Mechanical properties and fracture observation of green innovative glass ceramic tile made from waste

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ABSTRACT – Green Innovative Glass (GIG) tiles uses waste glass powder as a part of the composition of the clay mixtures. There are two types of GIG tiles formulation, namely green and white formulation. Mechanical testing for GIG tiles and unglazed porcelain ceramic tiles were carried out and their fracture behaviors were analyzed in order to correlate its mechanical properties performance with the structural characteristic of the GIG and its sintering mechanism. The performances and behavior are also compared to unglazed porcelain ceramic tiles (UPCT). Methodology of work involved sample identification, three-point bending test followed by fracture analysis on the fractured surface. Green GIG shows the highest stress absorption with 46 kN/mm^2, while white GIG is 36 kN/mm^2 and unglazed porcelain ceramic tiles is 33 kN/mm^2. XRD analysis shows that green and white GIG consists of wollastonite, cristobalite, and fosterite. In contrast, unglazed porcelain ceramic tiles consist of cristobalite and para-wollastonite. Fracture analysis shows that the unglazed porcelain ceramic tile is having an alignment of crack propagation originated to large grains in material. While in the GIG samples, cracks propagate more disperse and caused by the microcracks due to transgranular and intergranular fracture. Green GIG shows the deepest crack as it is able to repel lots of stress with less elongation.

1. INTRODUCTION

Green Innovative Glass (GIG) Ceramic tile is a ceramic tile that uses waste glass powder arising from municipal wastes. The basic raw material used for fabricating GIG is soda lime silica glass (SLSG) originated from waste glass containers or bottles. The GIG tile is produced by direct sintering method via viscous sintering mechanism at lower sintering temperature of 850^{o}C compared to the unglazed porcelain ceramic tiles, which is produced, by solid-state sintering mechanism at higher sintering temperature of commonly 1200^{o}C. The sintering mechanism would influence the mechanical properties and fracture behavior of the ceramic tiles according to previous studies [1]. Therefore, the mechanical performance and fracture observation of unglazed porcelain ceramic tiles with GIG tiles were analyzed in this work. The comparison based on the mechanical performance and fracture behavior in relation to the crystal phases identified of GIG and unglazed porcelain ceramic tiles is essential to relate on how the sintering mechanism influence the performance of the GIG tiles. This enables better understanding of the performance of GIG and unglazed porcelain ceramic tiles related to its sintering mechanism.

2. EXPERIMENTAL PROCEDURE

White GIG tile are made using 90 wt. % transparent waste soda lime silicate glass (SLSG) and 10 wt.% clay while green GIG tile are using 85 wt. % green waste SLSG and 15wt% clay. Samples were formed using uniaxial die press and sintered at 850^{o}C for 2 hours soaking duration with 10 ^{o}C/ min heating and cooling rate. The unglazed porcelain ceramic tiles were bought from a common distributor. Crystalline phases analyses were preformed using XRD, Cu Kα (α= 0.15406 nm) radiation in a Panalytical Xpert Pro system in 2θ angle in a range of 20-80^{o}C with step size 0.05. The sample size was 10mm x 10mm x 10mm. Three-point flexural test were conducted according to ISO 10545-4 for determination of modulus of rupture (MOR) and breaking strength of ceramic tiles. All samples were 100mm x 50mm with constant thickness of 10mm and each testing employed 10 pieces of samples. Loads applied evenly with a constant increasing rate of 1 N/mm^2 per second. Samples which fractured within the central contact point of the samples and the loading rods were taken as a valid sample for fractured surface observation using optical microscope.

3. RESULTS AND DISCUSSION

3.1 Modulus of Rupture and Breaking Strength

Figure 1 shows the maximum stress and stroke for unglazed porcelain ceramic tiles, white and green GIG tiles use for the calculation of Modulus of rupture for each type of tiles. For the 10 samples of unglazed porcelain ceramic tiles, the maximum stress is 33 kN/mm^2 ± 6.42%. While for white and green GIG tiles, the maximum stress is 36 kN/mm^2 ± 10.47% and 46 kN/mm^2 ± 16.02%; respectively. Here, the green GIG tiles are able to resist higher amount of stress compared to white GIG tiles and unglazed porcelain ceramic tiles.

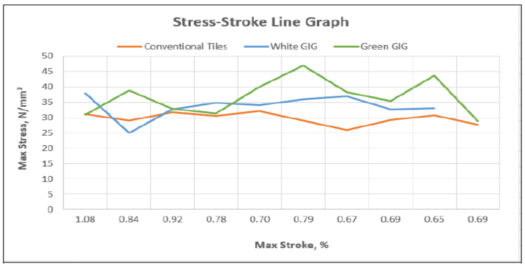


Figure 1 Maximum stress and stroke for unglazed porcelain ceramic tiles, white and green GIG

3.2 *Phase Analysis*

Figure 2 shows the XRD diffractogram of unglazed porcelain ceramic tiles and white and green GIG tiles. In unglazed porcelain ceramic tiles, cristobalite peaks are identified at 20.79° and 26.58, while para-wollastonite is identified at 33.19° and 25.25°. In contrast, for white and green GIG tiles, wollastonite (18.80°, 27° and 29°), cristobalite (21.86°) and fosterite (29.93° and 32.32°) were identified in each diffractogram. In GIG tiles, waste SLSG supplied more silicon to enable formation of more silicate crystalline phases. During the viscous glass sintering of GIG, the SLSG waste glass reacts with clay forming a glass ceramic system that contributes to high mechanical properties. GIG tiles have high peak of wollastonite and cristobalite which correspond to the major phase of glass. This is in contrast to the unglazed porcelain ceramic tiles that use clay, quartz and feldspar (common ceramic material) and formed via solid-state sintering mechanism as previous study [2].

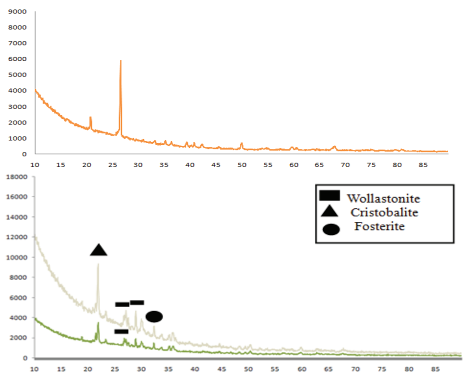


Figure 2 XRD Diffractogram of a) unglazed porcelain ceramic tiles b) white and Green GIG

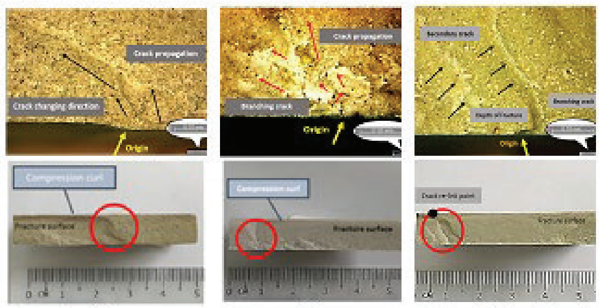
3.3 *Fracture Observation*

Figure 3(a) shows the fracture on the unglazed porcelain ceramic tiles were not properly align compared to white GIG ceramic tiles fracture alignment (Figure 3(b)) and green GIG tiles (Figure 3(c)). It also shows that GIG tiles have more consistent fracture alignment from the centre line (point of contact) compared to the unglazed porcelain ceramic tiles.

(a) (b) (c)

Figure 3 The fractured sample observation of a) unglazed porcelain ceramic tiles b) white GIG and c) Green GIG

Figure 4 shows the fracture propagation of unglazed porcelain ceramic tiles and GIG tiles. Generally, all samples fractured in a brittle manner with practically no ductility. The cracks on sample of green GIG are deeper than the other two types of samples. This shows that the Green GIG is able hold high amount of stress as it creates deeper cracks.



(a) (b) (c)

Figure 4 Fracture propagation of a) unglazed porcelain ceramic tiles b) white GIG and c) Green GIG

4. CONCLUSIONS

Green GIG possesses the highest amount of maximum stress prior to fracture. GIG tiles consist of wollastonite, cristobalite, and fosterite. While, unglazed porcelain ceramic tiles consist of cristobalite and para-wollastonite. The increased mechanical properties of GIG tile is due to the viscous sintering mechanism that had produced GIG tile of glass ceramic system. This is evidence by the deep crack observation of fracture propagation in all the GIG samples. In contrast, an unglazed porcelain ceramic tile is based upon ceramic system produced via solid state sintering.

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