Properties of Lightweight Concrete Containing Treated Pumice by Alkaline Solution

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ABSTRACT

The properties of lightweight concrete containing pumice treated with sodium hypochlorite (NaOCl) were experimentally investigated in this study. The study used treated pumice as 100% replacement of fine and coarse aggregates in concrete mixtures. Untreated pumice aggregates were used to prepare reference mixtures. In addition, the study investigated the effect of sodium hypochlorite on pumice properties. The concrete compressive strength at ages of 7 and 28 days was tested. The results showed that the compressive strength of concrete that contained treated pumice increased by 200% as compared to concrete containing untreated pumice. The pumice aggregate treated with NaOCl increased the pumice strength and improved its physical characteristics as the mean of specific gravity and abrasion resistance.

KEYWORDS: Lightweight concrete, Pumice, Alkaline solution.

INTRODUCTION

Lightweight concrete (LWC) is a suitable construction alternative whenever it is essential to reduce dead loads in structures and to save energy whenever there is an abundance of local lightweight aggregates (Yeoh et al., 2005). However, for many purposes, the advantages of lightweight concrete outweigh its disadvantages, and there is a continuing worldwide trend towards more lightweight concrete in applications such as pre-stressed concrete, high-rise buildings and even shell roofs. In general, lightweight concrete has a density ranging between 800 and 1800 kg/m^3 (Kan and Demirboga, 2009). Using porous lightweight aggregates instead of traditional material can lower concrete density. Pumice is frequently used as a lightweight aggregate mainly for lightweight structural concretes. Pumice aggregate exists in several places around the world, where volcanoes have erupted (Kornev et al., 1980). Large number of researchers studied the properties of concrete containing pumice aggregate; many of them investigated admixtures such as superplastizers and silica fume to enhance the properties of concrete. Limited number of studies considered that using treated pumice with sodium hypochlorite could improve lightweight concrete strength. Abdulla et al. (2010) studied the effect of using treated rubber on the properties of lightweight cement mortar.

Kılıc et al. (2009) studied the effect of aggregates on lightweight concrete's (LWC) unit weight and strength characteristics. Five different lightweight concrete mixtures with five different aggregates were used to achieve the study objective: pumice aggregate lightweight concrete (PLWC) a scoria aggregate lightweight concrete (SLWC) and three scoria-pumice comixture aggregate lightweight concretes (SPLWC-I), (SPLWC-II) and (SPLWC-III). Average dry unit weights of (PLWC), (SLWC), (SPLWC-I), (SPLWC-

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II) and (SPLWC-III) mixtures were 1368, 1696, 1638, 1477 and 1997 kg/m^3, respectively. Specimens' compressive and flexural tensile strength and unit weight were determined at 28-day period. The result shows that the (PLWC), (SLWC), (SPLWC-I), (SPLWC-II) and (SPLWC-III) mixtures generated 15.8, 44.1, 30.5, 27.6 and 23.3 MPa compressive strength, respectively. Uğur (2003) studied the ability of improving the strength of lightweight concretes containing pumice aggregate using several additional admixtures and mixes. The experimental investigation conducted on Turkish pumice lightweight concretes showed that different types of additives could increase the strength of pumice. The increase in fine aggregates yielded high strength; thus, it is not desired to use high quantities of line aggregates, because of high density. Binici (2007) studied the effect of using crushed ceramic and basaltic pumice as fine aggregates on concrete mortars' properties. Results indicated that ceramic wastes and basaltic pumice concretes had good workability. It was also found that abrasion resistance has increased as the rate of fine crushed ceramic and crushed basaltic pumice increased. Fine crushed ceramic concrete had 30% lower abrasion than crushed basaltic pumice concrete. The compressive strength of concrete increased with fine crushed ceramic content.

Finally, results of this study showed that we can use fine crushed ceramic and crushed basaltic pumice very conveniently in concrete to achieve high abrasion resistance and high compressive strength. Abdulla et al. (2012) studied the properties of lightweight cement mortar using porcelain stone as fine aggregate. Porcelain stone as fine aggregate was used to produce lightweight cement mortar with good compressive strength. The porcelain stone was treated with sodium hypochlorite to improve the mechanical properties of this lightweight stone. The results show a significant improvement in the mechanical properties of cement mortar and a decrease in absorption of porcelain stone with a small increase in density of less than 8%.

This paper presents the results of an experimental investigation on the effect of using treated pumice stone as fine and coarse aggregates on lightweight concrete properties. Treated pumice was used as 100% replacement of fine and coarse aggregate in concrete mixtures. Untreated pumice aggregate was used to prepare reference mixtures. This study also investigated the effect of sodium hypochlorite on pumice properties. The experimental program was conducted on (150 x 150 x 150 mm) cubes and (150 x 300 mm) cylinders. Compressive strength was tested at an age of 7 and 28 days. Additionally, 100 x 100 x 100 mm cubes of pumice stone were used to determine pumice stone compressive strength, specific gravity, unit weight and abrasion resistance.

MATERIALS AND METHODS

Materials

Cement: Ordinary Portland cement (Type 1 produced by Lafarge Company) was used, where it was confirmed by ASTM C-150, Type 1.

Pumice: Pumice rocks used are from Al-Safawi region, east of Jordan. Pumice cubes were cut to cubes with approximately 100 mm cross-sectional dimension. Pumice cubes were crushed into different sizes to be used as fine and coarse aggregates (maximum size 20 mm) which were used to prepare control and treated concrete specimens. Table 1 shows the characteristics of pumice stone. Table 2 shows the sieve analysis test results for pumice aggregate.

Alkaline solution: Sodium hypochlorite (NaOCl) 0.1M, pH =12, was used to treat pumice stone.

Treatment and Mixing

Treatment: A total of six pumice cubes were immersed in NaOCl alkaline solution for 24 hours, then washed very well and dried in oven to remove the effect of alkaline solution on concrete. Thereafter, the compressive strength was tested. Table 1 shows characteristics of treated pumice as fine and coarse aggregates. Specific gravity and absorption for fine and coarse aggregates were obtained according to (ASTMC128-88) and (ASTMC127-88). Sieve analysis and abrasion were conducted according to (ASTM

C136-84a) and (ASTM C131-88). Figure 1 shows treated pumice cubes before and after crushing.

Mixing

All concrete mixtures were of the same proportions of concrete ingredients. The proportions of cement content, water content and pumice as fine and coarse aggregates were 336 kg/m^3, 246 kg/m^3, 519 kg/m^3 and 415 kg/m^3, respectively. The maximum aggregates size was 20 mm. The proportions were determined according to ACI-211mix design procedure and Neville and Brooks design of lightweight aggregate (ACI, 1991; Neville and Brooks, 2010) to achieve a 20 MPa compressive strength and 9.5 cm slump. Slump test was according to ASTM C143. Casting and curing of concrete cylinders and cubes were carried out according to ASTM C 39-86.

Table 1. Characteristics of pumice aggregate before and after treatment

Physical properties	Untreated pumice as fine aggregate	Untreated pumice as coarse aggregate	Treated pumice as fine aggregate	Treated pumice as coarse aggregate
Color	Dark grey	Dark grey	Black	Black
Compressive strength (MPa)	19.4		30.49	
Density kg/m^3	1096.5		1174.5	
Specific gravity	1.66	1.8	1.7	1.88
Absorption	8%	6.6%	6%	3.4%
Abrasion	-	55%	-	45%

(a) (b)

Figure (1): Treated pumice cubes (a) before crushing (b) after crushing

Table 2. Sieve analysis test results for pumice

Sieve size	Passing percent % for pumice aggregate
10.00 mm	97
5.00 mm	93
2.36 mm	77
1.18 mm	40
600 μm	33
300 μm	15
150 μm	11

RESULTS AND DISCUSSION

Color

Pumice cubes' color changed from dark grey to black after treating by NaOCl.

Density

Pumice cubes' density increased by about 7% under the effect of NaOCl solution, as shown in Table 3 and Table 4.

Specific Gravity

NaOCl solution caused a slight increase in the pumice specific gravity. Specific gravity of treated pumice used as fine aggregate is approximately 2.4% higher than untreated pumice, whereas specific gravity of treated pumice used as coarse aggregate is approximately 2% higher than untreated pumice, as shown in Table 1.

Absorption

Results showed that NaOCl solution decreased absorption percentage by about 25% and 48% for fine and coarse pumice aggregates, respectively, as shown in Table 1.

Abrasion

NaOCl solution increased pumice abrasion resistance. NaOCl solution decreased pumice abrasion ratio by about 3.85%, as shown in Table 1.

Compressive Strength of Limestone and Pumice Cubes

Table 2 shows the results of untreated pumice cubes' compressive strength. The results indicated that the average compressive strength of untreated pumice cubes is equal to 19.4 MPa. Table 3 shows that treated pumice cubes have an average compressive strength of 30.49 MPa. NaOCl solution increased compressive strength of pumice cubes by about 36% as compared with untreated pumice cubes. Figure 2 shows the compressive strength of treated pumice.

Table 3. Compressive strength of untreated pumice cubes

Cube #	Cube cross-sectional area (mm^2)	Sample volume (mm^3)	Sample mass (g)	Sample density (kg/m^3)	Compressive strength (N/mm^2)
1	96303	956697	1103	1152	21.8
2	10506	1071612	1198	1118	20.1
3	10100	99990	1075	1075	20.2
4	9120	866400	1032	1191	19.2
5	10815	1146390	1141	995	20.2
6	11128	1179568	1236	1048	15.2
Sum	147972	5320657	6785	6579	116.6
Av.	33273.5	1614103	2077.8	2001	35.2

Compressive Strength of Concrete Cubes and Cylinders

Table 5 shows that the compressive strength of concrete containing treated pumice cubes at ages of 7 and 28 days increased about 208% and 203%, respectively as compared with concrete containing untreated pumice aggregate. Table (6) shows that the average compressive strength of treated pumice concrete cylinders increased about 189% and 209% at ages of 7 and 28 days, respectively. Figures 2 and 3 summarize the results graphically. Figure 4 shows the compressive strength of treated pumice concrete cubes and cylinders.

The results show the high effect of a very inexpensive alkaline solution on the increase of concrete strength.

Table 4. Compressive strength of treated pumice cubes

Cube #	Cube cross-sectional area (mm^2)	Sample volume (mm^3)	Sample mass (g)	Sample density (kg/m^3)	Compressive strength (N/mm^2)
1	8648	769672	1013	1310	26.5
2	9408	921984	1075	1166	27.3
3	11448	119592	1136	954	36.1
4	10710	1145970	1162	1014	35.3
5	8930	866210	1126	1230	28.6
6	8740	795522	1092	1373	29.2
Sum	57884	4618950	6604	7047	182.9
Av.	17853.3	1411371	2032.5	2130.7	56.6

Table 5. Average compressive strength of concrete cubes with untreated pumice and treated pumice

	Age (days)	Untreated Pumice (MPa)	Treated Pumice (MPa)	Increment (%)
Mixture 1	7	14.2	30.7	216%
	28	23.2	46.2	208%
Mixture 2	7	15.5	32.3	200%
	28	23.8	47.2	198%

Table 6. Average compressive strength of concrete cylinders with untreated pumice and treated pumice

	Age (days)	Untreated Pumice (MPa)	Treated Pumice (MPa)	Increment Percent (%)
Mixture 1	7	14.2	26.9	189%
	28	21.2	44.5	209%

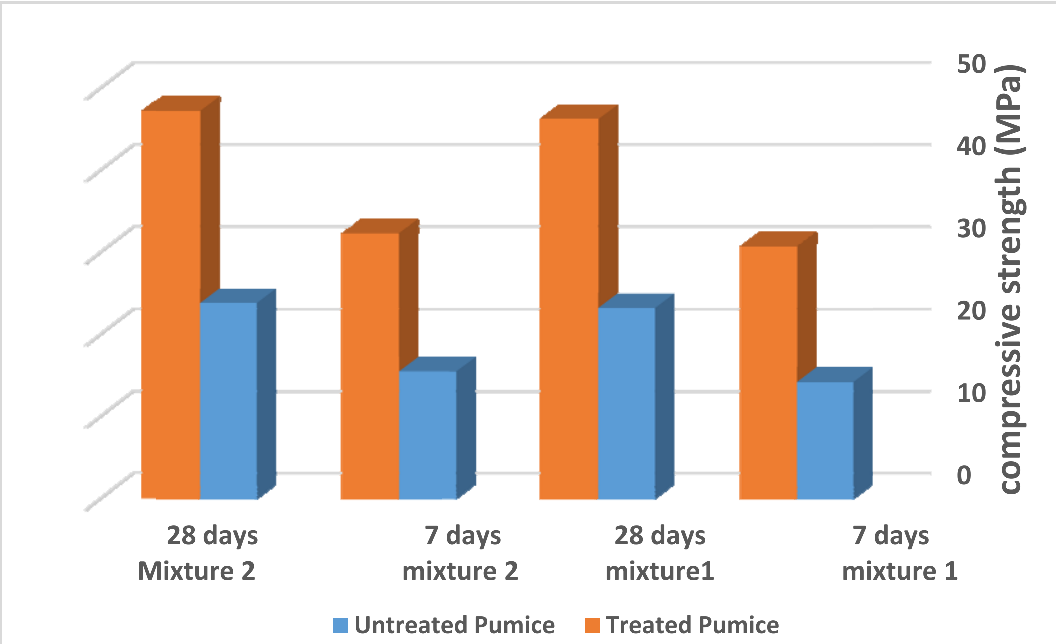

Figure (2): Average compressive strength of concrete cubes with untreated pumice and treated pumice

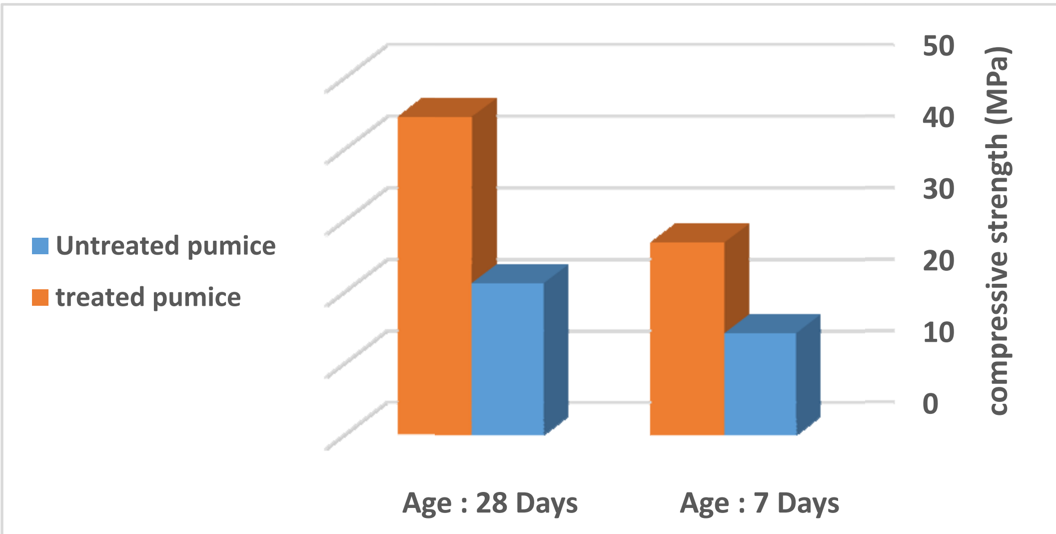

Figure (3): Average compressive strength of concrete cylinders with untreated pumice and treated pumice

(a) (b)

Figure (4): Compressive strength testing of (a) treated pumice concrete cubes (b) treated pumice concrete cylinders

CONCLUSIONS

NaOCl solution improves pumice properties, and thus the properties of concrete that contains treated pumice are improved. The following remarks can be summarized as per to the experimental study. It showed that NaOCl increased pumice density and specific gravity by about 7% and 2.4%, respectively. NaOCl also affected pumice abrasion resistance, where the abrasion percentage decreased by about 3.85%. With that said, NaOCl adversely affects pumice absorption and increases pumice compressive strength by app. 36% as compared to untreated pumice aggregate. Using treated pumice increases concrete compressive strength more than ten times compared to its original strength. Finally, using treated pumice is recommended to produce lightweight concrete with high strength.

Recommendation for Future Works

The author recommends to conduct SEM (Scanning Electronic Microscope) tests on concrete that contains pumice treated with NaOCl solution as well as several physicochemical tests on pumice treated with NaOCl.

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