Strength properties of double blend and triple blend self-compacting concrete subjected to different curing methods

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Abstract: The behaviour of Self Compacting Concrete is complex with the addition of both chemical and mineral admixtures. The use of supplementary cementing materials such as Metakaolin, FlyAsh, GGBS and Silica fume is required to improve the flow properties of fresh concrete, to decrease the cement contents, to increase the strength as well as durability of cement and to reduce cement consumption for environmental and economical concern. The hydration mechanism, strength, and setting characteristics of SCC are all influenced by the curing process. As a result, the findings of an investigation into the effects of curing methods on the compressive strength of SCC using Metakaolin as the primary supplementary cementing material are described in this paper. FlyAsh, GGBS and Silica fume are used individually for triple blend binders with OPC and Metakaolin. The Grade of concretes made were Standard concretes of M50. The concretes' compressive strengths were assessed at 7 and 28 days. The traditional water pond approach was used as a reference, and wax-based liquid membrane and polymer-based liquid membrane curing compounds were used for testing. To reduce the water cement ratio and increase the flow and filling capacity of SCC, a superplasticiser based on a polycarboxylic ether polymer with long lateral chains is used. The performance of the Polymer based membrane curing compound is better than Wax based membrane curing compound. In addition to this, the polymer based membrane allows plastering and painting over the concrete surface. The early gain in strength is observed in all the membrane cured cubes at 7 days, but the rate of gaining strength is reduced after 7 days when compared with the Water pond cured cubes.

Key words- Compressive strength, SCC, Metakaolin; Triple Blends, Membrane curing

1. Introduction

Concrete proportioning is just as critical as concrete curing. When day-to-day monitoring and inspection of curing is not feasible, water-curing concrete becomes more expensive and time-consuming. The foundations of towers and their copings for chimneys in scattered places, remote areas, deserts, wetlands, hilly terrains, and across rivers, concrete structures with vertical, sloped, and curved surfaces, tall chimneys, cooling towers in thermal power plants, and pillars of viaducts in cities are all suitable and cost-effective. Three different curing methods were used in this study: traditional water pond curing, wax-based liquid membrane forming compound, and polymer-based membrane curing compound. The use of self-compacting concrete (SCC) was favoured in this study due to its rapid development. Because of faster building, reduced site manpower, better surface finishes, easier placement in heavily reinforced buildings, increased reliability, greater design freedom, thinner concrete parts, lower noise levels, and absence of vibration, SCC has been
dubbed the most innovative breakthrough in the concrete construction industry. For the experiments, 100\,\text{mm} concrete cubes made of M50 standard SCC with OPC and Metakaolin as supplementary cementing materials were prepared. For triple blend binders with OPC and Metakaolin, FlyAsh, GGBS, and Silica fume are used separately. Metakaolin is a pozzolanic mineral admixture that improves the efficiency of cement-based mortars, concretes, and related products in a variety of ways. Metakaolin is made from distilled kaolin clay, a white, amorphous alumino-silicate that reacts vigorously with calcium hydroxide, a by-product of normal cement hydration, to form cementious compounds. In this plant, metakaolin was used as the primary supplementary cementing material.

2. Materials

The cement used was ordinary Portland Cement of Grade 53, which complies with IS12269-1987. Fine Aggregate is river sand that meets IS 383-1970 zone II requirements. Coarse Aggregate is 12\,\text{mm} HBG graded and meets IS 383-1970 requirements. Metakaolin was found to be white, highly pozzolanic, and highly reactive. The table 1 shows the physical and chemical properties. The liquid membrane forming curing compounds are wax-based compounds that, when applied to concrete, form a smooth film that helps to prevent water from evaporating through the concrete’s capillaries. ASTM C 309 is met by this compound. This wax-based white pigmented compound lasts up to 28 days. The dose varies from 4 to 6\,\text{m}^2/\text{litre}. Another liquid membrane forming curing compound is a high efficiency polymer based film forming curing agent conforming to BS 7542-1992. The recommended coverage rate is between 3.5 and 5.0 \,\text{m}^2/\text{litre}. Superplasticisers based on polycarboxylic ether polymer with long lateral chains were used, which meet ASTM C 494-92 Type F and IS 9103 –2007 requirements.

### Table 1. Physical and Chemical properties of Metakaolin

| Physical properties | Chemical Properties |
|---------------------|---------------------|
| 1. Brightness       | 85 ± 1              | 1. SiO$_2$ | 52.8\% |
| 2. Oil absorption (%) | 60 ± 5              | 2. Al$_2$O$_3$ | 36.3\% |
| 3. Moisture (%)     | 0.5                 | 3. FeO$_2$ | 4.21\% |
| 4. Particle size: Average | 1 ± 1             | 4. MgO | 0.81\% |
| < 10 Microns (%)    | 95 ± 2              | 5. CaO | <0.10\% |
| < 2 Microns (%)     | 80 ± 1              | 6. K$_2$O | 1.41\% |
|                     |                     | 7. LOI | 3.53\% |

3. Preparation Of SCC and Tests

“To proportion, blend, and test the fresh properties of SCC concrete, the European guidelines for self-compacting concrete - May 2005” were used. To compare the strength properties of differently cured cubes of 100\,\text{mm} size prepared with 53 grade OPC and Metakaolin, four different SCC mixes were chosen. There were a total of 96 cubes cast. Laboratory trials were used to check the properties of the initial mix composition in relation to the listed characteristics and classes specified in European guide lines and EFNARC. Adjustments to the mix composition were made to determine the demand for water and superplasticizer, sand, and the dose of Metakaolin to achieve the desired robustness, as well as to boost the paste’s flow and stability. When the performance of the mixes was not sufficient, they were revamped.

After the tests on fresh concrete were finished, cubes were cast, and the top surfaces of 50\% of the cubes were painted with liquid membrane forming curing compounds when the concrete was touch dry. Some of the cubes were submerged in water the next day, while the others were painted with liquid membrane forming curing compounds $@$ 4\,\text{Sq.mt/Litre} the next day. The compressive strengths of both water cured and membrane cured cubes of M50 are tabulated in Tables 3, 4, 5 & 6. The tests on hardened concrete were conducted at 7 days and 28 days, and the test results on fresh and hardened concrete are tabulated in Table 2. The comparison among strengths is shown in Bar Chart 1.
Table 2. SCC Mix proportions and compressive strengths

| Slump-Flow classes Class | Slump-flow in mm | Viscosity classes Class | T_{500}, s | V-funnel time in s |
|--------------------------|-----------------|-------------------------|------------|--------------------|
| SF1                      | 550 to 650      | VS1/ VF1                | ≤ 2        | ≤ 8                |
| SF2                      | 660 to 750      | VS2/ VF2                | > 2        | 9 to 25            |
| SF3                      | 760 to 850      |                         |            |                    |
| Passing ability classes (L-box) Class | Passing ability |                         |            |                    |
| S.No. | Description       | Unit | Quantity | Quantity | Quantity | Quantity | Quantity |
|-------|-------------------|------|----------|----------|----------|----------|----------|
| 1     | Fine aggregate    | kg   | 949      | 949      | 949      | 949      |          |
| 2     | Coarse aggregate  | kg   | 779      | 779      | 779      |          |          |
| 3     | Total Binder      | kg   | 574      | 592      | 592      | 592      |          |
| 4     | Cement            | kg   | 267      | 239      | 239      | 239      |          |
| 5     | Metakaolin        | kg   | 307      | 148      | 148      | 148      |          |
| 6     | FlyAsh            | kg   | 0        | 205      | 0        | 205      |          |
| 7     | GGBS              | kg   | 0        | 0        | 0        | 0        |          |
| 8     | Silica Fume       | kg   | 0        | 0        | 0        | 205      |          |
| 9     | Water             | kg   | 228      | 213      | 206      | 213      | 276      |
| 10    | water/binder      | ratio| 0.4      | 0.36     | 0.35     | 0.47     |          |
| 11    | Super plasticizer | kg   | 4.4      | 6.9      | 4.7      | 10.72    |          |
|       | % SP1/Total binder| %    | 0.77     | 1.17     | 0.8      | 1.81     |          |
|       | *Ref. European Guide Lines(2005)* | | SF2, VS1/VF1, PA2 - Good | SF2, VS1/VF1, PA2 - Good | SF2, VS1/VF1, PA2 - Good | |
|       | **CLASS(Ref: Appendix-A)** | | SF2, VS1/VF1, PA2 - Good | SF2, VS1/VF1, PA2 - Good | SF2, VS1/VF1, PA2 - Good | |

### Compressive Strength-7 days

| Water Pond cured cubes | MPa | 42.62(70%) | 38.66 (70%) | 64.34 (82%) | 30.72 (62%) |
| Wax Membrane cured cubes | MPa | 44.26(81%) | 40.11 (85%) | 58.53 (90%) | 29.01 (72%) |
| Polymer Membrane cured cubes | MPa | 46.79(83%) | 48.76 (92%) | 59.10 (83%) | 29.73 (70%) |

### Compressive Strength-28 days

| Water Pond cured cubes | MPa | 60.76 | 55.76 | 78.17 | 49.96 |
| Wax Membrane cured cubes | MPa | 54.81 | 47.07 | 64.88 | 40.16 |
| Polymer Membrane cured cubes | MPa | 56.43 | 53.01 | 71.32 | 42.66 |
### Mix-1 (Cement+Metakaolin) M50

| Age of Concrete | Water Pond Cured Cubes (MPa) | Wax Membrane Cured Cubes (MPa) | Change in Strength | Polymer Membrane Cured Cubes (MPa) | Change in Strength |
|-----------------|-----------------------------|-------------------------------|-------------------|----------------------------------|-------------------|
| 7 Days          | 42.62                       | 44.26                         | + 3.85 %          | 46.79                            | + 7.44 %          |
| 28 Days         | 60.76                       | 54.81                         | - 9.79 %          | 56.43                            | - 7.13 %          |

**Table 3. Comparison of Compressive Strengths of SCC Mixes**

### Mix-2 (Cement+Metakaolin+FlyAsh) M50

| Age of Concrete | Water Pond Cured Cubes (MPa) | Wax Membrane Cured Cubes (MPa) | Change in Strength | Polymer Membrane Cured Cubes (MPa) | Change in Strength |
|-----------------|-----------------------------|-------------------------------|-------------------|----------------------------------|-------------------|
| 7 Days          | 38.66                       | 40.11                         | + 3.75 %          | 48.76                            | + 26.13 %         |
| 28 Days         | 55.76                       | 47.07                         | - 15.58 %         | 53.01                            | - 4.93 %          |

**Table 4. Comparison of Compressive Strengths of SCC Mixes**

### Mix-3 (Cement+Metakaolin+GGBS) M50

| Age of Concrete | Water Pond Cured Cubes (MPa) | Wax Membrane Cured Cubes (MPa) | Change in Strength | Polymer Membrane Cured Cubes (MPa) | Change in Strength |
|-----------------|-----------------------------|-------------------------------|-------------------|----------------------------------|-------------------|
| 7 Days          | 64.34                       | 58.53                         | - 9.03 %          | 59.10                            | - 8.14 %          |
| 28 Days         | 78.17                       | 64.88                         | - 17.00 %         | 71.32                            | - 8.76 %          |

**Table 5. Comparison of Compressive Strengths of SCC Mixes**

### Mix-4 (Cement+Metakaolin+Silica Fume) M50

| Age of Concrete | Water Pond Cured Cubes (MPa) | Wax Membrane Cured Cubes (MPa) | Change in Strength | Polymer Membrane Cured Cubes (MPa) | Change in Strength |
|-----------------|-----------------------------|-------------------------------|-------------------|----------------------------------|-------------------|
| 7 Days          | 30.72                       | 29.01                         | - 5.56 %          | 29.73                            | - 3.22 %          |
| 28 Days         | 49.96                       | 40.16                         | - 19.62 %         | 42.66                            | - 14.61 %         |

**Table 6. Comparison of Compressive Strengths of SCC Mixes**
4. Analysis On Results

1. At 7 days, the compressive strength difference between water and wax based liquid membrane cured cubes of Mix-1 is +3.85 percent, but at 28 days, the difference is -9.79 percent. At 7 days, the difference in compressive strengths of water and polymer-based liquid membrane cured Mix-1 cubes is +7.44 percent, but at 28 days, the difference is -7.13 percent.

2. At 7 days, the difference in compressive strengths of water and wax based liquid membrane cured cubes of Mix-2 is +3.75%, but at 28 days, the difference is -15.58 percent. At 7 days, the difference in compressive strengths of water and polymer-based liquid membrane cured Mix-2 cubes is +26.13 percent, but at 28 days, the difference is -4.93 percent.

3. At 7 days, the difference in compressive strengths of water and wax based liquid membrane cured Mix-3 cubes is -9.03 percent, but at 28 days, the difference is -17.00 percent. At 7 days, the difference in compressive strengths of water and polymer-based liquid membrane cured Mix-3 cubes is -8.14 percent, but at 28 days, the difference is -8.76 percent.

4. At 7 days, the compressive strength difference between water and wax based liquid membrane cured cubes of Mix-4 is -5.56 percent, but at 28 days, the difference is -19.62 percent. At 7 days, the difference in compressive strengths of water and polymer-based liquid membrane cured Mix-4 cubes is -3.22 percent, but at 28 days, the difference is -14.61 percent.

5. Membrane cured cubes of Mix-1 and Mix-2 have higher 7-day compressive strengths than water pond cured cubes, while membrane cured cubes of Mix-3 and Mix-4 have lower 7-day compressive strengths than water pond cured cubes.

6. An abnormal early compressive strength of +26.13% over the water cured cubes is observed for the polymer based liquid membrane cured cubes of Mix-2. The loss in compressive strengths are about -19.62% and -14.64% for wax and polymer membrane cured cubes, respectively for Mix-4 when compared to water pond cured cubes at 28 days.

7. The 7 days’ strength of Water cured cubes of Mix-1 is 70% of the 28 days’ strength, but it is 81% for Wax membrane cured cubes and 83% for Polymer membrane cured cubes. The 7 days’ strength of Water cured cubes of Mix-2 is 69% of the 28 days’ strength, but it is 85% for Wax membrane cured cubes and 92% for Polymer membrane cured cubes. The 7 days’ strength of Water cured cubes of Mix-3 is 82% of the 28 days’ strength, but it is 90% for Wax membrane cured cubes and 83% for Polymer membrane cured cubes. The 7 days’ strength of water cured cubes of Mix-4 is 62% of the 28 days’ strength, but it is 72% for Wax membrane cured cubes and 70% for Polymer membrane cured cubes.
8. Conclusions

1. The major finding out of the above results is “the performance of the Polymer based membrane curing compound is better than Wax based membrane curing compound”. In addition to this, the polymer based membrane allows plastering and painting over the concrete surface.

2. The early gain in strength is observed in all the Membrane cured cubes at 7 days, but the rate of gaining strength is reduced at 28 days when compared with the Water pond cured cubes.

3. The early gain in strength of Membrane cured cubes of triple blends Mix-2(OPC+MK+FA) & Mix-3 (OPC+MK+GGBS) is more than double blend Mix-1 (OPC+MK).

4. The reasons for the early gain in strength for the membrane cured cubes are Duration of Hydration process, Heat of Hydration, Fineness of SCMs and Capillary water. Water pond cured cubes receive water through capillaries, hence the hydration process continues slowly. The Membrane cured cubes develop more heat of hydration which promotes early gain in strength and the capillary water, which helps in hydration process, evaporates and no further supply of water externally.

9. References

[1] Application of Statistical Analysis for Mixture Design of High-Strength Self-Consolidating Concrete Containing Metakaolin by Ahmed A.Abouhussien, M.A.Sc. and Assem A.A.Hassan, Ph.D., M.A.Sc., M.Sc. Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, Newfoundland, Canada, ASCE Journal

[2] L.Garcia1; M.Valcuende, Ph.D. S.Balasch, Ph.D. and J.Fernández-LLebrez-, Department of Architectural Constructions, Universidad Politecnica de Valencia, Spain, Study of Robustness of Self-Compacting Concretes Made with Low Fines Content, ASCE Journal, April 2013.

[3] Selcuk Turkel and Ali Kandemir, Department of Civil Engineering, Dokuz Eylul University, Izmir, Turkey, published an article in the ASCE Journal in October 2010 titled "New and Hardened Properties of SCC Made with Different Aggregate and Mineral Admixtures."

[4] Properties of Self-Consolidating Concrete Rendered with High Volumes of Supplementary Cementitious Materials by Hassan El-Chabib and Adnan Syed, Department of Civil Engineering and Construction, Bradley University, Peoria, ILLINOIS, published in the ASCE Journal in November 2013.

[5] Ahmed Ibrahim, Ph.D., A.M.ASCE; Hassan El-Chabib, Ph.D., and Ahmed Eisa, Ph.D., Department of Civil Engineering and Construction, Bradley Univ., Peoria, ILLINOIS, November 2013 - Ultra strength Flowable Concrete Made with High Volumes of Supplementary Cementitious Materials by Ahmed Ibrahim, Ph.D., A.M.ASCE; Hassan El-Chabib, Ph.D. Hydration mechanism and power of OPC and blended OPC with Fly ash in the presence of Metak in IJRET May-2015 Anamika Singh, Sukirti Gupta, Jaunavi Singh and N.P.Singh, Department of Chemistry, UPA college, Varanasi.

[6] M.V.Krishna Rao (CBIT), P.Ratish Kumar (NIT,Warangal), and Azhar M. Khan, FACTA UNIVERSITATIS-2010, A report on the effect of curing on the strength of a standard grade concrete mix (NIT,Warangal).

[7] M V Jagannadha Kumar, K Jagannadha Rao, B Dean Kumar and V Srinivasa Reddy, Development of Self-Curing Concrete Using Polyethylene Glycol as Internal Curing Agent, International Journal of Civil Engineering and Technology, 9(7), 2018, pp. 1133–1141.http://www.ieeme.com/jicit/issues.asp?IType=IJCIET&VType=9&IType=7

[8] K Satya Sai Trimurthy Naidu, M V Seshagiri Rao and V Srinivasa Reddy, Analytical Model for Predicting Stress-Strain Behaviour of Bacterial Concrete, International Journal of Civil Engineering and Technology, 9(11), 2018, pp. 2383–2393

[9] C Chandana Priya, M V Seshagiri Rao and V Srinivasa Reddy, Studies on Durability Properties of High Strength Self Review, International Journal of Civil Engineering and Technology (IJCIET) 2018, pp. 2218–2225.

[10] Srinivasa Reddy, V. Seshagiri Rao, M.V. Shrihari, S, Strength conversion factors for concrete based on specimen geometry, aggregate size and direction of loading, International Journal of Recent Technology and Engineering, 2019, 8(2), pp.2125-2130

[11] Naidu, K.S.S.T. Rao, M.V.S. Reddy, V.S. Microstructural characterization of calcite mineral precipitation in bacteria incorporated concrete, International Journal of Innovative Technology and Exploring Engineering, 2019, 8(9),Special Issue 2, pp. 641-642
[12] Supriya, Y. Srinivasa Reddy, V. Seshagiri Rao, M.V. Shrihari, S., Strength appraisal of light weight green concrete made with cold bonded fly ash coarse aggregate, International Journal of Recent Technology and Engineering, 2019, 8(3), pp.5381-5385

[13] Jyothi Kumari Ganta, M.V. Seshagiri Rao, Seyed Sina Mousavi, V. Srinivasa Reddy, Chandrasekhar Bhojaraju.

[14] Ganta, J.K. Seshagiri Rao, M.V. Mousavi, S.S. Srinivasa Reddy, V. Bhojaraju, C., Hybrid steel/glass fiber-reinforced self-consolidating concrete considering packing factor: Mechanical and durability characteristics, Structures, 2020, 28, pp. 956-972, ISSN 2352-0124, https://doi.org/10.1016/j.istruc.2020.09.042.