MODIFIED GLASS BATCH CAN HAVE INCREASED ALUMINA CONTENT BY USING FELDSPAR TO IMPROVE GLASS PROPERTIES

Ekarat Meechoowas*, Kanit Tapasa, Usuma Naknikham, and Tepiwan Jitwatcharakomol

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Abstract

The original glass composition of $72SiO_2$-$15Na_2O$-7CaO-4.5MgO-$1.5Al_2O_3$ (in weight percent), made of sand (SiO_2), soda ash (Na_2CO_3), dolomite ($CaMg(CO_3)_2$, sodium sulfate (Na_2SO_4), and feldspar ($KNaAlSi_3O_8$), was modified by adding more feldspar to increase the alumina content in glass compositions from 1.5 to 2.5 wt%. In glass, alumina (Al_2O_3) is a network modifier that can improve the mechanical strength and the water resistance of the glass. The results of the experiments of increasing the alumina from 1.5 to 2.5 wt%, the result indicated that the mechanical properties, tested by Vickers micro hardness, increased from 5000 MPa to 5300 MPa and the water solubility decreased from 0.80 to 0.40 mg Na_2O per 50 ml H_2O. The melting ability of the modified batches was investigated by using the batch-free time method. The thermal property was examined by a viscometer (fiber elongation method). The results showed that the melting ability of new batch did not significantly change and the thermal property remained moderately similar to the original. In summary, glass properties can be improved by adding feldspar to increase the alumina content up to 2.5%.

Keywords: Batch modification, alumina, glass melting ability, glass properties

Introduction

Soda-lime silicate glass is produced with sand (SiO_2), soda ash (Na_2CO_3), dolomite ($MgCa(CO_3)$)), or lime stone ($CaCO_3$) and feldspar ($KNaAlSi_3O_8$) to form the glass structure. In addition with effective additives such as sodium sulfate (Na_2SO_4) sodium nitrate ($NaNO_3$) antimony (Sb_2O_3) and arsenic (As_2O_5) or carbon (C) function as refining agent and a redox control during the melting process (Vogel, 1985; Cable, 1998). Alumina (Al_2O_3) in glass can be obtained from various sources and functions as an intermediate oxide (coordinate between silica networks) in the glass structure. Glass properties such as mechanical strength and water solubility can be improved by adding alumina (Al_2O_3) in the glass batch (Shelby, 2005). Alumina reduces the tendency to crystallize, increases

Thailand Center of Excellent for Glass, Department of Science Service, Bangkok, 10400 Thailand. E-mail: ekarat@dss.go.th; kanit@dss.go.th, usuma@dss.go.th, tepiwan@dss.go.th

* *Corresponding author*

hardening, and improves the chemical and thermal-shock resistance (Andrukhina and Stoshkus, 1987). However, the problem of adding pure alumina to a glass batch is that it requires higher energy (the melting temperature of corundum is 2050°C and the eutectic point of the 2 components Al_2O_3-SiO_2 system is 1545°C) and this can interfere with the glass production. The alumina sources are shown in Table 1 (Tooley, 1974). There are other source of alumina with lower chemical enthalpy than pure alumina such as feldspar and pyrophyllite ($Al_2Si_4O_{10}(OH)_2$) with which it is possible to reduce the energy requirement (Meechoowas *et al.*, 2012; Tapasa and Jitwatcharakomol, 2012). This means that the melting process can be completed more easily than the batch with alumina. Melting batches faster with gibbsite [$Al(OH)_3$] or boehmite [$AlO(OH)$] as an alumina source produced substantially less foaming than a batch with corundum (Al_2O_3) (Pierce *et al.*, 2012). In the glass block production, alumina is replaced by feldspar which does not produce any complication in the process. The 0.1 wt% increases the concentration of Al_2O_3 in the glass and it is possible to save ~0.1 kg of soda ash per 100 kg of glass. The original glass composition as $72SiO_2$-$15Na_2O$-$7CaO$-$4.5MgO$-$1.5Al_2O_3$ was selected for this study and alumina is added, and the effects on the glass properties are investigated.

Materials and Methods

Soda-lime silicate glass is made of sand (SiO_2), sodium carbonate (Na_2CO_3), dolomite ($CaMg(CO_3)_2$) alumina (Al_2O_3), and feldspar ($KNaAlSiO_3$), and all the raw materials are made at a glass factory. The glass composition target is given in Table 1 to increase the alumina content from 1.5 to 2.5 wt%. Batches A, B, and C had the alumina contents from feldspar and batch D had the addition of pure alumina. The experiment is separated into 2 parts: first, a comparison of the melting ability by using the batch-free time method to feed the batch with melted cullet and kept in a crucible for different lengths of time, (Bieler and Bunting, 1984; Samkham, 2005; Meechoowas *et al.*, 2012) in which the batches were melted in an electrical furnace (Carbolite BLF 17/3, Carbolite Ltd., Hope Vally, UK) and annealed at 570°C in a box furnace (Carbolite CWF 1100) (Figure 1); second, the glass properties were investigated by comparing the difference in the batches. One hundred and fifty g of glasses was melted

Table 1. Sources of aluminous materials (Tooley, 1974)

Name	Formula	Theoretical	mol% Al_2O_3 Actual
Microcline or Orthoclase (Feldspar)	$K_2O.Al_2O_3.6SiO_2$	18.3	16-19
Albite (Feldspar)	$Na_2O.Al_2O_3.6SiO_2$	19.4	16-20
Kaolin	$Al2O_3.2SiO_2.2H_2O$	39.5	36-39
Alumina Hydrate	$Al_2O_3.3H_2O$	65.4	65
Calcined Alumina	Al_2O_3	100	100
Diaspore	$Al_2O_3.H_2O$	85.0	Variable
Bauxite	$Al_2O_3.2H_2O$	73.9	Variable
Gibbsite	$Al_2O_3.3H_2O$	65.4	Variable
Kyanite	$Al_2O_3.SiO_2$	63.0	50-60
Sillimanite	$Al_2O_3.SiO_2$	63.0	50-60

at 1500°C for 2 h and annealed at 570°C. After the chemical composition of the prepared samples was determined using a wavelength-dispersive XRF spectrometer (S8 Tiger, Bruker AXS GmbH., Karlsruhe, Germany). The thermal properties were determined by the dilatometeric method, (Netzsch DIL 402 PC, Netzsch-Geratebau GmbH, Selb, Germany), and fiber elongation method, (VIS 402, BÄHR-Thermoanalyse GmbH, Hullhorst, Germany). The physical properties were measured by micro hardness testing, (Shimadzu HMV 2000, Shimadzu Corp., Kyoto, Japan) and the optical properties were measured by UV/Vis spectro- photometer, (Analytikjena Specord 250, Analytik Jena AG, Jena, Germany). The water solubility was tested in accordance with standard ISO 719 Glass - Hydrolytic resistance of glass grains at 98°C - Method of test and classification (ISO 719, 2011).

Results and Discussion

The melting ability of the various glass batches that are presented in Table 2 is compared by glass batch for the same time and condition at 40 and 50 min in the furnace. The result for every batch is slightly different. Batches A, B, and D gave quite similar results, but batch C had less insoluble particles remaining in the crucible than the others. Therefore increasing the feldspar in the batch can result in it being easier to melt. Batches

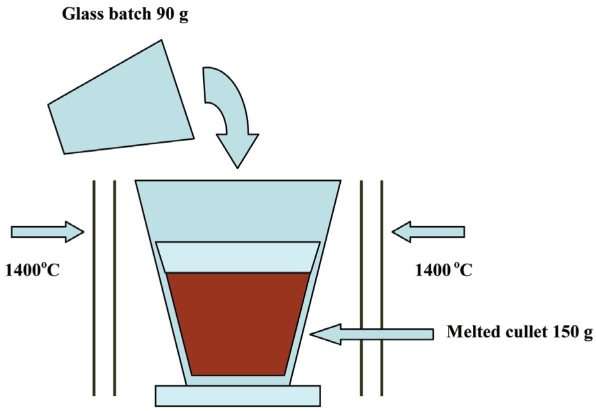


Figure 1. Batch-free time testing

Table 2. Batch composition

Raw material (wt%)	Batch A	Batch B	Batch C	Batch D
Sand (SiO_2)	46.67	45.48	43.94	46.38
Sodium Carbonate (Na_2CO_3)	15.73	14.69	14.20	15.64
Dolomite ($CaMg(CO_3)_2$)	13.12	12.92	12.49	13.04
Feldspar ($KNaAlSi_3O8$)	4.34	6.79	9.26	4.30
Cullet	20.14	20.12	20.11	20.09
Alumina	-	-	-	0.55

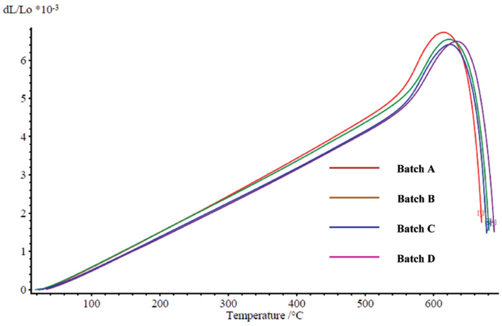


Figure 2. Linear expansion using dilatometric method

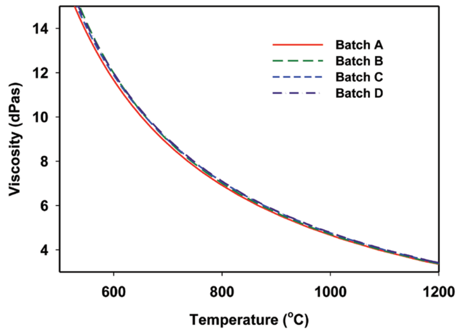
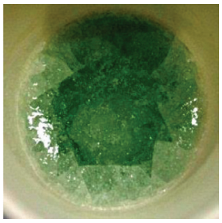
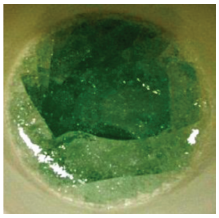
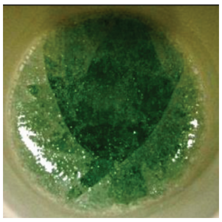
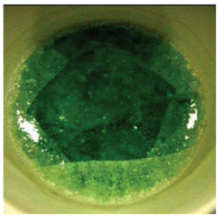
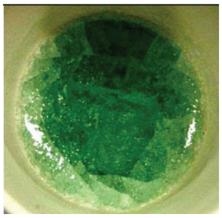
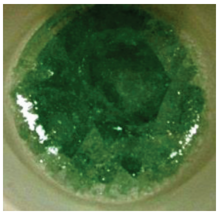
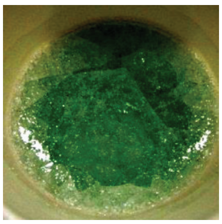
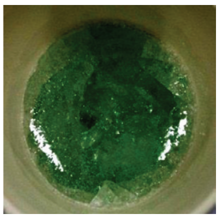


Figure 3. Viscosity of glass using fiber elongation method

Table 3. Batch-free time tested

	40 min	50 min
Batch A		
Batch B		
Batch C		
Batch D		

A, B, C, and D have various concentrations of alumina between 1.5 to 2.5 wt% from difference ratios of raw materials (Table 2). After preparation of the samples, the glasses composition is investigated by using wavelength-dispersive XRF and the result is given in Table 4. This confirmed the composition target as calculated, especially that the alumina content increased with increasing the feldspar and adding alumina. The results of the thermal properties using the dilatometric method are shown in Figure 2 and Table 5. The coefficient of the thermal expansion is decreased by increasing the alumina content and glass transformation temperature (Tg), and the softening point slightly shifts to a higher temperature. Consistency with the viscosity curve is investigated by the fiber elongation method shown in Figure 3, with an increased alumina content the temperature profile of the viscosity curve shifts to a higher temperature. According to the ISO 719 hydrolytic resistance test, Na_2O leached from glasses is measured by using atomic absorption spectroscopy. The results shown in Figure 4, are that the Na_2O that is leached decreases with increasing the alumina content. For that reason, the chemical resistance is increased, and the mechanical property is measured by using the Vickers micro hardness test. From Figure 5, it can be seen that, increasing alumina content, it will improve the mechanical properties. Batches C and D have almost

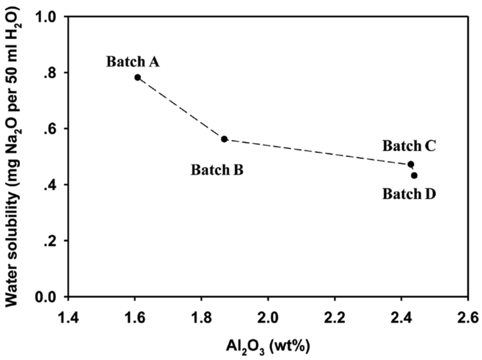


Figure 4. Na_2O leached measured using atomic absorption spectroscopy

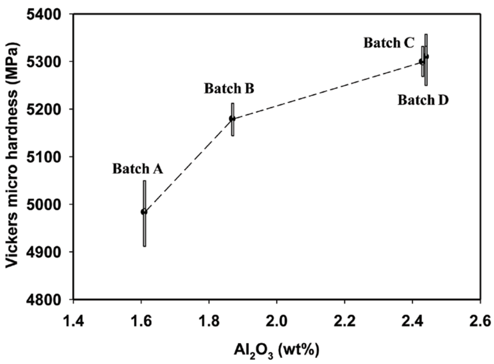


Figure 5. Test of Vickers micro hardness

Table 4. Chemical composition of the batches of glasses

Composition (wt%)	Batch A	Batch B	Batch C	Batch D
SiO_2	72.33	72.53	72.21	71.67
Al_2O_3	1.61	1.87	2.43	2.24
CaO	6.49	6.50	6.48	6.63
MgO	3.95	3.85	3.82	3.91
Na_2O	14.98	14.55	14.26	14.90
K_2O	0.24	0.33	0.43	0.24
Fe_2O_3	0.03	0.03	0.04	0.04
TiO_2	0.03	0.04	0.04	0.03
SO_3	0.34	0.30	0.29	0.34

the same as alumina content from the results. In the final experiment, one of the main concerns is to using feldspar because it has a high iron content, and this will have an effect on the glass color. The result of color determination using UV-Vis spectroscopy is shown in Figure 6 and Table 6. Batches B and C, which have high amounts of feldspar, are slightly more greenish than Batches A and D. However, the glass color is in the range which can be controlled by a reducing agent.

Conclusions

The experimental results represent improved glass properties especially the chemical and mechanical properties by increasing the alumina content up to 2.5 wt% by increasing the amount of feldspar or adding alumina. The melting ability when adding feldspar to the batches was better than when adding alumina, but the batches with added alumina did not show any significant change when

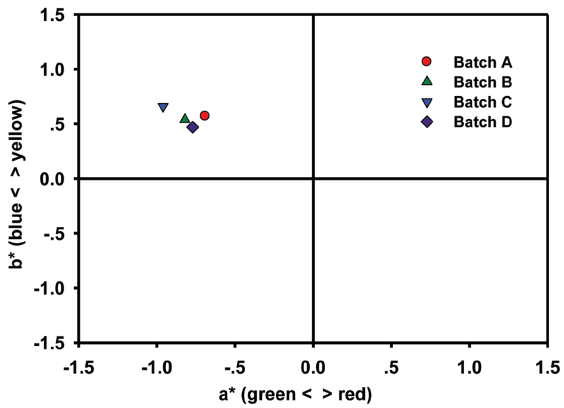


Figure 6. Color determination in CIE L*a*b* system

Table 5. Thermal properties using the dilatometric method

Thermal properties	Glass			
	Batch A	Batch B	Batch C	Batch D
The coefficient of thermal expansion 50-300°C (× 10^{-6} °C^{-1})	9.17	9.02	8.58	8.52
Glass Transformation temperature (°C)	549.4	559.3	559.5	560.9
Dilatometric softening point (°C)	628.1	639.3	641.9	639.7

Table 6. Color determination in CIE L*a*b* system

Glass	Color		
	L*	a*	b*
Batch A	96.16	-0.69	0.57
Batch B	95.78	-0.82	0.54
Batch C	96.09	-0.96	0.66
Batch D	96.03	-0.77	0.47

compared with the other batches. And the colors of the modified batches are similar to the original and are in the range which can be controlled. This methodology was to check the possibility of modifying the glass before changing the batches into a production scale.

Acknowledgments

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