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Soda-Lime-Silicate Float Glass: A Property Comparison

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by Andrew Cachiaras
Science and Mathematics Academy at Aberdeen High School, Aberdeen, MD

Luke Gilde
Oak Ridge Institute for Science and Education, Oak Ridge, TN

George D Quinn
National Institute of Standards and Technology, Gaithersburg, MD

Jeffrey J Swab and Parimal J Patel
Weapons and Materials Research Directorate, ARL

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14. ABSTRACT

Soda-lime-silicate (SLS) float glasses with low iron content were obtained from 3 US glass manufacturers. These glasses are possible components in some transparent armor systems. Thus, it is necessary to measure and compare the chemical composition as well as the physical and mechanical properties of each glass to determine if any differences are present that may have an influence on the performance of the transparent armor systems. The results of this study show that all 3 SLS glasses have essentially the same chemical composition and the same physical and mechanical properties, indicating they can be used interchangeably in transparent armor systems without adversely affecting system performance.

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1.   Introduction

Soda-lime-silicate (SLS) glass is a ubiquitous material used in architectural and automotive windows, glass beverage containers, and cookware and bakeware. SLS glass is also a common component in some transparent armor systems because it is inexpensive and readily available in large sizes. Large sizes of SLS are available because SLS is manufactured using a float process. In this process molten glass is floated on a bed of molten metal, typically tin, that results in a glass sheet with very uniform thickness and a very flat surface. There are several companies, domestic and foreign, that manufacture SLS using the float process. As a result it is necessary to characterize SLS glass produced by these manufacturers to determine if there are property or compositional differences that might influence the performance of a transparent armor system containing SLS glass. This report summarizes the property and compositional results for 3 US-manufactured SLS glasses.

2.   Materials

SLS float glasses, with low iron content, were procured from Saint-Gobain Glass (Diamant), Guardian (UltraWhite), and Pittsburgh Plate Glass (Starphire). Plates 150 mm^2 with a thickness of 6.5 mm were obtained from the respective sheet of glass by scoring and snapping (Swift Glass Co, Elmira, NY). All scoring was done on the air side and all specimen edges were hand swiped without lubricant using a 100-grit silicon carbide grinding belt, to minimize edge damage and increase safety during handling. After the scoring and snapping was completed, the surface condition of the plate received from Swift Glass was considered as the "as-received" state and nothing was done to reduce the number of processing or handling flaws present on the surface.

3.   Experimental Procedure

The average thickness of each plate was determined by measuring the thickness near each corner with a micrometer while the edge dimensions were measured with calipers. Thirty plates from each SLS glass manufacturer were measured and then subsequently weighed. The density of each plate was calculated using the edge lengths, average thickness, and weight.

Resonant ultrasound spectroscopy (Quasar RUSpec System, Magnaflux, Albuquerque, NM) was used to determine the bulk, shear, Young's modulus, and Poisson's ratio using the same 30 plates from each glass manufacturer.

Knoop hardness/load curves were generated for all 3 SLS float glasses by determining the hardness (Wilson 2100B, Instron, Norwood, MA) at indentation loads of 2.9, 4.9, 9.8, 19.6, 49.0, and 98.0 N. The hardness testing procedures in ASTM C1326[1] were followed to determine hardness of both the air and tin sides of the glass plates.

The methodology and equations in the ASTM C1499[2] were followed to determine the equibiaxial flexure strength of the tin and air sides of the 3 glasses. Ring-on-ring equibiaxial flexure testing was performed using a load/support ring ratio of 0.5, which consisted of a 42.5-mm-diameter load ring and an 85-mm-diameter support ring. Prior to flexure strength testing the air and tin sides of each glass plate were identified using a tin side detector (Model TS2300; EDTM, Inc., Toledo, OH). A total of 60 specimens were tested for each glass with the number of plates tested split evenly to obtain a strength value for the air and tin sides. Data from plates that had the fracture initiate outside the load ring diameter or at the plate edge were considered invalid and not included in the determination of the average strength.

Beam specimens, nominally $3 \times 4 \times 50$ mm in size, were machined from a plate of each SLS glass for use in determining the fracture toughness following the single-edge precracked beam (SEPB) method outlined in ASTM C1421.[3] The SEPB fracture toughness was determined in a dry nitrogen environment to eliminate any effect of environmentally assisted slow crack growth. Full-length precracked specimens were tested in 4-point bending with 20- $\times$ 40-mm fixtures and half-length precracked specimens (the broken halves from the full-length specimens) were tested on 10- $\times$ 20-mm fixtures. Complete details on the procedures and nuances associated with determining the fracture toughness of glass using the SEPB method, and why the SEPB method is the preferred method to determine the toughness of glass, can be found in Quinn and Swab.[4]

Chemical analysis was conducted at Dirats Laboratories (Westfield, MA) on the 3 glasses using inductively coupled plasma-optical emission spectrometry following ASTM specifications E1097[5] and E1479[6].

4.   Results and Discussion

The measured properties of the 3 SLS float glasses are summarized in Table 1. This data show that there are no significant property differences. The mean values of density, Knoop hardness at 2kg (19.4 N), fracture toughness, and the equibiaxial flexure strength of the tin side, as well as all of the elastic properties, are virtually identical. It is possible there is a slight difference in the mean value of the

equibiaxial flexure strength of the air side, with the Starphire being stronger than the Diamant and UltraWhite, but this difference appears to be minimal.

Table 1   Properties of SLS glasses from US manufacturers

Property	Diamant	UltraWhite	Starphire
Density (g/cm^3)	2.493 ± 0.005	2.488 ± 0.005	2.498 ± 0.007
Elastic Properties[a]			
Bulk modulus (GPa)	40.9 ± 0.5	41.1 ± 0.8	42.2 ± 0.9
Shear modulus (GPa)	30.7 ± 0.2	30.3 ± 0.2	30.4 ± 0.3
Young's modulus (GPa)	73.6 ± 0.2	72.9 ± 0.3	73.6 ± 0.5
Poisson's ratio	0.200 ± 0.004	0.204 ± 0.006	0.209 ± 0.006
HK_2 (GPa)			
Tin	4.63 ± 0.11	4.57 ± 0.06	4.59 ± 0.13
Air	4.70 ± 0.10	4.53 ± 0.11	4.61 ± 0.06
Equibiaxial Strength (GPa)[b]			
Tin	113 ± 31 (30)	107 ± 33 (30)	104 ± 29 (30)
Air	125 ± 41 (23)	140 ± 35 (24)	196 ± 53 (23)
SEPB K_{Ic} (MPa√m) [b]	0.75 ± 0.04 (10)	0.78 ± 0.03 (10)	0.75 ± 0.03 (15)

[a]Tests to determine density and elastic properties were conducted on a minimum of 30 plates of each manufactured SLS.

[b]The numbers in parenthesis next to the equibiaxial flexure and fracture toughness values are the number of valid tests.

While there appears to be no statistically significant difference in any of these properties, there are a couple of observations to discuss. Previous studies[7,8] have shown that the air side of a float glass is consistently stronger than the tin side. However, that does not appear to be the case for the Diamant and UltraWhite. An air/tin strength difference is evident in the Starphire, but both of these values are lower than the previously reported strength values of 249 ± 58 MPa for air and 143 ± 31 MPa for tin.[7] The lack of an observed air/tin strength difference in the Diamant and UltraWhite, as well as the lower strength values for both sides of the Starphire, could be due to how the plates were handled prior to strength testing. It could also be due to the environmental conditions the glass was exposed to prior to strength testing as it is well documented that glass strength is highly influenced by environmental conditions. The environmental conditions at the time the strength tests were conducted were essentially the same for all strength testing: temperature of approximately 25 °C and humidity approximately 25%–50%.

A previous study[8] showed that the tin side of both soda-lime and borosilicate float glasses were more resistant to ring crack initiation under an applied indentation load than the air side, implying that the tin side is the harder of the 2 sides. The Knoop hardness/load curves for the air and tin side of each SLS glass are shown in Figs. 1–3. Hardness is shown on the vertical axis with an expanded scale, starting at 4 GPa, which tends to emphasize hardness differences. Had an axis with a zero starting point been used instead, the curves would show very little difference. Over the 20- to 50-N load range, there does not seem to be a difference in the hardness between the air and tin sides. At lower or higher loads, the data differ but overlap. Based on these plots, there is no difference in hardness between the air and tin side of each glass or between each glass.
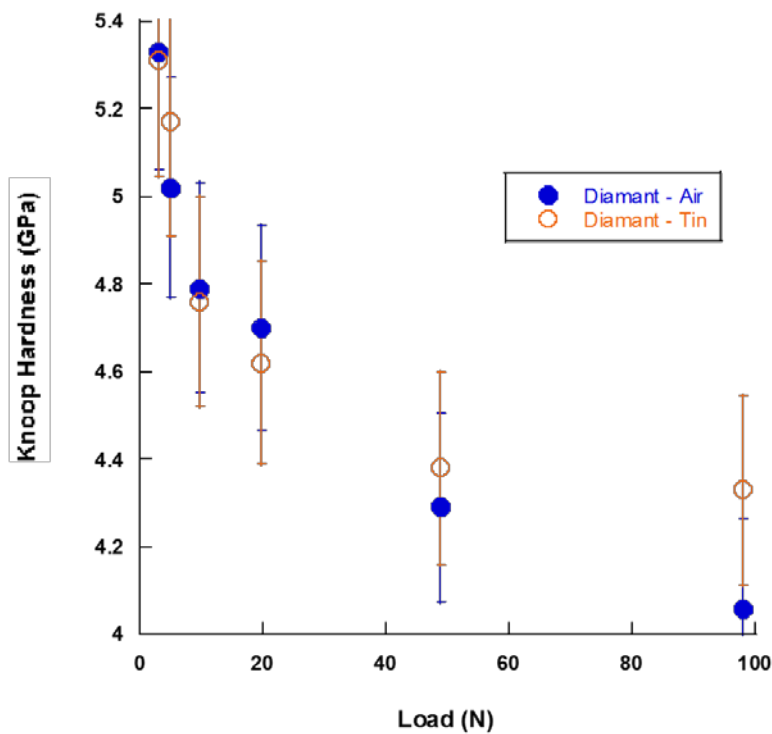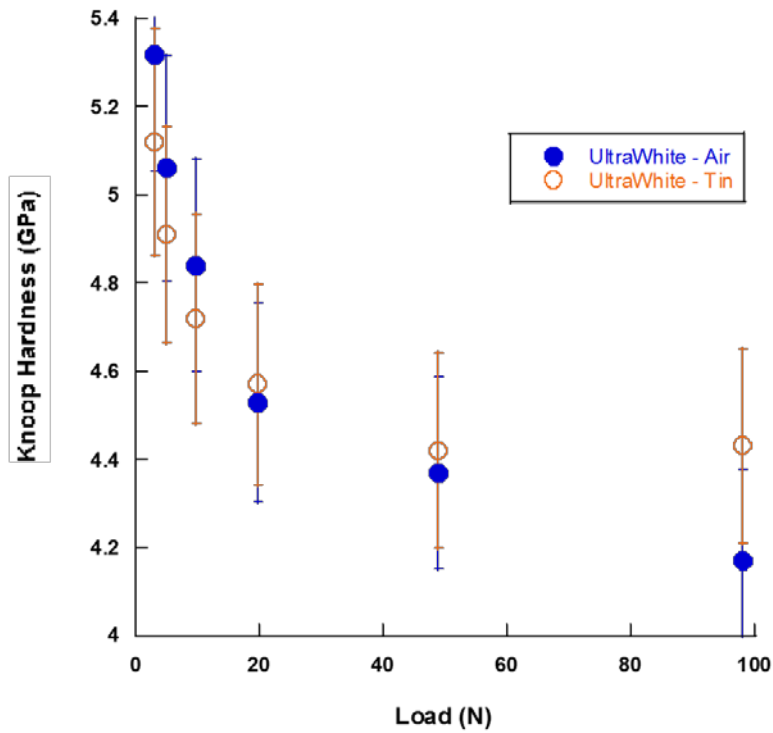

Fig. 1   Knoop hardness/load curve for Diamant SLS

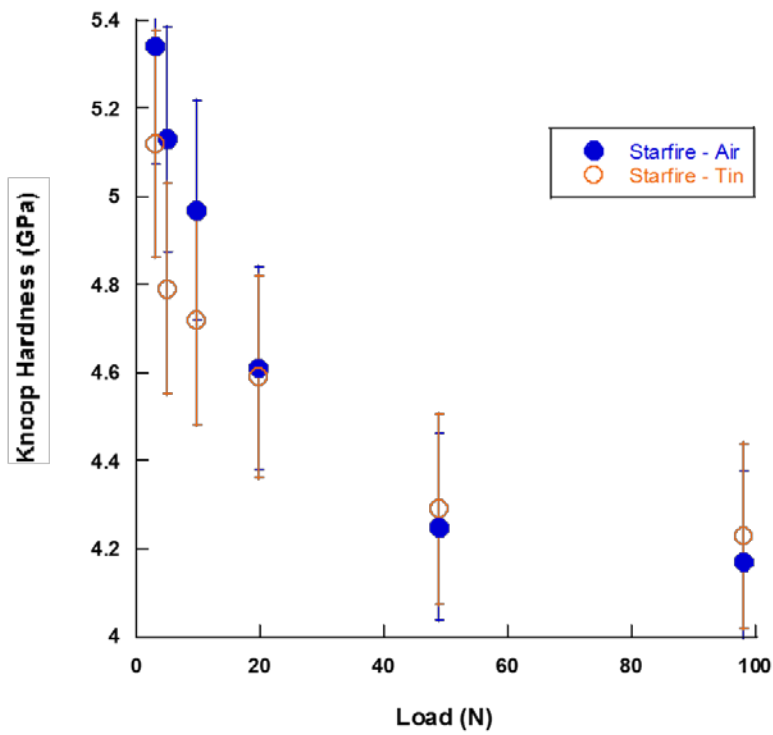**Fig. 2   Knoop hardness/load curve for UltraWhite SLS**

Fig. 3   Knoop hardness/load curve for Starphire SLS

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The results from the chemical analysis are shown in Table 2. Like the mechanical property results, the table reveals that there is no significant difference in the chemical composition of these US-manufactured SLS glasses.

Table 2   Chemical analysis results

Compound (%)	Diamant	UltraWhite	Starphire
Al_2O_3	0.21	0.79	0.01
B_2O_3	. . .	0.02	0.01
CaO	1.08	1.3	1.02
Cr_2O_3	0.01	0.01	. . .
Fe_2O_3	0.01	0.04	. . .
K_2O	0.01	0.03	0.01
MgO	0.93	0.88	0.56
Na_2O	14.97	15.74	16.07
P_2O_3	0.01	0.01	0.02
SiO_2	82.75	81.14	82.26
SnO	. . .	0.01	. . .
TiO_2	0.02	0.01	0.01
ZnO	. . .	. . .	0.02

5.   Conclusion

The mechanical property results and chemical analysis data obtained in this study show that there are no significant differences between the SLS float glasses fabricated by 3 different manufacturers. This implies that these glasses are essentially the same and can be used interchangeably in transparent armor systems without compromising performance.

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