EFFECT OF DENSIFICATION ON CRACK INITIATION UNDER VICKERS INDENTATION TEST

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ABSTRACT

Relationship between crack resistance and plastic deformation was investigated using various kinds of commercial glass. Crack resistance was evaluated by an applied load initiating crack under Vickers indentation test. The observed cracks were radial cracks with their origins beneath the indenter. It is widely accepted that crack initiation is affected by plastic deformation. The extent of plastic deformation is indicated by Vickers hardness, but crack resistance did not have an apparent correlation with it. Plastic deformation consists of two processes: densification and plastic flow. Then densification was evaluated by recovery of Knoop indentation depth after heat-treatment. An apparent correlation between crack resistance and densification was found, indicating that glass with more densification has higher crack resistance. Densification causes a reduction in the interstitial space of the 3-dimensional network by a decrease in atomic bond angle and distance. If more reduction of the space occurs, the region of glass beneath the indenter deforms more easily to fit the contour of indenter. So it is considered that densification lessens stress concentration, leading to an increase of crack resistance. Densification is the fundamental property to determine crack resistance rather than Vickers hardness.

1. INTRODUCTION

The fracture of glass is determined by crack initiation and subsequent crack propagation. In order to understand the crack initiation behavior, crack resistance is often evaluated by a load initiating crack after a Vickers indentation test (Wada[1]). It is accepted widely that the plastic deformation zone beneath the indenter affects crack initiation (Lawn[2], Chiang[3], and Chiang[4]) .Vickers hardness is used to express the extent of plastic deformation of glass. Sehgal[5] proposed that the plastic deformation consists of two processes: densification and plastic flow. Densification is the plastic deformation that occurs with a decrease in volume, and plastic flow is the plastic deformation without any decrease in volume. However, few quantitative data exist which deal with how much each process in plastic deformation affects crack resistance. In this study, the relationship between crack resistance and plastic deformation for various commercial glass compositions was investigated.

2. EXPERIMENTAL

Eight types of commercial glass were used in this study. The list of the glass compositions and their properties are shown in Table 1. All of these glasses were polished to get optically smooth surfaces, which were used for the following indentation test.

Crack resistance was measured under a Vickers indentation test. A microhardness tester (MXT50, Matsuzawa Seiki Corp., Japan) was used. The glass was indented by a Vickers diamond indenter and the corners where cracks appeared were counted under an optical microscope. The percentage of crack formation was obtained by dividing the number of the corners with the cracks by the total number of the corners observed. The applied load was increased step-by-step from 10gf to 2000gf and twenty indentations were made for each applied load. The percentage of crack formation was plotted against the applied load to determine the load at which the percentage would be 50% as "crack resistance".

The Vickers hardness was measured by the microhardness tester described above. The applied load was 100gf.

Densification was evaluated by recovery of indentation depth after heat-treatment. Vickers indentation tends to produce various cracks, which obstruct the measurement of the indentation depth. Therefore, a Knoop indenter was used because of its tendency to inhibit crack formation. Knoop indentation was carried out at an applied load of 100gf and the depth of the indentation was measured by a laser scanning microscope (VK-9500, Keyence, Japan). The indented specimen was heat-treated at temperature of 0.9 x *Tg* (*Tg*: glass transition temperature in ℃) for 2 hours, and the indentation depth was measured again. The ratio of the depth change to the depth before the heat-treatment was defined as recovery of indentation depth.

3. RESULTS

In all of the glass compositions examined, radial cracks appeared during the crack resistance measurements. A microscopic image of Vickers indentation for glass C is shown in Figure 1 as an example. The radial cracks appear to originate at a ridge of indentation near the bottom.

Crack resistance and Vickers hardness of the glass compositions are shown in Table 2, and the relationship between them is plotted in Figure 2. All of the glass compositions except G have Vickers hardness near 600, but crack resistance of these glasses ranges widely from 30 gf to 1280 gf. On the other hand, although Vickers hardness of Glass G is about 100 lower than those of Glasses E and F, the crack resistances of these three glasses are close. There is no apparent correlation between crack resistance and Vickers hardness.

Indentation depth before and after heat-treatment, and recovery of indentation depth are also shown in Table 2. Recovery of indentation depth of Glass D (soda-lime glass) is calculated by using the recovery of diagonal length of indentation (6%) (Yoshida[6]) and the recovery of volume (28%) (Yoshida[7]). It seems that there is a strong correlation between crack resistance and recovery of indentation depth, shown in Figure 3. Glass compositions with more recovery have higher crack resistance.

Table 1. Glass compositions examined and their properties.

Name	Composition*	Density (g/cm^3)	*Tg* (℃)
A	SiO_2-B_2O_3-K_2O	2.28	500
B	SiO_2-B_2O_3-Na_2O	2.36	570
C	SiO_2-Al_2O_3-B_2O_3	2.48	710
D	SiO_2-Na_2O-CaO	2.49	540
E	SiO_2-Na_2O-SrO	2.76	520
F	SiO_2-SrO-K_2O	2.81	630
G	SiO_2-PbO-B_2O_3	4.44	470
H	SiO_2-Al_2O_3-Li_2O	2.43	710

* The column of composition shows three of the most oxide components in glass.

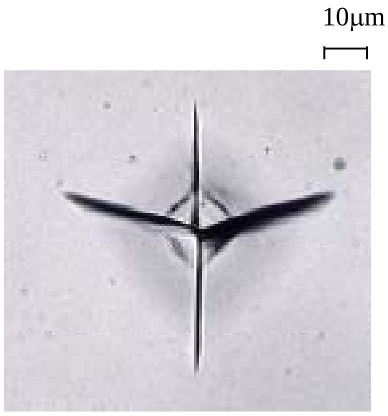

Figure 1. A microscopic image of Vickers indentation for Glass C, 1200gf.

Table 2. Crack resistance, Vickers hardness *Hv*, indentation depth before and after heat-treatment, d_{before} and d_{after}, and recovery of indentation depth.

Name	Crack resistance	*Hv*	Indentation depth* d_{before}	d_{after}	Recovery
	(gf)		(μm)	(μm)	(%)
A	1270	580	0.97	0.66	32
B	1030	620	1.00	0.66	34
C	1180	590	1.04	0.69	34
D	150	570	-	-	(22)**
E	50	570	1.05	0.87	18
F	40	580	0.99	0.84	16
G	30	460	1.25	1.20	4
H	1000	630	1.05	0.65	38

* Indentation depth and recovery are averages of 10 indentations.

** Calculation from recovery of indentation diagonal length (6%, Yoshida[6]) and that of indentation volume (28%, Yoshida [7]).

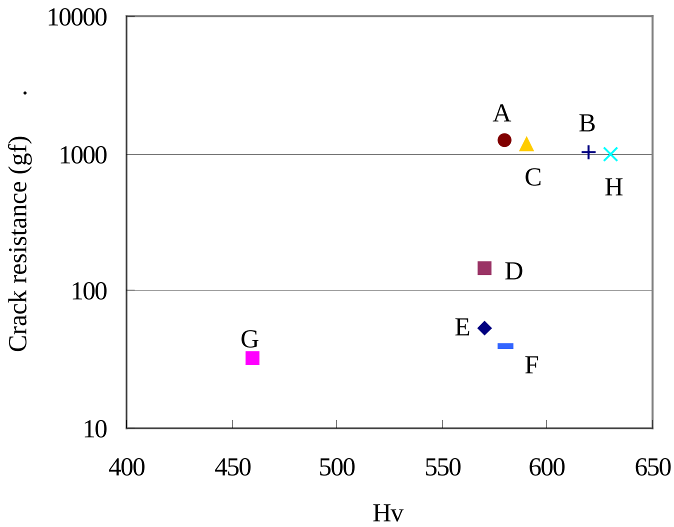

Figure 2. A relationship between crack resistance and Vickers hardness.

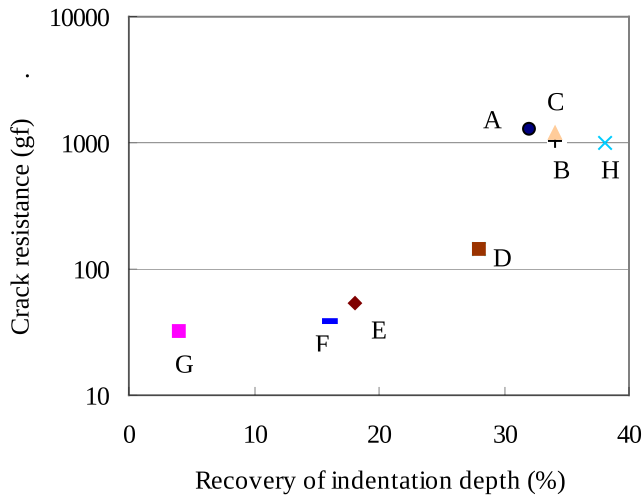

Figure 3. A relationship between crack resistance and recovery of indentation depth.

4. DISCUSSION

As for the glass compositions examined in this study, densification has a stronger effect on crack resistance rather than Vickers hardness. Densification causes a reduction in the interstitial space of the 3-dimensional network by a change in the atomic bond angle and distance. If more reduction of interstitial space occurs, the region beneath the indenter deforms more easily as to fit the contour of indenter. So it is considered that densification lessens stress concentration beneath the indenter by the above deformation, leading to an increase in crack resistance.

Densification is determined by the openness of the glass structure. Glasses E and F shows less densification than Glasses A, B, C, and H, although these six glasses show a similar Vickers hardness. Glasses E and F contain of much alkaline oxide and alkaline earth oxide which work as network modifiers, so they have less open structures with large ions in interstitial positions. On the other hand, Glasses A, B, C, and H contain of much Al_2O_3 and B_2O_3 which form their glass networks, so they have more open structures with large interstitial free spaces. It is understood easily that glass compositions with more free space exhibit more densification.

5. CONCLUSION

The relationship between crack resistance and plastic deformation was investigated using various kinds of commercial glass. Crack resistance has an apparent correlation with densification rather than Vickers hardness. Glass compositions with more densification have higher crack resistance. It is considered that densification lessens stress concentration beneath the indenter, leading to an increase in crack resistance. Densification is fundamental to determining crack initiation properties rather than hardness.

6. REFERENCE

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