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# POSSIBILITY OF USING RECYCLED WASTE MEDICAL-GLASS AS FINE AGGREGATE IN NORMAL-STRENGTH CONCRETE

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## Abstract

The possibility of using recycled waste medical-glass aggregate (RGA) as a fine aggregate in the production of normal-strength concrete was investigated in this study. The influence of RGA as crushed sand (CS) replacement at different levels (by volume) of 0 – 100% (an interval of 20%) on the engineering properties and durability of concrete was also studied. Results show that the replacement of CS by RGA insignificantly affected the workability and unit weight of fresh concrete mixtures. Besides, using RGA to replace 20 – 60% CS was beneficial in terms of compressive strength, drying shrinkage, and ultrasonic pulse velocity (UPV). At these replacement levels, the dry density values were found to increase and the water absorption values were reduced as well. However, replacing CS with RGA up to 80% and 100% caused a reduction in compressive strength, dry density, and UPV and an increase in water absorption and drying shrinkage of concretes. Closed correlations among the above-mentioned concrete properties were also found in this study. All of the concrete samples obtained compressive strength values higher than the target strength (≥ 25 MPa) and they were classified as very good quality concretes with UPV values of above 4100 m/s. The experimental results demonstrate a high possibility of producing normal-strength concrete with a fine aggregate of RGA as either partially or fully replacement of CS. This also provides an environmentally-friendly solution for recycling waste medical glass in construction materials for sustainable development.

*Keywords:* normal-strength concrete; recycled waste medical-glass aggregate; engineering properties; compressive strength; durability.

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## 1. Introduction

Treating and recycling medical wastes are always the most concerning problem. Especially after the Covid-19 pandemic, a large number of medical wastes have been eliminated, such as plastics, face masks, and glasses [1–4]. Total medical waste generated in Asia is around 16,659.48 tons/day, followed by Iran, Pakistan, Saudi Arabia, Bangladesh, and Turkey with the medical waste generation of approximately 1000 tons/day [2]. Particularly, the medical wastes in China and Barcelona are

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daily generated over 240 tons and more than 275 tons, respectively [5]. In Vietnam, the daily generated amount of wastes in 2020 was 800 tons. In which, the glass bottles of medical drugs account for 3% and only Hue Central Hospital of Vietnam daily discharges approximately 300 kg medical glass bottles [6]. Currently, the most common treatment method for medical solid wastes is burning [7]. However, this method causes air contamination in the long term. The medical wastes are more dangerous than general solid wastes because it contains lots of viruses, germs, chemical pollutants, and even radioactive materials [8]. Therefore, it is necessary to study another effective treatment for medical wastes to reduce environmental and health problems.

In recent years, several studies have been pointed out that waste medical glass can be re-used as a source of construction materials. In which, waste medical glass can be used as a binder to replace cement [6] or as aggregates [4]. Additionally, bacterias combined with waste medical glass were added into bio-concrete to enhance the engineering properties of the concrete [4]. The waste medical glass containing a high percentage of silica exhibits high potential application for concrete production [9]. Mohammed et al. [10] studied the influence of replacing natural fine and coarse aggregates with waste glass aggregates (at the replacement ratios of 0%, 5%, 10%, 15%, and 20% by volume) on the mechanical properties of concrete including compressive strength, splitting tensile strength, and flexural strength. The authors found that the substitution of natural aggregates by waste glass aggregates reduced the compressive strength, flexural strength, and density of concrete while the splitting tensile strength and water absorption of some concrete mixtures were increased. Although the incorporation of waste glass aggregates negatively affected the mechanical strength of concrete samples, they still could be used for structural applications. On the other hand, Chen et al. [11] evaluated the properties of concrete blocks including waste glass cullet aggregates as a partial substitution for natural fine aggregates in the concrete mixtures. The authors stated that the irregular shape of the glass aggregates may reduce the compactness of the concrete block and the weak bond between waste glass aggregate and cement paste also reduced the compressive strength of the concrete blocks. However, a minimum compressive strength value of 30 MPa could be obtained for concrete containing up to 50% glass aggregates. Besides, Ling and Poon [12] investigated the use of waste funnel glass as a fine aggregate in concrete blocks produced at different aggregate-to-cement ratios. In which, the waste glass aggregate was used to replace the recycled fine aggregate in the concrete mixtures at the replacement levels of 50% and 100% (by volume). The authors reported that the inclusion of waste glass limits the growth of shrinkage and water absorption of the concrete blocks due to the hydrophobic nature and low absorption capacity of the waste glass. The results also pointed out a high possibility of using waste funnel glass in concrete blocks at a high percentage when a proper aggregate-to-cement ratio and an appropriate casting method were used. Moreover, Truong and Le [13] studied the feasibility of using medical glass as a coarse aggregate, where the medical glass aggregate was used to fully replace natural coarse aggregate in concrete mixtures. The compressive strength and thermal conductivity coefficient of the medical glass concrete were determined. The authors concluded that the concrete incorporating 100% medical glass as coarse aggregate achieved a compressive strength value at 28 days of about 17 MPa, which could be applied to non-bearing concrete structures. The authors also reported that the medical glass concrete exhibited better heat isolation than the normal aggregate concrete. Furthermore, adding waste glass can remove nitric oxide thanks to the photocatalytic performance of concrete surface layers [14], and using waste glass helps to cut down the amount of $CO_2$ emission as well as the consumption of natural aggregates [15, 16].

In Vietnam, although the official reports on the disposal of waste medical glass from the local hospitals have been limited, the real quantity of such waste is significant and the waste medical glass has been recycled as an aggregate in concrete for a few years [13]. A previous study showed that waste medical glass could be used successfully in the production of low-grade concrete [13]. Also, most of the above-mentioned studies [4, 6, 9–13] focussed on the mechanical properties of concrete/ blocks containing waste glass from different sources. Other important characteristics of waste medical glass-concrete such as ultrasonic pulse velocity (UPV) and drying shrinkage as well as the correlations among the concrete properties have not been well-discussed. Therefore, the utilization of the locally available waste medical glass as fine aggregate in the production of normal-strength concrete is investigated in this study. The waste medical glasses sourced from a local hospital (in Southern Vietnam) were collected and recycled into a fine aggregate, which was used to partially or fully replace a crushed sand (CS) in normal-strength concrete mixtures with the target strength of 25 MPa (grade M25). The effects of the recycled waste medical-glass aggregate (RGA) substitution on both fresh (workability and unit weight) and hardened properties (dry density, compressive strength, water absorption, drying shrinkage, and UPV) of concrete were studied and discussed. Furthermore, this study also provides an environmentally friendly solution for recycling waste medical glass in construction materials. By the way, both the environmental pollution and the depletion of natural resources (natural aggregates) were limited effectively for the goal of sustainable development.

## 2. Materials and experimental works

### *2.1. Materials and mixture proportions*

(a) Cement (b) FA (c) CS

(d) RGA (e) Stone (f) SP

Figure 1. Raw materials used in this study

Raw materials used for the preparation of concrete samples are presented in Fig. 1. In which, type-PCB40 Portland cement blended (Fig. 1(a)) and type-F FA sourced from a thermal power plant in Southern Vietnam (Fig. 1(b)) with a respective specific gravity of 3.09 and 2.22 were used as binder materials. Chemical compositions of both cement and FA are shown in Table 1. Besides, CS (Fig. 1(c)) and RGA (Fig. 1(d)) were used as fine aggregates with their gradation, density, water absorption, and fineness modulus (FM) were shown in Fig. 2. Whereas, natural stone (Fig. 1(e)) with density and water absorption of 2711 kg/m$^3$ and 0.6%, respectively was used as coarse aggregate. The procedures for the preparation of RGA are briefly described in Fig. 3. The gradation and water absorption of the aggregates were determined following TCVN 7572-2:2016 [17] and TCVN 7572-4:2016 [18], respectively. Type-G superplasticizer (SP) (Fig. 1(f)) with a density of 1150 kg/m$^3$ was utilized to modify the workability of fresh concrete mixtures and local tap water was used for the mixing of concrete. Once again, it is important to note that the RGA was prepared by crushing and sieving the waste medical glasses collected from a local hospital in Southern Vietnam.

Table 1. Chemical compositions of cement and FA used in this study

| Compositions (% by mass) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | LOI. | Others |
|---|---|---|---|---|---|---|---|
| Cement | 23.5 | 6.0 | 3.7 | 2.0 | 59.9 | 1.1 | 3.8 |
| FA | 59.2 | 26.7 | 6.1 | 0.9 | 1.1 | 3.9 | 2.1 |

Note: LOI. = Loss on ignition.

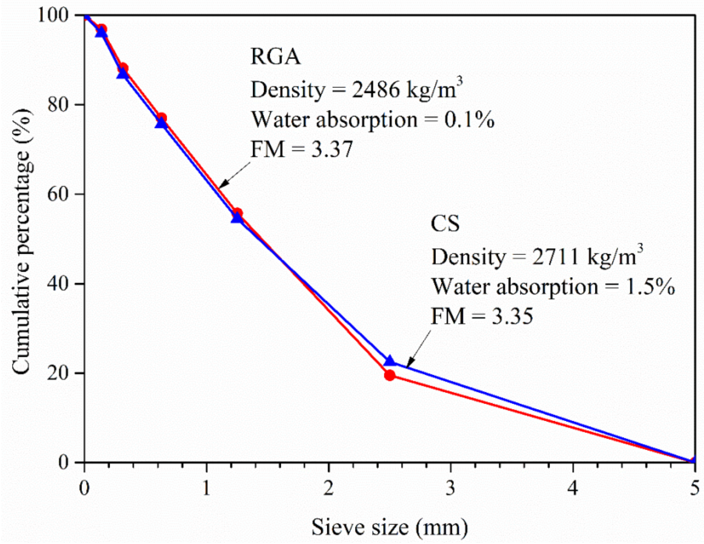

Figure 2. Gradation curves of fine aggregates

A densified mixture design algorithm (DMDA) technology as previously described by Chen et al. [19] was applied for the mix proportioning of concretes with a target strength of grade M25 (≥ 25 MPa at 28 days) according to TCVN 6025:1995 [20]. To investigate the effect of RGA incorporation on the engineering properties of the concrete, six concrete mixtures were designed with the same water-to-binder ($w/b$) ratio of 0.45 (see Table 2) and RGA was used to either partially or fully replace CS at different replacement levels (by volume) of 0% (G00 mix), 20% (G20 mix), 40% (G40 mix), 60% (G60 mix), 80% (G80 mix), and 100% (G100 mix).

Figure 3. Procedures for the preparation of RGA

Table 2. Mixture proportions of concrete samples

| Mix designation | Cement (kg/m$^3$) | FA (kg/m$^3$) | CS (kg/m$^3$) | RGA (kg/m$^3$) | Stone (kg/m$^3$) | Water (kg/m$^3$) | SP (kg/m$^3$) |
|---|---|---|---|---|---|---|---|
| G00 | 300 | 86 | 904 | 0 | 962 | 174 | 2.11 |
| G20 | 300 | 86 | 718 | 180 | 962 | 174 | 2.19 |
| G40 | 300 | 86 | 536 | 357 | 962 | 174 | 2.31 |
| G60 | 300 | 86 | 355 | 532 | 962 | 174 | 2.38 |
| G80 | 300 | 86 | 176 | 706 | 962 | 174 | 2.50 |
| G100 | 300 | 86 | 0 | 877 | 962 | 174 | 2.54 |

Note: FA = fly ash; CS = crushed sand; RGA = recycled waste medical-glass aggregate; SP = superplasticizer.

### 2.2. *Sample preparation and test methods*

All of the raw materials were prepared according to the proportions as calculated in Table 2. It is noted that SP was mixed with water before being used. Based on previous experiences [21, 22] and ensuring the homogeneous mixtures, the procedures for preparing the concrete samples were briefly summarized in the following steps: Step 1: cement, FA, and a part of SP-water were mixed in a mechanical mixing bowl for 2 minutes. Step 2: fine aggregates including CS and RGA were added to the mixer and mixing continued for additional 3 minutes. Step 3: coarse aggregate was finally added to the mixture followed by the last part of the SP-water and mixed continuously for further 2 minutes to obtain a homogenous mixture. Step 4: Right after that, the fresh concrete mixture was immediately checked for workability and then concrete samples of various sizes were cast for different test methods. Step 5: The concrete samples were de-molded after 24 hours and cured in saturated-lime water until the testing time. Exception for the drying shrinkage test, after casting, the concrete samples were cured at a temperature of 23°C and relative humidity (RH) of 100%. These samples were then de-molded and immediately taken initial length reading. After that, these samples were cured at an ambient temperature of 23°C and an RH of 60% until the testing time [23].

Slump and unit weight of fresh concrete mixtures were measured right after mixing following the TCVN 3106:1993 [24] and TCVN 3108:1993 [25], respectively. The apparatus used for testing slump and fresh unit weight of fresh concrete mixtures are shown in Figs. 4(a) and 4(b), respectively. The test of compressive strength of the 150 × 150 × 150 mm concrete samples was conducted at 7 and 28 days in accordance with TCVN 3118:1993 [26], using a computer-controlled compression testing machine with 3000 kN capacity (Fig. 4(d)). In addition, water absorption, dry density, and UPV of concretes were determined at 28 days according to the guidelines of TCVN 3113:1993 [27], TCVN 3115:1993 [28], and TCVN 9357:2012 [29], respectively. The cubic concrete samples of 150 × 150 × 150 mm were used for water absorption and dry density measurements (Fig. 4(c)) while the UPV of cylindrical concrete samples of ∅100 × 200 mm were measured using an ultrasonic concrete tester as shown in Fig. 4(e). Moreover, a length comparator (Fig. 4(f)) was used to measure the drying shrinkage of the concrete samples of 75 × 75 × 285 mm in dimensions at 0, 7, 14, and 28 days after casting following the guidelines of TCVN 3117:1993 [30].

(a) Measurement of the slump

(b) Measurement of fresh unit weight

(c) Measurement of water absorption

(d) Measurement of compressive strength

(e) Measurement of UPV

(f) Measurement of drying shrinkage

Figure 4. Apparatus used for testing of concrete properties

## 3. Results and discussion

### 3.1. Properties of fresh concrete

To ensure the homogeneity of the concrete's engineering properties evaluation, the slump values of all of the concrete mixtures designed for this study were controlled in the range of 10 ± 2 cm, which are the common slump values used in real practice, by using various SP dosages (see Table 3).

A typical slump of fresh concrete mixtures is shown in Fig. 4(a). It could be observed from the experiment that the dosage of SP required for the concrete mixtures containing different RGA contents to get the slump value in the designed ranges was changed insignificantly. This is due to the similar geometry granular of RGA in comparison to CS. On the other hand, it is found that the fresh unit weight of the concrete increased when the CS was replaced by RGA up to 60% and then declined at the replacement levels of above 60%. The slight increment of the unit weight values of fresh concrete mixtures containing 0 – 60% RGA may be due to the increase of solid materials and the reduction of water content in the mixture, which was attributable to the extremely low water absorption of RGA in comparison with that of CS. In the case of replacing CS with RGA at relatively high levels (80% and 100%), the slight reduction in the unit weight of the concrete mixtures was mainly due to the lower density of RGA in comparison with the CS [9, 10].

Table 3. Slump and unit weight of fresh concrete mixtures

| Mix designation | Slump (cm) | Unit weight (kg/m$^3$) | % SP |
|---|---|---|---|
| G00 | 11 | 2397 | 0.55 |
| G20 | 10 | 2426 | 0.57 |
| G40 | 11 | 2429 | 0.60 |
| G60 | 10 | 2451 | 0.62 |
| G80 | 10 | 2330 | 0.65 |
| G100 | 11 | 2322 | 0.65 |

### 3.2. Compressive strength

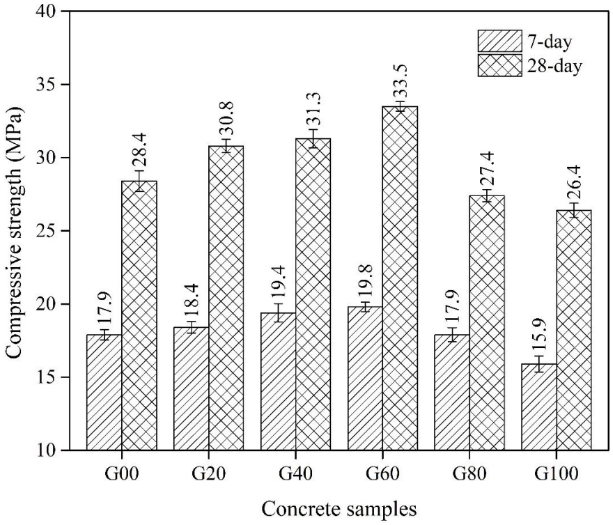

Figure 5. Compressive strength of concrete samples

The results of the compressive strength measurement for all concrete samples at the ages of 7 and 28 days are displayed in Fig. 5. The compressive strength value of the RGA-free sample at 28 days was 28.4 MPa. Partially replacing CS by 20%, 40%, and 60% RGA positively contributed to the strength growth as the compressive strength values of the concretes increased by 8.5%, 10.2%, and 18.0%, respectively. The increase in compressive strength may be attributed to the angular shape of the RGA particle, which has a greater surface area than that of CS [31], leading to better bonding between aggregates and paste and resulting in a stronger concrete matrix [31]. Another possible reason for the increased strength was the very fine RGA particles may have a pozzolanic reaction with the cement hydration product, forming cementitious products [32] and hence improving the compressive strength of concretes.

However, the compressive strength values of concrete samples were slightly dropped after replacing more than 60% CS by RGA. The concrete samples containing 80% and 100% RGA had the compressive strength values at 28 days of 24.7 MPa and 26.4 MPa, which was about 3.5% and 7.0% lower than the strength value of the no RGA concrete sample, respectively. One of the main reasons for the declined compressive strength at very high RGA replacement levels (80% and 100%) was that the irregular shape of RGA particles might reduce the compactness of the concrete samples and reduce the adhesive between the surface of the RGA and paste matrix [31, 33]. Additionally, with an extremely low water absorption rate as compared to CS, the incorporation of a high amount of RGA caused a reduction in bonding strength due to the limited penetration of hydrated products at the interfacial transition zone [11, 15, 34]. In this study, although the compressive strength values of concrete samples with more than 60% RGA were decreased, they still reached the target strength (≥ 25 MPa) of grade M25 concrete.

### *3.3. Dry density*

The results of dry density measurement of all concrete samples at 28 days are presented in Fig. 6. The dry density values of concrete containing 0, 20, 40, 60, 80, and 100% RGA were 2261, 2299, 2302, 2322, 2195, and 2181 kg/m$^3$, respectively. It could be observed that the dry density of concretes slightly increased with RGA content up to 60% and then declined at higher RGA contents. A similar explanation of compressive strength of the concrete as mentioned above, the slight increase in dry

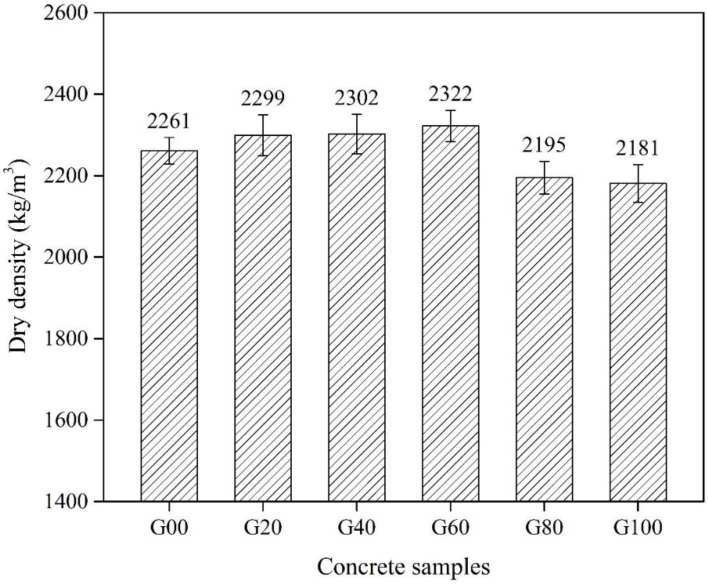

Figure 6. Dry density of concrete samples

density values of the concrete samples incorporating ≤ 60% RGA was due to the pozzolanic reaction of very fine RGA, which may take place together with the cement hydration product, forming more cementitious products [31] that making a denser concrete structure and hence higher concrete density. In contrast, the reduced dry density values of concretes at 80% and 100% RGA replacement levels were mainly attributable to the lower density of RGA in comparison with CS [9, 10] as well as the less compactness [32] and the introduction of microscopic voids within the system [35], resulting in the reduction in dry density of concretes.

A linear equation of $y = 0.04x - 67.29$ with a high coefficient of determination $R^2 = 87\%$ was used to express the relationship between dry density and compressive strength of the concrete samples at 28 days (see Fig. 7). The increase in the concrete density corresponded well to the increased compressive strength as the higher the density, the higher the compressive strength of concretes. Thus, the density of concrete directly affected its strength. Fig. 7 further supported the results of both compressive strength and dry density measurements as above discussion.

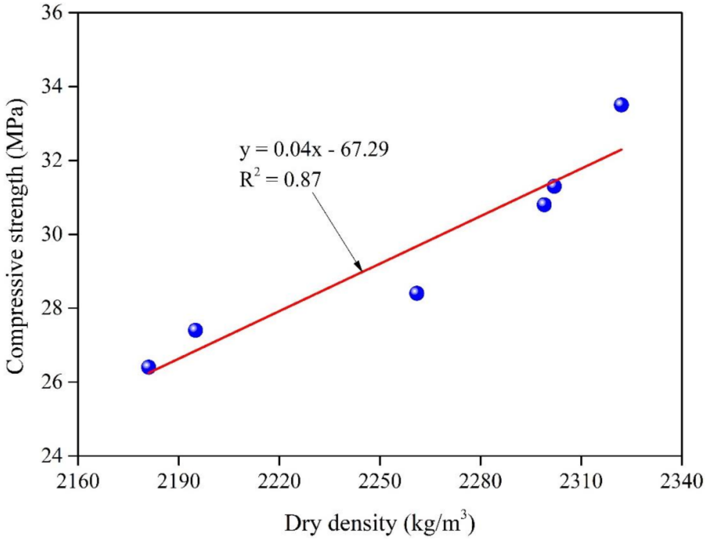

Figure 7. The relationship between dry density and compressive strength of concrete at 28 days

### 3.4. *Water absorption*

Fig. 8 shows the water absorption values of concrete samples at 28 days. It can be seen that water absorption reduced when replacing 20 – 60% CS by RGA in concrete mixtures. This result came from the non-hydrophilic nature of the RGA [11] as well as the extremely low water absorption capacity of the RGA particles as compared to the CS particles (see Fig. 2). The concrete samples with 0%, 20%, 40%, and 60% RGA had the respective water absorption values of 7.4%, 7.2%, 7.1%, and 6.8%. On the other hand, the concrete samples with 80% and 100% RGA contents exhibited higher water absorption values (7.6% and 7.8%, respectively). In this study, although RGA has significantly lower water absorption capacity than CS, replacing CS with RGA at very high replacement levels (> 60%) also increased the water absorption of the concretes. This phenomenon happened was because the irregular shape of RGA particles might reduce the compactness of the concrete samples [33] and consequently introduce more microscopic voids within the system [31], increasing the void volume and consequently raising water absorption of the concrete samples.

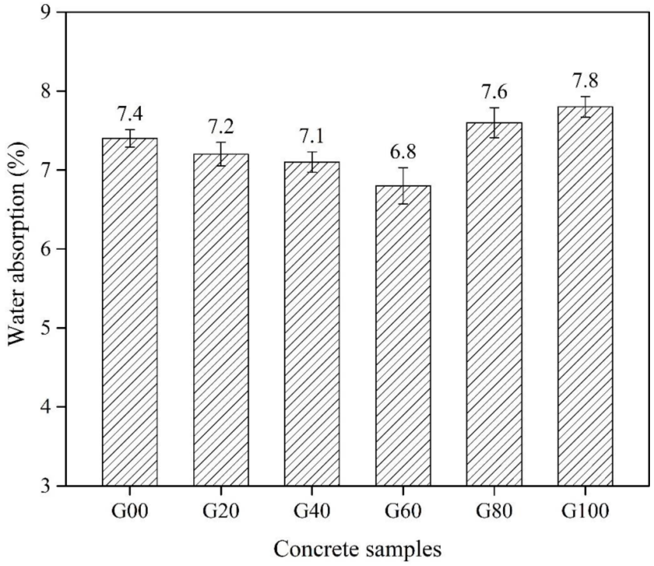

Figure 8. Water absorption of concrete samples

Fig. 9 expresses a strong relationship between compressive strength and water absorption of concrete samples at 28 days through the linear equation of $y = 83.73 - 7.39x$ with a very high coefficient of determination ($R^2 = 98\%$), which demonstrated a closed correlation between these properties.

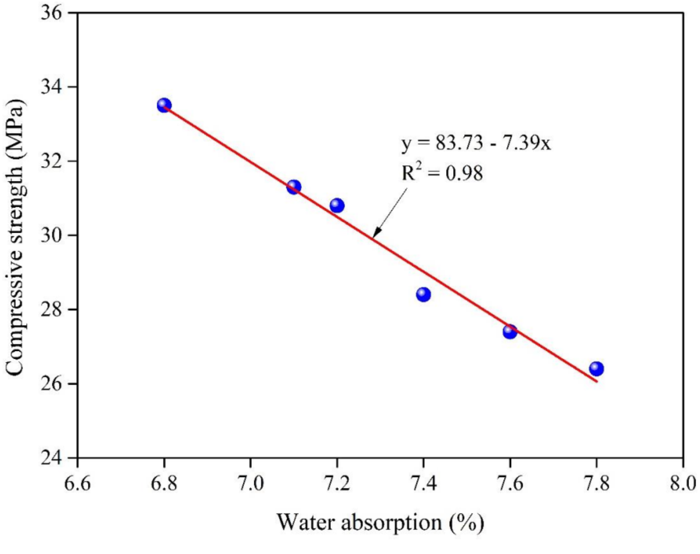

Figure 9. The relationship between water absorption and compressive strength of concrete at 28 days

Similarly, the correlation between water absorption and dry density of the concrete samples at 28 days is displayed in Fig. 10. An approximation linear equation of $y = 3413.36 - 157.63x$ was used to express this correlation ($R^2 = 89\%$). From Figs. 9 and 10, it could be concluded that the concrete samples with higher density contain less void (or denser structure, in other words), thus register lower water absorption and achieve higher compressive strength values.

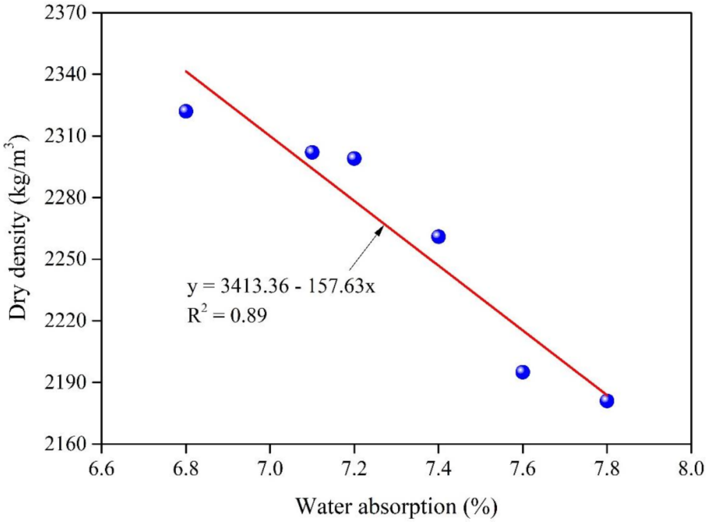

Figure 10. The relationship between water absorption and dry density of concrete at 28 days

### 3.5. Drying shrinkage

Drying shrinkage is a crucial property of concrete, resulting from the contraction of a hardened concrete mixture due to the loss of capillary water, leading to cracking, internal warping, and external deflection, and significantly affecting the durability of concrete [36]. The results of drying shrinkage measurement, which is indicated by the change in length up to 28 days of the concrete samples are illustrated in Fig. 11. Concrete samples containing different RGA contents showed different development patterns. The drying shrinkage of the concrete samples reduced significantly when ≤ 60% RGA was used to partially replace CS in the concrete mixtures. In other words, the used of RGA to partially replace CS at the replacement levels of no more than 60% positively improved the drying shrinkage behavior of the concrete samples. The reason for this phenomenon was the extremely low water ab-

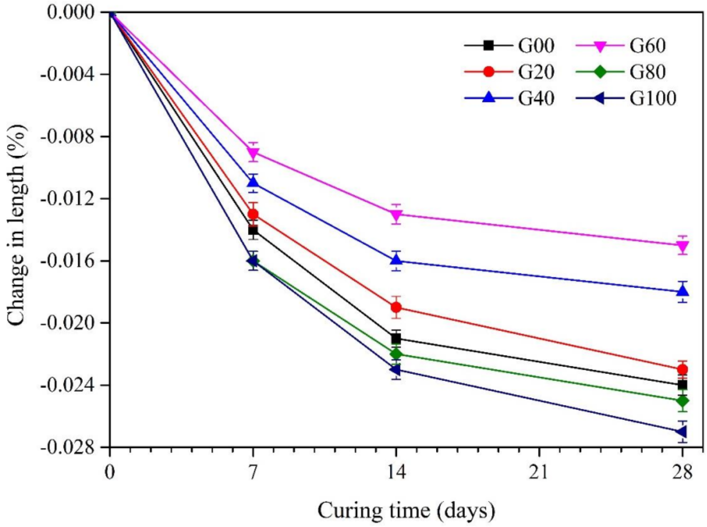

Figure 11. Drying shrinkage of concrete samples

sorption rate of the RGA particles (see Fig. 2). Therefore, the inclusion of RGA in concrete restricted water migration as well as reduced the loss of capillary water during the hardening process and thus reduced the drying shrinkage value of the concretes [11]. In addition, pozzolanic reaction [32] of RGA might contribute to a strong and dense concrete, resulting in less drying shrinkage. Moreover, RGA had an angular grain shape, which provided better resistance to drying shrinkage [37]. Nevertheless, when the RGA content was higher than 60%, the drying shrinkage increased significantly. This behavior occurred due to the appearance of microscopic voids introduced when the RGA was used at high percentages (> 60%) as aforementioned [31, 33], which led to subsequent higher drying shrinkage of the concrete samples.

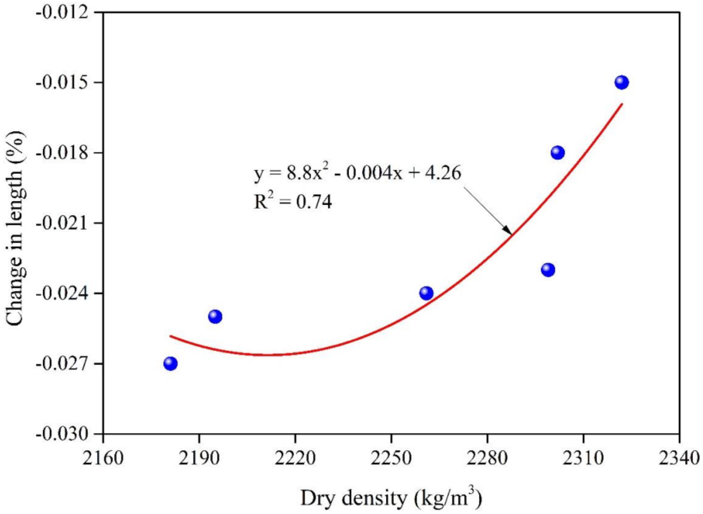

Figure 12. The relationship between drying shrinkage and dry density of concrete at 28 days

Furthermore, this study also found that the drying shrinkage of the concretes had a closed relationship with their dry density. This relationship could be expressed by an approximate polynomial equation of $y = 8.8x^2 - 0.004x + 4.26$ ($R^2 = 74\%$) as shown in Fig. 12. Thus, the concrete samples with lower density tended to shrink more. This finding is in good agreement with the results of dry density and drying shrinkage measurements as above-discussion.

### *3.6. Ultrasonic pulse velocity*

The UPV values of all concrete samples at 28 days were measured and presented in Fig. 13. The same trend with the compressive strength and dry density was observed for the UPV results of the concrete samples as the UPV increased with RGA replacement levels up to 60% and then reduced at the replacement levels of 80% and 100%. At an appropriate amount, the benefit of the pozzolanic reaction of fine RGA particles was attributable to the denser concrete structure [32, 38], consequently resulted in a higher UPV value. However, a negative effect on UPV values of concrete samples was observed when SC was replaced by RGA at high percentages (80% and 100%). This may be attributed to the less compactness and inconsistent structure of concretes with more voids [31, 33], which increased the travel time of ultrasonic pulse through the samples and thus reduced the UPV values. All of the concrete samples prepared for this study had UPV values of all above 4100 m/s. Therefore, these samples were cataloged with very good quality according to [39].

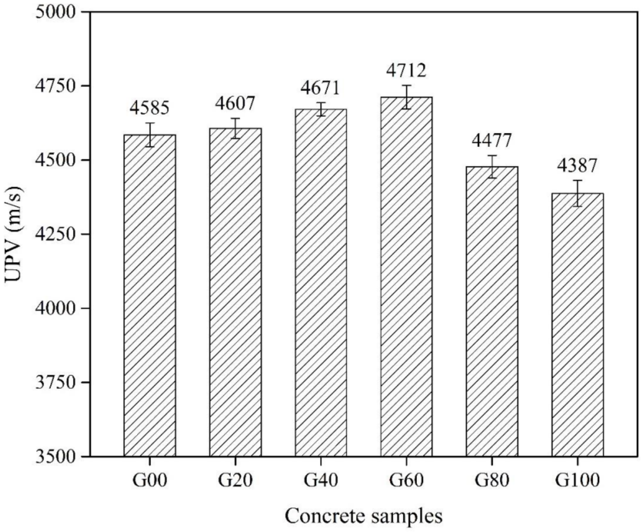

Figure 13. UPV of concrete samples

It can be seen that UPV values of concrete samples were closely associated with their compressive strength values. The higher the compressive strength, the higher the UPV values of concretes (see Fig. 14). Logically, the concrete samples with high compressive strength value usually exhibited compact structures with less void, which consequently led to high UPV values. In other words, the high UPV values supported the high compressive strength value of concretes.

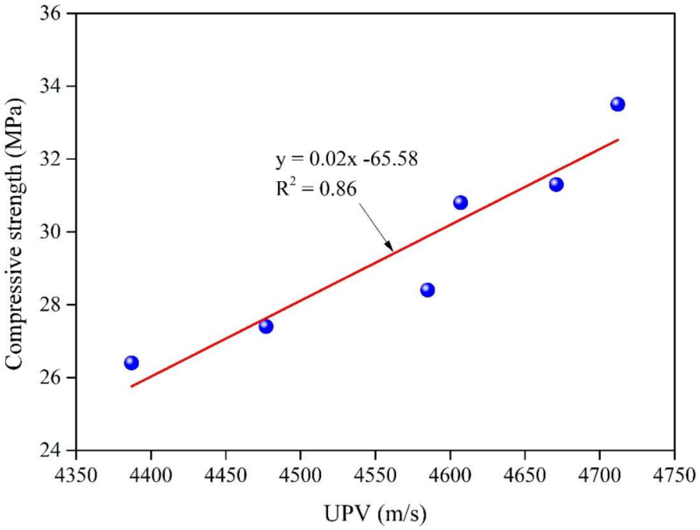

Figure 14. The relationship between compressive strength and UPV of concrete at 28 days

## 4. Conclusions

This study investigates the possibility of using recycled waste medical-glass as fine aggregate in the production of normal-strength concrete. The effect of replacing CS by RGA on the engineering properties and durability of concrete was evaluated. Based on the experimental results, the following conclusions can be drawn:

- The replacement of CS by RGA insignificantly affected the workability and unit weight of fresh concrete mixtures. Particularly, the unit weight of fresh concrete mixtures slightly increased with the RGA substitution up to 60% and then decreased at further substitution levels (80% and 100%).

- Utilizing RGA to replace CS at the replacement levels of 20 – 60% was beneficial in terms of compressive strength, drying shrinkage, and UPV. At these levels, the dry density values were found to increase and the water absorption values were reduced as well. However, replacing CS with RGA up to 80% and 100% reduced the compressive strength, dry density, and UPV while increased water absorption and drying shrinkage of concretes.

- The compressive strength values of all concrete samples at 28 days satisfied the target strength of at least 25 MPa (grade M25). Based on the UPV testing results, all of the concrete samples regardless of the RGA contents were classified as good quality concrete. Closed correlations among the concrete properties (compressive strength, UPV, dry density, water absorption, and dry density) were also found in this study.

- The results of this study demonstrate a high possibility of producing normal-strength concrete with a fine aggregate of RGA. This study also provides an environmentally-friendly solution for recycling waste medical glass in construction materials and limits environmental pollution as well as the depletion of natural resources for sustainable development.

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