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ORIGINAL ARTICLE

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Tuning the mechanical toughness of the metal nanoparticle-implanted glass: The effect of nanoparticle growth conditions

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Abstract

Recently, a novel framework for toughening brittle oxide glass by implanting a soft secondary material using an electrofloat method was proposed. Softening of a glass surface owing to the presence of metal nanoparticles as a secondary material evidenced by experiments and partially supported by numerical simulations was found to be important in the increased toughness. However, only limited experimental conditions of the process of nanoparticle growth were explored in the aforementioned study. Thus, we further investigated the experimental conditions in this study to optimize the magnitude of the applied voltage, its duration time, and the temperature during the process. We found that the crack initiation load (CIL) and the indentation fracture toughness increase at the appropriate voltage and time duration, and at a temperature higher than 1000°C. From observational analysis, the size, density, and depth of the nanoparticle-implanted layer are related to the toughness. In particular, when metal nanoparticles in a glass matrix are larger and denser up to half the total volume fraction, the mechanical toughness of the hybrid glass seems to get higher. Additionally, implantation of a softer metal, such as silver, was conducted to consider the dependence of secondary materials, and the silver nanoparticle-implanted glass showed the highest toughness. In the course of the investigation of the toughening mechanism for the two different materials using nanoindentation technique, a clear evidence of increased plastic deformation was observed for Cu implantation, while a decrease in Young's modulus was only seen for Ag implantation. Peridynamics simulation was performed to examine the effect of the toughening due to the composite glass surface layer with the different Young's modulus. It is shown that the Young's modulus of the composite has an optimal value to maximize the toughness.

KEYWORDS

crack growth resistance, indentation, nanoparticles, soda-lime-silica, strength

1 | INTRODUCTION

Excellent homogeneity of glass gives rise to high optical transparency and uniform properties, which make oxide glass a unique material for a variety of applications.[1] Further, glass can be easily shaped, and hence, it is suitable for mass production in uniform conditions. However, such homogeneity of glass induces tensile stress concentration at around a crack tip once a microcrack appears at the glass surface or a bubble is generated inside the glass.[2] Hence, the generation of high

