Experimental Study of Different Types of Concrete in Uniaxial Compression Test

Khashayar Jafari, Mostafa Jafarian Abyaneh, Vahab Toufigh

Abstract**—**Polymer concrete (PC) is a distinct concrete with superior characteristics in comparison to ordinary cement concrete. It has become well-known for its applications in thin overlays, floors and precast components. In this investigation, the mechanical properties of PC with different epoxy resin contents, ordinary cement concrete (OCC) and lightweight concrete (LC) have been studied under uniaxial compression test. The study involves five types of concrete, with each type being tested four times. Their complete elastic-plastic behavior was compared with each other through the measurement of volumetric strain during the tests. According to the results, PC showed higher strength, ductility and energy absorption with respect to OCC and LC.

Keywords**—**Polymer concrete, ordinary cement concrete, lightweight concrete, uniaxial compression test, volumetric strain.

I. Introduction

THE evolution of civil engineering has led to an increasing demand for the development of higher performance engineering materials possessing greater strength, toughness, energy absorption and durability. Early humans used mud to construct buildings, which lacked these parameters. At the beginning of 19th century, concrete was discovered as an engineering material; and since then, it has been widely used in construction all over the world with a variety of applications. In the decade of the 1950's, PC was found as a novel type of concrete, and become well-known in the 1970's for its use in repair and rehabilitation of structures, as well as for the construction of thin overlays, floors and precast components [1].

The term concrete can be applied to any construction material that has two types of components, aggregates and cementitious material. The latter can be made of Portland cement powder with the addition of water, or liquid resin, which results in PC. PC is a composite material resulting from polymerization of a monomer/aggregate mixture [2]. The most widespread resins for PC are epoxy resin, unsaturated polyester resin, methyl methacrylate resin, furan resin, urea-formaldehyde resin, polyurethane resin [3].

Superior characteristics of PC include high compressive strength, fast curing, high specific strength, low permeability, and resistance to chemical attack [4]. Early applications of PC have been reported to be mainly for building cladding. It was extensively used as a repair material because of rapid curing, excellent bond to cement concrete and steel reinforcement [5], and high strength and durability [6]. Moreover, PC has better vibration damping properties than conventional materials of machine structures such as cast iron [7], [8]. Hence, it is used in precise machine tools, as well as the base foundations of them [9]-[12].

In the literature, there are several researches on normal, high-strength and LC that addresses its mechanical behavior under uniaxial compression loading [13], [14]. However, few similar studies have been conducted on mechanical properties of PC subjected to uniaxial compression loading [15]-[17]. Moreover, its characteristics have been mostly considered without lateral or volumetric strain. Whereas, the plastic behavior of concrete depends on volumetric plastic strain, similar to other granular materials such as soil. Therefore, there is an increasing demand for predicting the mechanical behavior of PC under uniaxial loading through its volumetric strain. In this research, the experimental program includes a wide range of experiments, in which different types of concrete specimens have been tested under uniaxial compression tests.

II. Materials and Mixture Design

A. Polymer

The polymer generally consists of two phases, base and hardener; both of them should be stirred separately before mixing to disperse any settlement. The epoxy resin used in this research was Nitobond EP, which included a 63.3% base and 36.7% hardener that should be mixed using a suitable slow-speed drill and mixing paddle for two minutes until a fully uniform color is obtained.

B. Aggregates

Concrete is made of two main parts including aggregates and a cementitious material, which bonds aggregates to each other. The main part of concrete is composed of aggregates; therefore, the overall quality and mechanical properties of concrete primarily depends on aggregates. Aggregates should provide the minimum void ratio in order to optimize epoxy resin content. They are divided to two groups, larger than 4.75 mm and smaller than 4.75 mm. The former is referred to as coarse aggregates and the latter is the fine aggregates.

For the assessment of fine aggregates, one kilogram was used in the sieve test and compared with ASTM C33 / C33M-13 [18]. According to ASTM guidelines, the fine aggregates were not in the standard range; hence, they had to be modified. Paying close attention to the results, since the aggregates remained on the sieve #4 and #8 were more than standard, all of the former and two thirds of the latter have been omitted;

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therefore, they are in the standard range (Fig. 1). Coarse aggregates have been obtained from three size ranges, which were combined with specific proportions to be in the standard range of ASTM C33 (Fig. 2).

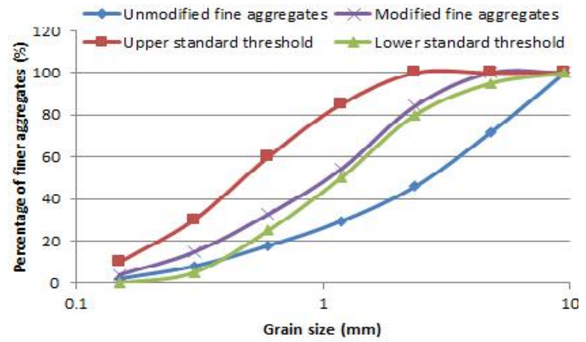

Fig. 1 Fine aggregate size distribution

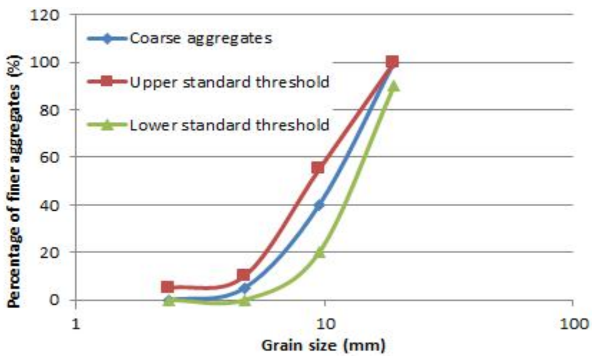

Fig. 2 Coarse aggregate size distribution

According to ASTM C29 / C29M-09 [19], bulk density values, the mixture of coarse and fine aggregates should have maximum weight per unit volume. Different percentages of fine and coarse aggregates that have been mixed are 40-60%, 45-55%, and vice versa, as well as 50-50%. After measuring, the maximum weight per unit volume was 50-50%.

C. Construction of Concrete Specimen

In this paper, different types of concrete specimens have been tested under uniaxial compression tests. These specimens were normal and LC, as well as PC saturated by 10%, 12%, and 14% epoxy resin. According to American Concrete Institute ACI committee 318 [20] and ACI committee 548 [21] guidelines, there is no standard method for the construction of PC in contrast to cement concrete.

First, plastic molds with a diameter of three inches and a height of six inches were attached to a flat surface. Since the aforementioned molds were plastic and rigid, the error caused by the deformation of the concrete during curing was marginal enough to be neglected. In order to prevent the concrete from sticking to the mold and to make it easier to demold, the inner surface of mold was first lubricated with oil.

The properties of PC depend on the conditions of preparation, binder content, aggregate size distribution, nature, and curing conditions. The aggregates size distribution is non-standardized and varies widely from system to system. The different concrete mixture designs used in this study are as follows:

OCC: According to ACI committee 318. (2014), for OCC aggregates should be saturated surface dry (SSD). [20] The concrete mixture design with strength of 28 MPa is shown in Table I. The determined quantity of aggregates was placed in a metal container, and then specific amounts of water and the whole cement were added. Afterwards, the mixture was stirred for five minutes causing it to become almost homogeneous. The concrete was poured into the mold in three layers, and each layer was pounded 25 times. The molds were placed on a vibrator table for 30 seconds, and finally the surface of the concrete was paved. The concrete was maintained in the molds covered by a wet sack for 24 hours at room temperature. After that, they were demolded and placed in a water pool for 28 days. Finally, they were extracted from the water, and the surfaces were then dried.

LC: The LC mixture design with the strength of 25 MPa is also shown in Table I. Since silica fume has extreme fineness and high silica content, it is a very effective pozzolanic material, which can be added to Portland cement concrete to improve its properties, in particular, its compressive strength, bond strength and abrasion resistance. These improvements are caused by pozzolanic reactions between the silica fume and free calcium hydroxide in the paste [22]. Silica fume used in LC mixtures in accordance with ASTM C1240 [23]. The method of mixing LC was the same as OCC.

TABLE I
MIXTURE DESIGN OF OCC AND LC

Concrete type	Coarse aggregate (%)	Fine aggregate (%)	Cement (%)	Water/cement ratio (%)	Silica fume (%)
OCC	46	30	17	42	0
LC	37.2	34.7	20	30	2.2

PC: Epoxy resin which has been explained before was added to aggregates, and the mixture was allowed to be blended for five minutes, in order to have a relatively homogeneous material. PC specimens were fabricated in three different epoxy resin ratios including 10%, 12% and 14%, as demonstrated in Table II. The determined quantity of aggregates was placed in a metal container, and then the specific amount of epoxy resin was added. The mixture was blended until all the aggregates were covered by epoxy resin. The PC was the poured into the mold in three layers, with each layer pounded 25 times. The molds were placed on a vibrator table for 30 seconds, and then the surface of the concrete was paved. The PC was maintained in the molds for 24 hours at room temperature. After that, they were demolded and held in 35 °C for five days.

TABLE II
MIXTURE DESIGN OF PC

Concrete type (%)	Coarse aggregates (%)	Fine aggregates (%)	Epoxy-resin (%)
PC with 10	45	45	10
PC with 12	44	44	12
PC with 14	43	43	14

III. Testing Procedure

The concrete specimens were placed in uniaxial compression apparatus as shown in Fig. 3. 4 linear variable displacement transformers (LVDT) have been used in this research; one of them measured the axial strain, and others measured the lateral strain, which were placed on a ring around the specimen with 120° between each other. All of the LVDTs were connected to a data logger, which can trace the changes in strains during the increase in applied load. Afterwards, the experimental diagrams were obtained from the uniaxial tests. The PC specimens failed at shear mode, which can be seen in Fig. 4.

IV. Results and Discussion

Fig. 3 Uniaxial compression test setup

Fig. 4 Specimens at the end of experiment

The PC showed excellent mechanical properties in comparison to cement concrete, such as strength, maximum strain, and energy absorption. Compressive stress-strain curves for three types of PC and two types of cement concrete have been depicted in Figs. 5 and 6, respectively. Since the experiments were under displacement-control loading, softening behavior was observed which attributed to more crack development. As cracks propagate in the sample, the volumetric strain changes from contraction to dilation mode. Figs. 7 and 8 show volumetric strain as a function of axial strain for three types of PCs and two types of concrete. For each specimen, two curves have been extracted; these curves are as follows:

1. Compressive stress versus axial strain curve.
2. Volumetric strain versus axial strain curve.

The maximum compressive stress and maximum axial strain of the PC specimens is higher than the OCC and LC, which makes it an excellent choice for purposes where strength and ductility are matter of concern. Three types of characteristics can be observed in the compressive stress-strain curve and volumetric strain variation due to the three types of material behavior; they include softening, plastic and hardening behavior, Fig. 9. It should be noted that in ideally elastic conditions, εv (volumetric strain) is defined by $\varepsilon a + 2\varepsilon l$ formula where εa and εl are values of axial strain and lateral strain under uniaxial compressive tests, respectively.

Three different plastic behaviors can be basically seen as cracks start to grow gradually. All of the PC, OCC and LC specimens showed softening behavior in the uniaxial compression tests as illustrated in Figs. 5-8. The dilation can be seen only in PC with 14% epoxy resin ratio and OCC, while all specimens experienced contraction. The lack of dilation for LC is mainly due to its brittle mechanical characteristics. Since, the area underneath the compressive stress-strain curve represents energy absorption, it can be concluded that PC specimens showed approximately four times more energy absorption than OCC and LC.

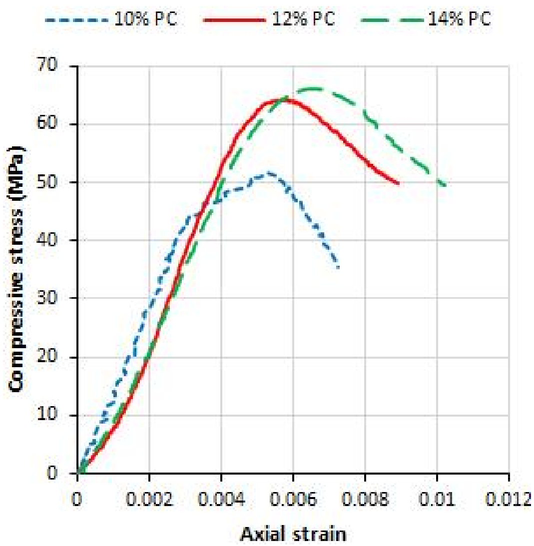

Fig. 5 Compressive stress versus axial strain curve for PC specimens with different epoxy resin ratios including 10%, 12% and 14%

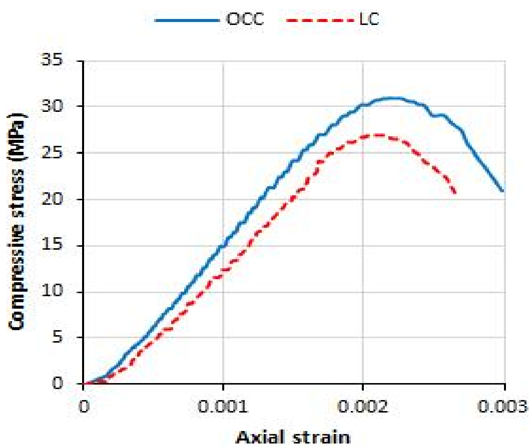

Fig. 6 Compressive stress versus axial strain curve for OCC and LC

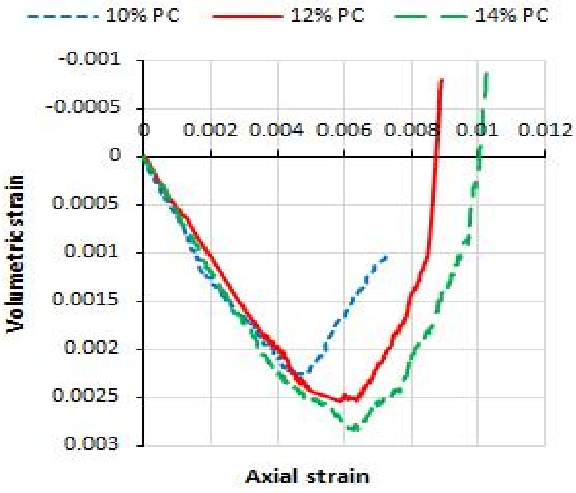

Fig. 7 Volumetric strain versus axial strain curve for PC specimens with different epoxy resin ratios including 10%, 12% and 14%

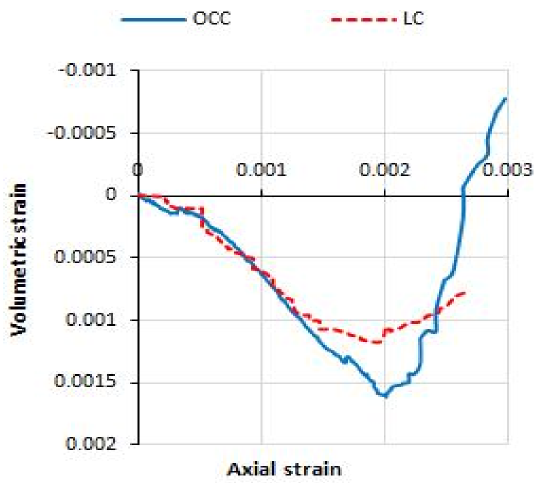

Fig. 8 Volumetric strain versus axial strain curve for OCC and LC

V. Conclusion

In this paper, the stress-strain curves of PC, OCC, and LC subjected to uniaxial compression loading were extracted. Since the volumetric strain plays an important role in plastic behavior of concrete, the volumetric and axial strains were recorded during the tests. The advantages of PC with respect to OCC and LC are as:

1. The strength of PC specimens is approximately two times larger than OCC and 2.5 times larger than LC.
2. The required time for curing of PC is only five days, whereas OCC and LC require 28 days to be cured. Furthermore, PC can reach to 90% of its ultimate strength in only three days.
3. It shows more ductile behavior than cement concrete; in other words, its maximum strain is more than two times larger than that of cement concrete leading to more ductility without a sudden breakage of the cylinder.
4. The area under the stress-strain curve for PC samples, which represents energy absorption, is almost four times more than that of OCC and LC.
5. All of the specimens showed dilation, except PC a with 10% epoxy resin ratio, and LC, which is primarily due to their low ductility.

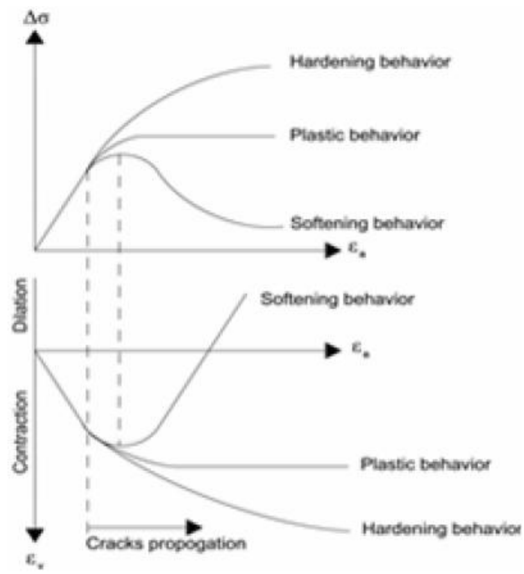

Fig. 9 The schematic diagram of compressive stress and volumteric strain versus axial strain

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