

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

ABSTRACT

This ~~paper e present study was to~~ reported 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. ~~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,~~ ~~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 aggregates ~~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 concretes. 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~~ makes 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 where ~~in~~ 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, furnaces 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~~ depends 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~~ makes ~~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~~ provides 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 ~~workstudy,~~ ~~compressive-compressive~~ strength and density ~~are to-bewere~~ also measured.

Furthermore, ~~t~~The analytical study ~~involves~~ involved thermal conductivity analysis of the LWAFc.

RESEARCH SIGNIFICANCE OF THE STUDY

This ~~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.

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 <u>on</u> Ignition
IQS	Iraqi Standards

Table 1. Chemical and physical properties of

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, ~~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 2.61 fineness 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:

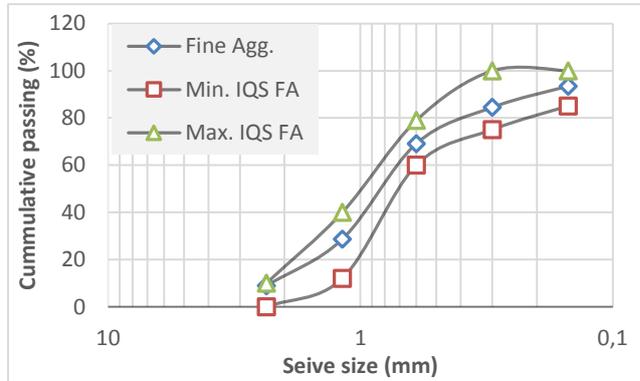
- Porcelanite as a fine aggregate replacement, and a partial ~~and~~ and a total replacement;
- Level of exposure temperatures, at an age of 60 days, the specimens at an age of 60 days were heated in an electric furnace, ~~—~~ and four maximum temperature levels were

selected (200, 300, 400, and 700°C) and the period of exposure at the maximum temperature was lasted two hours.

MIXTURE PROPORTIONS AND DETAILS

~~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:– (mixtures details ~~are~~ were presented in Table 4)
- Series II – MSPF, MSPPF, and MPPF:– (mixtures 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/m ³	600	740	ASTM 29/C29M/02
Dry rodded unit weight, kg/m ³	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 ₂ O ₃	4.78		
Fe ₂ O 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 ₂ O ₃	4.9	-
Iron oxide, Fe ₂ O 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 ₃ S	50.96	-
C ₂ S	21.77	-
C ₃ A	7.77	-
C ₄ AF	9.36	-

Physical properties		
Specific surface area (Blaine method), (m ² /kg)	304	230 m ² /kg lower limit
Setting time (vicate apparatus)		Not less than 45 min
Initial setting, hrs. : min	2:05	Not more than 10 hrs
Final setting, hrs. : min	3:60	
Compressive strength (MPa)	20.4	Not less than 15 MPa
For 3-days	28.2	Not less than 23 MPa
For 7-days		
Expansion by Autoclave autoclave method	0.23-%	Not more than 0.8 %

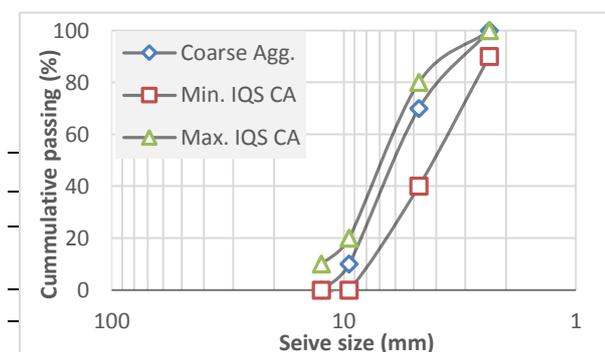


Figure-2. Particle size distribution of coarse aggregate

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~~. 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 mixtures 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 Table 4-~~2~~ Mixture composition of all experiment series, kg/m³

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/m³

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

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. It ~~was~~ 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 200°C and 7% at 300°C, 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].

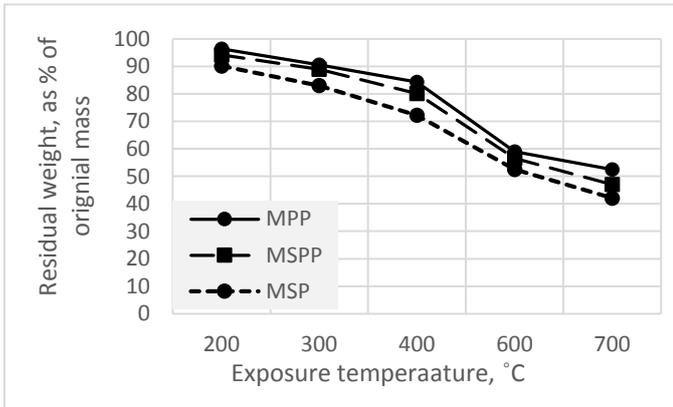


Figure- 3. Residual weight as the percentage of original weight of LWAC

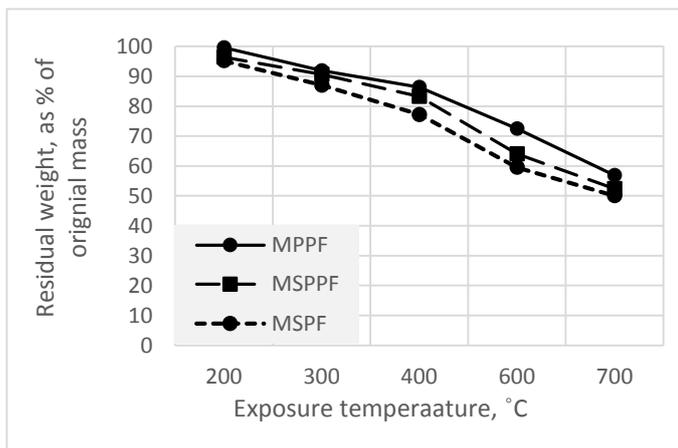


Figure- 4. Residual weight as the percentage of original weight of LWAFc

Compressive Strength

The residual compressive strength of Series I₁ and II ~~decreases-decreased~~ with the increase ~~of-in~~ temperature degrees ~~as presented in-Figs-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 MPP₁; 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 MPP₁; respectively. At 400°C, the residual strength ~~is-was~~ 38, 44, and 50)% for MSP, MPPS, and MPP₁; respectively. At 600 °C, the residual strength ~~is-was~~ approximately roughly (23, 34, and 41)% for MSP, MPPS, and



MPP₁; 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 MPP₁; respectively. ~~Furthermore, the r~~Residual 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 coarsening 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 Figure 6. ~~Residual-The~~ residual compressive strength at 200°C for Series II ~~is-was~~ approximately (80, 87, and 91)% ~~of-for~~ MSPF, MPPSF, and MPPF₁; 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 MPPF₁; respectively. At 400°C, the residual strength ~~is-was~~ (61, 63, and 69)% ~~of-for~~ MSPF, MPPSF, and MPPF₁; respectively. At 600 °C, the residual strength ~~is-was~~ approximately about (47, 49, and 50)% ~~of-for~~ MSPF, MPPSF, and MPPF₁; respectively. ~~Residual-The~~ residual compressive strength at 700°C for Series II ~~is-was~~ approximately about (40, 44, and 47)% of MSPF, MPPSF, and MPPF₁; 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 MPPF₁ ~~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 (Porcelaniteporcelanite).

At 700°C, Series I₁ and Series II specimens experienced considerable cracks as well as spalling. The color of specimens also ~~changes-turnedto~~ 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~~ lesser

tendency to spalling and loss of lesser proportion of ~~its~~ their original strength with the rise in temperature [18].

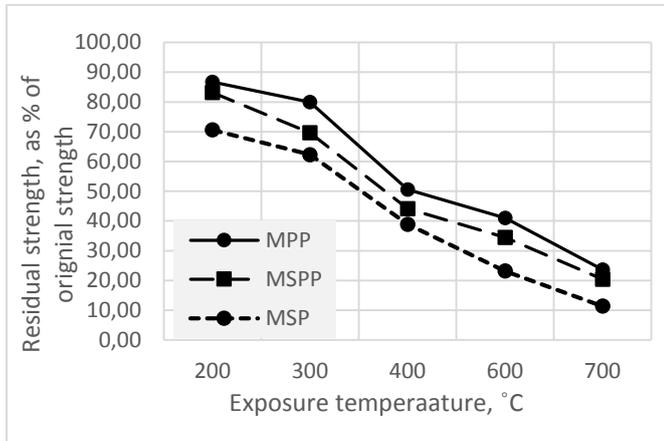


Figure- 5. Residual strength as percentage of original strength of LWAC

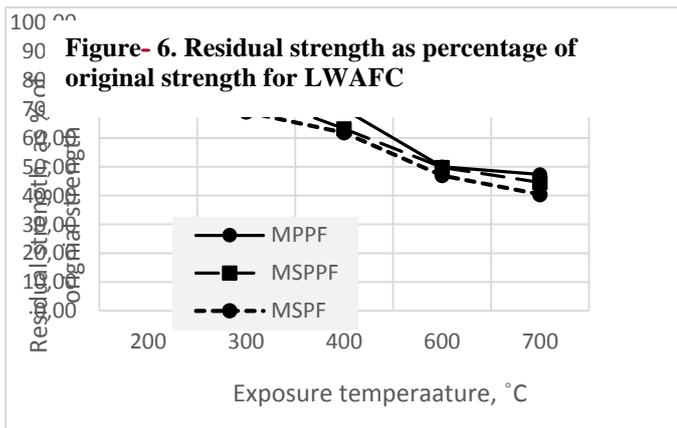


Figure- 6. Residual strength as percentage of original strength for LWAFc



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 Figure 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

Table 5- Summary of mechanical properties

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 ~~Poreclanite~~ 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 minerals and has with low thermal conductivity compared ~~with to~~ crystalline silica [19]. The results also showed that the addition of foaming agent could gives 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.

Conclusions

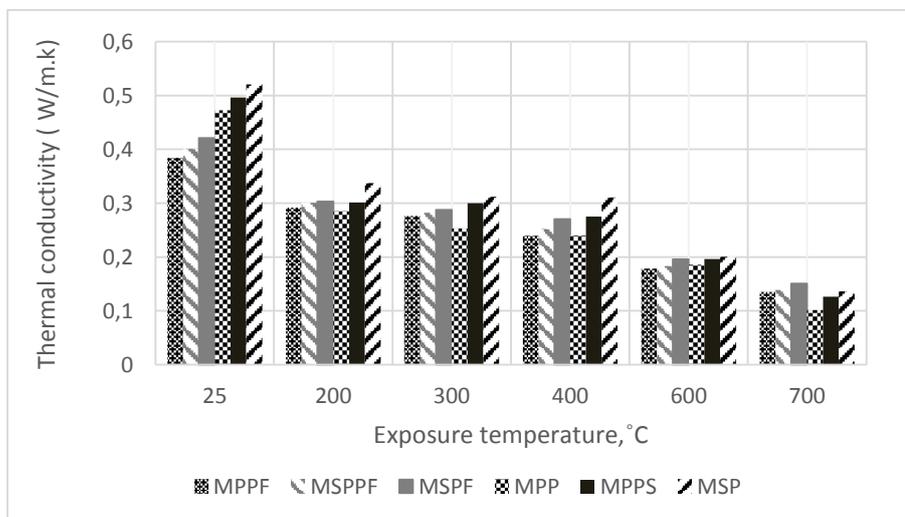
The following conclusions ~~can could~~ be drawn from this study:

- 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 of in the replacement Poreclanite porcelanite replacement with sand. The proportional loss in strength between normal concrete LWAFc containing 50% (MSPPF) and 100% fine ~~Poreclanite~~ 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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