Influence of mineral admixtures on impact strength of self-compacting concrete under elevated temperatures

Mervin Ealiyas Mathews*, N Anand and Nandhagopal M
Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore

*Email Id- mervi.567@gmail.com

Abstract: Self-Compacting Concrete (SCC) is a special type of concrete that can be placed in its own weight and compacted without any vibrations. One of the biggest problems of its use in structures subject to high temperatures was the fire resistance of SCC materials. The grade of concrete used for this study is M20. Different replacement methods were adopted for the comparative performance study of supplementary mineral admixtures such as Fly Ash (FA), Silica Fume (SF) and Meta-Kaoline (MK). Fine aggregate and coarse aggregate are replaced with FA by 5% and 3% respectively. Fine aggregate is replaced with SF by 3%. Fine aggregate and coarse aggregate are replaced with MK by 4% and 2% respectively. Specimens are cast in cylinders of 150mm diameter and 63.5mm height and cured for 28 days. After 28 days, specimens were heated in the muffle furnace at 500, 750 and 1000°C. Then all the specimens were tested and observed for impact strength, colour change and weight loss.

1. INTRODUCTION

SCC can also be used in casting non-congested structures where restricting concrete consolidation or the required period of operation may minimize construction costs as well as noise, which may be important in some urban areas. This can lead to an increase in construction site working conditions and overall productivity. Because of the highly stable nature of SCC, its use will allow deep parts to be cast in fewer lifts without increased risk of settlement, segregation or bleeding. This can reduce the number of lifts in deep areas, thus reducing the time needed for construction and labour. The lack of strict performance standards for basement construction and the need for rapid construction frequently contribute to the installation of highly fluid concrete so that the concrete discharge can proceed rapidly with minimal consolidation requirements. This concrete is often proportioned to be self-leveling and self-consolidating, with high water content. Such structures however often display low in situ permeability and cracking resistance. Basements can, therefore, be humid and have the poor visual quality to be used as permanent surfaces. Use properly designed SCC can retain the high workability needed to encourage placement (constructability criteria) while maintaining sufficient stability and homogeneous distribution of in situ engineering properties and durability. Even in highly congested Reinforced Concrete (RC) members, SCC can be applied in complex formworks. Consequently, in recent years, the interest in using SCC in representatives of concrete framed structures has increased manifold.

Neelam Pathak et al [1] have been studied the SCC characteristics in high-temperature exposures, for example, compression strength, tensile resistance and chloride permeability. Class-F FA mixes have been prepared for comparison in a range from 30-50 percent replacement; also, an adjustable mix without FA has been produced. The specimens were heated to 20°C, 100°C, 200°C, and 300°C. SCC mixes were made using Ordinary Portland Cement (OPC). The compression strength ranged between
21.43 and 40.68MPa and the tensile capacity ranged between 1.35 and 3.60MPa.

Hanaa Fares et al [2] carried out an experimental study into the properties of high-temperature SCC. Two mixtures of SCCs and one mixture of vibrated concrete were tested. At temperatures level of 1°C per minute, all specimens were heated up to 150, 300, 450 and 600°C. The temperature was kept steady for 1 hour before cooling at maximum temperature to maintain a uniform temperature throughout specimens. Physicochemical properties and the microstructural properties have been studied. Thermo-gravimetric analysis, thermos-differential analysis, diffraction of X-rays and SEM observations were performed. The outcomes of the study revealed that the residual compressive force increased between 150 and 300°C.

Sivaraja. M[3] conducted an experimental study on SCC at high temperatures. The mechanical strength characteristics of five SCC mixes were considered to have a high-temperature effect. Five specific SCC blends, such as standard concrete, FA-SCC, SF-SCC, Rice Husk Ash (RHA) - SCC and Quarry Sand (QS)-SCC were developed. Specimens were kept in a hot furnace for 1 hour at high temperatures of up to 500°C and 1000°C. Mechanical properties such as compressive force, split tensile strength, and rupture modulus was obtained. At higher temperature levels, QS shows the best performance at 500°C and FA at 1000°C. Similarly, RHA displays the best performance in rupture modulus at both 500°C and 1000°C temperatures.

Jin Tao et al. [4] reported lab experiments conducted to investigate the effects on compressive strength of SCCs with a variety of water-cement ratios and high strength concrete of high SCC temperatures from room temperatures to 800°C. The compressive strength of the SCC decreases with increasing temperature. And the addition of Poly Propylene (PP) fibers also reduced the resistance and probability of explosive spalling. In conclusion, the influence of PP fibers on SCC’s fire behavior is double. Adding PP fibers may remove SCC’s spalling tendency.

In comparison with the standard vibrated concrete of the same strength, Wenzhong Zhu et al [5] has presented experiments on the permeation properties several different SCC mixes. The SCC mixtures with a strength of 40 and 60MPa strength are designed either for extra powder filling or to prevent filling except for the use of a viscosity agent. The results show that the SCC mixtures are substantially less oxygen permeable and sorptivity than the typical vibrated reference concrete in the same strength category. Compared with conventional vibrated reference concretes with the same strength level, the SCC mixes showed significant reduction in the coefficient of permeability and the water absorptiveness. The diffusiveness of chloride was very dependent on the type of additional powder used in concrete. The SCC and the PFA reference mixes displayed significantly lower chloride migration coefficient values.

Shazim Ali Memon et al. [6] have conducted an experimental research on the interaction with commercially available Viscosity Modifying Admixture (VMA) of fresh SCC products containing varying amounts of RHA. The analysis is carried out at different doses of super plasticizers, which holds cement, water and coarse aggregates continuously. This paper also discusses the use of RHA to increase the amounts of fines and thereby make for Pakistan's building sector economically acceptable. And it was concluded that low-cost SCC with RHA could be produced. By adding the main ingredients of concrete and super-plasticizer a certain amount of RHA is used for the flow capacity to produce low-cost SCC. The application of RHA in SCC addresses a solution to environmental problems with the construction sector while preserving emission-free air conditions.

To understand the behavior of SCC beams of various grades exposed to 900°C temperature and then the application of flexural loading, Prince Arulraj et al [7] carried out a study. Results show that the strength loss of high-strength SCC beams was higher than the strength of low-strength SCC beams. It shows that the decrease in compressive, tensile and flexural tolerance of the specimens depends on the
heating and cooling conditions. The higher the moisture content, the greater the risk for deterioration.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Materials
For the investigation the OPC compatible with IS 12269 was used [20]. The specific gravity was 3.15. The fine aggregate was the locally available river sand. The sand's average specific gravity was 2.62 and complied with the IS 383 (1970) conforming to zone II [18]. The coarse aggregate had a specific gravity of 2.71. For mixing and curing, tap water from well was used. Class 920-D SF of private limited (India) Elkem India is commercially available. The ASTM Type-F FA low calcium is used. The super plasticizers used are the Master Glenium Sky 8233. Materials utilized for the investigation is shown in Figure 1.

![Materials](image)

**Figure 1.** Material used (a) SF (b) FA (c) MK

2.2. Mix Design

The mix design for cement mortar from IS 10080 (1982) were designed. Concrete was made as per the procedure given in IS 10262 (2009)[19]. Fine aggregates and coarse aggregates are replaced with SF, FA and MK for various proportions. Table 1 represents the optimized mix for the developed SCC.

| Grade | Cement (kg/m³) | FA (kg/m³) | CA (kg/m³) | Admixture (kg/m³) | w/c ratio | w/p ratio | SP (lt/m³) |
|-------|----------------|------------|------------|-------------------|-----------|-----------|------------|
| SF    | 360            | 961.17     | 932.14     | 29.727            | 0.49      | 0.45      | 4.67       |
| FA    | 360            | 911.63     | 885.58     | 125.83            | 0.49      | 0.36      | 5.43       |
| MK    | 360            | 941.35     | 903.21     | 77.479            | 0.49      | 0.40      | 4.37       |

2.3. Test on Hardened Concrete

A wide-ranging laboratory study was carried out to examine the influence on the impact strength of SCC by mineral admixtures. Tests have been conducted on concrete cylinder with 150mm diameter and 63.50mm height. The samples were casted and cured for 28 days and tested for impact strength.

2.4. Heating of Specimens

SCC specimens were placed within the furnace and the furnace was heated from room temperature to 500°C, 750°C and 1000°C. The specimen undergoing heating in the furnace is shown in Figure 2.
2.5. Testing of Specimens
To evaluate the impact capacity of the specimen, the drop weight hammer (ACI 544.2R). M20 grade specimen was cast. Tests on the 150mm diameter and 63.50mm height concrete cylinders were performed. The impact testing apparatus is shown in Figure 3.

3. ANALYSIS OF RESULTS
3.1. Results for Impact Tests
The impact strength of the reference specimen (unheated specimen) is found to be increased up to the optimum percentage replacement. Whereas the impact strength of the heated specimen is decreasing with an increase in temperature and powder content[8,9]. It is noted that the rate of decrease of impact strength of water-cooled specimens is more than that of air-cooled specimens[10]. This is because when concrete underwent high-temperature cracks are developed and further when allowed for sudden cooling i.e. water-cooling additional micro-cracks are developed which leads to a higher rate of decrease strength[11].

CSH dehydrates to CaO at between 400 to 450°C with a 45% reduction in its size. CSH gel disintegration can take place at less than 850°C. The mechanical characteristics of OPC deteriorate with high temperatures up to 400°C, as the hydrated phases in the binder change chemically and physically[12]. The thermal treatment induces drying and loss of chemically bound water, primarily due to CSH dehydroxylation, which leads to a decrease in chemical bonding and energy. The dehydration of concrete can be due to the reduction of impact strength of the concrete following exposure to high temperatures by releasing free water and fractional water for the hydration of concrete. It is important to note that the expansion of the structure plays a major role in reducing the
intensity of the impact of concrete after exposure to high temperatures[13].

Due to the loss of water above 400°C, calcium hydroxide can decompose into calcium oxide. Once cooled, the calcium hydroxide reforms. As a result of these volume changes, concrete can crumble[14]. Tables 2, 3 and 4 represent the results of the impact test for specimens cooled with air and water.

Table 2. Impact test results for FA specimens

| Type of specimen | Impact energy N-mm (Air-cooled) | Impact energy N-mm (Water-cooled) |
|------------------|---------------------------------|-----------------------------------|
| FA UH            | 651.31                          | 651.31                            |
| FA 500           | 101.76                          | 81.41                             |
| FA 750           | 40.70                           | 40.70                             |
| FA 1000          | 20.35                           | 20.35                             |

Table 3. Impact test results for SF specimens

| Type of specimen | Impact energy N-mm (Air-cooled) | Impact energy N-mm (Water-cooled) |
|------------------|---------------------------------|-----------------------------------|
| SF UH            | 447.77                          | 447.77                            |
| SF 500           | 81.41                           | 61.06                             |
| SF 750           | 40.70                           | 40.70                             |
| SF 1000          | 20.35                           | 20.35                             |

Table 4. Impact test results for MK specimens

| Type of specimen | Impact energy N-mm (Air-cooled) | Impact energy N-mm (Water-cooled) |
|------------------|---------------------------------|-----------------------------------|
| MK UH            | 3663.64                         | 3663.64                           |
| MK 500           | 61.06                           | 61.06                             |
| MK 750           | 20.35                           | 20.35                             |
| MK 1000          | 20.35                           | 20.35                             |

3.2. Loss of Weight

The weight loss variation of the concrete samples from various mixes with a change in the temperature of the maximum exposure is indicated. As the peak temperature is raised, weight loss is observed. The weight loss of the concrete was also observed as the temperature as well as the FA content increased. For water cooling weight loss is comparatively smaller than in air cooling [15]. This is due to the penetration of water through micro-cracks that occur when the temperature is high. At a higher temperature, crack forming helps the vapor to dissipate through additional crossings and thereby reduces the concrete's weight. The most pronounced method for disintegration was concrete subjected to a temperature of 1000°C. A breakdown of the hydro-calcium silicates and drainage of chemical water from lime are the main reasons for this process [16]. The weight loss of specimens that were tested is presented in Figure 4 and Figure 5. The detailed results of weight loss are presented in Table 5.
Figure 4. Loss of weight (%) for air-cooled specimens

Figure 5. Loss of weight (%) for water-cooled specimens

Table 5. Loss of weight in percentage

| Types of specimen | Air-cooled 500°C | 750°C | 1000°C | Water-cooled 500°C | 750°C | 1000°C |
|-------------------|-------------------|------|--------|-------------------|------|--------|
| FA                | 2.14              | 5.34 | 7.91   | 3.53              | 7.12 | 8.70   |
| SF                | 2.48              | 7.39 | 9.93   | 3.57              | 8.24 | 11.66  |
| MK                | 4.90              | 11.56| 14.04  | 6.55              | 13.61| 18.03  |

3.3. Colour Change

The variations in color on the specimen are due to a loss of moisture when the temperature is high. The heating leads to the drying of the material. The amount of water drawn from a heated concrete specimen is determined by the energy that attaches the water with the solid. Free water thus evaporates first, with capillary water then physically bound water. The first color shift is due to the progressive evaporation of water from a cement paste and the progressive removal process that is chemically associated with cement hydrates. Another reason for the change in the colour of concrete after heating is the reduction of C₄AF[17]. Figure 6(a) to 6(d) shows the colour changes in the specimen.
4. CONCLUSION

Impact strength of reference concrete (unheated concrete) specimens were found to be increased up to the optimum replacement. But at elevated temperature impact strength is decreased with an increase in temperature. This decrease in strength is due to the formation of micro-cracks developed due to the action of high-temperatures.

- When concrete is subjected to high temperature (above 500°C) colour of concrete is changed. This is due to the loss of water present in concrete. Surface water, capillary water and physically bonded water losses at a temperature of more than 750°C.
- Concrete weight loss is higher when the temperature increases. Initial mass loss was caused by evaporation of capillary water, followed by the exhaust of adsorbed and interlayer water, while chemical combined water was later released.

REFERENCES

[1]. Pathak N & Siddique R “Properties of self-compacting-concrete containing fly ash subjected to elevated temperatures” Construction and Building Materials, 2011 30 274
[2]. Fares H, Noumowe A & Remond S “Self-consolidating concrete subjected to high temperature Mechanical and physicochemical properties” Cement and Concrete Research, 2009 39 1230

[3]. Sivaraja M “Self-Compacting Concrete under Elevated Temperature” International Journal of Engineering Research & Industrial Applications, 2010 03 295

[4]. Tao J, Yuan Y & Taewae L “Compressive Strength of Self-Compacting Concrete during High-Temperature Exposure” Journal of Materials in Civil Engineering, 2010 22

[5]. Quinn W Z J & Bartos P J M “Aspects of Durability of Self-Compacting Concrete” Advanced Concrete and Masonry Centre, 20021044

[6]. Memon S A & Shaikh M A “Utilization of Rice Husk Ash as viscosity modifying agent in Self Compacting Concrete” Construction and Building Materials, 2011 25 1044

[7]. Anand N & Prince S Arulraj G “Effect of Grade of Concrete on the Performance of self- Compacting Concrete Beams Subjected to Elevated Temperatures” Fire Technology, 2014381269

[8]. Anand N, Prince S Arulraj G & Aravindhan C “Stress-Strain Behaviour of Normal Compacting and Self-Compacting Concrete under Elevated Temperatures” Journal of Structural Fire Engineering, 2014563

[9]. Jalal M, Pouladkhah A R, Harandi O& Jafari D “Comparative study on effects of Class F fly ash, Nano silica and silica fume on properties of high performance self-compacting concrete” Construction and Building Materials, 2013 94 90

[10]. Sahana G K, Shepur N T, Shivakumaraswamy B & Vijaya S “Experimental Study on Strength of Self Compacting Concrete by Incorporating Metakaolin and Polypropylene Fibre” International Journal of Engineering Research & Technology, 2014 03 1216

[11]. Ganeshram G S “An Experimental Study on Impact Strength of Self Compacting Concrete” International Journal of Engineering Research & Technology, 2015 041184

[12]. Jalal M., Mansouri E, Sharifipour & Pouladkhah A R “Mechanical, rheological, durability and microstructural properties of high-performance self-compacting concrete containing SiO2 micro and nanoparticles” Materials and Design, 2013 34 389

[13]. Heiza K M “Mechanical, rheological, durability and microstructural properties of high-performance self- compacting concrete containing SiO2 micro and nanoparticles Challenge” Journal of Concrete Research Letters, 2012 03 406

[14]. Khaliq W & Kodur V “Thermal and mechanical properties of fiber-reinforced high performance self-consolidating concrete at elevated temperatures” Cement and Concrete Research, 2014 41 1112

[15]. Nuruddin M F, Azmee M N& Yung C K “Effect of fire flame exposure on ductile self-compacting concrete (DSCC) blended with MIRHA and fly ash” Construction and Building Materials, 2012 2050388

[16]. Gencel O, Ozel C, Brostow W& Barrera G M “Effect of fire flame exposure on ductile self-compacting concrete (DSCC) blended with MIRHA and fly ash” Materials Research Innovations, 2011 25 216

[17]. Vasusmitha R&Rao P S “Effect of Elevated Temperature on Mechanical properties Of High Strength Self-Compacting Concrete” International Journal of Engineering Research & Technology, 2012 0101

[18]. IS: 383 1970 Indian Standard Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi

[19]. IS: 10262 2009 Indian Standard Concrete Mix Proportioning - Guidelines, Bureau of Indian Standards, New Delhi.

[20]. IS: 12269 2013 Ordinary Portland Cement, 53 Grade - Specification, Bureau of Indian Standards, New Delhi.