POROUS GLASS-CERAMIC COMPOSITE FROM RECYCLED SODA LIME SILICA GLASS AND CHARCOAL CARBON

Z. Mustafa[1*], N. F. Ishak[2], Z. Shamsudin[3], N. F. Sapari[4]
J.M. Juoi[5]

[1, 2, 3, 4, 5] Advanced Manufacturing Centre, Faculty of Manufacturing,
Universiti Teknikal Malaysia Melaka, 76100 Durian Tunggal Melaka, Malaysia

ABSTRACT

Glass ceramic composite was produced from soda lime silicate waste glass, ball clay and charcoal carbon as an alternative method to recycle waste glass. The objective of the study was to investigate the effects of charcoal carbon content (wt. %) to the sintered glass ceramic on their modulus, water absorption, apparent porosity, linear shrinkage and bulk density. The powder mixtures of soda lime silicate glass, ball clay and carbon were compacted by uniaxial pressing method and sintered at 850°C with heating rate of 2°C/min and one hour dwell time. The main phase identified by X-ray diffraction method in sintered samples are quartz and wollastonite. It was observed that higher carbon content results in higher porosity, higher water absorption and lower bulk density and modulus of rupture. SEM analysis showed that there was significant variation in morphology of the porosity with the changes in carbon content. The optimised properties is at 1 wt.% of carbon content containing average pore size of 5 μm to12 μm, with lowest porosity percentage of 1.79%, water absorption of 0.77%, linear shrinkage of 12.89% and highest bulk density and modulus of 48.2 MPa and 4.3% respectively. This study shows that low-density and porous materials can be made from recycled soda lime silicate and ball clay mixed with charcoal additive.

KEYWORDS: *Soda lime silicate glass; porous; charcoal carbon; waste glass*

1.0 INTRODUCTION

To-date, the increase in the population density and modern living standard has witness the raise in waste management problems from both residential and industrial sectors, which continue to pose threat to the environment. Thus, recycling of waste is considered as an effective effort to minimize waste, as well as reducing the demand for consuming raw materials, which consequently promotes sustainability in manufacturing (Chinnam, Francis, Will, Bernardo & Boccaccini, 2013; Eckelman & Chertow, 2009). Glass-ceramic is an inorganic silicate material consisting of crystals, corresponding to one or more phases and usually prepared via traditional method involving melted glass, nucleation and crystallization process. However, this process can be simplified by adopting sinter-crystallization of glass powders, on which can be cost effective and make it possible for the waste glass to be recycled to form new products (Ayoob, Juoi,

* Corresponding Email: zaleha@utem.edu.my

Rosli & Rosli, 2011). Porous ceramics are normally used for filtration and separation, sound absorption, heat isolation, lightweight materials and others. It remains a popular choice as they can be tailored to specific requirements due to their surface characteristics (Efavi, Damoah, Bensah, Arhin & Tetteh, 2012; Vu, Wang, Nam, Bac & Chu, 2011). Porous glass-ceramic normally are produced by using sacrificial materials (polymer porogens, organic materials etc.) or template methods (Bernardo, 2007). Charcoal is one of the most common additives used as pore former to produce porous specimens (Mustafa et al., 2015; Efavi et al., 2012; Phonphuaka & Thiansem, 2011). Charcoal is produced when wood, bones, cellulose, or other carbonaceous substances are fired in limited air presented resulting a very porous residue of microcrystalline graphite. It is often found in the form of amorphous carbon.

The present work aim to investigate the effects of charcoal addition mixed with waste glass to produce porous and lightweight glass-ceramic. Different amount of charcoal (0 %, 1 %, 5.0 %, 10 %, 20 % and 30 % by weight) were added to the mixture and fired at the chosen temperature. The microstructural and phase changes in the fired specimen were investigated using scanning electron microscope and X-ray analysis. The basic physical and mechanical properties of specimens including compressive strength (MOR), water absorption, apparent porosity and bulk density were examined and analysed.

2.0 MATERIALS AND METHODS

2.1 Materials

Transparent soda lime silicate glass (SLSG) and charcoal carbon (C) were collected from residential waste. Both materials were prepared using a method that has being previously described in previous study by Mustafa et al. (2015). Ball clay (Sibelco Malaysia) was used as a binder to aid the sample fabrication.

2.2 Sample preparation

In order to determine the extent of the pore-forming effects of charcoal additive, charcoal carbon powder with particle size of $d_{0.5}$ = 75 μm were used in this study. They were added to the grinded SLSG powder and ball clay and divided into six different batches mixed with increasing charcoal content (0%, 1%, 5.0%, 10%, 20% and 30% in weight) as shown in Table 1. Each batch was mixed in a rotary mill to ensure homogenous mixing. Approximately 5 wt. % to 10 wt. % of water was added to the mixture during plastic condition in order to aid in the forming process. Ten grams of the mixture was compressed under 3.5 tonnes in rectangle-shaped specimens with an internal dimension of 65 mm x 15 mm x 5 mm. The green body were air dried at room temperature for 24 hours, followed by oven dried at 110 ± 5 °C for a further 24 hours to remove water content. The specimens then was sintered at 850°C, 2°C/ min with one hour of dwell time in a high temperature furnace and subsequently cooled to room temperature.

2.3 Experimental

Phase analysis studies of the raw materials and sintered glass-ceramic specimens were carried out using a PANalytical X-ray diffraction unit (model X'Pert Pro MPD PW3060/60) operating at room temperature using Cu K_α radiation (α =1.54178 Å). The percent of linear shrinkage, apparent porosity, bulk density and water absorption of the sintered glass–ceramic were carried out according to ASTM C373 standard. Modulus of rupture (MOR) was calculated from 3-point bending testing using an Instron Universal Testing Machine. The test was carried out using 50 mm span and 1.0 mm/min crosshead speed as per ASTM C1161. Fracture morphology of the specimens were inspected using SEM EVO 50 (Carl Zeiss SMT, UK) at accelerated 15 Kv. Prior to the testing, the samples surface were gold coated using SC-7620 Mini Sputter Coater (Quorum, UK).

Table 1. The green body formulation of glass-ceramic

SLS glass [wt. %]	**Ball clay [wt. %]**	**Carbon content, C [wt. %]**
85	15	0
84	15	1
80	15	5
75	15	10
65	15	20
55	15	30

3.0 RESULTS AND DISCUSSION

Figure 1 shows the XRD pattern of each specimens after heat treatment with the increased of carbon content. In general, the main crystalline phases present in the specimens are quartz (ICDD: 00001-0649, 2θ = 25.6° and 35.6°), and wollastonite (ICDD 00002-0689, 2θ = 30.1° and 26.9°).

Figure 2 shows that the firing shrinkage, porosity and water absorption of glass-ceramic increased with an increase in the carbon content. In addition, a gradual increase was also observed in the porosity of the first two carbon content loadings, with the percentage of linear shrinkage increased significantly ($p < 0.05$) as early as at 5 wt.% C. The highest porosity value is given at maximum loading of 30 wt. % C which is 30.79%. The water absorption for the specimens is in the range of 0.77% to 7.05%, showing a similar trend as in the bulk porosity of the fired body. The highest apparent water absorption was 7.05 % (30 wt. % C) and the lowest being approximately 0.77% (1 wt. % C), suggesting that high percentage of charcoal carbon in the specimens caused an increase in porosity. Furthermore, the water absorption of fired bodies is indicative of the quantum of overall apparent porosity. Past researches have reported on several contributing factors to the formation of porosity in glass-ceramic. One of them is the amount of glass addition, which directly influence the volume of pore formed in the glass-ceramic (Juoi, Arudra, Rosli, Hussain, & Jaafar, 2013; Mangutova, Milosevski, & Bossert, 2004). The porosity increased as the glass powder is reduced due to lack of glassy form which can be attributing to a change in viscous flow. However, carbon is a well-known pore former material. During the sintering process, the carbon powder is

burnt into gas leaving pores in the matrix. This observation is in agreement with the literature (Mustafa et al., 2015; Phonphuaka, & Thiansem, 2011; Ugheoke, Onche, Namessan & Asikpo, 2006).

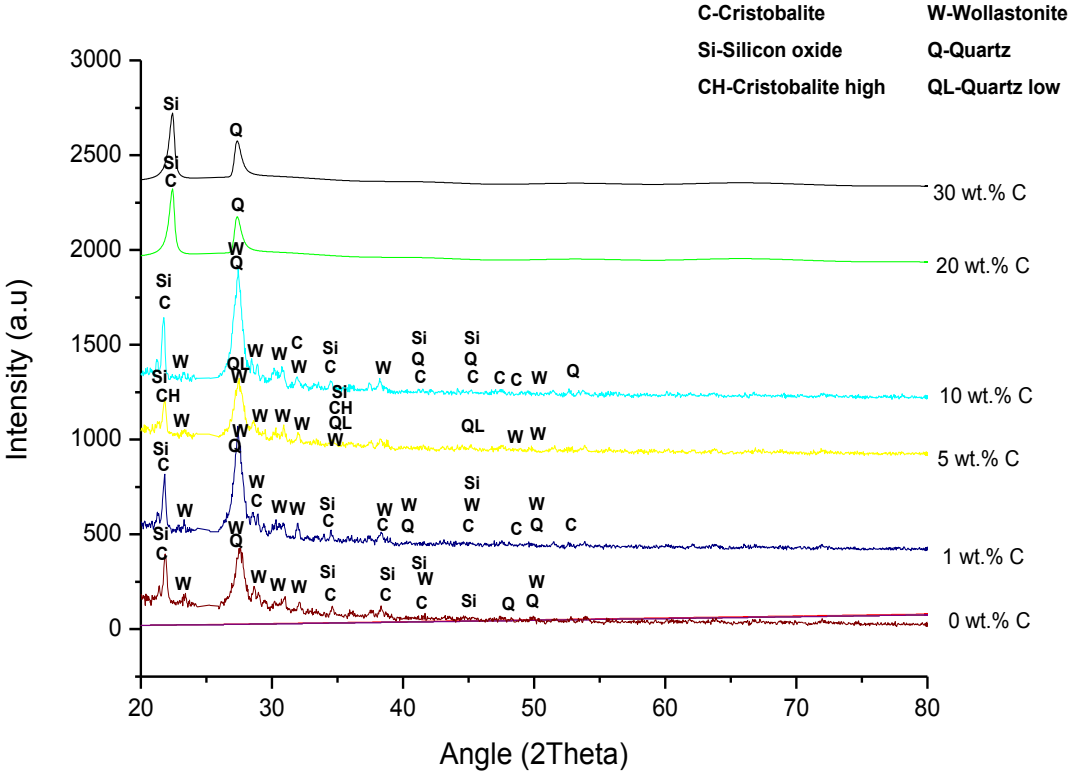


Figure 1. XRD patterns of recycle SLS glass-ceramic at various carbon content (at 0, 1, 5, 10, 20 and 30 by weight, wt. %) and ball clay (15 wt. %)

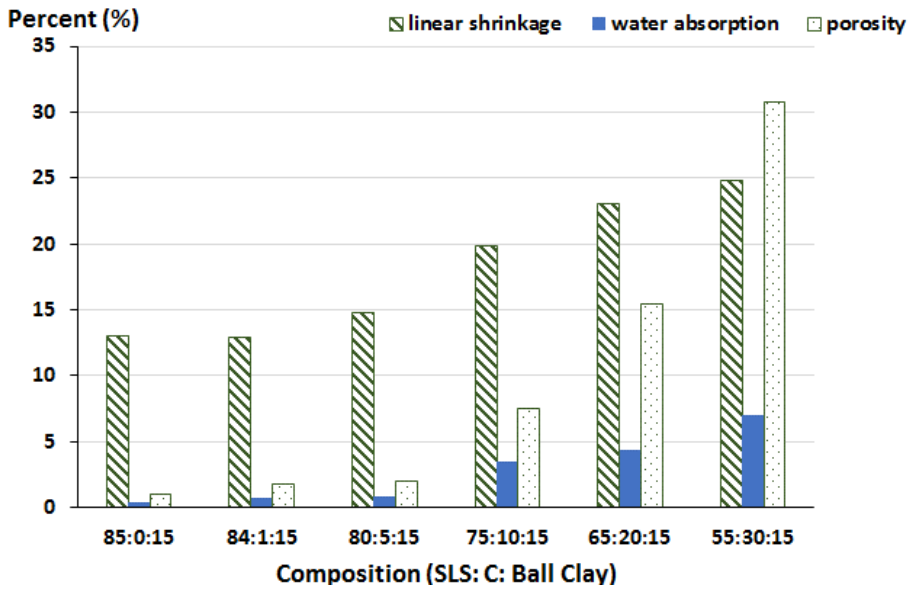


Figure 2. The percentage of linear shrinkage, water absorption and apparent porosity of porous recycled SLS glass-ceramic at various carbon content, wt. %

The value of modulus of rupture (MOR) and bulk density of the porous glass-ceramic at various carbon content are shown in Figure 3. While the formation of apparent porosity of the sintered glass-ceramic occurred as a direct result of burnt out of charcoal carbon, the density of the sintered body may be influenced by many factors such as specific gravity of clay, manufacturing process and degree of burning. The bulk densities of the specimens were inversely proportional to the charcoal content in the mixture. Apparently, at the same sintering temperature, with an increase in carbon addition, the bulk density of the fired specimens reduced gradually from 4.37 g/cm^3 to 4.19 g/cm^3 at 0 wt.% C and 10 wt.% C respectively, before further increase to 2.01 g/cm^3 at 30 wt.% C. A similar trend was observed in the modulus of rupture where insignificant changes of 48.20 MPa to 48.36 MPa was observed in the first three carbon content (1 wt.%, 5 wt.% C and 10 wt.% of C) before significantly (p <0.05) reduced to 46.53 MPa and 19 MPa with addition of 20 wt. % C and 30 wt. % C respectively. The reduction in the mechanical properties of the fired specimens is due to the presence of high porosity (15-30 %) at the two higher carbon content. Thus, as the carbon content increase, the MOR and density decrease due to an increase in their porosity. This finding is similar to those reported in literatures (Juoi et al., 2013; Phonphuaka, & Thiansem, 2011; Vu et al., 2011; Mangutova, Fidancevska, Milosevski & Bossert, 2004).

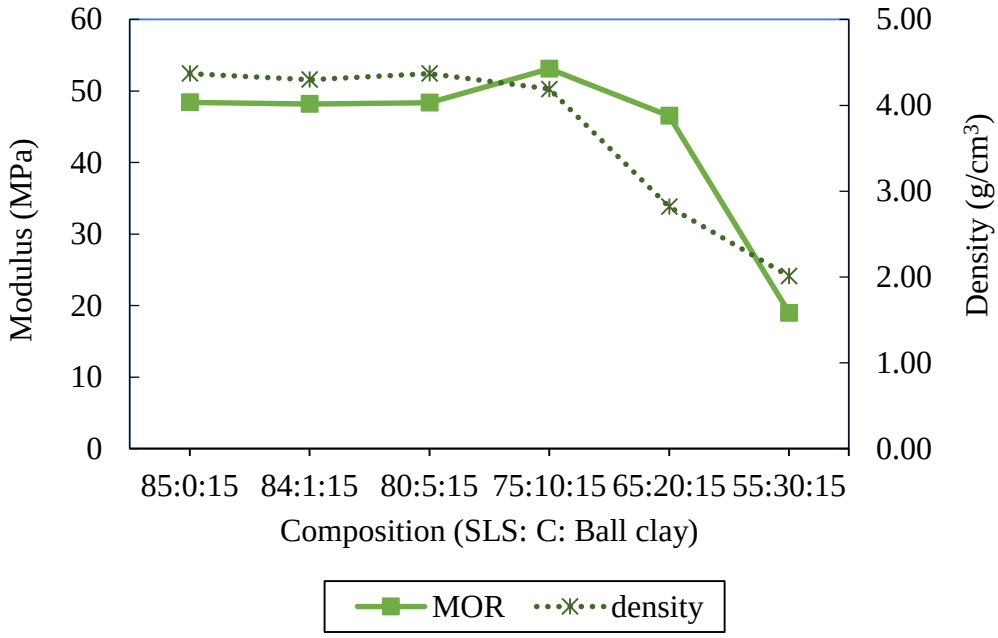
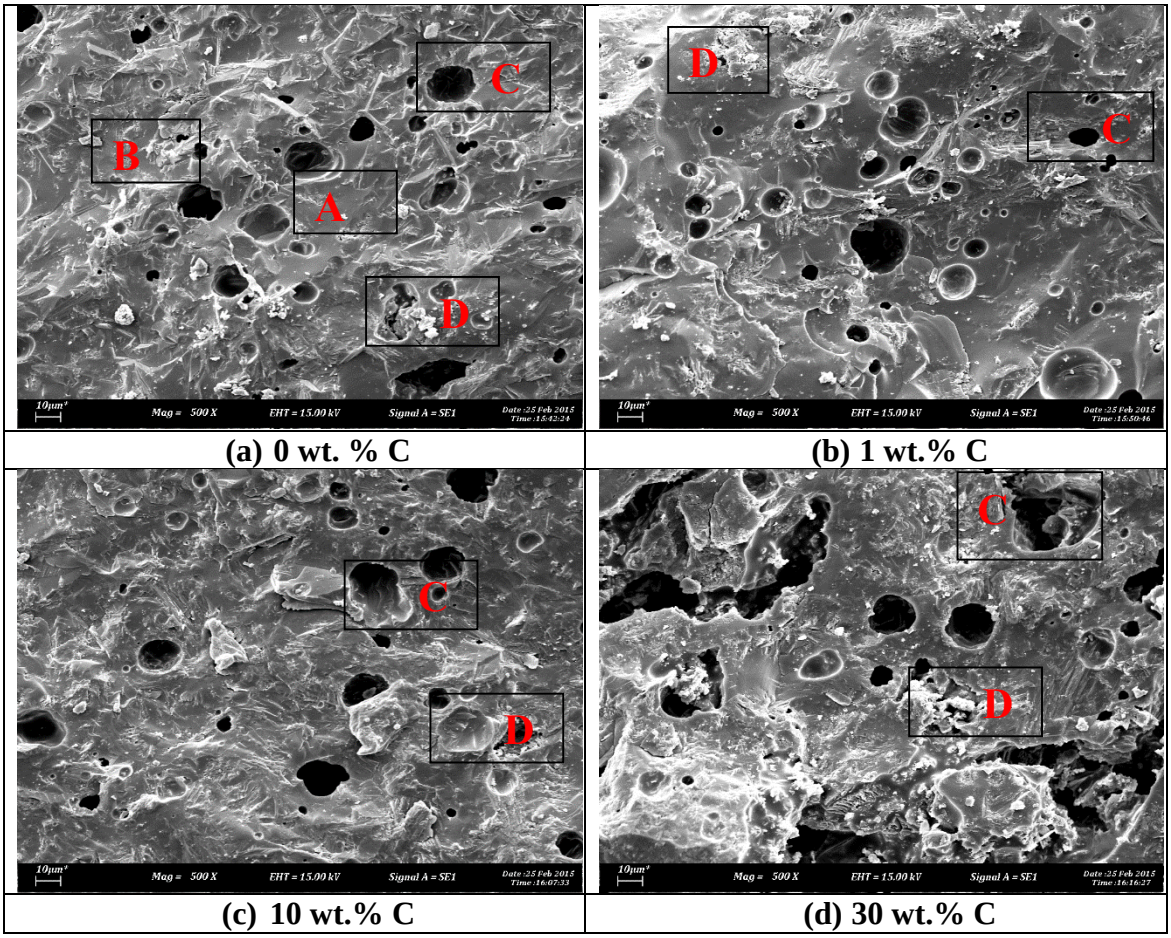


Figure 3. The modulus (MOR) and bulk density of SLS glass-ceramic with various carbon content, wt. %

The SEM micrographs of bending fractured surface of the sintered glass-ceramic filled with 0, 1, 10, 30 wt. % C are shown in Figures 4 (a) to (d). It was observed that the surface microstructure consisted of three main features which is a dense surface (A), coarse feature (B), open pores (C) and closed pores (D). The even dense surface shows a smooth appearance possibility representing quartz phase (Joui et al., 2011). In the

absence of charcoal content, the apparent pore size is in the range of 5 μm to 12 μm (Figure 4(a)). At 1 wt. % C, the distribution of the open and close pores is appeared to be similar with the unfilled fired specimens (Figure 4(b)). The fired specimens with addition of the lowest wt. % C fine charcoal powder exhibited the lowest water absorption capacity, which could be explained by the least porosity. At 10 wt. % C, the number of pores is become more apparent with average size of 27μm (Figure 4(c)). It is also observed that the appearance of the dense fracture surface is rougher and the distance between the pores is nearer. As the carbon content increased to 30 wt. % C, the pores size increased with average of 42 μm and appeared to be more interconnected, possibly due to agglomeration of the carbon powder as well as their higher amount on which reduce the distance between the carbon particles (Figure 4(d)). This morphology finding is in correlation with the porosity and modulus analysis. All the fired specimens exhibited discoloration due to release of large volumes of CO_2 from the combustible charcoal.



(a) 0 wt. % C **(b) 1 wt.% C**

(c) 10 wt.% C **(d) 30 wt.% C**

Figure 4. SEM micrographs of fracture surface glass-ceramic with different carbon loading: (a) 0 wt.% C; (b) at 1 wt.% C; (c) at 10 wt.%C; (d) at 30 wt.% C

4.0 CONCLUSION

Glass-ceramic material incorporating ball clay and SLS waste glass filled with carbon powder was produced by firing at 850°C at a rate of 2°C/min and one hour soaking time. The addition of charcoal is mainly designed to produce lightweight and more porous fired specimens. Phase analysis of the fired body revealed the main types of crystalline phases, which are quartz and wollastonite. The effect of carbon powder content (wt. % C), on physical, mechanical and microstructural properties were studied. The linear shrinkage, porosity and water absorption of the glass-ceramic increased with an increase in carbon content. In contrast, however, their modulus of rupture and density value reduced with the carbon content. The optimized strength of the carbon filled glass-ceramic is shown at 1 wt. % C with MOR of 48.2 MPa, bulk density of 4.3 % and projected the lowest porosity percentage of 1.79%, water absorption of 0.77%, linear shrinkage of 12.89% and average pore size between 5 μm to 12 μm. The microstructure of optimized sintered glass-ceramic consist of dense even surface with small amount of open pores. It was also observed that the pore size could be controlled by the addition of charcoal carbon content. This glass-ceramic composite may be used as potential porous as well lightweight materials, humidity-controlling building material and other applications.

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