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Dependence of Hardness of Silicate Glasses on Composition and Thermal History

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Introduction

From an industrial point of view, it is desirable if the hardness of a glass can be predicted from its composition and manufacturing conditions.

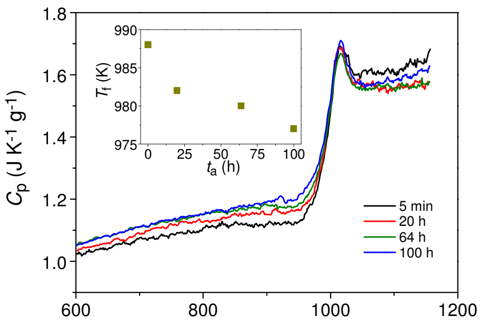
Hardness of crystals may be calculated using a semi-empirical approach. So far, this is not possible for glasses. The aim of this study is to discuss the factors that should be taken into account in the calculation of hardness of glass.

Effect of thermal history: E-glass (aluminoborosilicate) is annealed at T_g for different durations → T_f and Vickers hardness (H_v) measured

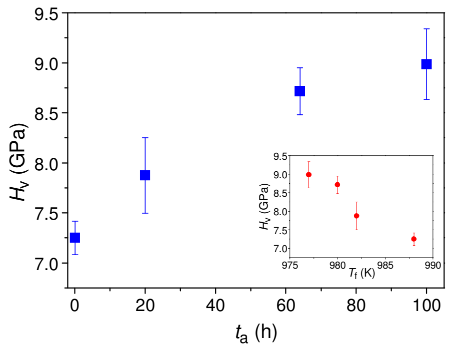
Effect of chemical composition
- Polymerisation effect: SiO_2-Al_2O_3-Na_2O of different Na_2O-content → H_v measured
- Modifying ion effect: $68SiO_2$-$1Fe_2O_3$-$8A_2O$-23RO (A = alkali, R = alkaline earth) → H_v measured

Thermal History

To study the annealing effect of the E-glass on the fictive temperature T_f, the heat capacity (C_p) –temperature curves are measured on the glasses annealed for various durations (t_a) at T_g . T_f is determined by Moynihan's enthalpy-matching approach.

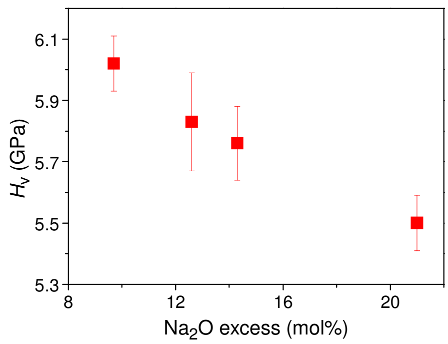


H_v increases with duration of annealing, whereas it decreases with increasing T_f. Trend is confirmed by nanoindentation on E-glass fibres (T_f =1166 K) [Lonnroth et al., JNCS 354, 3887 (2009)]

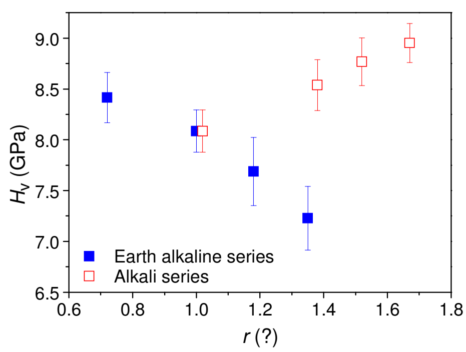


Chemical Composition

The four SiO_2–Al_2O_3–Na_2O glasses contain different amounts of Na_2O. The Na_2O excess is calculated as the amount of Na_2O that does not participate in AlO_4^- charge balancing. H_v decreases with the excess amount of Na_2O, i.e., the network deplymerization degree.



The effect of the type of network-modifying cation on hardness for $68SiO_2$– $8Na_2O$–$1Fe_2O_3$–23RO glass series (R = Mg, Ca, Sr, and Ba) and 68SiO2–23CaO–1Fe2O3–8M2O series (M = Na, K, Rb, and Cs). The opposite trends for the two series are observed.



Conclusions

1) Annealing lowers T_f and thereby increases the structural density of glasses. This leads to an increase of hardness.
2) For alkali ions, hardness increases with increasing ionic radius, whereas the opposite trend is observed for alkaline earth ions.
3) The structural changes of the network occurring at the atomic scale must be taken into consideration when predicting the effect of chemical composition on hardness.

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