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The Effect of Elevated Temperature on the Lightweight Aggregate Concrete

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Abstract: ***The use of lightweight concrete has become widely spread in concrete structures in the last years. Fire can be considered as a destructive hazard that attack concrete structures. In this research the effect of elevated temperature on lightweight aggregate concretes is studied. For this purpose, 81 cube shaped specimens were prepared from three different lightweight aggregate concrete mixes. After moist curing periods for 3, 7 and28 days, the specimens were subjected to ambient and elevated temperatures of 450℃ and 650℃ for 2hrs.The weight of the specimens before and after exposure to elevated temperatures was determined and the residual strength results for the specimens were compared. The results showed that, the elevated temperature induces a decrease in strength and significant weight losses in lightweight aggregate concrete.***

Keywords: Lightweight aggregate concrete, elevated temperature, compressive strength, residual strength, weight loss

1. INTRODUCTION

Lightweight aggregate concrete was first presented by the Romans in the Mediterranean region 2000 years ago where 'The Roman temple Pantheon, Port of Cosa and the Coliseom have been built using lightweight aggregate [1]. From there on, the use of lightweight concrete has been widely spread across other countries such as USA, United Kingdom, Sweden and Malaysia.

The main specialties of lightweight concrete are its low density and thermal conductivity. Its advantages are; that there is a reduction of dead load, faster building rates in construction, and lower transport and handling costs. The building of 'The Pantheon' of lightweight concrete material is still standing eminently in Rome until now for about 18 centuries, shows that the lighter materials can be used in concrete construction and brings many economical advantage [2].

The lightweight aggregates that are used for producing lightweight concrete can be natural aggregate such as pumice, scoria and all of those of volcanic origin and the artificial aggregate such as expanded blast-furnace slag, vermiculite and clinker aggregate [3].

Fire causes real defects in the structures, exposing concrete to elevated temperature results in a loss in strength and occurrence of cracking. Elevated temperature weakens the bond between cement paste and aggregate, and breakdown of the cement gel structure which leads to the consequent loss in the load bearing capacity, increased tendency of drying shrinkage and structural cracking [4, 5]. Strength deterioration of concrete exposed to elevated temperature may be due to several factors: temperature level, rate of heating, heating time, cooling method, applied load, type of aggregate, type of mineral admixture and air humidity [6-8]. Therefore, there are broadly variable results regarding the exposure of concrete to elevated temperature [9].

A number of studies have shown that an increase in temperature in cement pastes causes the release of physically absorbed water, chemically bonded water and the decomposition of hydration products [10, 11]. A well-hydrated cement paste generally consists of calcium silicate hydrate, calcium hydroxide and calcium sulphate aluminate hydrate. A saturated paste also contains a large amount of free water, capillary water and gel water (chemically bonded water). When concrete is heated to 300°C, the free water and some of the chemically bonded water of hydration products are lost. Exposure to 500°C results in further dehydration due to the decomposition of calcium hydroxide. A complete decomposition of calcium silicate hydrate occurs at temperatures beyond 900°C [12]. Lightweight concrete is more fire resistant than ordinary normal weight concrete because of its lower thermal conductivity, lower coefficient of thermal expansion and the inherent fire stability of lightweight aggregate. Exposing to elevated temperatures up to 800°C induces in a sharp drop of compressive strength for lightweight concrete made with fly ash and lightweight aggregate [13].

Due to its widely usage in construction sector in the last years, investigating the behavior of lightweight aggregate concrete after exposure to elevated temperature is of prodigious importance. The main objective for this research is determining the residual strength for lightweight aggregate concrete after exposure to elevated temperatures of 450^{o}C and 650^{o}C.

2. MATERIALS AND METHODS

In this research, Ordinary Portland cement (Type I) obtained from Mass Company was used. The fine aggregate (crushed Leca), passed from sieve 4.75 mm, having the fineness modulus of 2.7 and specific gravity of 1.3 was used. The used coarse aggregate was Leca having the maximum size of 12 mm and the specific gravity of 1.087.

Three different lightweight aggregate concrete mixes C1, C2 and C3 were prepared. The mix proportions, by weight, per one meter cube of lightweight concrete are shown in Table 1. The slump test was performed to determine the consistency for the mixes. The density for C1, C2 and C3 mixes was 1315, 1350 and 1370 Kg/m^3 respectively. From each mix 27 (100*100) cubes were casted. The specimens were moist cured for 3, 7 and28 days in a water tank. After curing, the specimens were taken out from the water tank, surface dried and exposed to elevated temperatures of 450^{o}C and 650^{o}C for 2 hrs. by using an electrical oven. The heated specimens were cooled to room temperature and subjected to compression test, beside the non-heated control specimens. The weight of the specimens before and after exposure to elevated temperature was determined.

Table 1 Mix proportions per one meter cube of concrete

Mix.	Cement Kg.	Gravel Kg.	Sand Kg.	Water Kg.	Concrete Density Kg/m^3	Slump mm
C1	370	465	280	200	1315	70
C2	340	520	300	190	1350	60
C3	320	550	290	210	1370	60

3. RESULTS AND DISCUSSION

3.1 Compressive strength

The compressive strength and relative compressive strength results for all of the specimens are given in Table 2 and Fig. 1. For relative compressive strength, the average compressive strength of 28 day moist cured non-heated specimens' for each concrete mix was taken as 100% (control specimen) and the compressive strength for the specimens was determined relating to this percentage.

3.1.1 Compressive strength at ambient temperature (26^{o}C)

Before exposure to elevated temperature the compressive strength for 3 days moist cured C1, C2 and C3 lightweight aggregate concretes were 6.82, 5.68 and 5.1 MPa respectively. For 3 day moist cured C1, C2 and C3 specimens the compressive strength was in the percentages of 69, 63 and 60% respectively when they related to control 28 day moist cured specimens. The strength was increased by increasing moist curing periods to become 9.89, 8.95 and 8.5 MPa for 28 day moist cured C1, C2 and C3 concrete specimens respectively. The higher recorded strength for C1 concrete is due to its higher cement content, and higher consistency which made the concrete to be more compacted when compared with the other lightweight aggregate concretes.

3.1.2 Compressive strength after exposure to 450^{o}C

The exposure to 450^{o}C resulted in a strength reduction for all 7 and 28 day cured specimens in different ranges. Slight or no decrease in compressive strength for 3 days moist cured specimens was recorded when compared to 7 and 28 day cured specimens once they related to their strengths before exposure to elevated temperature. The relative strength rates for 3 days specimens remains approximately around 69, 61 and 61%, of the 28 day control specimens, for C1, C2 and C3 specimens respectively before and after exposure to 450^{o}C. Early age concrete specimens contain a reasonable amount of non-hydrated cement particles which by the presence of heat and moisture get hydrated to produce high amounts of calcium silicate hydrate that is responsible for the strength of concrete which by turn made the early age lightweight aggregate concrete specimens to show higher residual strength. The lower residual strength for later age specimens is due to the deterioration for the binder material after exposure to 450^{o}C.

3.1.3 Compressive strength after exposure to 650^{o}C

The exposure to 650^{o}C caused a dramatic reduction in compressive strength for all specimens. The residual strength for 28 day moist cured lightweight aggregate concrete specimens was around 58 to 59% of their original strengths before exposure to 650^{o}C. When the comparison is made within the curing age for each group of the specimens, once again the early age specimens showed higher residual strength than the later age specimens.

Table 2The compressive strength results for the specimens

Compressive strength for different curing periods after exposure to different temperatures (MPa)											
C1				C2				C3			
	3Day	7day	28day		3Day	7day	28day		3Day	7day	28day
26°C	6.820	7.563	9.893		5.680	6.727	8.947		5.120	6.150	8.547
450°C	6.813	6.203	7.607		5.427	5.207	7.267		5.200	5.000	7.547
650°C	6.430	5.993	5.790		4.440	4.600	5.177		4.053	4.500	5.033

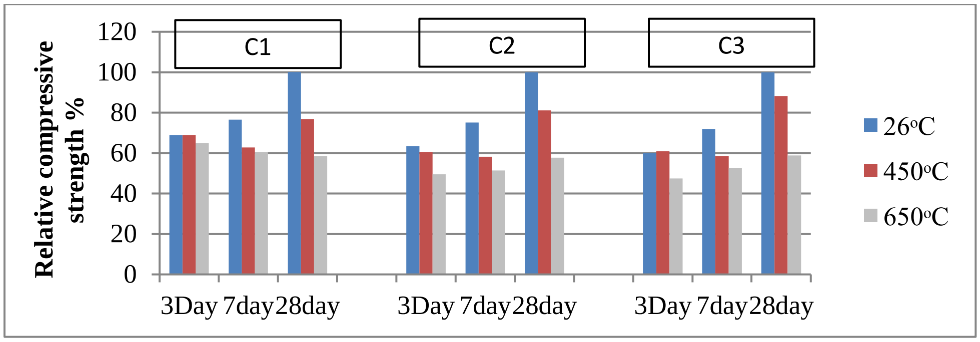

Fig. 1 Relative compressive strength for C1, C2 and C3 concrete before and after exposure to elevated temperatures at different moist curing periods

3.2 Weight loss

The relative weight loss for the specimens upon exposing to elevated temperatures of 450°C and 650°C is given in Fig. 2. For determining the relative weight loss, the average weight for the specimens before exposure to elevated temperature was accounted as 100%. Then the relative weight for the specimens after exposure to elevated temperature was calculated according to this rate and subtracted from 100.

From Fig. 2 it can be seen that by elevating the exposure temperature from 450°C to 650°C, the weight loss of the specimens increased at all curing periods and for all three lightweight aggregate concretes. This phenomenon is due to the higher degradation of the binder material (calcium silicate hydrate) at 650°C by losing a part of the chemically bonded water which the reduction in compressive strength at this temperature is related to. The higher loss in the weight of the specimens after exposure to high temperature indicates higher loss in compressive strength.

The 3 day moist cured specimens showed lower weight loss than 7 and 28 days moist cured specimens after exposure to elevated temperatures of 450°C and 650°C. This behavior is mostly due to the participation of heat and moisture in accelerating the hydration process of non-hydrated cement particles in this early age for producing further binder material.

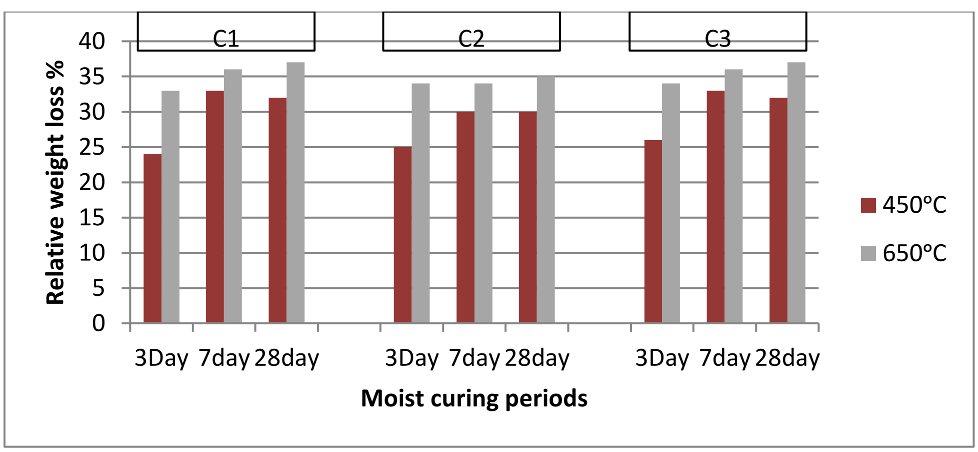

Fig. 2 Weight loss for lightweight aggregate concrete specimens after exposure to 450°C and 650

4. CONCLUSIONS

The following conclusions are drawn from this research:

- 28 day moist cured lightweight aggregate concrete loses 12 to 23% of their compressive strength after exposure to 450^{o}C.
- The residual strength for 28 day moist cured lightweight aggregate concrete is around 58 to 59% of their original strength after exposure to 650^{o}C.
- The residual strength after exposure to elevated temperatures at early ages is higher than the later ages for each age group of the specimens.
- Lightweight aggregate concrete loses 24 to 37% of its weight after exposure to elevated temperatures of 450^{o}C and 650^{o}C.
- The higher exposure temperature related to the higher weight loss.
- The higher loss in the weight of the specimens after exposure to high temperature indicates higher loss in compressive strength.

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Biography

Rahel Khalid Ibrahim was born in Erbil/Iraqi Kurdistan in 1973. He got his; BSc degree from Civil Engineering departmen/Salahaddin University in 1996, MSc from department of Civil engineering/EGE university Izmir/Turkey in 2001 and PhD degree from the department of Civil and Structural Engineering/University Kebangsaan Malaysia in 2013. Currently he is Director of Research Center and lecturer at Civil Engineering Department Faculty of Engineering Koya University. His Google scholars cite is as following:

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