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Effect of Glass Batch Composition on the Efficiency of Bottle Production

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Abstract. Glass batch from a bottle manufacturing facility was sampled at twelve different times during a year. The quality of the bottles produced from this batch was investigated and correlated with the chemical composition of the glass. It was found that the cords, devitrification and density directly affect the efficiency of the products. Increasing the Al_2O_3 and Na_2O concentration in the glass inhibited the formation of cords and crystal glass. On the other hand, increased levels of silica (SiO_2) and calcium oxide (CaO) favored the formation of wollastonite ($CaSiO_3$) crystals.

Introduction

The presence of cords and/or devitrification in glass production is a major defect and can cause trouble in manufacturing. When the batch composition is incorrectly proportioned, or batch segregation is occurring, the formation of cords and/or devitrification will occur. This may cause some defects in the physical and mechanical properties of glass.

In the soda-lime-silica glass based system, the optimum factor for glass production with respect to cost, durability and ease of manufacture is the composition of the batch. Throughout the world, the composition being used is approximately 72% silica, 15% soda, 10% lime and magnesia, 2% alumina and 1% miscellaneous oxides. Magnesia is used primarily to reduce the cost, minimize devitrification, and provide a mixed alkaline earth effect by substitution of dolomite limestone for calcite. The alumina content improves chemical durability and decreases tendency of crystallization during the forming operations, a process called devitrification [1; p. 152].

The devitrification product is α and β - Wollastonite ($CaSiO_3$) and it occurs by decomposition of devitrite ($Na_2O.3CaO.6SiO_2$) or due to local high lime concentration. Devitrite and wollastonite may occur separately or together [2; p. 34].

This paper presents the effects of soda-lime-silica glass composition on the cords and crystal formation and their effects on the properties of glass products.

Experimental Program

Glass composition and preparation

Two major series were considered in this investigation. The first one was of nine batches to determine the variation of glass density and its relationship to SiO_2 and CaO content. The batch constituents by weight and glass oxide composition in percent for the first series are tabulated in Tables 1 and 2, respectively. The second series was to determine the effect of batch composition on the efficiency of glass products as presented in Table 3. The batches and the composition of glass were selected over 12 month of manufacturing. It was assured that the glass composition varied throughout the selection period.

Table 1. Batch constituents for density measurement

Batch No.	Batch constituents (Kg)			
	Sand (S)	Limestone (L)	Soda Ash (A)	Cal. Alumina+Sulphate (C)
1	957	286	336	15.54+7.5
2	957	284	334	15.54+7.5
3	965	284	334	15.54+7.5
4	965	280	334	15.54+7.5
5	965	277	334	15.54+7.5
6	965	288	328	15.54+7.5
7	965	293	328	15.54+7.5
8	965	288	328	15.54+7.5
9	727	209	251.5	11.60+7.5

Table 2. Glass oxide compositions (%) and density of glass bottles

Batch No.	Glass oxide compositions (%)					Density
	SiO_2	Al_2O_3	CaO + MgO	Na_2O	Fe_2O_3	gm/cm³
1	72.12	1.49	11.28	15.04	0.07	2.5029
2	72.23	1.49	11.22	14.99	0.07	2.5036
3	72.39	1.48	11.16	14.90	0.07	2.5043
4	72.51	1.48	11.02	14.92	0.07	2.5037
5	72.56	1.48	10.91	14.94	0.07	2.5036
6	72.43	1.49	11.32	14.65	0.07	2.5040
7	72.34	1.48	11.49	14.62	0.07	2.5051
8	72.47	1.49	11.32	14.65	0.07	2.5062
9	72.60	1.47	10.93	14.93	0.07	2.5053

Table 3. Batch constituents for density and efficiency

Batch No.	Batch constituents (Kg)				Mix ratio
	Sand (S)	Limestone (L)	Soda Ash (A)	Cal.Alumina + Sulphate (C)	$\left(\frac{S+L}{A+C}\right)$
1-a	727	209	251.5	11.6+5.61	3.48
2-a	727	211	253.5	11.6+5.61	3.47
3-a	723	209	251.5	11.6+5.61	3.44

Glass bottles of 240 ml capacity were produced from an ordinary continuous tank furnace at the national glass bottles factory in the Kingdom of Saudi Arabia. This glass is melted at about 1500°C yielding homogeneous and bubble-free glass of good workability traits. Local Saudi silica sand, lime stone, and chemically pure Na_2CO_3, Al_2O_3 and Na_2SO_4 were used as starting materials for batch preparation [3; p. 8].

Density

The density of the glass bottles were determined by the Archimedes method using xylene as the buoyancy liquid.

Production efficiency

The efficiency is defined by the number of bottles passes the production line per hour without any physical and mechanical defects. This was observed by an electronic system using ultraviolet ray and as measured by a pressure test as per ASTM standard [4; pp. C147].

Differential thermal analysis (DTA)

DTA was carried out using the computerized Perkin Elmer (PE) DTA 7 series under dynamic N_2 purging gas atmosphere (at a constant rate of 60 cc/min). About 70 mg of the powdered glass sample was used against Al_2O_3 powder as a reference material. A heating rate of 10°C/min was maintained for all the DTA runs.

Test Results and Discussions

The density of glass measured for the nine glasses of the first series is presented in Table 2 with their oxide composition. The relationships between density and sand-lime content and soda-alumina are shown in Figures 1 and 2, respectively. It can be seen that the density is affected linearly by the SiO_2+CaO and inversely by Na_2O+Al_2O content. Although the correlation factor (R^2) was not high due to scatter in the test results. Nevertheless, the relationship in general showed an increase in the SiO_2+CaO content and decrease in the Na_2O+Al_2O content will increase the density of glass.

Table 4 presents the results of density and efficiency of glass bottles. The mix ratio is calculated by:

Mix Ratio = Sand + Lime/ Soda Ash + Calcined Alumina and Sulfate.

$$R = (S + L) / (A + C) \quad (1)$$

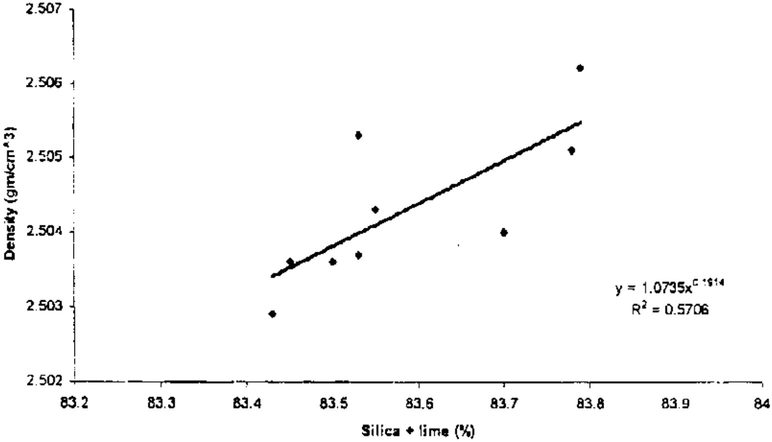

Fig. 1. Relationship betwen density and silica + lime content.

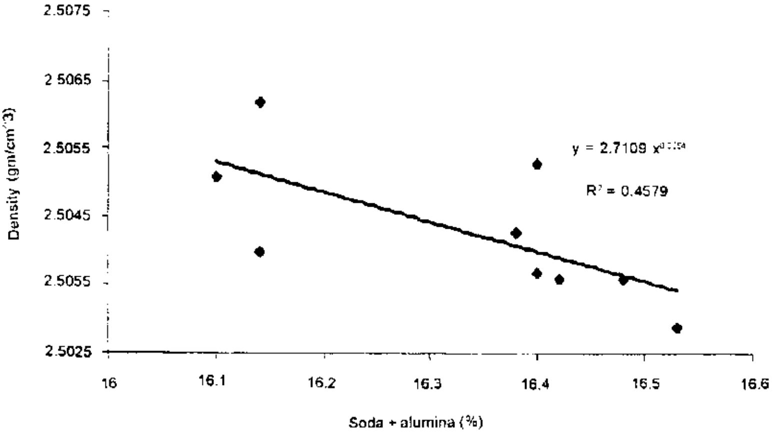

Fig. 2. Relationship betwen density and soda + alumina content.

Table 4. Density and efficiency of glass bottles

Batch No.	Glass oxide composition					Density (gm/cm^3)	Efficiency (%)	Cost of batch (SR)
	SiO_2	Al_2O_3	CaO+MgO	Na_2O	Fe_2O_3			
1-a	72.59	1.5	10.93	14.93	0.07	2.5045	74	303
2-a	72.52	1.5	11.02	14.92	0.07	2.5035	78	306
3-a	72.31	1.5	11.07	15.07	0.07	2.5028	80	315

It can be seen (Fig.3) that as the density increases, the efficiency decreased. In other words, (see Table 4) increasing SiO_2+CaO and reducing Na_2O+Al_2O_3, will produce unreliable and non-durable glass bottles. The primary crystallization product for this type of glass is devitrite ($Na_2O.3CaO.6SiO_2$) which can occur due to high silica and lime concentrations which induce wollastonite (SiO_2.CaO) formation [5].

For both series of mixes, the silica + lime (SiO_2+CaO) content and its variations were higher than the recommended value which is the main cause of high density and hence the presence of cords and crystal glass [6; p. 9]. This will, in fact, lower the physical and mechanical properties and, consequently, lower efficiency. It was stated by Babcock [7] that Soda-lime-silica glass has different phase-substructure types. Among these phases are cristobalite, tridymite and quartz crystals which are primarily dependent on silica content. Therefore, decreasing the silica content by about 0.38% will minimize the crystal glass and, hence, increase the efficiency from 74 to 80%. On the other hand, alumina has the tendency to decrease the crystal phase in glass. The increase in efficiency will lead to slight (about 3 %) higher cost for glass production.

The DTA traces of the investigated glasses are shown in Fig. 4 and presented in Table 5. The DTA traces were somewhat similar to each other in their general characteristics exhibiting an endothermic effect at 540°C (onset) and up to 560°C (transform). This endothermic reaction was caused by transformation of glass structure at amorphous state due to an increase in heat capacity[8]. The glass transition temperature (Tg), increased until it reached the softening temperature (Ts) (at 600°C) without any exothermic effect. As a matter of fact, the broad exothermic effect indicates a sluggish crystallization propensity nature. This could be a slower crystallization rate and/or a surface crystallization character [9], which is the case in this investigation (see Fig 4).

Conclusion

Based on the results obtained, it can be concluded that precise control of batch composition is very important in glass production. Increase of the SiO_2 and CaO contents will increase the density, and the formation of wollastonite crystals in the glass will reduce the production efficiency.

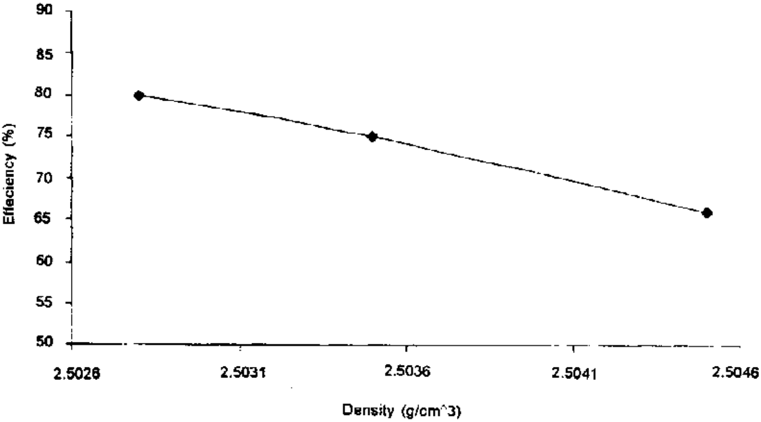

Fig. 3. Density and efficiency of some investigated glasses.

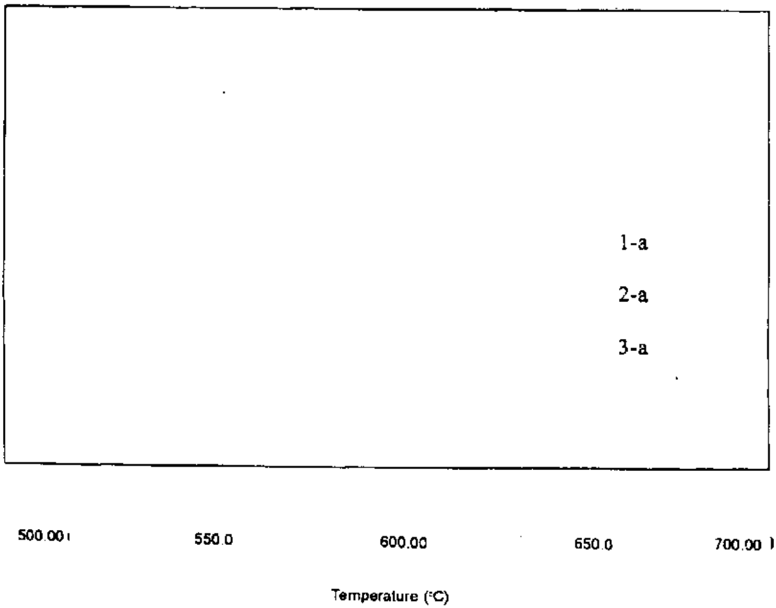

Fig. 4. Differential thermal analysis (DTA) of glass bottles.

Table 5. DTA results of the investigated glasses

Glass No.	Transition temp (Tg) °C	Endothermal (onset) °C	Softening temp (Ts)
1-a	567	544	590
2-a	560	540	585
3-a	560	540	582

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تأثير تركيب الزجاج على كفاءة إنتاج القوارير الزجاجية

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ملخص البحث. تم اختيار عدد 12 تركيبة زجاجية على فترات مختلفة لدراسة تأثير مكونات الخلطات الزجاجية على كفاءة إنتاج القوارير الزجاجية. كما تم دراسة تأثير التركيبات الزجاجية على كفاءة الإنتاج وعلاقتها بالاحبال (CORDS) والبلورات الزجاجية والكثافة. خلصت الدراسة إلى أن زيادة ثالث أكسيد الألمونيوم وأكسيد الصوديوم تمنع من تكوين الأحبال والبلورات الزجاجية بينما زيادة نسبة أكسيد الكالسيوم وثاني أكسيد السيلكون تعمل على تكوين بلورات زجاجية من معدن الولاستونيت (WOLLASTONITE).