Physical Properties of Porcelain Ceramic with Influence of Milled Alkali Resistant (AR) Fibreglass for Sewer Pipes Application

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ABSTRACT

The aim of the present work is to explore the use of commercial porcelain ceramic with influence of milled Alkali Resistant (AR) fiberglass for sewer pipes application. In this study, AR fiberglass was milled into an average particle size of 90µm and mixed with porcelain in different weight percentages of 3 wt%, 6 wt%, 9 wt%, and 12 wt%. The sample was prepared by using powder compaction and fired for 2 hours at 900°C, 1000°C, 1100°C and 1200°C. The result of apparent porosity and bulk density were recorded for each sample. Scanning Electron Microscope (SEM) were used to observe the microstructural morphology for some samples. Based on the result, the best sintering temperature was at 1200°C. In which the optimum apparent porosity obtained was 0.30% with addition of 9wt% AR glass. Meanwhile, the best value for density gained was 2.45g/cm^3 at 3wt% of AR glass. Reduction of porosity with formation of glassy phase due to the addition of AR glass and elevation of sintering temperature were evident from the microstructural image.

Keywords: *Pipes, porcelain, AR Glass, density and porosity*.

Introduction

The application of pipes can be seen essential in this day and normally, it is used in water and sewage system. The materials involved in pipes

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manufacturing include cast iron, plastic, concrete and ceramic. Commonly, industrial and municipal demand a tough pipe for sewer pipes application that required a resistance to mechanical load and chemical attack. The used of clay material for sewer pipe application is satisfactory due to their high resistance to chemical, corrosion, heat and abrasion [1].

The process to manufacturing these pipe involve mixing of three different materials, i.e, feldspar and grog. The mixture is then extruded in a pug mill and dried before sintering process that takes places at 1250 °C [2]. However, mixing and manufacture sewer pipes form these three materials are time and cost consuming. Therefore, porcelain is selected as alternative material to manufacture the pipe because it is comprising of tri-axial body with least cost in contrast to the current materials (Terra Cota clay, feldspar and grog). Hence, mixing can be eliminated. Moreover, porcelain normally used in chemical ware application and it is vitreous (no porosity) to enhance the physical properties of the pipe material [3]. It can be conclusively observed that, porcelain shows better properties from other white ware ceramic. Table 1 shows a typical value of physical properties for white ware ceramics.

Table 1: Typical value of Physical properties for white wares ceramic [4]

Description	Earthenware	Stoneware	Porcelain
Bulk Density (g/cm^3)	2.20	2.30	2.40
Apparent porosity (%)	5 - 20	0 - 5	0.0 0.5

The study by Ghugal & Deshmukh [5] reveals that the strength of Portland cement maintains for long period with inclusion of AR glass. Moreover, AR glass was potential to prolong the strength of the material when embedded with ceramic compared to E glass which their durability affects by alkali and corrosive attack. As expected form this study, the inclusion of Alkali Resistant (AR) glass will function as fluxes to form a eutectic and satisfy the typical value of physical properties at optimal sintering temperature.

Experimental setup

The main raw materials utilised for this study is porcelain are ceramic clay and Alkali Resistant (AR) glass fibre. Both of the material were refined into powder with size less than 90µm using planetary ball mill with speed of 150 rpm. Then, AR glass powder is mixed with the porcelain ceramic as in different weight percentages of 3 wt%, 6 wt%, 9 wt% and 12 wt%. Polyethylene Glycol (PEG) is added at 1 wt% to the mixture as binder for green body formation. The sample is fabricated according to ASTM C1161-15 using configuration C (rectangular bar). The powder mixture is compacted using uniaxial pressing technique with 3 Ton of pressure load at one minutes of holding time. The green body of compact sample then assigned for sintering process with temperature of 900 °C, 1000 °C, 1100 °C and 1200 °C. Figure 1 displays the sintering profile for this study.

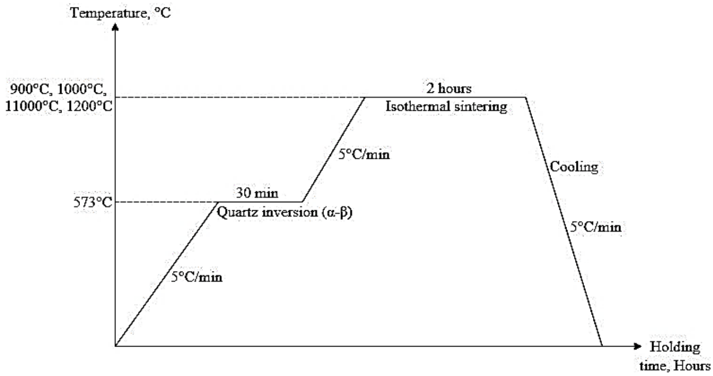


Figure 1: Sintering profile for this study

Initially, the microstructure morphology is observed at surface of the sample using Field Emission Scanning Electron Microscope (Hitachi, Japan) with 3000x magnification and an accelerating voltage of 15kV. Then, all samples had undergone the porosity and density measurements. These measurements were conducted according to ASTM C373-14, whereby the entire sample is submerged into water and boiled for five hours. After that, the entire sample is soaked at ambient temperature in 24 hours. The test was conducted by taking the weight of dry, suspended and saturated mass for all samples.

Results and discussion

Apparent porosity

The strength of ceramic structure would depend on the amount of porosity formation because large void formation tends to reduce the strength of ceramic product. Figure 2 displays the relationship between apparent porosity and addition of AR glass.

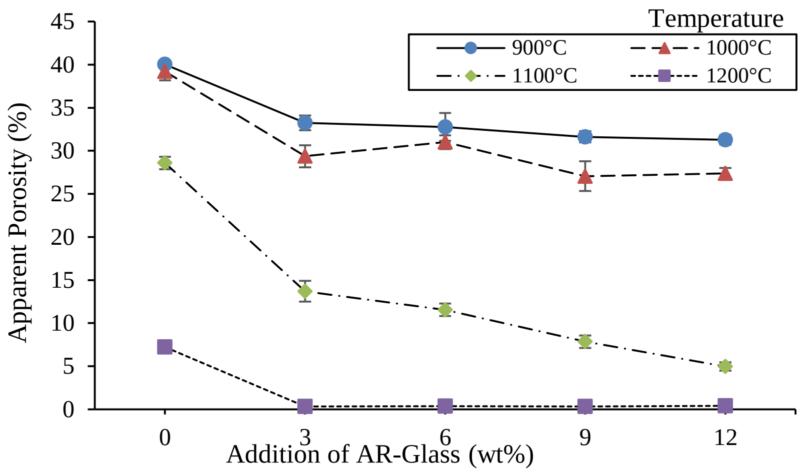


Figure 2: Graph of apparent porosity of samples with and without addition of AR glass, sintered at various temperatures

It is clear that sintering temperatures of 900 °C and 1000 °C produces higher percentage of porosity with ranges of 27.06% to 40.05% as compared to 1100 °C and 1200 °C. The highest value of porosity found to be 40.05% for samples with no addition of AR glass. Sintering temperature line series denoted that the sintering temperature is significant in lowering the apparent porosity of ceramic material. The 1200 °C series can be interpreted as optimum sintering temperature condition. The higher porosity formation is due to non-contact surface at low sintering temperature that produces a large void [6]. Meanwhile, the temperature of 1100 °C and 1200 °C displayed a lower apparent porosity at ranges 0.30% to 28.59%. This is because, higher sintering temperature will cause the formation of liquid phase that functioned to aid the particle consolidation [7]. The lowest apparent porosity value was observed on samples with 9 wt% of AR glass addition sintered at 1200°C resulting 0.30%. It can be observed that the addition of AR glass to the porcelain ceramic shows the effect of lowering the apparent porosity significantly.

The trend appears to be decreasing when AR glass was embedded but the addition of AR glass composition to the porcelain ceramic produces a small different in reducing porosity since the trend is only slightly decreasing. It can conclusively state that the optimum value of porosity occurs at 1200°C with addition of AR glass as in line with typical value of porosity for porcelain ceramic that is 0% to 0.5%.

Bulk Density

The result of density is provided based on AR glass addition and sintering temperature. Density is normally correlated with apparent porosity in view of the fact that the void formation will decrease the density of the ceramic product. The result of density is illustrated in Figure 3.

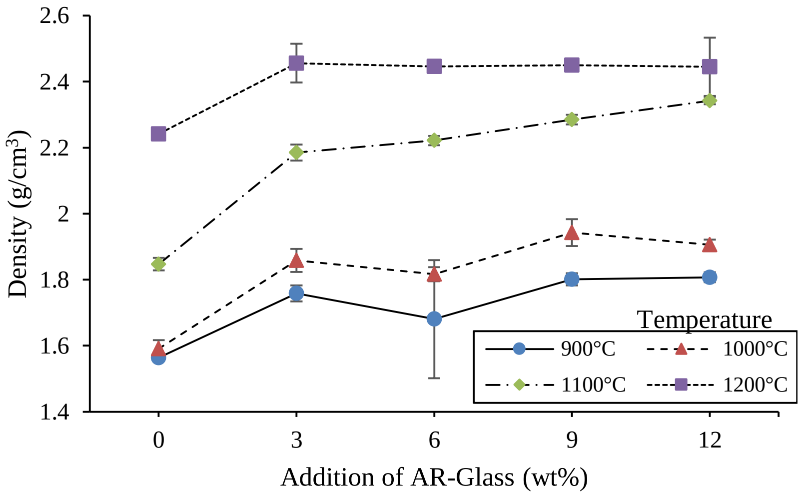
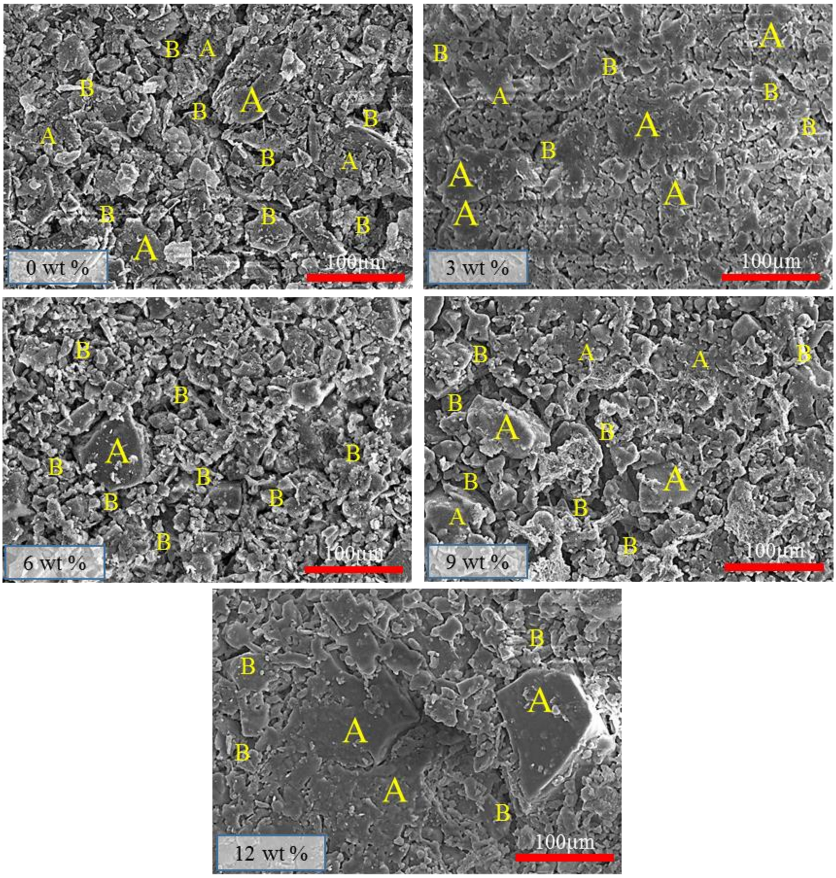


Figure 3: Density of samples with and without AR glass at different sintering temperatures

Based on Figure 3, its reveal the sintering temperatures of 900°C and 1000°C yield lower density which is around 1.56g/cm^3 to 1.94g/cm^3. The higher densified body starts to form at 1100 °C and 1200 °C with ranges of 2.18g/cm^3 to 2.45g/cm^3. As reported by Jumali et al., grain growth intensifies the liquid phase in higher amount and assists the arrangement as well as diffusion of particle when the sintering temperature rises [8]. The lowest value of bulk density is found to be 1.56g/cm^3 while highest density value turns out at 2.46g/cm^3. It can be observed that elevation of sintering temperature denoted a higher value of bulk density where the maximum density produces at upper line series (1200°C). The addition of AR glass can be seen increasing the value of density significantly but it is visible that the multiplication of AR glass addition shows insignificant rises. This may be due to the trapped of closed pores in low viscosity at quasi-liquid phase which obstruct the body shrinkage [9]. Thus, it can be said that the temperature of 1200 °C produces a high density and fulfil the standard value of bulk density for porcelain (2.4g/cm^3).

Microstructural Morphology

Figure 4 displays the microstructural image for 1000°C with different AR glass composition.



A – Quartz Relict, B – Porosity/void

Figure 4: Morphology of samples with various addition of AR glass at 1000°C

It is obvious from Figure 4 that the incomplete grain growth results in large and numerous porosity formations. The image manifest that the existence of some quartz relict as well as scatter particle diffusion can be seen, which affecting lower density to the body due to the non-existence of glassy phase.

The image corresponds to the higher porosity and lower density values (Figure 3, 1.5g/cm^3 to 1.9g/cm^3). Figure 5 reveals a microstructural image of selected samples sintered at 1100 °C.

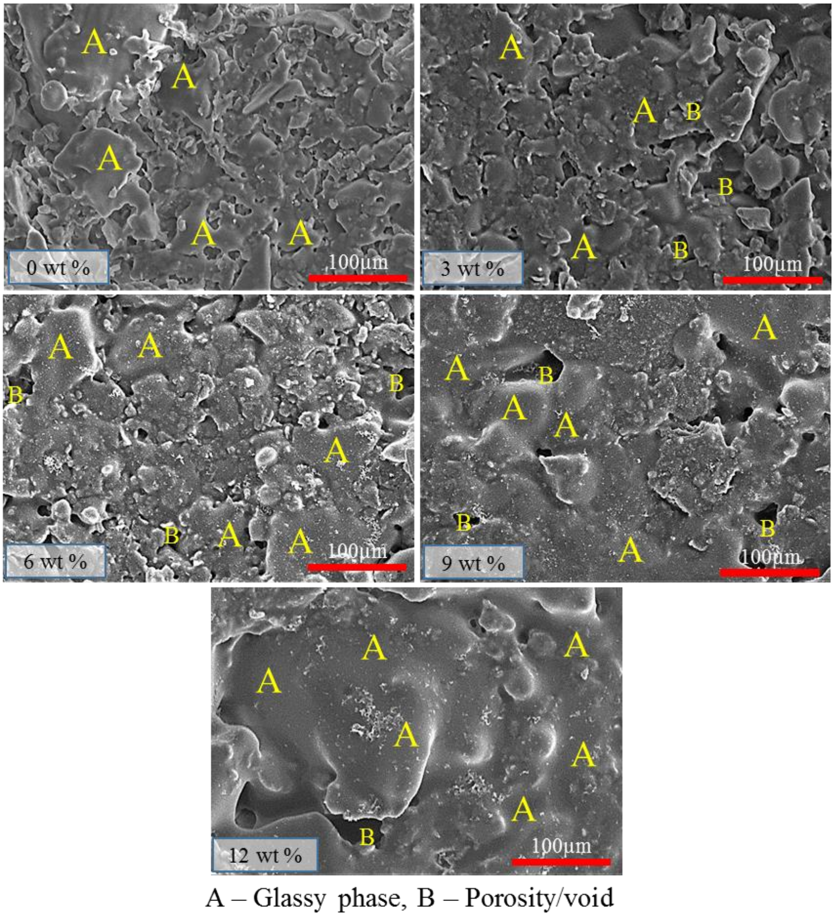


Figure 5: Morphology of samples with various additions of AR glasses sintered at 1100°C

It can be observed from the Figure 5 that occurrence of porosity reduction is caused by existence of glassy phase which yielded a dense body. The existence of glass phase occurs due to the elevation of sintering temperature which encourages the formation of liquid phase and helps the merging of particles producing a dense body [10]. Thus, the addition of AR glass can be seen as fluxes where much glass phase was acquired.

Conclusion

In this study, the attempt of using porcelain as alternative material to manufacture pipes for sewer application was successfully done. The feasibility of using porcelain with milled AR glass as fluxing agent has been demonstrated. In which the AR glass can speed up the vitrification process to the porcelain ceramic where addition of 9 wt% shows favourable properties (1.8g/cm3 to 2.45g/cm3) of porcelain ceramic. The optimum porosity and density value with sample sintered at 1200°C where the result satisfy the typical value of physical properties for porcelain where the result produce was lower than 0.5 of apparent porosity and more than 2.4g/cm^3 for bulk density.

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