Mechanical characteristics of concrete containing basalt fiber and recycled aggregate

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Abstract: The potential of construction waste as an alternative to the constituents of concrete has been generally examined to demonstrate their utility and ensure the climate and/or environment of its otherwise ill effects. The mechanical characteristics of concrete are investigated to comprehend its behaviour under compressive, tensile, and flexural loads. This experimental study investigates the effect of supplanting proportions of river aggregates with waste coarse aggregates in addition to the effect of basalt fiber additions on concrete mixes with (25 and 50%) substitutions of recycled waste coarse aggregates (RWCA). The workability of concrete mixes was negatively affected with recycled aggregates and/or basalt fiber inclusions. Using recycled aggregates with 25 and 50% replacements decreases the strength of concrete. On utilizing discrete proportions of basalt fiber with natural coarse aggregates, the strength was higher as compared to control mix however increasing the percentage of basalt fiber from 1% to 3% the compressive strength was reduced. On incorporating additions of basalt fiber with different proportions of RWCA, the strength of concrete was deteriorated as the percentage of fiber was increasing. For natural aggregates, the inclusion of fibers has negative effect on compressive strength however the tensile strength was increased with higher percentage of fibers. The inclusions of fibers to 25% recycled aggregate mixes, split tensile strength was much higher as compared to control mix. It was concluded that addition of basalt fibers provides a viable option to recycle recycled aggregate in concrete production.

Keywords: Waste materials, recycled aggregate, basalt fiber, mechanical characteristics, compressive strength.
1. Introduction

The degree of construction waste has expanded immensely over the globe in recent decade. Especially in non-industrial or developing nations like India, the new drafting local laws, urbanization, and industrialization, re-erecting older constructions, and highways for increased traffic demands have impelled tremendous quantity of demolished waste. To achieve the expanding requests of highway and key development, the construction and demolition waste is a viable replacement for river aggregates. Accordingly, to build a sustainable future the recycling of waste aggregates in concrete production will be beneficial from monetary along with ecological viewpoint. Utilizing demolition waste in concrete construction weakens quality of concrete with increased level of substitutions because of adhered mortar [1]. RCWA was more permeable in nature because of adhered mortar [2] and has a lower viscosity when compared with regular natural concrete because of lower specific gravity of reused totals [3]. On full replacing natural aggregates with RWCA in concrete there was moderate drop in strength however it was plausible to be implemented in low quality concrete applications [4]. For quasi static loading, stress-strain characteristics for RWCA was analogous with river coarse aggregate concrete even though irregularities were observed in characteristics between them [5].

One major weakness of concrete under tensile stresses can be overcome with the use of fibers. Workability was found to be plummeting with chopped basalt fibers additions nevertheless slight increase in compressive strength was expected [6]–[8], despite the fact significant enhancements were observed in flexural and splitting tensile strength on varying fiber dosage from 0% to 5% by the weight of cement with intervals of 1% [9]. With the variation of volume fraction from 0 to 2% of basalt chopped fibers the compression strength decreased marginally while split tensile strength was improved by 15% when basalt fiber volume was 2% added to concrete [10].

2. Research significance

Investigation is carried out for mechanical characteristics for concrete mix having basalt fibers and recycled aggregate as partial alternative to river coarse aggregates at different percentages (25% and 50%) with and without basalt fiber addition was employed. The influence of basalt fiber additives with different percentages (1%, 2% & 3%) for compressive, splitting tensile and flexural strength test are investigated. Eventually, mechanical characteristics were studied for 7- and 28-days concrete age. Study will highlight utilization of RWCA in construction application for the sustainability of the construction industry with addition of basalt fiber to enhance the strength of RWCA concrete.

3. Materials and methods

3.1 Materials
3.1.1 Cement

Ordinary Portland cement [11] with a specific gravity of 3.15 g/cm³ was utilized as a binder. Standard consistency of 28% and fineness of 290.5 m²/kg was recorded. The initial and final settling time was 110 minutes and 240 minutes respectively and 7- and 28-days strength was recorded at 42.5 N/mm² and 55 N/mm², respectively.

3.1.2 Natural aggregates

Natural river aggregates graded as per [12] was utilized. As per [13] standards, coarse aggregates passing 20 mm and fine aggregates passing sieve no. 4 were utilized.

3.1.3 Construction demolition waste aggregates

RWCA were obtained from demolished cube specimens in laboratory. The recycled coarse aggregates were used because of green building concept and eco-friendly environment. As per [13] standards, RWCA were pounded to similar gradation as river aggregates.

3.1.4 Basalt Fiber

Basalt fibers having typical length as 4.2 mm were utilized.

3.1.5 Water

As per [14] standards, ordinary water with pH 7—8 was utilized.

3.2 Mix proportions and testing

As per [15], control mix was proposed for 1m³ with water to binder ratio as 0.5 taking cement quantity as 383.16 kg and constituents of fine sand and coarse aggregate as (1: 1.93: 2.90). The RWCA was replaced for 25% and 50% with river coarse aggregates. Further, fiber addition of 1%, 2% and 3% by binder weight was also exercised. Consistency of all mixes was kept at 50 – 80 mm range. Fine and coarse aggregates were utilized at surface saturated dry state. The detailed description of mixes was reported in Table 1. To each batch, consistency test was performed as per [16], and thereafter stuffed in moulds and vibrated using vibrated table for proper compaction. The specimens were kept for one day prior to demoulding and water cured at room temperature to appropriate period.

3.2.1 Testing procedure

Specimens were tested as per [16] for cube compressive strength and cylindrical splitting tensile strength after 7 and 28 days in compression testing machine. Flexural strength was examined after 28-days.

| Series                          | Description | Specimen count               |
|---------------------------------|-------------|------------------------------|
| A series- Natural aggregate     | C:FA:CA     | 6 cube, 6 cylinder and 3 beam. |
B series for recycled coarse aggregate

| Series       | Composition                                      | Tests                                      |
|--------------|--------------------------------------------------|--------------------------------------------|
| B1 series    | 25% recycled aggregate concrete                  | C:FA:CA (25% replacement with recycled aggregate) | 6 cube, 6 cylinder and 3 beam. |
| B2 series    | 50% recycled coarse aggregate                    | C:FA:CA (50% replacement with recycled aggregate) | 6 cube, 6 cylinder and 3 beam. |
| C series     | Concrete with Basalt Fiber                       |                                            |
| C1           | Addition of 1% BF by weight of cement             | C:FA:CA + 1% BF                           | 6 cube, 6 cylinder and 3 beam. |
| C2           | Addition of 2% BF by weight of cement             | C:FA:CA + 2% BF                           | 6 cube, 6 cylinder and 3 beam. |
| C3           | Addition of 3% BF by weight of cement             | C:FA:CA + 2% BF                           | 6 cube, 6 cylinder and 3 beam. |
| CB series    | Concrete with basalt fiber and 25% recycled       |                                            |
| CB1          | Addition of 1% BF by weight of cement             | C:FA:CA (25% replacement with recycled aggregate) + 1% BF | 6 cube, 6 cylinder and 3 beam. |
| CB2          | Addition of 2% BF by weight of cement             | C:FA:CA (25% replacement with recycled aggregate) + 2% BF | 6 cube, 6 cylinder and 3 beam. |
| CB3          | Addition of 3% BF by weight of cement             | C:FA:CA (25% replacement with recycled aggregate) + 3% BF | 6 cube, 6 cylinder and 3 beam. |
| CB’ series   | Concrete with basalt fiber and 50% recycled       |                                            |
| CB’1         | Addition of 1% BF by weight of cement             | C:FA:CA (50% replacement with recycled aggregate) + 1% BF | 6 cube, 6 cylinder and 3 beam. |
| CB’2         | Addition of 2% BF by weight of cement             | C:FA:CA (50% replacement with recycled aggregate) + 2% BF | 6 cube, 6 cylinder and 3 beam. |
| CB’3         | Addition of 3% BF by weight of cement             | C:FA:CA (50% replacement with recycled aggregate) + 3% BF | 6 cube, 6 cylinder and 3 beam. |

4. Results and Discussion

4.1 Fresh concrete characteristics of various concrete specimens
Fresh properties of concrete mixes were tested for consistency as per [16]. The control mix has a consistency of 77 mm. Addition of fibers decreased the slump flow value of basalt fiber mixes from 70 to 57 mm for 1-3 % addition respectively. For RWCA, consistency reduced from 68 to 60 mm on increasing the percentage of RCA from 25 to 50% as shown in Figure 1. The reason due to the old, attached mortar in RCA which increases porosity of RCA mixes results in higher water absorption by recycled coarse aggregates thereby decreasing the value. The combination of RCA and basalt fiber mixes further reduced workability whilst the proportion of RCA and BF increased resulted in further reduction in workability of concrete. Therefore, it is recommended to use the aggregates in surface saturated dry condition for the optimal workability.

\[\text{Fig. 1: Slump values of different mixes}\]

4.2 Effect on various mixes on compressive strength

Hardened properties of various mixes are tested as per [17] for 7- and 28-days age compressive strength. Increasing amount of RWCA in concrete mix results in more reduction in strength. The inclusion of fibers enhanced the compressive strength. On adding 1% fiber content (mix C1), strength of concrete mix showed increase in 7- and 28-days strength as 26.82 MPa and 34.97 MPa respectively. The inclusion of basalt fiber in concrete mix enhanced the strength of concrete, however, with further additions (mix C2 and C3) the compressive strength tends to decrease but still higher than control mix for C2 mix. The addition of fibers to RWCA concrete has contrary results. Using 25% RWCA replacements and basalt fiber (mix CB), strength obtained for 7 and 28 days is marginally deteriorated in contrast to mix lacking fibers. As fibers content increased in concrete mix, the compressive strength tends to decline for 7- and 28-days age of concrete. Increasing the fiber content tends to segregate the concrete mix which in turn results in reduction in strength. Comparison of compressive strength among various mixes was shown in Figure 2. For
CB’ mixes consisting of 50% RCA with varying basalt fiber additions, the compressive strength showed further decrement in strength. On comparing, the fibers have little to no encouraging impact on concrete strength and reduction is more prominent in higher addition of fiber content on strength of RWCA concrete.

Fig. 2: Effect of various mixes on 7- and 28-days compressive strength

Difference in strength as compared to control mix was shown in Figure 3. The inclusion of fiber, C1 mix has a maximum strength gain of 9.89% whereas the replacement of natural aggregates with RCA results in decrement of strength. The difference in strength in more prominent in 7 days age of concrete in contrast to 28 days concrete age. Maximum strength drop was attained for CB3’ mix with a reduction of 20% in strength in contrast to control mix. Inclusion of higher percentages of basalt fibers has contrary effect on the strength of concrete. Optimum substitution proportion for basalt fibers was 1% which results in strength gain of concrete mix. The use of recycled aggregates is mainly dependent upon the source and generally higher strength of aggregates results in marginal differences in strength in contrast to control mix. Using RWCA can be employed as maximum reduction in strength with 50% RCA is only 6%.
Fig. 3: Difference in compressive strength w.r.t control mix

4.3 Effect on various mixes on Split tensile strength

Supplementing basalt fibers to RWCA concrete has enhanced splitting tensile strength of concrete. For 25% RCA replacement, the gain in strength at 28 days for 1, 2 & 3% fiber addition is 3.92, 3.54 and 2.49 MPa respectively, which is higher as compared to control mix. For 50% replacement levels, the improvement in splitting tensile strength has mixed behaviour in which the strength firstly increased for 1% replacement then decreases for 2% and then increases for 3% basalt fiber addition. The addition of fibers had significant improvements for 25% RCA replacement as compared to 50% replacement levels. At lower replacement levels, the tensile strength is governed by fiber inclusions whereas higher replacements have marginal outcome on splitting strength. The fiber inclusion has significant improvement on splitting strength of concrete mix. Fiber addition has improved the splitting strength from 1.96 MPa to 2.65 MPa for 1% basalt fiber addition as shown in Figure 4. Further additions of fiber content have increased the splitting strength of concrete mix and because of bridging action of fibers the tensile cracks are mitigated which helps in higher tensile strength.
4.4 Effect on various mixes on flexural strength

The hardened properties of concrete mixes were examined following [17] for 28 days age of concrete. For recycled aggregates, the flexural strength has marginal decrement due to the low strength aggregates present in the concrete matrix. Fiber supplements has reduced the flexural strength; however, the strength was still superior to control mix for basalt fiber mixes. The basalt fibers utilization to RWCA concrete has notably enhanced the flexural strength in contrast to concrete mix devoid of fibers. However, gain in strength was only visible for 1% basalt fiber addition as 3.35 MPa and 3.15 MPa for 25 and 50% RCA replacements and further fiber addition has resulted in decrement of strength as shown in Figure 5. The optimum addition of basalt fiber is 1% addition and further additions resulted in lower flexural strength maybe because of predominating effect of RWCA which hinders fibers bridging effect due to weak adhered mortar as shown in Figure 6.
5. Conclusions

The experimental investigation on strength properties of concrete mixes having basalt fibers and recycled aggregate concluded as:

1. The workability was reduced on utilizing RWCA and further lowered on inclusions of basalt fibers.

2. The compressive strength was reduced with increasing percentages of recycled aggregates.

   The inclusion of basalt fibers reduced the strength of natural aggregate concrete as well as recycled aggregates concrete.
3. The splitting strength was reduced on substituting recycled aggregates. For concrete mix with basalt fiber, splitting tensile strength enhanced with higher proportion of fiber, however for recycled aggregates, the splitting strength was attained much higher as compared to natural aggregates for 25% replacement and was reduced with the additions of fibers.

4. The flexural strength was found to be reduced with the substitution of recycled aggregates. Basalt fiber additions enhanced flexural strength of natural aggregates and 2% additions attained optimal strength value. For recycled aggregate concrete, the inclusion of fibers increased their flexural strength however increasing the percentage of fibers deteriorated the flexural strength.

5. It was concluded that additions of basalt fibers to recycled aggregates concrete at 1% addition was a viable option to compensate its scrawny mechanical properties and encourage reutilizing of discarded demolition waste.

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