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UTILIZATION OF GLASS WASTE AS FINE AGGREGATE IN CONSTRUCTION MATERIALS

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Abstract

As the dwindling amount of raw material and its contribution to climate change are of concern recently, the employment of waste material in concrete technology for sustainable construction is inevitable and has gained attention worldwide. The usage of glass as fine aggregates in concrete can help to relieve the environmental issue related to both waste glass and concrete industry. The mechanical properties (workability, compressive strength, tensile splitting strength, flexural strength and elastic modulus) and the alkali-silica reaction (ASR) of concrete with different proportion of glass replacement on fine aggregates were evaluated. Concrete with different percentage of glass replacement by mass (25%, 50%, 75%, 100%) was tested and compared with control mix (0% replacement). The incorporation of glass into the concrete has detrimental effect on workability and compressive strength but it brings beneficial effect on density, tensile strength, flexural strength and elastic modulus of concrete. The incorporation of glass into mortar will not cause unacceptable ASR expansion even with 100% replacement. A 25% replacement is the most suitable proportion to have best performance of workability and mechanical properties and can be used in construction practice for economic and environmental benefits.

Keywords: Concrete; Fine aggregates replacement; Glass; Mechanical properties; Alkali-silica reaction

1.0 INTRODUCTION

Rapid urbanization and population growth has brought forth parallel increase of municipal solid wastes worldwide. According a study conducted by World Bank, it is estimated that approximately 1.3 billion tonnes of solid waste are generated annually and the number was predicted to increase to 2.2 billion per year at 2025 [1]. In Malaysia, specifically, an average of 51,655 tonnes of solid waste will be generated daily by year 2025 and glass waste constituted approximately 3%, i.e. 1550 tonnes per day [2]. Among the 3%, only 10% of disposed glass were recycled [3]. The low recycling rate is due to its limitation on the shortage of good-quality glass waste and high recycling cost [4], [5]. Despite this, the chemical properties of waste glass have made itself useful in the concrete industry. In a concrete mixture, natural aggregate account for 70% of its total volume [6], [7]. To cater this major composition construction material in concrete, 8 to 12 million tonnes of natural aggregate are consumed annually [6]. This raises issues on the environmental impacts of the quarrying process and depletion of the natural resources [8]. Thus, recycling of waste glass is one of the sustainable methods to reduce the landfill space and the demand of natural aggregate [9], [10].

Substitution of waste glass a potential concrete raw material has been studied as early as 1970's, in which, the glass was used as coarse aggregate [11]. Nonetheless, the outcome was unfavourable because of the reduction of compressive, flexural and indirect tensile strength as the content of waste glass increased [12]. Following the undesirable results, the attention was shifted to replace fine aggregate with waste glass in concrete mixture. Generally, fine aggregate comprise of natural sand or crushed gravel that is chemically known as silica. As waste glass consists of at least 70% silica content, its replacement as fine aggregate in concrete is appealing [13]. Previous studies have found the incorporation of waste glass in concrete mixture improved the compressive strength but decrease the workability [14]-[16]. No ASR expansion has been reported with particle sizes up to 100 µm [17]. The 2 zero ASR expansion was due to the suppression by supplementary cement materials such as fly ash and metakaolin [18, 19]. However, there is no evaluation of the ASR expansion solely on waste as fine aggregate. To obtain a more reliable data, an evaluation on the ASR expansion with no supplementary cement materials addition should be conducted. Up to date, most studies focused on the substitution of waste glass up to 50% instead of 100% to uncover the full potential of waste glass as fine aggregate surrogate [18, 20-23]. Furthermore, past researches only employed bottle glass waste, which possess higher recyclable potential, over a non-recyclable flat glass waste. Therefore, the utilization of non-recyclable flat glass needs to be emphasized.
In this study, non-recyclable flat glass was used to substitute fine aggregate in concrete mixture. The mechanical properties of the concrete including density, workability, compressive strength, tensile splitting strength, flexural strength and elastic modulus at different proportion of flat glass to natural fine aggregate were evaluated. In addition, the alkali-silica reaction (ASR) of concrete with different proportion of glass replacement on fine aggregates was also examined.

2.0 METHODOLOGY

Material Selection

Ordinary Portland cement was chosen in accordance to BS EN 197-1. Coarse and fine aggregates used were crushed granite with maximum size of 12.5mm and natural river sand with maximum size of 1mm, respectively. Non-recyclable flat glass waste was collected from a glass panel manufacturing factory that was cleaned with water to remove any impurities. Cleaned flat glass waste was then oven-dried at 105°C for 20 minutes followed by its crushing with a Los Angeles Abrasion Testing Machine. Crushed flat glass waste was sieved with 1mm wire mesh sieve and the retained cullet was crushed again until it achieved the desired size.

Concrete Mix Design

The determination of the concrete mixture proportion was according to "Design of Normal Concrete Mixes" by Building Research Establishment 1997. The mixtures were required to attain characteristic strength of 30 N/mm2 with targeted slump of 100mm. Water-cement ratio of 0.5 was employed in this study. The natural fine aggregate was substituted with finely crushed flat glass waste at a proportion of 0%, 25%, 50%, 75% and 100% . The mix proportions are shown in Table 1.

Percentage (%)		0	25	50	75	100
Mass (kg)	Sand	23.9	17.9	12.0	6.0	0.00
	Fine Glass	0.0	6.0	12.0	17.9	23.9
	Cement	16.6	16.6	16.6	16.6	16.6
	Water	8.3	8.3	8.3	8.3	8.3
	Stone	29.2	29.2	29.2	29.2	29.2

Table 1. Mass of materials for each proportion

Mechanical Properties Testing

The consistency of the concrete mixture was determined using slump test based on BS EN 12350-2:2009 [24]. Meanwhile, the compressive, tensile splitting and flexural strength tests of the hardened concrete were examined according to BS EN 12390-3:2009, BS EN 12390-6:2009 and BS EN 12390-5:2009, respectively [25], [26], [27]. Briefly, the hardened concrete in different moulds, namely cubes, cylinders and prisms, were cured in water for 28 days prior to the strength examination. All tests were conducted in triplicates. For static modulus of elasticity in compression was conducted according to BS EN 12390-13:2013, where stress equivalent to one third of the average compressive strength was applied on the hardened concrete [28]. This was followed by unloading the stress until it 0.5MPa was reached. After two repetition of stress loading and unloading, the stress was applied until the specimen fails. All the strain values were recorded throughout the testing and the secant modulus was calculated.

Alkali-Silica Reactivity Testing

The potential alkali-silica reactivity of the finely crushed flat glass waste was assessed using the mortar bar test (ASTM C1260) . Three (3) 25mm x 25mm x 285mm mortar prisms were casted by using cement-aggregate ratio of 1:2.25. The fresh samples were left air-dried for 24 hours. After that the mould was removed and the initial length of mortar bar was measured. The mortar bar was then been immersed in 1N sodium hydroxide (NaOH) solution at 80oC for another 12 days. At 14 days age, the specimens were taken out and the new length was measured immediately. The difference between initial length and the final length was recorded as expansion. The expansion with less than 0.1% of initial length showed that the aggregate used is non-reactive.

3.0 RESULTS AND DISCUSSION

Workability

Figure 1 shows the slump value for fresh concrete at different proportion of fine aggregate replaced with crushed flat glass. In general, workability of the concrete mixture decreased with the increasing crushed flat glass percentage except for 25%. At 25% of fine aggregate replacement, workability of the concrete increased to 110mm compared to 90mm of the control. It seems that replacement of fine aggregate by a quarter can produce better workability owing to the smooth surface and low water absorption of the glass aggregate [23]. Additionally, lower cohesion between glass and cement could also lead to higher workability [22]. Nonetheless, the increase of glass aggregate by 50% onwards enhances the internal friction caused by the shape irregularity after crushing thus decrease the workability of the concrete [30]. Although there seems to be affecting the quality of the concrete, it still suits to be employed on normal reinforced concrete structure.

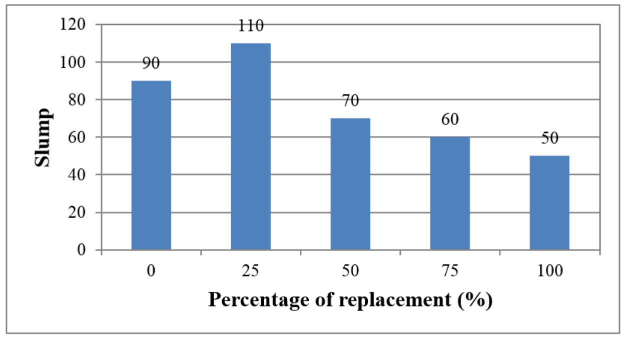

Fig. 1. Slump against Percentage of Glass Replacement

Compressive strength

The compressive strength of the hardened concrete containing different ratio of crushed flat glass waste is presented in Figure 2. The results revealed that compressive strength of the specimens dropped as the content of the glass aggregate increased. At 25% of replacement, the compressive strength only declined 2% which is insignificant. However, 15% and 17% decrement were observed when the replacement percentage doubled (50%) and tripled (75%), respectively. The strength reduced to 28% when all fine aggregate was fully replaced with the crushed flat glass waste. The declining compressive strength agreed well with those found in previous studies [22], [31]-[33]. The reduction in strength might be due to the weaker bonding between smooth glass surfaces and cement paste at Interfacial Transition Zone (ITZ) [31]. Furthermore, micro-cracking in the glass aggregate possesses high possibility in weakening the load-bearing capacity of glass that would not happen in natural fine aggregate [34]. Therefore, the application of 25% replacement of the fine aggregate with glass waste was considered to be acceptable. Higher percentage of replacement is not recommended to prevent any impairment on the structure under high load.

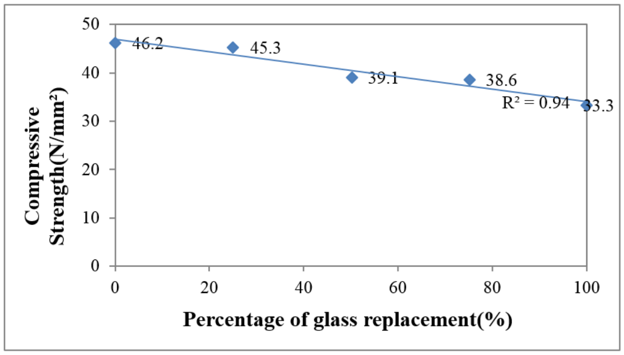

Fig. 2. Compressive Strength versus Percentage of Glass Replacement

Tensile strength

Figure 3 shows the result of indirect tensile strength for different proportion of glass replacement. In total, the tensile strength increased less than 10% when glass waste was substituted as fine aggregate. Similar observation was also found in Sadoon Abdallah and Fan [30]. The enhancement of tensile strength could be due to the potential pozzolanic activity occurred in the concrete. This is beneficial especially in concrete crack control caused by the internal expansion from ASR or temperature changes. With this, it makes the mortar possessing a better atheistic value without any reinforcement to control cracking. It also improves the concrete cover that prevents corrosion of reinforcement by external contaminant.

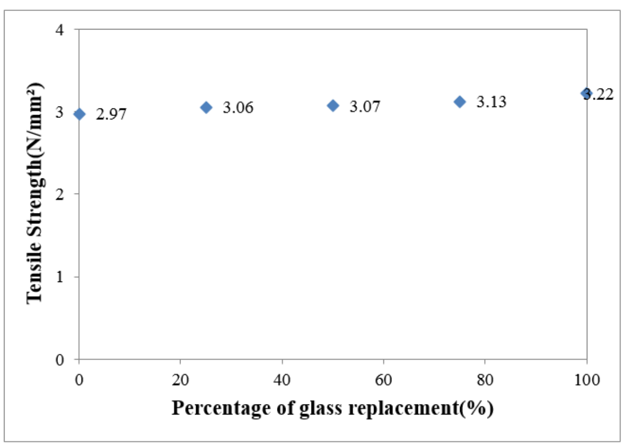

Fig. 3. Tensile Strength versus Percentage of Glass Replacement

Flexural strength

The performance of flexural strength at different proportion of glass waste is depicted in Figure 4. The results showed that flexural strength increased 9.7% at the proportion of 25%. Nonetheless, further replacement of natural fine aggregate with glass waste did not enhance the flexural strength. The improvement in the strength was also observed in Oliveira, de Brito [35], Ismail and Al-Hashmi [36], Corinaldesi, Gnappi [17]. The mixture of the glass particles contributed to the calcium-silicate-hydrate gel formation; thus, elevate the flexural strength [34]. Higher flexural strength is encouraging for pavement of highway structure where no reinforcement needs to be installed and all bending stress will be sustained by the concrete itself. Similar study conducted by other researchers [12, 22, 37, 38]. However, disclosed an opposite trend. The contradiction in strength may be due the different type of glass waste employed, i.e. bottle glass versus flat glass waste.

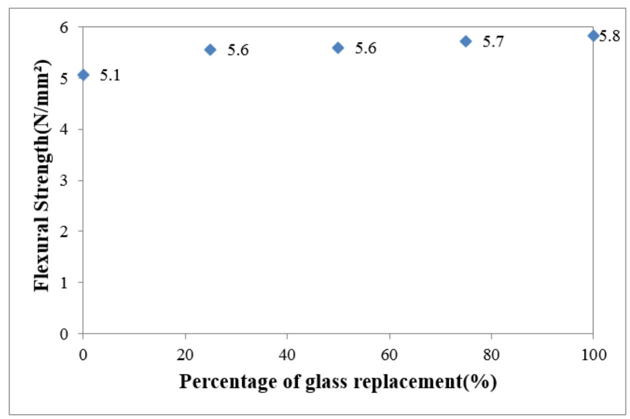

Fig. 4. Flexural Strength versus Percentage of Glass Replacement

Static modulus of elasticity

Figure 5 depicts the results of secant modulus of elasticity at different percentage of glass waste applied in the concrete mixture. Overall, the increment in the glass waste percentage decrease the secant modulus of elasticity. The decrement ranged from 9.9% to 18.3%. The results of elastic modulus test from this experiment were in line with Tan and Du [37], Ali and Al-Tersawy [22], Topçu and Canbaz [12]. The decline in elastic modulus can be due to higher porosity in concrete when fine natural aggregate was replaced with glass waste which leads to weaker bond at ITZ. Although the elasticity of the concrete decreased by almost 20%, it is still higher than the minimum requirement signifying the applicability of glass waste as fine aggregate substitution.

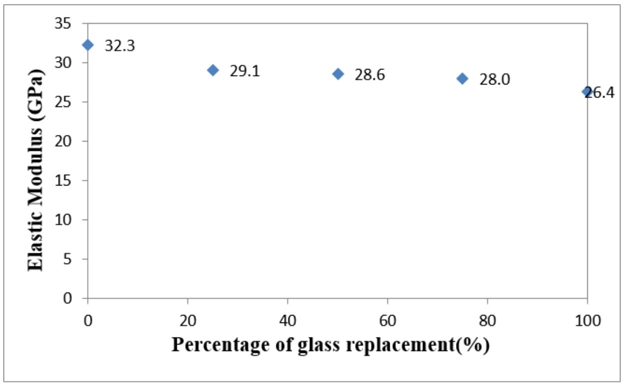

Fig. 5. Elastic Modulus versus Percentage of Glass Replacement

ASR Expansion

Figure 6 presents the results of 16-days expansion of mortar bar in 80oC 1M NaOH solution for different quantity of glass replacement. When 25% of fine glass was incorporated into mortar bar, the percentage of expansion for mortar bar, compared to control, decreased and hit the minimum value of 0.017%. The expansion of mortar bar for 75% (0.025%) and 100% (0.029%) replacement were more than that of the control (0.022%). It was observed that the expansion of mortar bar for every proportion did not exceed the limit of 0.1% specified in ASTM 1260 and the glass waste can be classified as innocuous material. The expansion pattern for this experiment was similar to Özkan and Yüksel [33]. In their results the minimum expansion is at 30% replacement, which is close to 25% replacement in this experiment. The rising trend with the increasing of glass content also meets the observation of Almesfer [39], Ling, Poon [40], Topçu, Boğa [19], Shayan and Xu [41], Park and Lee [42]. From this experiment, it can be deduced that when nominal amount of glass is added into the concrete, it would be able to relieve the ASR expansion to appreciable level.

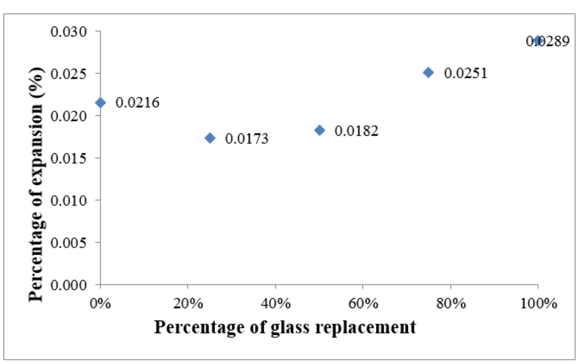

Fig. 6. Percentage of Expansion versus Percentage of Glass Replacement

4.0 CONCLUSION

The experiments carried out had reached the objectives of this research. Hence, it can be concluded that the incorporation of glass into the concrete does have detrimental effect on workability and compressive strength but it also brings beneficial effect on density, tensile strength, flexural strength and elastic modulus of concrete. A 25% replacement is the most suitable proportion to have best performance of workability and mechanical properties. The incorporation of glass into mortar will not cause unacceptable ASR expansion even with 100% replacement. Glass aggregate is considered innocuous material and even have beneficial effect in reducing the expansion at 25% replacement. As the recommendation for further research, a full-scale field test can be carried out to test the performance of concrete with glass replacement under actual environment. Besides, different size and gradation of glass aggregates can be experimented to obtain optimum size for the best performance. The cost-benefit analysis can also be done by study the cost of glass processing to calculate the margin of cost reduction using glass in concrete.

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