

Evaluation of Mechanical Properties of Lightweight Concrete with Pumice Aggregate

Malik Salman Shafiq¹, Fasih Ahmed Khan^{2*}, Yasir Irfan Badrashi²,
Fayaz Ahmed Khan², Muhammad Fahim², Asim Abbas², Waqas Adil²

¹ CECOS University of I.T. and Emerging Sciences, Peshawar, Pakistan

² University of Engineering & Technology, Peshawar, Pakistan

* Corresponding author's email: fasiahmad@uetpeshawar.edu.pk

ABSTRACT

This paper presents the findings of a study carried out for evaluation of the mechanical behavior of lightweight concrete. Pumice, a rock resulting from cooling of lava, having entrapped air bubbles, has been used as a lightweight coarse aggregate. Evaluation of the mechanical behavior of the Pumice Lightweight Aggregate Concrete (PLWAC) has been carried out in comparison with the conventional concrete while comparing the mechanical properties of the two. Complete replacement of the coarse aggregate by volume had been carried out in the PLWAC. The testing regime consisted of conducting laboratory tests on concrete samples for evaluation of the mechanical properties including compressive strength, tensile strength, workability and dry density. It was concluded from the results that the use of lightweight aggregate resulted in a reduction in workability, as indicated by the slump test. Moreover, the dry density of PLWAC was also reduced by 30% as compared to the conventional concrete. A significant decrease (49%) in the compressive strength of PLWAC as compared to conventional concrete while a minor difference was observed in the tensile strength of the two (2.9%). Based on the results of this study, it is recommended that PLWAC cannot be used in structures subjected to heavy loading conditions. However, PLWAC has a good potential to be used in low-cost structures with accompanying benefits of weight reduction.

Keywords: lightweight concrete, pumice lightweight aggregate, saline water curing

INTRODUCTION

Concrete, the second only to water, is the most consumed material on the earth with an estimated annual production is about five billion cubic yards. It is twice of all other building materials used combinedly in construction all over the world. Lightweight concrete (LWC) defined as concrete with a minimum 28 day compressive strength of 17 MPa and an equilibrium density between 1120 and 1920 kg/m³ [1]. Such lower density of lightweight structural concrete significantly reduces structural weight and concrete member sizes which in turn minimize the cost of the project, transportation, and foundation design [2–5]. Lightweight aggregate concrete, made from natural volcanic materials, was used 2000 years ago in the early age of the

Roman empire, however, its use was limited until the early 1900s, when rotary-kiln-produced expanded shale and clay aggregate lightweight concrete used in ship construction. Lightweight aggregates (LWAs) now days are naturally available as pumice and scoria while shales, clays, slates, fly ashes, or blast-furnace slags are artificially manufactured in plants.

Research had been focused on the performance of lightweight aggregates concreted such as expanded clay aggregate, lightweight crushed bricks, starch-based aggregate, palm oil shells aggregate, etc. [6–8] Pumice aggregates, an alumino-silicate of volcanic origin, formed on rapid solidification of gas-rich glassy lava, have been used since last decades in the production of lightweight concrete.

Pumice aggregates gradation and addition of admixtures simultaneously have shown significant improvement in compressive strength, density, and workability of concrete [3]. Pumice aggregate to cement ratio has a significant effect on strength, particularly, when properly graded aggregates are used. For well-graded pumice aggregates, higher aggregate to cement ratio's gives comparable strength to that of two graded aggregates used with lower aggregate to cement ratio [4, 9].

Lightweight aggregates are highly porous, when used in concrete, resulted in higher water absorption thus reducing the workability as compared to normal weight aggregate [11]. The workability of lightweight aggregate concrete was improved by pre-wetting aggregates before mixing in concrete. The influence of pre-wetting time of lightweight aggregate on the workability of concrete, in the absence of water-reducing admixture, along with partial replacement of cement by Fly Ash was investigated. It was concluded that soaking of aggregates for an optimum time of 30-minutes and replacement of cement with Fly Ash up to 30%, significantly improved the workability and strength of lightweight aggregate concrete [12]. Different pre-wetting methods investigated lead to the conclusion that vacuum-soaking and water-soaking of lightweight aggregates before mixing improved the workability and compressive strength [1].

The development of concrete strength is directly affected by curing time. Prolonged curing has significantly increased the strength of, same batch concrete, compared to short-duration curing. (Gonnerman and Shuman 1928). The use of saline water for the curing of concrete was

investigated [13, 14]. The effect of saline water curing of normal weight concrete for different ages was studied. It was concluded, long-duration curing with saline water reduces strength up to 30% compare to curing with fresh water. However, for a short duration, strength was not significantly reduced. In literature, barely a study was conducted on the use of saline water for the curing of lightweight aggregate concrete.

Many researchers have reported research works on lightweight concrete with pumice aggregates [2, 15÷21]. Limited research is available for the evaluation of PLWAC when cured with water that contains sodium sulphate solution. The main objective of this research is to check the compressive strength of concrete when aggregate is replaced with pumice. To check and investigate the effects of salty curing water on the compressive strength of normal concrete and pumice concrete.

MATERIAL AND METHODS

Materials

The cement that was used in the research was ASTM type 1 [22] cement locally available in Pakistan with a brand name of “Kohat Cement”. The cement is manufactured by the Kohat cement factory in Pakistan. It contains 95% clinker and 5% gypsum content, with a specific gravity according to ASTM C187 [23] and fineness according to ASTM C786 [24] were found to be 3.15 and 99% (passing through sieve #200) respectively. The chemical and physical properties for the cement used is given in Table 1.

Table 1. Chemical and physical properties of Kohat cement

Chemical			Physical		
Item	ASTM C150 spec. limits [23]	Test result (%)	Item	ASTM C150 spec. limits [23]	Test result
SiO ₂	Not applicable	20.78	Blaine fineness (m ² /kg)	430 max	315
Al ₂ O ₃	6.0 max	5.81	Compressive strength (MPa)	min	
Fe ₂ O ₃	6.0 max	2.99	3 days	7	14
CaO	Not applicable	62.18	7 days	12	26
MgO	6.0 max	1.52	28 days	28	45
SO ₃	3.0 max	1.89	Time of setting (minutes)(vicat)	–	–
Ignition loss	3.5 max	2.31	Initial not less than	45	145
Insoluble residue	1.5 max	0.75	Not more than	375	240
Free limestone	5.0 max	0.68	–	–	–



Fig. 1. Pumice aggregate

Pumice aggregate was obtained from Rabbani & Sons, Lahore, Pakistan. It was used as a coarse aggregate in preparation for the concrete mixes. Pumice aggregate used was having a maximum size of 20 mm and a Nominal maximum size of 15 mm as can be seen in Figure 1. The chemical and physical properties of pumice aggregate are shown in Table 2. The silica (SiO_2) content is quite high which indicates the type of pumice is acidic. For the construction sector, acidic type pumice is preferred [25].

The sand was from a local source of Lawrencepur, located in Pakistan. The sand fineness modulus was calculated to 2.5 as per ASTM C136 [26]. The available moisture absorption (%), available moisture content (%), bulk specific gravity (g/cc), and apparent specific gravity (g/cc) were calculated using ASTM C127 [27] and was found to be 8.6, 1.25, 2.68 and 2.7 respectively. To check the sand for organic impurities the sand was tested and it observed lighter color when compared with the standard solution prepared as per ASTM C87 [28].

For the preparation of mixes as well as curing purpose of the concrete the water used is clean and portable. This is also suitable for human drinking and washing purpose. All standards of ASTM 1602 [29] were taken into consideration while selecting the source of water.

Concrete mixtures composition

For this research work, mixes containing pumice as coarse aggregate were prepared. For the concrete mix preparation 1:2:4 ratio. Every mix had the same water to cement ratio of 0.5.

Slump test

To check the workability of the concrete prepared from pumice aggregate slump test was performed in accordance to ASTM-C143 [30].

Unit weight

The unit weight of PLWAC was found after measuring the weight of standard concrete cylinder having a volume of 0.0056 m^3 . The weight of each cylinder was measure with the help of digital weigh balance.

COMPRESSIVE STRENGTH

The cylinder specimens for compression tests were prepared and tested as per ASTM C470 [31] and ASTM C39 [32] respectively. A Standard 152.4 mm diameter and 304.8 mm height cylinder molds were used. A total 50 cylinders were casted, and were cured for 3, 7, 14 and 28 days in potable/ drinking water in accordance to ASTM C192 [33].

Durability study (sulphate attack)

After casting of the concrete specimens, they were demolded and were set for curing under three different groups. These groups were placed in different tanks having following sulphate concentration.

- 1) 1% Solution of Na_2SO_4 ,
- 2) 3% Solution Na_2SO_4 ,
- 3) 5% Solution Na_2SO_4 .

The specimens were left for 27 days in sodium sulphate exposure. The effect of sulphate concentration on the performance of normal and pumice aggregate concrete cements was evaluated by measuring the reduction in compressive strength.

RESULTS

Slump test

The results are presented in Figure 2, with the replacement of aggregate with 100% light weight pumice aggregate the slump value decreased 11%. The decrease in the slump value of PLWAC is due to high rate of absorption of the pumice aggregate as shown in Table 2. The pumic aggregate has a lesser density as compared to normal aggregate due to which PLWAC slump value is not as much as normal density concrete with has the same workability [34].

Unit weight

The unit weight of CM was 2401 kg/m^3 and PLWAC was having a 1674 kg/m^3 (Figure 3). A

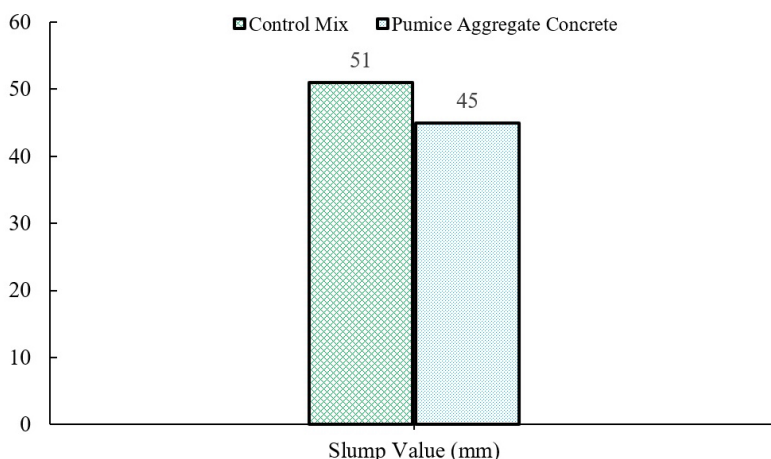


Fig. 2. Slump test of fresh concrete

Table 2. Pumice chemical and physical properties

Chemical analysis		Physical properties of pumice aggregate	
Element (%)	Pumice	Item	Standard [28]
SiO ₂	71.75	Bulk specific gravity	1.26
Al ₂ O ₃	12.33	Apparent specific gravity	1.36
Fe ₂ O ₃	1.98	Water absorption (%)	28.80
FeO	0.02	–	–
MgO	0.12	–	–
CaO	0.7	–	–
Na ₂ O	3.59	–	–
K ₂ O	4.47	–	–
MnO	0.07	–	–
TiO ₂	0.11	–	–
P ₂ O ₅	0.008	–	–
SO ₃	0.18	–	–
H ₂ O+	3.71	–	–

reduction 727 kg was observed, which makes 30% reduction in the unit weight of the PLWAC when compared with conventional concrete.

COMPRESSIVE STRENGTH

The results of compression tests on concrete cylinders are shown in Figure 4. Compressive strength result at 28 days shows that when pumice aggregate is used in concrete as a replacement for coarse aggregate and cured in normal water, the compressive strength dropped by 50 %. The decrease of strength at as observed at various days of testing is shown in Figure 5. The initial gain of strength of CM and PLWAC was similar but with the increase of time, the strength gain of PLWAC reduce by 50%.

Normal concrete compressive strength under different curing solutions

The effect of the different concentration of sodium sulphate solution curing on the compressive strength was observed up to 28 days. There was a clear decrease of compressive strength observed with the increase in the sodium sulphate solution concentration as reported in Table 3. The decrease in the compressive strength was dominated up to 14 days of testing but on the 28 days of curing the decrease in the strength was reduced only to 1 percent approximately. A maximum of 12.8 percent of strength was observed at 7 days of testing, which indicates that sodium sulphate solution concentration in the concrete in the curing water can decrease the initial strength gain but has a very small effect on the final strength gain on the normal strength concrete as can be seen in Fig. 6.

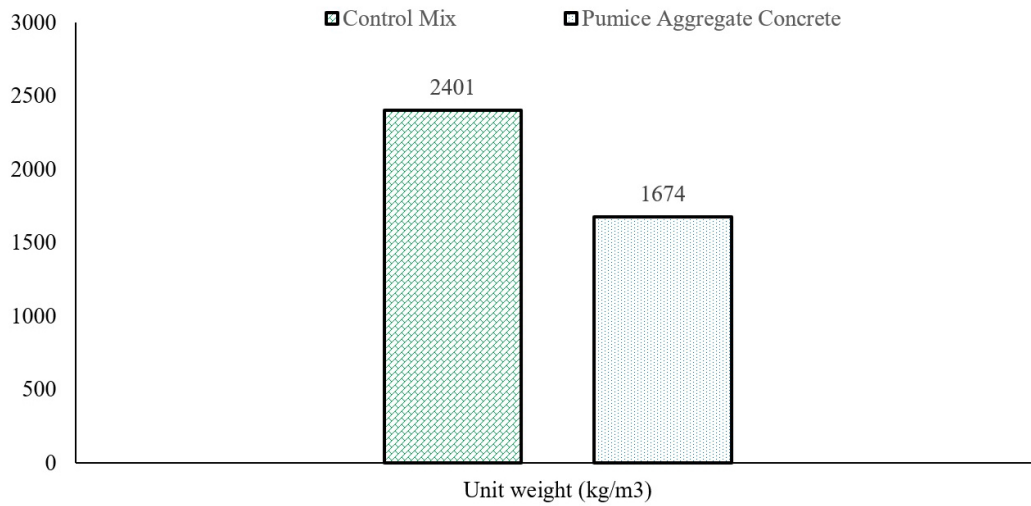


Fig. 3. Unit weight of PLWAC in comparison with normal concrete

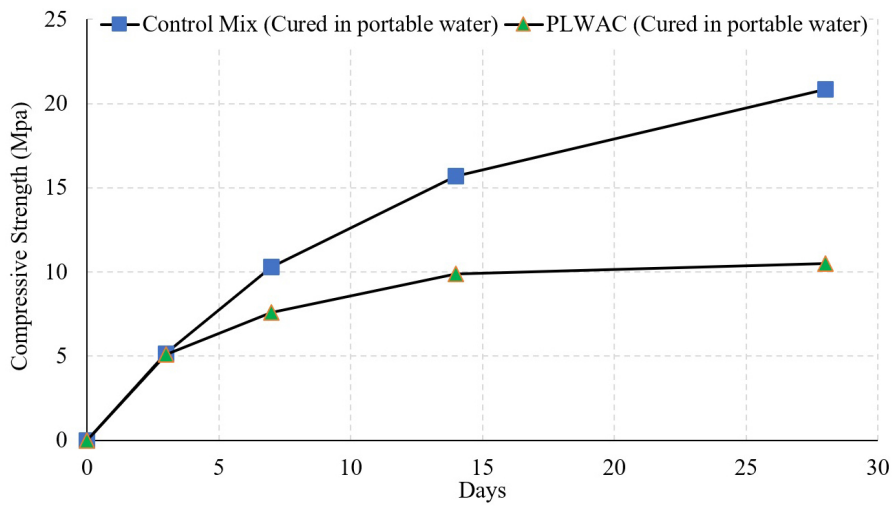


Fig. 4. Compressive strength of CM and PLWAC cured with portable water

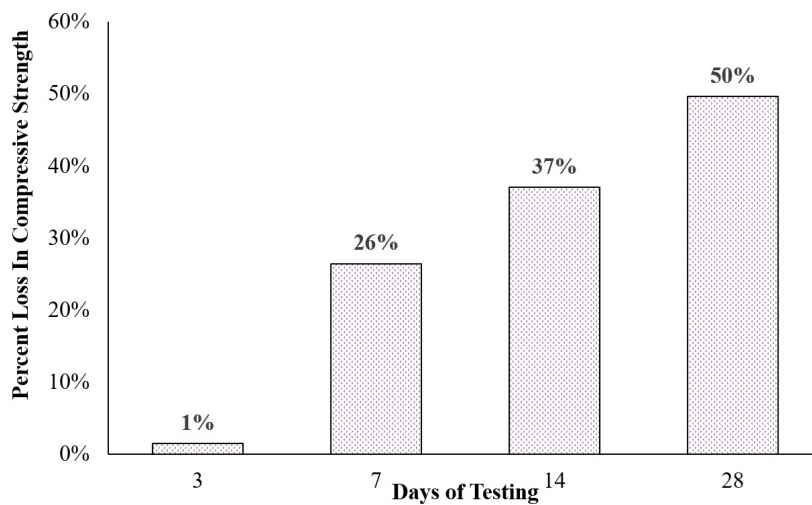


Fig. 5. Percentage loss of compressive strength of PLWAC

Table 3. Normal concrete compressive strength, (fc') MPa under different concentration of sodium sulphate solution

Normal concrete				
Days	Compressive strength (MPa)			
	Under portable water curing	1% Solution curing	3% Solution curing	5% Solution curing
3	5.2	5.0	4.8	4.7
7	10.3	9.7	9.1	9.0
14	15.7	15.0	14.1	13.9
28	20.9	20.8	20.7	20.7

Table 4. PLWAC compressive strength, (fc') MPa under different concentration of sodium sulphate

PLWAC				
Days	Compressive strength (MPa)			
	Under portable water curing	1% Solution curing	3% Solution curing	5% Solution curing
3	5.1	4.6	4.3	4.3
7	7.6	7.4	5.8	5.3
14	9.9	7.8	7.2	6.3
28	10.5	10.4	10.3	10.3

PLWAC Compressive strength under different curing solutions

The effect of the different concentration of sodium sulphate solution curing on the compressive strength was observed up to 28 days for PLWAC. The compressive strength showed a decrease with the incorporation of pumice aggregate. There was further decrease observed, when cured in sodium sulphate solution. The was a clear decrease of compressive strength observed with the increase in the sodium sulphate solution concentration as reported in Table 4. The decrease in the compressive strength was dominate up to 14 days of testing

but on the 28 days of curing the decrease in the strength was reduced only to 1 percent approximately. A maximum of 36.1 percent of strength was observed at 14 days of testing, which indicates that sodium sulphate solution concentration in the concrete in the curing water can decrease the initial strength gain but has a very small effect on the final strength gain on the normal strength concrete as can be seen in Figure 7.

Split tensile strength.

The specimens were tested for split tensile strength at 28 days. The result of split tensile tests

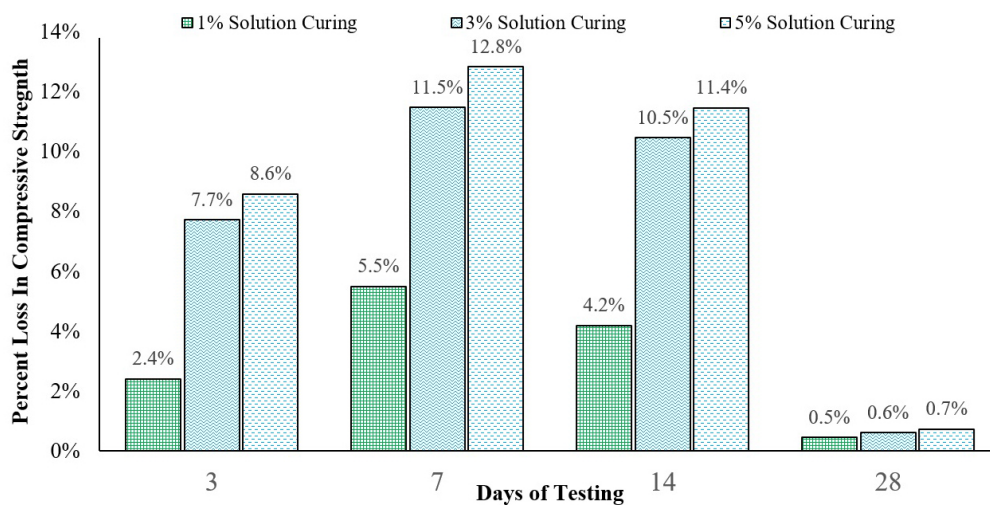


Fig. 6. Percent loss in the compressive strength (fc') of normal concrete under different curing condition of sodium sulphate concentration

Table 5. Split tensile strength test results

Mix type	Percentage replacement of coarse aggregate replaced with pumice	Average tensile strength (MPa)	Percent decrease in the tensile strength
CM	0	1.19	0
PLWAC	100	1.15	3.36

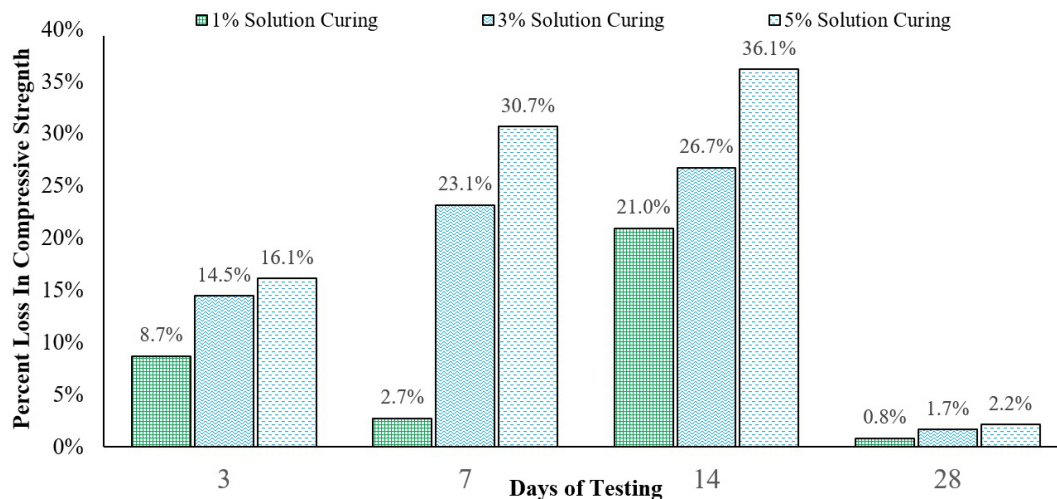


Fig. 7. Percent loss in the compressive strength (fc') of PLWAC under different curing condition of sodium sulphate concentration

on concrete cylinders is shown in Table 5. Split tensile strength of concrete at 28 days is having near values to that of Normal concrete.

CONCLUSIONS

The following conclusions are drawn from the study carried out to evaluate the suitability of lightweight concrete using Pumice rock.

1. PLWAC when cured in potable water was tested and the result showed 1%, 26%, 37 % and 50% drop in its compressive strength at 3 days, 7 days, 14 days, and 28 days, respectively.
2. Normal concrete when cured in potable water having 1% sodium sulphate solutions showed a compressive strength loss of 2.4%, 5.5%, 4.2% and 0.5% at 3, 7, 14 & 28 days respectively.
3. Normal concrete when cured in potable water having 3% sodium sulphate solutions showed a compressive strength loss of 7.7%, 11.5%, 10.5% and 0.6% at 3, 7, 14 & 28 days respectively.
4. Normal concrete when cured in potable water having 5% sodium sulphate solutions showed a compressive strength loss of 8.6%, 12.8%, 11.4% and 0.7% at 3, 7, 14 & 28 days respectively.
5. The maximum strength loss of PLWAC when cured in 1%, 3 % and 5% sodium sulphate

solutions was 36.1% at 14 days at 5% sodium sulphate solution.

6. After using of 100% replacement of coarse aggregate with pumice aggregate resulted in 3.36% decrease in split tensile strength at 28 days.
7. The unit weight of control mix was 2401 kg/m³ and PLWAC was 1674 kg/m³ which makes it 30% lighter than the conventional concrete.
8. From the compressive strength of concrete at 28 days which is below the structural requirement according to ASTM C 330-82a although pumice concrete can be used for insulating purposes, partition walls construction, panel walls in the frame structure, blocks and roof floors etc.

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