Effect of Silica Fume and Metakaolin combination on concrete
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ABSTRACT

The use of supplementary cementitous materials is fundamental in developing low cost construction materials for use in developing countries. By addition of some pozzolanic materials, the various properties of concrete viz, workability, durability, strength, resistance to cracks and permeability can be improved. Silica fume is a by product resulting from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or silicon alloys. Silica fume is known to improve both the mechanical characteristics and durability of concrete. The principle physical effect of silica fume in concrete is that of filler, which because of its fineness can fit into space between cement grains in the same way that sand fills the space between particles of coarse aggregates and cement grains fill the space between sand grains. As for chemical reaction of silica fume, because of high surface area and high content of amorphous silica in silica fume, this highly active pozzolan reacts more quickly than ordinary pozzolans. The use of silica fume in concrete has engineering potential and economic advantage. Metakaolin is also one of such waste/ non-conventional material which can be utilized beneficially in the construction industry. This paper presents the results of an experimental investigations carried out to find the suitability of silica fume and metakaolin combination in production of concrete. The optimum doses of silica fume and metakaolin in combination were found to be 6% and 15% (by weight) respectively, when used as part replacement of ordinary portland cement.

Keywords: Silica fume, metakaolin, pozzolan, compressive strength, OPC.

1. Introduction

The use of supplementary cementitous materials (SCMs) is fundamental in developing low cost construction materials for use in developing countries. Concrete is the most widely used and versatile building material which is generally used to resist compressive forces. By addition of some pozzolanic materials, the various properties of concrete viz, workability, durability, strength, resistance to cracks and permeability can be improved. Many modern concrete mixes are modified with addition of admixtures, which improve the microstructure as well as decrease the calcium hydroxide concentration by consuming it through a pozzolanic reaction. The subsequent modification of the microstructure of cement composites improves the mechanical properties, durability and increases the service-life properties. When fine pozzolana particles are dissipated in the paste, they generate a large number of nucleation sites for the precipitation of the hydration products. Therefore, this mechanism makes paste more homogeneous. This is due to the reaction between the amorphous silica of
the pozzolan and calcium hydroxide, produced during the cement hydration reactions (Sabir et al. 2001, Rojas and Cabrea 2002, Antonovich and Goberis 2003). In addition, the physical effect of the fine grains allows dense packing within the cement and reduces the wall effect in the transition zone between the paste and aggregate. This weaker zone is strengthened due to the higher bond development between these two phases, improving the concrete microstructure and properties. In general, the pozzolan effect depends not only on the pozzolan reaction, but also on the physical or filler effect of the smaller particles in the mixture. Therefore, the addition of pozzolanas to ordinary portland cement (OPC) increases its mechanical strength and durability as compared to the referral paste, because of the interface reinforcement. The physical action of the pozzolanas provides a denser, more homogeneous and uniform paste.

Silica fume is a by product resulting from the reduction of high purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or silicon alloys. Silica fume is known to improve both the mechanical characteristics and durability of concrete. The principle physical effect of silica fume in concrete is that of filler, which because of its fineness can fit into space between cement grains in the same way that sand fills the space between particles of coarse aggregates and cement grains fill the space between sand grains. As for chemical reaction of silica fume, because of high surface area and high content of amorphous silica in silica fume, this highly active pozzolan reacts more quickly than ordinary pozzolans. The use of silica fume in concrete has engineering potential and economic advantage.

Metakaolin is another pozzolanic materials which is manufactured from selected kaolins, after refinement and calcination under specific conditions. It is a highly efficient pozzolana and reacts rapidly with the excess calcium hydroxide resulting from OPC hydration, via a pozzolanic reaction, to produce calcium silicate hydrates and calcium aluminosilicate hydrates (Luc Courard et al. 2003). It is quite useful for improving concrete quality, by enhancing strength and reducing setting time, and may thus prove to be a promising material for manufacturing high performance concrete (Li and Ding 2003).

Both the Silica fume and Metakaolin are useful pozzolanic materials. In the present work, the results of a study carried out to investigate the effects of combination of these two materials on strength and workability of concrete are presented. The referral concrete M25 was made using 43 grade OPC (Birla) and the other mixes were prepared by replacing part of OPC with Silica Fume and Metakaolin. The replacement levels were 5%, 6%, 7%, 8%, 9% and 10% (by weight) for Silica Fume and 10%, 15%, 20% and 25% (by weight) for Metakaolin.

2. Materials and Method

In the present investigation, the coarse aggregate of size 12.5 mm and down from Bharatkap quarry was used. The sieve analysis of the aggregates was carried out and the same distribution / FM was maintained throughout the experiment. The important properties of the coarse aggregate were: Fineness Modulus = 6.29; Flakiness index = 20% (< 40%, OK, BS 882-1992); Elongation Index = 7%; Moisture content = 0.52% (<2%, OK); Crushing value = 18.2% (<30, OK); Specific gravity = 2.72 (2.6-2.8).

The fine aggregate used in the investigation was ‘Jamuna’ sand. The properties of fine aggregate found as per IS-383 were: Fineness Modulus = 2.5; Moisture content = 0.52% (<2%, OK); Specific gravity = 2.54. The gradation of fine aggregate (Zone III) was maintained throughout the experiment.
Silica fume for the present investigation was obtained from M/s ELCOM Enterprises, Mumbai. The silica fume was sieved and the fraction passing 100μ IS sieve was used in the experiments.

Metakaolin (Metacem) for the present investigation was obtained from M/s Riddhi Enterprises, Mumbai. The Metakaolin was sieved and the fraction passing 100μ IS sieve was used in the experiments. The physical and chemical properties of silica fume and metakaolin viz-a-viz, OPC are presented in Table 1.

| Properties               | OPC       | Silca Fume | Metakaoline |
|--------------------------|-----------|------------|-------------|
| **Physical**             |           |            |             |
| Specific gravity         | 3.1       | 2.2        | 2.5         |
| Mean grain size (μm)     | 22.5      | 0.15       | 2.54        |
| Specific area cm²/gm     | 3250      | 150000-300000 | 150000-180000 |
| Colour                   | Ivory to Cream | Dark to Light Grey | Dark Grey   |
| **Chemical compositions (%)** |         |            |             |
| Silicon dioxide (SiO₂)   | 20.25     | 85         | 60-65       |
| Aluminium oxide (Al₂O₃)  | 5.04      |            | 30-34       |
| Iron oxide (Fe₂O₃)       | 3.16      |            | 1.00        |
| Calcium oxide (CaO)      | 63.61     | 0.2-0.8    | 0.2-0.8     |
| Magnesium oxide (MgO)    | 4.56      | 0.2-0.8    | 0.2-0.8     |
| Sodium oxide (Na₂O)      | 0.08      | 0.5-1.2    | 0.5-1.2     |
| Potassium oxide (K₂O)    | 0.51      |            |             |
| Loss on ignition         | 3.12      | <6.0       | <1.4        |

The binder used in the present investigation was 43 grade OPC (Birla). The properties of cement were determined in accordance with IS – 8112: 1989 were: Fineness = 6.8% (<10%, OK); Consistency = 31%; Initial Setting Time = 60 minutes (>30 minutes, OK); Final Setting Time = 480 minute (<600 minutes, OK).

For the present investigation, mix design for M25 grade of concrete (Target strength = 31.6 MPa) was carried out using the above coarse aggregate, fine aggregate, and the binder. The proportion of the materials by weight was 1:1.89:2.17:0.49 (Cement: Fine aggregate: Coarse aggregate: Water). To investigate the effect of inclusion of silica fume and metakaolin combination (as part replacement of cement), 100 mm cubes were cast for referral and other mixes having variable silica fume and metakaolin content as given in Table 2. The workability (Slump value) and the compressive strength of different mixes were tested at 7 and 28 days as per the procedure laid down in IS: 516 - 1981. The results obtained from the above investigation are presented in Table 2.

### 3. Results

The compressive strength of the cubes at different ages and different silica fume and metakaolin combination are presented in Table 2. The slump values of the different mixes are also included in the same table.
Table 2:

| Replacement level (%) | Silica Fume | Metakaolin | Compressive Strength (MPa) | Slump (mm) | Compaction Factor |
|------------------------|------------|------------|---------------------------|-----------|------------------|
|                        |            |            | 7 Days | 28 Days                  |            |                  |
| 0                      | 0          | 0          | 24     | 33                      | 60        | 0.92             |
| 5                      | 10         | 10         | 21.03  | 39.38                   | 61        | 0.92             |
| 5                      | 15         | 15         | 22.29  | 40.62                   | 58        | 0.92             |
| 5                      | 20         | 20         | 17.29  | 37.50                   | 54        | 0.91             |
| 5                      | 25         | 25         | 15.84  | 36.87                   | 50        | 0.90             |
| 6                      | 10         | 10         | 24.16  | 52.09                   | 62        | 0.92             |
| 6                      | 15         | 15         | 33.12  | 54.37                   | 59        | 0.92             |
| 6                      | 20         | 20         | 26.66  | 46.25                   | 55        | 0.91             |
| 6                      | 25         | 25         | 28.12  | 48.75                   | 51        | 0.90             |
| 7                      | 10         | 10         | 23.75  | 31.66                   | 63        | 0.93             |
| 7                      | 15         | 15         | 23.34  | 31.88                   | 60        | 0.92             |
| 7                      | 20         | 20         | 23.75  | 33.12                   | 56        | 0.92             |
| 7                      | 25         | 25         | 22.50  | 35.62                   | 52        | 0.91             |
| 8                      | 10         | 10         | 20.62  | 42.91                   | 63        | 0.93             |
| 8                      | 15         | 15         | 22.91  | 47.50                   | 60        | 0.92             |
| 8                      | 20         | 20         | 25.00  | 45.00                   | 57        | 0.92             |
| 8                      | 25         | 25         | 18.75  | 37.50                   | 53        | 0.91             |
| 9                      | 10         | 10         | 20.62  | 35.62                   | 64        | 0.92             |
| 9                      | 15         | 15         | 22.91  | 45.00                   | 60        | 0.92             |
| 9                      | 20         | 20         | 23.75  | 45.62                   | 56        | 0.91             |
| 9                      | 25         | 25         | 18.54  | 37.50                   | 51        | 0.90             |
| 10                     | 10         | 10         | 17.50  | 40.00                   | 64        | 0.92             |
| 10                     | 15         | 15         | 18.75  | 41.25                   | 60        | 0.92             |
| 10                     | 20         | 20         | 16.25  | 44.37                   | 57        | 0.92             |
| 10                     | 25         | 25         | 15.84  | 30.00                   | 52        | 0.91             |

The curves showing the variation of compressive strength of concrete, made using silica fume and metakaolin combination, with different metakaolin content at a specific silica fume content are presented in Figs 1 to 6. The curves show the variation of strengths at 7 and 28 days.

![Figure 1: Variation of Compressive Strength with Metakolin content at 5% Silica Fume](image)
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Figure 2: Variation of Compressive Strength with Metakolin content at 6% Silica Fume

Figure 3: Variation of Compressive Strength with Metakolin content at 7% Silica Fume
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Figure 4: Variation of Compressive Strength with Metakolin content at 8% Silica Fume

Figure 5: Variation of Compressive Strength with Metakolin content at 9% Silica Fume.
4. Conclusion

The following conclusions are derived on the use of Silica fume and Metakaolin combination in concrete making.

1. The 28 day compressive strength of concrete generally increases with the Metakaolin content upto its optimum content, at all the Silica fume contents, and thereafter declines.

2. The 7 day compressive strength of concrete generally decreases with the increasing Metakaolin content at all the Silica fume contents.

3. The optimum dose of Silica fume and Metakaolin in combination is found to be 6% and 15% (by weight) respectively at both 7 and 28 day compressive strength.

4. The slump is found to decreases with increase in Metakaolin content at all the Silica fume contents considerably.

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