Pressure vessel made by free forming using underwater explosion

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ABSTRACT
Explosive forming is one particular forming technique, in which, most commonly, water is used as the pressure transmission medium. In recent years, we have done the development of the method which obtains a necessary form of the metal by the control of underwater shock wave acts on the metal plate, without a metal die. On the other hand, the pressure vessel is required in various fields, but we think that the free forming using the underwater shock wave is advantageous in the production of pressure vessel of a simple spherical, ellipse, parabola shape. In this paper, we will introduce an experiment and several numerical simulations that we carried out for this technical development.

1. INTRODUCTION

We have been researching a metal forming using underwater shock wave. This method is called an explosive forming by causing the underwater shock wave is generated by underwater explosion of an explosive. In recent years, we have done the development of the method which obtains a necessary form of the metal by the control of underwater shock wave acts on the metal plate, without a metal die [1] [2]. Without using the metal die, the forming method with only the overhang the metal plate is called free forming. It is possible the regulation of the pressure strength, pressure distribution, action time to the metal plate of the underwater shock wave by changing the distance between the explosive and the metal plate and quantity of the explosive. On the other hand, what we are thinking as this example, is the production of a pressure vessel. The pressure vessel is required in various fields, but we think that the free forming using the underwater shock wave is advantageous in the production of pressure vessel of a simple spherical, ellipse, parabola shape.

In this paper, we will introduce an experiment and several numerical simulations that we carried out for this technical development.

2. EXPERIMENTAL PROCEDURE

The device in Fig. 1 is a food processing device using the pressure vessel. Fig. 2 shows a schematic diagram of this pressure vessel. These are one of example of the pressure vessel. The bottom of the pressure vessel is spherical shape. We have been developing the technique that produces thus pressure vessel by free forming using the underwater shock wave.

Figure 1 Food processing device using the pressure vessel.

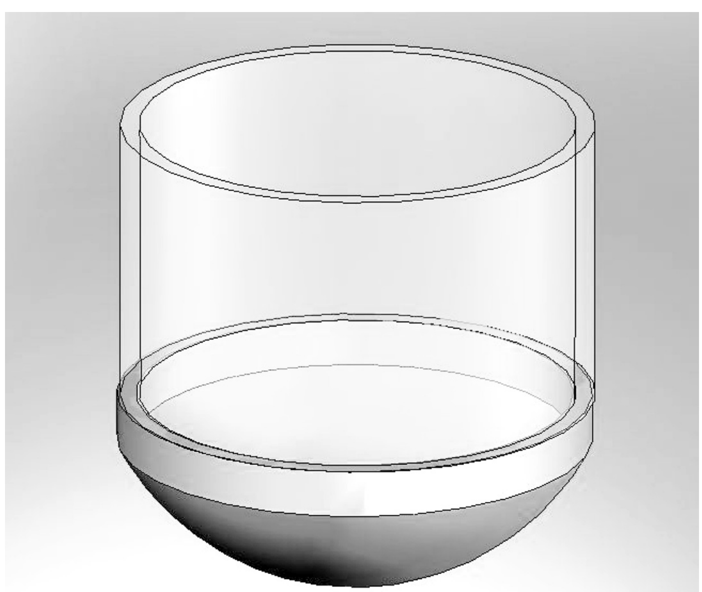


Figure 2 A schematic diagram of pressure vessel for food processing device.

Fig. 3 shows a schematic diagram of the experimental device. Fig. 4 shows the general view photograph. The free forming of stainless steel plate was carried out. Size of the stainless steel plate was 780 × 780 mm and its thickness was 1.5 mm. The explosive used in this experiment was an high explosive, SEP and its mass was 80g. The density, detonation

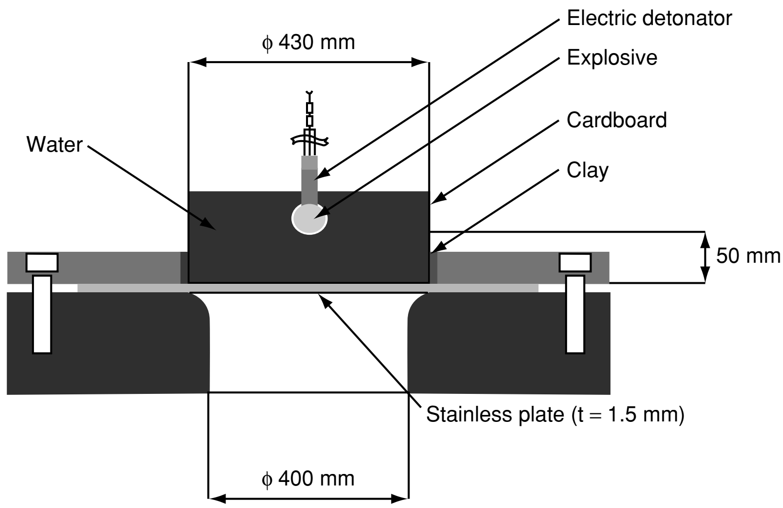


Figure 3 A schematic diagram of experimental device.

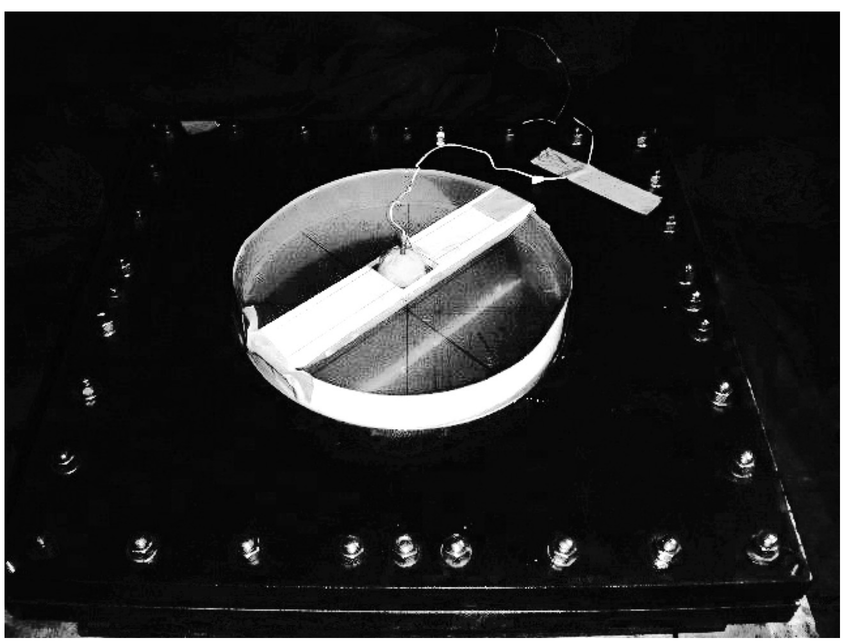


Figure 4 A photograph of the equipment of explosive forming.

pressure and detonation velocity of this explosive are 1.31g/cm^3, 15.9GPa and 7000m/s, respectively. In this experiment, an vessel made of cardboard was used. The explosive set at top of this vessel and it exploded by an electric detonator. The height of this cardboard was 90 mm and the distance between the stainless steel and the explosive was 50 mm.

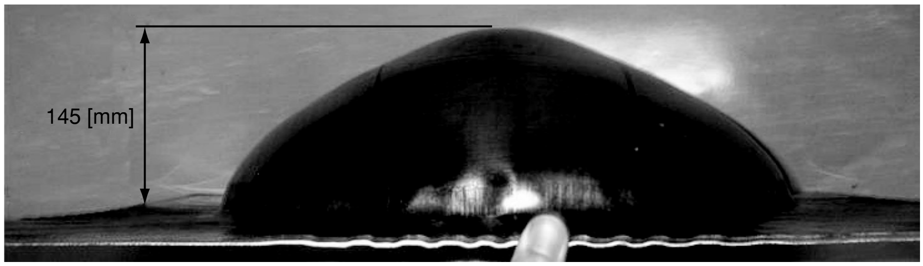
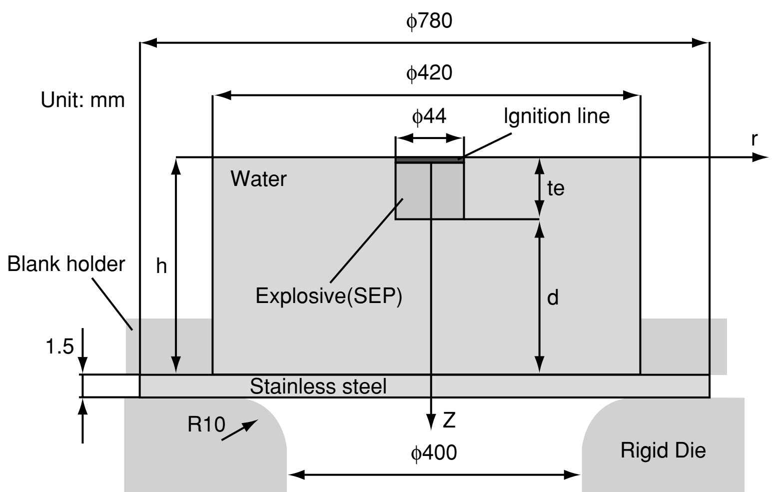


Figure 5 Side view of the stainless steel plate after the free forming.



Figue 6 Simulation model for explosive forming of stainless steel.

3. EXPERIMENTAL RESULT

Fig. 5 shows a photograph is side view of the stainless steel plate after the free forming. The stainless steel plate formed spherically, and its central part was projected. In this experimental result, the bulge depth of stainless steel plate was 145 mm.

4. NUMERICAL SIMULATION

In order to clarify the forming mechanism, the numerical simulation was carried out. Fig. 6 shows a simulation model. This numerical simulation is done using our self cord based on the finite difference method [3]. This model was axis symmetrical model, r and z coordinate were set like this figure. Where, the size and thickness of the stainless steel plate was same as the experimental set-up. And also, W is the mass of explosive, d is the distance between the explosive and stainless steel plate, te is the thickness of the explosive and h is the height of the water. These parameters were changed in the numerical simulation.

Table 1 shows the condition of the simulation. Each parameter was changed on the simulation. Condition, No.1 is same as the experimental condition. The top surface and side of the water was free surface and the die was as the rigid body. The initial mesh size of the water and explosive was 1×1 mm, one of the stainless steel plate was 0.5×0.5 mm.

Table 1 Simulation conditions for free forming of stainless steel

	Simulation Number				
	1	**2**	**3**	**4**	**5**
W (g)	80	80	100	100	100
h (mm)	90	80	100	90	80
te (mm)	40	40	50	50	50
d (mm)	50	40	50	40	30

Table 2 Mie-Grüneisen parameter

	ρ_0(kg/m^3)	C_0(m/s)	S	Γ_0
Water	1000	1490	1.79	1.65
SUS304	7896	4569	1.49	2.17

Table 3 JWL parameter for SEP

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

The pressure calculation of each element is calculated every time step in this calculation method. The pressure calculation for the water and stainless steel were solved by Mie-Grüneisen equation of state[4] as described in eqn. (1), where, P is pressure of water, e is internal energy, ρ_0 is the initial density, Γ_0 is the Grüneisen parameter, and η is described in eqn. (2).

Mie-Grüneisen parameter for water and stainless steel were given in value of table 2.

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

$$\eta = 1 - \rho_0/\rho \tag{2}$$

The pressure of explosive element was calculated by JWL (Jones-Wilkins-Lee) equation of state [5] is shown in eqn (3), where, V= ρ_0 (initial density of an explosive)/ρ (density of a detonation gas), P* is pressure of explosive, E is specific internal energy, A, B, R1, R2 and ω are JWL parameter. JWL parameter of explosive SEP was used in this numerical simulation is described in table 3. These values calculated by experiment in Kumamoto University.

$$P^* = A\left[1 - \frac{\omega}{VR_1}\right] exp\,(-R_1 V) + B\left[1 - \frac{\omega}{VR_2}\right] exp(-R_2 V) + \frac{\omega E}{V} \tag{3}$$

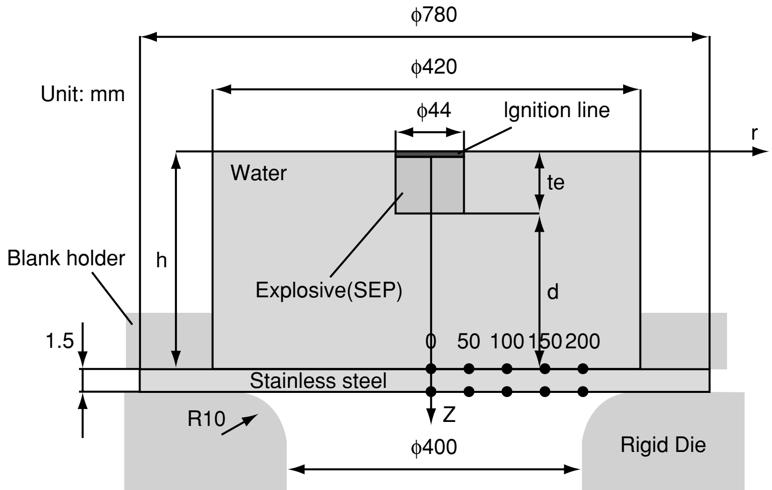


Figure 7 Pick up position of the pressure and velocity.

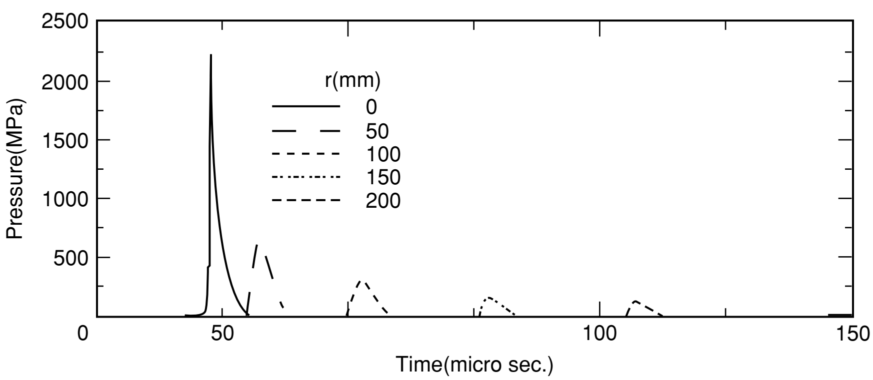


Figure 8 Pressure profile of water element on the stainless steel plate up to 150 μs.

The internal stress and strain of the stainless steel are calculated. The constitutive equation of stainless steel is used stress calculating was equation (4), where, σ_y is equivalent plastic stress and ε_p is strain. After the strain of stainless steel is calculated by the deformation of element, the stress is calculated by this constitutive equation. This equation was calculated by tensile test of stainless steel at room temperature.

$$\sigma_y = 280 + 580\varepsilon_p^{0.57} \tag{4}$$

5. SIMULATION RESULT

We pick up the pressure of water element on the stainless steel and the plate velocity of z direction. Both data got on five points from center to outer position with 50 mm intervals, as shown in Fig. 7.

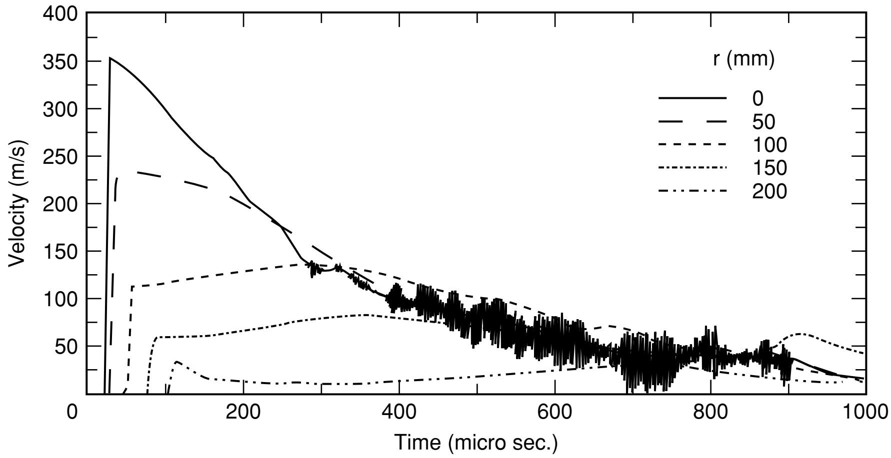


Figure 9 Pressure profile of water element on the stainless steel plate up to 1000 μs.

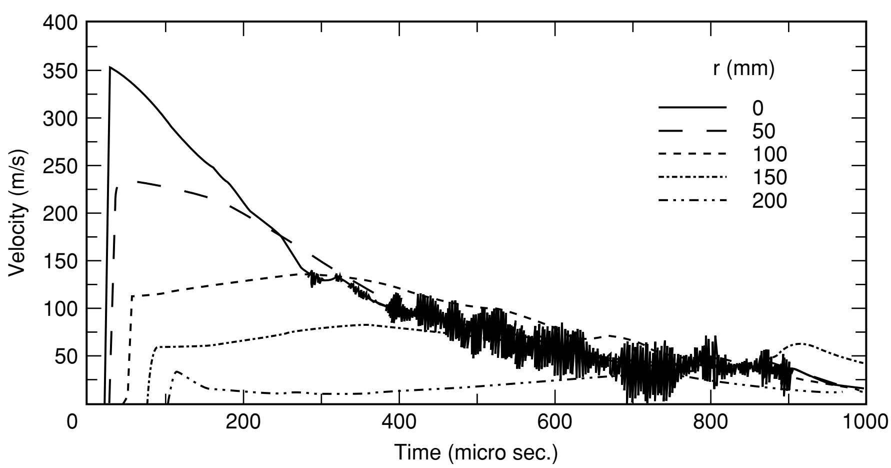


Figure 10 z direction velocity profile of stainless steel.

Fig. 8 and 9 show the pressure profile of the water on the stainless steel plate. Fig. 8 shows the pressure profile from 0 to 150 μs. Fig. 9 shows up to 1000 μs. The peak pressure on center of the stainless steel is the largest, its value was approximately 2.2 GPa. The pressure increase is not seen in all the places after 300 μs.

Fig. 10 shows the z direction velocity profile of the stainless steel plate from the center to outer in 50 mm intervals. The peak value of this velocity of center is the largest and it becomes smaller with outer position.

Fig. 11 shows the deformation process of the stainless steel plate. At the finally, the bulge depth was 138 mm. In the case of the experiment, it was 145 mm. It was confirmed that a little error is happening to the calculation result and experimental result.

Fig. 12 shows the final deformation shape of the stainless steel plate in the simulation result and experimental result this slide. We can see the both shape is almost similar. We will

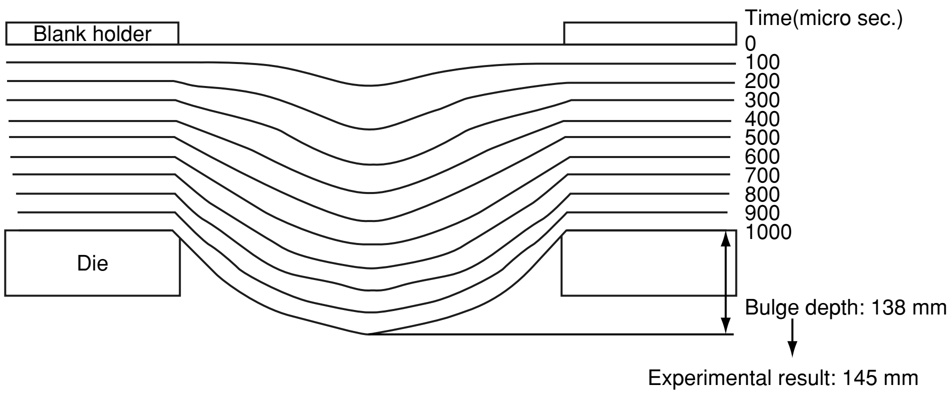


Figure 11 Deformation process of stainless steel.

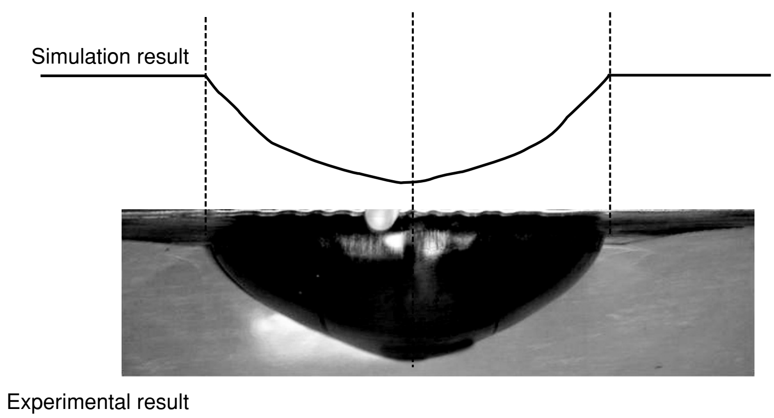


Figure 12 Comparison of final deformation shape of the stainless steel.

introduce comparison the final deformation shape in this analysis condition and other conditions.

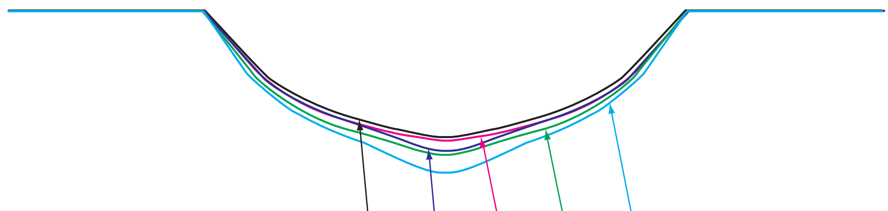
Fig. 13 shows the final deformation shape of the stainless steel plate on each condition. The bulge depth was measured. From the result, maximum value was 168 mm on the No. 5.

6. CONCLUSION

We have been developing the method of free forming using underwater shock wave in order to produce the pressure vessel. In this paper, an experiment and several numerical simulations were carried out. These results are concluded as the following contents.

(1) The free forming using underwater shock of the stainless steel of 1.5 thickness plate wave was carried out. In this experiment, the bulge depth was 145 mm.

(2) The numerical simulation by self cord of free forming was carried out. On the deformation process of the stainless steel plate, at first, the central part of it began to form and whole of stainless steel plate become to spherical shape,



	Simulation No.				
	1	2	3	4	5
w(g)	80	80	100	100	100
h(mm)	90	80	100	90	80
te(mm)	40	40	50	50	50
d(mm)	50	40	50	40	30
Bulge depth(mm)	138	149	141	153	168

Figure 13 Comparison of final deformation shape on each simulation conditions.

gradually. In the case of the same condition of the experiment, the bulge depth was 138 mm. We could confirm the little error to the experiment.

(3) Several numerical simulations with changing the mass of explosive, W and the distance between the explosive and stainless steel, d were also carried out. When W was 100g and d was 30 mm, the bulge depth of stainless steel plate was 168 mm.

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