Evaluation of material performance of coir fibre reinforced quaternary blended concrete

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Abstract: The experimental investigation was conducted to evaluate the impact of coir fibre of quaternary blended concrete on strength and durability performance. M35 grade of concrete was considered in this study. Fly ash, Granite powder and Nano silica were considered for developing the quaternary blended concrete. Fly ash and Granite powder were added as partial replacement of cement by 25% and 10% respectively and Nano-silica was considered as third mineral admixture varies from 0 to 2% of cementitious content. In order to improve the ductility of concrete, the coir fibres are supplemented in concrete at 0.25, 0.5, 0.75, 1.0, and 1.25% by volume of concrete. The performance of hardened concrete was examined in terms of compressive strength, rebound hammer test, flexural strength and durability was examined by sorptivity test. The results showed that the addition of coir fibres causes the reduction of slump value but improve the mechanical properties up to 1% addition of coir fibres in concrete. The sorptivity of Nano-silica blended quaternary blended concrete is increased up to 15% with the presence of 1% coir fibre

Keywords: Quaternary blended concrete, Coir fibre, Compressive strength, Rebound hammer, Flexural strength, Sorptivity.

1. INTRODUCTION

The usage of blended cement in construction industry is continuously booming to improve the performance of cement concrete structural elements. The construction engineers are concentrating the durability properties of concrete now-a-days and hence special consideration was given in developing blended cement instead of Ordinary Portland cement (OPC) by blending with reactive mineral admixtures during manufacturing process. Accordingly the IS codes for OPC 53 and OPC 43 grade cement was revoked and a single IS code was presently practiced commonly as IS 269-2015 [1] for all the grade of cement. For considering the sustainability of cement production, the mineral additives [2-8] are added as partial replacement of cement for developing the blended cement. The substitution of mineral additives acts as filler materials and promote the pozzolanic reaction due to the presence of amorphous silica in the blended cement. A non-water-soluble calcium silicate hydrate (C-S-H) was produced during secondary hydration which fills the invisible pores and make the concrete mass as more dense in nature. The slower setting time and strength development of blended cement creates much attention to researcher to overcome the drawback of blended cement. Consequently the ternary blended cement was developed [9-10] and presently the quaternary blended cement is create more attention in research. A super fine mineral additives like silica fume (SF) was practiced as the third cementitious material for developing the ternary blended cement and presently Nano-silica (NS) particles are being tested as fourth mineral additive for developing the quaternary blended cement in order to improve the performance of cement [11-17]. Patel and Dave (2016) proved that the...
quaternary mix provides high early strength than binary blended concrete [14]. The quaternary blends with SF and Ground Granulated Blast furnace Slag (GGBS) retards setting time and increases the consistency [15]. The experimental report with 70% OPC, 15% Flyash (FA), 7.5% SF and 7.5% GGBS combined quaternary blended concrete has shown more early strength and also improved later strength [16].

The quaternary blend solves problem of bleeding of ternary mix and requires less quantity of superplasticizer than ternary blend [15]. The quaternary cementitious blends with FA, GGBS and SF provide the best performance in sorptivity, permeability and other durability properties [16]. The quaternary mix of cement with 20% fly ash, 10% of lime stone powder and 10% of RHA was reported to enhance the strength as well as corrosion resistance [17]. The incorporation of Nano-silica (NS) are improved the performance of RHA blended mortar on compressive strength, chloride permeability, electrical resistivity and capillary absorption of ternary blended mortars [19]. An investigation report had shown good results in acid resistance and also shown in good performance in Ultrasonic Pulse Velocity (UPV) results of NS based quaternary blended concrete with FA and SF as the other two mineral admixtures [20]. The addition of steel fibre in ternary blended concrete with condensed SF and Metakaolin (MK) was performed excellently in compressive strength and flexural strength [21-22]. The glass fibre based ternary blended concrete had shown promising results than the binary blended concrete [23]. The other research report revealed that the steel and glass fibre combined hybrid fibre was enhanced the compressive strength and flexural strength of ternary blended high strength concrete [24]. The agriculture based natural fibre like banana fibre and coconut fibre are also used as fibres in concrete and able to resist the cracks and improve the strength performance [25].

Granite waste in the form of fine powder is now creating attention to the researchers for using as ingredient in concrete. The granite powder (GP) was normally disposed into landfill areas and create environmentally discomfort to the habitant. However it has a reasonable amount of silica and react as pozzolanic materials in cement concrete. The research finding suggests that the GP can be used as fine aggregate and also binder in concrete [23]. Though there are few experimental results available with GP as supplementary cementitious material in concrete, further investigations are required to utilize the GP as a regular ingredient in concrete and also research is essential to ensure the compatibility of coir fibre in multiple blended concrete. Hence, this investigation was intended to carry out a study with GP and NS based quaternary blended concrete with coir fibre on the mechanical properties and durability properties.

2. EXPERIMENTAL PROGRAM

2.1. Materials used

Ordinary Portland cement (OPC) belongs to 53 grade as per IS: 269-2015 [1] available in the market was utilized throughout the research. The physical properties such as specific surface area and specific gravity of the cement was determined and found as 257 m²/g and 3.15 respectively and the chemical composition of cement is shown in Table 1. Class F type fly ash was obtained from NTPC, Ramagundam, Telangana State. The chemical properties of fly ash are mentioned in the Table 1. GP was obtained from local granite cutting industry and the sample is shown in figure 1. The specific surface area and specific gravity of GP was found as 225 m²/g and 2.61 respectively. The grain size distribution of GP was conducted and found that more than 40% of GP was less than 150 microns and more than 50 % of GP were less than 45 micron. The chemical composition of GP is shown in Table 1. The chemical compositions revealed that GP contains more than 72.5% SiO₂ and shows suitable for cementitious materials in concrete. The locally available coir fibre was used, as shown in figure 2, was added into the concrete mix. The Nano-silica was collected from the local supplier. The specific gravity of the NS was obtained as 2.24. The fine aggregate was obtained from the local river which belongs to grade zone II and the physical properties like specific gravity and fineness modulus were determined and found as 2.67 and 2.72 respectively. The coarse aggregate of maximum size 20 mm
with specific gravity of 2.67 and 10 mm with specific gravity 2.69 were used in this investigation with 60:40 ratio. The grain size distribution test was also conducted and the coarse aggregate found as well graded aggregate.

| Chemical compositions | OPC | Fly ash | Nano-silica | Granite Powder |
|-----------------------|-----|---------|-------------|----------------|
| SiO₂                  | 21.92 | 57.43 | 99.65 | 72.5 |
| Al₂O₃                 | 5.71 | 29.97 | 0.267 | 11.61 |
| Fe₂O₃                 | 3.23 | 3.72 | 0.004 | 4.87 |
| CaO                   | 60.37 | 4.55 | 0.098 | 5.23 |
| MgO                   | 1.65 | 1.43 | -     | 0.49 |

2.2. Mix Proportioning

This investigation was conducted by two stages. In stage-I investigations, the research works was conducted to develop quaternary blended concrete with 25% fly ash and 10% GP, based on the preliminary investigation conducted for developing the ternary blended concrete, by varying Nano-silica from 0 to 2% of cementitious content. M35 grade of concrete was considered and designed as per the guidelines of IS 10262:2019 [26]. The mix proportioning of quaternary blended concrete are shown in Table. 2. The stage-II was conducted with coir fibre varying at 0.25, 0.5, 0.75, 1.0, and 1.25% by volume of concrete for developing the fibre reinforced quaternary blended concrete and mix proportioning is shown in Table 3.
2.3. Experimental Procedure
The compressive strength of the concrete cube specimens was determined by dividing the maximum load applied for failure the specimen by cross sectional area. The rate of load applied was followed at the rate of 2.5kN/s as per IS:516-1959 as shown in figure 3. The elastic modulus of concrete was calculated by developing stress strain curve from the cylindrical specimens of 150 mm diameter and 300 mm height. The deformation of cylindrical specimen due to the axial compressive load was measured by using deflectometer as shown in figure 4. As per IS: 13311(2)-1992 specification [27], the rebound hammer test was conducted as shown in figure 5. The 100 mm size cube specimens were casted for conducting the sorptivity tests. Epoxy resin coating was applied to the four sides of the cube to prevent water penetration from sides of the cube. Then the sample was placed in a water bath as shown figure 6. The sorptivity coefficient was calculated using the following formula [5,28]:

\[ \text{Sorptivity coefficient (m/s)} = \frac{q}{\sqrt{t}} \]

Where, \( q \) = Volume of water penetrated per unit surface area and \( t \) = Time of exposure

3. RESULTS AND DISCUSSIONS
3.1 Effect of Nano-silica in quaternary blended concrete
The quaternary blended concrete was developed by adding NS as the third mineral admixture in 25% fly ash and 10% GP based ternary blended concrete. The variations of 7, 28 and 90 days compressive strength of quaternary blended concrete with various percentage of NS substitution is shown in figure 7. The results mentioned in this report was determined as an average of three specimens. The significant increase in compressive strength of quaternary blended concrete was noted up to 1-2% substitution of NS than ternary blended concrete and further addition of NS did not contribute the strength development. The increase in the strength of concrete due to the presence of NS is attributed
to reaction of reactive silicates produced early additional C-S-H in the paste form [18]. However, relatively higher compressive strength was observed than any other concrete specimen at 1.5% NS presence in the concrete as shown in figure 6. The 7 day compressive strength after adding 1.5% NS exhibited progressive improvement up to 32.97 MPa. Similar strength development variations was noticed in 28 days and 90 days compressive strength of quaternary blended concrete. The compressive strength of 28 and 90 days cured specimens for 1.5% NS addition was calculated as 45.23 and 47.25 MPa. Hence the quaternary blended concrete was developed with 25%, fly ash, 10% GP and 1.5% NS with OPC. Similar effect on compressive strength was found in varying the w/c ratio [18]. This quaternary blended combination was considered as the control concrete for the stage-II of this investigation called coir fibre reinforced concrete.

3.2 Effect of coir fibre in compressive strength of quaternary blended concrete
The effect of coir fibre on compressive strength variations of quaternary blended concrete are shown in figure 8. It can be seen that the compressive strength of quaternary blended concrete increases as the coir fibre content increases. After the addition of coir fibre of 0.25%, 0.5%, 0.75%, 1.0% and 1.25%, the 28 days compressive strength increases by 2.87%, 4.73%, 6.17%, 6.83% and 3.55%. Figure 8 shows that the addition of fibre content up to 1.0%, the compressive strength increasing in a linear fashion and the reduction of compressive strength was observed after adding more than 1% of coir fibre. Similar kind of results were observed in 90 days cured specimens also. The reduction of compressive strength after the optimum level 1.0% of fibre is mainly due to the presence of more entrapped air and also reduction of bond between paste form and aggregate form. The result obtained from M60 grade GGBS and MK mixed ternary blended concrete with 2% steel glass fibre based hybrid fibre reinforced concrete are similar the present investigation for M35 grade concrete with 1.5% coir fibre [24].

3.3. Effect of coir-fibre in Elastic modulus of quaternary blended concrete
The effect of coir fibre on elastic modulus variations of 28 days cured quaternary blended concrete are shown in figure 9. It can be seen that the elastic modulus of quaternary blended concrete increases as the coir fibre content increases. After the addition of coir fibre of 0.25%, 0.5%, 0.75%, 1.0% and 1.25%, the 28 days elastic modulus increases by 1.68%, 2.99%, 3.31%, 3.40% and 1.90%. Figure 10 shows that the addition of fibre content up to 1.0%, the elastic modulus was gradually increasing and the reduction of elastic modulus was observed after adding more than 1% of coir fibre. The 90 days cured cylindrical specimens are also showing the same variations in fibre reinforced concrete comparable with the polypropylene polyethylene mixed hybrid fibres reinforced concrete [28].

3.4. Effect of coir-fibre in relationship between compressive strength and elastic modulus of quaternary blended concrete
Elastic modulus of concrete is a key factor for designing a flexural member and also the correlation between the compressive strength and elastic modulus was played a key role for predicting the elastic modulus from compressive strength. The code provisions are expressed that the elastic modulus is a function of compressive strength. The IS:456-2000 code provide the relationship as $E=5000\sqrt{f_{ck}}$ for normal strength concrete [29]. However the correlation is differ due to the modifications in the concrete composites. From the results obtained in this investigation from the coir fibre reinforced quaternary blended concrete, the correlation was developed as $E = 4533.7 \,(f_{ck})^{0.5273}$ with higher correlation coefficient [30] and shown in figure 10.
Figure 7. Effect of Nano-silica on the compressive strength of quaternary blended concrete

Figure 8. Effects of coir fibre on compressive strength of quaternary blended concrete

3.5 Effect of coir-fibre in rebound hammer number of quaternary blended concrete

The effect of coir fibre on rebound hammer number of quaternary blended concrete are shown in figure 5. The surface hardness of concrete was determined through the Schmidt Hammer test as per IS: 13311-1992 (Part 2) [27] and the energy absorbed by the concrete is correlated to the strength of concrete. The rebound hammer number was observed in four sides of three cube specimens. From figure 11, it can be seen that the rebound hammer number of quaternary blended concrete increases as the coir fibre content increases. The results obtained from this investigation were statistically analysed to determine the best correlation between the rebound number and compressive strength. From figure 12, it can be noticed that there is a perfect correlation between the rebound number and compressive strength [30]. It is also noticed that when the compressive strength increases the rebound hammer number is also increases. A non-linear model was predicted as $f_c = 18.124 e^{0.0192N}$ with higher regression coefficient of 0.945. Aliabdo and Elmoaty (2012) predicted a similar general correlation between rebound number and compressive strength using marble powder as partial replacement of cement [31].

3.6 Effect of coir-fibre in sorptivity behaviour of quaternary blended concrete

The sorptivity variations due to the presence of coir fibre in quaternary blended concrete is shown in Figure 13. From the sorptivity results, it can be seen that the capillary absorption of water is sustain up to the addition of 1.0% coir fibre in the quaternary blended concrete. The sorptivity coefficient of quaternary blended concrete without fibre was determined as 0.082 mm/min0.5 for 28 days cured specimen. After the addition of 1% coir fibre, the sorptivity was increased insignificantly to 0.089 mm/min0.5. The rate of capillary absorption of water was noticed in higher rate while adding 1.25%. The similar kind of results were observed in 90 days cured specimens also. However the sorptivity of 7 days cured specimens had shown the gradual increasing up to 1% coir fibre addition due to the presence of un-hydrated cementitious compound in the concrete. The reduction of capillary rise in 28 days and 90 days emphasis that the dense concrete mass was created due to the secondary hydration products developed in the presence of NS in quaternary blended concrete [32]. The comparison of sorptivity coefficient of ternary blended concrete (without NS), quaternary blended concrete (1.5% NS) and coir fibre reinforced quaternary blended concrete (1%) is shown in figure 14. From figure 14, it was clearly noticed that the quaternary blended concrete is lower rate capillary water absorption than the ternary blended concrete due to the pozzolanic action of NS particles and improving the interfacial transition zone as well as the pore filling action of GP in the concrete. However the coir fibre reinforced quaternary blended concrete had shown relatively higher capillary water absorption behaviour than the quaternary blended concrete due to the greater absorption capacity of coir fibre in concrete.
4. CONCLUSIONS

The effect of coir fibre on strength and durability performance of Nano-silica (NS) mixed quaternary blended concrete was investigated. Based on the results obtained from this investigations, 1.5% NS was employed for developing 20% FA and 10% GP added quaternary blended concrete. The coir fibre was considered at the rate of 1% of cementitious compound and was predicted as the optimum level of fibre added for developing fibre reinforced quaternary blended concrete as per the results obtained from compressive strength, elastic modulus and rebound hammer number. The experiential relationship between elastic modulus and compressive strength was developed as \( E = 4533.7 f_{ck}^{0.5273} \) with higher correlation co-efficient of 0.9712. Non-linear relationship between compressive strength and rebound hammer number was observed and relationship was also predicted as \( f_{ck} = 18.124 e^{0.0192 N} \) with correlation co-efficient of 0.945. The durability performance of quaternary blended concrete was tested by the sorptivity test and insignificant increasing capillary absorption was noticed up to the presence of 1% coir fibre and further addition of coir fibre had shown more amount of absorption. The sorptivity of coir fibre quaternary blended concrete had shown marginally higher order than the quaternary blended concrete without coir fibre.
Figure 13. Sorptivity variations in coir fibre reinforced quaternary blended concrete

Figure 14. Sorptivity comparison of ternary, quaternary and fibre reinforced quaternary blended concrete

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