Influence of waste glass powder and crushed cobblestone on mechanical properties of concrete

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Abstract. This research includes the study of the mechanical properties of normal concrete and concrete made of waste aggregates, such as stress-strain behavior and flexural strength. The waste aggregate contains fine waste glass powder and waste crushed boulders (cobblestone type) as coarse aggregate. The stress-strain behavior shows higher values of compressive strength and modulus of elasticity and larger area under stress-strain curve comparing with ordinary concrete which is containing ordinary aggregates. Also, the flexural strength is increased when using waste aggregates. The most benefit of this study is the cost decrease of concrete and clean environment by using waste materials in addition to higher values of compressive and flexural strengths. Total replacement of normal aggregate with waste aggregate gives the largest area under stress-strain curve. Compressive strength is increased from 36.4 MPa for control mix to 43.1 MPa for total replacement. The modulus of elasticity was about 30.6 GPa for waste aggregate concrete of total replacement whereas in the normal aggregate concrete it was 26.4 GPa. In normal concrete, larger area under stress-strain diagram for waste aggregate concrete is achieved and that means higher toughness concrete. Also, high strength concrete is achieved by 75% and 100% replacement of normal aggregate with waste glass and cobblestone, respectively. The study includes the freezing-thawing cycles effect on concrete and the results show higher strength by using crushed glass and cobblestone aggregates. The aim of this study is to improve mechanical properties of concrete and durability of concrete to freezing and thawing by using waste glass aggregate and crushed cobblestone.

Keywords: Concrete, crushed cobblestone, mechanical properties, and waste glass powder

1. Introduction
Using waste aggregate in concrete has a lot of advantages such as decreasing cost of concrete, obtaining clean environment, and sometimes leading to higher mechanical properties of concrete. Many advantages are achieved by using high strength concrete in structures. American Concrete Institute (ACI) defined the high strength concrete as concrete with minimum compressive strength of 41 MPa for cylinder tests [1]. High strength concrete can reduce the amount of concrete needed in concrete structures [2] due to its higher compressive strength and modulus of elasticity compared to the normal concrete. In high strength concrete, the high modulus of elasticity leads to decrease the deflection values which affects the design spans between supports of buildings or spans between pears.
in concrete bridges [3,4]. The materials used in high strength concrete (HSC) can lead to higher concrete cost compared to the normal strength concrete [5]. Many investigations studied the use of waste aggregates in concrete to reduce the cost and getting clean environment. The resulting concrete strengths depend on the type and strength of waste aggregate [6,7]. Waste bricks can be used as coarse aggregates and give slight increase in compressive, tensile, and flexural strengths with 50% replacement of normal coarse aggregate [8]. The objective of this study is to produce concrete with higher mechanical properties by using waste fine and coarse aggregates.

2. Experimental Program

2.1. Materials

Coarse and fine aggregate gradings are shown in Tables 1 and 2, and are confirming with Indian standards I. S-383 for coarse and fine aggregate gradings [9]. The fine powder waste glass is used with zone 4 of coarse waste aggregate obtained from waste boulder (type cobblestone) which is produced with the same grading of ordinary coarse aggregate. The cobblestones are used with dimensions ranged between 6-8 cm and crushed by hand to smaller pieces to obtain coarse aggregates. Some properties of cobblestone used in the study are shown in Table 3. Ordinary Portland Cement is used in all mixes. Super-plasticizer is used with specification shown in Table 4. The type of super-plasticizer is integral water proofing admixture (IWP) which works with two phases. In the first phase, it works as super-plasticizer water reducing and higher workability for concrete. In the second phase, it works as polymer admixture with polymer particles that fill pores and block capillaries inside concrete in order to give low permeability for concrete or mortars and high durability. The dosage of integral water proof admixture IWP used in the study was taken as 2.0 liter for each 100 kg cement. Table 5 shows the ingredients of concrete and mix proportions used in the study.

| Sieve size | Passing by weight (%) | Passing for Indian Standards I.S-383 (%) |
|------------|------------------------|----------------------------------------|
| 40 mm      | 100                    | 100                                    |
| 20 mm      | 99.3                   | 95-100                                 |
| 10 mm      | 51.8                   | 25-55                                  |
| 4.75 mm    | 6.8                    | 0-10                                   |

| Sieve size | Passing by weight (%) | Passing for Indian Standards I.S-383 (Zone4) (%) |
|------------|------------------------|-----------------------------------------------|
| 10 mm      | 100                    | 100                                           |
| 4.75 mm    | 100                    | 95-100                                        |
| 2.36 mm    | 100                    | 95-100                                        |
| 1.18 mm    | 96.7                   | 90-100                                        |
| 600 microns| 88.3                   | 80-100                                        |
| 300 microns| 23.6                   | 15-50                                         |
| 150 microns| 1.2                    | 0-15                                          |
Table 3. Some properties of cobblestone used as coarse aggregate.

| Property of cobblestone | Color          | Dimension         | Compressive strength | Flexural strength | Density          |
|------------------------|----------------|-------------------|----------------------|-------------------|------------------|
|                        | Light brown –light grey | 6-10 cm (approximate) | 160-170 MPa | 21 MPa | 2600 – 2700 kg/m³ |

Table 4. Some properties of IWP super-plasticizer used in the study.

| Form   | Color       | Chemical composition                                                                 | Density  | Dosage range                  |
|--------|-------------|--------------------------------------------------------------------------------------|----------|-------------------------------|
| Liquid | Dark brown  | Poly-Carboxylate liquid polymer-based plasticizer and organic polymer compounds(co-polymer) | 1.1 g/cm³ | 2 liters for each 100 kg cement |

Table 5. Ingredients and mix proportion of concrete used in the study.

| Ingredient                      | Cement | Fine aggregate | Coarse aggregate | water | Super plasticizer | Mix proportion |
|---------------------------------|--------|----------------|------------------|-------|-------------------|----------------|
| 1 kg for 1 cubic meter of concrete | 500 kg | Poly-Carboxylate liquid polymer-based plasticizer and organic polymer compounds(co-polymer) | 1150 kg | 150 kg | 2 liters for each 100 kg cement | 1:1.3:2.3 w/c=0.3 |

2.2. Testing Procedure

Stress-strain behavior tests were conducted by using 150×300 concrete cylinders. The strain values were obtained by using mechanical strain gauges attached on the concrete specimens as shown in Fig. 1. The specimens were subjected to constant stress rate and tests followed the ASTM-C-469 [10]. From stress-strain curves, the modulus of elasticity values were obtained from the straight line of the curves (initial tangent modulus), and the maximum compressive strengths were obtained from stress-strain curves.

Flexural strengths were conducted by using 100×100×400 mm beams that were loaded after 28 days of curing for the third point loading tests. The flexural strength for each concrete specimen is obtained according to Eq. 1. Where $F_b$ is the flexural strength of concrete, $P$ is the maximum load from machine, $L$ is the length of beam (between supports), $b$ and $d$ are width and height of beam (both are 100mm). A concrete beam specimen prepared for flexural strength test is shown in Fig. 2.

$$F_b = \left( P \times L \right) / bd^2$$  \hspace{1cm} (1)
2.3. Freezing-Thawing Testing Procedure

Freezing-thawing cycles tests were conducted on ordinary concrete control mixes and mixes with waste aggregates by using 100×100×100 mm cubes of concrete and subjected to 12 hours of freezing with -200°C and then 12 hours in +20°C to study the durability of concrete to freezing and thawing effects. The range of temperature is according to the freezing and thawing specification test of concrete CEN/TS 12390-9 [11]. One cycle includes 1 day with 12 hours of freezing and 12 hours of thawing. 30 and 60 cycles of freezing and thawing were used in this study. After the cycles, the concrete cubic specimens were tested to obtain the reduction in strength due to cycles. Fig. 3 shows some specimens during cycles of freezing-thawing.
3. Results and Discussion

Table 6 shows the maximum compressive strength and modulus of elasticity obtained from stress-strain curves for different mixes. Figs. 4, 5, 6, 7 and 8 show stress-strain behaviours of control mix and mixes with 25%, 50%, 75% and 100% replacement of normal aggregate with waste glass powder and crushed cobblestones as coarse aggregate. Fig. 9 shows comparisons of stress-strain between control mix and mixes with total replacement.

Compressive strength with 25% replacement of aggregate with waste glass and cobblestone aggregate was increased from 36.4 MPa to 38.3 MPa as shown in Table 6. Also, it is increased gradually to 43.12 MPa for total replacement. This can be attributed to the action of fine glass powder which is different from normal fine aggregate used in control mixes. Sharp edges of glass powder aggregates give more bond with cement paste. Another reason for gaining higher compressive strength by using waste aggregates is due to mechanical properties of cobblestones which have more compressive strength compared to normal aggregates. The normal aggregates have a range of compressive strengths specified in ASCE [12], which provides compressive strengths of normal coarse aggregates (gravel) ranged between 50-80 MPa whereas cobblestone’s compressive strengths exceed 160 MPa. This gives higher strength to concrete.

Modulus of elasticity values were increased from 26.4 GPa for control mix to 30.6 GPa for mixes with 100% replacement with waste aggregates as shown in Table 6. This is attributed to the higher compressive strengths and lower strain values under loading. This improvement is very essential because higher moduli of elasticity mean lower deflections in concrete structural members or spans such as slabs, beams, or girders [13,14].

Stress-strain behavior is improved by replacement with waste aggregate. Fig. 8 shows comparison between normal aggregate concrete and waste aggregate concrete. The area under the stress-strain relation becomes larger compared to the ordinary concrete which means higher concrete toughness. Flexural strength is increased by using crushed glass and crushed boulders as replacements. Table 7 shows the flexural strength increases by replacing normal aggregates with waste aggregates. Flexural strength of control mix was 3.12 MPa, and 3.8 MPa for 25% replacement with waste aggregate. For 50% replacement, the flexural strength is increased to 4.5 MPa and for 100% replacement, it is increased to 4.98 MPa. One of the reasons for concrete flexural strength improvement is due to cobblestone itself that has high value of flexural strength that is about 21 MPa as shown in Table 3.

The increases in compressive strength, modulus of elasticity, and flexural strength by replacing normal aggregates with crushed glass and crushed cobblestones can be attributed to the good bond properties of waste glass powder that has sharp edges with cement paste. Also, crushed cobblestones have sharp angular faces that can tightly bonded to the cement paste and give higher concrete strength [15]. Fig. 10 shows the relationship between % of replacement of coarse and fine aggregates and flexural strength.

Table 6. Compressive strength and modulus of elasticity for mixes used.

| Mix type                               | Max. compressive strength, MPa | Static modulus, GPa |
|----------------------------------------|--------------------------------|---------------------|
| M1 (Control)                           | 36.45                          | 26.4                |
| M2 (with 25% replacement of aggregates) | 38.30                          | 27.0                |
| M3 (with 50% replacement)              | 40.85                          | 28.8                |
| M4 (with 75% replacement)              | 42.63                          | 30.2                |
| M5 (total replacement)                 | 43.12                          | 30.6                |
Table 7. Flexural strength for concrete mixes.

| Mix type                                      | Flexural strength, MPa |
|-----------------------------------------------|------------------------|
| M1 (Control)                                  | 3.12                   |
| M2 (with 25% replacement of aggregates)       | 3.84                   |
| M3 (with 50% replacement)                     | 4.56                   |
| M4 (with 75% replacement)                     | 4.70                   |
| M5 (total replacement)                        | 4.98                   |

Figure 4. Stress-strain diagram of control mix.

Figure 5. Stress-strain curve of concrete with 25% replacement with waste aggregates.
Figure 6. Stress-strain curve of concrete with 50% replacement with waste aggregates.

Figure 7. Stress-strain curve of concrete with 75% replacement with waste aggregates.
Figure 8. Stress-strain curve of concrete with 100% replacement with waste aggregates.

Figure 9. Stress-strain behavior (as comparison) between normal aggregate concrete (the blue curve) and 100% waste aggregate concrete (the red curve).
Figure 10. Relationship between flexural strength and % of replacement of aggregate.

Table 8 and Fig 11 shows the results obtained after cycles of freezing and thawing for cubic specimens mixed with waste glass powder and cobblestone aggregates. Results show less reduction in compressive strength after 30 days and 60 days cycles compared to control mix, and that can be attributed to the glass fine aggregate which has less absorption to water compared to the normal sand or fine aggregate. This gives less ice formation inside concrete which is responsible for additional stresses inside concrete due to cycles. This leads to less reduction in strength for mixes with higher replacement of glass powder and cobblestone.

| Mix type   | Compressive strength without cycles, MPa | Compressive strength with 30 cycles, MPa | Compressive strength with 60 cycles, MPa | Reduction in strength after 60 cycles, % |
|------------|----------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|
| M1- control | 41.1                                    | 25.9                                    | 16.3                                    | 60.3                                    |
| M2         | 44.5                                    | 34.0                                    | 25.3                                    | 43.1                                    |
| M3         | 47.9                                    | 36.7                                    | 28.7                                    | 40                                      |
| M4         | 48.7                                    | 37.8                                    | 30.2                                    | 37.9                                    |
| M5         | 49.5                                    | 38.5                                    | 32.3                                    | 34.7                                    |
Figure 11. Compressive strength due to freezing-thawing cycles.

4. Conclusions

- Mechanical properties of concrete can be improved by using waste aggregates.
- Using crushed cobblestone as coarse aggregate and waste glass powder as replacement of normal aggregates improves the compressive strength, stress-strain behavior, modulus of elasticity and flexural strength of concrete.
- Achieving high strength concrete with 75% and 100% replacement of aggregates. The control specimen has cylinder compressive strength of 36.4 MPa. With 75% replacement, it is increased to 42.6 MPa and with 100% replacement, it is increased to 43.1 MPa.
- Low reduction in strength due to freezing-thawing cycles on concrete containing waste glass and cobblestone aggregates compared to concrete control mixes.

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