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Influence of Elevated Temperature on Performance of Ultra High Strength Fiber Reinforced Self Compacting Concrete (UHSFRSCC) Produced from Local Materials

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Abstract : Exposure of concrete structures to elevated temperatures extremely affects its durability and service life. Therefore, evaluating the concrete performance after being exposed to high temperatures is very essential. This study investigates the effect of elevated temperatures (25 ℃, 200 ℃, and 300 ℃) in the furnace with a heating time of 1 h on residual mechanical, transport and microstructure properties of different UHSFRSCC concrete. This study presents a systematic experimental investigation to evaluate the effect of Silica fume (SF) (partially replaced by 20% cement), blended 5% Metakaolin (MK) with 15%SF (partially replaced by cement)and, Limestone (LS) Powder (partially replaced by 20% cement), and Quartz Powder (QP) (partially replaced by 34% sand) on fresh characteristics, the mechanical (compressive and splitting tensile strength), transport properties (sorptivity) and microstructure (SEM-EDS) properties of UHSFRSCC. The results reveal that, incorporating QP to UHSFRSCChas not significant effect on its rheological classes (flowability, viscosity and passing ability) while MK significantly decrease it.The mix containing 20%SF has a compressive, splitting tensile strength of 120.7 MPa and 13.6 MPa respectively after 28 days water curing .Moreover, incorporating 20%LS as cement replacement and replacing 5% MK by SF to mixture contained 34% QP as sand replacement improves compressive, splitting tensile strength and sorptivity by 9.6, 16.9 and 40.7% respectively under normal ambient temperature. Although relative residual compressive, splitting tensile strengths, transport and microstructure properties were gradually degraded by exposure to elevated temperature up to 300℃, relative residualstrengths, transport and microstructure properties of UHSFRSCC were significantly increased with incorporating compound LS and/or MK powders as a cement replacement material.Incorporating compound 20%LS and 5%MK increases residual compressive strength by 10% and 19%while, residual splitting tensile strength significantly increases by 21% and 28% after exposure to elevated temperatures 200℃ and 300℃ respectively. Furthermore, residual sorptivity decreases by 39% after exposure to elevated temperatures. Microstructure results explain and consistent with compressive, splitting tensile strengths and transport properties.

Keywords: UHSFRSCC - Elevated Temperature – Basalt Fiber -Sorptivity -SEM

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1. INTRODUCTION

The global demand towards the development of the construction industry has increased by improving different types of applicable concrete or by using natural materials to produce a solution to the recent challenges facing engineering developers, so some studies are producing Self-Compacted Concrete (SCC) as the latest improvement the filling ability in narrow spaces and shortening construction time with high workability, thus reducing cost [1].However, the rapid increase in civil engineering has produced another new generation of cement materials as a type of concrete with superior properties; the strength, durability, ductility and fine structure defined as UHPC is a ultra-high performance concrete that can withstand harsh environments and has a wide role in retrofitting and building bridges around the world, moreover, the excellent performance in earthquake resistance and blast resistance these applications are increasing in recent years[2-4].Self-compacting concrete (SCC) is classified with a dense microstructure due to fine aggregate with the same characteristic as UHPC as packing theory is the main concept [5,6].While, their methods of preparation conditions are different because SCC reduces labor requirements, has passing ability and packing ability, elimination of vibration process and excellent workability with high strength and heavy concrete[7, 8]UHPC requires special processing and mixing technology with steam[9-12]. Pozzolanic materials as silica fume and metakaolin have a significant effect on the fresh, mechanical properties and durability of self-compacted concrete and high-performance concrete[13-16]. Natural and synthetic fibers have applications in all types of concrete especially SCC. Fiber glass, polypropylene and steel fiber content, reinforced

orientation, effect on strength and bonding properties of SCC [17-21]. Fillers are used as glass powder, crushed quartz powder, and rice husk ash in UHPC[22-25]. The inert and pozzolanic additions are commonly used to improve and maintain the cohesion and segregation resistance of SCC. These additions will also regulate the cement content in order to reduce the heat of hydration and thermal shrinkage.Human safety in the event of a fire is a consideration in the design of residential, public and industrial buildings. Concrete has a good service record in this regard [26]. Sudden exposure to high temperatures severely modifies the behavior of concrete. To increase the level of safety of concrete structures in the event of a fire, the design calculation should take into account thermomechanical properties taking into account the temperature. Moreover, a lot of research has shown that concrete can pose a risk of thermal instability with rapid increases in temperature. This phenomenon is usually called spalling. Moreover, high-strength concrete appears to have an increased susceptibility to instability[27]. The low porosity of UHP may lead to failure by explosive at high temperatures. The use of steel and polypropylene fibers has been shown to reduce spalling at high temperatures. Heating causes various changes in its properties, in particular, changes in the microstructure accompanied by a loss of mechanical strength. Polypropylene fibers have a melting point at about 170 ° C. When the concrete heats up past this point, the fibers dissolve and diffuse into the surrounding matrix [28].Low density concrete, accumulated pressure is generally not the case severe due to the high pore size in the concrete [29]. UHPC is manufactured using fine aggregates, high amounts of cement, silica fume, and quartz powder. Workability properties are achieved through improved "granular packing" and the use of high-range additives to reduce water the fibers increase the ductility and mechanical strength of the concrete, reduce its plastic shrinkage, and increase its resistance to impact at room temperature [30].Basalt fiber is a relatively new type of inorganic fiber that is produced by environmentally friendly smelting process of volcanic rocks in a non-hazardous manner with less energy consumption in a production method similar to glass fibers, so it is less expensive than carbon fiber and fiberglass, so its effect on the properties of concrete such as compression, tensile, flexure, inter-bonding, thermal conductivity, dry and wet conditions and microstructure were finally examined in the case of lightweight concrete, geopolymer concrete, high-strength concrete, self-consolidating concrete, fiber-reinforced concrete, concrete combining nanomaterials and high-performance concrete [31-37].Development of Ultra High Strength Basalt Fiber Self Compacted Concrete (UHSBFSCC) with higher content of waste powder as active and/or inert is challenge. Furthermore, the influence of these compound powders on residual properties of UHSBFSCC exposed to elevated temperature need to be investigated. Therefore, **the main objective** of this research is to develop self-compacted concrete ultra-high strength basalt fibers concrete using local materials such as quartz powder (QP) as sand replacement, lime stone (LS) and/or silica fume (SF) and metakaolin (MK) as a cement replacement. Therefore, six mixtures were performed. Fresh and Mechanical properties, including compressive strength and splitting tensile strength, sorptivity tests for all design mixtures were investigated. The effect of exposure to elevated temperature up to 300 ℃ on residual mechanical, sorptivity and microstructure properties of designed UHSBFRSCC were also investigated. Finally, the microstructure analysis was performed to interpret all these experimental results.

2. Experimental Program

2.1. Raw Materials

The four types of binder (supplementary cementitious materials, SCMs) used in this study namely cement, SF, MK and LSwere locally provided. CEM I (52.5)was purchased from MisrBeniSuef Co. SF with silica content equal 96% according to ASTM C1240-15 was provided by Sika Co. MK and LS were brought from local market, MK was brought from Asfour CO. and LS was providing from mills limestone in Egypt. All binder characteristics are listed in **Table 1**. Both SF and MK are used as a pozzolanic cement replacement material (Type II)while, LS powder is considered as inert cement replacement material (Type I) according to European SCC Guidelines 2005 [38].Quartz powder (QP) was used as a fillers material to partially replace sand to optimize the packing density of UHSFTSCC and hence reduces the paste volume. Quartz powder was produced from grinding pure sand with high SiO_2 content from Suez Companyfor minerals. Particle size distribution of the used Powders is illustrated in **Figure 1.** Fraction Retained on 45μm sieve less 1% and moisture less than 0.5%. To achieve SCC requirements a Master Glenium C 315 superplasticizer provided by BASF Co. was used as a high range water reducer admixture according to ASTM C 494 type G. with a specific gravity of 1.08. Two sizes of coarse basalt aggregate were used in this study. Size1 passing from sieve 10 mm and retained on 4.75 mm while, Size2 passing from 4.75 mm and retained on 2.36 mm. The coarse aggregate mixture contains 70% Size1:30% Size2. The aggregate used in saturated surface-dry (SSD) condition with the water absorption, specific gravity, and

maximum grain size of 1.71%, 2.7, and 10 mm, respectively. Natural sand with the water absorption, specific gravity, and maximum grain size of 0.65%, 2.81, and 2.36 mm, respectively was used.The grading of the used fine and coarse aggregate is presented in **Figure 1**. The chopped Basalt Fibers (BF) shown in **Figure 2**was provided by the HaininAnjie Composite Materials Co. The physical properties of BFwere shown in **Table 2**were supplied by the manufacturer. Tap water was used in the mixing and curing process.

Table 2 Characteristics of the used Basalt Fiber

Properties	Value
Tensile stress	2.8 GPa
Modulus of Elasticity	86 GPa
density	2.7 t/m^3
Elongation	3.15%
Diameter	16+0.2 µm
Length	24 mm

Figure 2 Basalt Fiber with Length 24 mm

2.2. Concrete Mix Design

The experimental program was built based on reference mixes identified from a series of trials by the authors to produce a mix design according to European SCC Guidelines 2005[38] with a combination of ultrahigh compressive strength and specifies fresh SCC characteristics. **Table 3** shows 6 Mixes designed to have UHSBFSCC of concrete grade (110-135) MPa. All these concrete mixes have the same binder content of 1100 kg/m^3 and contain basalt as a coarse aggregate and basalt fiber with content 540 and 8.1 kg/m^3 (0.3% by volume) respectively.

Table 1 Chemical composition and Physical properties for the used SCM materials

Compound (%)	C	SF	MK, %	LS	QP
SiO_2	21.20	96.0	55	3.61	99.20
AL_2O_3	5.50	0.10	42.7	0.33	0.35
Fe_2O_3	3.20	1.0	1.40	0.18	0.04
CaO	63.4	0.20	0.30	53.26	0.15
MgO	0.70	0.15	0.30	0.85	0.02
SO_3	2.40	0.10	0.01	0.050	---
Na_2O	0.10	0.10	0.30	0.02	0.01
K_2O	0.50	0.20	0.0	0.36	0.01
loss on ignition	3.00	2.15	0.90	41.34	0.2
Color Powder	Gray	Light Gray	Light Beige	white	white
Grain Size	90 µm	1 µm	0.50 µm	20 µm	45 µm
Specific Gravity	3.15	2.15	2.5	2.65	2.70
Bulk Density (t/m^3)	1.51	0.355	1.2	1.0	1.28

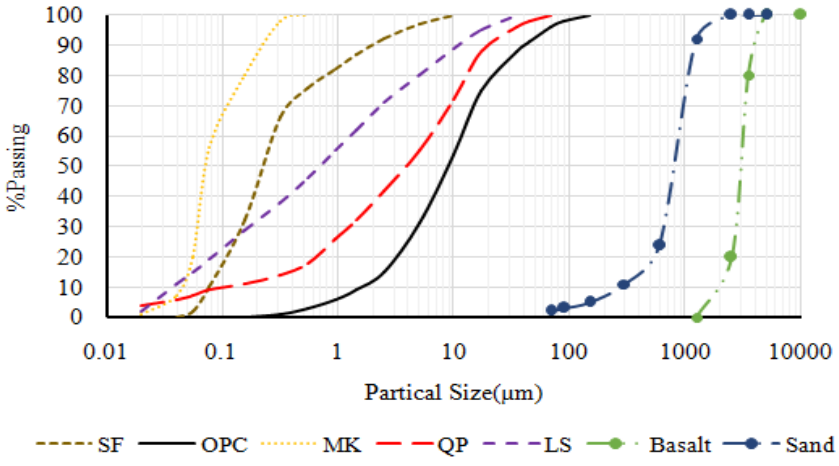

Fig1 Particle Size Distribution of used Powders

The six mixes are divided into 3 groups. Each group includes two mixes. In the first group (G1) only sand (S) is used as a fine aggregate and the cement was replaced by 20% active powder (SF and or MK). The first mix (M1) incorporates 22% SF as cement replacement while mix M2 contains 11%SF +11%MK. In second group (G2) the sand is replaced by 34% QP and cement is replaced by the same replacement ratio as in the mixes in G1. In the third group (G3), the sand was replaced by 34%QP and furthermore cement is replaced by 20%LS (total cement

replacement ratio 42%). The Water/ binder was kept constant as 0.182 (water content 200 kg/m^3), the ratio of fine/total aggregate equal 0.52 (between 0.48 and 0.55 according to European SCC Guidelines 2005) and quantity of SP (rang 3.5-4.1 % by weight of binder) was added to satisfy workability requirements according to European SCC Guidelines 2005 [38]. The mix codes, shown in Table 3 are based on a) Group number, b) Silica fume content, c) Metakaolin content. Example, G1S15M5: G1 represents concrete mixes group that containing only sand, while S15M5 represent concrete mix containing 15% SF (S15) and 5%MK (M5) as a SCM.

Table 3 Concrete Mixes (Kg/m^3)

M#	Group	Code	C	SF	M	LS	CA	FA	QP	SP	BF	PV%
M1	G1 S	S20M0	880	220	0	0	540	590	0	40	8.1	0.56
M2		S15M5	880	165	55	0	540	590	0	42	8.1	0.56
M3	G2 QP	S20M0	880	220	0	0	540	390	200	40	8.1	0.56
M4		S15M5	880	165	55	0	540	390	200	42	8.1	0.56
M5	G3 QP+LS	S20M0	660	220	0	220	540	390	200	41	8.1	0.57
M6		S15M5	660	165	55	220	540	390	200	43	8.1	0.56

M#=Mix number, C=Cement, LS=Limestone, SF=Silica Fume, M=Metakaolin, CA= Basalt Coarse Aggregate, FA=Fine Aggregate, QP=Quartz Powder, W=Water, SP=Superplasticizer, BF= Basalt fiber, PV= Paste volume, G1=group containing S (sand), G2=group containing QP as sand replacement and G3=group containing both QP as sand replacement and LS as cement replacement.

2.3. Mixing, Casting and curing Processes

The mixing process was performed using a pan concrete mixer of 10 liters capacity. The mixture components weighted carefully then, the sol component (Basalt, sand and cement) mixed to obtain homogenous mix. Pozzolanic material (SF, MK, LS) and basalt fibers were added to the mix. The water and the super plasticizer mixed then added to the dry contents in the drum then mixed till the mixture is in suitable consistency to be cast (time of mixing differ from mix to the other according to mixtures components). For each of the concrete mixtures, cubic specimens (100 mm) and cylindrical specimens (diameter 100 mm, height 200 mm) were cast. Each mold was filled with concrete in three layers and each layer was lightly vibrated to remove air voids. After finishing the concrete surface specimens were covered by plastic sheets to preventwater evaporation .After 48 hours the specimens were demoded and cured in controlled hot water (75^{o}C± 2 ^{o}C) for 3 days to accelerate rate of strength gained [39].Then the specimens were left in the water tank at 25^{o}C± 2 ^{o}C for 25 days until the age of testing, where all of mixes were test at age 28 day.

2.4. Furnace and Heating Rate

After 28 days water curing, the specimens were removed from the tank and dried in an oven for two days at a temperature of 105 °C before subjecting them to higher elevated temperature in an electric muffle furnace to reduce their moisture content by evaporation to lower degree and hence minimize the possibility of early explosive spelling of specimens when exposed to elevated temperatures in the furnace. For exposures to elevated temperatures, electric furnace was used to elevate the temperature at a heating rate of 5 °C/minute. To ensure homogeneous heating environment around the specimens, a distance of about 20mm was kept between specimens as shown in **Figure 3.**Elevated temperatures of 200°C, 300°C were considered as a fire condition for concrete. These temperatures were selected based on several trials to avoid explosive spelling of specimens inside the furnace and also based on temperature of the fire flames in open ultra-high strength concrete structure member in the range of 320–400 °C beside according to previous investigations[40-42]. Once the required temperature was reached, the samples were kept at this temperature for 1 hour to ensure a uniform the rmal environment around the specimens. It was estimated, according to test results in a previous investigation [42]. At the end of each exposure period, the power was turned off and the specimens were allowed slowly cooled inside the furnace while keeping the furnace door closed to prevent possible effects of large thermal gradient on the specimens. The exposure temperature–duration relationship was established as depicted in **Figure 4**. All tests carried out after high temperature exposure were performed after the temperature of specimens had returned to ambient temperature.

Fig3 Specimens inside the furnace

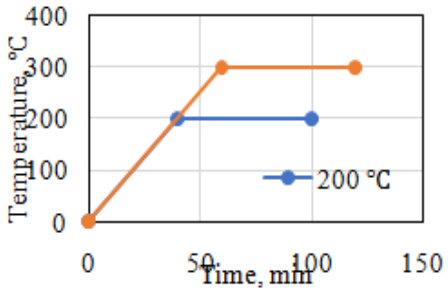

Fig4 Heating and Cooling Rate

2.5. Testing Properties and Procedures

i.Fresh characteristics

In this study three characteristics (flowability, viscosity and passing ability) of the fresh concrete are evaluated. European SCC Guidelines 2005 [38], these characteristics assess by using slump flow, V-funnel, and L-box apparatus. Slump flow test was used as a preliminary test to describe the flowability characteristics of SCC. The diameter of the fresh SCC was measured in two directions and the average diameter was recorded as slump flow diameter (Sf). Passing ability of fresh concrete was estimated using L-box test where the fresh SCC in the vertical box was allowed to flow through the bars to the horizontal box. When the mixture flow stopped, the aspect ratio (h2/h1) (PA ratio) was determined to evaluate the passing ability of SCC. V-funnel flow test used to describe the indirect viscosity characteristic of the SCC mixtures based on the flowing rate. The time measured in the V-funnel flow test is the elapsed time between the beginning and end of flowing of SCC from the funnel (T_v).

ii.Mechanical Properties

Compressive strength test was performed on 3 cubes of 10*10*10 $cm^3$for each concrete mix according to ASTM C109[43]using ELE digital testing machine of 2000 ton maximum capacity, the specimens were tested at 28 days. Splitting tensile strength was examined on 3 cylindrical specimens of 100mm diameter and 200mm height for each concrete mix according to ASTM C494/C495M[44].

iii.Sorptivity

Water absorption by capillary (sorptivity) test was performed on 50 mm slice taken from prepared cylindrical specimens of 100 mm diameter and 200 mm height according to ASTM C1585[45].To achieve a nearly constant mass the specimens were dried in an oven for three days at a temperature of 50 °Cthen sealed in bags for minimum 15 days. The test was performed before and after exposure to elevated temperature (200-300 °C). After exposure to predetermined elevated temperature, the specimens were cooled down to room temperature and weighted .Then the samples were coated with paraffin wax around side surfaces except the base to prevent any water from reaching the specimens. The constant head of 2-3 mm over the bottom of the specimen for its simple absorption by capillary action .Mass change after testing time of one hour was measured and sorptivity is calculated as the follow:

$I=A*St^{0.5}$ ……. (1)Where;

I, represents the change in weight before and after testing in grams

A, represents the exposed area of the specimens in mm^2area (7854 mm^2)

S, represents the sorptivity in $gm/mm^2/sec^{1/2}$

t, is the testing time, measured in second (3600 sec).

iv.Microstructural Properties

The microstructural properties were established only on selected specimens at 28 days. The Scanning Electron Microscope (SEM) was used to observe the transition zone between paste and aggregate. The Energy-dispersive X-ray spectroscopy (EDS) analysis was also utilized to determine the chemical components of the paste in the transition zone.

3. Results and Discussions

3.1 Fresh Properties of UHSBFSCC

Table 4 illustrates the fresh propertiesfor all designed concrete.Notably, as shown in Table 3the amount of superplasticizer added for each concrete mix slightly increases with increasing the amount of active and inert powders (MK, LS and QP) to achieve SCC workability requirement according European SCC Guidelines 2005 [38].As can be seen (from mixes in G1 and G2)for the same binder type and content, flowability and passing ability in terms of decrease in slump flow diameter, increase in time in V-funnel and decrease in h2/h1 ratio in L-box of UHSBFSCC gradually decreased with incorporating QP as a sand replacement. However,

rheological classes are not affected due to their practically wide limits. Moreover, for the mixes in each group MK inclusion as a partial replacement of SF results in lower slump-flow values, higher V-funnel flow times and lower L-box ratios than in the reference SF concrete.The significant higher reduction in rheological properties due to MK inclusion is reflected on rheological classes.On contrary, with an inclusion of limestone powder (LS) as a partial replacement of cement (the difference in fresh characteristic between mixes in G2 and G3), the flowability slightly improves.As shown in **Table 4** flowability of mix S20M0 in group G3 which contains 20% SFas active powders and 20%LS as inert powder(790 mm) is higher than mix S20M0 in group G2which contains only 20% SF(770 mm). However, the flowability class is not changed. This effect may be due to the higher percentage of the added super plasticizer. Therefore, LS incorporation has not a significant negative effect on fresh properties of UHSBFSCC. This agree with the results obtained in [46].On the other hand, comparing the rheological characteristics of the mixtures containing MK in G2 and G3 reveals that not only MK inclusion significantly decreases the flowability but also decline its classes. This effect can be attributed to the higher specific surface area of MK compared to SF, as well as the irregular or plate like shape of MK particles are considered to be the two main factors for the loss of both flowability and passing ability and the increase in viscosity [47]. Obviously, the greatest improvement in rheological characteristics occurs in mix (G3S20M0) due to the presence of LS and absence of MK. While the worst rheological characteristics recorded in mixture (G2S15M5) which contains 5%MK as active powder and 34%QP as inert powder .This effect could be attributed to the higher water demand due to the decreased particles size and the increased specific surface area of both MK compared to (SF) and QP compared to (sand). A similar effect has been reported in previous literature [48].

Table 4 The fresh properties for all designed UHSBFSCC.

M#	Group	Mix code	Flowability		viscosity		Passing ability	
			Slump flow (Sf),		V-funnel (Tv), sec		L-Box (h2/h1)	
M1	G1S	S20M0	780	SF3	7	VF2	0.97	PA2
M2		S15M5	750	SF2	9	VF2	0.95	PA2
M3	G2QP	S20M0	770	SF3	8	VF2	0.9	PA2
M4		S15M5	730	SF2	11	VF2	0.85	PA2
M5	G3QP+ LS	S20M0	790	SF3	7	VF1	0.95	PA2
M6		S15M5	760	SF3	10	VF2	0.9	PA2
According to FNARC [36]			550-850		8-25		≥ 0.8	
Classes			SF1	550-650	VF1	<8	PA1	with 2
			SF2	660-750	VF2	8-25	PA2	with 3
			SF3	760-800				

3.2 Hardened Properties of UHSBFSCC

Mechanical properties in terms of compressive and splitting tensile strength, durability related properties and microstructure properties were determined for all designed concrete at normal ambient temperature (25 ±2 ºC) as well as after exposure to temperature 200 and 300ºC.

3.2.1 Compressive strength (CS)

Figures. 5, and 6 show the compressive and splitting tensile strengths for all designed UHSBFSCC at ambient temperature 25 °C and specified elevated temperatures 200 and 300 °C. As expected, all specimens showed non-explosive failure .At ambient temperature 25 °C clearly noticed in each group that replacing SF by 5%MKhas compressive strength higher than replacing SF by 0%MK respectively in the same group. However, the percent of strength improvement is less than 4.1%. This observation is in agreement with the results found in previous studies [49,50]. Moreover, the mixtures having QP and /or LS powder possess higher CS, irrespective of the presence of active powder (MK or SF). The mixtures in G3 have higher compressive strength than corresponding mixtures in G1 and G2 respectively. Comparing mixture in G2 and G3 indicates that LS inclusion has better contribution to CS of UHSBFSCC and the percent of improvement reaches 7%.While, on comparing mixtures in G1 and G2 clears that replacing 34% sand with QP somewhat increase CS by 3%. It is

well known that the improved mechanical and durability properties of concrete containing fine powder (QP and LS) could be attributed to the its pore-filling effect resulting densified and more compacted microstructure [46, 47, 51].Obviously, CS for G1, G2 and G3 concrete groups was ranged from 115.8-124.4 MPa, from 121.3-128.3 MPa and from 124.2-132.3 MPa, respectively. The concrete containing (5%MK+15%SF+20LS) as a cement replacement beside 34%QP as a sand replacement has the greatest CS (132.3 MPa). While the mixtureS20M0 in G1 has the least CS (117.04 MPa).The enhanced CS of MK blended UHSBFSCC is mainly due to quick pozzolanic reaction of MK with calcium hydroxide, the acceleration of OPC hydration as well as its higher micro-filler effect due to its high surface area[52].**Figures. 5 and 6**,indicate that the studied mechanical properties for all designed concrete generally decrease with increasing elevated temperatures. However, the degree of strength degradation depends on the type and amount of the used active and/or inert powder as well as on the degree of exposure temperature. The change in the relative compressive strength (RCS) which is the ratios of CS after a particular exposure temperature, $(f'_c)_T$, to that of control specimens, $(f'_c)_{25}$for all mixtures is gently decreased(0.9-0.99) at 200 °C and (0.84-0.97) at 300°C.

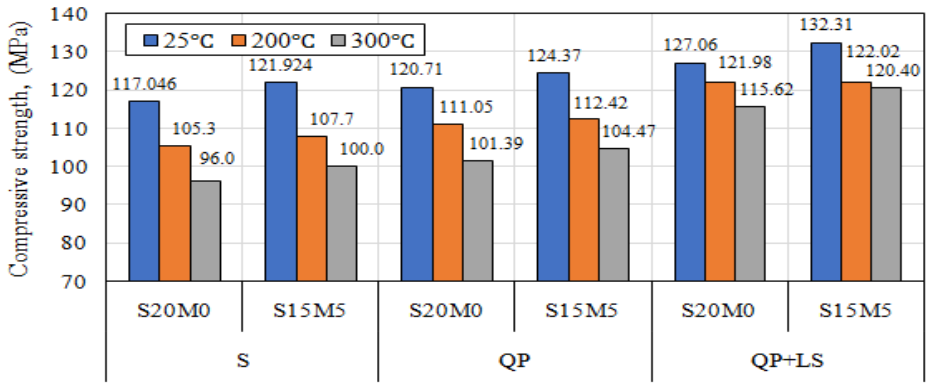

Fig 5. Compressive Strength of UHSBFSCC before and after exposure to elevated temperatures.

This could attribute their results to the densified microstructure of the matrix by formation of more secondary CSH and CSAH gels as a result to enhancing hydration process as well as enhancing pozzolanic reaction of SCM due to effective curing process from pore vapor pressure generated at elevated temperature[53-54]. It is clearly observed that the RCS enhance with incorporating QP and LS as well as with increasing MK content. LS addition improves RCS by 1.2-4.2% and 6.0-7.7% after exposure to 200 and 300 °C respectively. RCS improvement due to LS decreases in mixes containing MK. While QP addition slightly improves RCS by 1.0-2.1% and 3.3-4.2% after exposure to 200 and 300 °C respectively. On contrary, incorporating 5% MK decreases RCS by percentage reaches 3.9% after exposure to 200°C while, has no effect after exposure to 300°C.

3.2.3 Splitting tensile strength

The tensile strength(STS) is very crucial for elevated temperature studies. It prevents spalling and cracking of concrete by resisting thermal stresses which were produced due to internal vapor pressures at high temperature (300°C-500°C) [55].**Figure 6** shows STSfor all studied concrete mixtures at ambient temperature 25 °C and specified elevated temperatures 200 and 300 °C.It is clearly notes that STS follows similar CS trend for control specimens containing different active and inert powder.STS decreases with increasing elevated temperature for all studied concretes up to 300°C.

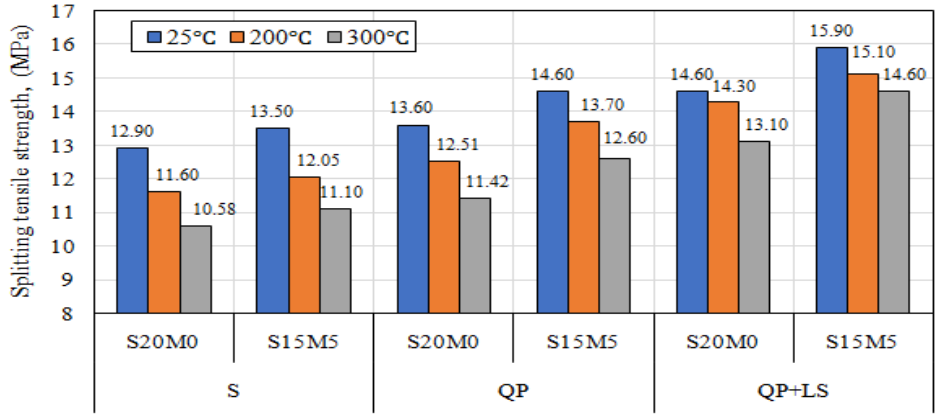

Figure 6. Splitting Tensile Strength of UHSBFSCC before and after exposure to elevated temperatures.

According to **Figure 6**inclusion of 5%MK and/or 20%LS enhances STS. However, the percent of improvement increases with increasing elevated temperature. 5%MK addition improves residual STS by 9, 10, and 11.5% while, LS improves it by 7-11%, 11-16.5% and 14.7-17.2% for specimens subjected to 25, 200 and 300°C respectively.Relative splitting tensile strength (RSTS) for all designed concretes after a particular exposure temperature shows gradual increase with incorporating QP, MK and LS powders. While decreases with increasing elevated temperature. RSTS significantly decreased at temperature beyond 200°C. However, the amount of reduction decreases with incorporating both MK and LS powder. This could be attributed to the improved microstructure of interfacial transition zone (ITZ) around both aggregate particle as well as the fiber due to the higher pozzolanic activity of MK. RSTS loss reaches 8 for samples containing 5 %MK at 300°C elevated temperature.

3.2.4Sorptivity

Exposure of concrete to elevated temperatures help the development of microcracks and pores. These developed pores and micro cracks have a major impact on durability properties like sorptivity. To determine the internal properties of UHSBFSCC at different exposure temperature water sorptivitytest was assessed. **Figure7**, shows results of sorptivity for designed concrete at different elevated temperatures. It can be noted that sorptivity increased with increasing temperature. This expresses the formation of surface microcracks due to thermal expansion resulted from elevated temperature. These microcracks allow water to penetrate inside the body of concrete increasing sorptivity.

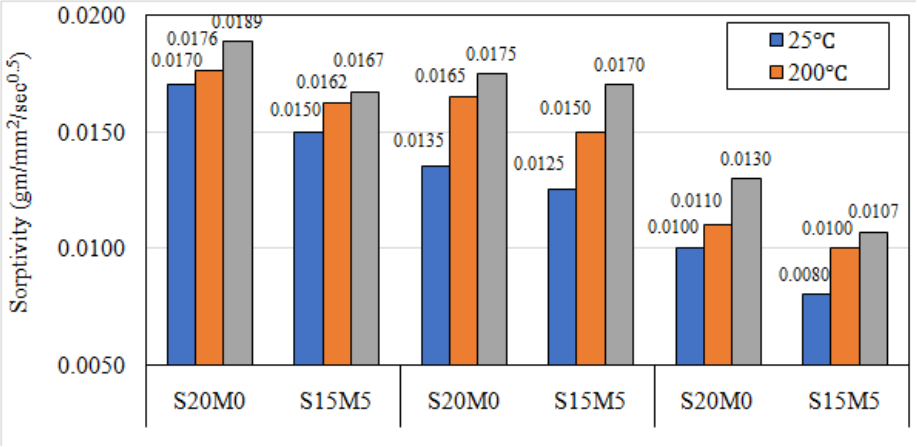

Fig 7 Sorptivity of UHSFRSCC before and after exposure to elevated temperatures

On contrary, sorptivity decreases with incorporating QP and LS powder. This could be attributed to the physical micro filler effect of these fine powder to fill pores between cement grains. Moreover, sorptivity decreases significantly with 5%MK inclusion. This may be attributed to the higher pozzolanic activity of MK resulting formation of more gels that fill micropores in the matrix. Sorptivity decreases by 26% and 17% with LS and QP incorporation to SF concrete respectively. Furthermore, replacing 5%MK decreases sorptivity by 20%.

On the other hand, after exposure to elevated temperature it is clearly observed that sorptivity declines by 33% and 26% with LS inclusion and by 19% and 13% with QP addition after exposure to 200°C and 300°C respectively. While incorporating 5%MK decreases sorptivity by 9% and 18% after exposure to 200°C and 300°C respectively. It is clear that,the combined powder decreases sorptivity and consequently improve durability of concrete subjected to different elevated temperature up to 300°C. Mixture G3S15M5 possesses the maximum reduction in sorptivity at different exposure temperatures.

3.2.5 Microstructure

The SEM images of selected samples (M3,M4in G2 and M5, M6 in G3) of designed UHSBFSCC with

different powders at temperatures 25°Cand300 °Care shown in **Figures. 8–9**.It is clear from **Figure8-a**,the concrete containing only SF at 25°Cthe presence of some cracks in bulk matrix and basalt fiber crosses this crack without breaking the fiber. The presence of cracks causes decrease in strength and increase the transport properties of SF concrete compared with other mixtures. These cracks could be attributed to thermal expansion and drying shrinkage as a results of higher cement content (880 kg/m^3).The number of these microcracks increases

with increasing thermal expansion due to high elevated temperature (300 ℃) as shown in **Figure8-b** and this effect consequently reflected on degradation in strength and transport properties. On the other hand, and for specimen containing 5%MK combined with 15%SFthe number of cracks at 25°C and 300 °Care less than SF concrete as shown in **Figure 8-c, d**. This could be attributed to high reactivity of MK than SF. Which leads to formation of high amount of CSH and CAH, which enhance the strength and transport properties.This observation is confirmed through EDS analysis where, Si/Ca ratio of concrete incorporating combined (5%MK+15%SF) has shown higher value compared to SF concrete at 25°C and 300 °C. Hence increased CS was observed at these temperatures.

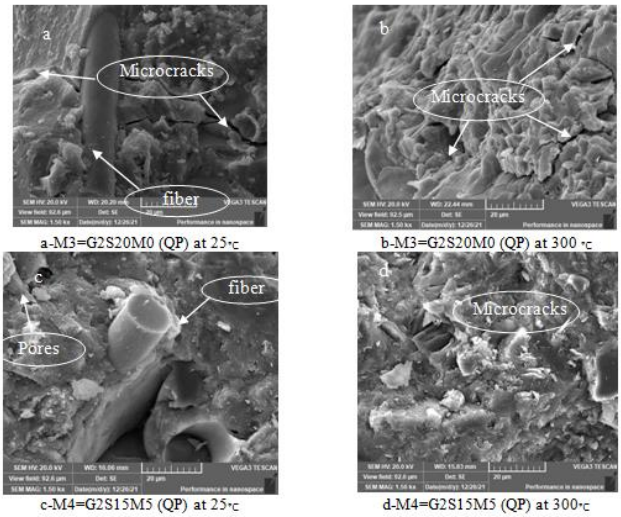

Fig8. SEM for samples M3 and M4 at both 25 °C and 300 °C

SEM images of concrete specimens containing LS, QP as inert powders beside SF and/or MK are shown in **Figure9 (a-d)** at both25 °C and 300 °C temperatures. Obviously, specimens incorporating LS powdershow dense microstructure with limited number of microcracks. This may be the reason for higher residual strength and transport properties.Moreover,SEM images for SF concrete specimen shows light higher number of microcracks than that incorporating combined SF/MK.EDS analysis reveal that Si/Ca ratio for concrete incorporating MK is higher than SF concrete. This led to densifying the microstructure of SF/MKspecimens than SF one. The enhanced microstructure consistent with strength and transport properties results.On the other hand, microstructure has been deteriorated at elevated temperature continuously, led to reduction in CS.The specimens containing combined SF/MK show less microcracks than that incorporating SF only.This complies with strength and transport properties and clarify the role of MK in concrete resistance to elevated temperature exposure.

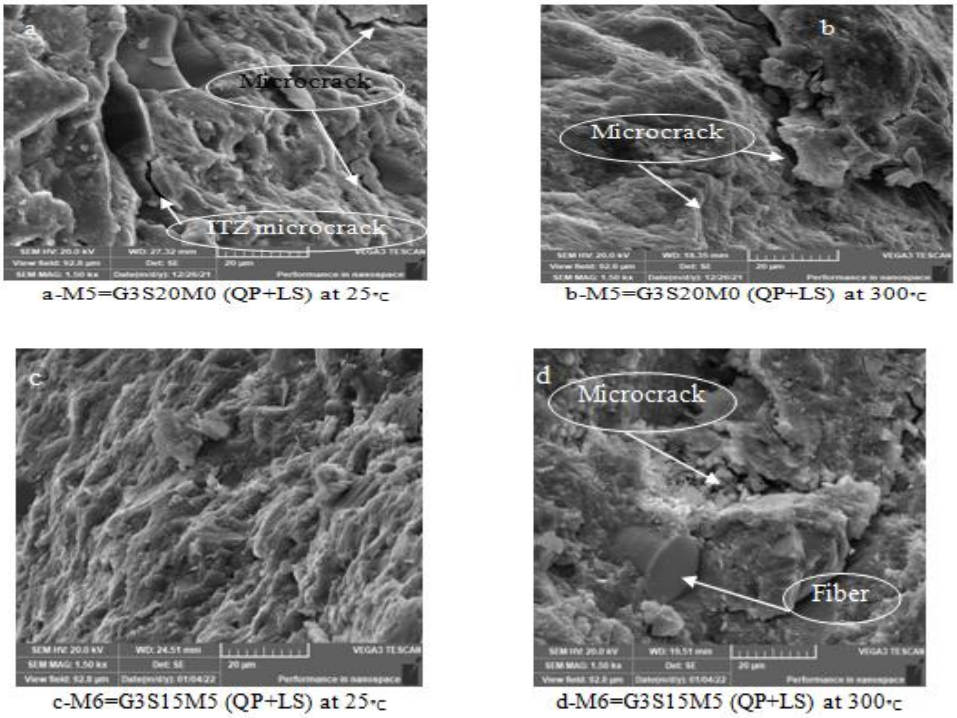

Fig9. SEM for samples M5 and M6 at both 25 °C and 300 °C

Conclusions

This experimental study investigates the influence of incorporating compounded active powder (SF and MK) and/or inert powder (QP and LS) onresidual properties of Ultra-High Strength Basalt Fiber Reinforced Self Compacting Concrete (UHSBFSCC) exposed to elevated temperatures up to 300 °C. Based on the obtained experimental results and analysis, the following conclusions can be drawn:

1- Based on local available powders with appropriate content, superplasticizer and Basalt fiber, it is possible to produced Ultra-High Strength Basalt Fiber Reinforced Self Compacting Concrete (UHSBFSCC).
2- Incorporating 20%LS as a partially cement replacement and/or 34%QP as a partially sand replacement to UHSFRSCC has nosignificant effect on its rheological classes (flowability, viscosity and passing ability) while, MK significantly decrease it.
3- Under normal ambient temperature, using powders separately does not significantly improve the mechanical, transport and microstructure properties of UHSBFSCC.However, the compound powders significantly enhances this.
4- Incorporating compound 20%LS and 5% MK to SF mixture contained 34% QP leads to improve compressive, splitting tensile strength and sorpativity by 9.6, 16.9 and 40.7%respectively under normal ambient temperature. Microstructure results confirms this.
5- Compressive,splitting tensile strengths, transport and microstructure properties were gradually degraded without explosive failure by exposure to elevated temperature up to 300℃.
6- Incorporating QP or MK slightly effect on residual strength and transport properties.
7- Incorporating compound 20%LS and 5%MK increases residual compressive and splitting tensile strengths by 10%, 19% and 21%, 28% while, decreases residual sorptivity by 38%,31% after exposure to elevated temperatures of 200℃ and 300℃ respectively.

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