Production of Lightweight Polymer Concrete with Pumice

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Abstract

Polymer matrix composites are popular for construction, aerospace and automotive industries due to offer manufacturing and handling ease. In the polymer matrix composites, polymer concretes have high strength. In this study, physical and mechanical properties of lightweight polymer concrete would be investigated by using pumice lightweight aggregate. In the production of polymer concrete, pumice aggregate in maximum size of 12 mm was used as lightweight aggregate. Pumice aggregate has indented and half-open porous surface texture, so it supplies a good bonding between the aggregate and binder paste. As binder material, epoxy resin based polymer was used with its hardener material. The binder/aggregate ratio was in ratio of 30% by weight. In addition, steel fibers were added to lightweight polymer concrete mixtures in ratio of 0%, 0.5% and 1%. After lightweight polymer concrete mixture was prepared, it was poured in the molds in size of 10x10x10 cm then, they were cured at 60 ^{o}C for two hours. On the hardened lightweight polymer concrete, compressive strength tests were determined. Moreover, ultrasonic pulse velocity, water absorption by weight, specific porosity and density experiments were carried out. The relation between physical and mechanical properties showed that polymer lightweight concretes become more durable depending on using ratio of steel fibers.

Keywords: *Polymer concrete, Lightweight, Pumice, Steel fiber, Properties.*

Introduction

In the world, the most often used material is concrete. Low costs, ease of application and high compressive strength are the main factors to be considered for a given application. Actually, concrete has disadvantages such as it can absorb water or be attacked by acids; property deterioration results in either case. These disadvantages can be remedied by using thermo-set polymer materials, which have hydrophobic nature and chemical inertness (Barrera and Brostow, 2009). The search for durable and sustainable construction materials inspires the developments in the world of cement

concrete, as well as in the world of concrete–polymer composites (Beeldens et al., 2004). In general when adding polymer it is desirable to obtain high compressive and flexural strength, high impact and abrasion resistance, service possible in adverse environments (wind, moisture, etc.), lower weight and lower costs. Polymer concrete (PC) materials have become a viable choice for the civil construction sector in developed countries, particularly in applications such as making reinforced slabs, overlays for highway pavements and bridge decks or pipe coatings (Fowler, 1999). PCs are also used in repairing deteriorated mineral concretes (Portland cement concrete) in situations when high strength, fast cure and durability are required (Bobadilla-Sanchez et al., 2009; Chen et al., 2006). Polymer concretes are composites in which the aggregates are bound together in a polymer matrix (ACI, 1997). They do not contain Portland cement. PC is a concrete-like composite, in which polymer such as epoxy resin or polyester resin, substitutes the cement binder (Czarnecki, 1985).

The main disadvantages of concrete polymer materials are their cost. The higher cost of polymer concretes makes its use almost forbidden for high volume applications except in cases where durability renders cement concrete unusable (Nóvoa et al., 2004). However, Oussama et al. (2012) reported that compressive, bending, ultrasonic wave's propagation, porosity and thermal conductivity tests show that when the polymer content is 13%, it leads to obtain the highest physical and mechanical properties at lowest cost. On the other hand, one way to minimize this limitation is the development of a lighter polymer concrete (Kılıç et al., 2010; Nóvoa et al., 2004). It can be produced easily with lightweight aggregates such as pumice. Pumice is essentially composed of solidified frothy lava which is generally rhyolitic in composition, but can also be produced in a less acidic form (Hossain and Lachemi, 2007). Aggregate strength ranges from very weak and porous, to stronger and less porous. Absorption is generally high, with the specific characteristics being largely dependent on the porosity and size of the aggregates (Topcu and Uygunoğlu, 2008; Uygunoğlu, 2008).

When the lightweight concrete containing the pumice was produced with the Portland cement, it has about from 5 MPa to 20 MPa compressive strengths depending on cement content, water to cement ratio. Also, if they contain the steel fibers, their strength and other mechanical properties can be increased. Sancak (1998) used the steel fibers in ratio of 0%, 0.5% and 1% by volume in the pumice lightweight aggregate concrete with 300 kg/m^3 Portland cement content. He used the pumice as coarse aggregate in his experiments. He reported that compressive strength of the specimens was 11, 17 and 13 MPa; density was 1835, 1860 and 1742 kg/m^3; water absorption was 10, 9 and 10%; modulus of elasticity was 18560, 22047 and 18526 MPa; ultrasonic pulse velocity was 3.15, 3.41 and 3.23 km/s depending on steel fiber content of 0, 0.5 and 1%, respectively. Düzgün et al. (2005) investigated the effect of steel fibers on the mechanical properties of pumice aggregate concrete. In order to determine the effect of steel fiber ratio on the mechanical properties of concrete, 25%, 50%, 75%, and 100% pumice ratios were used instead of natural aggregate by volume, 0.5%, 1.0%, and 1.5% steel fiber ratios were used by volume of the sample and also, 300 kg/m^3 cement dosage were used. The test results showed that the increasing pumice aggregate ratio decreased the unit weight and the mechanical properties of the concretes. When compared to the control sample that contains no fiber, with the increase of steel fiber ratio in the mixtures unit weight, compressive strength, splitting-tensile strength and flexural strength of concretes increased up to 8.5%, 21.1%, 61.2% and 120.2%, respectively. Altun (2006) produced the lightweight aggregate concrete with pumice in 400 dosages. He added steel fibers to

the lightweight concrete in the amounts of 10, 20, 30, 40, 50 and 60 kg/m^3. The specimens had compressive strength of from 18 to 19 MPa and density of 1431 to 1588 kg/m^3 depending on steel fiber content. Rossignolo and Agnesini (2004) investigated the some properties of lightweight polymer concrete produced with rubber latex such as corrosion resistance, durability to chemical effects and water absorption properties. Dry density of the lightweight polymer concretes were changed between 1450 and 1650 kg/m^3, and compressive strength ranged from 40 to 52 MPa at 7 days. In other study, Rossignolo and Agnesini (2002) investigated the mechanical properties of lightweight polymer concrete produced with rubber latex. They reported that water absorption is decreased, tensile and compressive strength was increased if the polymer lightweight concretes are used.

In this study it was aimed that obtaining the concretes which have higher strength, lower water absorption and lighter than Portland cement lightweight concrete by using polymer, steel fiber and pumice aggregate.

Experimental Study

Materials Used

Polymer concretes are produced by using dry pumice aggregates and monomers (binders) that undergo polymerization (curing, hardening). Epoxy resin which has a large variety of applications was used. It exhibits good dimensional stability, high heat resistance, high mechanical strength and chemical resistance. The selection of the type of epoxy resin was based on the requirement of curing at room temperature, heat evolved during curing on the low side and pot-life suitable for industrial applications. It has two components as A and B (hardener) in density of 1050 kg/m^3 and 1100 kg/m^3, respectively.



Figure 1. Steel fibers used in the lightweight polymer concrete

Also, steel fibers used in the production of polymer specimens. The fiber lengths (l) was 13 mm, the diameters (d) was 0.6 mm; therefore, the aspect ratio (l/d) was 21.7 (Fig. 1). All aggregates (fine and coarse) were pumice in maximum size of 12 mm. Pumice was supplied from Isparta/Turkey and its characteristic properties and grain size are presented in Table I and Table II, respectively.

Table I. Characteristic properties of pumice

Properties	**Pumice**	**Standard**
Density, kg/m^3	739	TS EN 1097-3
Water absorption, %	28.75	TS EN 1097-6
Loss of wear resistance (coarse) (Los Angeles), %	52.62 (LA_{53})	TS EN 1097-2

Table II. Sieve analyses of lightweight aggregates

Sieve, mm	16	8	4	2	1	0.5	0.25
Passing, %	100	59	46	39	27	17	9

Production of Specimens and Tests

For cubic meter 1000 kg pumice were used. Epoxy resin ratio was 30% after pre-productions. So, at lower values, mixture was not made by stirring. Epoxy was used as a component is 285 kg and B component is 142 kg for cubic meter. Except for control series, steel fibers were added to mixture 100.6 kg and 213.3 kg, respectively, to produce the 0.5% and 1% steel fiber (by volume of concrete) polymer concrete. Before the specimens are poured, epoxy separator was sprayed on the steel molds. The fresh polymer lightweight concrete (PLC) was placed in 100x100x100 mm cubic molds without shaker and they were de-moulded after 24 h.

The specimens were cured in at 60 ºC for 2 h, and then they were kept for 7 days. On the specimens, compressive strength was defined according to TS EN 12390-3 (2010) by compressive machine with a rate of loading controller. Unit weight, specific porosity and water absorption were defined on 7 days aged specimens according to Archimedes principle. It was made by the weight measurements of saturated specimens on air and in water, and dry weight (oven drying at 105 ºC to constant weight). Ultrasonic pulse velocity was defined on the cube specimens. Dynamic modulus of elasticity was also calculated from ultrasonic pulse velocity and density of testing materials at direct transmission of testing samples. Dynamic modulus of elasticity E_d (MPa) was calculated according to (2):

$$E_d = V^{2\rho}(1+\upsilon)(1-2\upsilon)/(1-\upsilon) \quad (1)$$

Where; E_d is dynamic modulus of elasticity; ρ is density (kg/m^3); V is ultrasonic pulse velocity (km/s); υ is the Poisson ratio (= 0.20).

Results and Discussions

The development of compressive strength of PLC containing the pumice aggregate is given in Fig. 2, showing the strengths at 7 days depending on steel fiber content. It was observed that compressive strength of PLC increased by improving the steel fibre content. It has compressive strength of 23, 26 and 24 MPa for steel fiber content of 0%, 0.5% and 1%, respectively. It can be also clearly seen that there was increase on compressive strength of PLC in ratio of about 18% and 9% by increasing of steel fiber content from 0.5 to 1%, respectively. Increase of fiber content resulted with decrease of strength because of decreasing the workability of concrete. But still PLC has two times compressive strength values at 7 days when compared to normal lightweight concrete (NLC) with pumice in dosage of 300 at 28 days (Sancak, 1998). Increase in compressive strength of PLC when compared to NLC mainly depends on strength gaining of the epoxy with its hardener and temperature. Epoxy resin gains higher strength values under temperature with strong cross-links (Brostow, 2007; Akınay et al., 2002). Also, the half-open porous structure of pumice aggregate is mostly influenced to increasing of compressive strength by improving to adherence between binder and aggregate. On the other hand, because of half-open surface structure of pumice, polymer concrete need more binding material (epoxy resin) than polymer concrete with normal aggregate. It may be a disadvantage for producing of PLC due to its expensive price.

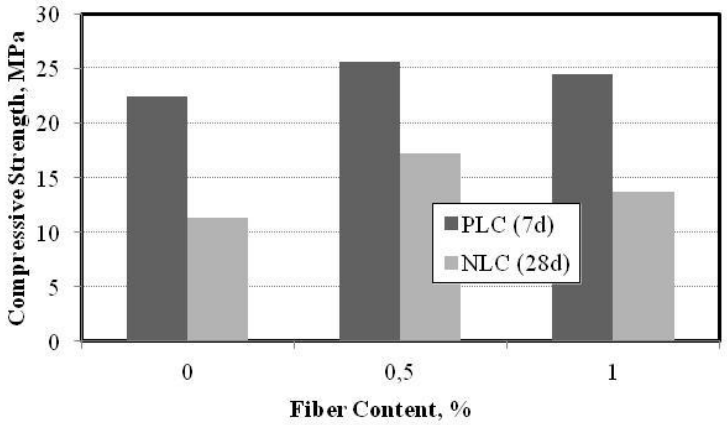


Figure 2. Compressive strength of LPC

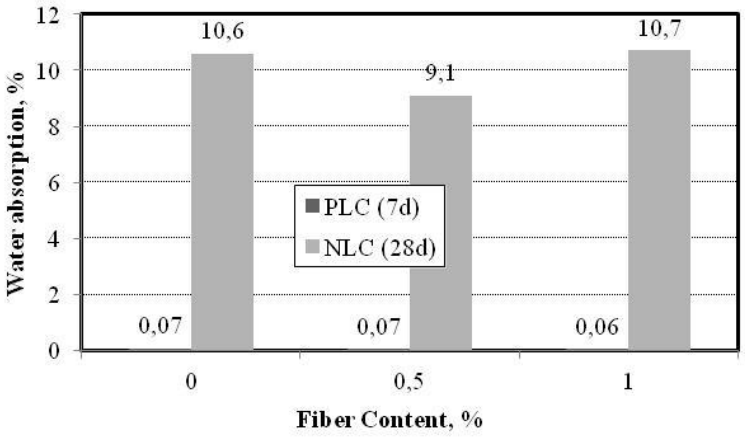


Figure 3. Comparison of water obsorption of PLC and NLC

As the another results in this study, it was observed that water absorption of PLC specimens almost zero (Fig. 3). So, they have water absorption values as 0.071, 0.07 and 0.06% by weight altougth they produced with lightweight aggregate (pumice) with water absorption ability of about 28%. On the other hand, NLC specimens have 11, 9 and 10% water absorption values (Sancak, 1998). It means that PLC specimens quite durable to chemical and physical effects depending on water transportation to inside of the specimens (Martinez-Barrera et al., 2011).

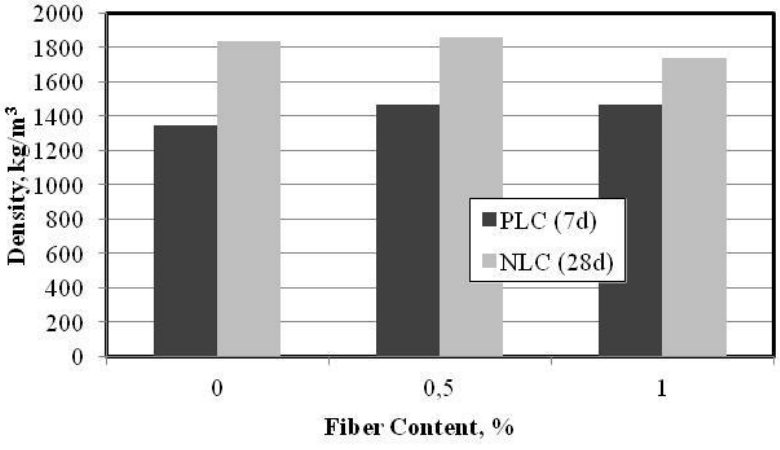


Figure 4. Density of PLC specimens

The most important aim of using lightweight concrete is to take advantage of their densities to decrease the dead-load of structures. When the density of PLC that given in Fig. 4 was analyzed, it can be clearly seen that density of PLC is lower than NLC in all the steel fiber content. The density of PLC is lower in ratio of 25%, 21,6% and 17% than NLC for 0, 0.5 and 1% fiber content, respectively. In other words, dead-load of the structures may be reduced at these ratios by using PLC instead of NLC. But their cost must be considered too.

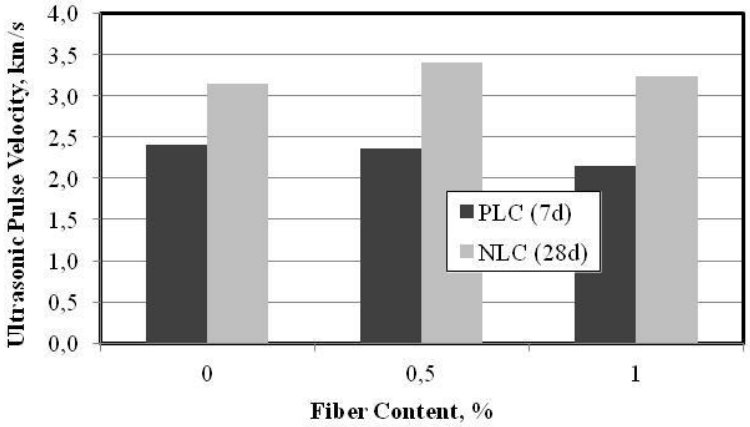


Figure 5. Ultrasonic pulse velocity of PLC

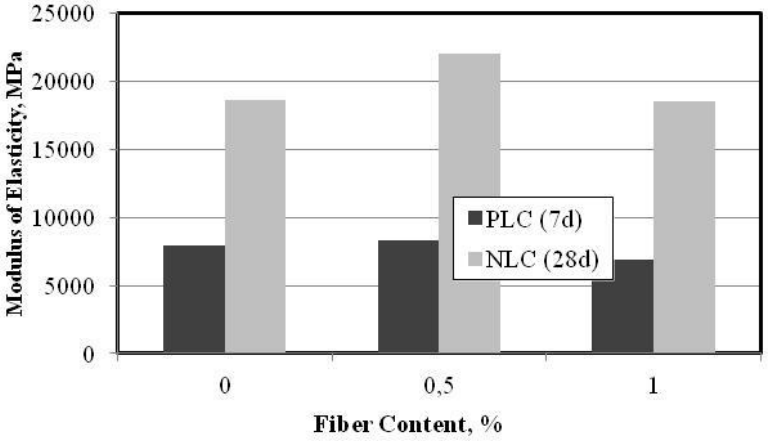


Figure 6. Dynamic modulus of elasticity of PLC

The ultrasonic pulse velocity (UPS) is used as an indicator for strength of cementing materials. So, there are many studies on relationship between UPS and strength of concretes. If the UPS increases, the quality of the cement based concrete becomes better, depending on its density or porous structure, when compared with low quality concrete. However, although the strength values of PLC are higher than NLC, the UPS values are lower than that of NLC. It may be understood from the Fig. 5 that UPS values are as an indicator for insulating properties of PLCs. So, as known from the literature, thermal conductivity mainly depends upon the density and moisture of concrete (Brito and Sanchez, 2000). The thermal conductivity increases with increase of density or compactness of concrete. It would be think that PLC has lower thermal conductivity than NLC depending on their density. Dynamic modulus of elasticity was given in Fig. 6. Dynamic modulus of elasticity of PLC changes between 6500 and 8000 MPa. But, it changes between 18000 to 23000 MPa for NLC. As seen, dynamic

modulus of elasticity of PLC is three times lower than that of NLC. Fiber content does not effect to elasticity in PLC. However, the highest dynamic modulus of elasticity was obtained in 1% fiber content.

Conclusions

In this study, usage of pumice aggregate as lightweight aggregate in the polymer concrete. According to experimental results, compressive strength is about twice according to Portland cement lightweight concrete with pumice. In addition, it doesn't absorb the water with absorption values of about 0.07%. The density is lower about 25% than NLC. In general, when experimental results are considered, it would be seen that PLC gives better mechanical and physical properties when compared to concrete type with ordinary Portland cement due to its unique and desirable properties such as higher compressive strength, very lower/without water absorption, lower density and lower ultrasonic pulse velocity values. But it was mentioned before, epoxy is expensive. Therefore it may be used for special applications.

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