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2 種類のガラスの反発硬さ試験における角錐圧子ハンマの動的挙動の比較

Comparison of the dynamic behavior of hammer with pyramidal indenter under the rebound hardness test for two kinds of glass

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1. Introduction

Rebound hardness test is one of the main categories of hardness measurements. This hardness test method has the characteristic that results can be obtained rapidly. In general, it has been known that the rebound hardness of metals is related with their elastic and plastic properties[1].

In the previous study, we have dropped hammers with diamond pyramidal indenter onto the surface of fused silica, and shown that the fracture phenomenon of specimen also affected the rebounding behavior of the hammer[2]. This result suggests that the rebound hardness test could be a promising method for evaluating durability against fracture of brittle materials.

In this study, the rebound behaviors of hammers for two kinds of glass with different mechanical properties were compared. The reasons for the variation and discrete of restitution coefficients were discussed in terms of fracture cracks and fracture toughness values measured by the IF method.

2. Experimental Method

The test apparatus for this experiment is the same as that used in the previous report [2]. The hammer is held in place by the motor hands, which are then released to let it fall freely to the surface of the specimen from heights ranging from 0.1 to 4 mm. Laser Doppler vibrometer is used to measure the rebounding motion of the hammer.

The shaft of the hammer is made of cemented carbide. The angles between the opposite faces of the pyramidal diamond indenter are 136 °, 160 ° and 172 °, and the mass of the corresponding hammers are 39.2 g, 39.0 g and 39.1 g, respectively. The specimen has a cylindrical shape of 40 mm in diameter and 10 mm in height. In this study, two kinds of optical glass are used as specimens. One is fused silica and the other is N-BK7. The correction fluid is used to glue the specimen onto the test stage.

The fracture toughness K_c (Pa•m$^{1/2}$) of the glass materials is estimated by the IF method of JIS R 1067, with the following formula (1).

$$K_c = 0.018\left(\frac{E}{HV}\right)^{1/2}\left(\frac{P}{C^{3/2}}\right) = 0.026\frac{E^{1/2}P^{1/2}a}{C^{3/2}} \qquad (1)$$

Where E is Young's modulus (Pa), P is the indented load (N), C is half of the average of crack length (m), and a is half of the average diagonal length of indentation (m). E from the commercial catalogue and calculated K_c are shown in Table 1.

3. Results and Discussion

3.1 Restitution coefficient

Figure 1 shows the relation between the coefficient of restitution e and the falling height h. In all cases, e tends to decrease slightly

Table 1　Mechanical properties of the glass

	Young's modulus E, GPa	Fracture toughness K_c, MPa·m$^{1/2}$
Fused silica	73	1.48
N-BK7	82	0.58

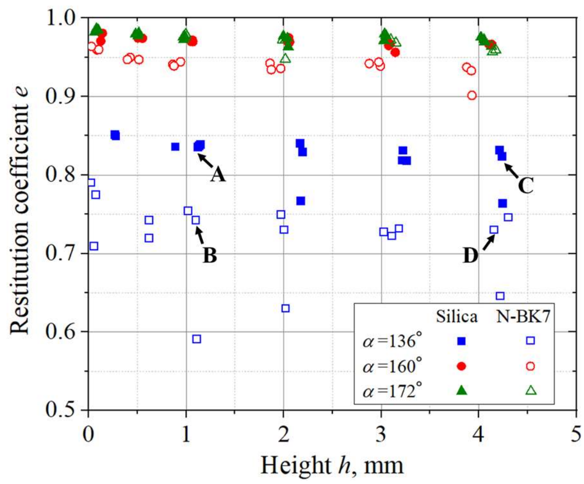


Fig. 1　Relationship between the restitution coefficient e and the falling height h for the three hammers

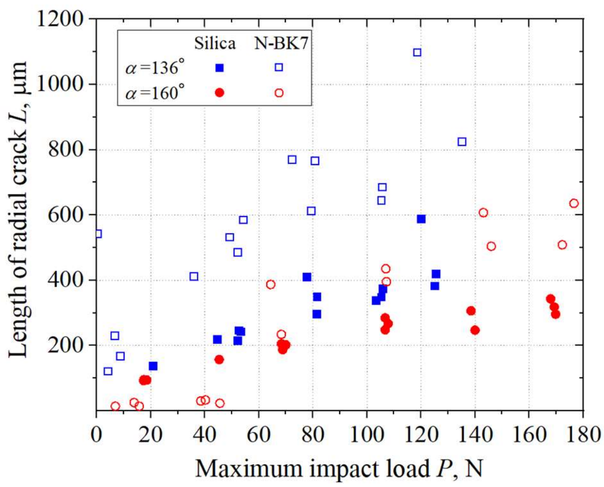


Fig. 2　Relationship between the length of radial crack L and the maximum impact load P

as h increases. For the hammer with α of 172°, there is little difference between the results for the two glass. However, the difference increases with decreasing α. In the case of α = 136°, there are results that show significantly smaller values than others even at the same falling height. When excluding smaller values, e of N-BK7 is about 0.1 smaller than that of fused silica. As can be seen, these two glass materials can be distinguished by e. This differentiation effect is significantly better of the indenter with a sharper tip (α=136°) than a blunter one (α=160° or α=172°).

3.2 Surface damage by the impact

Figure 2 shows the relationship between the indentation radial crack length L and the maximum impact load P. In all cases, L increases as P increases, despite the larger dispersion of the crack length measured. The crack length obtained from N-BK7 specimen is larger than that of silica glass with the same P and α. And this difference is more pronounced for the hammer with a smaller vertex angle. Young's modulus of N-BK7 is 112% of fused silica, as shown in Table 1, while the fracture toughness of N-BK7 is only 39% of fused silica. It seems that it is mainly the energy consumed in generating cracks during plastic damage that affects the rebound behavior of the hammer, so the corresponding restitution coefficient of the hammer is reduced.

Figure 3 shows images of impacted surfaces by hammers of α=136° and α=160° with the falling height around h = 4 mm. The delaminated area is observed in black in images. It can be seen that the damage aspect is different between N-BK7 and fused silica.

3.3 Hammer motions

To understand the reason of different results for two kinds of glass with the same height in Fig. 1, the corresponding acceleration waveform and amplitude spectra at points of A and B (h≅1mm), C and D (h≅4mm) are plotted in Figure 4. In the previous study [3], it was reported that the oscillation magnitude of hammer's acceleration after rebound is proportional to the wave component of impact load, corresponding to the frequency of oscillation. . Therefore, it is presumed that the factors affecting the impact load occur before the maximum acceleration. Compare N-BK7 to Silica, the intensification of the vibration can be observed from the waveform and a large peak is obtained at the natural frequency (101kHz) of the hammer irrespective of the falling height.

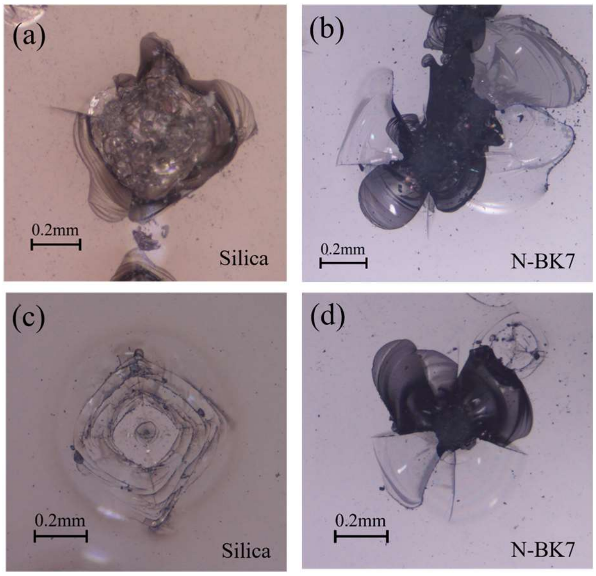
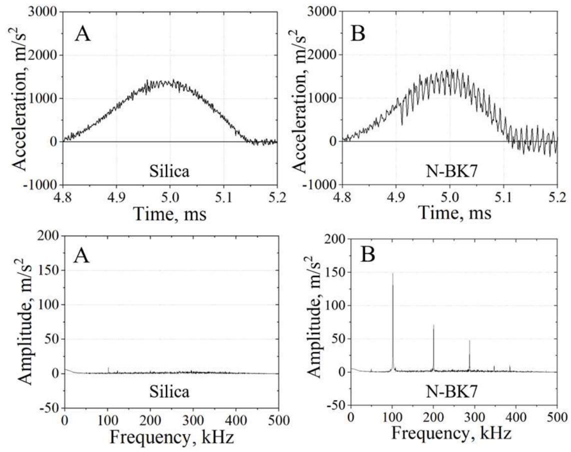
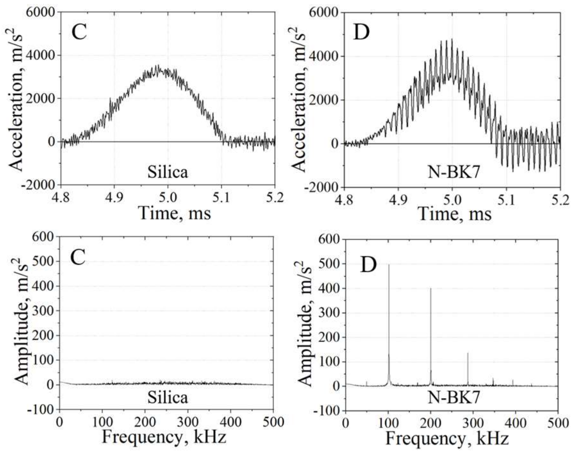


Fig. 3 The indentation images of (a) $\alpha = 136°, h = 4.23$ mm, $e = 0.824$ (b) $\alpha = 136°, h = 4.16$ mm, $e = 0.730$, (c) $\alpha = 160°, h = 4.13$ mm, $e = 0.966$ and (d) $\alpha = 160°, h = 3.93$ mm, $e = 0.901$



(a) α=136 ° , h=1.12mm, e=0.836 (b) α=136 ° , h=1.10mm, e=0.742



(c) α=136 ° , h=4.23mm, e=0.824 (d) α=136 ° , h=4.16mm, e=0.730

Fig. 4 The acceleration variation (top) and spectrum (bottom) of the hammer with the indenter of α=136°, corresponding to (a) A, (b) B, (c) C and (d) D in Fig. 1.

4. Conclusions

In this study, the rebound behaviors of hammers for two kinds of glass with different mechanical properties were compared. It was found that the difference in the type of glass strongly affects the hammer motion and that energy consumed during cracks generation could affect the restitution coefficient.

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References

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2) S. Okajima, L. Chen & K. Matsuda, Rebound Hardness Test of Glass by Using Hammer with Pyramidal Indenter, Proc. JAST Tribology Conference, Tokyo (2022-5) 156.
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