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Influence of Elevated Temperature on Various Grades of High Performance Concrete, Containing Artificial Sand and Pozzolanic Admixtures

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ABSTRACT

The authors had investigated effect of elevated temperature on durability property of high performance concrete (HPC) produced using 100 % artificial sand as fine aggregate. Many researchers were carried out the research on effect of elevated temperature on various grades of normal concrete, produced using natural sand or partially replaced natural sand. As there is growing tendency of long and heavy constructions, and less availability of natural sand in market, use of high performance concrete (HPC) with some other fine aggregate, is a present need in construction industry. In this study, investigation was carried out on HPC of M 65, M 75 and M 85 concrete grades. These mixes were produced using 100% artificial sand, microsilica & fly ash, as pozzolanic admixtures. The concrete mixes were made as per IS 10262- 2019. After proper curing, it was subjected to elevated temperature ranging from 27^{0}C to 700^{0}C for 2 hours soaking period. It was observed that, concrete was sustained without damage up to 300^{0}c elevated temperature. Also, from microstructure investigation, it was observed that, after 500^{0}c temperature, micro cracks were started to develop .and decreases content of C-S-H matrix in concrete. Compressive strength was decreased with increasing content of fly ash. From this investigation, authors concluded that, HPC was sustaining permissible compressive strength up to 3000C elevated temperature.

Keywords
HPC, Pozzolanic material, Artificial sand, Elevated temperature, Compressive strength

Introduction

Concrete is most widely used construction material in the construction industry, Normal concrete is used for small buildings, roads, culverts. For requirement of high strength structures, use of HPC is preferred. [4]. [5]. [6]. [7]. HPC is one of the emerging concrete used in multi-storeyed structures, bunkers, atomic plants, sea shore structures etc. The main ingredient for all such concrete is cement and binding materials. [8]. [9]. Out of major ingredients used in concrete, fine aggregate was one of the most important binding material. Therefore, along with the properties of cement and fine aggregate in concrete was very much essential in view of binders. [11]. [13]. Presently, due to continuous use of natural sand from long back, natural sources, were depleting. Therefore, to search for use of other alternative, the artificial sand is one of the source, to fulfil the requirement of fine aggregate and to produce HPC. Also, it is essential to produce durable HPC by using proper admixtures incorporating in concrete against physical and mechanical properties. Out of different physical properties, fire was a serious threat to the safety of concrete structures. The relative properties of concrete are of great importance in terms of serviceability of building. [3]. [8]. [13]. [16]. However, there were still need of recognition of elevated temperature and its effect on HPC. In this investigation, optimized concrete grades of M 65, M 75 and M 85 were produced using microsilica, fly ash and artificial sand. After 28 days curing, these are allowed to dry for 24 hours in open and dry air. Further, these cubes were subjected to elevated temperature ranging from 27oc to 700oc. Physio-mechanical properties of concrete were observed and compared for different grades of concrete. The results were also compared with the literature.

Thermal Properties of Concrete

Thermal conductivity is property of concrete to transfer heat from outer layer to core part of specimen. It was relevant to temperature gradient and depends on rock and aggregate properties. Conductivity was related to use of specific aggregates in concrete. [15]. [16]. Generally, in India, aggregates of Basalt, Granite Dolomite, Quartzite, Limestone, Sandstone, Granite are used. The thermal conductivity values for these rocks were 2.00 3.3 and 3.5, 3.2, 2. 9,2.60 J/m2/s

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respectively. Out of these rocks, Basalt rock is available in various parts of countries. Generally, in Deccan area, aggregates of Basalt rock are commonly used in construction. These aggregates are having low conductivity value. Also, these aggregates are siliceous nature. Due to such properties of aggregates, Basalt aggregates are more strong and stable for concrete works. Also, they are transferring heat slowly, from outer layer to central core layer of concrete and the bond between concrete ingredients will remain strong and stable for long period.

Experimental Program

Materials

To produce required grade of concrete specific characteristics of materials are necessary. Ordinary portland cement of 3.15 specific gravity, with 53 grade, confirming to IS - 269 -2015 is used. Fine aggregate and coarse aggregates are made from basalt rock, having specific gravity 2.77 and 2.74 respectively. The coarse aggregate passing from 20 mm and fine aggregate passing from 4.75 mm size sieves are taken. All aggregates are selected as per Zone – II of standard gradation curve. [5]. [6]. [11]. [12]. Both aggregates were confirming to IS 383-2016 and satisfies gradation curve. Densified microsilica [11] having specific gravity 2.2, and confirming to IS- 9103 was used as a mineral admixture. In order to improve the workability of concrete, Master Gallium Sky 8521 superplasticizer, polycarboxylic ether (PCE) based chemical admixture with specific gravity 1.10 was used. It was water repellent. Finally, fresh potable water, free from acid and organic substance, was used during casting. An experimental work is carried out on optimized mix HPC grade M 65, M 75 and M 85. [1]. [2]. [12]. [15]. As per optimization process, the mix proportions for M 65, M 75 and M 85 grade concrete are done using cement, artificial sand, course aggregate, PCE based superplasticer and microsilica.

Methods of exposure and testing

The specimen of size 150 x 150 x 150 mm is casted in research laboratory and cured in water for 28 days. These specimens were taken out from water and allowed to dry in air. Weight of each specimen is taken before heating, using digital balance. An electric furnace with a maximum operating temperature capacity of 10000C is used to heat the specimen. Initially, temperature in furnace is (27 0C + 20C). The required further temperature of furnace was to be set using digital panel control board of the furnace. The furnace was airtight. After achieving a required elevated temperature, it was kept constant for 2 hours soaking period. Then furnace was switched off and specimens were allowed to cool down to room temperature for24 hours. The specimens further were removed from furnace and weight of specimens were taken. They were tested on compression testing machine having loading capacity of 3000 kN

Figure 1. Panel board of Electrical heating furnace.

Figure 2. An electrical furnace with specimen

Experimental Data

Column heading notations for table 1, 2, and 3
A = Temperature (t) ^{0}C
B = Weight before temperature exposure in kg
C = Weight after temperature exposure in kg
D = B – C, in kg
E = Percentage difference
F = compressive strength - N/mm^2
G = Reduction in strength w.r.t. control mix - N/mm^2
H = Percentage reduction in strength w.r.t. control mix
I = Residual strength w.r.t. control mix %

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Table 1. Results of M-65 grade concrete

A	B	C	D	E	F	G	H	I
27	9.238	9.238	0.00	00	75.11	00	00	100
100	9.330	9.241	0.089	0.95	73.77	1.34	1.78	98.22
200	9.288	9.148	0.140	1.507	71.77	3.34	4.44	95.56
300	9.033	8.730	0.303	3.35	71.73	3.38	4.50	95.50
400	9.338	8.751	0.587	6.28	62.19	12.92	17.20	82.80
500	9.088	8.046	1.042	11.47	52.51	22.60	30.10	69.90
600	9.177	7.799	1.378	15.02	38.69	36.42	48.50	51.50
700	9.126	7.295	1.831	20.06	25.39	49.72	66.20	33.80

(Control mix strength at Temperature 27 0c = 75.11 N/ mm^2)

Table 2. Results of M-75 grade concrete

A	B	C	D	E	F	G	H	I
27	8.918	8.918	00	00	85.33	00	00	100
100	8.661	8.638	0.023	0.27	84.18	1.15	1.34	98.66
200	8.948	8.826	0.122	1.363	82.44	2.89	3.38	96.62
300	8.713	8.443	0.270	3.14	80.17	5.16	3.60	96.40
400	8.776	8.326	0.450	5.120	72.11	13.22	15.50	84.5
500	8.898	7.950	0.948	10.650	56.45	28.88	28.94	71.06
600	8.898	7.950	0.948	13.260	40.88	44.45	46.10	53.90
700	9.023	7.441	1.582	17.53	26.88	58.45	64.51	35.49

(Control mix strength at temperature 27 ^{0c} = 85.33 N/mm^2)

Table 3: Results of M- 85 grade concrete

A	B	C	D	E	F	G	H	I
27	8.593	8.593	00	00	95.11	00	00	100
100	8.491	8.476	0.015	0.18	93.88	1.23	1.29	98.71
200	8.453	8.376	0.077	0.914	91.93	3.18	3.34	96.66
300	8.526	8.260	0.266	3.12	89.40	5.71	3.40	96.60
400	8.160	7.753	0.407	4.99	80.53	14.58	15.33	84.67
500	8.841	8.020	0.821	9.280	69.07	26.04	27.38	72.62
600	8.936	8.003	0.933	10.44	53.17	41.94	44.10	55.90
700	8.410	7.313	1.097	13.04	37.11	58	60.98	29.02

(Control mix strength at temperature 27 ^{0c} = 95.11 N/mm^2)

After subjecting the cube samples of various grades to elevated temperature ranging from 100 0c to 700 0c, they were tested on compression testing machine of 3000 kN capacity. These in fig. 2 a, fig. 2b and fig. 2 c.

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Figure 3: M 65 grade cube subjected to elevated temperature 400^{0}C

Figure 4: M 65 grade cube subjected to elevated temperature 400^{0}C

Experimental Program

Change in Colour

Because of gradual water removal from concrete due to elevated temperature, the aggregates are heated. During this process, as temperature goes on increasing, original colour of cubes are changing gradually. Fig. 5, 6 and 7 are indicating effect of colour change.

From Fig. 5, 6 and 7 It is observed that, at 27^{0}C, concrete cube is light grey in colour. As temperature of concrete increases up to 300^{0}C, original colour remains same. As temperature reaches up to 4000C, concrete changes to light brownish colour. Further addition in temperature up to 600^{0}C, causes dark brown colour with small surface holes in concrete. Finally, when temperature reached at 700^{0}c, concrete seen from brown to grey. Also it is observed that, spalling of concrete not seen during entire process of heating.

Loss in weight

The results of percentage loss in weight is observed for M-65, M-75, M-85 grades of HPC. They are shown in fig. 8.

From Fig. 4, it is found that, total percentage loss in weight from 27 to 700 0c is 20.06% for M 65 grade concrete, 17.53 % For M 75 grade concrete and 13.04%. for M 85 grade concrete respectively.

Figure 5: Reddish colour at 400^{0}C

Figure 6: Greyish colour at 600 ^{0}C

Figure 7: Greyish colour at 600 ^{0}C

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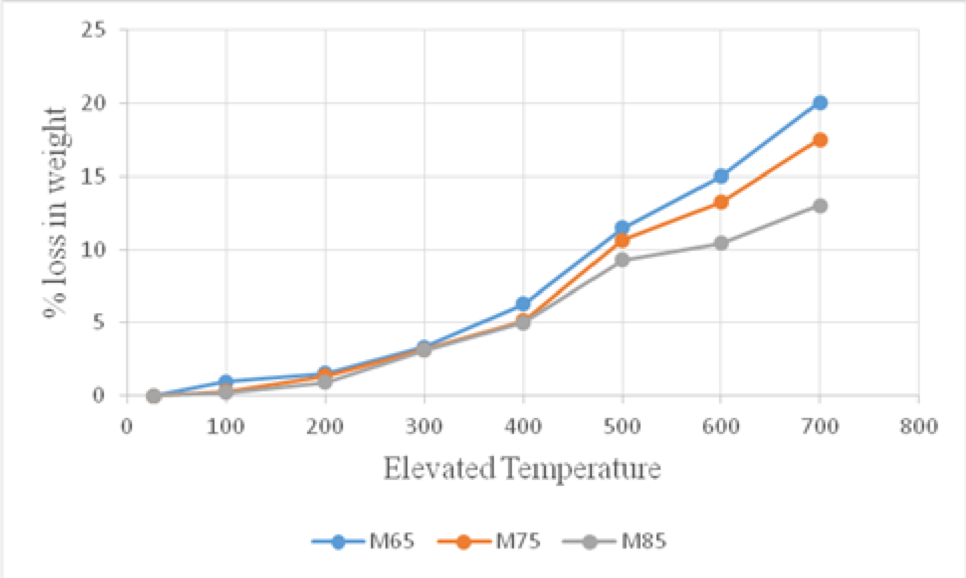

Figure 8: Elevated temperature and percentage loss in weight

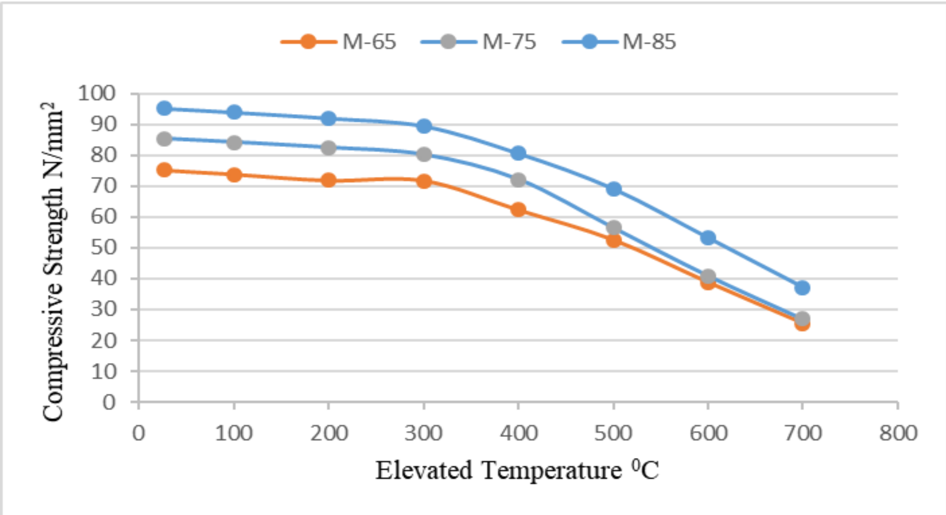

Figure 9: Elevated temperature and compressive strength (Grade M 65, 75 and 85 N/mm^2)

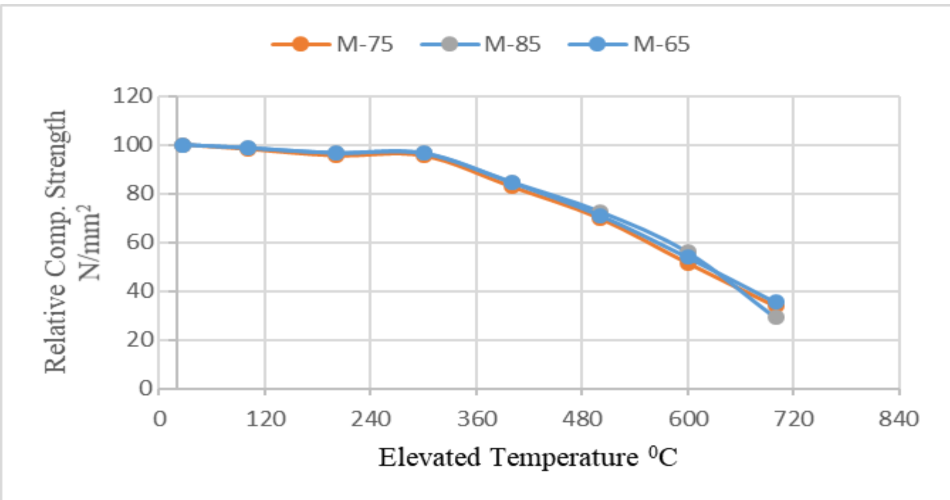

Figure 10: Elevated temperature and residual compressive strength with (Grade M 65 ,75, 85 N/mm2)

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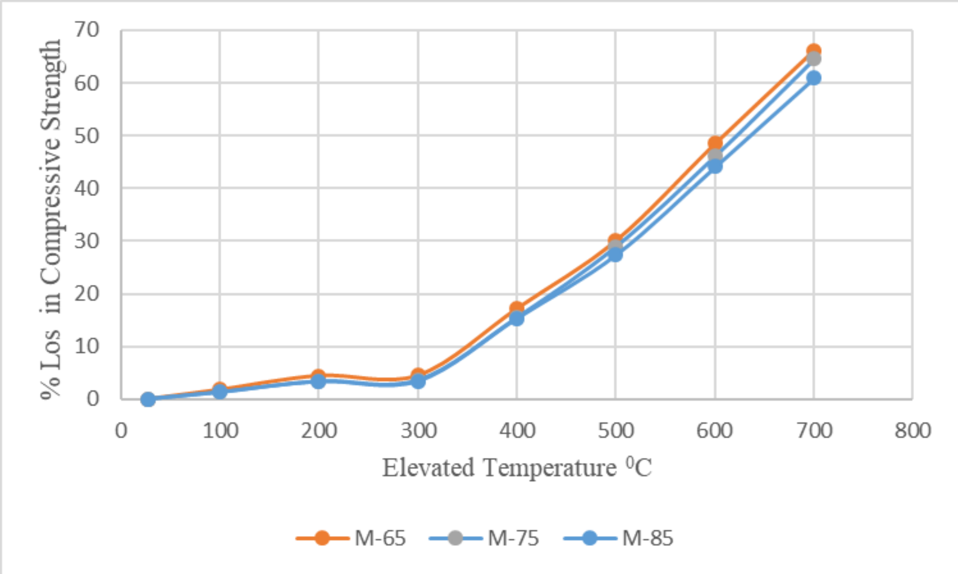

Figure 11: Elevated temperature and percentage loss in compressive strength for M 65, 75, 85 N/mm2

Compressive strength

The results of elevated temperature and compressive strength of concrete for M-65, M-75, M-85 grades of HPC are shown in fig.5. Also the results of elevated temperature and residual compressive strength in percentage, for same grade of concrete are shown in fig.11.

From fig.8, it is found that, compressive strength decreases from 27 to 7000C continuously. The variation of reduction in strength for M 65 grade is from 75.33 to 35.39 N/mm2, for M 75 grade is from 85.33 to 26.88 N/mm2 and for M 85 grade is from 95.11 to 37.11 N/mm2 respectively. The residual compressive strength variations are shown in fig.11. After 300^0C, reduction in strength suddenly increasing with considerable change in strength for each concrete grade.

From fig.11 it is found that, total percentage loss in strength from 27 0c to 700 0c is 66.20 %, for M 65 grade concrete, 64.51 % for M 75 grade concrete and 60.98% for M 85 grade concrete respectively. It is observed that, strength loss is less than 5% up to 3000c compared with control specimen strength.

Rise in temperature up to 400^0c, increases percentage loss of strength at slow rate. Beyond 400^0c, there is fast and sudden loss in strength.

Scanning Electron Microscope (SEM)

For investigation of microstructure of concrete at various temperature, sample material from core section at a depth of 50 mm from outer surface of cube are selected for test. The images obtained from microscope observation are shown in fig. 12 a to f, fig. 13 a to f and fig. 14 a to f.

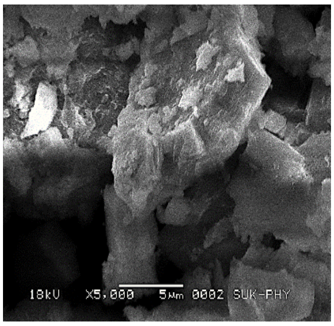

Figure 12 a: M65 grade concrete at 27^0C

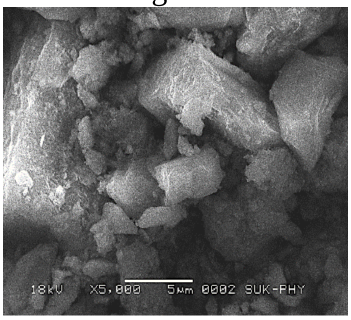

Figure 12 b: M65 grade concrete at 300^0C

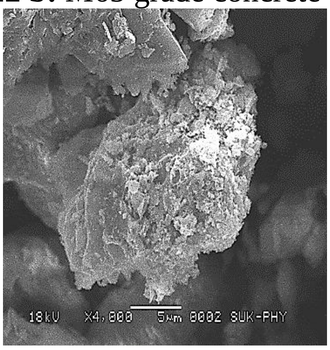

Figure 12 c: M65 grade concrete at 400^0C

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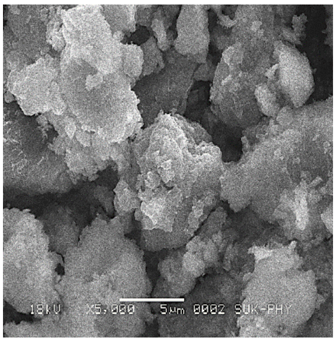

Figure 12 d: M65 grade concrete at 500^0C

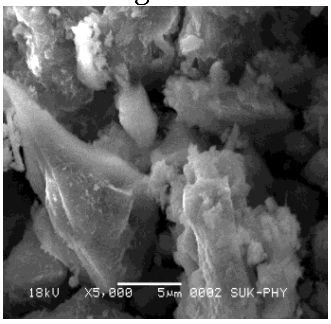

Figure 12 e: M65 grade concrete at 600^0C

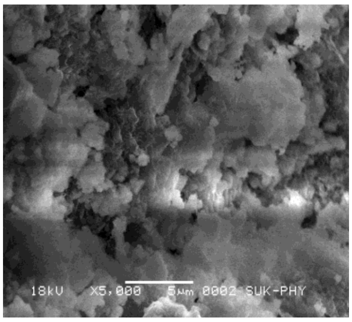

Figure 12 f: M65 grade concrete at 700^0C

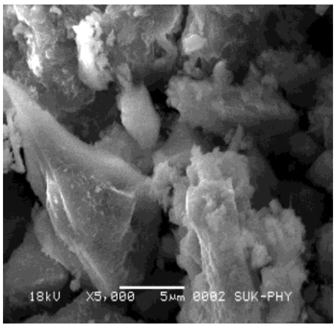

Figure 13 a: M75 grade concrete at 27^0C

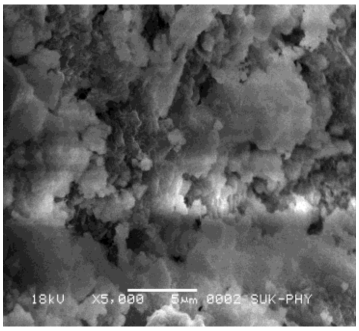

Figure 13 b: M75 grade concrete at 300^0C

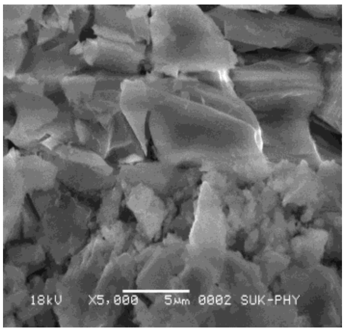

Figure 13 c: M75 grade concrete at 400^0C

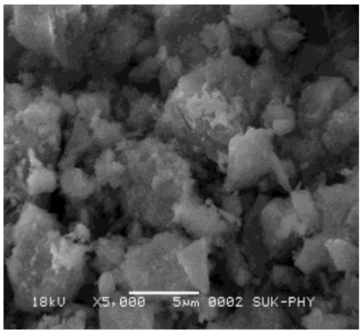

Figure 13 d: M75 grade concrete at 500^0C

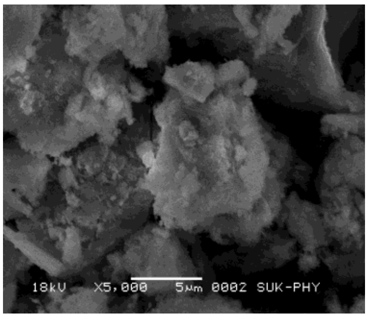

Figure 13 e: M75 grade concrete at 600^0C

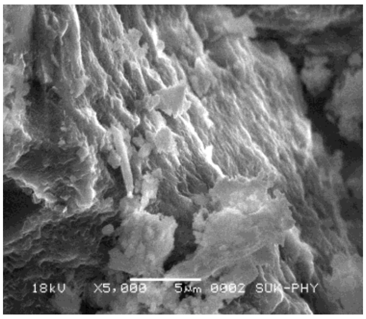

Figure 13 f: M75 grade concrete at 700^0C

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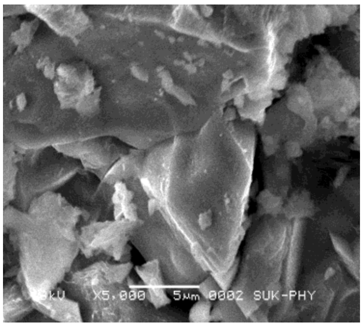

Figure 14 a: M85 grade concrete at 27^{0}C

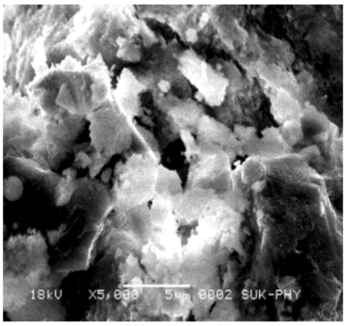

Figure 14 b: M85 grade concrete at 300^{0}C

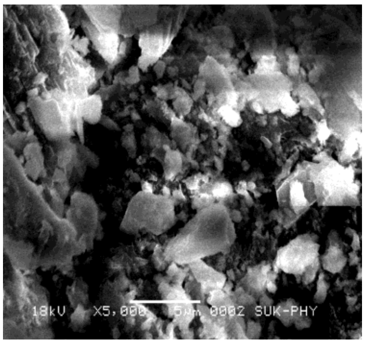

Figure 14 c: M85 grade concrete at 400^{0}C

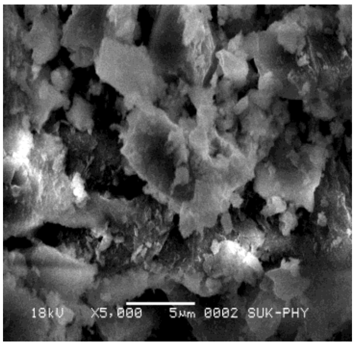

Figure 14 d: M85 grade concrete at 500^{0}C

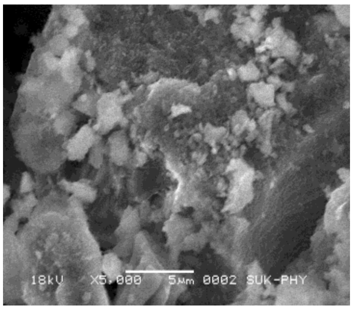

Figure 14 e: M85 grade concrete at 600^{0}C

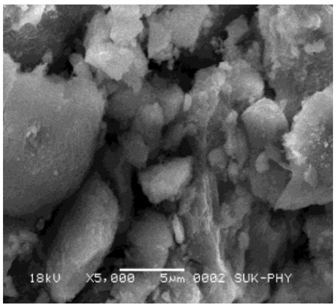

Figure 14 f: M85 grade concrete at 700^{0}C

Fig 12 a, fig 13 a and fig.14 a indicate concrete mixes at 27^{0}C of concrete grade M 65, M75 and M85 respectively. Fig.12b, fig.13b and fig.14b indicate concrete grades of M 65, 75 and M 85 subjected to elevated temperature at 300^{0}C respectively. They show microstructure having saturated C-S-H gel in bright dark matter and coarser lumps. Matrix is hydrated and evenly packed. Formation of C-S-H gel were thicker in M75 and M85 concrete grades. Few micro cracks are observed in all concrete samples. When temperature rises at 400^{0}C, Matrix is less packed. The bond between ingredients are slightly weaker. At 500^{0}C temperature, wide micro cracks 2 to 4 µm with scattered matrix are visible. At 600^{0}C, matrix is partially dry and free. Brightness of C-S-H gel are reduced in the matrix. Width of cracks are in the range of 2 to 5 µm. At 700^{0}C, width of cracks was in range of 3 to 6 µm. Matter is scattered and loose bond is developed between ingredients with dry C-S- H gel.

CONCLUSIONS

On the basis of results obtained from research work, the following conclusions are summarized.

- High performance concrete produced using 100% artificial sand is performing better for elevated temperature up to 300^{0}C, with loss of compressive strength less than 5%, compared with control specimen strength.

- When temperature crosses by 300^0C, bond between concrete ingredients started to break. It causes sudden reduction in weight of concrete. As spalling in concrete is not developed,
  and particles in concrete are not dispersed, it indicates bond between concrete is strong,
- From experimental results, as percentage of fly ash in concrete increases from 0% to 7.5%, percentage reduction in compressive strength decreases from 66.20 % to 60.98%. Rate of change of reduction in strength is not specific for any grade of concrete. Also, additional percentage of fly ash in concrete is not suitable to sustain in higher temperature.
  - From microstructure investigation it is concluded that, finer material in concrete are more sensitive for higher temperature, develop cracks and weak bond between ingredients.
  - Finally, it is concluded that, optimized HPC produced using 100 % artificial sand is reliable to resist elevated temperature up to 300^0C, without using any other fire resisting admixture in concrete.

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