Strength aspects of High Performance Concrete by using Waste Material as replacement of Fine Aggregate in various percentages

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Abstract. High Performance Concrete (HPC) is becoming extremely popular now a day in applications, which require substantial improvements in structural capacity and resistance to aggressive environments. Several researchers have tried different mineral admixtures like Fly Ash (FA), Silica Fume (SF) and Ground Granulated Blast Furnace Slag (GGBS) in producing HPC. These admixtures are generally by-products of other industries and hence their properties are not identical and it is very difficult to assure the quality. This paper proposes a relatively new mineral admixture called High- Reactivity Metakaolin (HRM) with potential utility in the production of High Performance Concrete. In recent years Metakaolin is identified as a new pozzolanic admixture which is cost effective, cheaper and can also be considered as best alternative to micro silica. To achieve the economy, Metakaolin which is derived from purified kaolin clay is adding with ordinary Portland cement as partial replacement. In additional strength add with Glass fiber to use for ordinary Portland cement. The Fiber used in this investigation is E – Glass fiber made from glass material of size 6mm and 12mm diameter respectively. Except for control concrete, quarry waste fine aggregate was used in all concretes as a partial replacement of natural sand. The effects of quarry waste fine aggregate on several fresh and hardened properties of the concretes were investigated. It was found that quarry waste fine aggregate and waste recycling coarse aggregate enhanced the slump and slump flow of the fresh concretes. But the unit weight and air content of the concretes were not affected. The overall test results revealed that quarry waste fine aggregate can be utilized in concrete mixtures as a good substitute of natural sand. The experimental work comprises of Compressive Strength test, Split Tensile strength test and Flexure test was conducted. In this experimental investigation, M30 grade were obtained by replacing 0 to 15% replacement of quarry dust instead of Fine aggregate, 0 to 10% of Metakaolin added as supplementary in cement. It shows better result in the mix of 7.5% of Metakaolin, 0.5% of fiber and 10% of quarry dust in concrete

Key words: Metakaolin clay, Glass fiber, Quarry dust, Ordinary Portland cement, Modulus of Elasticity.

1. Introduction

High performance is generally assumed to be synonymous with high strength, although this is not true in every case. Unacceptable rates of deterioration due to environmental effects indicate that only compliance with strength requirements, although need, is not adequate to ensure long – term, durability, which is the primary requirement for high performance. It is generally accepted, that the high performance of the very concrete contributes to low permeability, stronger and denser transition zone between aggregate and cement paste in the concrete. This also adds to the abrasion
according to ACI, high-performance concrete is defined as concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing and curing practices [1]. Examples of HPC are high workability concrete, self-compacting concrete (SCC), high strength concrete, foamed concrete, no-fines concrete, water proof concrete, etc. [4].

Enhancement of the permeation properties of concrete can be achieved through the use of pozzolanic materials and fillers as ingredients of concrete. Materials falling within this category include. Research works have been done already to improve the tensile properties of concrete by the way of using conventional reinforcement steel bars. This will provide tensile strength to concrete members. Development of tensile crack in plain concrete can very soon lead to failure. By adding High Reactive Metakaolin, Glass Fibre the load carrying capacity of concrete in tension side is increased [5].

The physical and chemical characteristics of the above materials are such that they can be effective either in blocking concrete pores on providing concrete with further cementitious products. Research work carried out using these materials, has revealed the following effects in decrease of capillary porosity, reduction of micro cracking within pore system, Decrease in the thickness of the week interfacial zone, increase in the thickness of the week interfacial zone around aggregate. In above High Reactive Metakaolin, Glass Fibre used concrete mixtures as a partial replacement of cement.

Fine aggregate is an essential component of concrete. The most commonly used fine aggregate is natural river or pit sand. The global consumption of natural sand is very high due to the extensive use of concrete. In particular, the demand of natural sand is quite high in developing countries owing to rapid infrastructural growth. Some alternative materials have already been used as a part of natural sand. For example, fly ash, slag, and limestone and siliceous stone powder were used in concrete mixtures as a partial replacement of natural sand. The present study has used quarry waste fine aggregate in concrete mixtures as a partial replacement of natural sand.

It has investigated the above three materials are testing for slump of the fresh concretes. In addition, this study has examined the effect of these materials for compressive strength, modulus of elasticity of concrete, Flexure test.

2. Materials

2.1. Material

2.1.1. Cement

Ordinary Portland cement of 53 grades available in local market is used in the investigation. The cement used has been tested for various proportions as per IS: 4031-1988 and found to be conforming to various specifications of IS: 12269-1987. The specific gravity was 3.15 and the fineness was 3300 cm$^2$/gm.

2.1.2. Coarse aggregate

Crushed angular granite metal from a local source was used as coarse aggregate. The specific gravity was 2.67, flakiness index of 4.58 percent and elongation index of 3.96.

2.1.3. Fine aggregate

Manufacturing sand was used as fine aggregate. The specific gravity and fineness modulus was 2.65 and 2.83 respectively.
2.1.4. Metakaolin

Metakaolin differs from other Supplementary Cementitious Materials (SCMs), like fly ash, silica fume, and slag, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under carefully controlled conditions. Metakaolin is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900 °C. This heat treatment, or calcination, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing.

Metakaolin reacts with portlandite (CH) to form calcium-silicate-hydrate (C-S-H) supplementary to that produced by Portland cement hydration. This reaction becomes important within the interfacial transition zone (ITZ) located between aggregate and paste fractions. This region typically contains a high concentration of large, aligned CH crystals, which can lead to localized areas of increased porosity and lower strength.

Metakaolin can react with some of the CH produced by cement hydration, thereby densifying the structure of the hydrated cement paste. The rates of pozzolanic reaction and CH consumption in metakaolin systems have been shown to be higher than in silica fume systems, indicating a higher initial reactivity. Because this reaction with CH occurs early and rapidly, metakaolin incorporation may contribute to reduced initial and final set times. In addition, this refinement in the ITZ can result in increased strength in metakaolin concrete.

Metakaolin is a lime-hungry pozzolan that reacts with free calcium hydroxide to form stable, insoluble, and strength adding cementitious compounds. When High Reactive Metakaolin – HRM (AS2) reacts with calcium hydroxide (CH), a cement hydration by products, a pozzolanic reaction takes place where by new cementitious compounds (C2ASH8) and (CSH) are formed. These newly formed compounds will contribute cementitious strength and enhanced durability properties to the system in place of the otherwise weak and soluble calcium hydroxide.

2.1.5. Glass Fiber

Glass fibers are formed from different types of glass. Their characteristics and properties are determined by mixing various ingredients. These ingredients are then melted in a high temperature furnace. The molten glass is then fed in to the fabrication equipment. The strands or silvers from the fiber forming stage can be wound on a tube by a high speed winder to give continuous filament stable is cut from strands to specific lengths referred as chopped strands.

Glass Fibers are generally classified by the fiber diameter, the chop length. The moisture content and the chemical contents of fibres are further characterized by their physical and chemical properties, which are governed primarily by the glass composition. There are several glass fibres types with different chemical composition.

E – Glass fibre: This is a family of glasses with calcium alumino borosilicate composition and a maximum alkali content of 2 %. E glasses are generally used as a general purpose fibre when high strength and high electrical resistivity is required. It gives good Compressive strength and cost is also very cheap. E glass fibers have an average fiber diameter of 15.9 µ.E glass fibre are available in a standard length of 1/4 ”, 1/2” and 3/4 ” (6 mm, 12 mm, 18 mm) - other lengths upon request.

The effect of reducing the crack propagation, it leads to an enhanced ductility of the concrete. In other words fiber reinforced concrete can undergo much larger deformations before failure as compared to plain cement concrete. The toughness of the concrete is enhanced by the use of fibers. Enhancement of concrete properties can be achieved by the use of fibers, provided these are randomly and uniformly distributed over the entire volume of concrete.
2.1.6. Quarry Dust

Quarry dust can be an economic alternative to the manufacturing sand. Quarry Dust can be defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks to form fine particles less than 4.75mm. Usually, Quarry Rock Dust is used in large scale in the highways as a surface finishing material and also used for manufacturing of hollow blocks and lightweight concrete prefabricated Elements. Use of Quarry rock dust as a fine aggregate in concrete draws serious attention of researchers and investigators.

2.2. Physical and Chemical Properties of Materials

The pozzolanic property of metakaolin is not only effective in enhancing the strength of concrete, but also improves the permeability of concrete. HRM is one of the newest SCMs that conform to ASTM C 618, Class N pozzolan specification. Very limited studies are reported detailing the usage of metakaolin in concretes as an admixture. Metakaolin is a purer form of calcined clay. It has high reactivity due to higher content of amorphous alumino–silicates and is generally devoid of impurities. Large reserves of kaolin are reported to be available in Rajasthan, Assam, Meghalaya, West Bengal and Bihar. Best quality metakaolin comes from Kundara in Kerala and from Singhbhum in Bihar. Chemical compositions based on IS 12269, IS 4032 and Physical Properties of OPC and HRM are compared in Table 1. Mechanical Properties of E-Glass Fiber listed in Table 2. Physical Properties of E-Glass Fiber listed in Table 3. Physical Properties of quarry rock dust and natural sand listed in Table 4. Chemical compositions of quarry rock dust and Manufacturing sand listed in Table 5.

| S.No. | Parameters     | Value     | Unit  |
|-------|---------------|-----------|-------|
| 1     | SiO2 (%)      | 21.80     |       |
| 2     | Al2O3 (%)     | 4.80      |       |
| 3     | Fe2O3 (%)     | 3.80      |       |
| 4     | CaO (%)       | 63.30     |       |
| 5     | MgO (%)       | 0.90      |       |
| 6     | Na2O (%)      | 0.21      |       |
| 7     | K2O (%)       | 0.46      |       |
| 8     | TiO2 (%)      | -         |       |
| 9     | SO3           | 2.20      |       |
| 10    | Insoluble residue | 0.40 |       |
| 11    | Loss of ignition (%) | 2.00 |       |
| 12    | Specific gravity | 3.15 |       |
| 13    | Specific surface (m²/gm) | 0.32 |       |

| S.No | Quantity         | Value     | Unit  |
|------|------------------|-----------|-------|
| 1    | Density          | 2600      | kg/cm³|
| 2    | Moisture content | <1%       |       |
| 3    | Strain at failure| 4.50%     |       |
| 4    | Young's modulus  | 73000 - 73000 | MPa  |
| 5    | Tensile strength | 1900 - 2600 | MPa  |
| 6    | Elongation       | 0 - 3.2   | %     |
| 7    | Specific gravity | 2.6       |       |
Table 3. Physical Properties of E-Glass Fiber

| S.No | Quantity | Value (%) |
|------|----------|-----------|
| 1    | SiO₂     | 73        |
| 2    | Al₂O₃    | 1         |
| 3    | Fe₂O₃    | 0.1       |
| 4    | MgO      | 4         |
| 5    | CaO      | 8         |
| 6    | Na₂O₃    | 13        |
| 7    | K₂O      | 0.5       |

Table 4. Physical Properties of quarry rock dust and natural sand

| Property                        | Quarry rock dust | Natural sand | Test method            |
|---------------------------------|------------------|--------------|------------------------|
| Specific gravity                | 2.54-2.60        | 2.60         | IS 2386 (Part III) 1963 |
| Bulk relative density (kg/m³)   | 1720-1810        | 1460         | IS 2386 (Part III) 1963 |
| Absorption (%)                  | 1.20-1.50        | Nil          | IS 2386 (Part III) 1963 |
| Moisture content (%)            | Nil              | 1.50         | IS 2386 (Part III) 1963 |
| Fine particles less than 0.075mm (%) | 12-15          | 06           | IS 2386 (Part I) 1963   |
| Sieve analysis                  | Zone II          | Zone II      | IS 383 - 1970          |

Table 5. Chemical compositions of quarry rock dust and Manufacturing sand

| S.No | Constituent | Quarry rock dust (%) | Natural sand (%) | Test method |
|------|-------------|----------------------|------------------|-------------|
| 1    | SiO₂        | 62.48                | 80.78            | IS: 4032-1968 |
| 2    | Al₂O₃      | 18.72                | 10.52            |             |
| 3    | Fe₂O₃      | 6.54                 | 1.75             |             |
| 4    | CaO         | 4.83                 | 3.21             |             |
| 5    | MgO         | 2.56                 | 0.77             |             |
| 6    | Na₂O       | Nil                  | 1.37             |             |
| 7    | K₂O        | 3.18                 | 1.23             |             |
| 8    | TiO₂        | 1.21                 | Nil              |             |
| 9    | Loss of ignition | 0.48               | 0.37             |             |

3. Experimental Programme

There is no specific method of mix design for high performance concrete. The absolute volume method was used to determine the quantities of different ingredients. In the mix proportions, air content for concrete was assumed as 1%. The M30 grade was obtained by replacing the mass of cement by metakaoline, Glass fibre and quarry waste fine aggregate was used in all concretes as a partial replacement of natural sand. The water binder ratio (w/b) of 0.43 for all mixes was maintained. These percentages of replacements are represented in the following as in Table 6. Quantities of materials required per 1 cum of high performance concrete and different materials mixes are listed in Table 7.
Table 6. Percentage of replacements

| Replacement of cement | Percentage of replacement (%) |
|-----------------------|-------------------------------|
| Metakaolin            | 0 | 5 | 7.5 | 10 |
| E glass fibre         | 0 | 0.25 | 0.5 | 0.75 |

Table 7. Quantities of materials required for various mixes of HPC

| Mix | Replacement of cement (%) | Replacement of Sand (%) | Cement (kg) | Fine aggregate (kg) | Coarse aggregate (kg) | W/C ratio |
|-----|---------------------------|-------------------------|-------------|---------------------|-----------------------|-----------|
|     | Metakaolin | E - Glass Fibre | Quarry Dust |                     |                       |           |
| M1  | 0          | 0                      | 0           | 446                 | 540                   | 1183      | 0.43     |
| M2  | 5          | 0.25                   | 5           | 423                 | 513                   | 1183      | 0.43     |
| M3  | 7.5        | 0.5                    | 10          | 410                 | 459                   | 1183      | 0.43     |
| M4  | 10         | 0.75                   | 15          | 398                 | 378                   | 1183      | 0.43     |

4. Specimen Casting and Testing

Specimens are casted and tested as per the IS 516: 1959 methods of tests for strength of concrete shown in Figure 1, Figure 2, Figure 3, and Table 8.

Table 8. Method of Testing

| Name of Test           | Size of Mould           | Number of Days |
|------------------------|-------------------------|----------------|
| Compression Test       | 150 x 150 x 150 mm     | 7              | 28             |
| Split Tensile Strength | Ht - 300 & Dia - 150 mm| -              | 28             |
| Flexure Strength       | 100 x 100 x 500 mm     | 7              | 28             |

The workability of concrete of M30 grade of concretes was estimated in terms of compaction factor for addition of M1 to M4. It was observed that the addition of HRM and glass fibres, the compaction factor of 0.92 to 0.98 was maintained for almost all Mixes of concrete.

4.1 Compressive Strength

The compressive strength tested specimens are shown in Figure 3. The results for various mixes M1 to M4 at the age of 7, 28 days are given in Table 9 & 10., the compressive strength values of different materials added concrete mixes and their values are observed to be varied from 22.67 to 32.59 N/mm² for 6 mm glass fibre in 7 days, 22.67 to 35.41 N/mm² for 12 mm glass fibre in 7 days, 31.11 to 40.59 N/mm² for 6 mm glass fibre in 28 days, 22.67 to 43.26 N/mm² for 12 mm glass fibre in 28 days. Whereas the maximum compressive strength obtained for M2 & M3 for 7 and 28 days (contains 10% of HRM and E – Glass and 0.75 %, Quarry Dust 15%) shown in Figure 1 and 2.
Figure 1. Compressive Strength of 6mm Fiber

Figure 2. Compressive Strength of 12mm Fiber

Figure 3. Compressive Strength Testing.

Figure 4. Split Tensile Strength Testing.
4.2 Flexural Strength

The Flexural strength tested specimens are shown in Figure 5. The tested results were obtained and presented in Table 9 & 10. Flexure strength values of different materials added concrete mixes and their values are observed to be varied from 3.05 to 3.42 N/mm² for 6 mm glass fibre in 7 days, 3.05 to 3.55 N/mm² for 12 mm glass fibre in 7 days, 4.35 to 4.82 N/mm² for 6 mm glass fibre in 28 days, 4.35 to 4.93 N/mm² for 12 mm glass fibre in 28 days. The maximum values are obtained for M4 mix (contains 10% of HRM and E – Glass and 0.75 %, Quarry Dust 15%). The M1 showed minimum value and it increases gradually for other mixes shown in Figure 6 and 7.

4.3 Split Tensile Strength

The Split Tensile strength tested specimens are shown in Figure 4. The tested results were obtained and presented in Table 9 & 10.Split tensile strength values of different materials added concrete mixes and their values are observed to be varied from 3.10 to 3.48N/mm2 for 6 mm glass fibre in 7 days, 3.10 to 3.61 N/mm2 for 12 mm glass fibre in 7 days, 4.46 to 4.70 N/mm² for 6 mm glass fibre in 28 days, 4.46 to 4.76 N/mm² for 12 mm glass fibre in 28 days. The maximum values are obtained for M3 mix (contains 7.5% of HRM and E – Glass and 0.5%, Quarry Dust 10%). The M1 showed minimum value and it increases gradually for other mixes shown in Figure 8 and 9.
Figure 7. Flexural Strength of 12mm Fiber

Figure 8. Split Tensile Strength of 6mm Fiber

Figure 9. Split Tensile Strength of 12mm Fiber
Table 9. Test results for different mixes with 6 mm E-Glass Fibre

| Mix | Compressive Strength (N/mm²) | Split Tensile Strength (N/mm²) | Flexural Strength (N/mm²) |
|-----|------------------------------|--------------------------------|--------------------------|
|     | 7Days | 28Days | 7Days | 28Days | 7Days | 28Days |
| M1  | 22.67 | 31.11  | 3.100 | 4.460  | 3.050 | 4.350  |
| M2  | 27.41 | 35.85  | 3.380 | 4.660  | 3.230 | 4.600  |
| M3  | 31.41 | 39.85  | 3.580 | 4.800  | 3.330 | 4.700  |
| M4  | 32.59 | 40.59  | 3.480 | 4.700  | 3.420 | 4.820  |

Table 10. Test results for different mixes with 12 mm E-Glass Fibre

| Mix | Compressive Strength (N/mm²) | Split Tensile Strength (N/mm²) | Flexural Strength (N/mm²) |
|-----|------------------------------|--------------------------------|--------------------------|
|     | 7Days | 28Days | 7Days | 28Days | 7Days | 28Days |
| M1  | 22.67 | 31.11  | 3.100 | 4.460  | 3.050 | 4.350  |
| M2  | 29.48 | 37.04  | 3.560 | 4.740  | 3.380 | 4.730  |
| M3  | 34.07 | 42.37  | 3.740 | 4.910  | 3.470 | 4.880  |
| M4  | 35.41 | 43.26  | 3.600 | 4.760  | 3.550 | 4.930  |

5. Conclusion

- A reduction in bleeding is observed by addition of HRM and glass fibers in the high performance concrete.
- Improved packing contributed by the very small size of the particles of HRM will improve the contact surface and thus the bond between fresh metakaolin concrete and the high performance concrete.
- A reduction in bleeding improves the surface integrity of concrete, improves its homogeneity and reduces the probability of cracks.
- The percentage increase of compressive strength of various grades of glass fiber concrete mixes compared with 7 and 28 days compressive strength is observed from 23 to 30 % and the percentage increase of flexural and split tensile strength of various grades of glass fiber concrete mixes compared with 28 days is observed from 10 to 20%.
- As the age of concrete increases, the compressive strength also increases. Addition of HRM increases the brittleness of the concrete.
6. References

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