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STRESS-STRAIN BEHAVIOUR OF UNCONFINED POLYMER CONCRETE

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ABSTRACT

Polymer concrete is becoming popular as a new construction material due to its high compressive, tensile and flexural strengths, short curing time, impact resistance, chemical resistance and freeze-thaw durability. It is reported to have used in a range of civil and structural applications such as bridge decking, concrete crack repair, pavement overlays, hazardous waste containers, waste water pipes and decorative construction panels. However its use can be limited due to the fact that well-agreed stress-strain relationships are not widely available. A research program has been initiated to improve fundamental understanding of this material and to provide the knowledge required for its broad utilization.

In the experimental part of this project, two types of resins (polyester and epoxy resin) combined with fly ash and sand were used to make the organic polymer concrete mortar. These mortar samples were tested for the compressive stress-strain relationship of polymer based concrete. This paper investigates the applicability of currently available stress strain relationships to predict the behaviour of polymer concrete observed in the experimental component of this project. Ultimately it describes a constitutive model for unconfined polymer concrete.

KEYWORDS

Polymer concrete, stress-strain relationship, polyester, epoxy.

INTRODUCTION

Polymer Concrete (PC) outperforms its counterpart Ordinary Portland Cement (OPC) concrete in terms of highly desirable structural engineering properties. PC is also known as synthetic resin concrete, organic polymer concrete and plastic resin concrete. PC is very strong, durable and cures very rapidly, an important factor in most of the civil engineering applications such as transportation, utility, marine and building components (Gorninski et al., 2004; Rebeiz et al., 1995). It is widely reported in the literature that polymer concrete has high compressive, tensile and flexural strengths as well as superior physical and chemical properties such as a short curing time, impact resistance, chemical resistance, electrical insulation, waterproofness and freeze-thaw durability (Jo et al., 2007; Mebarkia and Vipulanandan, 1995; Yeon, 2009).

PC is reported to have used in a range of civil and structural applications such as bridge decking, concrete crack repair, pavement overlays, hazardous waste containers, waste water pipes and decorative construction panels (Jamshidi and Pourkhorshidi, 2012; Jo, Park and Lee, 2008; Jo, Park and Park, 2008). PC is used very efficiently in precast components for buildings, bridge panels, machine bases, and in various utility and transportation components (Abdel-Fattah and El-Hawary, 1999). As PC generally has a very short working time to be positioned, using precast members is the ideal use of PC, as this can be done very efficiently. Although these are specialist types of polymer concretes being used for specific applications, polymer concrete has superior mechanical properties compared to ordinary Portland cement and is in general an improvement upon OPC.

There has been research into the mechanical properties of polymer concretes that have been prepared using a single type of resin and differing fillers. Fly ash and silica fume being the focus of a study (Bărbuţă et al., 2010), finding that differing contents of these fillers changed the mechanical properties of PC. The properties of PC are dependent on the type of polymer used and the gradation of aggregates used, with attributes obtainable for specific uses. A study into the use of PC reinforced with glass fibers as an overlay (Nossoni and Harichandran, 2010) proved that the use of PC as an overlay gave the structure a much better resistance to corrosion as well as having greater bonding with the existing concrete substrate. This is one of the many functions that polymer concrete can be adapted to perform. The feasibility of using a polymer concrete bed for a milling machine was investigated recently and shown that PC has advantages with this specific application (Suh and Lee, 2008). In this particular application, PC was proved to have a greater vibration dampening effect than Ordinary Portland Cement; as polymer concrete has a higher tensile strength and more elasticity.

However there is a need to predict the stress-strain relationships for PC so that it can be widely used in structural applications. This is the gap in knowledge that the authors tried to address in this paper.

EXISTING CONSTITUTIVE MODELS

Based on the test results, various stress-strain models for unconfined/confined concrete have been proposed in the literature (Cusson and Paultre, 1995; Kent and Park, 1971; Mander et al., 1988; Popovics, 1973; Sargin, 1971; Sheikh and Uzumeri, 1982). Existing stress strain models for confined, unconfined normal as well as high strength concrete can be divided into three broad categories.

One group of researchers used a form of equation proposed by Sargin et al. (1971) which has a general form as shown in Eq. 1.

$$Y = \frac{AX + (D-1)X^2}{1 + (A-2)X + DX^2} \tag{1}$$

There have been many developments of this basic equation although the definitions of *X* and *Y* remain the same. *X* is defined as the ratio of axial strain (ε) and the axial strain at peak axial stress (ε_{co}) while *Y* is defined as the ratio of axial stress (σ) and the peak axial stress (f_c) of unconfined concrete. Widely accepted definition for parameter *A* (Ahmad and Shah, 1982; Assa et al., 2001; El-Dash and Ahmad, 1995) is,

$$E_c / E_p \tag{2}$$

Where E_c is the modulus of elasticity of unconfined concrete and E_p is the ratio between peak axial stress and corresponding strain. Parameter *D* is mainly responsible for the general shape of the descending branch of the stress-strain curve and different researchers used different definitions for this. Sargin et al. (1971) used Eq. 3 to define parameter *D*.

$$D = 0.65 - 7.25 f_c \times 10^{-3} \tag{3}$$

The second group of researchers proposed second order parabola for the ascending branch and a straight line for the descending branch and their studies were based on equations proposed by Kent and Park (1971). A generic equation for the ascending branch is given in Eq. 4.

$$f_c \left[2\left(\frac{\varepsilon}{\varepsilon_{co}} \right) - \left(\frac{\varepsilon}{\varepsilon_{co}} \right)^2 \right] \tag{4}$$

Definitions of the parameters terms ε and ε_{co} in Eq. 4 are the same as previous explanation. This equation was further extended to show the stress-strain relationship for confined concrete by replacing

f_c by the peak stress of confined concrete and replacing ε_{co} by the corresponding axial strain. Eq. 4 was later modified by including another parameter into it (Mendis et al., 2000; Razvi and Saatcioglu, 1999). Descending branch of the stress-strain curve was defined as shown in Eq. 5. Z_m is the slope of the descending branch.

$$f_c\left[1 - Z_m\left(\varepsilon - \varepsilon_{co}\right)\right] \tag{5}$$

The third group developed stress strain relationships based on equations suggested by Popovics (1973). In these models, selected parameters were included in the stress-strain curves and then they were calibrated using the test results. In this original model by Popovics (1973), ascending and descending branches were conveniently given by only one equation as follows (Eq. 6).

$$f_c \frac{\varepsilon}{\varepsilon_{co}}\left(\frac{n}{n-1+\left(\varepsilon/\varepsilon_{co}\right)^n}\right) \tag{6}$$

n is a modulus parameter. This single equation has been very popular among the research community (Mander et al., 1988). However, modified versions of Eq. 6 was used for the ascending branch and an exponential function was used for the descending branch later by some researchers (Hoshikuma et al., 1997; Wee et al., 1996).

The aim of this research paper is to investigate the applicability of the existing three types of generic equations for unconfined/confined concrete for the unconfined polymer concrete. Stress-strain curves for unconfined PC were obtained from the experimental program described below.

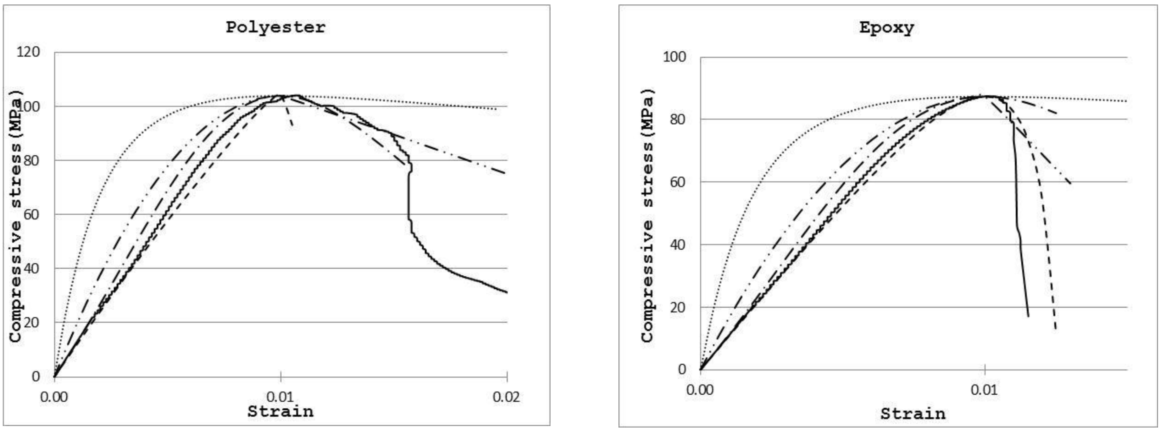
EXPERIMENTAL PROGRAM

In this research, PC mortar was made by mixing resin with sand and fly ash was used as the filler material. Resin and fly ash acted as the binder in this mix. Two resin types were used, namely polyester and epoxy resin. Medium reactivity, rigid orthophthalic polyester resin was used. Thixotropic epoxy resin used in this study was formulated to use with proper hardener to cure at room temperature. A medium hardener was used with epoxy resin. Fly ashes used in the investigation were Type F (low calcium) fly ash of approximately 15 µm. It was sourced from Pozzolanic Millmerran in Queensland, Australia. Fine dry sand used in the investigation had a bulk density of 1494 kg/m3, water absorption of 8% and particle size smaller than 425 µm. In this laboratory testing, fine sand was dried in the oven to a constant mass at a temperature of 110 ℃ for 24 hours as per ASTM C128 [20]. It was then allowed to cool to comfortable handling temperature (approximately 30 ℃). This dry sand was used to prepare specimens. It was observed in this research that the percentage of free air voids in industrial sand obtained from Wagners, Queensland, Australia was 40%. This 40% of air voids was filled with different proportions of resin and fly ash to minimise the air voids. Resin was the main binding material for the polymer concrete and was required to be mixed with a catalyst. The purpose of incorporating the catalyst was to chemically start the curing process of the resin and hence harden the mix. Resin and catalyst proportions were selected based on the supplier recommendations. Dry materials (sand and fly ash) were mixed together separately. Finally the resin catalyst mix was combined with the dry materials and mixed properly to gain a uniform mortar. The size of the PC mortar cylinders for compressive strength testing was 50 mm in diameter and 100 mm in height. The plastic moulds were waxed to ensure easy removal of the cured samples.

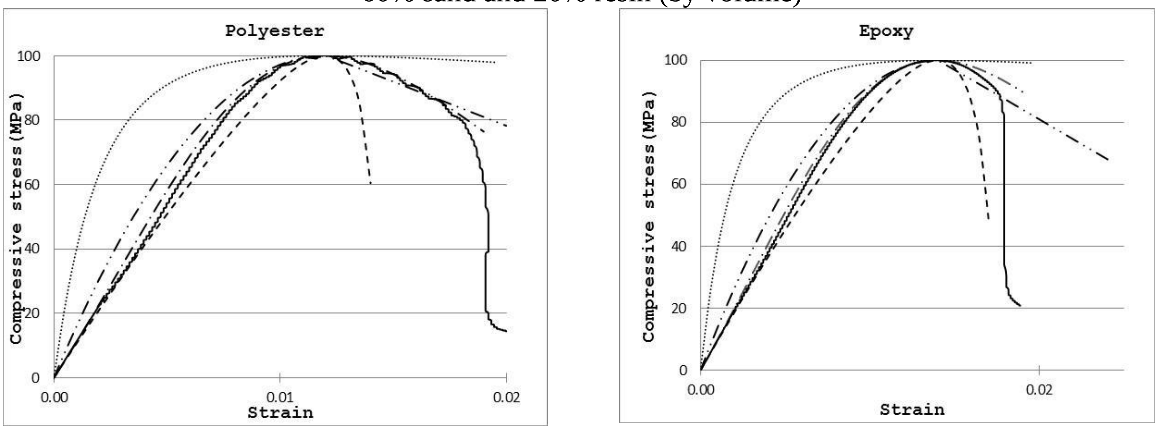
Figure 1. Compression testing

The compressive tests were performed using an AVERY testing machine with 500 kN loading capacity at a constant cross head speed of 2 mm/min (Figure 1). Axial strains were measured using platen to platen method and two longitudinal strain gauges glued diagonally opposite in the middle third of the specimen height. A commercially available data logging system named “System 5000” was used as the data acquisition system, which required a host computer for entering commands, reading the returned data and for managing the output channels. Compression testing was performed as per ASTM D 695 (ASTM-D695, 2010). Details of this experimental program can be found elsewhere (Lokuge and Aravinthan, 2013).

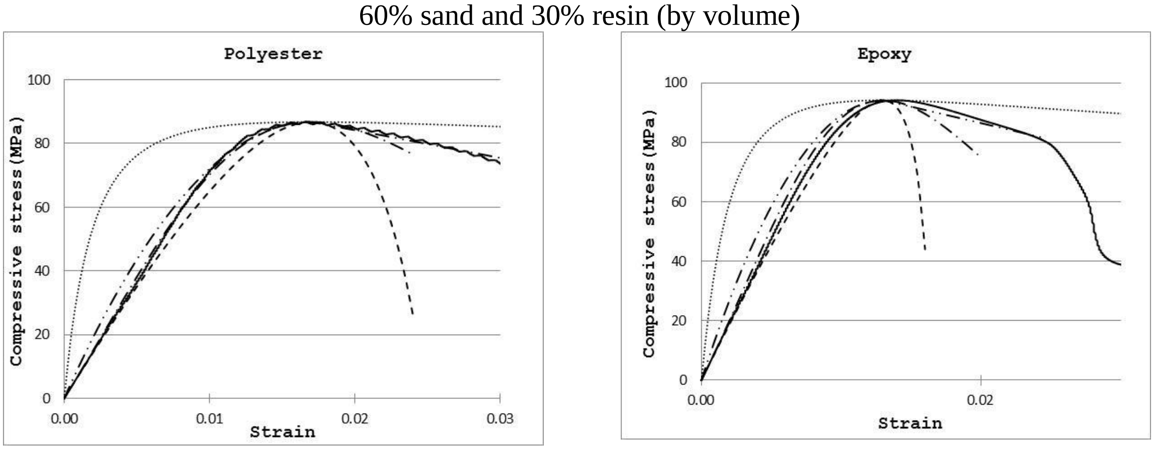
RESULTS AND DISCUSSIONS



60% sand and 20% resin (by volume)



60% sand and 30% resin (by volume)



60% sand and 40% resin (by volume)

Experimental — Sargin et al. (1971) model — Popovics (1973) model

Kent and Park (1971) model — Proposed model

Figure 2. Experimental and predicted stress-strain relationships

The experimental stress-strain relationships obtained in the main experimental program were compared with the three generic relationships reported in the literature and discussed previously in this paper. Model comparisons for Sargin et al. (1971), Kent and Park (1971) and Popovics (1973) are shown in Figure 2. Ascending branches proposed by Sargin et al. (1971) and Kent and Park (1971) seem to have small variations with those of the experimental curves irrespective of the resin type used in the PC. However the single equation proposed by Popovics (1973) is not matching either for the ascending or the descending branches of the curves. Kent and Park (1971) model gives a closer descending branch. However getting the slope of the descending branch is an approximation in this. Sargin et al. (1971) model shows a steep descending branch which is not matching with the experimental results reported in this research. Therefore the authors have modified Sargin et al. (1971) model to better predict the complete stress-strain curve for PC. It will include Eqs. 1 and 2 together with a modified version of Eq. 3 (as shown below in Eq. 7).

$$D = 0.65 - 0.25 f_c \times 10^{-3} \qquad (7)$$

Figure 2 includes the curves for the proposed model as well. The discrepancies experienced with the previous model comparisons in both the ascending and descending branches could be alleviated using the proposed model.

CONCLUSIONS

This paper has investigated the applicability of the existing stress-strain models for unconfined/confined concrete in predicting the same relationships for polymer concrete. Existing models can be categorised into three broad categories; models that are based on Kent and Park (1971), Sargin et al. (1971) and Popovics (1973). The following conclusions can be drawn from the investigations reported in this paper:

- Modified version of Sargin et al. (1971) model for unconfined/confined concrete is proposed to predict the stress strain behaviour of polymer concrete mortar.
- Both the ascending and descending branches of the experimental stress-strain curves match well with those of the predicted curves using the proposed model.
- Proposed model is validated for a compressive strength range of 80 – 100 MPa.

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