Improve melting glass efficiency by Batch-to melt conversion

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Abstract

Soda–lime silicate glasses are composition used recently in container, table ware, float glass, etc. Most of soda-lime silicate glasses are produced by major component sand (SiO_2), soda ash (Na_2CO_3) and lime stone ($CaCO_3$) by adding additive such as dolomite ($CaMg(CO_3)_2$), sodium sulfate (Na_2SO_4), alumina (Al_2O_3), etc. During melting process, around 550 °C, soda ash is reacted with lime stone to produce $Na_2Ca(CO_3)_2$ melting at 780 °C. Sodium calcium carbonate is reacted with sand generate formation of Na_2SiO_3 and $CaSiO_3$ at 900°C. The alternative way of Batch-to Melt conversion is to replace lime stone by natural wollastonite. This reaction has occurred by crossing over the step of the reaction. This means that the melting process can be emerged easier than batch with lime stone; batch with wollastonite requires lower energy. From the calculated thermodynamic exploited heat of glass batch includes wollastonite which is required 10 % lower than using lime stone. When the lime stone is replaced by wollastonite, the kinetic is investigated by Thermal gravity and Differential Scanning Calorimeterv (TG/DSC). Then the next analysis is the melting process of both batches by using Batch-Free Time method with the same condition. The concern of wollastonite is minor impurity because can present color for clear glass production. From this experiment, wollastonite can be replaced lime stones and some parts of silica. Regarding to this experiment, batch containing wollastonite melts easier than lime stone batch. In conclusion, the results demonstrated that the two composite glasses were of the same properties.

Theory

Standard of glass formula is soda-lime silicate glass, $74SiO_2$-$16Na_2O$-$10CaO$

The thermodynamic calculation uses to calculate the theoretical heat demand (exploited heat, H_{ex}).

Batch (25 °C) $\Rightarrow$ Glass + batch gases (25 ° C) (1)

And the heat ΔHT(glass) physically stroed in the glass melt (relative to 25 °C) at melting temperature

$\Delta H^{\circ}_{chem} \Rightarrow H^{\circ}_{(glass)} + H^{\circ}_{(gas)} - H^{\circ}_{(batch)}$ (2)

$H_{ex} \Rightarrow \Delta H^{o}_{chem} + \Delta H_{T(glass)}$ (3)

The reaction is occurred by difference raw material.

First, glass composition (Glass A) is prepared by SiO_2, Na_2CO_3 and $CaCO_3$.

$Na_2CO_3(s) + CaCO_3(s) \Rightarrow Na_2Ca(CO_3)_2$ (occur between 450-650 °C) (4)

$Na_2Ca(CO_3)_2 + 2SiO_2 \Rightarrow Na_2SiO_3 + CaSiO_3 + 2CO_2$, (react at 900 °C) (5)

Second glass composition is prepared by SiO_2, Na_2CO_3 and $CaSiO_3$ (Glass B)

$74SiO_2(s) + 16Na_2CO_3(s) + 10CaCO_3(s) \Rightarrow 74SiO_2\text{-}16Na_2O\text{-}10CaO(glass) + \mathbf{26CO_2}$ (6)

$64SiO_2(s) + 16Na_2CO_3(s) + 10CaSiO_3(s) \Rightarrow 74SiO_2\text{-}16Na_2O\text{-}10CaO(glass) + \mathbf{16CO_2}$ (7)

Experimental

Raw materials used in batch to melt conversion are silicon dioxide (SiO_2), sodium carbonate (Na_2CO_3), calcium carbonate ($CaCO_3$) and natural wollastonite ($CaSiO_3$). Composition of two glasses targeted as same composition $74SiO_2$-$16Na_2O$-$10CaO$. First, kinetic was studied by TG/DSC (Thermal gravity and Differential Scanning Calorimeter) and Batch-Free Time method. Second, glass properties were investigated by melting 150 g of glass at 1500 °C for 2 hours. The experiment were performed the chemical composition by using Wavelength-dispersive XRF spectrometer, dilatometeric method, fiber elongation method, micro hardness testing and optical property by colors determination using UV/Vis spectrophotometer.

Result

The thermodynamic calculation of exploited heat (H_{ex}) at melting temperature (T_{ex}, 1500 ° C).

H_{ex} (Glass A) as 2.3 GJ/tglass 10% higher than H_{ex} (Glass B) 2.1 GJ/tglass.

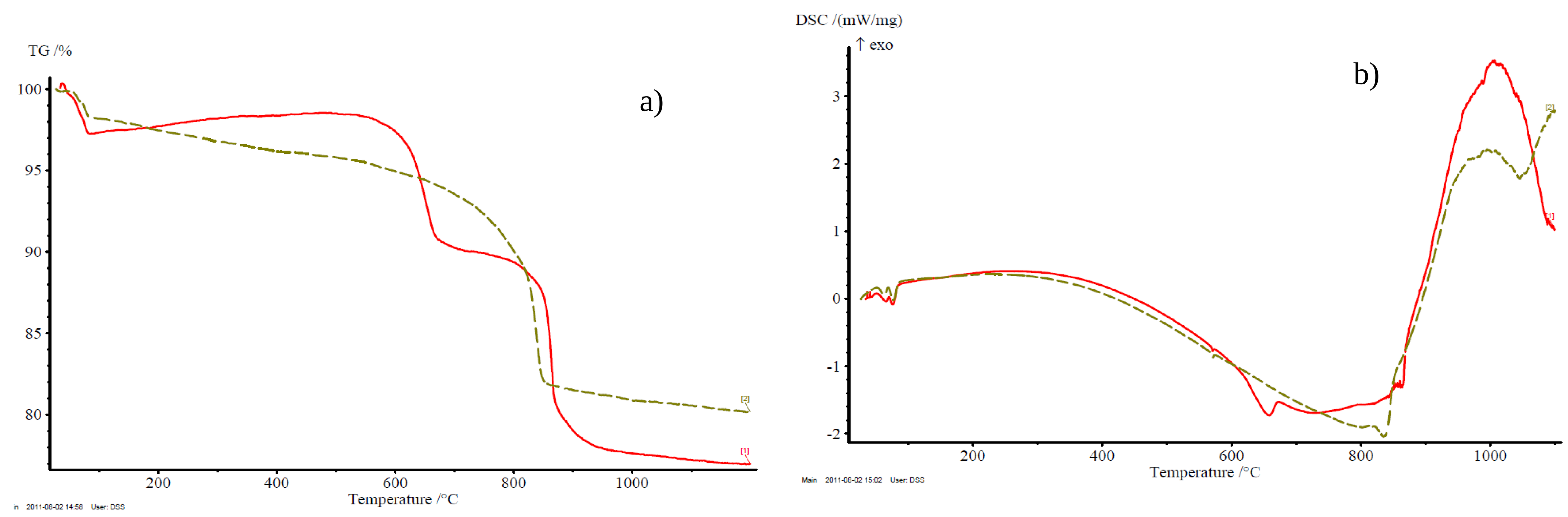

Fig. 1.a) Thermal gravity b) Differential Scanning Calorimetric curves (Glass A red line and Glass B green line)

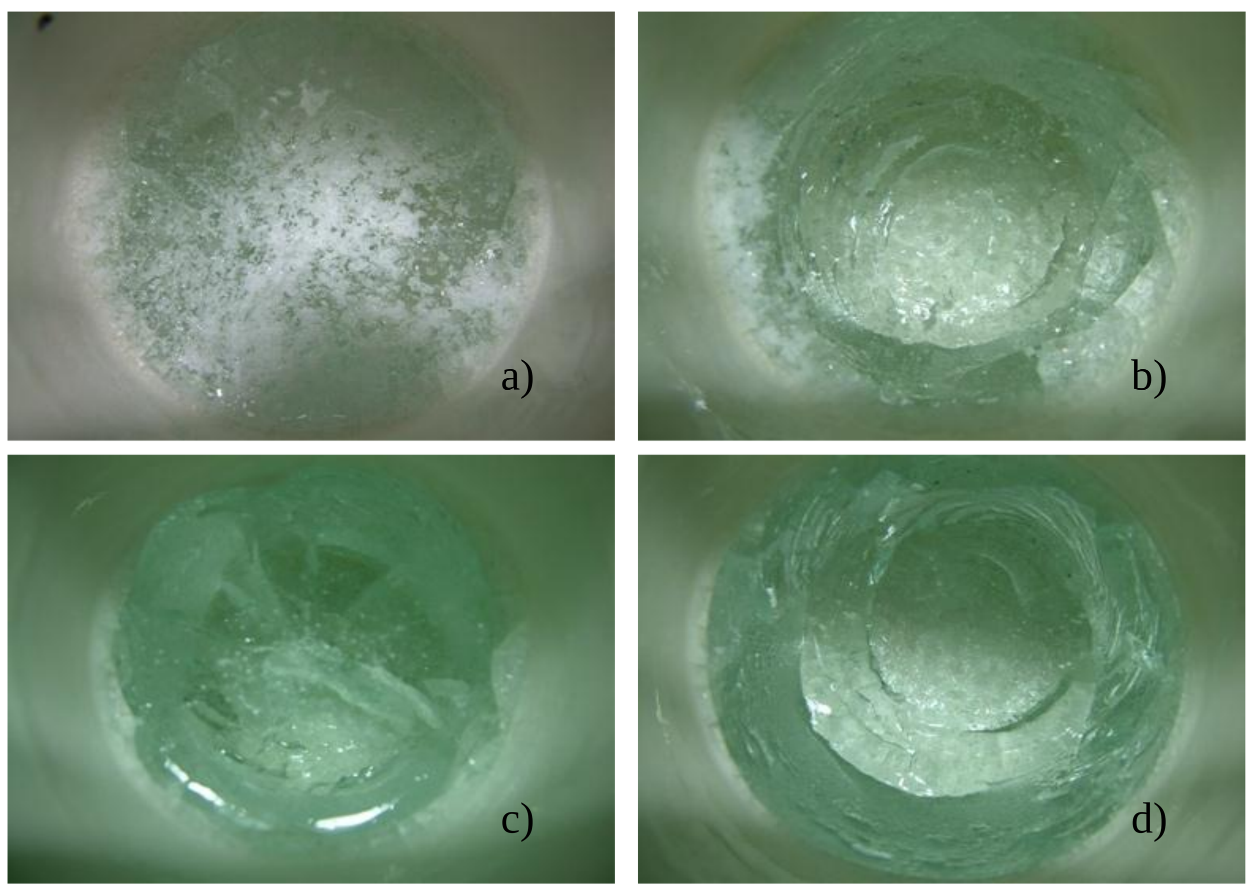

Fig. 2. Batch-Free Time testing a) Glass A 30 min b) Glass A 40 min c) Glass B 30 min d) Glass B 40 min

Table 1. Chemical composition of glasses

Composition (weight %)	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	Fe_2O_3	ZrO_2
Glass A	15.63	0.09	0.27	74.67	0.05	9.16	0.07	0.04	0.01
Glass B	16.61	0.40	0.31	73.61	0.05	8.88	0.06	0.06	0.01

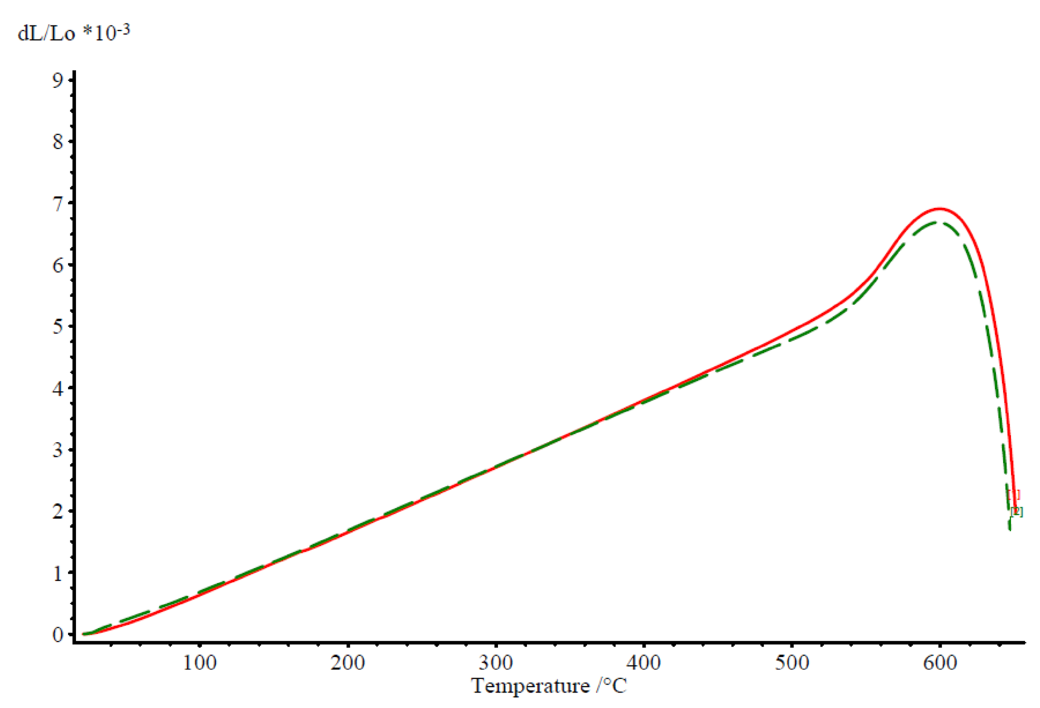

Fig. 3. The thermal properties by dilatometeric method. (Glass A, red line and Glass B green line)

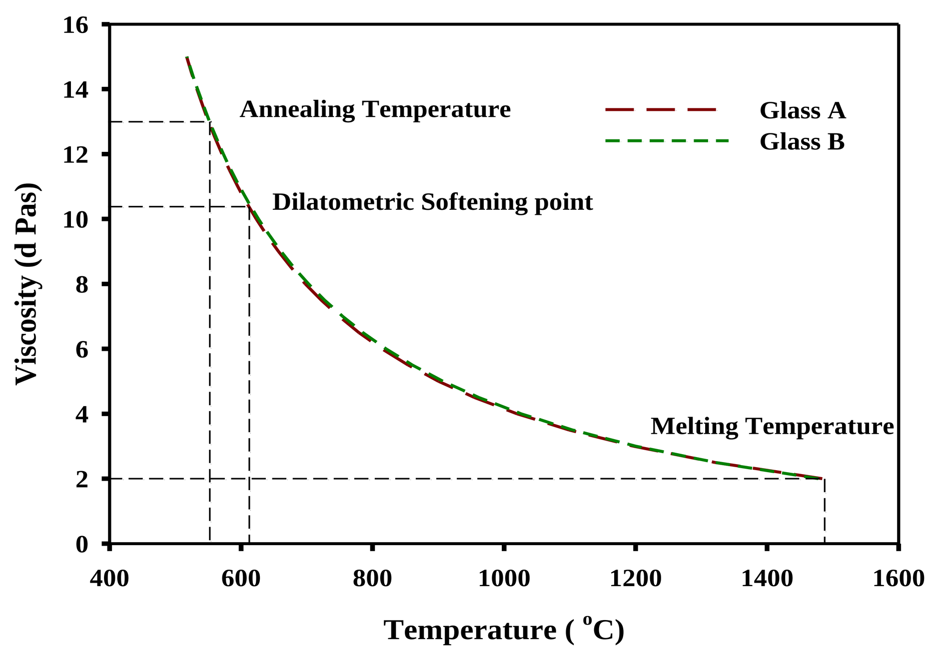

Fig. 4. Viscosity curve by fiber elongation (Glass A, red line and Glass B, green line)

Table 2. Calculated color from glass transition in CIE L*a*b* system by UV/Vis spectroscopy.

Calculated color	Glass A	Glass B
L*	86.24	89.19
a*	-1.17	-1.28
b*	0.65	0.85

Table 3. Vickers Micro hardness testing

Glass	Vickers Hardness (HV)
A	509 ± 16
B	516 ± 11

Conclusion

This research results represented efficiency of the melting glass by Batch-to melt conversion. From thermodynamic calculation, wollastonite replaced lime stone can be reduced approximately 10% of energy requirement. The kinetic investigation was used to confirm this study. Moreover, the properties experiment of glasses from both batches showed composition and properties giving the same result. This meant that replacing wollastonite in soda-lime silicate glass batch can improve energy efficiency and also reduced CO2 emission on glass melting process.

Acknowledgements

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