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Evaluation of Durability of Ultra High Performance Fibre Reinforced Concrete (UHPFRC) Through Extreme Temperature

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***Abstract*—** In the present era of modern concrete technology Ultra High Performance Fibre Reinforced Concrete (UHPFRC) is new cement based material. An inclusion of fibers shows to increases both mechanical and durability properties of UHPFRC. The aim of this study is to determine durability of UHPFRC containing fly ash and Metakaolin. Durability of UHPFRC after exposed to extreme temperature is evaluated. UHPFRC gives better fire resistance. The specimens were exposed to high temperature, specially 200ºC, 400ºC, and 600ºC for 1 hour. The fire resistance of specimen was classified on the basis of their compressive strength and weight loss. Strength loss was not significant at low temperature; up to 200ºC.Metakaolin shows the better performance as compared with fly ash. SEM analysis was also carried out to study effect of extreme temperature on microstructure of UHPFRC.

***Keywords*—** Compressive strength, Fly ash, Metakaolin, Steel fibres, UHPFRC, SEM

I. INTRODUCTION

UHPFRC is relatively new construction material, which is combination of high performance concrete and fibre reinforcement [1, 2]. Due to low water binder ratio, high binder dosage and relatively high fibre dosage in UHPFRC it has superior mechanical properties [3-7]. Silica fume, lime, fly ash and granulated blast furnace slag used as partial clinker replacement in the production of UHPFRC [8, 9].UHPFRC with hybrid fibre reinforced concrete have better mechanical properties than the concrete with only a single type of fibres [10-16]. Rossi was firstly proposed the application of different types of fibre combined in one concrete [17].

However developing construction industry, concrete expect the compressive strength is also required to high flexural strength , workability and durability, which resulted the development of ultra-high performance concrete (UHPC) and UHPFRC [18,19].

The dense matrix with extremely low permeability allows use of UHPFRC, for example as water proofing layer in bridge deck considering economical & practical reasons, only UHPFRC can be used in field application without heat and pressure curing.

Ultra-high performance fibre reinforced concrete is an expansive because high silica fumes content and other expensive raw materials. In most of countries, they demand that to find an alternative to the silica fume. Our choice was to optimize the use of Metakaolin [20, 21].

Water present in fine pores evaporates under temperature extremities and pressure builds up internally. Spalling occur in concrete when stress can't be withstood. It is unpredictable if can occur during heating or cooling of UHPFRC [22]. This type of concrete not only reduces amount of concrete required but also increase serviceability and durability of the resulting structure.

II. MATERIALS AND METHODS

A. Materials

The cement used in this research is ordinary Portland cement (OPC). Standard consistency of cement is 29.2%. Fly ash and Metakaolin is used as a partial replacement in concrete. To make concrete denser it is necessary to used Metakaolin. P63 grade fly ash is used in this study. Quantity and fineness of fly ash plays an important role. Higher fineness shows higher workability and strength with early duration of heating. But more fine ash requires more water and addition of water plays an important role in strength the comparative study of fly ash/Metakaolin is carried out by keeping many parameters of formulation constant (super plasticizer/binder ratio, Metakaolin or fly ash/binder). Steel fibres, 40mm length and 0.6mm diameter, were employed. Poly-carboxylate based super plasticizer was used. To achieve good flow ability and minimum water/cement ratio it is essential to used super plasticizer in UHPFRC. Tap water was used for mixing purpose. Specific gravity of fine aggregate is 2.5. Fine sand was used of size 2.36-1.18mm.

B. Mixing Procedure

Materials were mixed in a concrete mixer in following order: cement, sand, micro silica and Metakaolin or fly ash. These materials were dry mixed until they were homogeneous. Then 80% of total water was added and after 2 min remaining 20% water were mixed with super plasticizer and then added to mixture and mixed. Mixing was continued until no dry materials remained. Finally, steel fibre were added and mixed. Total time of mixing of concrete with fly ash is 12 min and with Metakaolin is 15 min.

C. Flow ability of UHPFRC

After mixing the concrete was placed in a mould (Hagerman cone) on a dry surface. Then cone was lifted straight upwards to allow a free flow of UHPFRC. Two concrete diameters perpendicular to each other were measured after lifting cone and the mean value of the flow is calculated, as shown in figure 1. Permitted value of the flow for UHPFRC is 280±10mm [23].

Figure 1 Flow measurement of UHPFRC

D. Curing conditions

The specimens were removed from moulds after 24 hours of casting and placed in curing tank for 28 days at normal room temperature.

E. Heating and cooling details

The specimen were heated to elevated temperatures (200, 400 and 600ºC) about 1hour in automatic electric furnace. The specimen were placed in the furnace starting from normal temperature and heated at a rate of 5ºC/min up to required temperature. After heating, the specimen were allowed to cool in furnace and tested after 24 hours.

F. Mixture details

Comparative study was carried out between fly ash/Metakaolin by keeping many parameters of the mixture constant (super-plasticizer/binder ratio, percentage of fly ash and Metakaolin).

Three reference mixtures with fly ash were cast:

- Fly ash with 2% steel fibres. (FA2)
- Fly ash with 3% steel fibres. (FA3)
- Fly ash with 4% steel fibres. (FA4)

The same mixtures with Metakaolin in place of fly ash were also cast:

- Metakaolin with 2% steel fibres. (MK2)
- Metakaolin with 3% steel fibres. (MK3)
- Metakaolin with 4% steel fibres. (MK4)

III. EXPERIMENTAL INVESTIGATION

A. Mix Proportion

Following table shows the mix proportion of UHPFRC with Fly ash (FA) and Metakaolin (MK).

Table 1. Mix design of UHPFRC

Materials	Quantity (kg/m^3)	
	Mix 1	*Mix 2*
Cement	876	876
Sand	1056	1056
Micro silica	44	44
Fly ash	220	-
Metakaolin	-	220
Water cement ratio	0.22	0.27
High Range Water Reducer	0.94%	0.94%
Steel Fibres	2%, 3%, 4%	

B. Compression test

Compression strength was determined using 100mm cubes, after 28 days. Results of compressive strength tests are presented in table II.

Analysis of these results shows that:

- Compressive strength of the concrete containing Metakaolin is generally equivalent to or slightly lower than those of the concrete with fly ash.
- The presence of the steel fibres increases the compressive strength slightly.
- Compressive strength of concrete exposed to

temperature up to 200˚C has minor loss in strength as compared to concrete exposed to temperature 400˚C and 600˚C. Following figure shows the arrangement for compression testing.

Figure 2 Compression test on specimen

IV. RESULTS AND DISSCUSSION

For compression test, at least three specimens for each mix were tested. The results of compressive strength of concrete mixes made with OPC, MK and FA are compared. Compressive strength of control specimen which was exposed to extreme temperature is decreases drastically as compared to the concrete which was made with fly ash and Metakaolin. UHPFRC made with 4% of steel fibre shows better strength than concrete made with 2% and 3% of steel fibre in both replacements (fly ash/Metakaolin).

Table 2. Average compressive strength of UHPFRC cubes.

Name of sample	Compressive strength (MPa)			
	Ambient temperature	*After 200˚C*	*After 400˚C*	*After 600˚C*
CS	48.2	37.2	26.3	9.56
FA2	94.2	87	75.1	52.5
FA3	97.4	93.5	88.5	60.4
FA4	113.5	109	93.2	70
MK2	93.4	88	79	66
MK3	96.1	91.4	85.7	72.5
MK4	110.8	101	90.2	73

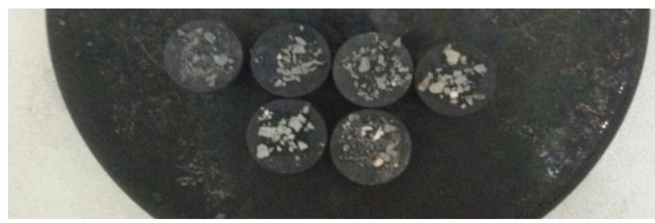


Figure 3 Preparation of sample of UHPFRC for SEM analysis

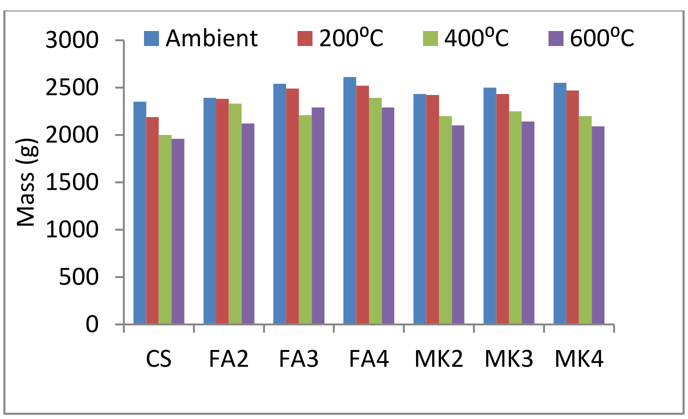


Figure 4. Reduction in mass of UHPFRC after exposed to extreme temperature

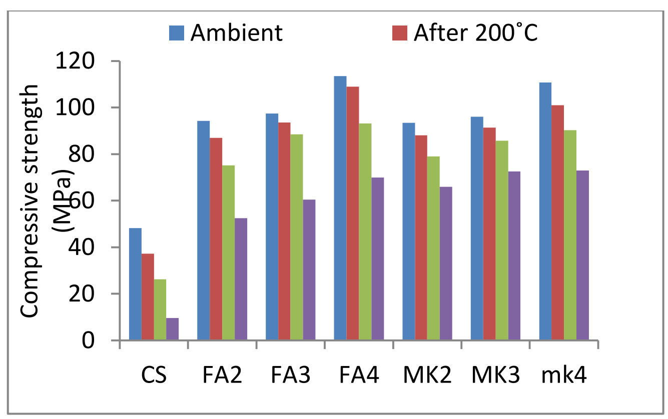
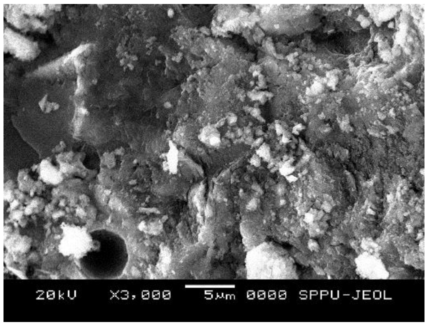
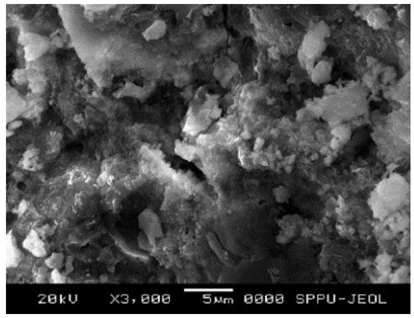


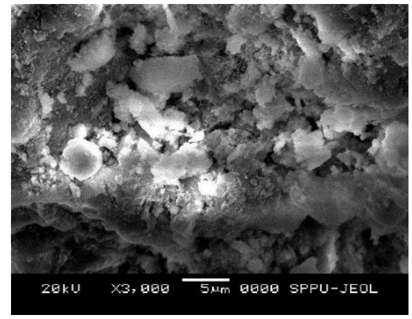
Figure 5. Compressive strength variation of UHPFRC at different temperature.



(a)Ambient temperature

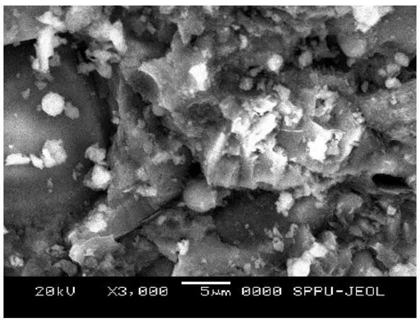


(b)200°C temperature

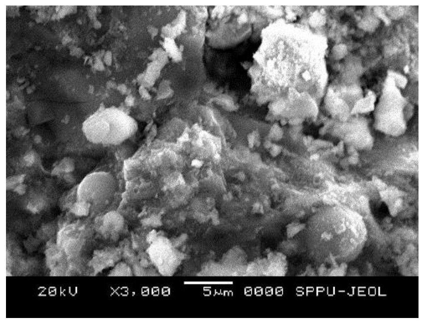


(c)600°C temperature

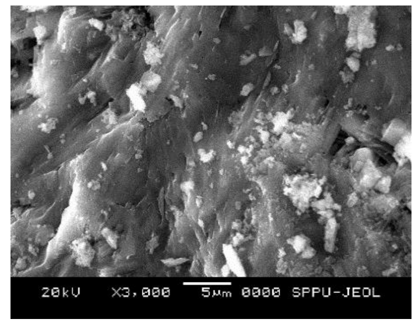
Figure 6. SEM micrographs of control specimen



(a) Ambient temperature

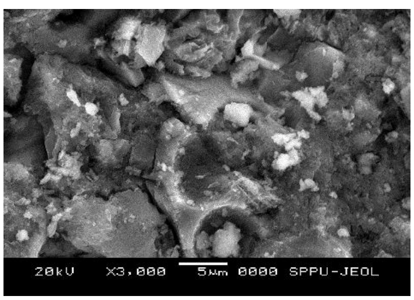


(b) 200°C temperature

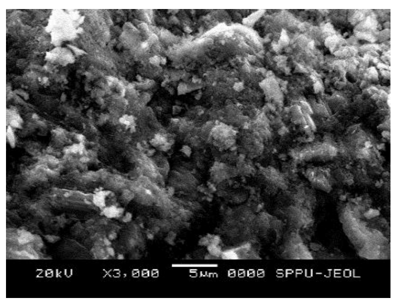


(c) 600°C temperature

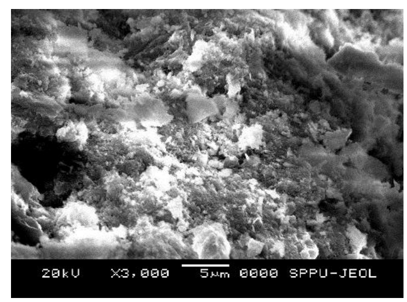
Figure 7. SEM micrographs of UHPFRC with Fly ash



(a) Ambient temperature



(b) 200°C temperature



(c) 600°C temperature

Figure 8. SEM micrographs of UHPFRC with Metkaolin

Microstructure image of the UHPFRC with fly ash and Metakaolin cured at ambient temperature and after that exposed to extreme temperature was obtained by scanning electron microscope. Figure 6, 7, 8 shows microstructure of Normal concrete and UHPFRC, before and after exposed to extreme temperature. In the SEM images of sample of normal concrete, one can observe a very dense structure before exposed to extreme temperature after exposed to extreme temperature voids present in concrete gets bigger, from fig 6 , one can observe that concrete after exposed to extreme temperature particales are separetaed and losses its dense structure. Figure 7 shows microstructure image of UHPFRC with fly ash, pores present in this asample at ambient temperature are less as compared to sample exposed to extreme temperature. Microstructure image of UHPFRC with metakaolin shown in fig 8 one can observe a very dense structure at ambient temperature and less number of pores are present as exposed temperature increases particales get separered and pores get bigger.

V. CONCLUSION

Steel fibres in UHPFRC have significant effect on improving compressive strength. Compressive strength of UHPFRC at 200ºC was not compromised, performed exceptionally well. UHPFRC started losing its strength after exposed to temperature 400ºC. Water required for mixing is less for fly ash as compared to Metakaolin. UHPFRC gives better result after exposed to extreme temperature as compared to normal concrete. At 600˚C the control specimens cannot be with stand. From SEM analysis we can conclude that as exposed temperature of UHPFRC increases voids presents in concrete also increases because of strength of concrete reduces.

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