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EXAMINING THE MECHANICAL FEATURES OF POLYMER CONCRETE BY ADDING VOLCANIC TUFF

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ABSTRACT

Despite a considerable amount of research on concrete, it still demands more examination and experiments as these materials have been expanded to a verity of forms including Nano concrete or polymer concrete. Polymer concrete is a material with high performance and by adding different amounts of volcanic tuffs to the polymer concrete we could examine the effects of these amounts on the properties and features. The results show that if a suitable amount of volcanic tuff is added to polymer concrete, the elastic and mechanical properties of the concrete is promoted; consequently, the volcanic tuff can make the structure of concrete homogeneous and dense. The aim of this research was to obtain a familiarity with the stages of the experiment and the samples of mixture design and finally the results of the experiment.

Keywords: polymer concrete, volcanic tuffs, flexural tensile, compressive strength, elasticity modulus

INTRODUCTION:

Since Iran enjoys a large amount of volcanic tuffs in Alborz mountain range, the significance of this material has been stressed more and more by the engineers. This study aims to identify the sources which could enhance the efficacy and amelioration of the materials. Although cement has been widely used due to its cost and availability, the experiments have confirmed that this cement lacks appropriate durability during the exploitation [14]. Since the last decade, more attention has been directed towards new composite materials such as polymer concrete (PC), and it intends to replace Portland cement in thepolymer modified concrete (PMC). The reports and studies have discovered some important benefits of PMC of which mention could be made of decreasing the corrosion and increasing the durability; as a result, permeability would be achieved [5].

The polymer concrete is considered as a material with the high performance; enhanced mechanical properties, its resistance against corrosion, weathering, being water and fire proof are some of the benefits of the polymer concrete [4].

The objective of the present study is to determine the benefits of using volcanic tuff as a filler in polymer concrete. Tuff has shown to have a great Pozzolanic activity when integrated with cement [16]. The effect of Pozzolan as a natural feature or generated feature which has been offered by the materials is enough to produce materials which would create adhesion properties through the chemical reactions with calcium hydroxide in the presence of enough humidity. Since there is no calcium hydroxide in polymer concrete, tuffs are used to replace them withaggregates in the river and this feature in the polymer concrete could enhance its mechanical properties and durability.

Epoxy Resin Materials:

When the temperature increases, the used epoxy resin gets hard. The employed chemical composition [13] is based on the existing diphenyl A in the market.Its dynamic viscosity is based on the 10000 to 15000megapascal per second (in the temperature of 25 Celsius) and epoxy weighs 182 to 196 grams.

Natural Aggregates:

This study favored manufactured aggregates in two types of aggregates: between 0 to 4 millimeters and 4 to 8 millimeters. They were oven-dried before being used in the mixture.

Volcanic Tuffs:

Volcanic tuffs are produced by the volcanic activities: these are dense stones which are produced when the volcanic ash gets cementation. Volcanic tuffs are usuallysoft and spongy. Since they lack resistance, they cannot be used as materials in buildings. Notwithstanding this, it has been proved that in the high temperature they have a greatPozzolanic activity.

In this article, tuff is broken enough to have grains with the maximum size of 75 centimeters. Our objective in this study was to replace some natural grains in the mixture. Considering tuffs as microfiller seems vital.

The Experiment:

The Ratio of Mixture and Samples:

The ratios of mixture, based on the polymer concrete, are presented in Table 1. The lowest level of used resin is 9 percent (of the total weight) and the most used amount of volcanic tuff is 16.2 percent, these percentages were chosen by considering some limitations. In addition to the six considered plans of the mixture, two plans of mixture have been employed using resin and natural aggregates to evaluate the effects of resin percentage on the engineering properties of the polymer concrete. Two kinds of aggregates with the similar percentage for each of the mixture ratios are presented in Table 1.

Table 1: The Ratio of the Considered Mixture in the Article

Type	Resin (%)	Volcanic tuff (%)	Aggregate sort I (0–4 mm) (%)	Aggregate sort II (4–8 mm) (%)
PC1	9	—	45.5	45.5
PC2	12.4	—	43.8	43.8
PCVT1	9	13	39	39
PCVT2	12.4	12.8	37.4	37.4
PCVT3	9	16.2	37.4	37.4
PCVT4	15	15	35	35

The mixtures of concrete were prepared by mixtures with capacity of 0.05 m3. The large aggregates (type 2) and sand (type 1) were initially mixed, then, the volcanic tuffs were added to them. Next resin with hardener powder were added to them. The mixed concrete was put in the molds of cube and cylinder and were compressed by a vibrator with a low speed.

The size of the cubic samples were (W*D*L) 7*70*210* mm and cylindrical samples were (D*H) 150*300MM and (D*H) 100*200 MM [9].

The samples were put outdoor for 24 hours. After removing the molds, they were kept in laboratory conditions with the temperature of 20 Celsius and 65 percent of humidity for 14 days.

The ratios of mixtures which are obtained only from epoxy resin and aggregates are shown with PC1 and PC2 (the source mixture plan) and for other ratios of mixtures containing volcanic tuffs as microfiller and its replacement with manufactured river aggregates are shown with PCVT.

The Experiment:

The unconfined compressive strengthfor each mixture on five cubic samples with the size of 70 mm, based on the standards [9], was conducted on thee samples. The test of compression resulted from the test of splitting tensile, was conducted using cylindrical samples that for each ratio of mixture three experimental tests and with the size of 150*300 mm, according to the standards [9], were conducted.

Young's modulus of polymer concrete was obtained from the cylindrical samples with the size of 100*200 mm, according to the standards [9], and with the speed load of 0.23 megapascal per second. Four cylinders for each mixture plan were prepared according to Table 1 and among which one is used to determine compressive strength of cylindrical concrete which was the maximum load it could contains: three cylinders were employed to determine the Young's modulus and from each three samples were loaded on six cycles, and at last based on the stress and strain of the concrete in the three last loading cycles the Young's modulus were evaluated. The strain used for the evaluation involves the mean of the granted values from three specified strain gauges on the cylinders which have an angle of 90 degrees.

Before any experiment, the size and weights of each cube and cylinder are calculated to obtain the density of polymer concrete, two models of basic mixture and polymer concrete with volcanic tuffs.

RESULTS AND DISCUSSION:

The obtained results from the density include different parameters and elastic properties. Different parameters involve different tensile- flexural strength, and tensile strength resulted from the experiment of splitting and one- axis compressive strength. The elastic properties taken into account for this study is Young's modulus.

Density:

Density is one the significant parameters which was achieved from the calculation. The specified density was obtained from the samples of 100*200 mm cylinders and before the loading cycle.

For each cylindrical sample, six-time reading of diameter (up, middle, and down) in two lines which are perpendicular to each other and four-time reading for the height using a digital caliper with an accuracy of 0.01 was achieved. After calculating the sizes of samples, their weights were obtained by a digital scale with an accuracy of 0.01.

As evident in Figure 1, by increasing the resin and volcanic tuff, the density decreases showing the low level of density of the two in aggregates. The values in the parenthesis in Figure (1) illustrates the difference between the mixture and source mixture.

The reduction of the density, however, is not important, for example when the mixtures of PC1 and PCVT1 have a similar Zerin, there is a 13 percent difference in the volcanic difference, their density difference is only

82% which seems that the density of the volcanic tuffs used as a filler has a similar density to that of manufactured river aggregates.

By observing the PCVT3 and PCVT1 mixtures, we found that the density of PCVT3 mixture is 0.96 less than that of PCVT1 mixture. Also, in the two models of source mixtures of PC1 and PC2, the density of PC2 is 5.7 less than that of PC1. By recomparing PC2 and PCVT2, a 1.82 difference was observed between the two, and the difference between PC1 and PCVT1 was a bit more and the increase of resin can make this difference of density a bit more.

In conclusion, the amount of used resin plays a pivotal role in the density of polymer concrete while the effect of volcanic tuff on the density is less.

Compressive Strength:

The experiments of one-axis compressive strength in 14 days [3] were achieved according to the standards [10].

As can be seen with an increase of 3.4 percent of resin, this amount plays an important role in the increase of 19 percent of compressive strength (see Table 2). Notwithstanding this, the increase of resin to 15 percent and volcanic tuff to the mixture can reduce the compressive strength a bit more.

The effect of adding volcanic tuff as a micro-filler seems to have a significant role only in mixtures with 9 percent of resin because the increase of compressive strength in PCVT1 is around 50 percent.

To put it differently, the re-increase of volcanic tuff in the mixture from 13 to 16.2 percent can reduce the strength in comparison with the source mixtures. This may imply that the volcanic tuff shows a low level of strength. The PCVT4 mixture has been produced by considering the limitations of concrete efficacy and the amount of its volcanic tuffs is similar to that of PCVT3 but its coefficient is more. In this research, the obtained compressive strength is equal to that of source PC1 sample, with this difference that total cost was more because resin increased.

It can be stated that the effect of adding volcanic tuffs to a mixture with 12.4 percent of resin is a small pressure on the strength (only about 2.39 percent) and it can be claimed that the mechanical properties of sand is a feature of material adhesion [8].

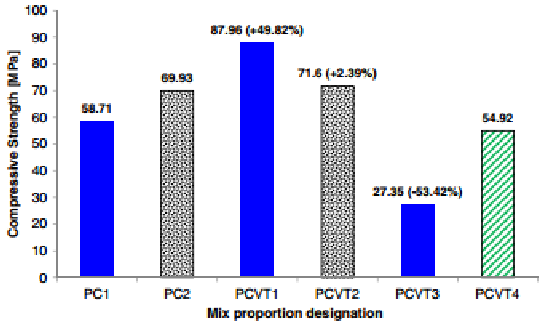

Figure 1. The Density of Polymer Concrete Mixtures: 9 percent resin (PC1, PCVT1, PCVT3), and 12.4 percent of resin (PC2, PCVT2), and 15 percent of resin (PCVT4).

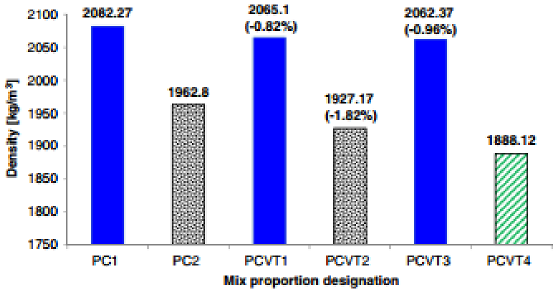

Figure 2. The Compressive Strength of Polymer Concrete Mixture Includes: 9 percent of resin (PCVT3, PCVT1, PC1), 12.4 percent resin (PCVT2, PC2), and 15 percent resin (PCVT4)

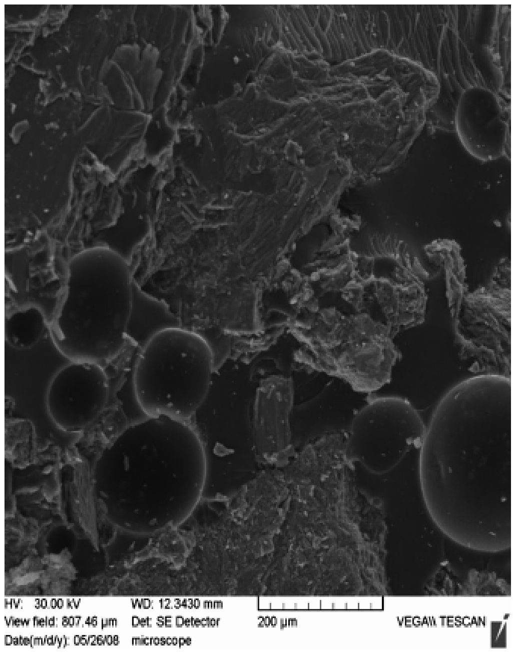

Figure 3: An Electron Microscope for Polymer Concrete for the Model of Source PC2 Concrete or 12.4 Percent of Epoxy Resin

To better understand these values like compressive strength, the formological studies have conducted on the analysis of micro-structural polymer concrete. Figure 3 illustrates the structure of the model of PC2 mixture which is formed of aggregates and epoxy resin. In this study, its compressive strength was more than that of PC1. In this figure, some holes can be seen on the polymer concrete and resin holds some big holes on different parts of concrete.

Figure 4 depicts the macro-structure of PCVT1 mixture with 9 percent of epoxy resin and 13 percent of volcanic tuffs as microfiller which has the highest compressive strength. In this figure, the micro-structure of polymer concrete gets more homogeneous as the holes between the aggregates is filled because of the volcanic tuffs. Thus, the number of holes decreases and the structure of polymer concrete becomes more polymeric.

Flexural and Tensile Strength Resulted from the Experiment of Splitting:

The flexural and tensile strength, according to [3], were conducted on three samples with size of 70*70*210 mm (W*D*H), and the results were reported in Table 2. The amounts related to the flexural and tensile strength are not similar to concrete with the high performance and this difference does not demand processing conditions.

The effect of microfiller for each two percentage of epoxy resin in relation with the compressive strength is important because their compressive strength is around 18 percent in comparison with the models of PCVT1 and PCVT2 mixtures. This implies that the percentage of volcanic tuff is more effective in comparison with the epoxy resin.

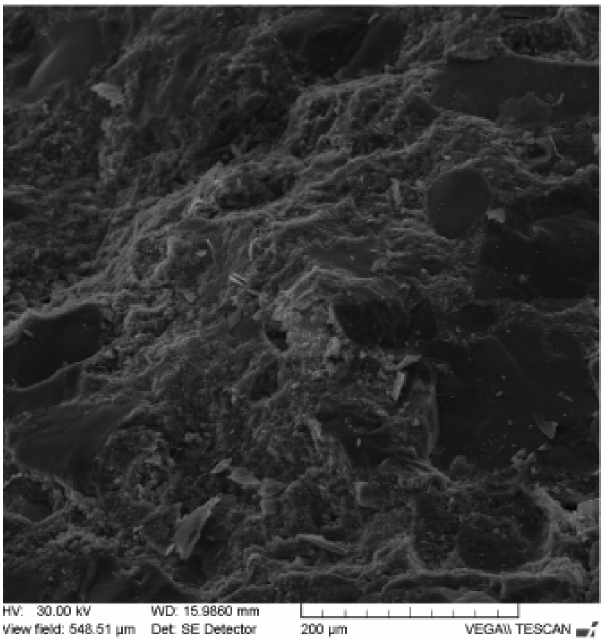

Figure 4: The Electronic Microscope for the Polymer Concrete for the Model of PCVT Mixture or 9 Percent of Epoxy Resin and 13 Percent of Volcanic Tuff

Table 2: The Flexural and Tensile Strength Resulted from the Experiment of Splitting the Polymer Concrete in 14 days (Each number in the table is the mean of three samples)

Type	Flexural tensile strength, f_{ti} (N/mm^2)	Coefficient of variation (%)	Splitting tensile strength, f_{td} (N/mm^2)	Coefficient of variation (%)
PC1	13.34	0.42	7.41	0.33
PC2	12.91	0.39	7.62	0.34
PCVT1	15.8	0.35	8.86	0.62
PCVT2	15.31	0.27	6.99	0.55
PCVT3	6.75	1.00	2.95	0.81
PCVT4	13.8	0.45	6.60	0.38

The experiments of flexural and tensile resulted from the experiment of splitting were conducted on the cylindrical samples in that for each model of mixture three samples were experimented and the size of the cylinder was 150*300 mm according to the guidelines [12].

The permitted amount of epoxy resin had the least effects on the amounts of the flexural and tensile strength resulted from the experiment of splitting in the PC1 and PC2 samples. Put it differently, adding the volcanic tuff seems to be useful since the expected amounts are more than the ratios of source mixture.

The amounts of ratios of small changes (COV) show the consistency in samples. The next experiment for the ratio of similar mixture led to the similar experimental results for the compressive strength resulted from the experiment of splitting.

Table 3 is presented among other data which will be discussed in the next section. These amount which have been used for the cylindrical compressive strength have been obtained in the research. In [6] to evaluate the compressive strength resulted from the experiment of splitting which is also called the strength of concrete feature of compressive axis, fctk is put into practice so as to obtain the application of these equations in the polymer concrete.

$$f_{ctm} = 0/3 \times f_{ck}^{\frac{2}{3}} f_{ck} \leq 50MPa \quad (2)$$

$$f_{ctm} = 2/12 \times \ln\left(1 + \frac{f_{cm}}{10}\right) \quad f_{ck} > 50MPa \quad (3)$$

Here fcm is equal to the mean of compressive strength of cylindrical samples which has been achieved through the following equation:

$$f_{cm} = f_{ck} + 8MPa$$

The flexural and tensile strength, $f_{ctm,fl}$ which has been shown as f_{ri} in Table 5, it, according to the standard [6], is calculated as:

$$f_{ctm,fl} = \max\left[\left(1/6 - \frac{h}{1000}\right) \times f_{ctm}, \quad f_{ctm}\right] \quad (4)$$

Here h is equal to depth of the member, based on mm, and f_{ctk} is achieved through (2) and (3).

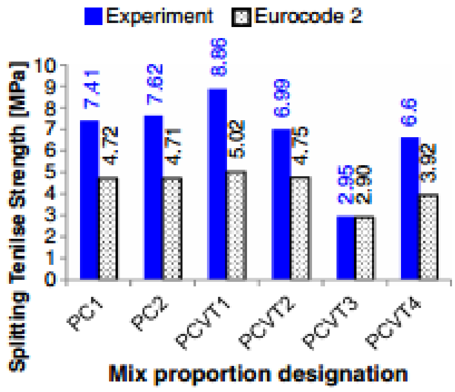

Figure 5-A: The Compressive Strength Resulted from the Experiment of Splitting

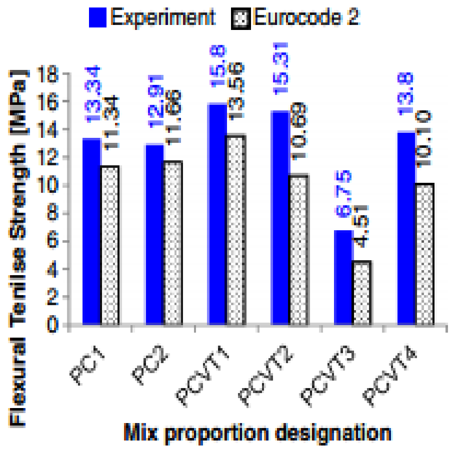

Figure 5-B: The Flexural and Tensile Strength of the Polymer Concrete

Figure 5-A shows the comparison of the experimental and calculation results for the compressive strength resulted from the experiment of splitting and Figure 5-B also illustrates the same comparison for the flexural and tensile strength. In both cases: the existing calculations used for the estimation of the compressive strength resulted from the experiment of splitting and the flexural and tensile strength with the obtained amounts from the polymer concrete differed. In other cases [15], based on the existing equations for the estimation of these cases, the amounts were conservative.

Notwithstanding this, in designing the performance of the new sample in designing the structure, there is a demand to expand the calculation with the high accuracy in the polymer concrete.

Table 3: Elastic Modulus of Polymer Concrete

Type	$f_{ck,exp}$ (N/mm^2)	$E_{cm,exp}$ (N/mm^2)	$E_{cm,EC2}$ (N/mm^2)[a]	$E_{c,1}$ (N/mm^2)[b]	$E_{c,2}$ (N/mm^2)[c]	$E_{c,3}$ (N/mm^2)[d]
PC1	62.33	21,432.4	38,091.83	28,154.53	25,617.45	31,461.44
PC2	62.26	20,414.18	38,078.99	25,755.13	22,091.48	28,780.97
PCVT1	68.35	23,342.66	39,160.14	28,845.52	25,855.89	32,137.41
PCVT2	63.02	22,950.89	38,217.85	25,177.72	21,185.92	28,127.35
PCVT3	30.03	16,926.99	30,597.74	21,031.91	19,725.98	22,951.14
PCVT4	47.29	16,010.45	35,063.36	21,828.32	18,335.41	24,391.87

[a] $E_{cm,EC2} = 22 \times (f_{cm}/10)^{0.3}$ in GPa, where $f_{cm} = f_{ck} + 8$ in MPa (Eurocode 2 2002).
[b] $E_{c,1} = (3{,}320 \times \sqrt{f_{ck}} + 6{,}900) \times (\rho/2{,}320)^{1.5}$, where ρ is the density of concrete (Carrasquillo et al. 1981).
[c] $E_{c,2} = 3.38 \times \rho^{2.5} \times (\sqrt{f_{ck}})^{0.65} \times 10^{-5}$, where ρ is the density of concrete (Ahmad and Shah 1985).
[d] $E_{c,3} = 0.043 \times \rho^{1.5} \times \eta \times \sqrt{f_{ck}}$, where $\eta = 1.1 - 0.002 \times f_{ck} \leq 1.0$ (Mendis 2001).

Young's Modulus:

Young's modulus of polymer concrete on the cylindrical samples with the size of 100*200 mm, according to the standards [2], were determined. The transformation curve of one cylindrical sample is shown in Figure 6. Just for last three circles of loading, Young's modulus were calculated based on the stress–strain curve of the concrete. As evident in Figure 6, the slope of the upper and lower lines of the power has remained constant which means that we could make use of the slope of this figure to calculate the elastic modulus.

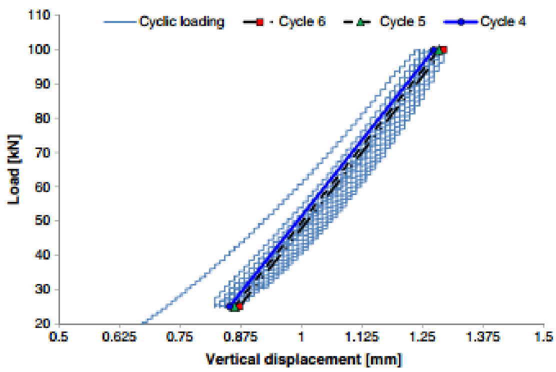

Figure 6: The Transformation Curve to Determine the Young's Modulus (related to the model of PC2 source mixture)

After the sixth circle of loading, the cylindrical samples were under loading till the dissociation so that the value of the strength of the compressive feature in the cylindrical samples of polymer concrete f_{ck} is determined.

In Table 3, the results of the compressive strength for the cylindrical sample, f_{ck} and Young's modulus were calculated and reported based on the experimental results like the calculation results, according to the standards [6]. It seems that the proposed equations by [6] for the calculation of elastic modules were not conservative.

As can be seen, all the equations employed in this research for the estimation of elastic modulus of polymer concrete along with volcanic tuffs as a microfiller in comparison with the experimental results are not conservative. The best estimation was proposed by [1] in that for the concrete with high compressive strength it is between 7 to 10 percent and for the concrete with lower compressive strength the difference was between 14 to 20 percent.

On the cylindrical samples, the elastic modulus equal to the compressive strength obtained from the cubic samples according to the standards [10]. This is the most amount of this PCVT1 mixture model with 9 percent epoxy resin and 13 percent volcanic tuffs and its mirco-structures could be seen in Figure 4.

By increasing resin, this amount is distributed between ratios of PC1 and PC2 source mixtures. Adding volcanic tuffs with the mixture ratio of 12.4 percent of resin could increase the compressive strength of the cylindrical sample and Young's modulus of polymer concrete a bit more.

For resin with more amount, it seems that epoxy resin properties dominantly affect. Also an increase in the use of volcanic tuffs can reduce the slope in amounts related to the elastic and mechanical features of the polymer concrete.

CONCLUSION:

This article aimed at determining the benefits of using volcanic tuffs as a filler in polymer concrete. Based on the achieved results, it can be concluded that adding volcanic tuffs could have positive effects in micro-structures of polymer concrete because these small materials are disturbed in the mixture and make it more homogenous and dens so that the mechanical features are promoted.

The amount of resin plays a significant role in the concrete density while the effects of the volcanic tuffs on the density is little. Adding volcanic tuffs as a micorfiller to the compressive strength of polymer concrete mainly affects the polymer concrete with 9 percent of resin. For example, in the PCVT1 sample the compressive strength increased up to 50 percent.

The effect of mircofiller on flexural and tensile strength for each two percent of epoxy resin in comparison with the compressive strength is important. According to the results, it can be stated that the percentage of volcanic tuffs in comparison with the resin percentage is more important. The results are also true for the flexural strength resulted from the experiment of splitting.

The compressive strength and elastic modulus for the cylindrical samples are similar to the determined compressive strength in the cubic samples, and the maximum amount goes to PCVT1 sample with 9 percent of epoxy resin and 13 percent of volcanic tuffs. With the increase of resin, the related amount would be close to PC1 and PC2: for example, adding volcanic tuffs to a structured mixture from 12.4 percent of resin could increase the compressive pressure and elastic modulus of the cylindrical sample of polymer concrete a bit more. In case the amount of resin increases, the behaviour of the samples is mainly affected by the epoxy resin properties.

By an increase in the volcanic tuffs, the mechanical and elastic features of polymer concrete is reduced. The maximum amount of elastic modulus is achievedprovided that the amount of volcanic tuffs and of epoxy resin should be similar.

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