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Full Length Research Paper

The effect of the rock type forming the aggregate in lightweight polymer concrete on compressive and flexural tensile strength

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In this study, lightweight polymer concrete samples were produced with limestone (Ceyhan, Adana), pumice (Nevsehir) and zeolite (Gordes, Manisa) as a binder resin, and compressive and flexural tensile strength of these samples were determined via laboratorial experiments. For the study, the cylinder and prismatic samples of polymer on normal aggregate concrete (NAC), polymer on normal and lightweight aggregate mixture concrete (NLAC) and polymer on lightweight aggregate concrete (LWAC) were prepared. The polymer concrete produced was cured 3, 7, 28 and 90 days. The concrete samples were cured at 65% relative humidity with 20°C temperature. The density and slump workability of concrete mixtures were also measured. Laboratory test results showed that lightweight polymer concretes can be produced by the use of limestone, pumice, zeolite and as a binder resin. The use of mixture was recomended due to its satisfactory strength development.

Key words: Polyester resin, compressive strength, flexural tensile strength, aggregate type, curing time.

INTRODUCTION

Polymer concrete (PC) is a concrete-like composite, in which a resin binder and polyester resin, substitutes the cement binder (Czarnecki, 1985). Today, PC is used very efficiently in precast components for buildings, bridge panels, hazardous waste containers, machine bases, and in various utility and transportation components (Abdel-Fattah and El-Hawary, 1999).

Polymer concrete that came into being years ago as a construction material and is still used in this way is considered by machine tool manufacturers as an alternative to cast iron and steel especially for the production of machine tools beds (Capuano, 1987; Czarnecki, 1985; Renker, 1985). Important applications include repair and anti-corrosion protection of concrete structures (including industrial floors) as precast elements, such as manholes, pipes and chemically resistant vessels (e.g. electrolytic cells) (Czarnecki et al., 2000).

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Resin or polymer concrete possesses higher strength, higher ductility and faster hardening than conventional concrete along with controlled shrinkage. Due to economic reasons, the use of resin concrete was limited to repair work. With the increasing number of manufacturers and the improved production technology, however, the cost of resins is declining and their structural use, other than repair, is becoming feasible. Resin concrete may be utilized in the manufacture of structural members or in casing joints or layers in conventional concrete to increase the ductility of the structure (El-Hawary and Abdel-Fattah, 2000).

Improved mechanical strength and chemical resistance are basic advantages of PC in comparison to ordinary Portland cement concrete (Czarnecki et al., 2001). According to the general classification of composites (Ashby, Jones, 1986), both the Portland cement concrete and PC can be treated as a particulate composite with two main constituents: A matrix and dispersed particles of strengthening phases (Czarnecki et al., 2001). The aggregate in concrete-like composites is mainly added to control the crack propagation and reduce material cost

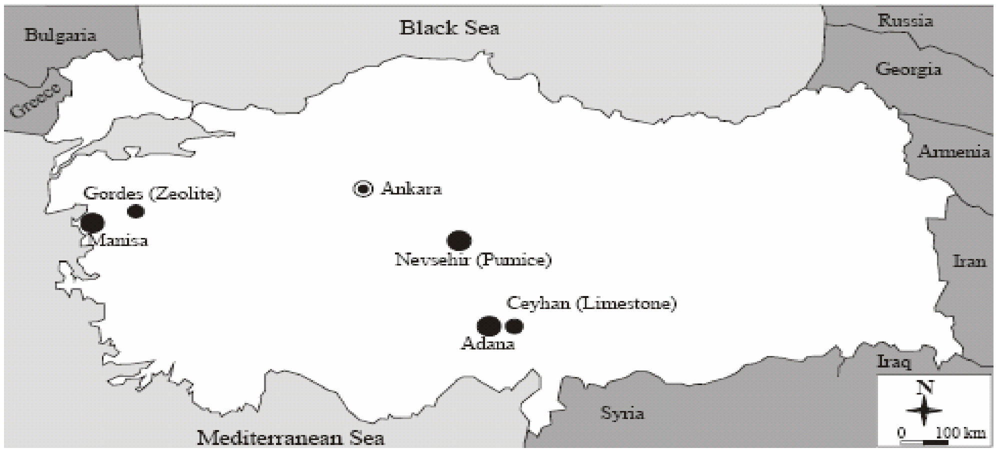

Figure 1. Location map of aggregates.

Table 1. The results of physical and mechanical properties of resin.

Properties	Values
Specific gravity (kg/m^3)	1285
Tensile module (GPa)	2.3
Shear module (GPa)	1.75
Flexural tensile strength (MPa)	78
Compressive strength (MPa)	140
Poisson ratio (%)	0.35
Viscosity (20°C, cps)	350
Elongation of failure (°C)	5
Thermal strain coefficient Cm/cmx°C^{-1}(×10)$^{-6}$	68
Utilization temperature (°C)	100
Tensile ratio (%)	9

(Brandt and Prokopski, 1993).

Polymer concrete (PC) and mortars (PM) have gained an increasing research interest due to their wide range of possible applications in civil construction (Fowler, 1999; Czarnecki, 2001; Letsh, 2002; Rebeiz and Craft, 2002).

The main limitation of concrete polymer materials is their cost. Even considering that the specific gravity of cement is about 21/2 times that of polymer, the cost per unit volume of polymer concretes is still significantly higher than Portland cement concrete. The higher cost of polymer concretes makes its use almost forbidden for high volume applications except in cases where durability renders cement concrete unusable. One way to minimize this limitation is the development of a lighter polymer concrete (Nóvoa et al., 2004).

The general class of lightweight aggregates encloses a wide range of products. From natural organic/mineral products (wood, cork, rice husk and products from volcanic source), to artificial products specially manufactured for the effect (expanded clay, shale or slate), as well as industrial sub-products and wastes (expanded slogs and civil construction debris), a large spectrum of lightweight aggregates has been produced and/or applied in the last years for construction purposes (Nóvoa et al., 2004).

The main objective of this investigation was to design a structural lightweight concrete with the use of limestone, pumice, zeolite and as a binder resin that will provide an advantage of reduction in dead weight of a structure; and is to obtain the a more mechanical durability of lightweight concretes.

MATERIAL USED IN THE INVESTIGATION

In this study, the employed limestone, pumice and zeolite were taken from Ceyhan (Adana), Nevsehir and Gordes (Manisa) respectively (Figure 1). The compressive and flexural tensile strength values of the polymer obtained using limestone on normal aggregate polymer (NAC), the polymer obtained using limestone, pumice and zeolite on normal and lightweight aggregate concrete (LWAC) and the polymer obtained using pumice and zeolite on lightweight aggregate concrete (LWAC) were calculated. The experiments were carried out by subjecting the samples to 3, 7, 28 and 90 days of curing periods.

Polyester resin

Polyester resin was chosen to produce the polymer. There are many kinds of polyesters available in the market. Among these, unsaturated isophatalic polyester resin was chosen.

Polymer concrete made from isophatalic polyesters is hard and rigid, and has high mechanical strength. Also, this resin was preferred because of its low cost, but there is the risk of cracking with thick block mouldings due to the internal stresses related to shrinkage of the resin (Saylan, 1991). The physical and mechanical properties are given in Table 1.

Aggregate

Ceyhan (Adana) limestone, Nevsehir pumice and Gordes (Manisa) zeolite was used as the aggregate in the production of lightweight polymer concrete. Chemical analysis of aggregates was carried out. Among aggregates, six samples were obtained from the area, and

Table 2. Chemical composition of aggregate.

Content (%)	Limestone	Pumice	Zeolite
CaO	55.26	2.85	1.85
SiO_2	0.29	65.25	70.75
Al_2O_3	0.62	14.25	12.88
Fe_2O_3	0.21	1.75	1.81
MgO	0.87	1.05	1.23
Na_2O	0.22	4.50	0.65
K_2O	0.02	6.25	3.62
TiO_2	-	0.35	0.1
LOI	42.51	3.75	7.11

Table 3. The results of physical and mechanical properties of aggregates.

Properties	Limestone	Pumice	Zeolite
Specific gravity (kg/m^3)	2650	2250	2850
Porosity (%)	0.68	75	12.45
Water absorption (%weigth)	0.08	76	12.50
Hardness (MOHs)	3	5.5	3.5
Spesific surface (cm^2/g)	4700	2820	13900
UCS (MPa) (dry samples)	98.2	0.41	49.5

the averages of the chemical testing results are shown in Table 2.

The physical and mechanical properties of the rocks were determined using testing methods recommended by International Society of Rock Mechanics (ISRM) (ISRM, 1981), and according to Turkish standards (TS) (TS 699, 1987) (Table 3). Aggregates were dried at 105°C for 24 h in oven and were divided in seven groups (0 - 0.25, 0.25 - 0.5, 0.5 - 1.0, 1.0 - 2.0, 2.0 - 4.0, 4.0 - 8.0 and 8.0 - 16.0 mm) by sieving.

MIXTURE PROPORTIONS AND SAMPLE PREPARATION

Polymer mortar mixture formulations were 1:4 polyester resin and aggregates. Mix proportions of polymer mortar formulations are presented in Table 4. For a good curing, an accelerator catalyst (Cobalt Octoat) was added into the resin, and the mixture was stirred properly. Subsequently, adequate hardener (MEK Peroxide with moderate reactivity) was inserted. For desired curing, the resin temperature was kept over 20°C.

Aggregates were crushed and separated according to their size. It was sieved using standard sieves and separated into seven groups consisting of 0 - 0.25, 0.25 -0.50, 0.50 - 1, 1 - 2, 2 - 4, 4 - 8 and 8 - 16 mm. The combinations of separated aggregates were obtained with such a grading that complies with the requirements of TSI 706 (TS 706, 1980). Grading of mixed aggregates was presented in Table 4. Mixed aggregate grading was between the lower limit and medium limit of the standard which was required.

With these binder formulations and mix proportions, polymer mortars were mixed and moulded to prismatic (40 × 40 × 160 mm) and cylinder (Ø 50 × 100 mm) specimens, according to the RILEM standard CPT PC-2. For each formulation, five prismatic and three cylinder specimens were cast. All specimens were allowed to cure for 3, 7, 28 and 90 days at room temperature and then post-cured at 70°C for 3 h, before being tested in compression and flexural tensile strength compression.

RESULT AND DISCUSSION

Average fresh and air dry unit weight of RS1, RS2, RS3, RS4, RS5 and RS6 polymer on normal aggregate concrete (NAC), polymer on normal and lightweight aggregates mixture concrete (NLAC) and polymer on light-weight aggregate concrete (LWAC) were given in Table 4.

The air dry densities of the polymer mixtures obtained depending on the aggregate types used in the study were varied. The air dry density of NAC, obtained using only limestone, was higher by nearly 28 - 58% compared to the density of NLAC obtained from RS2, RS3 and RS4 mixtures. However, the air dry density of LWAC, obtained from RS5 and RS6 mixtures by using light aggregate was quite lower than that of NAC (from 90 - 94%).

The average cylinder compressive strengths of the polymer concrete are presented in Figure 2. The compressive strength of polymer concretes varied depending on the utilized aggregate type and the curing time. The compressive strengths values of NAC, obtained from RS1 mixture, was found to be 74.10 MPa for 28 cure days, whereas, it was 56.45 - 64.45 for NCAC, obtained by RS2, RS3 and RS4 mixtures. As to LWAC, obtained from RS5 and RS6 mixtures, it was found to be 54-55.75 MPa. The standard variations of the compressive strength varied from (28 days-3 months of age) 5 - 8% (Table 5).

The average flexural tensile strength of the polymer concrete studied was presented in Figure 3. The flexural tensile strength values of polymer concretes varied depending on the utilized aggregate type and the curing time, like in the compressive strength. The compressive strength of polymer concretes varied depending on the utilized aggregate type and the curing time. The compressive strength values of NAC obtained from RS1 mixture, was found to be 13.85 MPa for 28 cure days, while it was 10.75 - 12 for NCAC obtained by RS2, RS3 and RS4 mixtures and 10.15 - 10.35 for LWAC obtained from RS5 and RS6 mixtures. The standard variations of the flexural tensile strength varied from (28 days-3 months of age) 2 - 5.5% (Table 5).

Either compressive or flexural tensile strength of obtained polymer concretes varies depending on the air dry densities of the mixtures (Figures 4 - 5). As the air density of the mixtures increases, the compressive and flexural tensile strengths increase too.

There is a fairly significant correlation (R^2 = 0.98) between the compressive and flexural tensile strength values of the polymer concretes obtained from the mixtures (Figure 6).

Table 4. Approximate polymer concrete mixture composition (kg).

		*RS1			RS2			RS3			RS4			RS5			RS6		
		405			405			405			405			405			405		
		*Lim.	*Pum.	*Zeo	Lim.	Pum.	Zeo.	Lim.	Pum.	Zeo.	Lim.	Pum.	Zeo.	Lim.	Pum.	Zeo.	Lim.	Pum.	Zeo.
Aggregate size in (mm) (sieve fractions)	8.0-16.0	300.0	-	-	150.0	75.0	75.0	75.0	150.0	75.0	75.0	75.0	150.0	-	300.0	-	-	-	300.0
	4.0-8.0	275.0	-	-	137.5	68.75	68.75	68.75	137.5	68.75	68.75	68.75	137.5	-	275.0	-	-	-	275.0
	2.0-4.0	250.0	-	-	125.0	62.5	62.5	62.5	125.0	62.5	62.5	62.5	125.0	-	250.0	-	-	-	250.0
	1.0-2.0	225.0	-	-	112.5	56.25	56.25	56.25	112.5	56.25	56.25	56.25	112.5	-	225.0	-	-	-	225.0
	1.0-0.5	195.0	-	-	97.5	48.75	48.75	48.75	97.5	48.75	48.75	48.75	97.5	-	195.0	-	-	-	195.0
	0.25-0.5	150.0	-	-	75.0	37.5	37.5	37.5	75.0	37.5	37.5	37.5	75.0	-	150.0	-	-	-	150.0
	0.0-0.25	125.0	-	-	62.5	31.25	31.25	31.25	62.5	31.25	31.25	31.25	62.5	-	125.0	-	-	-	125.0
	*Tot %	100.0	0.0	0.0	50.0	25.0	25.0	25.0	50.0	25.0	25.0	25.0	50.0	0.0	100.0	0.0	0.0	0.0	100.0
	Tot (g)	1620.0	0.0	0.0	810.0	405.0	405.0	405.0	810.0	405.0	405.0	405.0	810.0	0.0	1620.0	0.0	0.0	0.0	1620.0
Fresh density (kg/m^3)			2385 ± 28			1855 ± 34			1530 ± 32			1505 ± 26			1250 ± 24			1225 ± 32	
Air dry density (kg/m^3)			2125 ± 33			1765 ± 23			1460 ± 27			1425 ± 21			1185 ± 35			1150 ± 18	

*RS: Resin; *Lim.: Limestone; *Zeo.: Zeolite; *Pum.: Pumice; *Tot.: Totale.

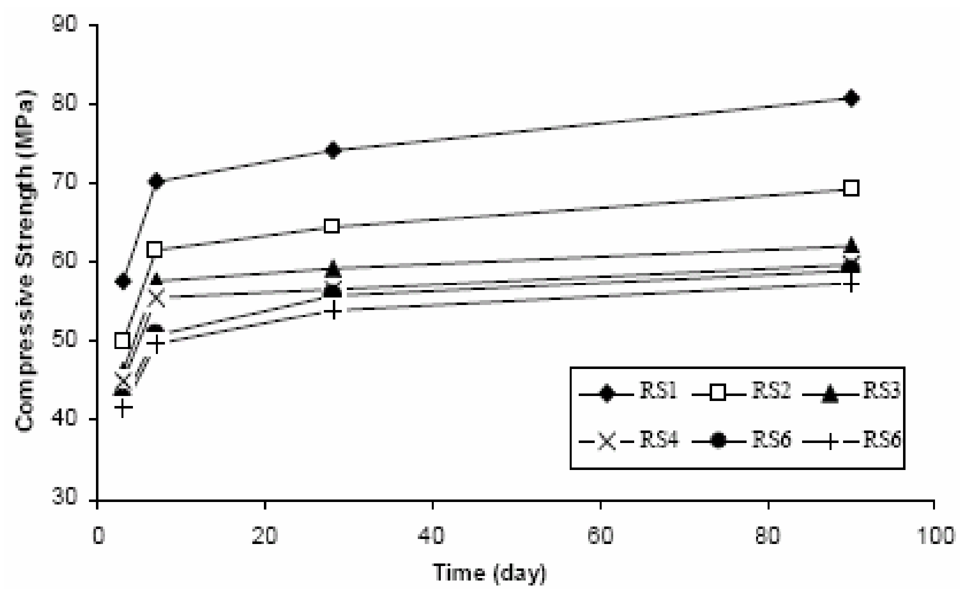

Figure 2. Compressive strength of lightweight polymer concrete.

Table 5. Compressive and flexural tensile strength of lightweight polymer concrete.

Mix code	Compressive strength (Mpa)				Flexural tensile strength (Mpa)			
	3 days	7 days	28 days	3 months	3 days	7 days	28 days	3 months
RS1	57.60	70.25	74.10	80.70	10.20	12.75	13.85	14.50
RS2	50.10	61.60	64.45	69.25	8.75	11.10	12.00	12.65
RS3	46.25	57.75	59.10	62.00	7.90	9.95	11.05	11.60
RS4	44.95	55.50	56.45	59.85	7.75	9.70	10.75	11.10
RS5	42.70	50.85	55.75	59.05	7.50	9.45	10.35	10.75
RS6	41.45	49.85	54.00	57.25	7.35	9.20	10.15	10.25

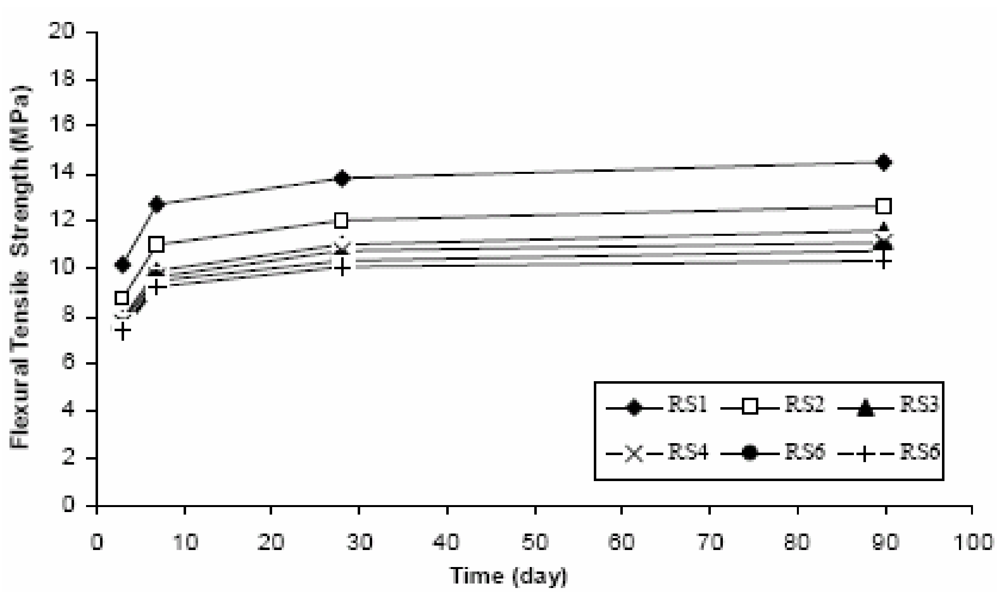

Figure 3. Flexural tensile strength of lightweight polymer concrete.

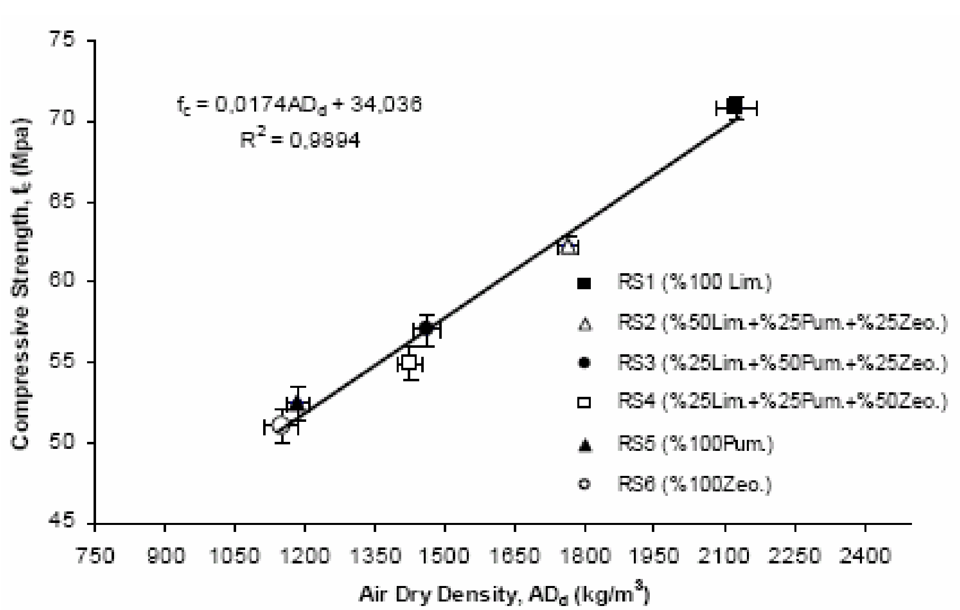

Figure 4. The relation between air dry density and compressive strength.

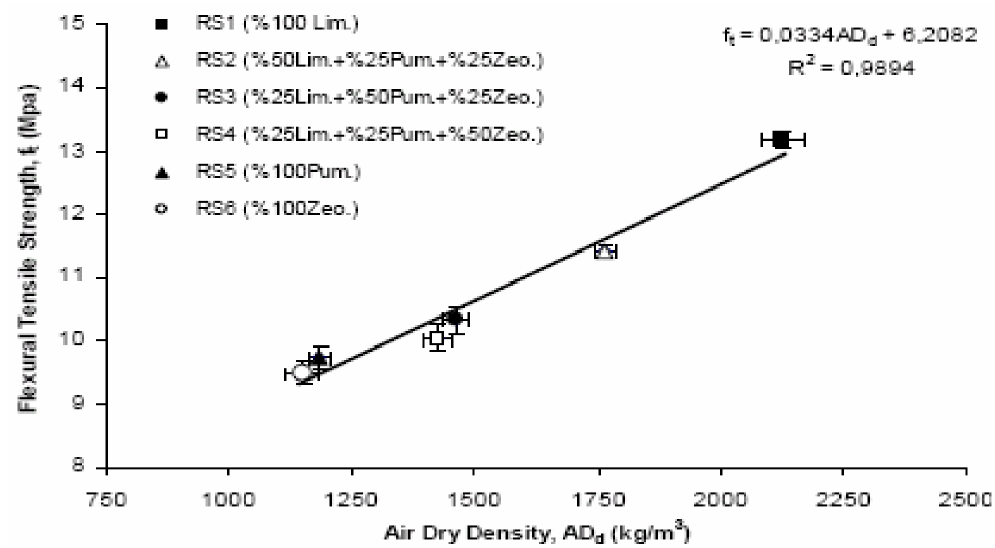

Figure 5. The relation between air dry density and flexural tensile strength.

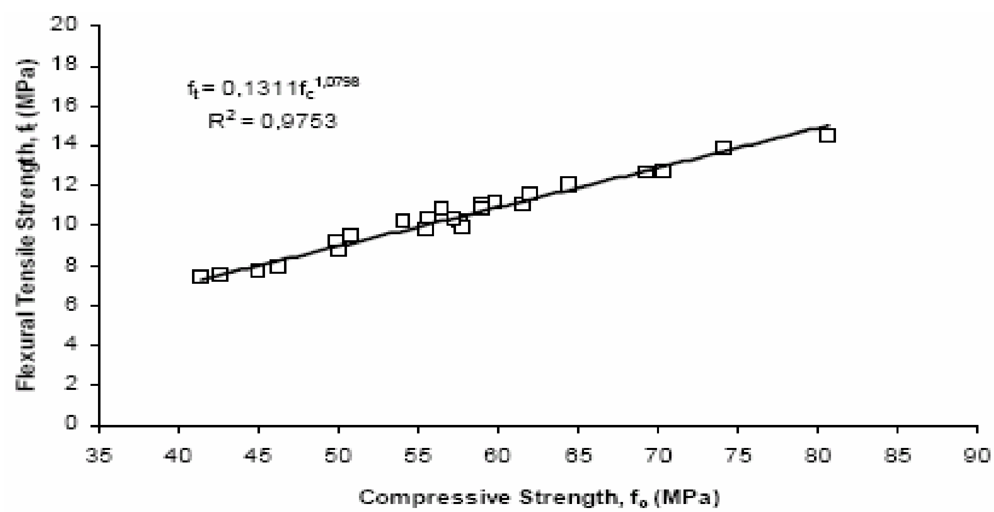

Figure 6. The relation between flexural tensile and compressive strength.

In general, all the polymer concretes produced developed satisfactory flexural tensile strength ranging from 10.30 - 13.85 MPa at 28 days of age.

The ternary LWAC mixture (RS5 and RS6) made with scoria aggregate developed 54 - 55.75 MPa compressive strength and 10.10 - 10.75 MPa flexural tensile strength at 28 days. The strength achieved is higher than 35 MPa, which is accepted as lower limit of compressive strength for SLWHSC (Holm and Bremner, 2000; Holm,1994).

Conclusions

Based on the results of experimental work, lightweight aggregate can be used in the production of NLAC and LWAC. As a result of the study, it was found that, for 28-days of curing period, the compressive strength values varied from 60 - 80 MPa while the flexural tensile strength varied between 6 and 8 MPa. Achieved values are rather high. The compressive and flexural tensile strength values of the polymer concrete samples which were obtained depending on the aggregate types were varied. LWAC light polymer concretes, which was obtained using Nevsehir pumice and Gordes (Manisa) zeolite, were very remarkable. The compressive strength (between 54 - 55.75 MPa) and flexural tensile strength (between 10.15 - 10.35 MPa) values of these polymer concretes for 28 days of curing were very high. On the other hand, their air dry densities were remarkably low (1150 - 1185 kg/m^3), which is a significant advantage.

In summary, the strength values of the produced lightweight concretes are rather high. Some parts of southern Turkey are in the first seismic danger zone, while some parts of it are in the second seismic danger zone of the country. The lightweight aggregate can be utilized in its locality to reduce the risk of earthquake acceleration by using it in the production of LWAC. Moreover, such polymer concretes enjoy certain features; making them reliable for being used in various field of the construction.

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