GLASSES WITH FICTIVE TEMPERATURE-INDEPENDENT PROPERTIES: MINIMIZATION OF INDENTATION SIZE EFFECT AND MAXIMIZATION OF CRACK RESISTANCE

By

Timothy Michael Gross

An Abstract of a Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: MATERIALS SCIENCE AND ENGINEERING

The original of the complete thesis in on file

in the Rensselaer Polytechnic Institute Library

Examining Committee:

Minoru Tomozawa, Ph.D., Thesis Advisor

Christoph Steinbruchel, Ph.D., Member

E. Bruce Watson, Ph.D., Member

Mutsuhiro Shima, Ph.D., Member

Rensselaer Polytechnic Institute
Troy, New York

April 2008
(For Graduation May 2008)

ABSTRACT

The fictive temperature of a glass is defined as the temperature at which the glass would find itself in equilibrium if brought to it suddenly from its given state. The cooling rate from a glass melt affects the fictive temperature, at which the supercooled liquid freezes to form the glassy state. A faster cooling rate will shift the fictive temperature higher. Glasses can be defined as normal or anomalous by the dependence of physical glass properties on fictive temperature. Normal glasses exhibit decreasing density, hardness, refractive index, and Young's modulus with increasing fictive temperature. Anomalous glasses exhibit the opposite trend in these properties. Intermediate glasses were prepared by melting calcium aluminosilicate glasses which fall between normal and anomalous glass compositions.

The fictive temperature of glasses can be modified by heat-treatment in the glass transition region. The fictive temperature will reach the heat-treatment temperature with time by structural relaxation. The properties of the newly developed intermediate glasses do not change as the fictive temperature is modified by heat treatment. It is also shown in this research that the fictive temperature of a glass can be increased by plastic deformation during Vickers indentation. A small region surrounding the indentation is plastically deformed and exhibits a fictive temperature increase. This fictive temperature increase will affect the properties in this region and influence indentation-related glass properties.

The glass developed with fictive temperature-independent density having a composition of 96 mol% SiO_2 2 mol% Al_2O_3 2 mol% CaO is shown to give a minimum in the indentation size effect (ISE) during Vickers microhardness testing. The indentation size effect is the load dependence on microhardness, i.e. microhardness increases at low loads. The amount of ISE is found to be proportional to the amount of newly formed surface area from shear bands and cracks in the vicinity of the indentation. In normal glass, the plastic deformation-induced fictive temperature increase is accompanied by volume expansion in the form of shear dilatation. The number of shear bands is then related to the amount of fictive temperature increase and the amount of ISE. In anomalous glass, the plastic deformation induced fictive temperature increase is

accompanied by a densification. Beneath the densified zone, much subsurface cracking occurs and this appearrs to lead to a high ISE. Glasses with fictive temperature-independent density show very few shear bands and very little cracking and as a result have a very low ISE.

It is also shown that the glass with fictive temperature-independent elastic modulus having a composition of 80 mol% SiO_2 10 mol% Al_2O_3 10 mol% CaO shows very high resistance to cracking under Vickers loading. The plastic deformation-induced fictive temperature increase in the vicinity of the indentation does not change the elastic moduli in this region from the bulk of the glass. Therefore the residual stresses are lower and this is believed to be the cause of this glass's crack resistance. It is also shown that 100 % SiO_2 glass has very low fictive temperature dependence on Young's modulus, however, it exhibits low resistance to cracking. This is shown to be attributed to the high water sensitivity of silica glass.