



Research Article

Effect of catalysts amount on mechanical properties of polymer concrete

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ABSTRACT

Polymer materials are used in different engineering applications because of their excellent engineering properties. The use of these materials in different engineering fields has increased in recent years. It is predicted that polymer materials will be one of the most remarkable and popular engineering materials in the near future because of their unique properties. This paper focuses on Methyl Ethyl Ketone Peroxide (MEKP), which is one of the main catalysts and investigate its effect on the mechanical properties of Polymer Concrete (PC). The main aims of the study are to understand the mechanical properties of the polymer concrete including different amount of MEKP and to investigate the influence of MEKP on the mechanical characterizations of the PCs. For this purpose, five different samples containing 0.15% (Mixture-1), 0.25% (Mixture-2), 0.35% (Mixture-3), 0.45% (Mixture-4) and 0.55% (Mixture-5) MEKP of the total weight were prepared and some experimental studies were performed on the prepared mixtures. The obtained strength values were discussed and evaluated effect of MEKP on mechanical properties of PCs.

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1. Introduction

Polymers are synthetic materials having a chain structure and atomic groups with chemical bonds. These synthetic materials might be categorized into three different groups as natural polymers, synthetic polymers and semi-synthetic polymers (Ozturk, 2013). General properties of polymers such as heat and electricity insulation, and resistance to chemical and environmental effects have put forward the importance of these materials. These materials are of utmost importance for the construction industry too thanks to their low shear resistance, high tensile and compressive strength, effective hardening time, and high surface hardness. High performance structural elements consisting of polymer concrete advanced the studies on the polymer industry.

The use of polymers in structural elements can be grouped into three: a combination of polymer and Portland cement concretes (PCCs), polymer impregnated concretes (PICs), and synthetic resin concretes (polymer

concretes, PCs). In the production to PCCs, the polymer is directly added to the concrete by consideration of the weight of cement. The permeability and compressive strength increase for this type of concrete, because of the decrease in the void ratio. PCCs are generally used in construction elements that necessitate repairs. On the other hand, PICs are obtained by impregnating the monomer into the hardened concrete. The monomer is provided to fill the voids in the concrete by applying pressure or vacuum. This process is generally applied to the structural elements needing reinforcement. Moreover, PCs is a composite material in which the binder consists of a synthetic polymer. In PCs, cement and water are not used in the production of concrete. Many different studies have been carried out on these three types of concrete. In previous studies, Kukacha (1978) concentrated on PICs. In the study, it was concluded that PICs are beneficiary especially in the strengthening and renovation works for the studies on the use of polymers in structures. In the study, it was concluded that the compressive

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strength significantly increased in PICs. In addition, it was emphasized that wear, chloride, acid, freeze-thaw resistance significantly increased, and water absorption rate decreased by 99% (Kukacha, 1978). In another study, Vipulanandan and Mebarkia (1993) conducted an experimental study on the flexural strength, toughness, and fracture properties of PCs.

In this study, the flexural behavior of the particulate fiber-reinforced polyester composite was investigated by changing the polymer and fiber content. The study used cobalt naphthenate (0.3% resin) and methyl ethyl ketone peroxide (1.5%) as binders. The study concluded that the use of aggregates and fibers treated with silane increased the strength of PCs. In addition to these studies, some studies were conducted on fiber reinforced polymer concretes (FRPCs). For example, Griffiths and Ball's (2000) studied flexural strength and fracture toughness values by using different fiber reinforced techniques and silane binders. The study determined that fiber reinforcement and silane binders significantly change the flexural strength. Achek and Aztekin (2011) performed an experimental study on the density and compressive strength of FRPCs. The study determined suitable polyester, hardener and catalyst ratios for FRPCs in the results of the study.

Another issue in polymer concrete is strongly rinse onto the catalyst used in the polymer concrete. Today, Methyl Ethyl Ketone Peroxide (MEKP) is one of the catalysts used in polymer concrete. MEKP is a material, which is active at room temperature for hardening of polyesters. By cross-linking between resin and monomers, the material initiates hardening. MEKP, which is

used as a catalyst in polymer concrete, is generally used in combination with materials such as cobalt, which have accelerating effect.

This study focuses on MEKP catalyst and effect of MEKP on mechanical properties of PCs. The main purpose of this study is (1) to understand the mechanical properties of the polymer concrete including different amount of MEKP and (2) to investigate the influence of MEKP on the mechanical characterizations of the polymer concrete.

2. Materials and Methods

The experimental program in this study was realized at Civil Engineering Laboratories at İstanbul Aydın University (IAU), with the collaboration of Mert Döküm Construction and Trade Inc. A part of the samples was supplied by Mert Döküm and the experimental tests were performed at Structural Materials and Structural Mechanics Laboratory and at IAU.

Polymer concrete consists of aggregates with different granulometry, binder, hardener and accelerator. In this study, size of 0.3–1 mm, 1–2 mm, 2–3 mm and 3–5 mm silica sands, polyester resin, MEKP and cobalt were used as an aggregate mixture, binder, hardener and accelerator, respectively. The aggregates used in the study were supplied by Yelten Mining and Kumsan Döküm from Kırklareli and İstanbul, Turkey. All aggregates were washed with clear water to remove any contaminated materials and dried before using. Its chemical composition is given in Table 1.

Table 1. Chemical composition of the aggregates.

Chemicals	Aggregates			
	0.3-1 mm	1-2 mm	2-3 mm	3-5 mm
MgO	0.10	0.06	0.06	0.06
Al ₂ O ₃	0.245	1.86	1.86	1.86
SiO ₂	98.86	94.15	94.15	94.15
CaO	0.01	0.39	0.39	0.39
Fe ₂ O ₃	0.148	0.46	0.46	0.46
SO ₃	-	0.10	0.10	0.10
K ₂ O	0.03	1.56	1.56	1.56
Na ₂ O	0.02	1.12	1.12	1.12
Ignition Loss	0.24	0.30	0.30	0.30

In this study, an experimental study was conducted in order to investigate the effects of MEKP on the flexural and compressive strength of PC at İstanbul Aydın University, Civil Engineering Department Laboratory with support from Mert Dokum Construction Industry and Trade Inc. For this purpose, five different samples containing 0.15% (Mixture-1), 0.25% (Mixture-2), 0.35% (Mixture-3), 0.45% (Mixture-4), and 0.55% (Mixture-5) MEKP of the total weight were prepared and compressive and flexural tests were performed on the prepared mixtures. A total of 15 pieces of specimen having

40x40x160 mm prisms and 40x40x40 mm cubes were prepared for each mixture (Fig. 1a). The chemical properties of MEKP used are shown on Table 2.

Before the basic specimens are produced; other variables have been kept constant and specimens have been prepared by using aggregates with different maximum diameters. The most suitable maximum aggregate grain diameter has been determined as 4 mm. Then the method for adding catalyst has been selected. Different methods are used for the addition of catalyst in PC production.

- a) The catalysts are mixed directly into the resin and then mixed with the aggregate,
- b) Addition of the resin after mixing the catalysts with the aggregate,
- c) Addition of catalysts after mixing of aggregates with resin

In this study, the wet mixture was prepared by adding the aggregates with resin. MEKP and the accelerators were added to the wet mixture in the final step. After completion of the mixing process, fresh concrete was cast in steel prism molds gradually (Fig. 1b). In order to

obtain full homogeneity and compaction, the fresh concrete was carefully compacted with shaking table during 120 second (Fig. 1c). The specimens were kept in the molds up to curing. After remolding, the specimens were stored at $20 \pm 2^\circ \text{C}$ in the laboratory for up to 7 days (Fig. 2). In the scope of the study, five different mixtures containing 0.15% (Mixture-1), 0.25% (Mixture-2), 0.35% (Mixture-3), 0.45% (Mixture-4) and 0.55% (Mixture-5) MEKP (the total weight of PC) were prepared. For each mixture, three samples were prepared, and the experimental studies were conducted by using these samples.

Table 2. Technical properties of MEKP.

Properties	Values
Flash Point	$> 80^\circ \text{C}$
Density	$1,12 \text{ g/cm}^3 (20^\circ \text{C})$
Viscosity	$19 \text{ mPa.s } (20^\circ \text{C})$
Self-Accelerating Decomposition Temperature (SADT)	$\geq 60^\circ \text{C}$
Active oxygen	9.7%
Free Hydrogen Peroxide Content	2.2%
Water Content	2.0%
pH	5.2
Critical Temperature (SADT)	65°C
Gel Time	18 min
Peak Time	48 min
Exothermic Temperature	106°C

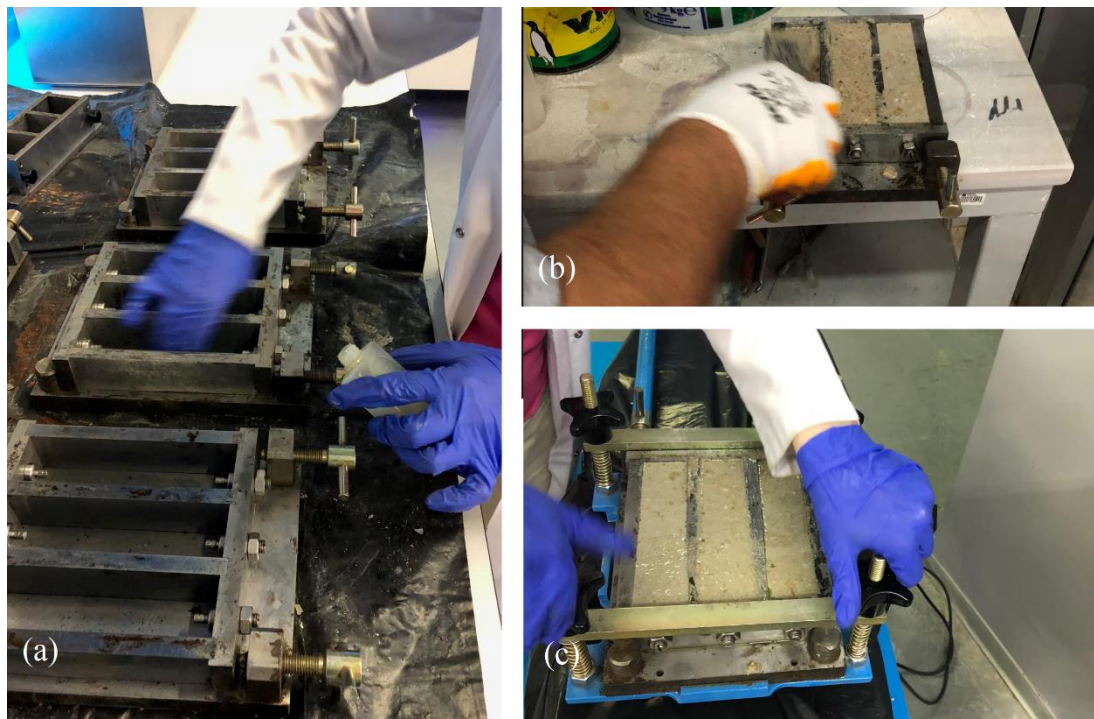


Fig. 1. Preparation of the PCs: (a) 40x40x160 mm steel molds; (b) cast in steel prism molds; (c) compaction with shaking table.



Fig. 2. Test samples.

3. Experimental Studies

Within the scope of the study, the experimental studies were carried out in two basic steps. The first step was to determine the initial and the final setting times, and the second step was to determine the mechanical properties of the materials with the mechanical tests. The initial and final setting times of the mixtures were determined by using VICAT apparatus.

After remolding, the samples were stored at $20 \pm 2^\circ\text{C}$ in the laboratory for up to 7 days. In the second step of the experimental studies, it was intended to investigate the mechanical properties of the samples. In the tests,

the densities of the samples were determined before the mechanical tests (Table 4). Then, three-point bending tests and compression tests were conducted the hardened specimens. All tests were carried out according to relevant Turkish and ASTM specifications at the laboratories of the Department of Civil Engineering at İstanbul Aydın University (IAU). The tests were conducted on three specimens at 7 days and all tests were performed on a U-Test hydraulic test machine (Fig. 3).

4. Results and Discussions

The use of polymer materials in different engineering fields is increasing and polymer materials are used effectively in different engineering applications. Thanks to its unique properties, these materials are considered to be among the most remarkable and popular engineering materials in the near future. This paper focuses on Methyl Ethyl Ketone Peroxide (MEKP), which is one of the main catalysts and investigate its effect on the mechanical properties of Polymer Concrete (PC).

The initial setting time and final setting time of the PCs is very short compared to conventional cement concretes. Therefore, in experimental studies, in the first step, the study concentrated on the initial and final setting times of the mixtures. Table 3 shows the initial and final setting times based on the amount of MEKP used. When the initial setting and final setting times were examined, it was determined that the Mixture-4 (0.45% MEKP) reached its strength in the shortest time and the Mixture-1 (0.15% MEKP) reached its strength in the latest time.

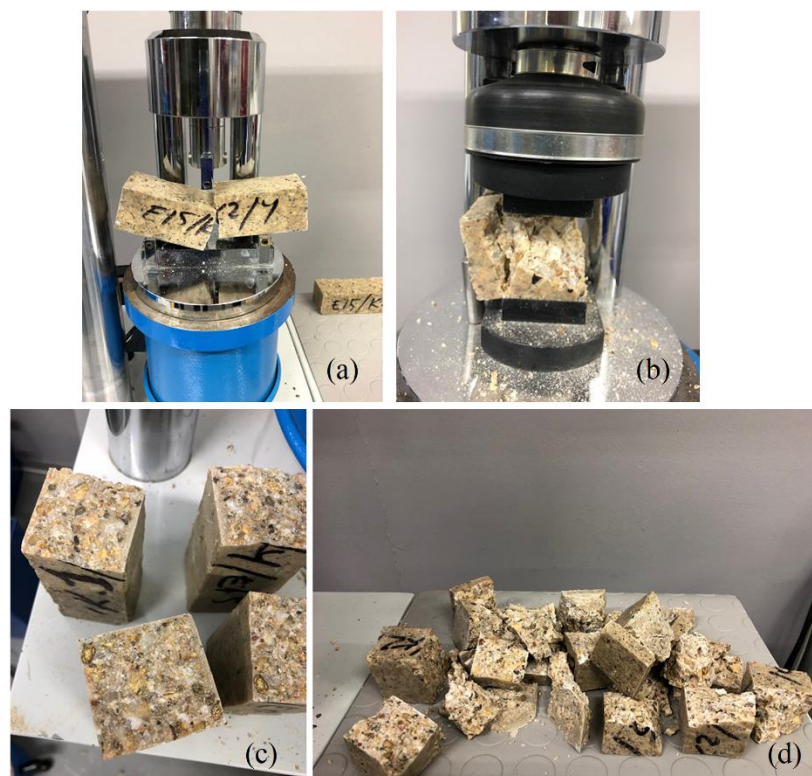


Fig. 3. Experimental Studies: (a) three-point bending tests; (b) compression tests; (c) crack pattern after the three-point bending tests; (d) failure mechanisms after the compression tests.

Table 3. Initial and final setting times of the samples.

Samples	Initial Setting Time (sec)	Final Setting Time (sec)
Mixture-1	240	1080
Mixture-2	220	840
Mixture-3	210	755
Mixture-4	180	660
Mixture-5	200	720

In the second step of the experimental studies, the mechanical tests were conducted. The loading rates were 0.05 kN per second and 2.4 kN per second for the three-point bending tests and compression tests, respectively. In the mechanical tests, the samples were loaded with this velocity until they collapse. Table 4 provides a summary of the mechanical test results.

It was found that the amounts of the MEKP played an important role in the mechanical properties of PCs. Sim-

ilarly, Khalid et al. 2015 and Mahdi et al. 2010 emphasized the same issue in the literature. When the mechanical test results were examined, the highest flexural strength was determined in the Mixture-2 and the highest compression strength was determined in the Mixture-1. The lowest flexural strength determined in the Mixture-1 and the lowest compression strength was determined in the Mixture-5. The average values are presented in Fig. 4 for easy evaluation.

Table 4. Mechanical test results.

Samples		Amount of MEKP (%)	Density (kg/m ³)	Flexural Strength (MPa)	Compression Strength (MPa)
Mixture-1	1	0.15	2105.98	19.03	109.55
	2	0.15	2104.14	21.05	110.31
	3	0.15	2103.12	20.13	109.96
	Average		2104.41	20.07	109.94
Mixture-2	1	0.25	2125.98	24.47	107.57
	2	0.25	2119.14	23.53	109.01
	3	0.25	2137.20	24.09	108.26
	Average		2127.44	24.03	108.28
Mixture-3	1	0.35	2095.98	22.52	108.11
	2	0.35	2104.14	22.73	108.87
	3	0.35	2091.09	22.61	108.46
	Average		2097.07	22.62	108.48
Mixture-4	1	0.45	2069.98	22.76	103.77
	2	0.45	2074.14	22.71	104.83
	3	0.45	2073.26	22.75	104.33
	Average		2072.46	22.74	104.31
Mixture-5	1	0.55	2135.98	22.41	103.21
	2	0.55	2144.14	21.02	104.13
	3	0.55	2138.11	21.67	103.64
	Average		2139.41	21.70	103.66

In the last step, the failure mechanics and crack patterns the samples were examined based on the flexural and compression tests. It was observed that fracture was brittle in all samples as expected. Fig. 5 shows that the failure generally occurred on the aggregate grains. Be-

cause of the brittle behavior, compression fractures became sudden and the specimens were separated into many pieces. Therefore, one might conclude that these PC specimens do not either have plastic deformation capacity or have low plastic deformation capacity.

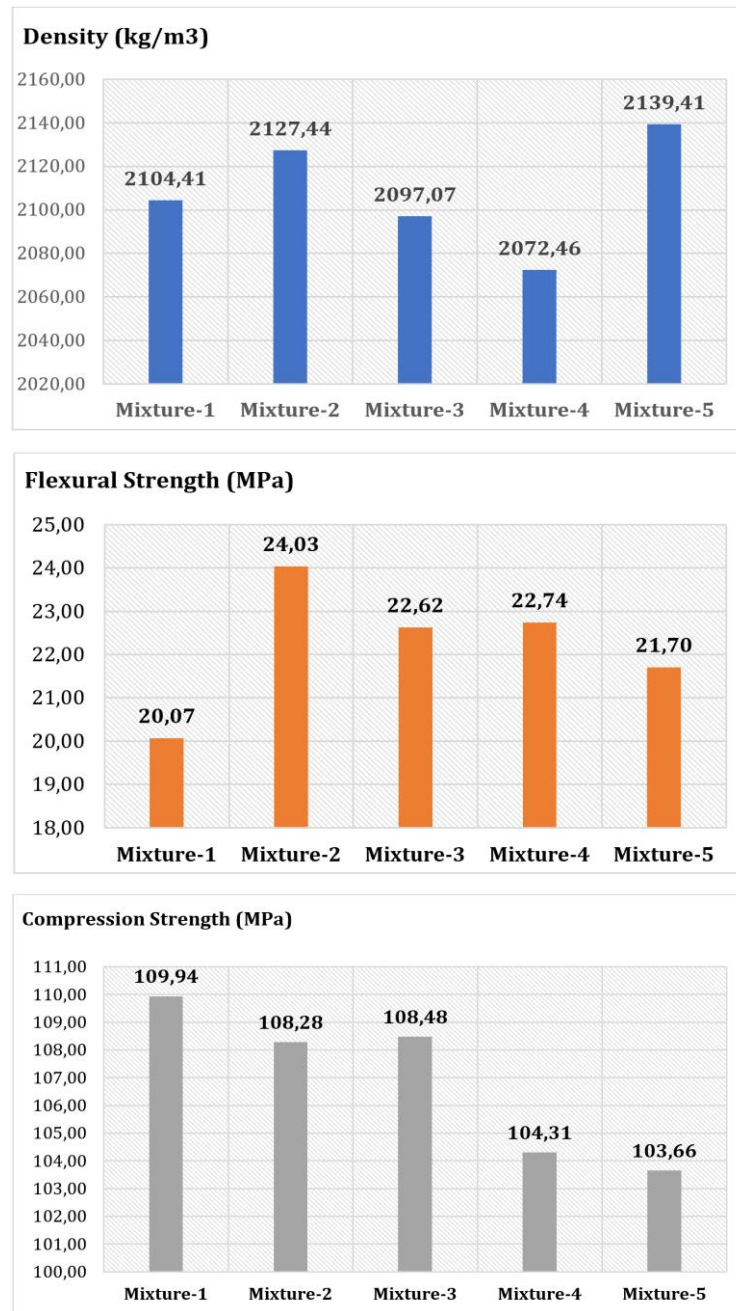


Fig. 4. Average values of the mechanical test results.



Fig. 5. Failure surface of the sample.

5. Conclusions

This study investigates the mechanical properties of the PCs including different amount of MEKP evaluates the influence of MEKP on the mechanical characterizations of the PCs. The main purpose of this study is (1) to understand the mechanical properties of the polymer concrete including different amount of MEKP and (2) to investigate the influence of MEKP on the mechanical characterizations of the polymer concrete. For this purpose, five different samples containing 0.15% (Mixture-1), 0.25% (Mixture-2), 0.35% (Mixture-3), 0.45% (Mixture-4) and 0.55% (Mixture-5) MEKP of the total weight were prepared and compressive and flexural tests were performed on the prepared mixtures. A total of 15 pieces of specimen having 40x40x160 mm in dimension were

produced for each mixture. The results of the experimental samples were examined comparatively, and the main results were listed below.

- The mechanical tests show that the flexural strength of Mixture-2 is better than the other mixtures. It was observed that the flexural strengths decreased in Mixture-3, Mixture-4 and Mixture-5. The lowest value of the flexural strength were determined in Mixture-1.
- Considering the compression strengths of the samples, Mixture-1 has the highest value in all respects compared to other mixtures. It was observed that compressive strengths decreased while MEKP amount increased. It was further determined that the compressive strengths, which are almost same in the Mixture-1, Mixture-2 and Mixture-3, however, the compressive strength of Mixture-4 and Mixture-5 decreased relatively.
- In the experimental tests, brittle fractures were observed in all specimens. As a result of the compression test, the specimens were broken into small pieces. Therefore, it was determined that these PC specimens either do not have plastic deformation capacity or have low plastic deformation capacity. Since all of the specimens have a brittle fracture, it can be concluded that the plastic deformation capacity is irrelevant of the amount of MEKP.
- In case of was prevented fracture of brittle, due to the advantages such as short hardening time, high flexural and compressive strength; polymer concrete's; drainage channels, manholes, bridge beams at flexural effect and bridge legs etc. are widely be used in prefabricated building elements. Therefore, the number of experimental studies in this area is encouraged.
- The amounts of the MEKP do not affect the crack patterns and failure modes of the samples.

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