

Fire Resistance of High Alumina Cement and Slag Based Ultra High Performance Fibre-Reinforced Cementitious Composites

A. Q. Sobia, M. S. Hamidah, I. Azmi, S. F. A. Rafeeqi

Abstract—Fibre-reinforced polymer (FRP) strengthened reinforced concrete (RC) structures are susceptible to intense deterioration when exposed to elevated temperatures, particularly in the incident of fire. FRP has the tendency to lose bond with the substrate due to the low glass transition temperature of epoxy; the key component of FRP matrix. In the past few decades, various types of high performance cementitious composites (HPCC) were explored for the protection of RC structural members against elevated temperature. However, there is an inadequate information on the influence of elevated temperature on the ultra high performance fibre-reinforced cementitious composites (UHPFRCC) containing ground granulated blast furnace slag (GGBS) as a replacement of high alumina cement (HAC) in conjunction with hybrid fibres (basalt and polypropylene fibres), which could be a prospective fire resisting material for the structural components. The influence of elevated temperatures on the compressive as well as flexural strength of UHPFRCC, made of HAC-GGBS and hybrid fibres, were examined in this study. Besides control sample (without fibres), three other samples, containing 0.5%, 1% and 1.5% of basalt fibres by total weight of mix and 1 kg/m³ of polypropylene fibres, were prepared and tested. Another mix was also prepared with only 1 kg/m³ of polypropylene fibres. Each of the samples were retained at ambient temperature as well as exposed to 400, 700 and 1000 °C followed by testing after 28 and 56 days of conventional curing. Investigation of results disclosed that the use of hybrid fibres significantly helped to improve the ambient temperature compressive and flexural strength of UHPFRCC, which was found to be 80 and 14.3 MPa respectively. However, the optimum residual compressive strength was marked by UHPFRCC-CP (with polypropylene fibres only), equally after both curing days (28 and 56 days), i.e. 41%. In addition, the utmost residual flexural strength, after 28 and 56 days of curing, was marked by UHPFRCC-CP and UHPFRCC-CB2 (1 kg/m³ of PP fibres + 1% of basalt fibres) i.e. 39% and 48.5% respectively.

Keywords—Fibre reinforced polymer materials, ground granulated blast furnace slag, high-alumina cement, hybrid fibres.

I. INTRODUCTION

IN the recent decades, the effectiveness of FRP composites as the retrofitting/ strengthening materials for RC buildings has been well established [1]. In addition to that, currently, it is also extensively implemented where renovation is desirable

because of the aging of building materials, explosion/fire, vehicle crash, earthquake or compulsory changes in the structural system by elimination of walls/columns or exclusion of slab openings, or extension and/or upgradation of the building structure is obligatory. This is because of the fact that FRP bears lower maintenance costs, high strength-to-weight ratio and electrochemical corrosion resistance. Besides, as an alternative for the restoration instead of demolishing and then re-building RC structures i.e. not mostly economically feasible for developing and under-developing countries, FRP is the excellent choice [1].

Behaviour of FRP has become a serious concern since its evolution and several researchers [2]-[4] have focused on this matter in the past. It was revealed that FRP system becomes worst in the incident of fire, which is mainly because of the presence of epoxy in the FRP matrix bearing reduced glass transition temperature (T_g), typically in the range of 65°C-150°C [5]. Therefore, the only solution to enhance the fire safety of FRP-strengthened RC structures is to toughen them against fire by delivering an appropriate passive fire protection (PFP) layer. The resistance of structural members against elevated temperatures, experienced in fire, could be improved by the use of PFP layer to a level that will offer sufficient time for the inhabitants of the building to escape to safety. Paramount PFP layer is the one that is entirely compatible with RC structural components; an obstruction against fire spread towards neighbouring buildings, non-combustible, and a shield to adequately maintain the low temperature of FRP and structural elements in case of fire.

FRP strengthened RC columns (stressed), protected with cement based PFP layers, were tested under ASTM E119 standard fire [6], after 33 minutes of fire, FRP temperature reached to the T_g of matrix. On the other hand, with the use of vermiculite-based cementitious insulation over FRP-strengthened RC beam, de-bonding of FRP occurred within 40 minutes of ASTM E119 fire. Performance of non-cementitious materials was even worst and the maximum ignition time of epoxy was reported as 16.6 minutes by the use of phenolic coating [2]. Due to the premier performance of cementitious composites over non-cementitious materials, several studies [7]-[18] were executed in the past based on different cementitious materials. However, hybrid fibre-reinforced

HAC-GGBS based UHPFRCC have not been well characterized at elevated temperatures.

The current paper is targeted to partially meet this gap in the existing knowledge and somehow identify the residual

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mechanical properties of HAC-GGBS based UHPFRCC. HAC is selected for this study due to its extraordinary resistance towards high-temperature as well as aggressive medium. However, GGBS was incorporated due to its complimentary effects on residual compressive and flexural strength of composites at high temperature in comparison to that of silica fume [19]. In conjunction with HAC and GGBS, different dosages (0.5%, 1%, 1.5% of total weight of mix) of basalt fibres (BF) and fixed amount (1 kg/m^3) of polypropylene (PP) fibres were also used. Basalt fibres possess high operating temperature resistance in the range of -269°C - 700°C [20] whereas PP fibres curb the phenomenon of explosive spalling in HPCC [18], [21]–[24].

II. EXPERIMENTAL PROGRAM

A. Materials

Calcium aluminate cement, utilized in this study, is also known as High-Alumina Cement–HAC, which was acquired from CALUCEM with the trademark of 'ISTRA 40'. The oxide content of HAC is shown in Table I. HAC meets the requirements of EN 14647 and its oxide content is shown in Table I. Very fine silica sand containing 99% SiO_2 was used and graded conforming ASTM C136 – 06. Aggregate and cement paste act like a thermal shield within UHPFRCC therefore very fine aggregates were used in order to prevent weak interface [25].

GGBS was supplied by YTL cement Sdn. Bhd. Chemical composition is shown in I. Basalt fibres and polypropylene (PP) fibres were complimentary provided by Kameney Vek and Maccaferri respectively. Physical properties of fibres are given in Table II. Tap water was used in all the mix conforming to ASTM C1602/C1602M – 12 that will be free from all sorts of oils, chloride, harmful chemicals and silt etc.

B. Mixture Proportions

Mix proportion was devised by considering literature review. Numerous pilot mixes were executed before the confirmation of mix proportion. Detailed mix proportion is given in Table III, as also given in [1]. Sand-binder ratio is same for all mixes i.e. 0.8. In the mix proportion, effect of addition of hybrid fibres i.e. polypropylene and basalt fibres was studied. Control mix (C) was prepared using 50% HAC and 50% GGBS. However, in the next mix (CP), in addition to the former materials, polypropylene (PP) fibres were also added by 1 kg/m^3 to the mix. In the subsequent mixes (CB1, CB2, CB3), basalt fibres were incorporated in three different dosages (0.5%, 1%, 1.5% of total weight of mix). In all of the mixes, amount of HAC, GGBS, sand-to-cement ratio, water-to-binder ratio and PP fibres was set to the constant value. The proposed mix proportion was derived after testing several mixes with different dosages of GGBS and comparatively low water/cement ratio [26].

C. Mixing

Mixing of UHPFRCC was done using SPAR high-speed mixer. Firstly, all dry materials were put in the mixer and mixed for about two and a half minute at slow speed (99

rotations per minute (rpm) of planetary shaft) after that water was added to the mixture and then further mixed for one minute at the same speed, followed by hand mix. Afterwards, PP fibres were added to the mixture and mixed for one minute followed by the addition of basalt fibres and mixed for one more minute at intermediate speed (176 rpm of planetary shaft). Finally, the speed was set to the highest level (320 rpm of planetary shaft) and the mixture was mixed for one and a half minute.

TABLE I
OXIDE CONTENT OF HAC AND GGBS

Oxides	HAC (%)	GGBS (%)
SiO_2	≤ 6	32.9
Al_2O_3	38-42	14.1
Fe_2O_3	13-17	-
CaO	37-40	43.1
MgO	< 1.5	4.8
SO_3	< 0.4	0.3
TiO_2	-	0.48
Mn_2O_3	-	0.3
Na_2O	-	0.16
K_2O	-	0.27
LOI	-	1.8

D. Casting

After mixing, the casting of the specimens was done for each mix. For residual compressive strength and residual flexural strength testing, prism shape specimens of dimensions $40 \text{ mm} \times 40 \text{ mm} \times 160 \text{ mm}$ were cast according to ASTM C348-08. Altogether, specimens were cast for 28 and 56 days of testing at ambient and elevated temperatures for each mix. Subsequently, specimens were kept into the conditioning room (details were reported in Section 2.5).

E. Curing Regime

After casting, all specimens were kept in the conditioning room ($20 \pm 2^\circ\text{C}$ at 60% relative humidity (RH)) for 24 hours after which they were de-moulded and cured in the conventional water tank for 28 and 56 days. Specimens were kept in the conditioning room in order to keep the hydration temperature low, which could give rise to the formation of C_3AH_6 (responsible for conversion) [27]. In addition to that, HAC emits 2.5 times more heat of curing as compared to ordinary Portland cement (OPC), which may cause cracking and strength reductions [28].

After de-moulding standard curing was carried out for all specimens in the water basin at average temperature of 28°C . Curing was done for 28 and 56 days.

F. Burning Regime for UHPFRCC

Elevated temperature of 400°C , 700°C and 1000°C were adapted to burn UHPFRCC specimen. Burning was done at the average rate of 5°C/min till it reached the target temperature and after that the target temperature was maintained for one hour in order to achieve the steady state. At each curing age (28 and 56 days), set of three cylinders of specimen was placed, at elevated temperature, in a gas

furnace, available at ceramic workshop, Faculty of Art and Design, Universiti Teknologi MARA (UiTM).

TABLE II
PHYSICAL PROPERTIES OF BASALT AND POLYPROPYLENE FIBRES

Fibre Type	Diameter (µm)	Length (mm)	Specific weight (g/cm ³)	Melting point (°C)	Ignition point (°C)	Elastic Modulus (GPa)	Tensile Strength (MPa)	Break Elongation (%)	Thermal Conductivity (W/m ² K)
Polypropylene Fibres	18	6	0.91	160	360	38	400	>20	0.15
Basalt Fibres	13	12.7	2.67	1450	-	100-110	4000-4300	3.15	0.031-0.038

TABLE III
UHPFRCC MIXTURE PROPORTIONS

Mix	Total Binder		PP Fibre (kg/m ³)	Basalt Fibre (%)	W/B	S/C
	HAC (%)	GGBS (%)				
C	50	50	0	0		
CP	50	50	1	0		
CB1	50	50	1	0.5	0.38	0.8
CB2	50	40	1	1		
CB3	50	35	1	1.5		

G. Testing Procedures and Methods

Prior to the mechanical testing, three identical specimens from each mix were weighed before and after exposure to elevated temperatures in order to measure the average mass loss at each temperature point (400°C, 700°C and 1000°C) with respect to their mass at ambient temperature. Subsequently following tests have been performed:

1) Mechanical Strength Testing

Compressive and flexural strength testing were performed for each mix (three identical specimens each) after 28 and 56 days of curing according to ASTM C349-08 and ASTM C348-08 respectively. Universal Testing Machine was used for testing. After each curing age, three identical specimens of each mix were exposed to the elevated temperatures of 400, 700 and 1000 °C afterwards used to calculate residual compressive strength (RCS) and residual flexural strength (RFS), using (1) and (2) respectively. Before being exposed to elevated temperatures, all specimens were kept in the open atmosphere for almost 24 hours in order to release excessive water. Specimens were allowed to cool down before residual strength is determined. Following are the equations used to calculate residual compressive strength (RCS) and residual flexural strength (RFS):

$$RCS (\%) = 100 - [(C_i - C_f) / C_i] * 100 \quad (1)$$

whereas C_i = Compressive strength at ambient temperature at the specific curing age; C_f = Compressive strength at respective elevated temperature at the specific age.

$$RFS (\%) = 100 - [(F_i - F_f) / F_i] * 100 \quad (2)$$

where F_i = Flexural strength at ambient temperature at the specific age; F_f = Flexural strength at respective elevated temperature at the specific age.

2) Thermal Conductivity Testing

The Thermal Conductivity was carried out at Polymer Composites Research (PoCRe) Laboratory located in the Faculty of Applied Science, UiTM. The thermal conductivity was measured using the Thermal Data Characterization System (TeDCas) as shown in Fig. 1. Test was performed according to BSI 874 (BSI 1998). The dimension of the specimen was 50 mm x 50 mm x 9 mm as shown in Fig. 2. Data recorded was easily managed since the recording was done in Microsoft Excel. Due to the limitations of TeDCas, thermal conductivity was measured up to 80°C only. Thermal conductivity was only measured for the specimen- CP and C.

III. ASSESSMENT OF EXPERIMENTAL RESULTS WITH DISCUSSIONS

A. Mass Loss in Specimens Burnt at Elevated Temperature

Cementitious composites tend to lose their weight as the temperature elevates due to the water loss from their matrix [29]. This phenomenon was also obvious in the UHPFRCC specimens. When the 28 days cured specimens (as shown in Fig. 3 (a)) were exposed to 400°C, specimen CB1 (with PP fibre + 0.5% basalt fibre) experienced the highest mass loss (11%) whereas CB2 (with PP fibre + 1% basalt fibre) showed the lowest mass loss value of 6%, which attributes the evaporation of capillary water and gel water. Specimen containing PP fibres only showed a slight more loss in mass as compared to the control specimen same as also experienced by [19]. Alternatively, at the exposure temperature of 700°C, the highest mass loss was indicated equally by two specimens; control and CB1 with the approximate value of 20% and the lowest value was shown by CB3 (with PP fibre + 1.5% basalt fibre) with 18.5% owing to the loss of crystal water from the matrix. Among all exposure temperatures, the highest mass loss (24%) was depicted by the control specimen after being exposed to 1000°C. The best performance was shown by CB1 with the lowest mass loss value of 22% after exposure to 1000°C, which was also the same after 56 days of curing (Fig. 3b). It shows that after 700°C, mass loss for specimens remains constant and is also independent of curing ages. This also explains that the decomposition of hydration products between 700°C to 1000°C has already been accomplished.



Fig. 1 Thermal Data Characterization System (TeDCas)



Fig. 2 Specimen used for Thermal Conductivity Testing

B. Compressive Strength of UHPFRCC Specimen

Compressive strength of specimens at ambient temperature is given in Table IV. The addition of polypropylene fibres to the control mixture caused the significant drop in the compressive strength due to the lower elastic modulus of PP fibres. However, with the addition of basalt fibre the compressive strength was increased because of their high elastic modulus value of 89 GPa [30]. Outcomes of the experiment indicated that compressive strength, of UHPFRCC (74.36 MPa) containing 1.5% of basalt fibres and 1 kg/m³ of PP fibres, was the highest among all specimens, that is 24% greater than the control specimen after 28 days of curing. On the other hand, after 56 days of curing, UHPFRCC containing 1% of basalt fibres + 1 kg/m³ of PP fibres and control specimen were equally better than other specimens bearing 80.5 MPa.

Abovementioned specimens with higher basalt fibre content marked higher strength that might be due to the good bonding of fibres with the cementitious matrix and secondly due to the good dispersion of fibres among the matrix [31]. Overall, the entire specimens endured the increase in compressive strength between 28 and 56 days of curing but control specimen portrayed the highest increase in compressive strength. The increase in compressive strength after longer curing age is corroborated with the slow reactivity of GGBS as reported elsewhere [27].

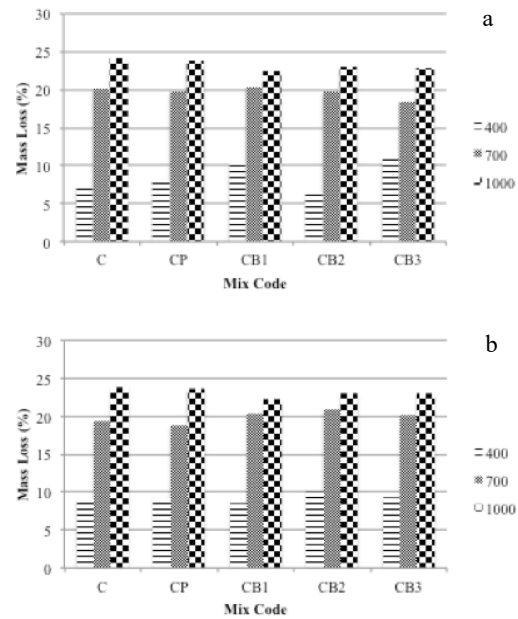


Fig. 3 Mass loss in specimens burnt at elevated temperature a) at 28 days b) at 56 days

Compressive strength of all the specimens relative to the control specimen at each temperature point is graphically shown in Fig. 3. For instance, compressive strength of UHPFRCC- CP (with PP fibres only) exposed to 400°C was comparable with the compressive strength of control sample exposed to 400°C. It was found that after 28 days of curing (as shown in Fig. 4 (a)), exposed to 400°C, CB1 (with PP fibres + 0.5% basalt fibres) bore the highest relative compressive strength i.e. 69.86%. However, at 700°C and 1000°C, CB3 (with PP fibres + 1.5% basalt fibres) attained the higher relative compressive strength value of 10% and 22% respectively, which interprets the positive effect of 1.5% addition of basalt fibres to the matrix as compared to the control specimen at elevated temperature. Instead, after 56 days of curing (as shown in Fig. 3 (b)) relative compressive strength of CB2 (with PP fibres + 1% basalt fibres) was reported the best among all specimens with the value of 97.81% at the exposure of 400°C. At the exposure of 700°C, CB2 (with PP fibres + 1% basalt fibres) was found almost equal to that of CB1 (with PP fibres + 0.5% basalt fibres) with approximately 99% of relative compressive strength whereas at 1000°C, only CB1 maintained the highest relative compressive strength value of 109%.

TABLE IV
COMPRESSIVE STRENGTH OF SPECIMENS AT AMBIENT TEMPERATURE

Mix Code	Compressive Strength (MPa)	
	28 days	56 days
C	60.00	80.41
CP	50.60	54.91
CB1	57.97	71.59
CB2	71.40	80.49
CB3	74.36	76.05

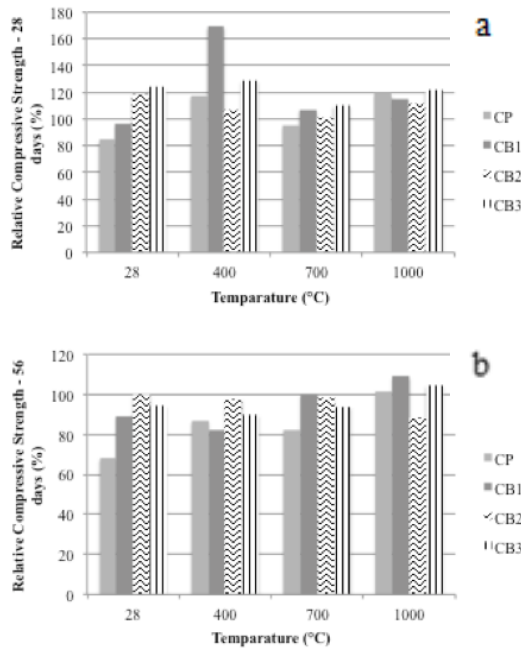


Fig. 3 Relative compressive strength of specimens burnt at elevated temperature a) at 28 days b) at 56 days

C. Flexural Strength of Specimens

In Table V, flexural strength of specimens at ambient temperature is listed. After 28 and 56 days of curing, CB1 (with PP fibres + 0.5% basalt fibres) and CP (with PP fibres only) manifested highest flexural strength, which is substantiated with the zero effect of 0.5% of basalt fibres on PP fibre based UHPFRCC. Alternatively, control specimen indicated the lowest flexural strength that was also obvious in former research study [32].

In order to compare all the specimens with the control sample at each temperature point, relative flexural strength has been computed as graphically shown in Fig. 4. Fig. 4a clearly shows that, CB3 (with PP fibres + 1.5% basalt fibres) signifies the best relative flexural strength of 149% and 167% at 700°C and 1000°C respectively after 28 days of curing. Moreover, CB1 (with PP fibres + 0.5% basalt fibres) bore the significant relative flexural strength value of 177% when exposed to 400°C. Furthermore, after 56 days of curing, CB2 (with PP fibres + 1% basalt fibres) showed the highest relative flexural strength value of 114% and 152% at 700 and 1000 °C. Although at 400 °C, CB3 (with PP fibres + 1.5% basalt fibres) marked the highest relative flexural strength of 141%.

TABLE V
FLEXURAL STRENGTH OF SPECIMENS AT AMBIENT TEMPERATURE

Mix Code	Flexural Strength (MPa)	
	28 days	56 days
C	8.33	7.14
CP	9.31	15.96
CB1	14.27	14.09
CB2	13.77	9.61
CB3	13.67	11.06

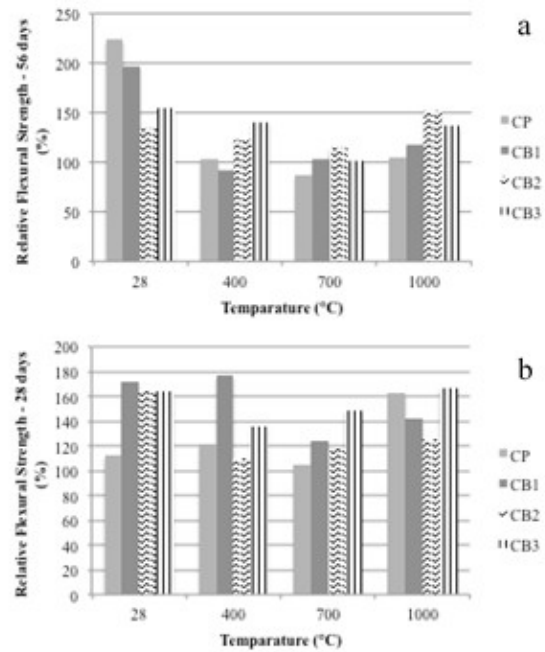


Fig. 4 Relative flexural strength of specimens burnt at elevated temperature a) at 28 days b) at 56 days

D. Residual Compressive Strength

Compressive strength test was performed for both ambient temperature specimens (C_i) and heated specimens (C_f). Formula for calculating residual compressive strength (RCS) for each mix at specific age is given in (1). Experimental results of residual compressive strength are graphically represented in Fig. 5. RCS was calculated using formula given in (1).

Results show that after 28 days of curing, CB1 (with PP fibres + 0.5% basalt fibres) performed the best in the range of 28-700 °C and marked the highest RCS value of 93.34% when exposed to 400 °C and 52.96% at 700 °C (almost equal to UHPFRCC with PP fibre only). However, afterwards there was a significant drop in RCS value of CB1 (with PP fibres + 0.5% basalt fibres) in comparison with CP (with PP fibre only) specimen. Finally, CP depicted the lowest strength drop in the range of 700-1000 °C with the highest RCS value of 41.31% at 1000 °C. This may be due to the melting of PP fibres in the UHPFRCC, which leaves behind the micro-channels to mitigate the vapour tension in the capillaries resulting in the improved residual compressive strength [33]. Overall, the lowest performance was marked by CB2 (with PP fibres + 1% basalt fibres) after both 28 and 56 days of curing.

The quasi-linear decrease in the residual compressive strength, at temperatures higher than 400 °C, might be translated due to the removal of bound water from the specimen. After 56 days of curing, CP possessed highest RCS value in all temperature range as compared to other mix. However, among basalt fibre specimens, CB1 rendered the highest RCS value at both curing ages. The reason behind the poor RCS value of specimens containing more than 0.5% of basalt fibres, could be due to the congestion of fibres, which

blocked the moisture-release path created by PP fibres resulting in a thermal cracking due to pore pressure development.

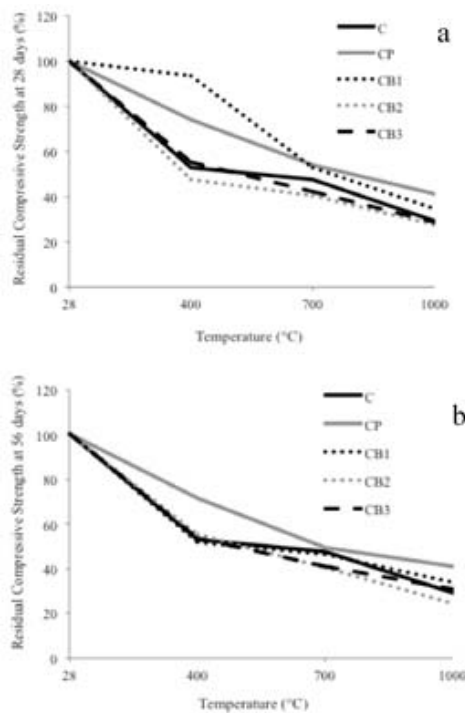


Fig. 5 Residual Compressive Strength of Specimens burnt at elevated temperatures a) at 28 days b) at 56 days

E. Residual Flexural Strength

Residual flexural strength was computed using the flexural strength readings of unheated (F_i) and heated specimens (F_f). Residual Flexural strength (RFS) of specimens was calculated using (2). Laboratory results show that after 28 days of curing (Fig. 6a) CP performed well throughout the elevated temperature exposure as compared to other specimens with 39.08% RFS value at 1000°C. On the other hand, at the exposure of 700°C RFS of control specimen was only 6% better than CP that is almost negligible. The lowest RFS value was marked by CB1 (with PP fibres + 0.5% basalt fibres) and CB2 (with PP fibres + 1% basalt fibres) i.e. approximately 19% less than CP specimen which may be due to the fact that glass transition temperature of basalt fibre was reached around 673°C [34] which made them less effective at elevated temperature beyond 1000°C.

Fig. 6 (b) illustrates the RFS value of specimens after burning to elevated temperature after 56 days of curing. UHPFRC containing 1% of basalt fibres (CB2) ascertained the best RFS value of 49%, which is 18% better than the control sample (C). Best performance of CB2 may affirm that even basalt fibres have reached to their glass transition temperature beyond 673°C [20] resulting in the weakening of the matrix but that feebleness of the matrix may be compensated by the improved reactivity of GGBS after 56

days of curing. Specimen CP performed the least after 56 days of curing unlike 28 days of curing.

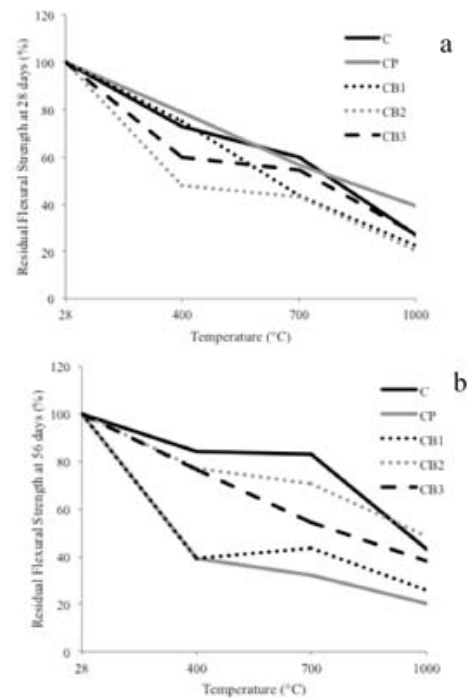


Fig. 6 Residual Flexural Strength of Specimens burnt at elevated temperatures a) at 28 days b) at 56 days

F. Thermal Conductivity

Thermal Conductivity results are shown in Fig. 7. It could be observed that with the addition of 1 kg/m^3 of PP fibres, the thermal conductivity (TC) reduced throughout the exposure at high temperature by 4% as compared to the control specimen (C). One of the probable reasons could be the improved structural stability due to the reinforcement action of PP fibres, which could effectively control the moisture mobility within the matrix, resulting in better hydration and hence better thermal conductivity. Secondly, it could be due to the good bonding between aggregate and binder matrix along with fibres (as shown in Fig. 8 (a)). This could be easily noticed in the ESEM image (as shown in Fig. 8 (b)), where the interfacial transition zone can be spotted without any micro cracks, showing the good bonding of aggregate grain with binder matrix. Actually, the minerals covering the surface of aggregate grains converts into the C-S-H phase making a smooth transition between aggregate and binder matrix.

Due to the limitations of the measuring equipment (TeDcas), thermal conductivity was measured only up to 80°C. In order to find the value of TC up to 900°C, data was extrapolated in accordance with the available thermal conductivity results for cementitious composites. Extrapolated data for the UHPFRC specimen CP is shown in Fig. 9 in comparison with the previously studied [35]–[37] models for concrete. It is noted that the trend of the variation of thermal

conductivity as a function of temperature is almost similar to that of the past models. However, thermal conductivity is much lower as compared to concrete.

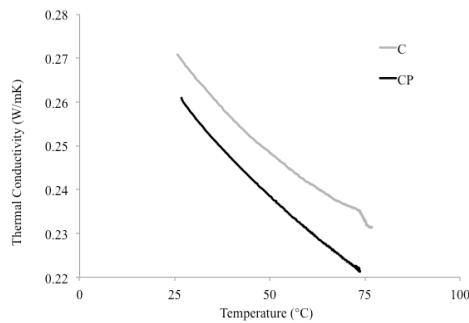


Fig. 7 Thermal Conductivity of UHPFRCC Samples cured for 56 days

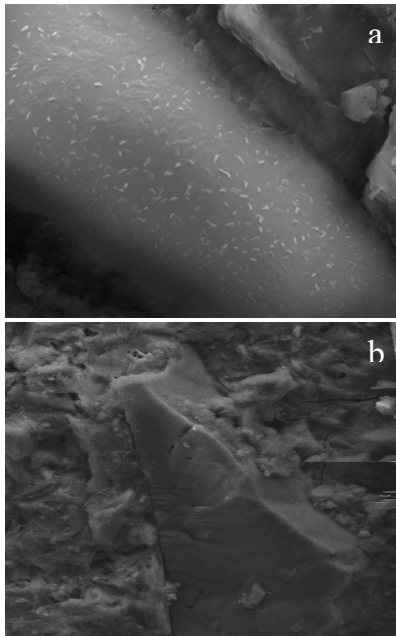


Fig. 8 ESEM Image of UHPFRCC-CP a) Interface between polypropylene fibre and binder b) Interfacial transition zone

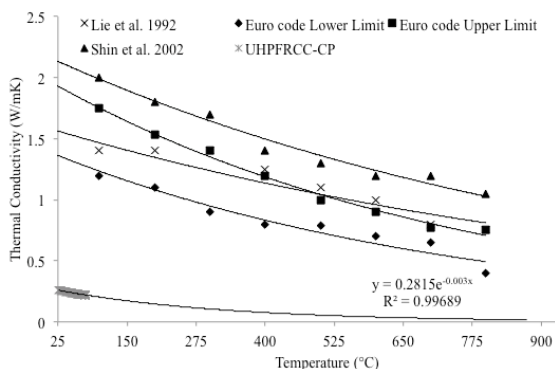


Fig. 9 Extrapolated Model for UHPFRCC-CP showing the Variation in Thermal Conductivity as a Function of Temperature

IV. CONCLUSIONS

Based on the experimental results, following conclusions could be drawn:

1. Mass loss was found to be significant between 400°C and 700°C for all UHPFRCC specimens. However, the lowest mass loss was experienced by the UHPFRCC (CB2) containing hybrid fibres (1 kg/m³ of PP fibres + 1% of basalt fibres).
2. Interestingly, after exposure to 1000°C, the UHPFRCC containing polypropylene fibre (CP) showed the best performance equally after 28 and 56 days of curing i.e. 41% in comparison to those tested at ambient temperature.
3. UHPFRCC cured for 28 days, containing polypropylene fibres (CP) showed the highest flexural strength of 39% after being exposed to 1000°C whereas the UHPFRCC (CB2) with hybrid fibres (1 kg/m³ of PP fibres + 1% of basalt fibres) depicted the premium residual flexural strength of 48.5% after 56 days of curing.
4. Highest ambient temperature compressive strength (74.36 MPa) was marked by the UHPFRCC (CB3) enclosing hybrid fibres (1 kg/m³ of PP fibres + 1.5% of basalt fibres) after 28 days of curing. Nevertheless, beyond 56 days of curing, hybrid-fibre based UHPFRCC- CB1 (1kg/m³ of PP fibres + 0.5% of basalt fibres) illustrated the highest compressive strength i.e. 80 MPa.
5. Optimum ambient temperature flexural strength (14.27 MPa) was marked by UHPFRCC-CB1 with hybrid fibres (1 kg/m³ of PP fibres + 1.5% of basalt fibres) and UHPFRCC- CP (15.96 MPa) containing polypropylene fibres only after 28 and 56 days of curing respectively.
6. Thermal conductivity of polypropylene based UHPFRCC (CP) is much lower as compared to the control specimen as well as the conventional concrete, which proves the UHPFRCC-CP as a potential fireproof coating.

In conclusion, the use of combined HAC/GGBS and inclusion of hybrid fibres (polypropylene+basalt fibres) can produce a UHPFRCC, which bears good mechanical properties as well as improved resistance against thermal load up to 1000°C. Such UHPFRCC is a promising friendly fire protection material for FRP strengthened RC structures.

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