The numerical analysis of food processing using shock wave

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ABSTRACT

In recent years, the use of the shock wave has increased not only in the fields of the material development and the metal processing, but also in the field of the medical treatment, of the environment as the science and technology upgrades. We have focused on the food processing by using an underwater shock wave. This process has various advantages such as short processing time and a very few energy consuming and no nutrient reduction due to non-thermal processing. An efficient food processing equipment is needed to evaluate the phenomenon of the shock wave loading, the numerical method for food processing by underwater shock wave is quite skillful and very important. Especially in the design for the suitable pressure vessels for food processing, the phenomenon in pressure vessel are very complex and 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, the purpose is to clarify unknown parameters of the potatoes by measuring Us-up.

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.

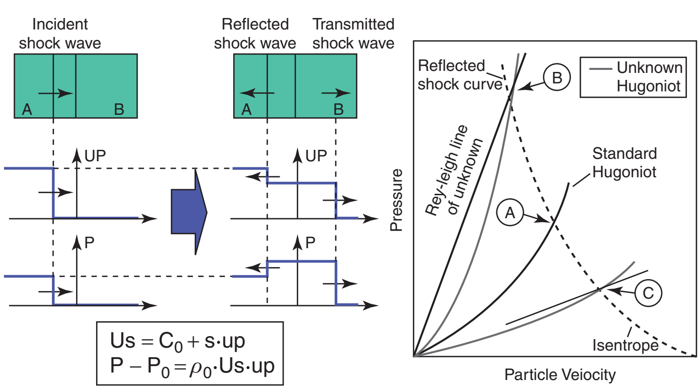
The final purpose is practical use of the food processing that use the underwater shock wave. However, it has several problems. Shape, strength, and reflection of shock wave and so on. It is necessary to develop an appropriate food processing vessel where these are considered. Moreover, much trial and 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 potato 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 rey-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].



Schematic of impedance matching method. 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 rey-leigh line of unknown materials. Point A denotes a shocked condition is the known materials, and point B and C denote hugoniot points driven in the unknowns. Gray thick curves indicate the expected hugoniot of the sample materials.

Figure 1 Impedance matching method.

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

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

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.

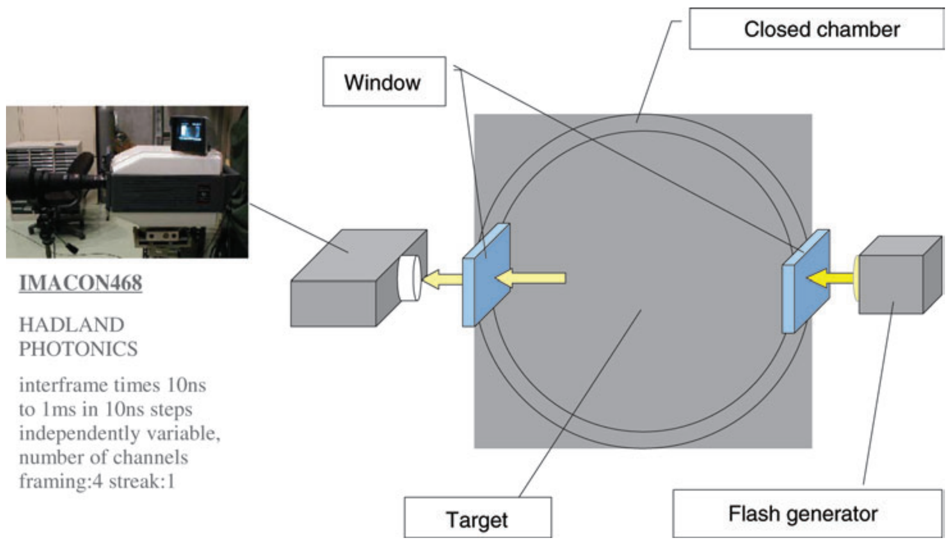


Figure 2 Optical observation setup using shadow graph method.

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.

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 50g. 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 methacylate] block (length: 50 mm, width: 50 mm, thickness: t mm), the potato (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 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 40µs.

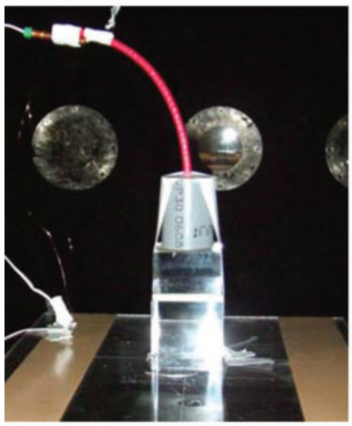
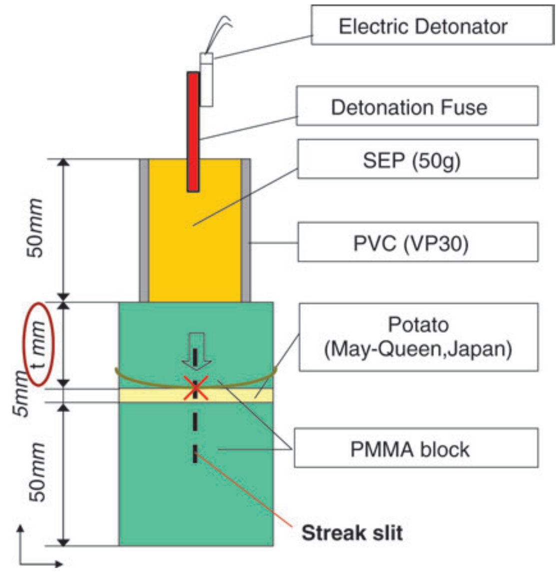



Figure 3 The photograph of experimental device (left) and the detail of device (right).

Table 1 Experimental condition

Experimental number	PMMA length t [mm]	Streak velocity [μs]
1	50	
2	50	
3	30	
4	30	
5	30	
6	10	
7	10	40
8	10	
9	10	
10	30	
11	30	
12	50	

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

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

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 3.11km/s was obtained

The other experimental result is shown in table 2. The hugoniot point of the potato 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 potato is calculated by the experiment is shown in figure 7. A horizontal axis is particle velocity, and the vertical axis is shock wave velocity. To obtain the equation, the function was approximated to these hugoniot points. Thus, the hugoniot equation of state of the potato is shown in expression [2]. A good result was obtained though some error is present.

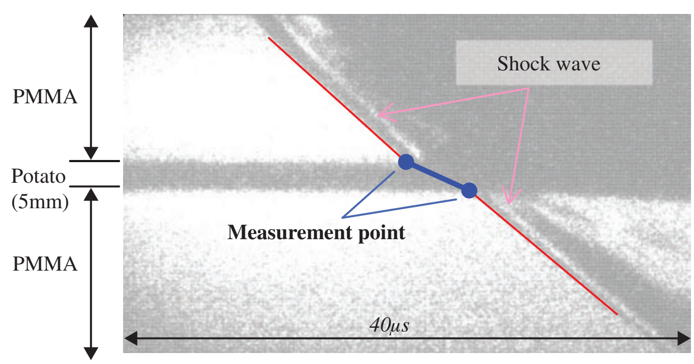


Figure 4 Streak photographs of shock wave.

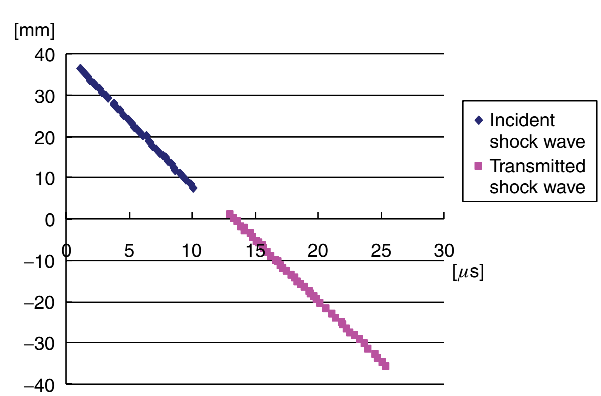


Figure 5 The result of image processing.

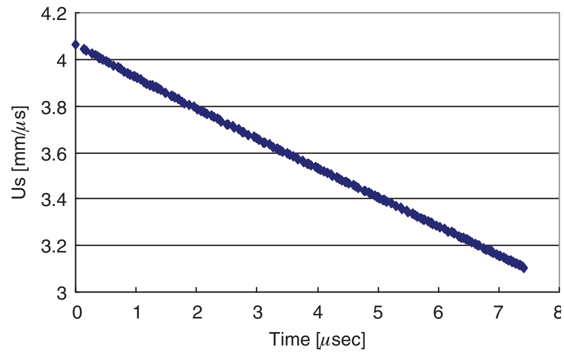


Figure 6 The incident shock wave using curve fitting method.

Table 2 The result of other experimental

Experimental number	PMMA Gap t [mm]	PMMA-potato*** Incident velocity Us (PMMA)[km/s]	PMMA-potato transmitted velocity Us[km/s]
1	50	2.8164	1.3298
2	50	2.8744	1.3817
3	30	3.1057	2.6584
4	30	3.0715	1.7463
5	30	3.3301	3.1834
6	10	3.5338	3.3961
7	10	3.9354	3.7044
8	10	3.1471	2.0885
9	10	3.1402	2.47
10	30	3.096	1.9471
11	30	2.852	1.582
12	50	3.3261	3.249

Table 3 The particle velocity up and the Pressure P.

Number	PMMA Gap, [mm]	Us‘ [km/s]	Up [km/s]	P [GPa]
1	50	1.3298	0.8160838	1.17205
2	50	1.3817	0.9955577	1.48560
3	30	2.6584	1.4010414	4.022491
4	30	1.7463	1.5327234	2.890722
5	30	3.1834	1.893845	6.51121
6	10	3.3961	2.3966878	8.790543
7	10	3.7044	3.4287169	13.71745
8	10	2.0885	1.665946	3.757675
9	10	2.47	1.542743	4.115421
10	30	1.9471	1.5506681	3.26085
11	30	1.582	0.8819511	1.506866
12	50	3.249	1.8664486	6.549219

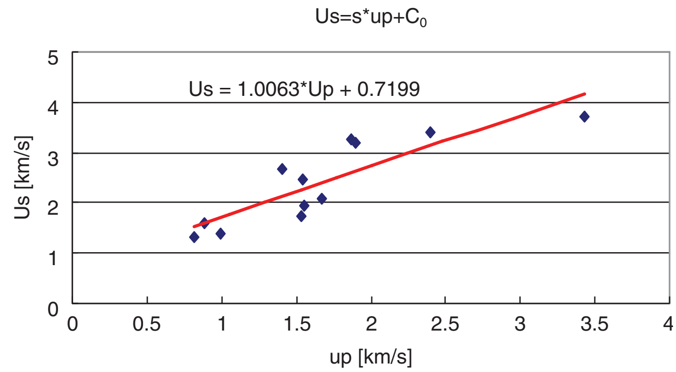


Figure 7 The hugoniot equation of state of potato.

$$Us = C_0 + s * u_p \begin{cases} C_0 = 719.9\,[\text{m/s}] \\ S = 1.0063 \end{cases} \qquad [2]$$

3.2 NUMERICAL ANALYSIS

The pressure measurement model of the numerical analysis was written by using hugoniot data obtained from the experimental results. As shown in this figure 8, what united SUS with the potato is placed underwater, and a detonating fuse is exploded. Each size is as shown in figure 8. The measurement point is at the position just before the potato.

The analysis conditions are shown in table 4. The model was analyzed using LS-DYNA. The result of the numerical analysis is shown in figure 9.

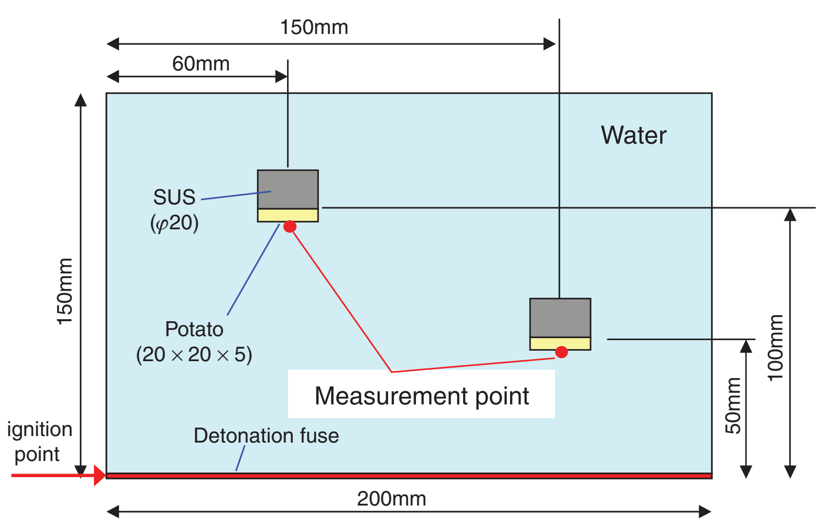


Figure 8 The pressure measurement model.

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

	ƒ ï [kg/m^3]	C_0 [m/s]	s	ƒ i0
Potato	1.08	719.9	1.0069	1.0

*f*Ï: initial density of the medium
C_0, S : Constant of material
fi_0 : Grüneisen coefficient

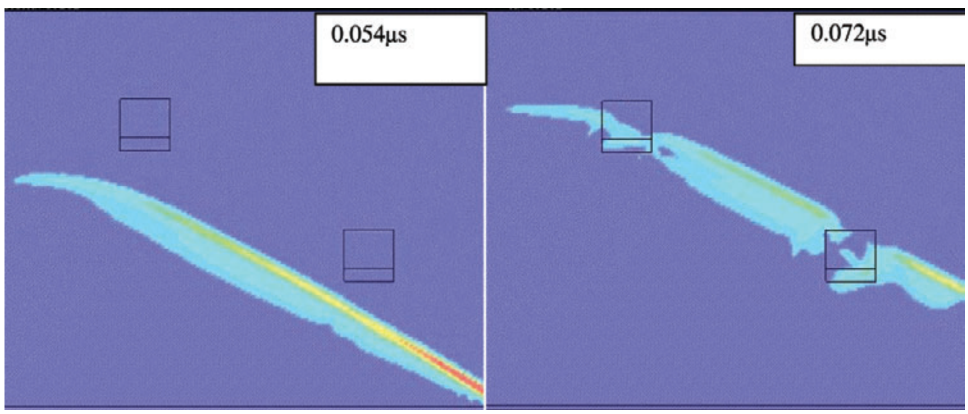


Figure 9 The result of numerical analysis.

The result of comparing the numerical analysis value of pressure with the experiment value of pressure is shown as follows. The relation between distances from detonation fuse and pressure by experiment is shown in figure 10. The peak pressure by the measurement point in numerical analysis is shown in figure 11.

The table 5 is a compared result. The experimental value was calculated from the equation obtained by experiment(4). You can see the value close. Therefore, As a result of comparison, we obtained the result that this numerical analysis contained a measure of accuracy.

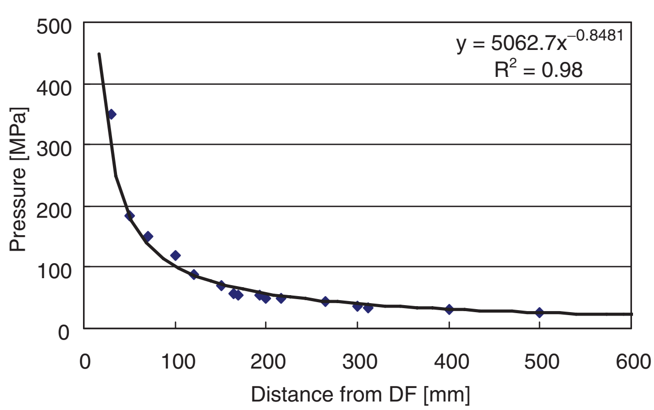


Figure 10 The relation between distances from detonation fuse and pressure.

4. CONCLUSION

The parameter of numerical analysis of potato was clarified by the use of the impedance match method from the result of an optical observation [Us=C_0 +s*u_p (C_0 = 719.9 [m/s],

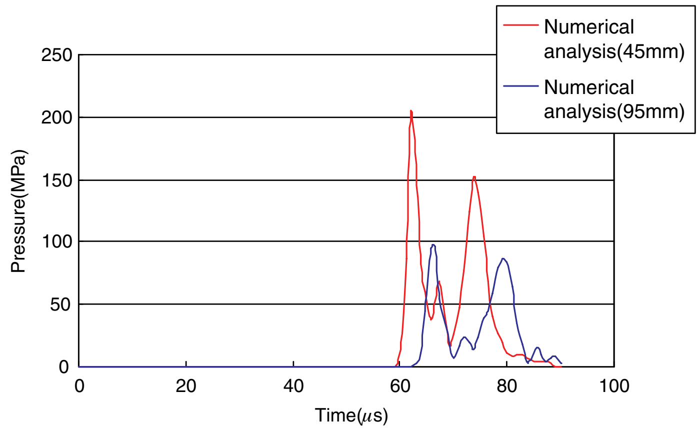


Figure 11 The peak pressure by the measurement point in numerical analysis.

Table 5 The comparing of pressure

	Experiment [MPa]	Numerical analysis [MPa]
45mm	200.58	203.89
95mm	106.43	97.28

s = 1.0063)]. 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 potato. Also in this, experiment for potato's parameter evaluation is important. Therefore, we will experiment like this figure in the future.

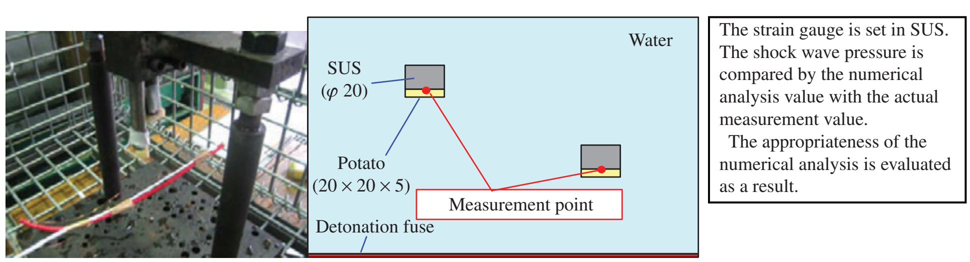


Figure 12 The pressure measurement for evaluation of potato's parameter.

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(4) MURATA Kenji, "Measurement of the underwater shock wave generated by underwater explosion of a detonating fuse (2)", Japan explosive society, 2001