Material performance of agro based hybrid natural fibre reinforced high strength concrete

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Abstract: The High Strength Concrete (HSC) is relatively higher brittle nature than normal concrete. Addition of fibre in concrete enhances the ductility properties. In the present research, agricultural products such as coir fibre (CF) and banana fibre (BF) were used to investigate the performance of HSC. The Fibre Reinforced High Strength Concrete (FRHSC) was developed with ternary blended combination using Metakaolin and Micro Silica. The concrete grades of M60 and M70 were designed for the study purpose. The fibre were added with 1.5% of volume of concrete and established three hybrid fibre combination such as 25% CF + 75% BF, 50% CF + 50% BF and 75% CF + 25% BF of total fibre content. The workability of FRHSC was maintained in the range of 100-120 mm with the assistance of superplastizer. The performance of FRHSC was determined using mechanical properties including the strength ratio and compared with the control HSC. The material performance of hybrid FRHSC was significantly improved and the ductility nature was increased up to 25% than the control HSC.

Keywords: High Strength Concrete, Hybrid Fibre, Material Performance, Strength ratio.

1. INTRODUCTION

The usage of High Strength Concrete (HSC) has been increased now-a-days in most of the special concrete structures and infrastructures. The rapid urbanization requires more demand for the HSC to minimize the size of structural elements as well as usage of natural resources. However the HSC is relatively brittle nature than the normal concrete and also lesser tensile strength [1]. The lower brittleness can be assessed by the ratio between tensile strength to compressive strength of concrete; the lower of strength ratio indicates the more brittleness of concrete [2]. Research findings have been reported that the addition of steel fibres reduces the slump value of fresh concrete but increase the tensile strength and flexural strength of concrete [3,4]. The ductility of concrete has increased due to the addition of polypropylene fibres and it has increased the impact energy absorption [5, 6]. The presence of glass fibers in HSC has controlling abrupt crack formation and thus enhancing concrete ductility [2]. In addition to the compressive strength, the impact resistance of concrete was increased after adding steel fibre [3]. Basalt fibres increases the strain value of maximum compressive strength and results only negligible contribution on elastic modulus of high performance concrete [7]. Compressive strength of glass fibre reinforced HSC increased from 57.85 to 66.6 MPa, splitting tensile strength increased from 3.06 to 4.92 MPa and the flexural strength increased from 4.84 to 7.27 MPa when glass fiber percentage increased from 0.0 to 1.2 respectively [8]. Naraganti et al [9] conducted an investigation on the comparison of steel-polypropylene hybrid fibre and steel-sisal...
fibres reinforced concrete based on the performance on impact resistance and concluded that the steel-polypropylene performed well. Apart from the usage of fibres, minimize the paste porosity and controlling the discontinuous invisible cracks by promoting the secondary hydration process due to the addition of reactive silica in the form of silica fume and other mineral admixtures are also improve the splitting tensile strength of concrete and other material performance[10-16].

In this research work locally available coir fibre and banana fibre from centre for construction methods and materials, S R Engineering College are utilized for developing the hybrid natural fibres. Both the fibres are normally used for making rope and other boards in regular practice. The fibres are natural and extracted from the coconut husk and banana stem respectively. South Indian states particularly Telangana state is an agriculture based state and the production of Coconut and Banana are the top cultivating crops. The potential use of the byproduct from the crops are attract the innovation in various other possibilities including concrete. In this background, the hybrid combination of both the fibres are considered in this investigation in order to evaluate the material performance of FRHSC. The HSC was developed with ternary combination of OPC, Metakaolin and Micro Silica.

2. EXPERIMENTAL PROGRAM

2.1 Materials used
53 grade ordinary Portland cement in accordance with IS: 269-2015 [17] was used in this study and the properties are shown in Table 1. Metakaolin and Micro Silica were used as supplementary cementitious materials for developing ternary blended concrete. The properties of OPC and other cementitious materials are shown in Table 1. Local River sand and granite coarse aggregate of 20mm and 10 mm fractions were utilized and the physical properties are shown in Table 2. The physical properties of coir fibre and banana fibre [figure 1 and figure 2] are shown in Table 3.

2.2 Experimental methods
Slump value of the fresh concrete was determined to find out the workability of HSC and FRHSC. The hardened concrete performance was evaluated through compressive strength and splitting tensile strength of 7, 14, 28 and 90 days cured 150 mm size cube specimen and 150 diameter and 300 mm height cylinder specimens respectively.

2.3 Mix Proportioning
M60 and M70 grade ternary blended concretes were designed as per the procedure given in IS: 10262-1982 [18] with OPC, Metakaolin and Micro Silica. The final mix proportions were obtained after testing the specimens by various trials. The final mix proportion considered for the study is specified in Table 4. The combined weight of coir fibre and banana fibre was taken as 1.5% of volume of concrete.

| Chemical compositions and Physical properties of Cement, Metakaolin and Micro Silica |
|---------------------------------|---------|----------|----------|
| Chemical compositions (%)       | Cement  | Metakaolin | Micro Silica |
| SiO₂                           | 21.92   | 54.83     | 72.52     |
| Al₂O₃                          | 5.71    | 31.91     | 11.61     |
| Fe₂O₃                          | 3.23    | 1.32      | 4.87      |
| CaO                            | 60.37   | 0.07      | 5.23      |
| MgO                            | 1.65    | 0.57      | 0.49      |
| Physical properties            |         |           |           |
| Specific gravity               | 3.153   | 2.62      | 2.21      |
| Fineness (m²/kg)               | 328     | 1400      | 21000     |
Table 2. Physical properties of aggregates

| Properties             | River sand | Coarse aggregate |
|------------------------|------------|------------------|
| Specific gravity       | 2.63       | 2.71             |
| Grading limit          | Zone - II  | Well graded      |
| Fineness modulus       | 2.67       | 7.69             |
| Bulk density (kg/m³)   | 1540       | 1580             |
| Water absorption (%)   | 1.25       | 0.78             |

Table 3. Physical properties of Coir fibre and Banana fibre

| Properties        | Coir fibre | Banana fibre |
|-------------------|------------|--------------|
| Diameter (µm)     | 200 - 250  | 150 – 300    |
| Density (kg/m³)   | 850 - 900  | 790 – 820    |
| Tensile strength (MPa) | 140 - 190 | 125 – 180    |
| Young’s Modulus (GPa) | 3.1 – 3.5 | 2.9 – 3.3    |
| Aspect ratio      | 25 - 40    | 35 – 50      |
| Elongation at break (%) | 26 – 30  | 32 – 35      |

Table 4. Mix proportioning of FRHSC

| Mix ID | Cement (Kg/m³) | Metakaolin (Kg/m³) | Microsilica (Kg/m³) | Coir Fibre | Banana Fibre | Sand (Kg/m³) | CA (Kg/m³) | w/c | Water (L/m³) |
|--------|----------------|-------------------|---------------------|------------|--------------|--------------|-------------|-----|-------------|
| 60C0   | 453.0          | 80.0              | 37.0                | 0          | 0            | 731          | 512         | 0.30| 171         |
| 60C A  | 453.0          | 80.0              | 37.0                | 1          | 1.75         | 0.5          | 0.58        | 731 | 512         |
| 60C B  | 453.0          | 80.0              | 37.0                | 0.75       | 1.31         | 0.75         | 0.87        | 731 | 512         |
| 60C C  | 453.0          | 80.0              | 37.0                | 0.5        | 0.875        | 1.0          | 1.16        | 731 | 512         |
| 70C0   | 490.0          | 90.0              | 40.0                | 0          | 0            | 0            | 0           | 700 | 640         |
| 70C A  | 490.0          | 90.0              | 40.0                | 1          | 6.2          | 0.5          | 3.1         | 700 | 640         |
| 70C B  | 490.0          | 90.0              | 40.0                | 0.75       | 4.65         | 0.75         | 4.65        | 700 | 640         |
| 70C C  | 490.0          | 90.0              | 40.0                | 0.5        | 3.1          | 1.0          | 6.2         | 700 | 640         |

Figure 1. Coir Fibre
3. RESULTS AND DISCUSSIONS

3.1 Effect of Hybrid fibre in compressive strength FRHSC

The compressive strength results obtained from the average three cube specimens of M60 and M70 grade concrete are specified in figure 3 and figure 4 respectively, which showed that speedy increase in compressive strength up to 14-20 days curing and gained more than 75% strength within 20 days of curing. This was due to the presence of micro silica in ternary blended combination in concrete and the strength development was observed beyond 28 days curing because of the presence of Metakaolin in the mix combination. The compressive strength of fibre reinforced concrete had shown the similar trend in the compressive strength development. However the compressive strength results of hybrid FRHSC were noticed in higher order than the control concrete. Addition of 0.75% CF with 0.25% BF in total fibre content increases 6% compressive strength at 28 days cured period of M60 grade concrete and similar trend was also observed in M70 grade concrete. In comparison of the selected three hybrid combinations, 0.5% CF and 0.5% BF combinations had shown relatively higher strength in all curing period of both the designed concrete. At the age of 28 days, the compressive strength of 0.5% CF and 0.5% BF hybrid fibre was more than 10% of control concrete. Ayub et al found nearly 2% strength improvement of metakaolin blended high performance concrete with 1% basalt fibre [19]. Chandra Mouli et al [20] and SuhasPawar et al [21] found that the increase in compressive strength of normal strength concrete up to 4-5% of banana fibres.
3.2 Effect of Hybrid fibre in splitting tensile strength and strength ratio of FRHSC

The Tensile strength results of 28 days cured cylindrical specimens and the % of increasing after adding the fibre contents are shown in Table 5. The results had shown that the tensile strength was increased after adding the fibres. Among the three combinations, the tensile strength of 0.5% CF + 0.5% BF based hybrid FRHSC had shown 25.45 and 23.47% increase in M60 and M70 grade concrete respectively than the control concrete. The increase in splitting tensile strength of the other two type of hybrid FRHSC were also shown more than 18.5% of control concrete. The relationship between compressive strength and splitting tensile strength of control concrete and hybrid FRHSC were developed and shown in figure 5 and figure 6 respectively. The predicted relationship with higher correlation co-efficient had also shown that the addition of hybrid fibre in HSC is increasing the splitting tensile strength.

Table 5. Increase in splitting tensile strength of hybrid FRHSC

| Grade | Strength (MPa) | Fibre combinations |
|-------|----------------|--------------------|
|       |                | 0%                 | 0.25%CF + 0.75%BF | 0.5%CF + 0.5% BF | 0.75%CF + 0.25% BF |
| M60   | Splitting tensile | 4.05               | 4.97              | 5.23            | 5.02             |
|       | -               | -                  | -                 | -               | -               |
| M70   | Splitting tensile | 4.26               | 4.99              | 5.26            | 5.12             |
|       | -               | -                  | -                 | 18.5%           | 23.47%           |

Figure 5. Relationship between compressive strength and splitting tensile strength of HSC
3.3 Effect of Hybrid fibre on the strength ratio between splitting tensile strength and compressive strength

The comparison of strength ratio between splitting tensile strength ($f_{st}$) to compressive strength ($f_c$) and the corresponding compressive strength was developed for both control concrete and hybrid FRHSC and shown in figure 6. The results can be explained that higher ratio between splitting tensile strength and compressive strength when the compressive strength was low. For example, the ratio is more than 0.08 for the compressive strength of concrete up to 40 MPa. However, the ratio is less than 0.055 when compressive strength is more than 70 MPa for control concrete. A non-linear reduction of splitting tensile strength was noticed when increasing the compressive strength. The correlation was predicted as $[f_{st}/f_c = 0.569f_c^{-0.53}]$ for control HSC. The addition of fibres increases the ratio between splitting tensile strength and compressive strength which indicate that the higher tensile strength was obtained in the same compressive strength of FRHSC. The ratio was observed as 0.095 and above in compressive strength of 40 MPa in hybrid FRHSC. The same higher order ratios were perceived in higher compressive strength of hybrid FRHSC. Similar to control concrete, non-linear reduction was noticed due to the reduction of tensile strength of corresponding compressive strength in hybrid FRHSC. The relationship was predicted as $[f_{st}/f_c = 0.626f_c^{-0.52}]$ as shown in figure 7. Form the results it is concluded that the ratio of splitting tensile strength to compressive strength $[f_{st}/f_c]$ is a function of compressive strength [22].

Figure 6. Relationship between compressive strength and splitting tensile strength of hybrid FRHSC

Figure 7. Ratio of splitting tensile strength to compressive strength versus compressive strength of HSC and hybrid FRHSC
4. CONCLUSIONS

The hybrid FRHSC was developed with 1.5% of coir fibre and banana fibre by weight of cementitious materials and the best combination of 0.75% of CF and 0.75% of BF was predicted from the results obtained in this investigation based on the compressive strength and splitting tensile strength. A non-linear correlation between splitting tensile strength and compressive strength were predicted with higher co-efficient and the hybrid FRHSC had shown higher correlation than the control concrete. The strength ratio between splitting tensile strength and compressive strength were predicted and evidences that the hybrid FRHSC was increasing up to 25% of tensile strength than the control concrete.

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