

The Numerical Analysis and Experiment of Shock Processing for *Bouef*

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ABSTRACT

When the shock wave processing is applied to food, it is understood to obtain the change in various physical properties. For instance, when hard beef is processed by the underwater shock wave, the tenderization of meat can be expected. In the future, it is a goal that the shock wave processor is spread in general as a home electrical appliance. In the design for the suitable pressure vessels for food processing, the phenomenon in pressure vessel are very complex in multi-physics manners. Therefore, in numerical calculation, a lot of parameter for the numerical analysis is need for pressure vessel material and various foods.

In this study, we chose a beef as a sample of the food processing.

First, we obtained an unknown parameter of the beef by measuring the front and the shock wave speed of the sample. Then, we will show some numerical results for shock loading of beef by using LS-DYNA3D. The experiments were carried out using the high-speed image converter camera, high-speed video camera and the explosive experimental facilities.

1. INTRODUCTION

The purpose of the food processing is to improve storing ability. Recently, the proportion of the processed food in the food cost is 50% or more. Therefore, the food processing is prerequisite in eating habits. In the processing method used for the food processing, there are chiefly heat-treatment and high-pressure processing. Presently, heat-treatment is generally used due to usability and the difficulty of the control of the high pressure.

However, High-pressure processing has the some advantages, which is no nutrient reduction as seen in thermal processing, new physical properties can be expected and short processing time and a very low energy consumption (1).

Therefore, the explosive and the high voltage electrical discharge are investigated as the high-pressure source. The food is processed in water to propagate the shock wave.

The final purpose is practical use of the food processing that use the underwater shock wave. However, it has several problems. Shape, strength, and reflection of shock wave and so on. It is necessary to develop an appropriate food processing vessel where these are considered. Moreover, much trial and error experimentation can cause damage to the device. Therefore, we focused Numerical analysis for design.

Many parameters for the numerical analysis are need for pressure vessel material and various foods. We studied Calculation of numerical analysis parameter of beef and Evaluation of accuracy of numerical analysis

2. CALCULATIONAL PROCEDURE AND EXPERIMENTAL SETUP

2.1. IMPEDANCE MATCHING METHOD

Necessary parameter in numerical analysis using shock wave is obtained by hugoniot equation of state. Now, the impedance matching method was used to calculate hugoniot equation of state. The principle of impedance matching method is shown in figure 1. We consider interface of A and B, where A is hugoniot data known material and B is hugoniot data unknown material. When the shock wave enters from A, the reflected wave is generated in A and the penetration wave is generated in B. This relation indicated the right graph. Solid curve is the incident shock wave of known material. Dot dash and dot curves are the reflected shock curve and isentrope of the known, respectively. Two straight lines show the examples ray-leigh line of unknown materials. Point A denotes a shocked condition in the known material, and point B and C denote hugoniot points driven in the unknowns. Gray thick curves indicate the expected hugoniot of the sample materials (2).

Therefore, this experiment measured the incident and the transmitted shock wave velocity at the interface of known material PMMA and unknown Beef.

The velocity of unknown material calculated by thickness of the Beef divided by transit time of the shock wave in Beef.

2.1.2. Shooting procedure

The shooting procedure is used to shadow graph method (3). The shadow graph method observes the shadow of light by the density change in the medium. The shadow is projected on the film of a screen and a direct camera. It is called a projective method directly. It is possible to make it to visible by using X rays even if it is an opaque medium to say nothing of a transparent medium. The setup of shadow graph method is shown in figure 2.

The experiments were carried out using the high-velocity image converter camera, flash generator and the explosive experimental facilities. The image converter camera is produced by HADLANDPHOTONICS.

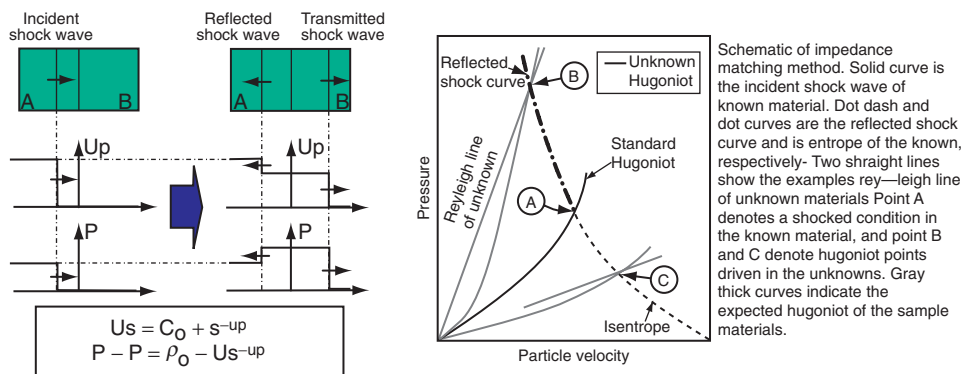


Figure 1 Schematic of impedance matching method.

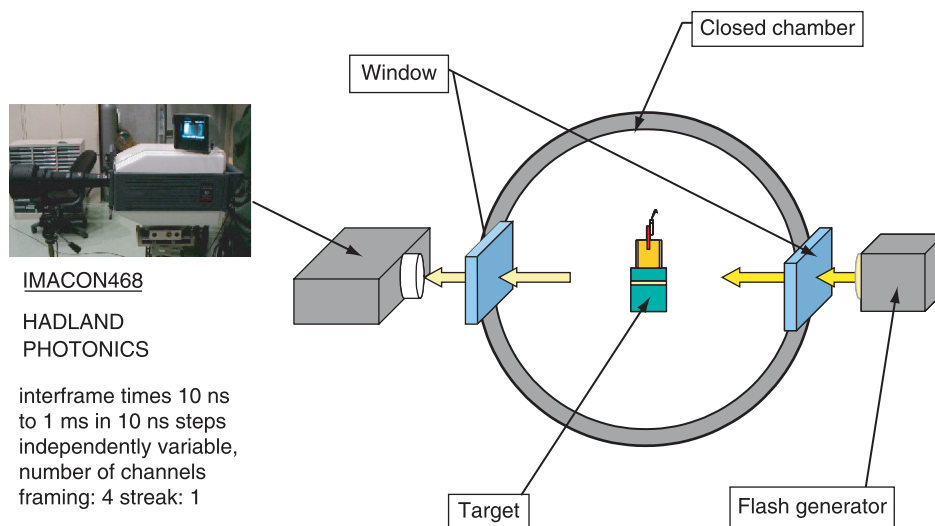


Figure 2 Optical observation setup using shadow graph method.

2.2. EXPERIMENTAL SETUP

2.2.1. Experimental device

The experimental device for measuring shock wave velocity is shown in Figure 3. High explosive SEP is set up as a shock wave source. High explosive SEP is loaded into the PVC container (inner diameter: 30 mm, height: 50 mm), and the amount of loading is 50 g. Moreover, the detonating fuse is used to match the timing of the shutter of the image converter camera and the electric detonator was used for the detonation.

It sets it up with the PMMA [poly methyl methacrylate] block (length: 50 mm, width: 50 mm, thickness: t mm), the Beef (thickness: 5 mm, May-queen, Japan), and the PMMA block (length: 50 mm, width: 50 mm, thickness: 50 mm). Because the PMMA is easy a machining and an optical observation, and is known the shock wave characteristic, it is

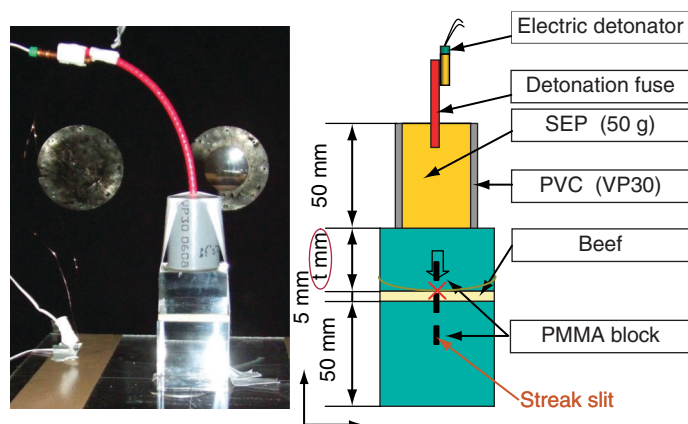


Figure 3 The photograph of experimental device (left) and the detail of device (right).

Table 1 Experimental condition.

No.	t [mm]
1	50
2	50
3	30
4	30
5	10
6	10

often used for observation of shock wave. The shock wave pressure is changed by changing thickness t of the PMMA block. The streak slit for the streak photograph is set on a center axis of the device. The portion which prepared the streak slit must be carefully set so that an air layer may not go into two interfaces. Because if air layer enters, behavior of the shock wave to change, accurate measurement becomes impossible.

2.2.2. Experimental condition

The relation between experimental number and experimental condition is shown in table 1. The upper thickness of PMMA is 10 mm, 30 mm, and 50 mm and streak velocity is $40\ \mu\text{s}$.

3. RESULTS AND CONSIDERATION

3.1. EXPERIMENTAL RESULT

Streak photographs were obtained by shadow graph method using the high-velocity image converter camera. The streak photograph of experimental number 2 is shown in Figure 4. A horizontal axis is time, and the vertical is a distance. The shock wave velocity is measured by image processing this photograph.

However, the transmitted shock wave is invisible by the opaque Beef. Thus, the average velocity was assumed to be a transmitted shock wave velocity.

First, the position of the shock wave was plotted from this streak photograph. The figure 5 is obtained by plotted point of the figure 4. Then, to calculate the incidence shock

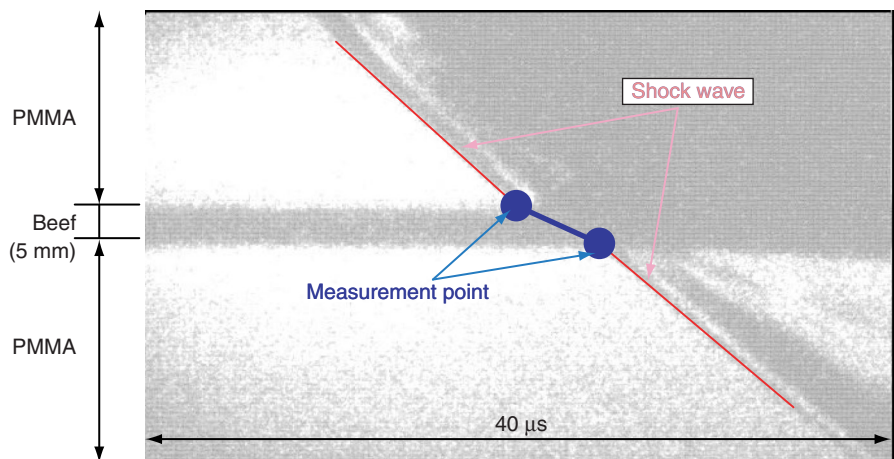


Figure 4 Streak photographs of shock wave.

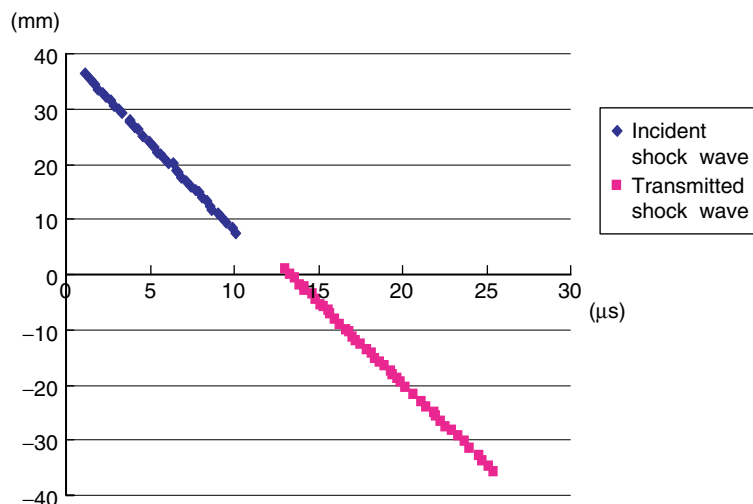


Figure 5 The result of image processing.

wave velocity, the function was approximated to this plot point by using the curve fitting method [1].

$$y = A_1 [1 - \exp(-B_1 t)] + A_2 [1 - \exp(-B_2 t)] + ct \quad (1)$$

The obtained incident shock wave is shown in figure 6. As a result, the incidence shock wave velocity in the interface became a velocity at the position that the circle showed and the result of about 2.93 km/s was obtained.

The other experimental result is shown in table 2. The hugoniot point of the Beef was calculated by using the impedance match method from these streak photographs based on obtained data. As a result, the particle velocity and pressure are shown in table 3.

Finally, the hugoniot equation of state of the Beef is calculated by the experiment is shown in figure 7. A horizontal axis is particle velocity, and the vertical axis is shock wave velocity.

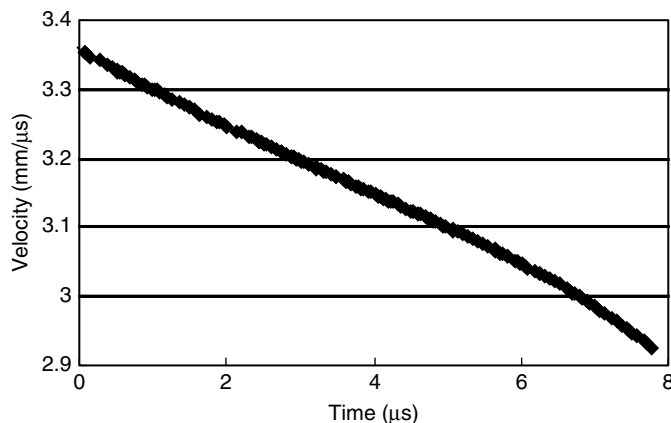


Figure 6 The incident shock wave using curve fitting method.

Table 2 The result of other experimental.

Experiment number	PMMA gap t [mm]	PMMA-beef 界面 incident velocity Us (PMMA) [km/s]	PMMA-beef 界面 Transmitted velocity Us' [km/s]
1	50	2.8576	2.2063
2	50	2.9256	2.3447
3	30	3.1528	2.8259
4	30	3.1647	2.6709
5	10	3.7688	3.4551
6	10	3.8158	3.5704

Table 3 The particle velocity Up and the Pressure P.

Number	PMMA Gap t [mm]	Us' (beef) [km/s]	Up [km/s]	P [Gpa]
1	50	2.2063	0.7933	1.8904
2	50	2.3447	0.9614	2.4346
3	30	2.8259	1.4939	4.5593
4	30	2.6709	1.5631	4.5088
5	10	3.4551	3.0410	11.3473
6	10	3.5704	3.1347	12.0876

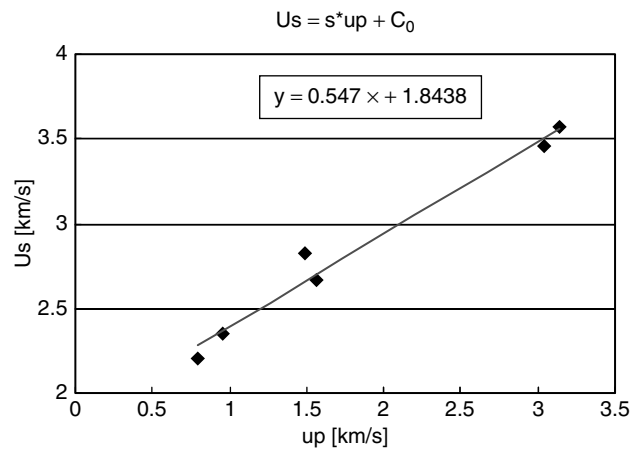


Figure 7 The hugoniot equation of state of Beef.

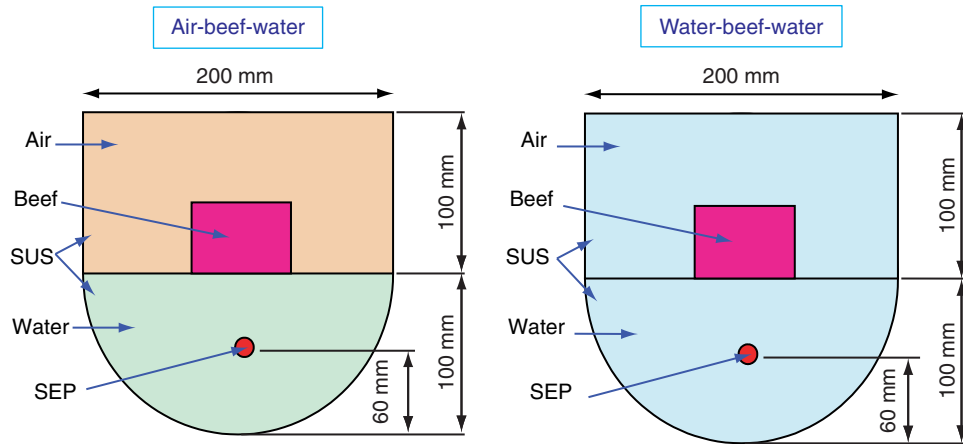


Figure 8 Food processing model by underwater shockwave.

To obtain the equation, the function was approximated to these hugoniot points. Thus, the hugoniot equation of state of the Beef is shown in expression [2]. A good result was obtained though some error is present.

$$Us = C_0 + s \cdot u_p \begin{cases} C_0 = 1843.8 [\text{m/s}] \\ s = 0.547 \end{cases} \quad (2)$$

3.2. NUMERICAL ANALYSIS

The shock treatment model of beef for the numerical analysis was written by using hugoniot data obtained from the experimental results. As shown in this figure 8, there is beef in a container made of the stainless steel. It is filled with water in the pot, and another is satisfied with air, and a high explosive is exploded. Each size is as shown in figure 8. Then, comparing of pressure value was seen by pressure history of numerical analysis.

The analysis conditions are shown in table 4. The model was analyzed using LS-DYNA.

The results of the numerical analysis are shown in figure 9 and figure 10.

Table 4 The numerical analysis parameter of Beef [Mie-Grüneisen Parameter].

	ρ [kg/m ³]	C_0 [m/s]	s	Γ_0
Beef	1.08	1843.8	0.547	1.0

ρ : initial density of the medium

C_0 , s : Constant of material

Γ_0 : Grüneisen coefficient

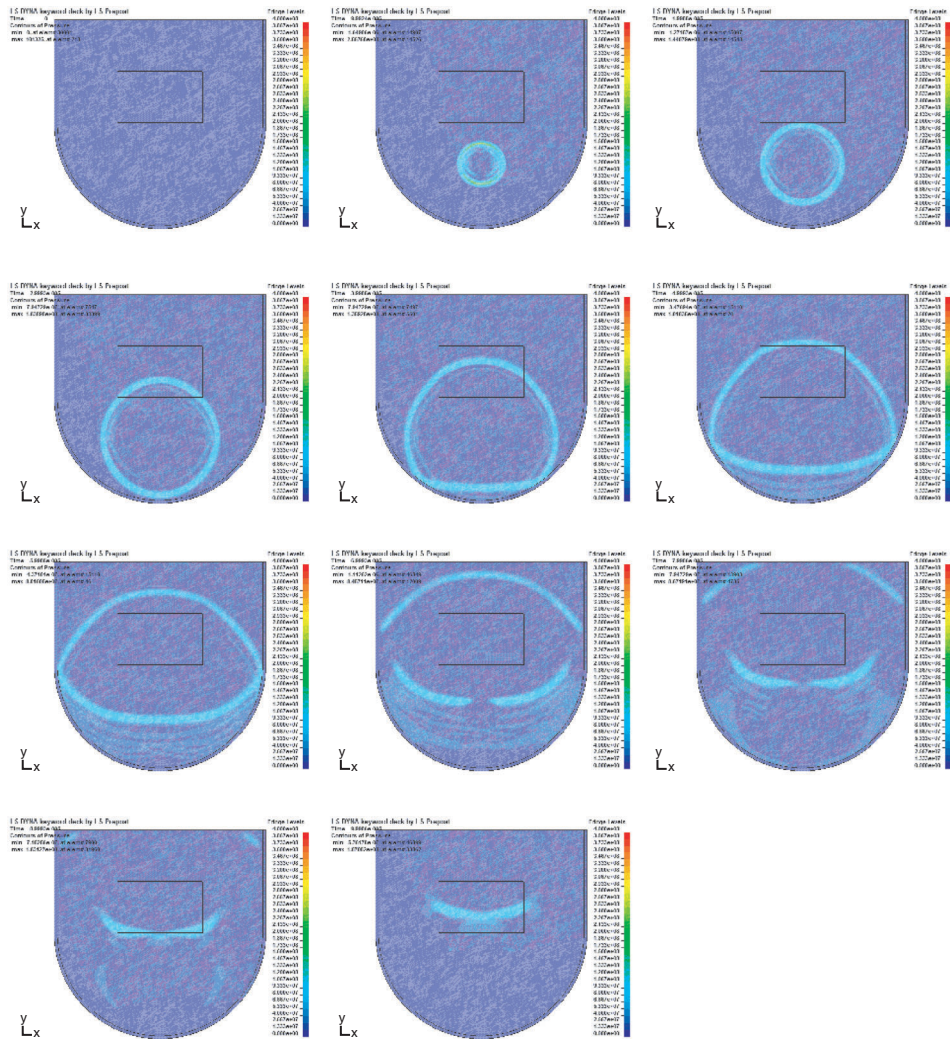


Figure 9 The result of numerical analysis for explosion in the water.

- **Calculation method** : Euler : Explosive (SEP), Water, Beef, SUS, Air
- **Equation of state** : JWL equation : Explosive (SEP)
Grüneisen equation: SUS, Beef, Water, Air
- **Mesh size** : $1 \times 1 \times 1$ [mm] element number: 31000
- **Initial condition** : Initial particle velocity: 1711 [m/s]

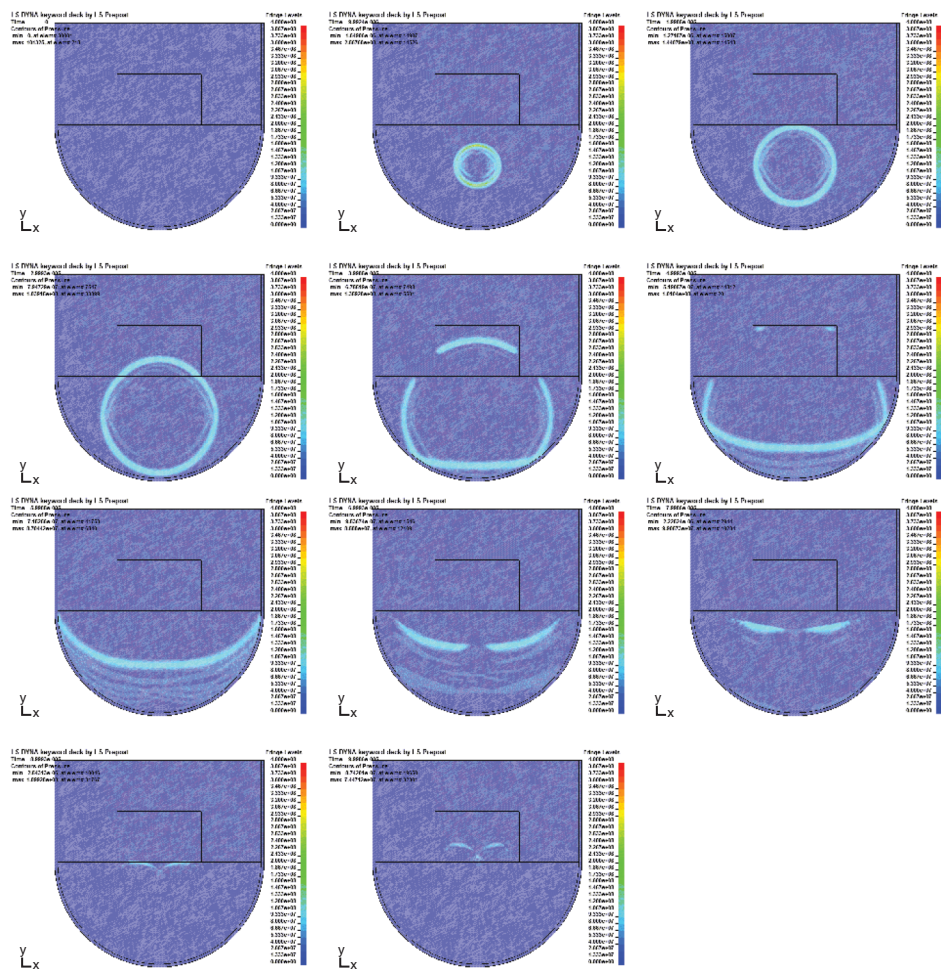


Figure 10 The result of numerical analysis for explosion in the air.

The result of comparing the numerical analysis value of pressure history is shown as follows. The pressure history by time in the beef surrounded by the air is shown in figure 11. The pressure history by time in the beef surrounded by the water is shown in figure 11. The table 5 is a compared result.

A pressure value has a difference in the surface (90 mm) of beef. It is higher among the water. Therefore, as for shock processing of beef, underwater is better.

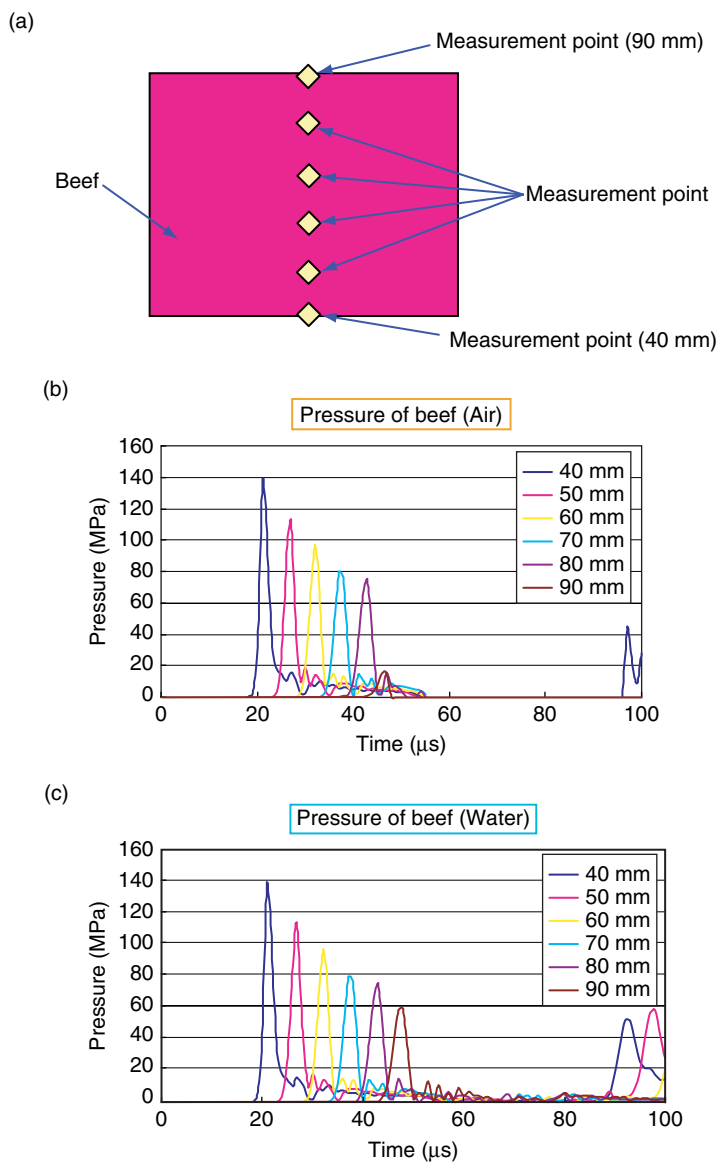


Figure 11 (a) Each pressure history point in the model. (b) The pressure history by time in the beef (Air). (c) The pressure history by time in the beef (Water).

Table 5 The comparing of peak pressure.

Distance [mm]	Air [MPa]	Water [MPa]
40	140	140
90	15	60

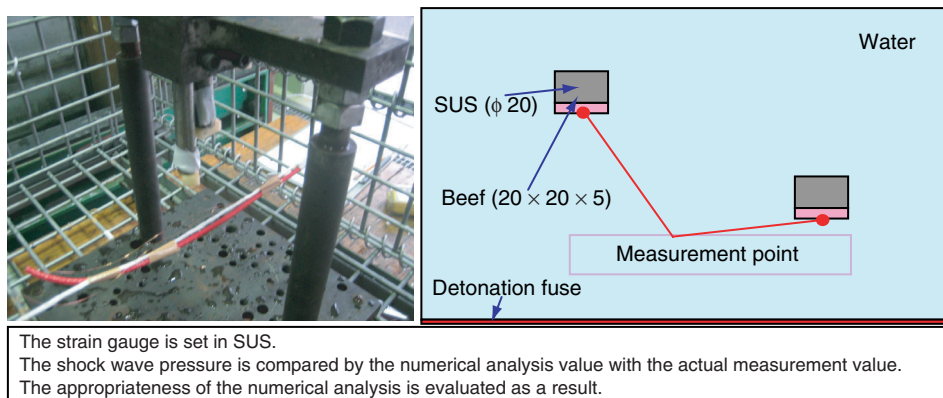


Figure 12 The pressure measurement for evaluation of Beef's parameter.

4. CONCLUSION

The parameter of numerical analysis of Beef was clarified by the use of the impedance match method from the result of an optical observation [$U_s = C_0 + s \cdot u_p$ ($C_0 = 1843.8$ [m/s], $S = 0.547$)]. The process of the spread of the shock wave was analyzed. In the food processing using shock wave, the load pressure value was able to be obtained.

As a future works, there is accurate calculation of equation of state. As solution, there are accurate measurements of shock wave velocity, calculation of data in high-pressure region, and appropriate parameter of Beef. Also in this, experiment for Beef's parameter evaluation is important. Therefore, we will experiment like this figure in the future (4).

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