Challenge Journal of Concrete Research Letters

Research Article

Effect of curing time on polymer concrete strength

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ABSTRACT

With the advancement of polymer technology, polymer concrete (PC) has become increasingly popular throughout the world and it has among the major construction materials due to its many advantages. The strength and durability of PCs are directly related to paste quality and curing time. The curing time is of the utmost importance to ensure desirable mechanical properties. An understanding of the strength-time relationship of PCs is crucial to understanding the effects of loading on concrete at an older age. The objective of this paper is to study the behavior of PC under different curing times with an emphasis on compressive and flexural strengths. Therefore, a total of 63 specimens were tested at seven different ages (1 day, 3 days, 5 days, 7 days, 14 days, 28 days, and 105 days) throughout the study. According to the results obtained from the tests, it is shown that the curing time plays a critical role in the flexural and compressive strengths of PCs. PCs gain more than 80% of their mechanical strength within three days, and the long-term strength does not change significantly after seven days.

ARTICLE INFO

Article history:
Received 28 January 2022
Revised 13 March 2022
Accepted 24 March 2022

Keywords:
Polymer concrete
Curing time
Compressive strength
Flexural strength

1. Introduction

Cement-based concretes (CBCs) are one of the most popular construction materials all around the world. Although these materials have many important characteristics such as high compressive strength and low cost, they have several limitations including low tensile strength, poor durability, and low chemical resistance. Hence, the search for new materials to replace CBCs and prepare concrete without cement are the most important research topic for civil engineering committees. CBC has been replaced by polymer-based concrete as the most popular alternative in the construction industry (Shaw 1985). In accordance with the American Concrete Institute (ACI), there are three types of polymer-based concretes; Polymer Portland Cement Concrete (PPCC), Polymer Impregnated Concrete (PIC), and Polymer Concrete (PC) (ACI 548.1R 2009). PPCC is a concrete mix that contains cement and polymer as binders. PPCCs are usually made by mixing polymer into fresh cement concrete (Justnes 2004; Czarnecki 2018). In PIC, hardened concrete is impregnated with polymers for 4–5 hours, and a polymer layer is formed around it (Kumar and Narayanan 2020). PC differs from PPCCs and PICs, as it lacks a cement binder and uses polymers instead of cement as a binder. Today, PCs have become the most emphasized materials since they do not contain cement. The most important characteristics of these materials are high pressure, tensile and shear strengths, as well as rapid hardening and surface hardness. Therefore, they can be effectively used in new and existing structures due to these superior properties (Bedi et al. 2013).

The quality of the mixture and the curing time determine the strength and durability of PCs. The curing period is one of the most important factors in determining the mechanical properties of the final product (Ohama and Demura 1982). The curing process has been proven by previous studies to be one of the most important steps to ensuring durable concrete. Particularly, early curing of concrete improves its performance considerably, so it is crucial to cure it appropriately of the start. Ohama and Demura (1982) emphasized that the compressive strength of polyester resin concrete generally increases with the addition of heat curing time, and virtually remains constant from about five to ten hours regardless of the amount of pre-curing time. Tae and Choi

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ISSN: 2548-0928 / DOI: https://doi.org/10.20528/cjcrl.2022.02.001

(2012) focused on the time-dependent behavior of polymer concrete using unsaturated polyester resin. It was concluded from the study that recycled unsaturated polyester resin-based polymer concrete achieved over 80% of its 28-day strength in seven days. Hoe Kwen et al. (2015) conducted an experimental study on accelerated curing regimes for polymer-modified cement. In the study, it was found that samples exposed to 8 hours of hygrothermal treatment were comparable to those exposed to 24 hours of treatment. Khalid et al. (2015) studied the effect of curing temperature and period on apparent density, compressive strength, and morphology properties of PCs. According to the study, PC based on the orthophthalic and isophthalic polymers had higher compressive strength when cured for at least six hours and three hours, respectively at cure temperatures of 50 °C and 70 °C. The compressive strength reached its maximum at 30 °C only after 16 hours of curing. Hong (2017) investigated the effects of curing temperature and curing time on the mechanical properties of polysulfide PC. According to this study, approximately 27% of the compressive strength of curing polysulfide PC formed within 6 hours and approximately 80% within 7 days of curing.

2. Materials and Method

A series of experiments was conducted to investigate the effects of curing time on the mechanical properties of the hardened PCs. In all mixes, all constituents were kept in a constant proportion by weight. This study utilized natural fine aggregate, polyester resin, acetylacetone peroxide (AAP) and cobalt naphthenate to prepare a composite material.

2.1. Aggregate

Natural fine aggregates of three different sizes, obtained from Istanbul and Kirklareli, Turkey, were used in the study. In order to eliminate contamination, all aggregates were cleaned thoroughly with clear water and naturally dried before use. The chemical composition of the aggregates is listed in Table 1.

2.2. Binder

In the scope of the study, general-purpose unsaturated polyester resin (UPR) with high filling wetting power was used. UPRs are thermosetting and can be cured from a liquid to a solid with the right conditions. Polyester resins account for the majority of resins used in the world today. The main polymeric chain of this resin contains ester bonds, which are formed by the compaction of a multifactorial alcohol compound and its multifactorial acid. The technical properties of the UPR are given in Table 2.

2.3. Hardener

During this study, acetylacetone peroxide, a fast-curing peroxide commonly used to cure unsaturated polyester resins, was used. Table 3 presents the technical information about the hardener.

Table 1. Chemical composition of the natural fine aggregates.

Chemicals	Aggregates		
	0.3-1 mm	1-3 mm	3-5 mm
MgO	0.10	0.06	0.06
Al_2O_3	0.245	1.80	1.86
SiO_2	98.86	94.20	94.15
CaO	0.01	0.45	0.39
Fe_2O_3	0.148	0.46	0.46
SO_3	-	0.10	0.10
K_2O	0.03	1.52	1.56
Na_2O	0.02	1.16	1.12
Ignition Loss	0.24	0.25	0.30

Table 2. Technical properties of the UPR.

Properties	Values
Flexural strength in 5% strain (MPa)	51.6
Compressive strength (MPa)	34.1
Impact strength (J/m)	12.9
Viscosity (mPa.s)	659
Shore hardness	80
Tensile modulus (MPa)	527
Density (g/cm^3)	1.225

Table 3. Technical properties of the hardener.

Properties	Values
Flash point	>60°C
Density, 20°C	1055 kg/m^3
Viscosity, 20°C	21 mPa.s
Self-accelerating decomposition temperature (SADT)	60 °C
Total active oxygen	4.0-4.2%
Peroxide content	33%
Diethylene glycol + water + diacetone alcohol	67%

2.4. Accelerator

Accelerators are used to speed up the reaction between the resin and the hardener. In general, accelerators raise the temperature in a system, which speeds up epoxy reactions. An accelerator for activating the curing agent was selected in this study as cobalt naphthenate. Table 4 presents technical information about the accelerator.

Table 4. Technical properties of the accelerator.

Properties	Values
Density	0.92 g/cm^3 (20°C)
Viscosity	300 mPa.s (20°C)
Self-accelerating decomposition temperature (SADT)	≥150°C
Flash point	62°C
Cobalt content	1.5%

3. Experimental Studies

Compression, flexural and density tests were performed to evaluate the hardened concrete properties. All tests were performed according to the ASTM specifications. A total of 42 concrete samples, consisting of 21 samples for flexural and 21 samples for compression tests, was cast and tested on the 1 day, 3 days, 5 days, 7 days, 14 days, 28 days, and 105 days of curing age for compressive strength and flexural strength. In the compressive and flexural strength tests, the hardened samples were tested until failure by using the Form-Test machine with 600 kN (Fig. 1). The experimental program in this study was conducted in the Research and Development (R&D) Engineering Laboratory at Mert Casting Inc., Turkey. The data obtained from the hardened concrete tests are summarized in Tables 5-11.

Fig. 1. Experimental studies.

Table 5. Mechanical properties at the curing age of 1 day.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	1	568.11	40	40	155	5.06	11.86	71.12	44.45
2	1	567.04	40	40	155	4.97	11.65	70.81	44.26
3	1	568.99	40	40	155	4.89	11.46	77.72	48.58
					Average	4.97	11.66	73.22	45.76

Table 6. Mechanical properties at the curing age of 3 days.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	3	566.16	40	40	155	8.88	20.81	136.12	85.08
2	3	569.54	40	40	155	8.87	20.79	139.81	87.38
3	3	566.95	40	40	155	8.87	20.79	136.72	85.45
					Average	8.87	20.80	137.55	85.97

Table 7. Mechanical properties at the curing age of 5 days.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	5	567.68	40	40	155	10.33	24.21	147.82	92.39
2	5	566.17	40	40	155	9.97	23.37	149.15	93.22
3	5	564.6	40	40	155	10.17	23.84	148.88	93.05
					Average	10.16	23.80	148.62	92.89

Table 8. Mechanical properties at the curing age of 7 days.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	7	567.67	40	40	155	13.36	31.31	157.73	98.58
2	7	568.40	40	40	155	12.96	30.38	156.94	98.09
3	7	563.99	40	40	155	12.03	28.20	161.22	100.76
					Average	12.78	29.96	158.63	99.14

Table 9. Mechanical properties at the curing age of 14 days.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	14	571.67	40	40	155	14.31	33.54	163.03	101.89
2	14	568.74	40	40	155	13.98	32.77	164	102.50
3	14	559.89	40	40	155	14.05	32.93	163.26	102.04
					Average	14.11	33.08	163.43	102.14

Table 10. Mechanical properties at the curing age of 28 days.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	28	561.61	40	40	155	14.55	34.10	163.88	102.43
2	28	570.74	40	40	155	14.50	33.98	164.89	103.06
3	28	569.96	40	40	155	14.21	33.30	163.67	102.29
					Average	14.42	33.80	164.15	102.59

Table 11. Mechanical properties at the curing age of 105 days.

Sample	Curing Time	Sample Weight	Sample Dimensions (mm)			Maximum Flexural Load	Flexural Strength	Maximum Compressive Load	Compressive Strength
	Days	(gr)	X	Y	Z	(kN)	(MPa)	(kN)	(MPa)
1	105	567.50	40	40	155	14.65	34.34	165.61	103.51
2	105	568.98	40	40	155	14.51	34.01	166.25	103.91
3	105	569.01	40	40	155	14.74	33.38	167.77	104.86
					Average	14.63	33.91	166.54	104.09

When focusing on the mechanical tests performed on the hardened concrete tests, it was seen that the compressive strength of the samples varies between approximately 45.76 MPa and 104.09 MPa at 1 day and 105 days, respectively (Fig. 2). According to the average compressive strengths, the PCs gain more than 40% of their strength 1 day after pouring. Within 3 days, PCs gained more than 80% of their compressive strength, and long-term compressive strength did not significantly change after 7 days (Fig. 2). When the flexural strengths of the samples were examined, the average flexural strength obtained on the 1st day was 11.66 MPa, while the average flexural strength obtained on the 105th day was 34.30 MPa (Fig. 3). When the time-dependent variation was examined, the long-term flexural strength of the materials became significantly unchanged after 7 days, as did the compressive strength of the materials (Fig. 4). When focusing on the densities of the materials, it was determined that the densities of the materials were generally very close to each other and the density to the medium was 568 gr/cm^3. In addition, it was seen that there was no significant time-dependent change in densities in general (Fig. 5). The results obtained in this study were examined to the results of studies carried out in the literature. Based on the examination, Tae and Choi (2012) concluded that the unsaturated polyester resin-based polymer concrete achieved over 80% of its 28-day strength in 7 days. Similarly, Hong (2017) emphasised the approximately 27% of the compressive strength of curing polysulfide PC formed within 6 hours and approximately 80% within 7 days of curing.

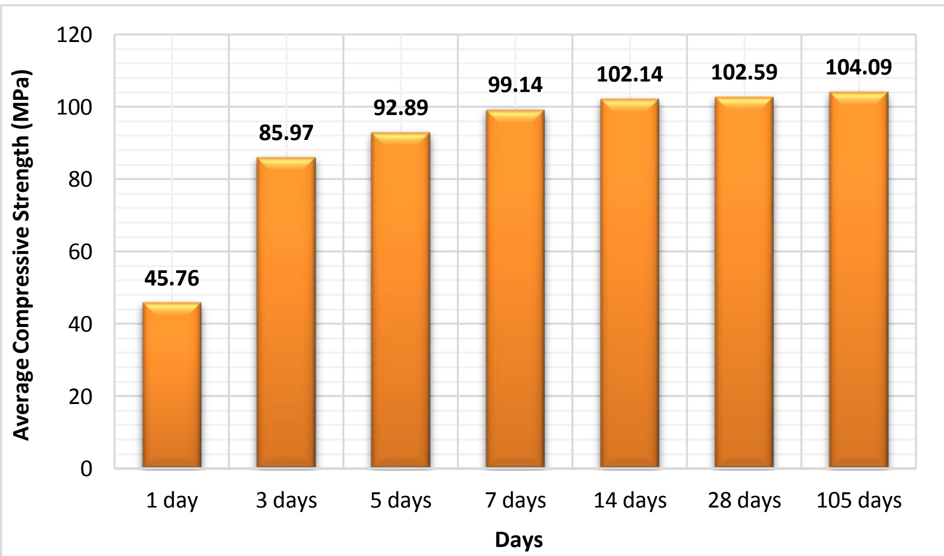

Fig. 2. The average compressive strengths (MPa).

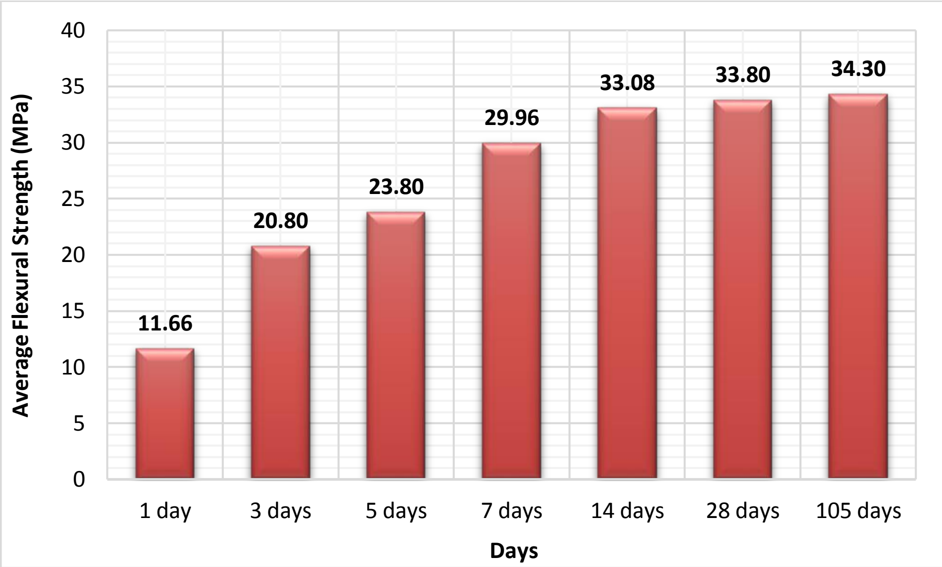

Fig. 3. The average flexural strengths (MPa).

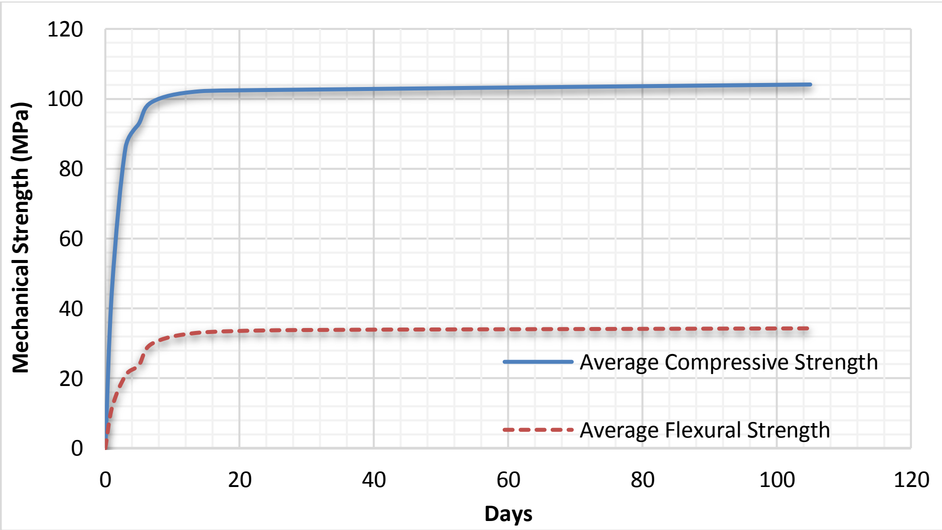

Fig. 4. Comparison between the average compressive and flexural strength considering the curing time.

Fig. 5. The average densities (gr/cm^3).

Comparing the results obtained from PCs with those obtained from cement-based concrete (CBC), it turns out that PCs gain strength earlier than CBCs. The American Concrete Institute (ACI) Committee emphasizes that the majority of the mechanical strength of cement-based concretes reached in 28 days (ACI 308R-01 2008). Figs. 6a and 6b illustrate the relationship between compressive strength and curing temperature, and the relationship between long-term compressive strength and curing age of CBCs.

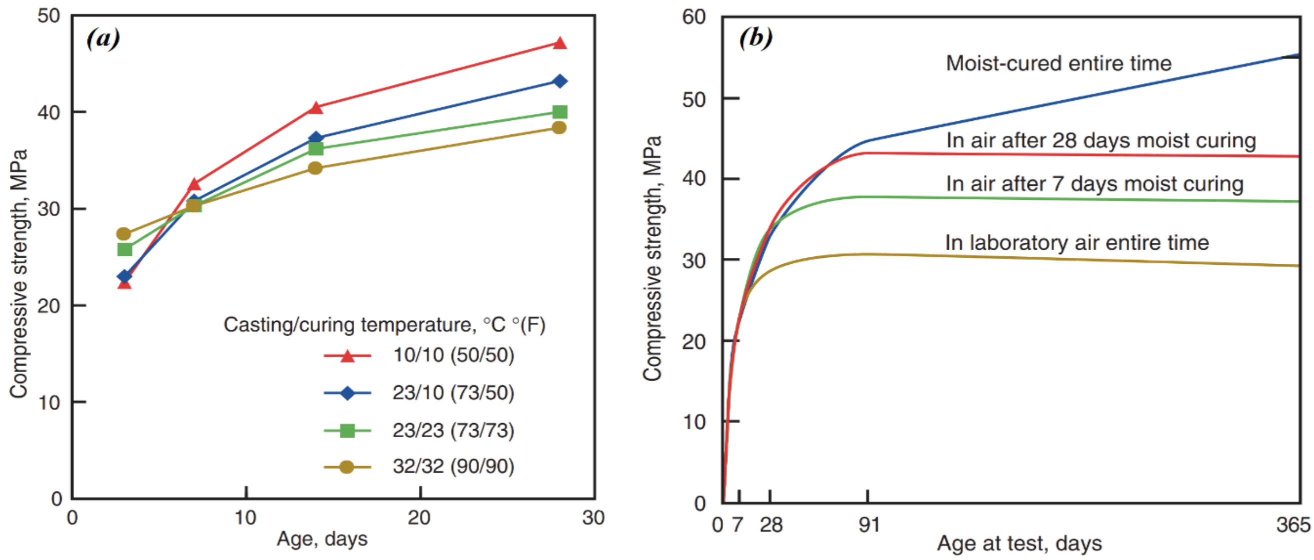

Fig. 6. a) Relationship between a compressive strength curing temperature;
b) Relationship between a long-term compressive strength and curing age of CBCs (Kosmakta et al. 2008).

4. Conclusions

Polymer concretes (PCs) have become increasingly common in many different industries in recent years and they are generally used as special concrete in various construction applications. PCs are seen as the best alternative to cement concrete because of their high performance. Compared to the CBCs, PCs produce a very different type of product. While cement is used as a binder material in CBCs, resins are used as binders in PCs. This study mainly focuses on the effect of curing age on PC strength and the paper explains how different curing times affect PC strength.

After performing mechanical tests on the hardened concrete samples, a compressive strength ranging from approximately 45.76 MPa to 104.09 MPa was determined at one day and 105 days, respectively. Based on the average compressive strength, PCs gain more than 40% of their strength a day after pouring. After three days, PCs regained more than 80% of their compressive strength, and their long-term strength remained unchanged after seven days. The flexural strength of 11.66 MPa was recorded on the 1st day, while the strength of 34.30 MPa was measured on the 105th day. After 7 days, the flexural and compressive strengths of the materials were unchanged considering the time-dependent variation. Regarding the densities, it was found that the materials have generally very close densities and that the density of the average is 568 g/cm^3. In general, it was found that densities did not change significantly with time.

Acknowledgements

The author would like to thank Mert Casting Inc. for its continuous support during the study.

Funding

The author received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

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