

EVALUATION OF FRACTURE BEHAVIORS IN GLASS CONTAINERS BY USING EXPLOSIVE ENERGY

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Abstract

The visualization of high-speed fracture process, the fracture mechanism and its application for recycle system of glass container were discussed. Here a new technique on generating the small fragments called "Cullet" by using underwater shockwave was proposed. Using commercial beer bottle, the relations between the "cullet" size and various explosive conditions were clarified by experiment. In this study, the visualization of the high-speed fracture process was discussed by using the framing photograph method and the shadowgraph method. As a result, the optimal fracture conditions were obtained and the behaviors of the underwater shock wave and the high-speed fracture process of the glass container became clear. Furthermore, the observed fracture process was corresponding well with that of FEM simulation results.

Key words

Underwater shock wave, Glass containers, High-speed fracture, Recycle, FEM Simulation

1. Introduction

The bottles made of the glass are used voluminously as the container for water, alcoholic drinks and medicine. Many of these glass bottles were reused as returnable bottle or recycled as the raw material of glass bottle which is called 'Cullet'. The small crushing fragment of the glass is called 'Cullet'. The recycling in conventional method by a large-scale crushing machine takes a lot of cost. Therefore, the ratio of this reproduction method becomes lower in comparison with that of the recycling as returnable bottle. In the medicine's ones, almost of them are dump as landfill dust[1],[2].

In this study, authors paid attention to the recycling technique for crushing the glass bottle by using an underwater shockwave[3],[4]. When this technology is used, the recycling cost of glass bottle falls down because of executing the crushing and washing process simultaneously. This propose method have a lot of advantages in comparison with a conventional large-scale crushing machine such as 1) The crushing fragments of glass do not scatter outside, and can be collected completely because the crushing work is done in the water container, 2) The washing are unnecessary before the crushing and the 'Cullet' are able to wash completely (This method can be also applied to the medicine glass container because it is washed at the same time as crushing), 3) The crushing and washing operation are able to do simultaneously. Therefore, it is necessary to make clear the high-speed fracture behaviors of the glass bottles by underwater shockwave quantitatively for the commercialization of this method.

The relation between the underwater shockwave and the fracture "cullet" grain size were discussed. Moreover the behaviors of the underwater shockwave were observed by framing photograph method, shadowgraph method, illumination photography method and the FEM simulation was executed in order to make clear the high speed fracture mechanism [5].

2. Experiment

2.1 Experimental conditions and specimen

Experimental conditions are shown in Table 1. The distance between the explosive and the bottle was chosen at 10, 20, 30, 40, 50, 100mm. Shape of explosive was used a string type. The inside of the bottle was charged with air. The explosive used was PETN (explosive rate: 6308 m/s) and electric detonator was used as igniter. The amount of explosive was changed to examine the influence of strength of the shock wave on the "Cullet" size. Specimen is shown in Fig.1. It is commercial beer bottle (500ml). The outline of the crushing test device by the shock wave is shown in Fig.2. Fig.3 shows the experimental unit of Explosion-proof container with specimen and explosive. The explosion proof container were set shown in Fig.3. The explosion-proof is made of steel. In addition, this container is stored in the experimental apparatus because of safety.

Table 1 Experimental conditions

	Conditions
Distance from specimen to explosive <i>l</i> (mm)	10, 20, 30, 40, 50, 100
Shape of explosive	String type
String Inside of a bottle	Air
Explosive type	PETN
Arrangement of bottles	Serials, Concentric



Fig.1 Specimen
(Beer bottle 500ml)

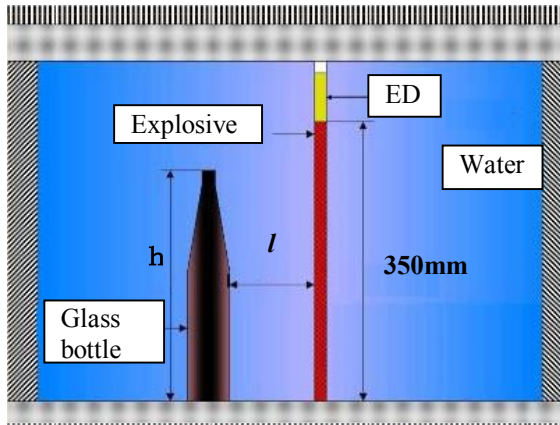


Fig.2 The outline of the crushing test device by the shock wave

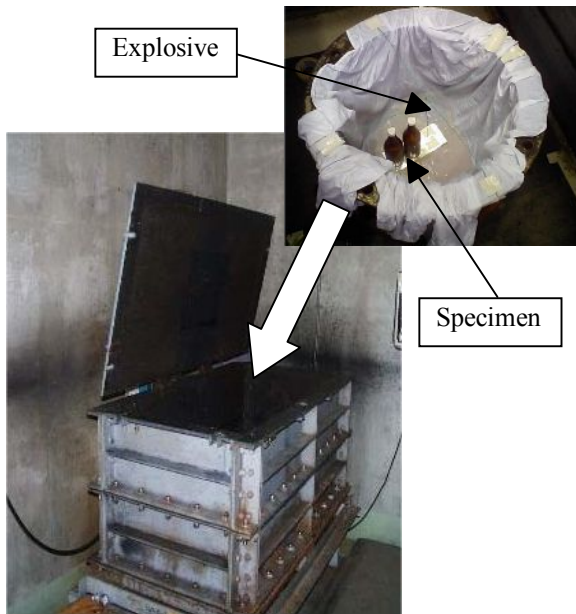


Fig.3 The experimental unit of Explosion-proof container with specimen and explosive

Moreover, the experiment was executed by the series arrangement and the concentric circular arrangement to obtain the optimal arrangement condition of a large amount of crushing of the bottle, and the condition of small "Cullet" generation of two or more bottles was examined. of several specimens. Fig.4 shows the serial arrangement of the bottles. The distance from explosive to the bottle was set to 30mm and 100mm for two rows. It was set to 30mm, 100mm, and 170mm for three rows. Fig.5 shows a concentric circle arrangement of the specimen for 4 bottles. In the case of concentric arrangement, the distance from explosive to the bottle was set to 40mm. In this condition, 1-6 bottles were arranged at the position of the concentric circular.

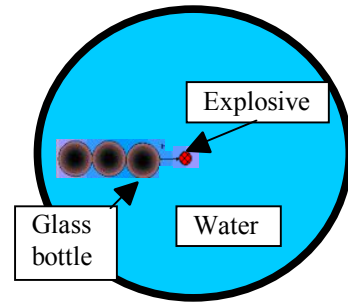


Fig.4 The serial arrangement of the bottles.

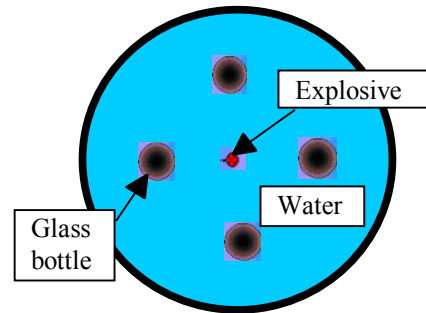


Fig.5 The Concentric arrangement of the bottles

2.2 Optical observation method for fracture process observation

In order to visualize the bottle fracture caused by underwater shock wave, the photograph was taken by using the High Speed Camera with a flashlight. Fig. 6 shows the fracture behavior observation device. The photograph of the experimental apparatus is shown in Fig.7.

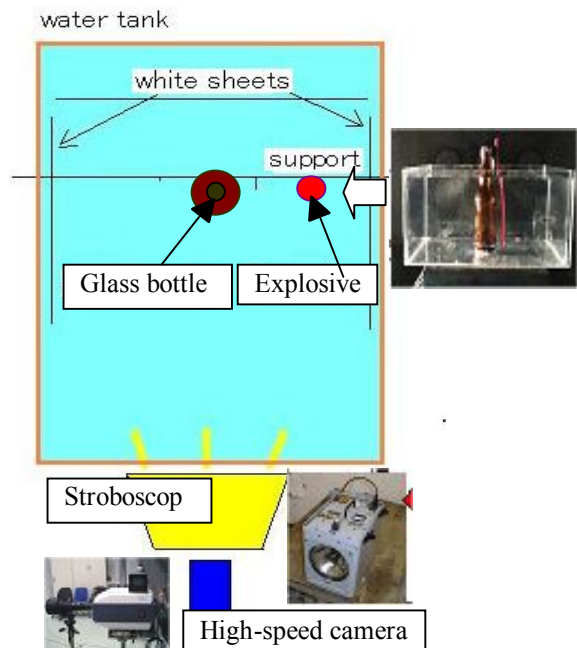


Fig. 6 Fracture behavior observation device of glass bottle

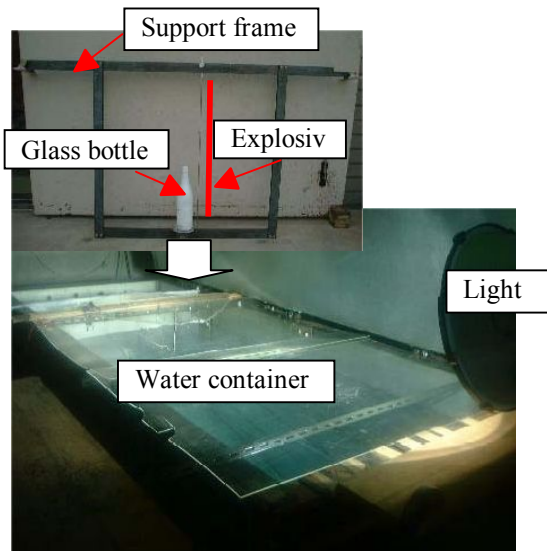


Fig.7 The photograph of the experimental apparatus

3. Results and discussions

3.1 The “Cullet” size distribution on the various crushing condition

After the glass bottles were charged the underwater shock wave by explosive, the “Cullet” of glass were collected and dried. The “Cullet” was classified by three kinds of serves (4.75mm, 2mm, 1mm) and the effect of experimental conditions on the “Cullet” sizes was examined. Classified grain sizes were the following four grades; more than 4.75mm, 2mm~4.75mm, 1mm~2mm and less than 1mm. Fig. 8 shows the effect of distance from specimen to explosive. The shorter distance of the explosive is, the smaller "Cullet" size becomes. It is found that the weight distribution depends on the distance from the explosive to the glass bottle.

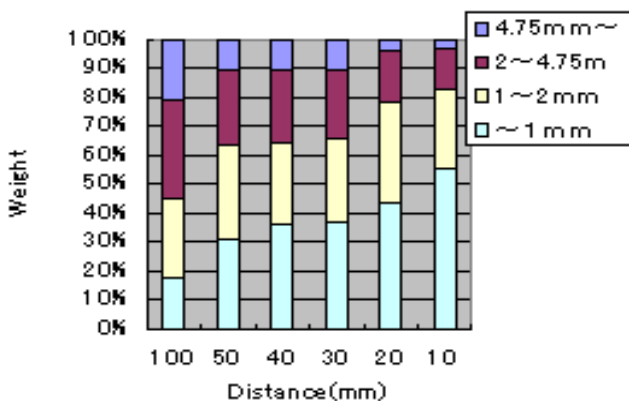


Fig. 8 The relation between the distance from specimen to explosive and “Cullet” size distribution.

Next figures show the influence on the cullet distribution ratio of the arrangement of the bottle. Figure 9

shows the “Cullet” size distribution in the case of serial arrangement. The ratio of a small “Cullet” decreases as the number of the glass bottles increases for the series arrangement. This is due to the fact that strength of the shock wave is weakened as the distance from the explosive increases.

The “Cullet” size distribution for the concentric circle arrangement is shown in Fig.10. As for the influence on the “Cullet” size distribution of the number of the glass bottles, the distribution ratio of each particle size is almost constant regardless of the number of the bottles. From this experimental result, the concentric circular arrangement of glass bottles is suitable to a large amount of crushing of the bottles.

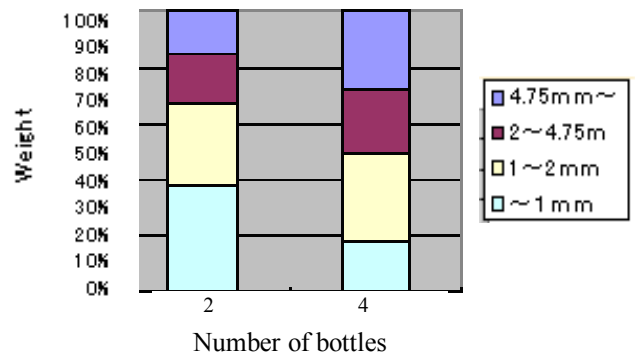


Fig.9 The “Cullet” size distribution in the case of serial arrangement.

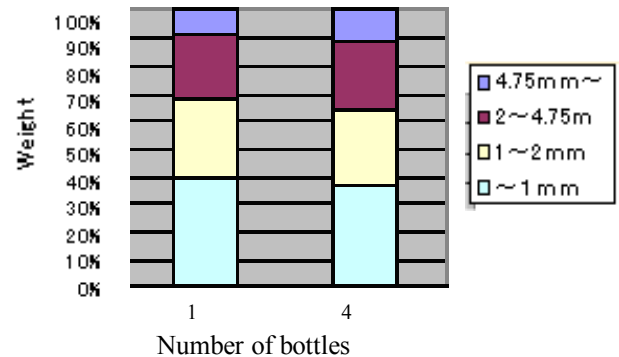


Fig.10 The “Cullet” size distribution in the case of concentric circle arrangement.

3.2 Observation of fracture behavior

After the glass bottles were charged the underwater shock wave by explosive. The high-speed fracture behaviors in glass bottles by using underwater shock wave could be observed by optical methods. The framing photograph was taken by using Image Converter High Speed Camera (IMECOM 468) and Xenon flashlight (HI/20/50 type). Fig.11 shows some examples of the high-speed framing photograph. Fig.11(a) shows the propagation process of underwater shockwave taken at 4μs intervals. In this time intervals, the appearance of the underwater shock wave propagation can be recognized, but

the bottle has not arrived at fracture in this framing interval range yet. Fig.11 (b) show the behavior of the fracture process taken at 32 μ s intervals. The fracture process of glass bottle can be recognized by the framing photograph shown in Fig.11(b). After the shock wave propagated, the generation of the explosive-gas was seen from the photographs. The behaviors of underwater shock waves cannot be captured at this time intervals.

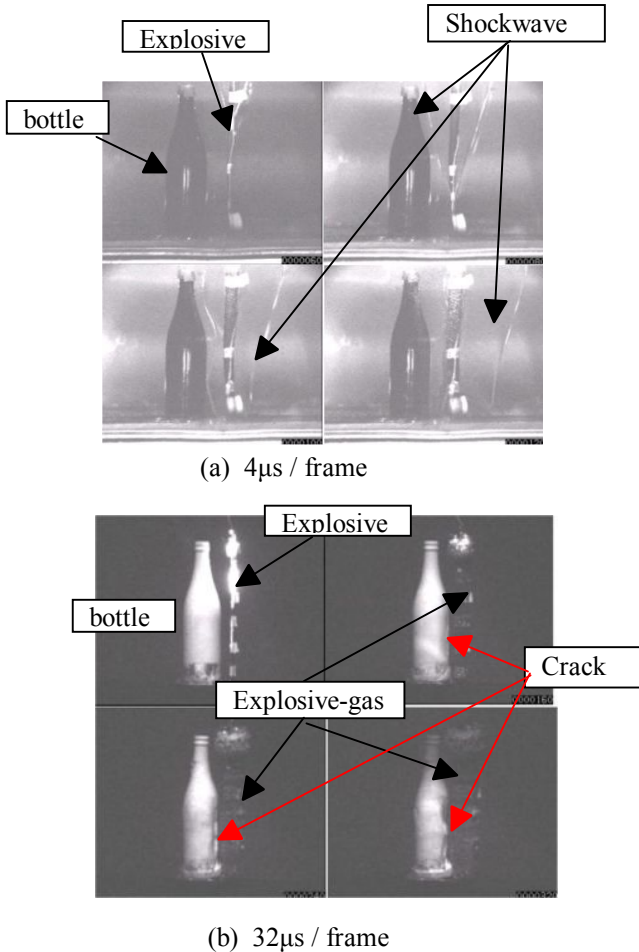


Fig.11 The propagation process of underwater shockwave and the high speed fracture behaviors

3.3. FEM simulation

The fracture behavior of bottle submitted to underwater shock wave was simulated by using FEM code “HyperWorks”. Fig.12 shows the propagation of underwater shockwave. Fig.12 and Fig.13 present three snapshots of analytical results. Fig.12 shows the propagation underwater shock wave and Fig. 13 shows the fracture behavior of glass bottle. The analytical results are corresponding to experimental results.

4. Conclusions

The relation between intensity of underwater shockwave and “Cullet” grain size was discussed and the high-speed fracture process was visualized by optical method. The results obtained are summarized as follows:

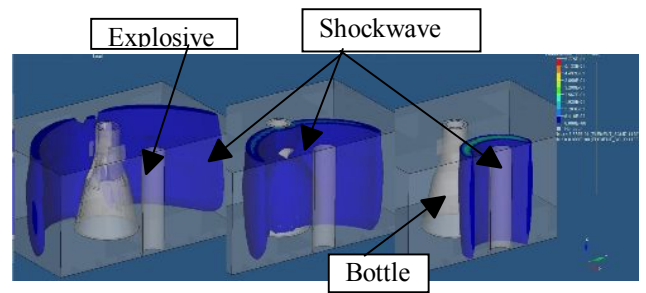


Fig.12 Propagation of underwater shockwave

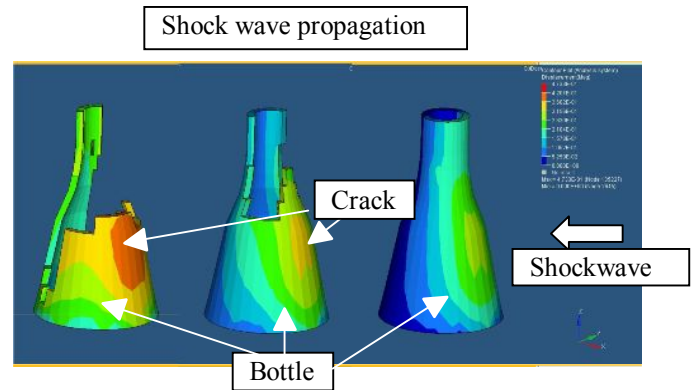


Fig.13 The fracture process of glass bottle

- 1) The weight ratio of the small ‘cullet’ grain sizes become high by short distance of the bottle and the explosive.
- 2) In serial and concentric arrangement, the underwater strongly depends on the distance from the explosive to the bottles..
- 3) In the concentric arrangement, the “Cullet” size is independent from the number of bottles.
- 4) The behavior s of the underwater shockwave propagation and the high-speed fracture process of the glass bottle were able to be observed by using the high-speed camera with the stroboscope.
- 5) The fracture process by underwater shockwave and underwater shockwave behaviors was simulated by HyperWorks and the analytical results were good agreement with experimental ones.

References

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