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Sustainable production of concrete containing discarded beverage glass as fine aggregate

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HIGHLIGHTS

- Waste glass is used in PPC based concrete as a replacement of fine aggregates at optimum (18–24%) percentages.
- Microstructural study illustrates generation of voids and cracks.
- Waste glass may be utilized as a substitute for fine aggregate up to 21% replacement level.

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ABSTRACT

Discarding of waste glass is creating major ecological issues across the globe. In recent years, the rate of disposal of this material has amplified. One conceivable approach is to employ this rejected material as a substitute of fine aggregate in concrete. Hence, this study examines the behaviour of concrete with waste glass as fine aggregate at various substitution levels (18%, 19%, 20%, 21%, 22%, 23% & 24%). Fresh, hardened and durability properties were evaluated in terms of workability, compressive strength, flexural strength, density and water absorption. The outcome of the present work indicates that inclusion of waste glass has led to the enhancement in quality of microstructure up to 21% substitution of fine aggregate. This has improved the mechanical properties of such concrete mixes. It is observed that water absorption and water permeability are negatively affected with increment of waste glass in concrete. Hence, it can be concluded that 21% of fine aggregate can be replaced by waste glass to manufacture concrete for non-aggressive environment.

1. Introduction

The abysmal state of virgin land is arising due to increase in percentage of landfilling by discarded waste materials [1]. Waste glass (WG) also significantly contributes to this landfilling problem. Due to glass's non-biodegradable nature, its land-filling is not an eco-friendly solution of disposing [2]. Hence, different techniques have to be contemplated to reduce this issue. WG can be utilized in various applications, for example in manufacturing abrasives [3]. Utilization of WG in construction industry for production of concrete also shows a positive step to diminish the cost of WG disposal [4]. Concrete prepared with glass generally referred as Glass Concrete (GC) can be utilized as substitute for conventional concrete in construction of road pavement and parking areas [5]. Such consumption of WG in concrete, reduces the environmental issues and also enhances the effective use of resources [6].

1.1. Literature review

The physical and chemical composition of WG shows comparable properties to that of sand [7]. However, changes have been observed in concrete property based upon colour, source and size of WG.

Taha and Nounu [8] evaluated the effect of using 5 mm sized mixed coloured WG on concrete mixes workability. They pointed out that such concrete mixes produced lower slump values when compared to mixes made with conventional fine aggregate. Park et al. [9] also noticed similar behaviour when WG of different colours were used individually. The outcomes presented by the studies conducted by Limbachiya [10] and Chen et al. [11] were no different. These two studies had examined the usage of WG of sizes lesser than 5 mm and 38–300 μ respectively as fine aggregate. Malik et al. [12] and Bohran [13] on the other hand showed

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improvement in workability due to poor cohesion between the WG.

Batayneh et al. [14] monitored the behaviour of concrete mixes when crushed WG (9.5 mm-75 μ) were used as fine aggregate. They reported that these mixes had better compressive resistance up to 20% substitution. When fineness of WG was increased, Du and Tan [15] observed no change in trend. This improvement in strength was mainly related to pozzolanic behaviour of WG. Borhan [13] also pointed out improved compressive nature of concrete, when WG of different colours were used. But this mechanical performance of mixes reduced when substitutions to the tune of 50% and 100% were made as demonstrated by Taha and Nounu [8]. On the contrary to these observations, Ismail and Al Hashmi [16] and de Castro and de Brito [17] studies depict decrement in compressive resistance of such concrete mixes even at lower replacement levels. These two studies have utilized crushed window glasses at substitution level of 5%, 10%, 15% and 5%, 10%, 20% of fine aggregate respectively. This anomaly in performance of concrete exists because of the nature of WG used here, which had smooth texture when compared to the rough surface of WG used by Ismail and Al Hashmi [16].

Ismail and Al-Hashmi [16] monitored reduced ASR expansion with incorporation of WG (4.75–0.15 mm) in concrete mixes at different substitution levels (10%, 15% and 20%). DU and Tan [15] also monitored similar results when WG used as a substitute of fine aggregate up to 100% substitution level. They noticed reduced ASR expansion by increasing the amount of WG.

As seen in compressive strength, flexural strength also shows contradictory observations with use of WG in concrete mixes. The rise or fall of this parameter is mainly dependent on the surface texture of glass used as discussed already [18]. When the surface of WG was sufficiently rough, improved resistance has been observed [19]. Rise in flexural strength was recorded up to a substitution level of 20% only. Beyond this percentage, fall in strength was observed [16]. Particle size has also determined the extent of variation of this mechanical property [20]. Turgut and Yahlizade [21] substituted white WG (4.75 mm) from 10 to 30% with increment of 10%. This study also shows that flexural strength increases up to 20% replacement. Some studies observed that strength of concrete mixes does not depends upon the colour of WG [22,23]. However, Tan and Du [24] stated that clear WG displayed lower strength as compared to other coloured WG.

WG incorporation has been proved to make concrete lighter [16]. Hardened density reduces, immaterial of particle size of WG used [25]. This characteristic reduction was due to glass's lower specific gravity when compared to sand [26].

The exposure of concrete materials to aggressive conditions through their service span is a point of concern [27]. Water absorption of glass concrete increases with increase in percentage of WG content in concrete was reported by Turgut and Yahlizade [21]. Limbachiya [10] pointed out that this increased water absorption capacity was due to increased porosity of WG concrete mixes. Similar behaviour of increased water absorption was also reported by Penacho et al. (2014) for mortar mixes [28].

With total porosity, inclusion of WG affects the water permeability of concrete also. Oliveria et al. [29] substituted WG from 0% to 100% in steps of 25% by weight. They concluded that as the percentage of WG content in concrete increases depth of water permeability (under constant pressure) also increases. Penacho et al. [28] also reported the similar observations for increase in water permeability with inclusion of WG in mortar.

The above mentioned studies have verified the suitability of WG as fine aggregate in concrete mixes at wide ranging percentage variation. Most of the researchers have reported increase in mechanical properties by using WG in concrete mixes as a substitute of fine aggregate in range of 15–25% [10,14–16]. In line with this outcome, in this present work an attempt has been made to arrive at an exact optimum substitution level (18%, 19%, 20%, 21%, 22%, 23% and 24%) to obtain best performance when WG size of 600–150 μm is used. This gradation of WG utilized in the present study has been arrived based on literature [10,15,18], where this size of WG has played a crucial role in enhancing overall parameters of concrete properties.

Necessary tests such as workability, compressive strength, flexural strength, water absorption (by immersion), density, water permeability (constant pressure) and sorptivity for constant w/c ratio (0.4) were performed. Micro-structural study using scanning electron microscope (SEM) and Fourier transform infrared radiation (FTIR) has also been conducted in the present work.

2. Experimental program

2.1. Materials

The properties of the materials used in the present work are shown in Table 1. Elemental composition of cement is reported in Table 2. WG was obtained from mechanical grinding of beverage bottles of different colours. The crushed form of WG was passed through 600 μ and retained on 150 μ sieve. The WG used in present work is shown in Figs. 1 and 2 presents the scanning electron microscopy (SEM) of WG which shows the smooth texture with sharp edges. Energy diffraction X-ray analysis (EDAX) was performed to determine elemental analysis of WG as shown in Fig. 3. Elemental composition of WG which was evaluated using EDAX presented in Table 3. The size distribution of sand shown in Fig. 4. Superplasticizer which is polycarboxylic ether polymer based was used to achieve suitable workability. Table 4 lists the physical and mechanical characteristics of cement, fine aggregate, coarse aggregate and WG.

2.2. Mix proportions

The substitution of fine aggregate from WG was used in concrete mixes at varying proportions of 0%, 18%, 19%, 20%, 21%, 22%, 23% and 24% as shown in Table 5 with constant w/c of 0.4. Replacement of fine aggregate with WG was made by weight basis. The quantity of superplasticizer was varied accordingly to attain a compaction factor of 0.9. Materials were mixed, casted and cured as per standard specifications.

3. Experimental plan

Workability of concrete mixes has been investigated by performing compaction factor test as per IS: 1199-1959 [30]. Mechanical properties has been conducted on three specimens of each mix

Table 1
Properties of raw materials.

S.NO	Material	Description	Specific Gravity
1	Cement	PPC	3.11
2	Sand	Zone 2	2.66
3	Coarse Aggregates	10, 20 mm	2.59
4	Waste Glass	150–600 μm	2.39

Table 2
Elemental composition of cement.

Element Composition	Symbol	Percentage (%)
Calcium	Ca	27.95
Oxygen	O	58.82
Silicon	Si	11.06
Aluminium	Al	1.01
Iron	Fe	0.28
Magnesium	Mg	0.55
Potassium	K	0.24
Sodium	Na	0.04
Phosphorus	P	0.03
Manganese	Mn	0.01