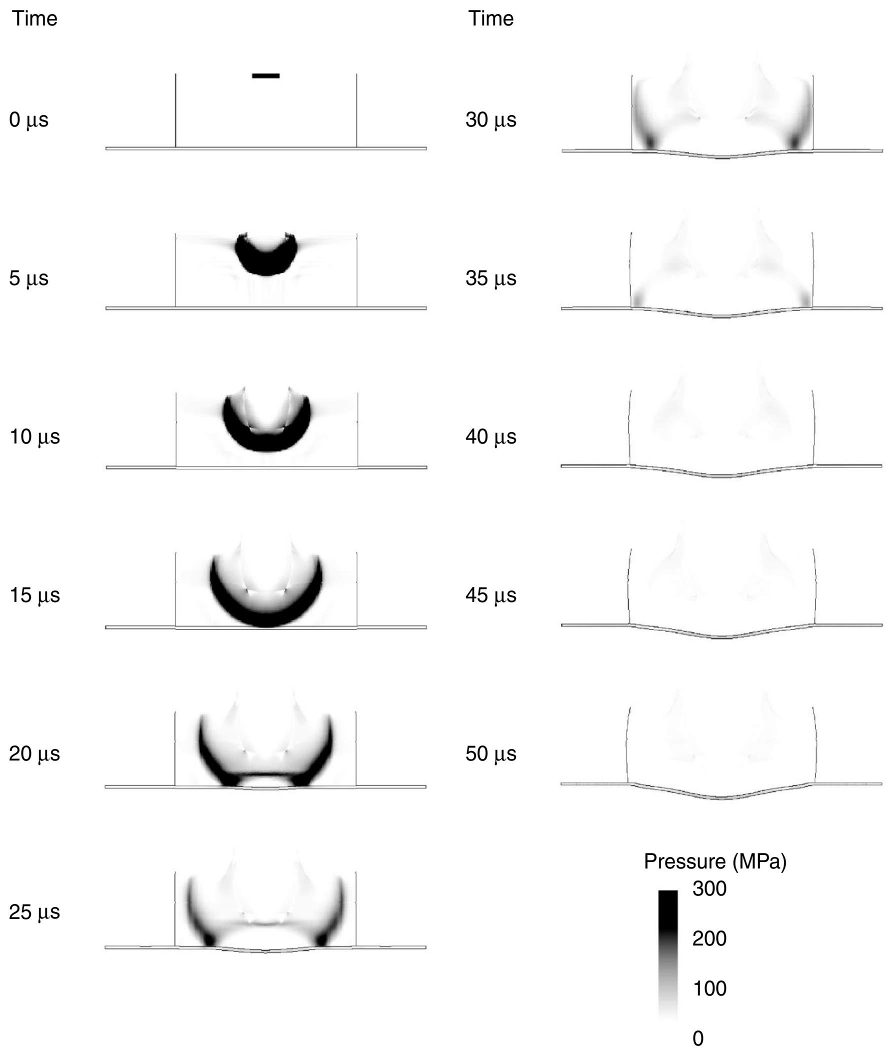


Figure 6 Propagation process of underwater shock wave.

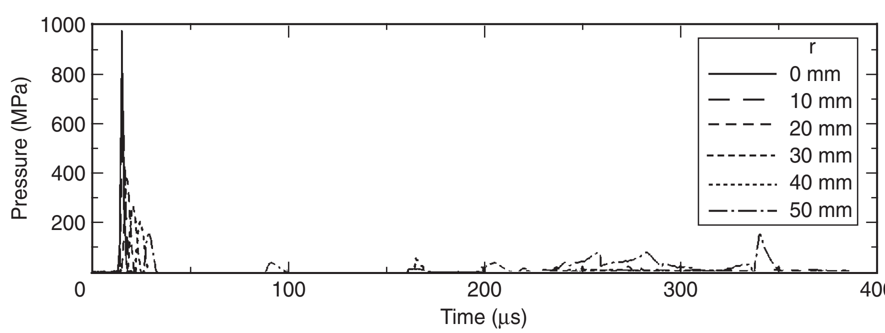


Figure 7 Pressure profile in water cell on the aluminum plate at r = 0,10, 20, 30, 40 and 50 mm.

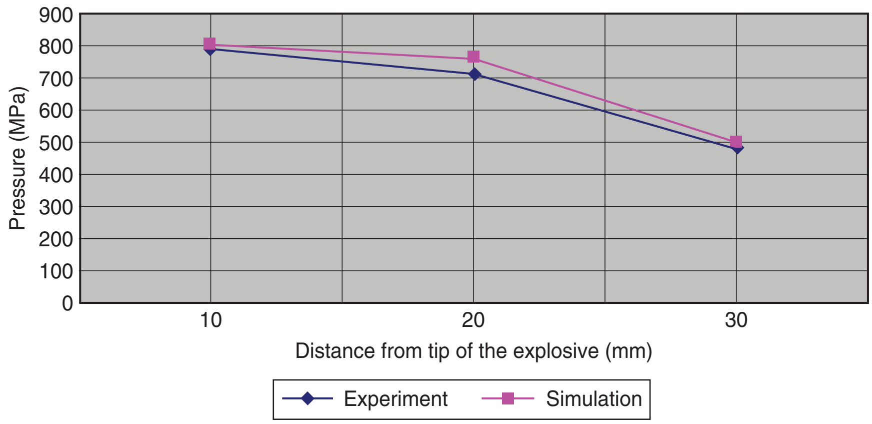


Figure 8 Comparison of pressure values of analysis result and experimental data.

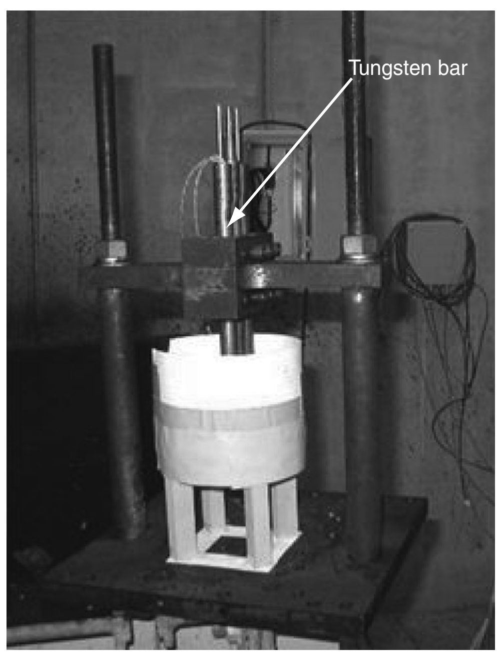


Figure 9 Experimental equipment for the measurement of pressure of water.

aluminum plate over the opening assuming a hemispherical shape in the final stage. The amount of deformation of the aluminum plate from top to bottom surface at 400 μs was shown as approximately 41.8 mm. In the experimental result, it value was 39 mm.

Fig. 11 shows the deformation z-direction velocity at r = 0 to 50 mm. When the shock wave acting on the central part of the plate is large, the deformation velocity rises rapidly to about 280 m/s. Movement of the initial velocity increase is from the central part of the aluminum plate gradually toward outer side, with the peak value decreasing as it moves from the central area to outer side.

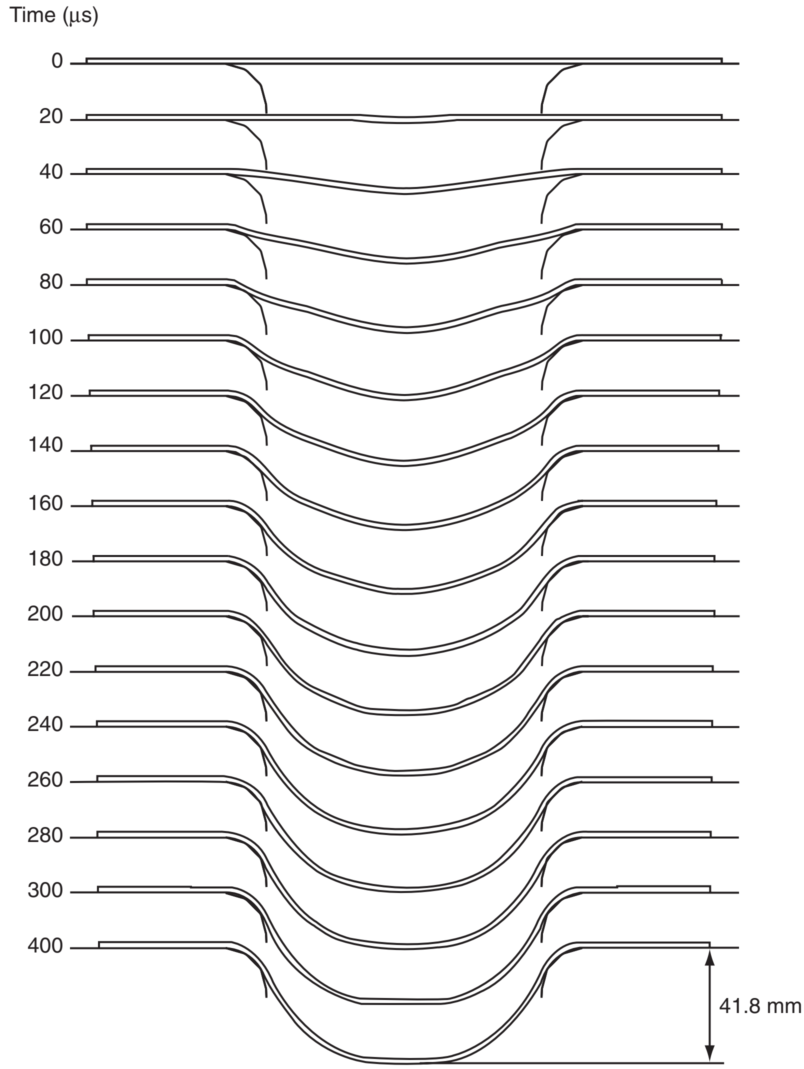


Figure 10 Deformation process of aluminum plate.

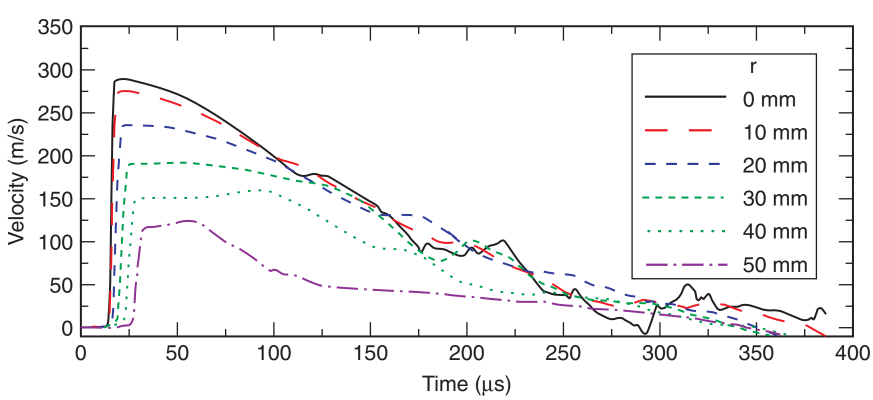


Figure 11 z-direction velocity on the bottom surface of the aluminum plate at r = 0, 10, 20, 30, 40 and 50 mm.

5. CONCLUSIONS

In this research, a numerical simulation was performed on the free forming of the aluminum alloy plate by explosive forming method.

(1) The propagation process of an underwater shock wave and the deformation process were simulated.

(2) From experimental and simulation results, both pressure values of the underwater shockwave agree well.

(3) Peak velocity at center of the aluminum plate increased up to about 280 m/s.

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