Properties and Performance of Mortar and Concrete Made with Recycled Glass Powder as Binder and Aggregate

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Abstract: Using C & D waste for product development in the domain of Civil Engineering is a global trend. Disposal C & D waste has become a severe issue in cities like Bengaluru. However, Bruhat Bengaluru Mahanagara Palike (BBMP) has identified several waste disposal dump site in their jurisdiction. Attempts are being made by many researchers to minimize/utilize waste by recycling it into other forms. Paper focuses on simple and easy way of characterization and simplified mix proportioning of Crushed Glass as binder and fine aggregates in mortar and concrete. Collected glass waste is crushed manually into the size of fine aggregate as per BIS codal provisions and graded as per BIS 383-2016 confirming to zone II. Simplified and comprehensive mix proportions are arrived as per BIS 2386 Part I to Part VI for mortar and M30 Grade concrete as per BIS 10262-2009 by replacing Crushed glass as binder and fine aggregates. The crushed glass is replaced with binder and filler in varying proportions of 0, 10,20,30,40 & 50% in mortar and concrete proportions. Studies are made to evaluate feasibility, workability, strength and durability properties of mortar and concrete proportioned with crushed glass powder as binder and aggregate. The experimental data revealed that in spite of higher water absorption by crushed glass powder and aggregates, mortar and concrete are found semi light weight, durable and less permeable.

Key words: Environmental concern, crushed glass, binder, Strength development.

1. Introduction

Cement the key binder of concrete and releases CO₂ during its manufacturing process which is about 5-8% of global CO₂ emission [1& 2]. In the present scenario there is an increase in the demand of aggregates for construction purpose. To meet the demand aggregates are excessively mined, also interference of sand and real estate mafia which has resulted in degradation of rivers and erosion of river banks as shown in Figure 1.1. The utilization of glass powder as an alternative to sand has been accepted in the industrially advanced countries. As a result of sustained research and development works with respect to increase in generation of industrial waste, glass powder is one among them which has got potential to re use as a building material. The use of waste glass in the concrete is feasible, as the cost of making concrete gets reduce. The quantity of waste glass is increasing over the years. Apart from recycling, the waste glass is being dumped into landfills which are undesirable, as they are non biodegradable.

Figure 1.1: Illegal Mining of Sand
2. Scale and intent of research
The present research is more focused to investigate the effect of use of crushed glass on concrete properties and check its suitability as an alternate construction material. The waste glass is added to concrete in various replacement levels to check the effects on workability, strength and durability in fresh and hardened state respectively. The scope work is to use glass waste and provide a low cost, eco-friendly and efficient construction material. Collected glass is crushed into fine powder and categorized into fine aggregates passing 4.75mm and retained on 75 micron and called Crushed Glass Aggregate (CGA), passing 90 micron as binder (cementitious material) and called Crushed Glass Powder (CGP). Study is more focused on utilizing CGP and CGA as binder and aggregate in mortar and concrete mixes, to evaluate their feasibility, strength, performance and durability aspects [1&3].

3. Materials and methods
In this study Ordinary Portland Cement 53 grade confirming to BIS 12269-2013 is used for mortar and concrete mixes. Natural river sand confirming zone II and coarse aggregate of particle size 12.5mm passing as per BIS 383-1970 are used as finer and courser aggregate. Collected glass waste are crushed manually and using mechanized jaw crusher thereafter for obtaining uniform gradation confirming to zone II as per BIS 383-1970. The crushed glass aggregate and powder are proportioned in concrete mixes with varying percentage of 0, 10, 20, 30, 40 and 50% targeting M30 grade concrete as per BIS10262-2009. Crushed glass aggregate and powder is proportioned in mortar mixes with varying percentage of 0,5,10, 15 and 20% for 1:4 mix as per BIS2386-1963 (Part I to Part VI) throughout the research workability of concrete is maintained for slump value ranging25mm to 50mm and 100± 10% flow for mortar. Studies are made on their compressive strength, density and durability parameters.

3.1 Workability of mortar and concrete mixes.
Workability of concrete is measured in terms of slump, for the proportioned mixes workability is between 25mm to 75mm and mortar workability is measured as resistance to flow of 100±10% as per BIS1199-1959. Slump of concrete and mortar mixes are depicted in Figure 3.1&Figure 3.2

4. Mix proportioning of concrete and mortar
Concrete is mix proportioned as per BIS 10262-2019 for slump of 25-50mm, w/c ratio of 0.55, water content of 188Ltrs/m³. The control mix proportion arrived is 1:2.66:2.75 with a w/c ratio of 0.55 and 50mm slump. Various mixes are proportioned with a varying percentage replacement of CGP as binder and CGA as Finer aggregate [1, 7 & 8]. Arrived mixes and their replacement level are portrayed in Table 4.1. Mortar mix is proportioned for 1:4 binders to aggregate ratio, w/c ratio for control mix and 5% replacement level of CGP and CGA was found to be 1.15. w/c ratios decreased to 1.10 for 10% replacement level and 1.05 for 15 and 20%. However free water content was maintained constant throughout and depicted in Table 4.2.
5. Experimental results and discussions

5.1: Compressive strength of concrete made with CGP and CGA

Compressive strength studies are made on various mixes proportioned with CGP as binder and CGA as finer aggregate for a curing period of 7, 14, 28 and 45 days, Cube size 100x100x100mm. Results revealed that compressive strength gradually decrease for incremental increase of CGP as binder, decrease in strength is found to be 10.5% at 30% replacement level and 43% at 40% replacement level[7,8&9]. However, at 40% replacement level concrete is fit to be used in RC structural elements as Per BIS 456-2000. Strength of concrete has shown an increasing trend with the incremental increase of CGA as fine aggregates, which proves crushed glass powder, has got some pozzolanic characteristics. About 11% of strength improvements is observed at 40% replacement level of CGA. Hence concrete may be proportioned using CGA as aggregate for all structural purposes. Compressive strength of concrete at various replacement levels of GCP and CGA are depicted in Table 5.1 and illustrated in Figure 5.1 & Figure 5.2.
Table 5.1: Compressive strength of M 30 Grade concrete proportioned with CGP and CGA

| Replacement level of CGP in % | Replacement level of CGA in % | 7day strength in MPa | 14day strength in MPa | 28day strength in MPa | 45 day Strength in MPa |
|-------------------------------|-------------------------------|----------------------|-----------------------|-----------------------|------------------------|
| 0                             | --                            | 12                   | 18                    | 30                    | 37                     |
| 10                            | --                            | 16                   | 23                    | 33                    | 35                     |
| 20                            | --                            | 9                    | 20                    | 32                    | 34                     |
| 30                            | --                            | 11                   | 19                    | 31                    | 33                     |
| 40                            | --                            | 6                    | 6                     | 17                    | 21                     |
| 50                            | --                            | 4                    | 5                     | 11                    | 14                     |
| --                            | 0                             | 12                   | 18                    | 30                    | 37                     |
| --                            | 10                            | 20                   | 23                    | 30                    | 31                     |
| --                            | 20                            | 21                   | 22                    | 31                    | 33.5                   |
| --                            | 30                            | 22                   | 25                    | 33                    | 35                     |
| --                            | 40                            | 24                   | 28                    | 37                    | 41                     |

5.2: Densities of concrete made with CGP and CGA

Dry densities of various mixes of M30 grade concrete made with CGP and CGA are presented in Table 5.2. It is seen that there is a decrease of 5% dry density at 30% and 4% at 40% replacement level of CGP [3&4]. There is no appreciable decrease in densities of concrete proportioned with CGA as aggregate at all replacement levels. Dry densities of all the mixes are illustrated in Figure 5.3 and Figure 5.4

Table 5.2: Densities of M30 grade concrete proportioned with CGP and CGA

| Replacement level of CGP in % | Replacement level of CGA in % | Density at 7day Kg/m³ | Density at 14day Kg/m³ | Density at 28day Kg/m³ | Density at 45day Kg/m³ |
|-------------------------------|-------------------------------|-----------------------|------------------------|------------------------|------------------------|
| 0                             | --                            | 2.23                  | 2.27                   | 2.33                   | 2.34                   |
| 10                            | --                            | 2.37                  | 2.33                   | 2.32                   | 2.32                   |
| 20                            | --                            | 2.35                  | 2.31                   | 2.3                     | 2.33                   |
| 30                            | --                            | 2.26                  | 2.26                   | 2.26                   | 2.26                   |
| 40                            | --                            | 2.25                  | 2.29                   | 2.29                   | 2.29                   |
| 50                            | --                            | 2.26                  | 2.23                   | 2.27                   | 2.27                   |
| --                            | 0                             | 2.23                  | 2.24                   | 2.33                   | 2.34                   |
| --                            | 10                            | 2.36                  | 2.36                   | 2.33                   | 2.33                   |
| --                            | 20                            | 2.27                  | 2.3                     | 2.33                   | 2.33                   |
| --                            | 30                            | 2.35                  | 2.32                   | 2.34                   | 2.34                   |
| --                            | 40                            | 2.32                  | 2.32                   | 2.35                   | 2.36                   |
5.3: Compressive strength of 1:4 mortar mixes made with CGP and CGA

Compressive strength studies on mortar mixes with 1:4 proportions with varying percentage of CGP as binder and CGA as finer aggregate is made. CGP and CGA are replaced with cement and natural river sand with an incremental increase of 0, 5, 10, 15, and 20% respectively of cube size 70.6x70.6x70.6mm [10]. Strength of mortar mixes are presented in Table 5.3. Results revealed mortar mixes may be easily proportioned up to 20%, replacing cement and natural river sand as there is marginal increase in strength in both the case. Strength gain in mortar mixes evidently proves that crushed glass has got pozzolanic characteristics. The strength development in mortar mixes is illustrated in Figure 5.5 and Figure 5.6.

| Replacement level of CGP in % | Replacement level of CGA in % | 7day Strength MPa | 28day Strength MPa | 45day Strength MPa |
|-------------------------------|-------------------------------|-------------------|-------------------|-------------------|
| 0                             | --                            | 5                 | 10                | 12                |
| 5                             | --                            | 5                 | 11                | 12                |
| 10                            | --                            | 6                 | 12                | 13                |
| 15                            | --                            | 6                 | 11                | 13                |
| 20                            | --                            | 6                 | 10                | 13                |
| --                            | 0                             | 5                 | 10                | 12                |
| --                            | 5                             | 5                 | 8.5               | 10                |
| --                            | 10                            | 7.2               | 12.2              | 13.5              |
| --                            | 15                            | 5.7               | 10.7              | 12                |
| --                            | 20                            | 6.7               | 13.5              | 14.6              |

Table 5.3: Compressive strength of 1:4 Cement mortar proportioned with CGP and CGA

Figure 5.5: Compressive strength of 1:4 mortar proportioned with CGP as Binder

Figure 5.6: Compressive strength of 1:4 mortar proportioned with CGA as aggregate
5.4: Densities of 1:4 mortar mixes made with CGP and CGA
Densities of 1:4 mortar mixes made with CGP as binder and CGA as aggregate are evaluated for 28 days. The experimental results revealed decrease in density of mortar mixes with the incremental increase of CGP and CGA shown in Table 5.4. About 7% of decrease in density at a replacement level of 20% of CGP there is no variation in density for replacing CGA as aggregate as shown in Figure 5.7 & Figure 5.8. However it can be concluded that high strength mortar mixes may be proportioned with marginally lighter densities suiting all applications of construction activities [7].

![Figure 5.7: Densities 1:4 mortar proportioned with CGP as Binder](image1)

![Figure 5.8: Densities 1:4 mortar proportioned with CGA as aggregate](image2)

| Replacement level of CGP in % | Replacement level of CGA in % | Density at 7 day Kg/m$^3$ | Density at 28 day Kg/m$^3$ |
|-------------------------------|-------------------------------|--------------------------|--------------------------|
| 0                             | --                            | 2.12                     | 2.13                     |
| 5                             | --                            | 2.12                     | 2.14                     |
| 10                            | --                            | 2.09                     | 2.15                     |
| 15                            | --                            | 2                         | 2.13                     |
| 20                            | --                            | 1.9                      | 2.01                     |
|--                             | 0                             | 2.1                      | 2.13                     |
|--                             | 5                             | 1.38                     | 2.13                     |
|--                             | 10                            | 1.32                     | 2.2                      |
|--                             | 15                            | 2.1                      | 2.15                     |
|--                             | 20                            | 2                        | 2.13                     |

5.5: Flexural and split tensile strength of concrete mixes made with CGP and CGA
Tensile strength of concrete mixes is indirectly found by conducting flexural strength and split tensile strength. Specimens of standard size as per the BIS codal provisions are cast, concrete mixes of CGP and CGA 30% replacement level are selected. The split tensile strength is found to be 2.6MPa and 2.8MPa for CGP and CGA respectively. Flexural strength is found to be 3.6MPa and 4.0MPa for CGP and CGA respectively. Figure 5.9 and Figure 10 shows specimen subjected to split tensile and flexural strength [10].

![Specimen size 150mm diameter and 300mm height](image3)

Figure 5.9: Split tensile testing on concrete specimen
5.6: Durability of concrete and mortar

Concrete and mortar specimens made with 30% replacement of CGP and CGA are chosen for the study. Specimens after attaining 28 Days age are immersed in 5% NaCl Solution in 4 Cycles, whereas one cycle consists of 7 days and 7 nights samples immersed in solution are kept open under the sun. At the end of each cycle samples are replaced in solution of same concentration and test repeated for a month (4 cycles) [5&6]. By the end of each cycle weight loss by the specimen is compared with control specimen, strength loss after completion of 4 cycles is evaluated. Densities and strength loss for selected concrete and mortar mixes are presented in Table 5.5 and illustrated in Figure 5.11 & 5.12. Results revealed that maximum density loss of 6% for T2 (Concrete with 30% CGA), minimum density loss of 3.8% for T3 (mortar with 30% CGP). Maximum strength loss of 20% was observed in T2Concrete with 30% CGA), minimum strength loss of 13% for T3 (mortar with 30% CGP)[7].

Table 5.5: Density and durability loss of concrete and mortar specimens

| Test Samples | 1st cycle Density loss in % | 2nd cycle Density loss in % | 3rd cycle Density loss in % | 4th cycle Density loss in % | Strength loss after 4th cycle % |
|--------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-------------------------------|
| T1           | 1.98                        | 2.50                        | 3.10                        | 4.50                        | 18                            |
| T2           | 2.00                        | 3.50                        | 3.90                        | 6.00                        | 20                            |
| T3           | 1.20                        | 2                           | 2.80                        | 3.80                        | 13                            |
| T4           | 2.00                        | 3                           | 4.00                        | 5.00                        | 16                            |

T1: Concrete with glass binder 30% replacement level  
T2: Concrete with glass aggregate 30% replacement level  
T3: Mortar with glass binder 30% replacement level  
T4: Mortar with glass aggregate 30% replacement level
6: Conclusions drawn on research work
Following are the conclusions drawn,
1. There is no strength loss at 30% replacement of cement in concrete with CGP. High strength is observed for concrete with CGA @ 40% replacement level
2. The 30% replacement level of CGP and CGA found optimal in mortar mixes and 40% of CGA is found optimal for concrete mixes.
3. Up to 40 % replacement of CGA may be used in concrete mixes and are recommended to use in RC structural members.
4. Use of CGP@ 30% replacement level gives nominal tensile and flexural strength
5. The 20% and 13% strength loss is observed when glass-crete and mortar subjected to durability test i.e. alternate wetting and drying.

6.1: Scope for future work
The following future works may be incorporated.
1. Reinforced concrete structural elements with CGP and CGA may be designed and evaluated for their strength.
2. Ultra-thin concrete for pavements and masonry work may be proportioned and evaluated for their performance.
3. Building Products like paver, kerb and masonry blocks may be proportioned with CGP and CGA to evaluate their performance.

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