EXAMINING THE STRENGTH OF LIGHTWEIGHT AGREGGATE FOAMED CONCRETE EXPOSED TO ELEVATED TEMPERATURES

ABSTRACT

Th~~is paper ~~e present study was to report~~ed~~ an investigation on six mixes of ~~Lightweight ~~lightweight ~~Aggregate~~ aggregate ~~Concrete ~~concrete (LWAC) ~~were ~~produced to ~~study ~~examine the effects of elevated temperatures (200 to 700 ˚C) on ~~the ~~their residual mechanical properties. ~~T~~To this end; the first three mixes were considered as reference mixes consisting of cement, ~~Porcelanite ~~porcelanite as coarse aggregate, and fine ~~Porcelanite ~~porcelanite as a partial replacement and a total replacement of sand. As well, ~~T~~two percent of foam agent by weight of water was added to ~~produce ~~manufacture ~~Lightweight ~~lightweight ~~Aggregate ~~aggregate ~~Foamed ~~foamed ~~Concrete ~~concrete (LWAFC). The testing results ~~of testing ~~showed that the ~~high elevated temperatures ~~resistance of the foamed concrete (FC) at elevated temperatures ~~is ~~was better in terms of the proportional loss in strength than that of normal concrete. ~~Also~~Furthermore, the mechanical properties of the ~~LWAFC ~~lightweight aggregate foamed concrete (LWAFC) containing 50% and 100% of fine ~~Porcelanite ~~porcelanite aggregate~~ are~~ had been less affected by high temperatures than those in the sanded lightweight aggregate foamed concrete (LWAFC)~~LWAFC~~.

Keywords: Lightweight Concrete, Foam Concrete~~;~~ , Elevated ~~temperatures~~Temperatures~~;~~ , Thermal Conductivity~~;~~ , Porcelanite~~.~~

INTRODUCTION

Numerous ~~S~~studies have been conducted extensively ~~widely ~~on ~~a large number~~lots of natural lightweight aggregate~~s~~ in order to manufacture lightweight concrete (LWC) [1-4~~].~~] because the ~~U~~use of natural lightweight aggregate instead of ordinary ~~aggregate ~~ones can reduce the costs of such concrete~~s~~. There are also ~~deferent~~ different types of natural lightweight aggregate such as perlite, pumice, Porcelanite, volcanic scoria, diatomite, etc.

Likewise, ~~T~~the cellular structure of a light weight aggregate (LWA) can make~~s~~ it inherently insulating, and this factor ~~is ~~can be assumed responsible for the high thermal insulation of the lightweight aggregate concrete (LWAC). Also, this type of LWC ~~has ~~is generally endowed with ~~generally a ~~lower thermal expansion than ~~Normal ~~normal ~~Weight ~~weight ~~Concrete ~~concrete (NWC~~),~~); therefore, it is more stable at elevated temperatures than ~~many ~~other dense aggregate concrete types. This property, combined with ~~the ~~better thermal insulation, can thus produce the inherent ~~fire ~~fire-resistance characteristic feature of the LWAC [5-7].

~~The ~~Moreover, heat exposure may be found in some industrial installations wherein concrete is used in places exposed to sustained elevated temperatures ranging from ~~(~~100~~-~~ to 1000~~)~~ °C as those utilized in foundations for blast furnaces and coke batteries, furnace~~s~~ walls and dampers, industrial chimneys, flues, kilns, ~~and ~~as well as nuclear~~-~~ reactors [3].

Since concrete is known as a composition of different materials, ~~the ~~its behaviour ~~of concrete ~~under elevated temperatures can largely depend~~s~~ on ~~its ~~the constituents~~.~~; in this respect, ~~T~~the aggregate type and the structure of the cement paste can have ~~has a great~~ significant effects on thermal conductivity of concrete. The highly porous microstructure of ~~lightweight aggregate (~~the LWA~~)~~ also gives it low density and better insulation ~~and ~~that can consequently make~~s~~ ~~the ~~concrete ~~made ~~produced with LWA exhibit lower thermal conductivity ~~than that of~~compared to ~~normal weight concrete (~~ the NWC~~)~~. Therefore, ~~Lightweight ~~lightweight ~~Aggregate ~~aggregate ~~Foamed ~~foamed ~~Concrete ~~concrete (LWAFC) can provide~~s~~ more effective fire protection than other types of concrete as it is less liable to spalling and ~~has ~~endowed with a higher thermal insulation [2].

~~Therefore~~In this regard, ~~many ~~numerous studies have been carried out to investigate the properties of ~~Lightweight Concrete (~~the LWC~~)~~ exposed to elevated temperatures ~~by ~~using various types of ~~Lightweight aggregate (~~LWA~~)~~. There are also ~~papers ~~investigations dealing with the effects of high temperatures on chemical and mechanical properties of the LWC [1-4~~],~~]; however, the impacts of high temperatures on chemical and mechanical properties of foamed concrete (FC) ~~there are~~cannot be observed except in few ~~papers dealing with~~research studies ~~the effect of high temperatures on chemical and mechanical properties of Foamed Concrete (FC)~~ [9]. So, ~~this investigation is~~ the present investigation was ~~suggested to study~~to examine the properties of ~~foamed concrete~~FC~~,~~ and ~~try ~~to make attempts to improve ~~their ~~these properties ~~by ~~using local and ~~low-~~low-cost materials. In this ~~work~~study, ~~compressive ~~compressive strength and density ~~are to be~~were also measured. Furthermore, t~~T~~he analytical study ~~involves ~~involved thermal conductivity analysis of the LWAFC.

~~RESEARCH~~ SIGNIFICANCE OF THE STUDY

Th~~is paper~~ e present study ~~focuses~~ focused on the use of ~~foamed concrete~~FC made with ~~Porcelanite~~ porcelanite as ~~a~~ coarse aggregate and as a partial and a total percentage replacement of fine aggregate. The primary scope ~~is~~ of this study was to ~~study~~ investigate the effect of ~~high~~ elevated temperatures on the properties of the LWAFC.

EXPERIMENTAL INVESTIGATION

The effects of various test parameters on the properties of the LWAC and the LWAFC were investigated in this study. To this end, ~~A~~all mixes were exposed to different temperature levels and the period of exposure at the maximum temperature ~~was~~ lasted two hours.

The investigation was based on using locally manufactured cement Type I (ordinary Portland cement: OPC) produced by Al Kubaisa Cement Factory, whose chemical and physical properties ~~are~~ were illustrated ~~shown~~ in Table 1 and ~~Porcelanite~~ porcelanite crushed stone obtained from the north of Al-Rutba Town in Al-Anbar Governorate ~~–~~, Iraq. Table 2 also ~~lists~~ listed some important physical and chemical properties for coarse and fine Porcelanite aggregate. Moreover, the EUCO-type ~~F~~foaming agent ~~type EUCO~~ was used in this study to produce the LWAFC with 2% foaming agent by weight of water [9]. Table 3 ~~indicates~~ indicated the technical description of the foaming agent.

The coarse aggregate used was 10 mm in all mixes. Porcelanite, as a partial and a total replacement for local natural sand with 2.61fineness modulus ~~The~~, was also used as fine aggregate ~~used Porcelanite as partial and total replacement with local natural sand whose fineness modulus 2.61~~. Its gradation ~~lies~~ lied in zone 3 and the grading test results ~~conform~~ were consistent with~~to~~ Iraqi Specification No.45/1984 as shown in Fig~~.~~ures 1 and 2 ~~which show~~indicating grading of fine and coarse aggregates used in this investigation. Potable water of Al-Risafa, Baghdad, was also used throughout this investigation for mixing and curing.

TEST PARAMETERS

The test parameters investigated in the present study were:

- Porcelanite as a fine aggregate replacement, and a partial ~~and~~ and a total replacement;
- Level of exposure temperatures, ~~at an age of 60 days,~~ the specimens at an age of 60 days were heated in an electric furnace~~, –~~ and four maximum temperature levels were selected (200, 300, 400, and 700˚C) and the period of exposure at the maximum temperature ~~was~~ lasted two hours.

MIXTURE PROPORTIONS AND DETAILS

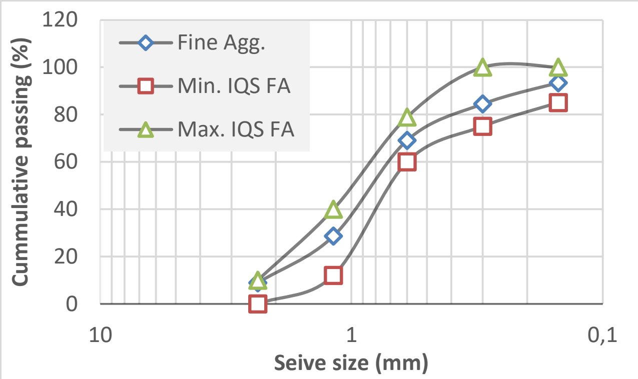
Abbreviations

LWAC	Lightweight Aggregate Concrete
LWAFC	Lightweight Aggregate Foamed Concrete
NWC	Normal Weight Concrete
OPC	Ordinary Portland Cement
ASTM	American Society for Testing and Materials
LOI	Loss ~~On~~ on Ignition
IQS	Iraqi Standards

Table 1. Chemical and physical properties of

~~Investigation~~ This investigation was carried out in three different series and the mix proportioning was calculated according to ACI 211-98 [10]. An extensive series of tests were also conducted to develop suitable LWAC~~,~~ and LWAFC reinforced with fiber~~, are~~ classified ~~into classified~~ into ~~two series~~:

- Series I – MSP, MSPP, and MPP~~: –~~ (mixture~~s~~ details ~~are~~ were presented in Table 4)
- Series II – MSPF, MSPPF, and MPPF~~: –~~ (mixture~~s~~ details were illustrated in Table 4)



Figure–1. Particle size distribution of fine aggregate

Table 2. Chemical and physical properties of fine and coarse Porcelanite aggregate

Physical properties			
Property	**Coarse aggregate**	**Fine aggregate**	**Specification**
Specific gravity	1.55	1.68	ASTM C127-04
Absorption, %	39	42	ASTM C127-04
Dry loose unit weight, kg/m³	600	740	ASTM 29/C29M/02
Dry rodded unit weight, kg/m³	685	860	ASTM 29/C29M/02
Aggregate crushing value, %	16		BS 812-part 110-1990
Chemical properties			
Oxides	% by Weight		
SiO_2	69.86		
CaO	10.57		
MgO	6.90		
SO_3	0.30		
Al_2O_3	4.78		
Fe_2O_3	2.09		
TiO_2	0.18		
L.O.I	4.25		
Total	98.97		

Chemical properties		
Oxides composition	**Content %**	**Limits of Iraqi specification No. 5/1984**
Lime, CaO	62.5	-
Silica, SiO_2	21	-
Alumina, Al_2O_3	4.9	-
Iron oxide, Fe_2O_3	3.08	-
Magnesia, MgO	1.5	5-% Max.
Sulfate, SO_3	2.3	2.8-% Max.
Loss on Ignition, (L.O.I)	1.5	4-% Max.
Insoluble material	1.1	1.5-% Max.
Lime Saturation Factor, (L.S.F)	0.937	(0.66-1.02)
Main compounds (-Bogue's equation-)		
C_3S	50.96	-
C_2S	21.77	-
C_3A	7.77	-
C_4AF	9.36	-
Physical properties		
Specific surface area (Blaine method), (m^2/kg)	304	230 m^2/kg lower limit
Setting time (vicate apparatus) Initial setting, hrs. : min Final setting, hrs. : min	2:05 3:60	Not less than 45 min Not more than 10 hrs
Compressive strength (MPa) For 3-days For 7-days	20.4 28.2	Not less than 15 MPa Not less than 23 MPa
Expansion by ~~Autoclave~~ autoclave method	0.23-%	Not more than 0.8 %

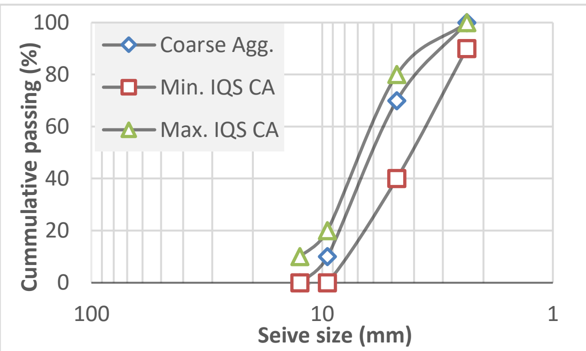


Figure-2. Particle size distribution of coarse aggregate

CONCRETE MIXING, TEST SPECIMENS, CURING, CONDITIONS, AND TESTING DETAILS

The mixing sequence was as follows: coarse aggregate and fine aggregate~~,~~ were added ~~in~~ into the mixer and the mixing continued for 1 minute, then the required quantity of dry cement was added, and the mixing continued for 3 minutes ~~at which~~in order to produce a good homogenous mix ~~was produced~~. Two thirds of the required ~~quantity water were~~quantity of water was then added to the dry materials, and the remaining water and the required quantity of foaming agent were added to the machine to make foam which was then added to the mix [9].

The slump of fresh concrete mixtures was determined as per ASTM C143. Sixty days of ~~compressive~~ compression were then determined by crushed 100mm cubes as per B.S. 1881: part 120: 1983, and flexural strength was ~~determined~~ specified by crushed (400×200×50) mm flags as per IQS No.1107, 1988 Type C [11]. Moreover, ~~T~~three specimens were ~~tested~~ examined for each test and their mean values were reported. Two specimens (200×100×50) mm were then cast for each concrete mixture~~s~~ in order to check the thermal conductivity as per B.S. 874:1973 [12].

HEATING PROCEDURE

For all the exposures, the specimens were slowly heated and cooled to allow the maximum exposure temperature to reach the centre of the specimens during heating and the rate of heating was such that it ~~should~~ did not exceed 2°C/min to avoid steep thermal gradient [1, 13].

RESULTS AND DISCUSSIONS

Fresh Properties

~~Effect~~ Investigating the effect of foaming agent, ~~-~~ Table 4 ~~shows~~ showed that the values of fresh properties (slump) of the LWAC varied from ~~(~~120~~-~~ to 160~~)~~ mm. For the LWAFC, these values were in the range ~~(~~of 242~~-~~ to 248~~)~~ mm~~. This~~ ~~indicated~~ indicating that Series II of lower w/c (0.4) had larger slump compared to Series I~~I~~. It was~~is~~ also observed that the addition of foaming agent had increased the workability due to the fact that cohesion ~~is~~ had been improved by the use of foaming agent and these observations were ~~consistent~~ in line with those reported by [4,9].

Influence of ~~High~~ Elevated Temperatures on LWAC and LWAFC

Loss of Weight

All the series exhibited smaller losses in weight with respect to exposure temperatures ~~are~~ as plotted in ~~Figs~~ Figures 3 and 4. The decrease in weight was not also more than 2% at 200ºC and 7% at 300ºC, for all mixes. This ~~is~~ was due to the removal of the capillary and the adsorbed water from the cement paste. On the other hand, it ~~has become~~ became obvious that there ~~is~~ was an increase in the loss of weight at a temperature above 300˚ C, and reduction of the weight ~~is~~ ranging from a minimum of about 17% to a maximum of about 41% at 700˚C. This ~~is~~ was due to ~~the~~ further dehydration of the cement paste as a result of the decomposition of calcium hydroxide.

It ~~has also been~~was noticed that in Series I, the sanded-LWAC specimens (MSP~~,~~ and MSPP) showed a larger reduction in their weight compared to the MPP specimens containing fine Porcelanite aggregate as a total replacement of natural sand. The results ~~show~~ demonstrated that the MPP mixes ~~are~~ were more thermally stable than the other mixes and the thermal stability of the concrete largely ~~depends~~ depended ~~largely~~ on the thermal stability of the aggregate (i.e.~~,~~ the thermal strain was ~~depends~~ dependent on aggregate used) [14].

Table 4~~–~~. Mixture composition of all experiment series, kg/m^3

Mixture ID*	Fine Aggregate		Coarse ~~Porcelanite~~ porcelanite	w/c	Water	Foaming agent	Slump (mm)
	Sand	Porcelanite					
MSP	540	-	787	0.4	160	-	120
MSPP	270	153	787	0.43	172	-	155
MPP	-	313	787	0.45	180	-	160
MSPF	540	-	787	0.4	160	3.2	242
MSPPF	270	153	787	0.42	168	3.36	245
MPPF	-	313	787	0.45	180	3.6	248

*Cement content in ~~All~~ all mixes ~~content cement~~ = 400 kg/m^3

** Aggregate~~s~~ in SSD condition~~,~~ wherein water quantities were adjusted before mixing

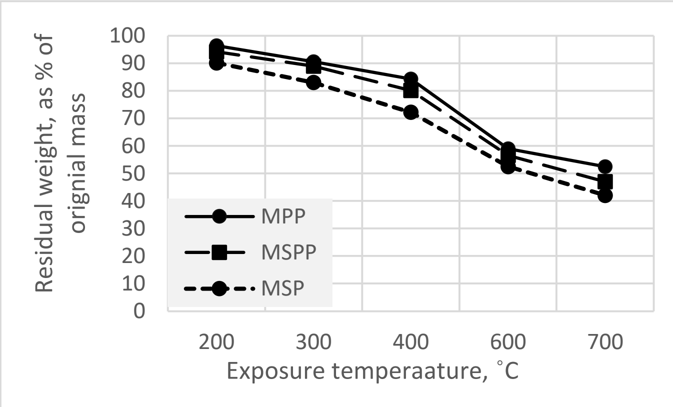
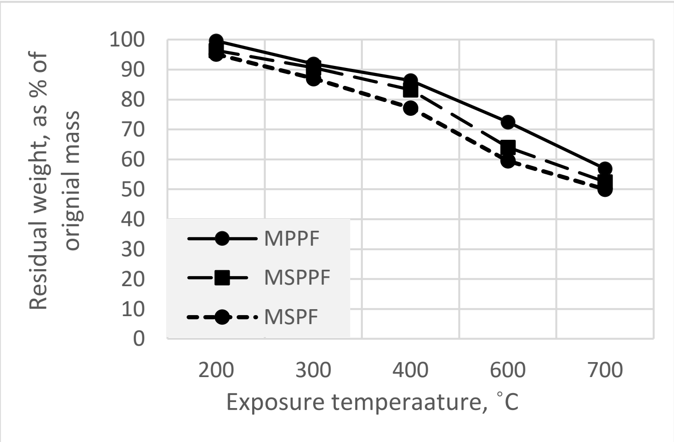


Figure- 3. Residual weight as the percentage of original weight of LWAC



Figure~~-~~ 4. Residual weight as the percentage of original weight of LWAFC

Compressive Strength

The residual compressive strength of Series I~~,~~ and II ~~decreases~~ decreased with the increase ~~of~~ in temperature degrees as presented in ~~-~~ Fig~~s.~~ures 5 and 6. The range of the properties of Series I and II concrete ~~presented~~ were also shown in Table 5. It should be noted that the ~~R~~residual compressive strength at 200˚C for Series I ~~is~~ was approximately ~~(~~70, 83, and 86~~)~~ % ~~of~~ for MSP, MPPS, and MPP;~~-~~ respectively. As well, the ~~R~~residual compressive strength at 300˚C for Series I ~~is~~ was ~~approximately~~ about ~~(~~62, 69, and 80~~)~~ % ~~of~~ for MSP, MPPS, and MPP; respectively. At 400˚C, the residual strength ~~is (~~was 38, 44, and 50~~)~~ % for MSP, MPPS, and MPP; respectively. At 600 ˚C, the residual strength ~~is~~ was ~~approximately~~ roughly ~~(~~23, 34, and 41~~)~~ % for MSP, MPPS, and MPP; respectively. It should be added that the ~~R~~residual compressive

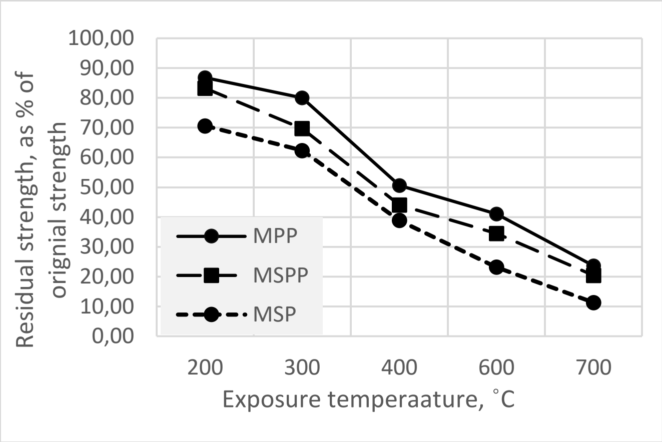
strength at 700˚C for Series I ~~is~~ was approximately ~~(~~11, 20, and 23~~)~~ % for MSP, MPPS, and MPP; respectively. Furthermore, the r~~R~~esidual strength of the MPP ~~is~~ was reported higher compared to the MSP when subjected ~~at~~ to different temperatures. The rate of loss of strength ~~is~~ was also significantly at 700 ˚C especially for MSP compared to the others~~, especially for MSP~~. The residual strength at 600˚C ~~is~~ was equivalent to half of the residual strength at 300˚C. It should be noted that ~~At high temperature,~~ the dehydration of cement paste at high temperatures results in its gradual disintegration~~. B~~ because the paste tends to shrink and aggregate may expands at high temperatures of above 600˚C~~,~~; moreover, the bond between the aggregate and the paste is weakened resulting in a great reduction in strength as confirmed in test results [15,16]. The deterioration of strength at elevated temperatures for such concrete types ~~can~~ could be attributed to the coursing of the pore structure and the increase in pore diameter [15, 16, 17].

The test results indicated ~~that~~ each temperature range for Series II ~~is~~ as plotted in Fig~~.~~ure 6. ~~Residual~~ The residual compressive strength at 200˚C for Series II ~~is~~ was approximately ~~(~~80, 87, and 91~~)~~ % ~~of~~ for MSPF, MPPSF, and MPPF; respectively. As well, the ~~R~~residual compressive strength at 300˚C for Series II ~~is~~ was ~~approximately~~ roughly ~~(~~69, 75, and 85~~)~~ % ~~of~~ for MSPF, MPPSF, and MPPF; respectively. At 400˚C, the residual strength ~~is~~ was ~~(~~61, 63, and 69~~)~~ % ~~of~~ for MSPF, MPPSF, and MPPF; respectively. At 600 ˚C, the residual strength ~~is~~ was ~~approximately~~ about ~~(~~47, 49, and 50~~)~~ % ~~of~~ for MSPF, MPPSF, and MPPF; respectively. ~~Residual~~ The residual compressive strength at 700˚C for Series II ~~is~~ was ~~approximately~~ about ~~(~~40, 44, and 47~~)~~ % of MSPF, MPPSF, and MPPF; respectively.

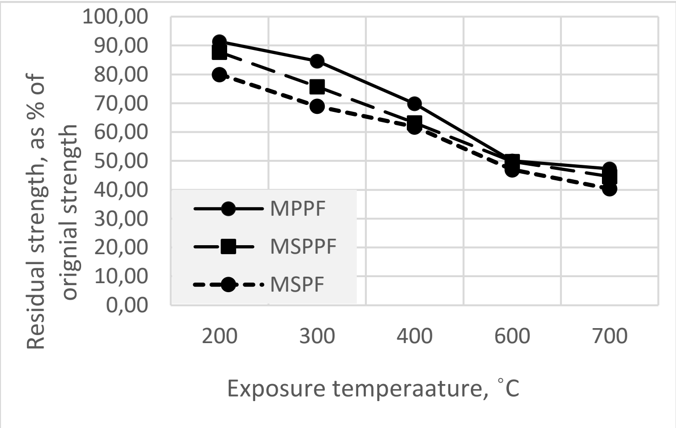
Generally, the strength loss in Series II ~~is~~ was lower compared to Series I when the temperature ~~is~~ varied from 200 to 700˚C. For instance~~,~~; at 700˚C, the residual strength ~~(~~was respectively 40, 44, and 47~~)~~ % of MSPF, MPPSF, and MPPF ~~respectively~~ which ~~are~~ were considered higher compared to those in Series I. This ~~is~~ was an indication of better performance of the LWAFC in retaining the strength at elevated temperatures ~~as~~ compared ~~with~~ to LWAC. This ~~can~~could be attributed to the less dense pore structure of Series II (compared to Series I) due to the presence of comparatively porous cement paste and ~~lightweight aggregate~~the LWA (~~Porcelanite~~porcelanite).

At 700˚C, Series I~~,~~ and Series II specimens experienced considerable cracks as well as spalling. The color of specimens also ~~changes~~ turned~~to~~ pink. The specimens then ~~undergo~~ demonstrated surface features when exposed to 600˚C ~~also~~ and showed color changes as well as some edge cracks but not as severe as those exposed to 700˚C ~~as~~ shown in Fig~~.~~ure 7.

Series II ~~should~~ could exhibit more resistance to ~~high~~ elevated temperatures than Series I due to much lesse~~r~~ tendency to spalling and loss of lesse~~r~~ proportion of ~~its~~ their original strength with the rise in temperature [18].



Figure~~-~~ 5. Residual strength as percentage of original strength of LWAC



Figure~~-~~ 6. Residual strength as percentage of original strength for LWAFC

Figure~~-~~ 7. Concrete specimens after 2 hrs. of ~~high~~ elevated temperatures

Thermal Conductivity

The variations in the thermal conductivity of all series of specimens with respect to ~~exposing~~ exposure temperature ~~are~~ were plotted in Fig~~.~~ure 8. The coefficient of thermal conductivity ~~will~~ decreased when the air-filled pores increased~~,~~ since air ~~being~~ is a very poor conductor of heat~~, –~~ ;thus, the results showed that the coefficient of thermal conductivity of ~~the~~ Series II ~~is~~ was lower compared ~~with~~ to Series I. Also, the thermal test ~~has~~ revealed a good indicator of the behavior of LWAFC under ~~high~~ elevated temperatures. Generally, the results showed that ~~the~~ Series II mixes ~~have~~ had more thermal stability compared to those in Series I. The thermal conductivity also dropped sharply for the sanded-~~-~~LWAFC (MSP) between 300 and 700 ˚C, by approximately ~~(~~35.2, 40.1, 40.3, 61.5, and 73.9~~)~~ % at ~~(~~200, 300, 400, 600, and 700~~)~~ ˚C; respectively, while the same mixes with the foaming agent could undergo a slight drop ~~approximately~~ about ~~(~~27.9, 31.6, 35.7, 53.5, and 64.2~~)~~ % at ~~(~~200, 300, 400, 600, and 700~~)~~ ˚C;~~-~~respectively. The thermal stability of the concrete also largely ~~depends~~ depended ~~largely~~ on the thermal stability of the aggregate (i.e~~., –~~. the thermal strain was ~~depends~~ dependent on the aggregate used) [13]. This ~~is~~ was firstly due to the cellular nature of ~~Porcelanite~~ porcelanite aggregate and secondly ~~due to~~because of the mineral composition of this type of aggregate which ~~consists~~ consisted of approximately 65% ~~Opal~~ mineral~~-~~type Opal-CT ~~which is~~ considered as amorphous siliceous mineral~~s~~ ~~and has~~ with low thermal conductivity compared ~~with~~ to crystalline silica [19]. The results also showed that the addition of foaming agent could give~~s~~ better thermal insulation to the LWAC mixes at 25˚C. Simply, the requirement for resistance ~~the~~ against ~~high~~ elevated temperatures ~~resistance requirement is~~ was based on thermal insulation.

Table 5~~–~~. Summary of mechanical properties

Conclusion~~s~~

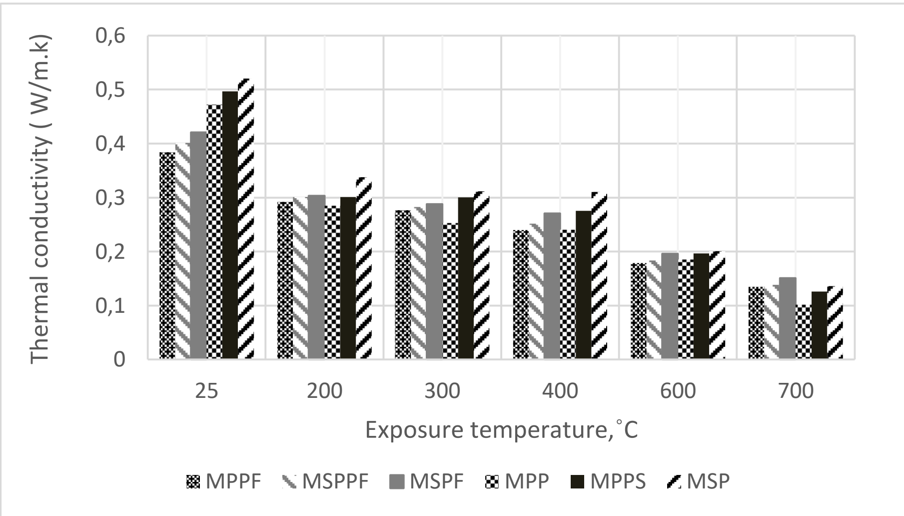
The following conclusions ~~can~~ could be drawn from this study:

- The addition of foaming agent by 2% was beneficial in terms of improving the workability of the LWAC. The slump values of the LWAFC between 242 ~~to~~ and 284 mm also showed satisfactory workability with no segregation or excessive bleeding specially for the MPPF mixture.

- The compressive strength and density decreased with the increase ~~of~~ in the replacement ~~Porcelanite~~ porcelanite ~~replacement~~ with sand. The proportional loss in strength between normal concrete LWAFC containing 50% (MSPPF) and 100% fine ~~Porcelanite~~ porcelanite aggregate (MPPF) also showed a little loss in mechanical properties compared ~~with~~ to the sanded-LWAFC (MSPF).

- The behavior of Series I mixtures under compressive strength was more sensitive to elevated temperatures than ~~that of~~those in Series II.
- The residual compressive strength of ~~series~~ Series II specimens was more than those in ~~series~~ Series I especially when exposed to high temperatures~~,~~ ; i.e. the residual strength ~~is (~~was 69, 50, and 47~~)~~ % of the MPPF at 400˚C, 600 ˚C, and 700˚C; respectively.
- MSP specimens ~~have~~ had a minimum residual strength in comparison ~~with~~ to the other ones, especially at ~~high~~ elevated temperatures, equal to ~~(~~38, 23, and 11~~)~~ % at 400˚C, 600 ˚C, and 700˚C; respectively.

Mixture ID*	Density, kg/m^3						Compressive strength, MPa					
	Temperatures, ˚C						Temperatures, ˚C					
	25	200	300	400	600	700	25	200	300	400	600	700
MSP	1500	1431	1345	1265	884	786	19.4	16.8	15.5	10	8	5
MSPP	1457	1372	1297	1169	823	685	18.5	15.4	13	8	6.4	4
MPP	1280	1154	1063	924	672	538	15.8	11.2	10	6	3.6	2
MSPF	1390	1385	1277	1201	1007	790	13	12	11	9	6.5	6
MSPPF	1351	1302	1225	1126	864	709	10	8.7	7.5	6.3	4.9	4.5
MPPF	1210	1159	1053	934	720	606	9.4	7.5	6.5	5.8	4.4	3.7



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