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Experimental study of the effect of polymer fiber based on epoxy resin on compressive and flexural strength parameters

A. Rahmati, K. Rahmani*, and S. Piroti

Department of Civil Engineering, Mahabad Branch, Islamic Azad University, Mahabad, P.O. Box 59133-43345, Iran.

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KEYWORDS

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Solvent;
Hardener.

Abstract. In this study, effective parameters for Polymer Concrete (PC) based on epoxy resin such as filler, hardener, and solvent are investigated. Rice husk and broom stem ashes as fillers with a mixture of 50–50% acetone-toluene as solvent in the preparation of PC samples were used. According to experimental results, the addition of fillers improved compressive, flexural, and chemical strengths of the PC samples. In the sample with 18.4% polymer, given the addition of rice husk ash with a ratio of filler-aggregate 0.075, compressive strength improved by 21%. For the sample with the broom stem ash ratio of filler-aggregate 0.09, the flexural strength improved by 27%. In addition, experimental data proved that the addition of optimum amount of solvent improved the performance and enhanced the compressive and flexural strengths. However, the excess amount of solvent may reduce the adhesiveness of the polymer; therefore, it may have negative impact on PC. The combination of hardener-resin may affect the strength of PC. Amine type of hardener with a low equivalent weight improved by 27% and 13% on compressive and flexural strengths. Moreover, elasticity modulus increased compared with the samples having a high equivalent weight of amine type hardener.

1. Introduction

Concrete is one of the most widely used building materials due to its low price, convenience, and ability to meet the requirements. Today, a wide range of materials and methods for improving the properties of cement concrete (Portland cement concrete) or replacing the use of cement in concrete are available, which are selected proportional to the costs depending on the required mechanical and chemical strength, structural issues, and existing conditions. The improvement of concrete properties is made in two general ways:

1. Reinforcing concrete using fibers and rebars, which are mainly used to improve the flexural strength and ductility of concrete;
2. Improving the quality of concrete by adding chemicals, pozzolans, and fillers.

Polymer has been considered as an option to improve the concrete properties for several decades. Polymer materials are used in both of the mentioned methods to improve the concrete properties. Solid and hardened polymer materials (such as polypropylene) or FRP (Fiber Reinforcement Polymer) rebars are used for concrete reinforcement.

The application of natural polymers in the construction of buildings dates back to a long time ago,

*. *Corresponding author.*
E-mail addresses: adelrahmati11@gmail.com (A. Rahmati); mohandes_so@yahoo.com (K. Rahmani); s.piroti@iau-mahabad.ac.ir (S. Piroti)

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the BC. Polymer materials have been used in the wall of China in 221 BC. The results of a study on polyester polymer concrete at temperatures of 23, 40, and 60°C showed that the compressive strength of concrete decreased slightly with the increasing temperature. However, a decrease in flexural strength and an increase in creep led to higher values.

Riberio et al. [1] investigated the effect of temperature on flexural strength in mortars made of polyester and epoxy resins. The resin content in both types of polymer mortar was 20% while no filler was used. They observed that temperature change was much more effective in epoxy mortars.

Mohammadhassani et al. [2] designed nine rectangular sections of High Strength Concrete (HSC) beams and cast based on the American Concrete Institute (ACI) code provisions with different tensile reinforcement ratios. They measured steel and concrete strains and deflections at different points of the beam's length for every incremental load up to failure. They showed that ACI bending provision was 10% conservative for assessing the ultimate bending moment in the low-reinforced HSC section, while its results were valid for the over-reinforced HSC sections. Sinaei et al. [3] numerically studied the effectiveness of composite fiber-reinforced polymer layers for exterior beam-column connections. Mohammadhassani et al. [4] used an adaptive euro-based inference system (ANFIS) for predicting shear strength of HSC beams without stirrups. They concluded that the predictions obtained from the ANFIS are harmonious with the test results not accounting for the shear span-to-depth ratio, tensile reinforcement ratio, and concrete compressive strength; the data of the average, variance, correlation coefficient, and coefficient of variation of the ratio between the shear strength predicted using the ANFIS method and the real shear strength are 0.995, 0.014, 0.969, and 11.97%, respectively.

Zhang and Li [5] performed an experimental study to investigate the combined effect of silica fume and polypropylene fiber on the workability and drying shrinkage of concrete composite containing fly ash. They concluded that the workability of the concrete composite improved and the drying shrinkage strain decreased gradually with the increase of fly ash content. However, polypropylene fiber has insignificant adverse effect on the workability of concrete composite. Some researchers have studied the properties of silica fume concrete including slump, air content, compressive strength, flexural strength, permeability, and permeable void volume and investigated the effect of the silica fume replacement ratio of cement [6–9].

Ozawa and Morimoto [10] carried out permeability tests on HSC (72 MPa) including 0.15% by volume of Poly Propylene Fiber (PPF). Results showed that the residual permeability increased 12 times after heating the PPF concrete to 500°C compared to the reference concrete. Thus, the improvement of permeability has increased and reduced the likelihood of explosive spalling [11].

Thus, polypropylene fiber, carbon fiber, plastic-glass based fiber, and steel fibers had started to be used in concrete. It is known that steel, nylon, and mixed fibers do not significantly affect the mechanical properties such as compressive strength and elasticity module and highly improve the mechanical properties such as bending - tensile strength, ductility, and toughness [12,13]. Rahmanzadeh et al. [14] experimentally investigated the effect of water-cement ratio on abrasion resistance, porosity, and hydraulic conductivity coefficient of nano silica concrete. They showed that the compressive strength of concrete at a particular temperature corresponded to two factors: water-cement ratio and density. In their research, decreasing the water-cement ratio from 0.46 to 0.30 improved the abrasion resistance of nano silica concrete by 42%, the hydraulic conductivity coefficient of concrete decreased from 28.5×10^{-15} to 1.7×10^{-15} m/s, and the porosity of concrete decreased to 13.1%. Rahmani et al. [15] studied the effect of nano silica on mechanical properties and durability of concrete containing polypropylene fibers.

According to extensive investigations carried out by researchers on polymer concrete, many changes occur in the strength and features of polymer concrete depending on the type and amount of polymer materials (resin and hardener) and admixtures [16–19]. For example, the compressive strength of polymer concrete can be between 50 and 160 MPa. This paper attempts to study the factors affecting the strength (especially, compressive and flexural strengths) of polymer concrete.

2. Research purposes

- *Studying the effect of gradation of aggregates on polymer mortar strength:* For this purpose, three gradations of aggregates were used: materials retained on the No. 16 sieve, materials passing the No. 16 sieve, and a combination of 60% passing the No. 16 sieve and 40% retained on the No. 16 sieve;
- *Investigating the effect of hardener-resin mixing ratio:* Five different mixing ratios (10%, 13%, 16%, 19%, and 22%) were used in the production of the samples. The proposed mixing ratio by the manufacturer company is 16%;
- *Investigating the effect of hardener type on polymer concrete strength:* Two types of amino hardeners were used for three different percentage rates of resin;
- *Investigating the effect of solvent on compressive and flexural strength of polymer concrete:* The acetone-

toluene solvent (with a ratio of 50% –50%) was used to reduce the viscosity of polymer. Samples were made of two different types of epoxy resins and two different percentage rates (8% and 10%) of polymers.

3. Used materials

3.1. Resin and hardener

The specifications of resins and hardeners are shown in Tables 1 and 2.

The used hardeners are of diethylenetriamine or triethylenetetramine type which belong to the aliphatic amines group. Then, the 5001 hardener was modified by reducing the number of active hydrogens. Reducing the active hydrogen increases the weight of the hardener equivalent. The HA 12 hardener has also been modified using cycloaliphatic amines.

3.2. Solvent

The used solvent is a combination of two common solvents for epoxy resin, namely acetone and toluene, with an equal weight ratio. The characteristics of solvents are shown in Table 3.

3.3. Rock materials (Aggregates)

The gradation of used materials is given in Table 4. Type-2 materials are in accordance with the sand gradation regulations of Iran Code (following the British Code BS 882) but slightly different from the presented standard in ASTM C 33-03. Type-2 aggregate gradation has a large fineness modulus that results in coarse aggregates relative to the standard range. The reason for choosing such a gradation is to create the necessary workability in the polymer concrete in which the filler was used. The specific area of materials decreases by increasing the aggregate size; hence, the need for polymer decreases, too.

The fineness modulus is usually calculated for fine aggregates. The fineness modulus, volumetric density, and specific mass for Type-2 aggregates were 3.21, 1.69 g/cm^3, and 2.81 g/cm^3, respectively. The specific mass for Type-1 aggregates was 2.64 g/cm^3.

Table 4. The gradation of aggregates used in polymer concrete samples.

Sieve size (mm)	Sieve no.	Percentage passing (by weight)	
		Type 1	Type 2
9.5	3/8 inch	100	100
4.75	4	77	100
2.36	8	51.2	75.8
1.18	16	27.6	51.9
0.6	30	16.6	31.2
0.3	50	9	15.9
0.15	100	4.1	4.5

Table 1. Specifications of R 805 resin and used hardeners.

Commercial title (brand)	Type	Color	Specific weight (g/cm^3)	Workable time, 20°C (minutes)	Setting time (hours)	Mixing ratio (by weight)
R 805	Resin	Colorless	1.15			100
HA 12 (H_1)	Hardener	Brown	1.02	< 30	< 2	12
5001 (H_2)	Hardener	Colorless	1.04	60	4	15

Table 2. Specifications of Dur 41 and Dur 42 resins and used hardeners.

Commercial title (brand)	Type	Color	Specific weight (g/cm^3)	Workable time, 20°C (minutes)	Setting time (hours)	Resin: Hardener mixing ratio (by weight)
Dur 41 (A)	Resin	White	1.18	30	2	1:4
Dur 41 (B)	Hardener	Black	1.02			
Dur 42 (A)	Resin	Yellow	1.12	30	2	1:6
Dur 42 (B)	Hardener	Brown	0.96			

Table 3. Characteristics of used solvents .

Solvent	Specific weight (g/cm^3)	Melting point (°C)	Boiling point (°C)	Viscosity (cp)	Solubility in water (g/lit)
Toluene	0.866	–95	110.6	0.59	0.47
Acetone	0.789	–95	56.2	0.31	Soluble

Table 5. Physical characteristics of rice husk ash and Sorghum bicolor ash.

Type	Specific weight (g/cm^3)	Density (g/cm^3)	Specific area (blain cm^2/g)
Rice husk ash	0.35	2.05	4400
Sorghum bicolor ash	0.27	2.16	3900

3.4. Filler

Two types of filler, namely rice husk ash and Sorghum bicolor ash, whose specifications are shown in Table 5 have been used for the first time in polymer concrete.

3.5. How to prepare samples

Various concrete ingredients are weighed based on calculated mixing ratios. Resin and hardener were poured into disposable containers for weighing. We should be cautious about selecting the disposable containers that cannot be dissolved by hardener or resin. Resins and, especially, hardeners should not be exposed to open air for a long time due to the possibility of evaporation and absorption of moisture. After weighing, the resin and hardener were poured into the mixing container and stirred for 3 minutes with the stirrer. Then, the filler was added and mixed well with polymer in two steps for about 2 to 3 minutes. In the final step, rock materials were added and mixed with polymer in three steps for about 3 to 5 minutes. The prepared mixture was poured into pre-cleaned and lubricated molds. The molds were opened after hardening of polymer concrete. It is better to store the samples in the oven at a temperature of 23 ± 2°C due to the effect of temperature on the properties of polymeric concrete. Samples are ready to be tested after seven days. Attempts were made to consider the conditions and limitations of relevant standards at all stages of preparation and testing of the samples. The following items should be considered in sample preparation:

- An electric stirrer is used to mix concrete components (especially resin-hardener);
- The ambient temperature should be noted down during mixing and at the time of testing;
- Materials should be mixed well and at an appropriate time. It should be noted that the total time of mixing, molding, and troweling of materials should not exceed the application time duration of polymer;
- All tools and molds should be thoroughly cleaned after mold opening;
- Some solvent (acetone or gasoline);
- Gloves at all stages of production should be used with necessary precautions taken in using chemicals.

4. Results

4.1. Investigating the effect of hardener-resin mixing ratio on polymer concrete strength

In these experiments, Dur-42 resin and Type-1 materials were used in the production of samples. The amount of the added polymer is 15% by the weight of concrete. The ambient temperature is 30–32°C during the production of samples. According to the discussion in Section 3, the mixing ratio of hardener-resin is calculated based on stoichiometric ratios. Typically, resin manufacturers determine the mixing ratio and provide it for purchasers. The hardener-Dur 42 resin-mixing ratio are shown in Table 2. Four mixing ratios were also used in the production of samples, in addition to the above ratio. Figures 1 and 2 show the values of compressive and flexural strengths obtained from the experiments, respectively.

According to the obtained results, a decrease in hardener-resin ratio increases the strength and hardener-resin ratio. Increasing the proposed amount (of hardener-resin ratio) decreases the compressive and flexural strength. In addition, strengths are extremely decreased by reducing the hardness-resin ratio (approximately to 5%). The elasticity moduli of polymer concrete samples for 10%, 16%, and 22% ratios are presented in Table 6. The elasticity modulus also shows similar variations. Increase in strengths and elasticity modulus of polymer concrete is a sign of increase in transverse bonds in polymer, which

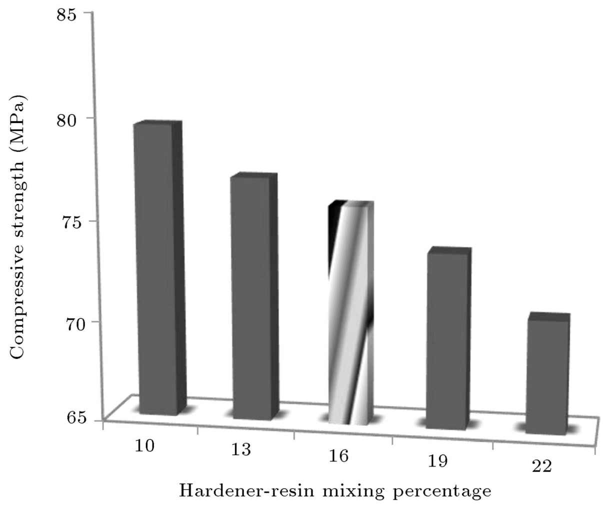

Figure 1. Compressive strength of samples with different hardener-resin mixing percentage rates.

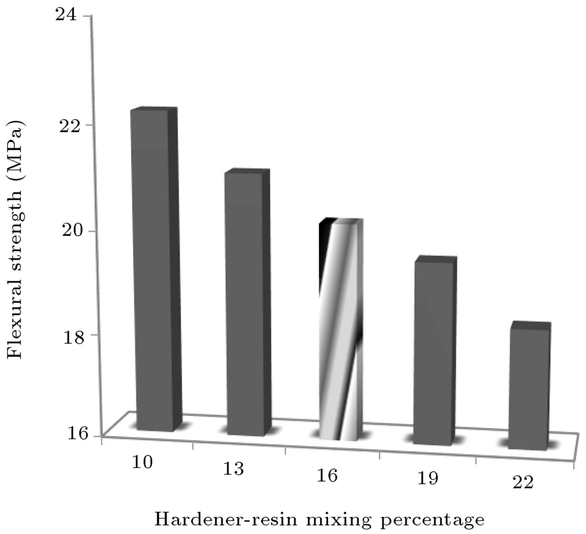

Figure 2. Flexural strength of samples with different hardener-resin mixing percentage rates.

Table 6. Elasticity modulus of polymer concrete with different hardener-resin ratios.

Characteristic	**Hardener-resin ratio (%)**		
	10	**16**	**22**
Elasticity modulus (GPa)	26.93	25.12	23.71

increases the stiffness and decreases the plasticity (ductility) of polymer concrete. Ambient temperature variation can affect the mixing ratio, especially in the case of amino hardeners. Increase in temperature decreases the mixing ratio. One of the reasons for reducing the mixing ratio in this study might be the high ambient temperature during the mixing process. One of the effective factors in the reduction of mixing ratio is the increase in mixing volume; therefore, it is better to check the proposed mixing ratio before testing. Such changes in the strength of concrete can be considered as not only the advantages but also as the disadvantages of polymer concrete, so that changes in the mechanical and chemical properties of polymer concrete can be made without changing the type of polymer or polymer-material ratio.

4.2. The effect of hardener type on polymer concrete properties

According to the previous discussion, the type of hardener is very effective in the properties of hardened polymer and polymer concrete. To illustrate the effect of hardener, the samples were made of an epoxy resin with similar materials, but with two different hardeners. R 805 epoxy resin, HA 12 (H_1) and 5001 (H_2) hardeners, and Type-2 stone materials were used in this experiment. The results of compressive and flexural strength tests are shown in Figures 3 and 4, respectively.

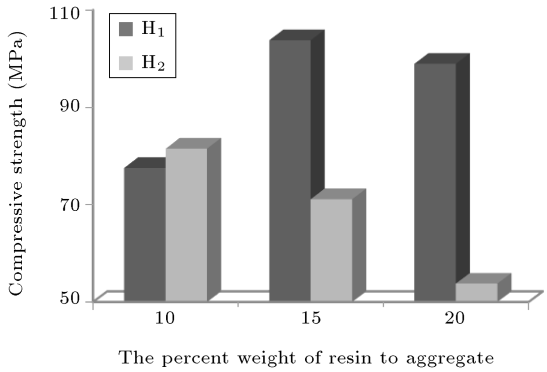

Figure 3. Compressive strength of polymer concrete with two different hardeners.

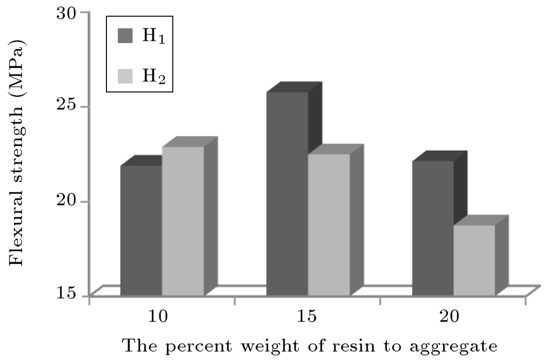

Figure 4. Flexural strength of polymer concrete with two different hardeners.

The horizontal axis of the above diagrams is based on the percentage by weight of resin rather than not the polymer which contains the resin and hardener together. It can be seen that changing the hardener type changes the compressive and flexural strengths. The maximum compressive and flexural strengths obtained from hardened concrete with H_1 hardener are about 27% and 13% higher than those of the concrete with the 5001 hardener, respectively. Moreover, the optimum amount of resin in these two types of polymer concrete is different. Increase in strength of concrete made of HA 12 hardener occurs because of an increase in transverse bonds in the polymer. Increase in transverse bonds makes the polymer brittle such that the outer surface of compressive specimens made of HA 12 hardener is layered after the test and is crushed more than specimens made of the 5001 hardener. Further, increase in stiffness due to increase in transverse bonds increases the elasticity modulus and improves chemical resistance. The properties of resulting concrete are insensitive to the (hardener-resin) mixing ratio, which is an important feature of high proportion of hardener (such as the 5001 hardener) in the mixing ratio. The toxicity of the 5001 hardener is less than HA 12 hardener due to the low vapor pressure.

These differences in the strength of concrete are observed where almost similar hardeners are used (both hardeners are of amine type). However, the application of different hardeners can make considerable strength differences. Due to the lack of information (precise chemical formula, viscosity, resin equivalent, and hardener active hydrogen content) provided by resin and hardener distributor companies, it is difficult to select different hardeners to investigate their effect on polymer concrete. Considering the considerable effect of hardener on obtained strengths, further research is required in this field based on polymer engineering sciences for polymer concrete.

4.3. Investigating the effect of filler

Resin, hardener, sand, and filler are the components of polymer concrete samples in this section. R 805 epoxy resin, 5001 hardener, and Type-2 materials were used in preparing samples. To investigate the effect of polymer content on polymer concrete strengths, three different percentage rates (13%, 23.4%, and 18%) of polymer were used. The usual range of polymer content for preparation of polymer concrete is between 7.5 and 20 (percent by weight). It is difficult to use a low-percentage polymer due to the use of filler. Two types of filler (rice husk ash and Sorghum bicolor ash) were used separately with different percentages in the preparation of samples. These fillers are obtained from agricultural wastes. The instructions for preparing fillers are given in Section 3.4. Stone materials (aggregates) smaller than 4.75 mm (passing the No. 4 sieve) were used. The use of sand aggregates results in the greater convergence of values obtained from the fracture of samples due to the small size of the samples.

The mixing ratio of various components of polymer concrete are shown in Table 7. Compressive and flexural strength, resistance to corrosive environments (sulfuric acid, acetic acid, and citric acid) and modulus of elasticity tests were considered and applied to the samples.

A number of studies have investigated the effect of using powdered Sorghum bicolor as filler due to having cellulosic materials and the possibility of bond formation with epoxy resin. However, no improvement has been observed in concrete strength, and the results have not been presented in this manuscript.

The specific weight of polymer concrete containing rice husk ash and Sorghum bicolor ash is presented in Figures 5 and 6, respectively.

The specific weight of polymer concrete decreases by increase in the amount of polymer which is due to the replacement of aggregates with polymer binders with a lower specific weight. More air is entrapped in polymer concrete due to an increase in the volume of polymer. The effect of bubbles on the surface of specimens is visible.

Except in polymer ratio of 13% (to the total weight of concrete), at other polymer ratios, a similar trend can be observed for both types of ash. The specific weight increases with an increase in the filler ratio and reaches the maximum value; however, the specific weight decreases if more values (of filler ratio) are used. This could be due to the reduced workability

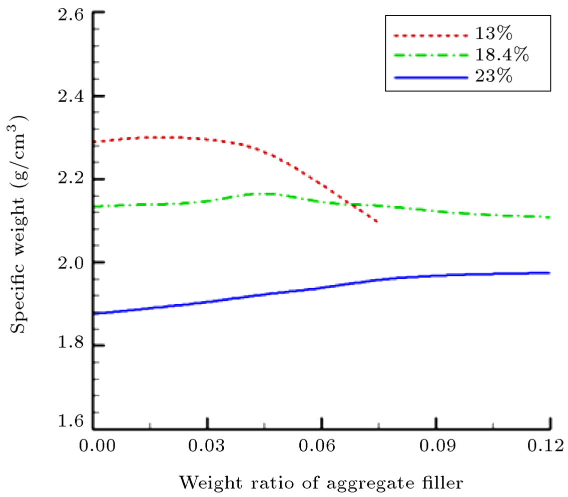

Figure 5. Specific weight of polymer concrete containing rice husk ash.

Table 7. Mixing ratios of polymer, aggregate, and filler.

Polymer (13%)			Polymer (18.4%)			Polymer (23%)		
Sample number	Materials (%)	Filler (%)	Sample number	Materials (%)	Filler (%)	Sample number	Materials (%)	Filler (%)
1	86.99	0	7	81.60	0	15	77.00	0
2	85.69	1.29	8	80.40	1.2	16	75.83	1.16
3	84.66	2.54	9	79.23	2.37	17	74.74	2.26
4	83.23	3.75	10	78.10	3.51	18	73.67	3.34
5	82.05	4.93	11	77.01	4.61	19	72.63	4.37
6	80.89	6.06	12	75.91	5.69	20	71.61	5.38
			13	74.87	6.74	21	70.62	6.38
			14	72.86	8.74	22	68.74	8.26

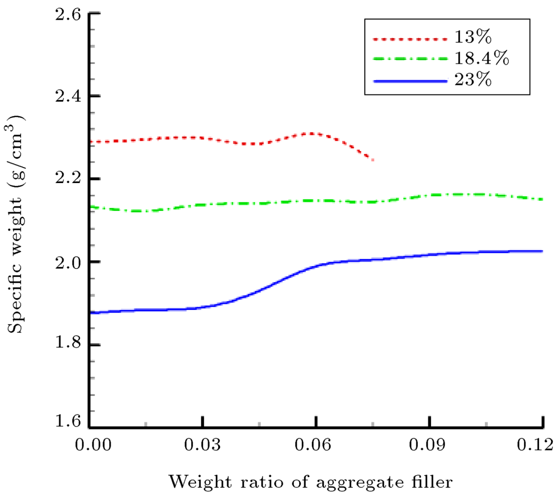

Figure 6. Specific weight of polymer concrete containing Sorghum bicolor ash.

and, consequently, incomplete compaction of mixture. The process of reducing the specific weight of polymer concrete occurs in lower filler-material proportions due to the higher specific area of rice husk ash.

One of the important effects of the addition of filler, which was observed during the samples preparing phase, is the reduction of polymer-aggregates separation and the rise of polymer on the surface, especially in samples with high polymer percentages. It should be noted that polymer concrete has a lower specific weight than cement concrete. According to Figures 7 and 8, in non-filler concrete, increase in the polymer percentage decreases the compressive strength. This reduction trend is accelerated with an increase in the polymer percentage.

Increasing the polymer content from 13% to 18.4% and 23% decreases the compressive strength by 12% and 34%, respectively. In samples containing 13% of polymer with rice husk ash, the addition of

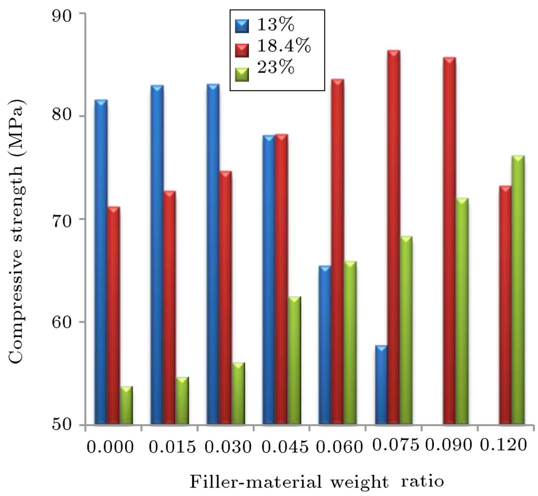

Figure 7. Compressive strength of samples containing rice husk ash.

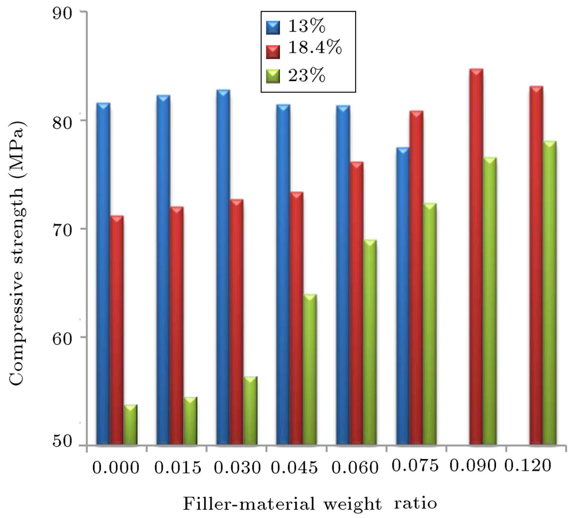

Figure 8. Compressive strength of specimens containing Sorghum bicolor ash.

filler up to 0.03 increases the strength of concrete, but increasing the filler content more than 0.03 decreases the strength of concrete. A similar trend is observed in samples containing Sorghum bicolor ash.

In concrete containing 18.4% polymer, the maximum compressive strength for samples containing rice husk ash and Sorghum bicolor ash is obtained at filler-aggregate ratios of 0.075 and 0.09, respectively. The addition of more fillers reduces the strength of concrete. The reduction trend is faster in samples containing rice husk ash. The maximum obtained compressive strength for concrete samples with rice husk ash is more than that of concrete samples containing Sorghum bicolor ash. Furthermore, the maximum obtained compressive strength for concrete with 18.4% of polymer containing filler is more than concrete with 13% of polymer.

Due to the sharp reduction of compressive strength, the addition of 23% of polymer to concrete is not recommended. Increase in the percentage of polymer in mass concrete causes a lot of heat release which in some resins may cause the polymer mixture to be boiled or burned. Such high percentage rates are used in particular cases. The addition of filler to concrete with 23% of polymer increases the compressive strength. It is observed that the effect of filler on the compressive strength of concrete increases with an increase in the percentage of polymer. The addition of rice husk ash to concrete with 13%, 18.4%, and 23% of polymer improves the compressive strength of concrete by 2%, 21%, and 41.6%, respectively.

The variation trend of flexural strength is almost the same as that of compressive strength (Figures 9 and 10). Filler effects on flexural strength increase with an increase in the percentage of polymer.

A significant point about flexural strength is that the maximum strength was obtained in samples

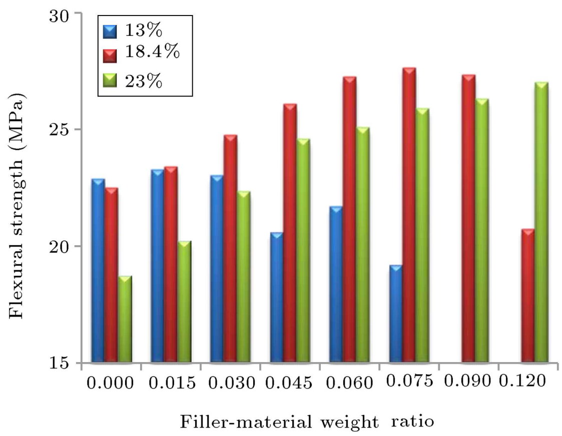

Figure 9. Flexural strength of samples containing rice husk ash.

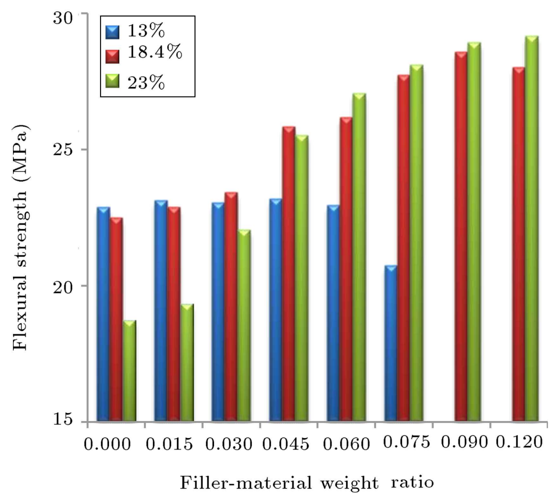

Figure 10. Flexural strength of samples containing Sorghum bicolor ash.

containing Sorghum bicolor ash. However, the addition of this filler to samples containing 13% of polymer does not improve their flexural strength considerably. Concrete samples, which had lost some of their flexural strength by increasing the polymer (to 23%), not only retrieve their strength but also increase it significantly. The flexural strength of samples containing 18.4% and 23% of polymer improves by the addition of Sorghum bicolor ash about 27% and 55%, respectively.

The chemical resistance of samples containing 18.4% polymer and 0, 0.045, and 0.09 of rice husk ash and Sorghum bicolor ash is shown in Tables 8 and 9, respectively. No significant change was observed in the appearance of the samples. The weight change of samples is negligible. Polymer concrete exhibits great resistance to corrosive environment. Resistance to corrosive environments increases with an increase in the filler-material ratio, which is due to the reduction of permeability by the addition of filler. It should be noted that greater strengths can be obtained by

Table 8. The effect of corrosive environment on polymer concrete containing rice husk ash.

Corrosive environment	Filler-aggregates weight ratio	Time (day)	Lost strength (%)
Sulfuric acid (10%)	0	7	7.4
		14	8.3
	0.045	7	5.4
		14	5.9
	0.09	7	5.2
		14	5.6
Acetic acid (10%)	0	7	12.9
		14	13.8
	0.045	7	8.5
		14	9.1
	0.09	7	7.7
		14	8.1
Citric acid (10%)	0	7	6.6
		14	6.9
	0.045	7	4.9
		14	5.3
	0.09	7	4.7
		14	5.1

Table 9. The effect of corrosive environment on polymer concrete containing Sorghum bicolor ash.

Corrosive environment	Filler-aggregates weight ratio	Time (day)	Lost strength (%)
Sulfuric acid (10%)	0	7	7.4
		14	8.3
	0.045	7	6.5
		14	7.2
	0.09	7	5.8
		14	6.2
Acetic acid (10%)	0	7	12.9
		14	13.8
	0.045	7	9.4
		14	10
	0.09	7	8.2
		14	8.8
Citric acid (10%)	0	7	6.6
		14	6.9
	0.045	7	5.7
		14	6.1
	0.09	7	4.9
		14	5.3

Table 10. Elasticity modulus for samples containing rice husk ash.

Characteristic	Filler-aggregates weight ratio		
	0	**0.045**	**0.09**
Elasticity modulus (GPa)	23.46	26.51	27.68

Table 11. Elasticity modulus for samples containing Sorghum bicolor ash.

Characteristic	Filler-aggregates weight ratio		
	0	**0.045**	**0.09**
Elasticity modulus (GPa)	23.46	26.02	28.11

selecting the appropriate polymer. The elasticity modulus was calculated for samples containing 18.4% polymer and 0, 0.045, and 0.09 of filler-material ratios. The results are shown in Tables 10 and 11. The addition of filler increases the elasticity modulus.

4.4. Investigating the effect of solvent

Two types of Dur 41 and Dur 42 resins and Type-1 stone materials were used in the manufacturing of the samples. The samples were made of 8 and 10% polymer. Resins were mixed before use to reduce the viscosity with solvent (acetone-toluene (50% -50%)), because there is no specific method for determining the performance of a polymeric concrete mix and conventional methods require high volume of mixing for cement concrete such as slump testing, compacting factor, silane table, and hemisphere penetration and they are not suitable for the volume of polymeric concrete made in this test. Therefore, a wicket needle of 1 mm and 1 cm diameter was used for comparison. Needle penetration was measured in 30 seconds. In addition, the amount of penetration of a 1-inch wicket needle was recorded by adding a 1 kg weight in 5 seconds. The results show that the addition of solvent generally increases the penetration rate of the needle; however, in concrete containing Dur 42 resin (viscosity of resin Dur 42 is less than Dur 41 resin), with increasing the ratio of solvent to resin from 0.05 to 0.1, no change in the penetration rate of the wicket needle is observed. Adding solvent to polymer concrete consisting of Dur 41 resin can increase the specific gravity of the concrete. Nevertheless, the addition of 10% solvent to polymer concrete made of Dur 42 resin can reduce specific weight. These results are shown in Figure 11. Increasing the polymer content will increase the specific gravity of the polymeric concrete made of both types of resin.

The effects of solvent on compressive and flexural strengths are shown in Figures 12 and 13. Even with the relatively low viscosity of the Dur 42 resin, as can be seen, adding 5% of the solvent increases its compressive

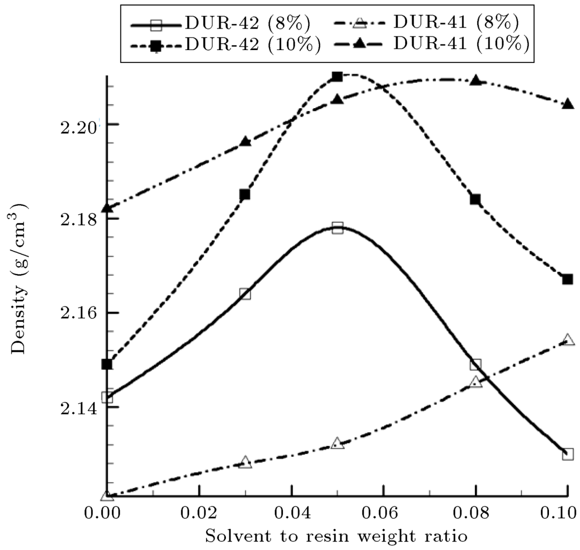

Figure 11. The effect of solvent on the specific gravity of polymeric concrete.

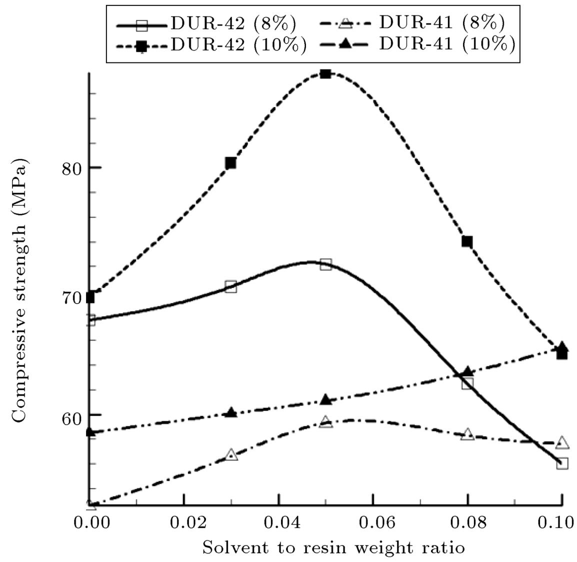

Figure 12. The effect of solvent on the compressive strength of polymeric concrete.

and flexural strength. This effect is more pronounced at a 10% resin-to-aggregate ratio (about 26% increase in compressive strength and 16% increase in flexural strength). According to Figures 12 and 13, increase in polymer content improves the compressive strength and flexural strength of the resin with a higher specific gravity (Dur 41). Increasing viscosity reduces surface tension in polymers. Decrease in surface tension increases the penetration of polymer into aggregates and lower surfaces.

5. Conclusion

This study attempted to investigate the effective factors in mechanical and chemical properties of polymer

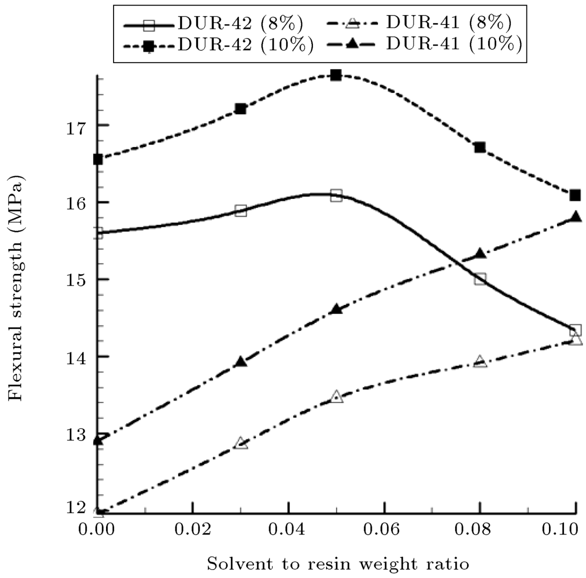

Figure 13. The effect of solvent on the flexural strength of polymeric concrete.

concrete through different experiments. It should be noted that the results, which are described below, can be used for the practical application of polymer in polymer concrete. Therefore, due to the different characteristics and features of different polymers and environmental conditions, necessary tests should be done to obtain the exact amount of strength and optimum amount of polymer. The results can be summarized as follows:

- The compressive strength of polymer concrete is several times greater than that of cement concrete. The maximum compressive strength obtained in this study was 103.8 MPa. The compressive strength of polymer concrete was affected by the type and amount of polymer, hardener, and admixtures;
- The replacement of cement with polymer increased the flexural strength considerably. The maximum flexural strength obtained from the experiments was 29.17 MPa. Effective factors in compressive strength were also found effective in flexural strength, but their optimum values can be different. One of the features of polymer concrete is the smaller flexural strength to compressive strength ratio (1/5 to 1/3);
- The specific weight of polymer concrete was found less than that of cement concrete (1.88 to 2.32 g/cm^3);
- Due to the lower elasticity modulus of polymer than that of materials, an increase in polymer percentage resulted in a decrease in the elasticity modulus of polymer concrete. The elasticity modulus of polymer concrete and cement concrete are not much different;
- The type of resin and hardener strongly affected the properties of polymer concrete. The use of two different types of amino hardeners caused 27% and 13% variations in the maximum compressive strength and flexural strength of polymer concrete, respectively;
- By changing the hardener-resin mixing ratio, a ductile or hard concrete with high elasticity modulus can be obtained.

Adding rice husk ash and Sorghum bicolor ash as a filler to polymer concrete showed that:

- The addition of filler can improve the compressive and flexural strength of concrete;
- Increase in the filler value increases the elasticity modulus;
- The effect of filler on concrete properties is influenced by the percentage of polymer;
- Concrete containing filler exhibits better chemical resistance;
- The specific area can be a major factor in the inductive properties of fillers on concrete;
- Both types of filler (rice husk ash and Sorghum bicolor ash) showed similar effects on polymer concrete;
- Adding the solvent can improve the performance of the mixture by reducing the viscosity of the resin. The addition of optimal solvent values improves the density of the mixture (specific gravity) and increases the compressive and flexural strength.

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Biographies

Adel Rahmati was born in Sanandaj in 1992. He received his BS and MS degrees in Civil Engineering from Islamic Azad University of Sanandaj and Mahabad in 2014 and 2017, respectively. His research interests include hydraulic structures, concrete technology, and structural engineering.

Kamal Rahmani received his BS degree in Civil Engineering from Islamic Azad University of Mahabad in 1998 and his MS and PhD degrees in Civil Engineering from Science and Research Branch of Tehran-Islamic Azad University in 2002 and 2017, respectively. His research interests include hydraulic structures, concrete technology, and structural engineering. He is an academic staff member at the Department of Civil Engineering at Islamic Azad University of Mahabad since 2004 an also has presented and published several papers in various national and international conferences and scientific journals.

Saber Piroti was born in Mahabad in 1977. He received his BS and MS in Civil Engineering from Islamic Azad University of Mahabad and Science and Research Branch of Tehran-Islamic Azad University in 1998 and 2002, respectively. He became an academic staff member at Islamic Azad University of Mahabad in 2004 and has held this position until now. He also received PhD degree in Civil Engineering from Islamic Azad University of Arak in 2017. His research interests include hydraulic structures, concrete technology, and structural engineering. He has presented and published several papers in various national and international conferences and scientific journals.