Mechanical properties of polymer concrete with different types of resin

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ABSTRACT: Polymer concrete is reported to have better mechanical properties than its counterpart, Ordinary Portland Cement (OPC) concrete. It is gaining increased popularity 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 can be used to repair concrete structures, build slabs and beams of small cross sections and sleepers. A research program has been initiated to improve fundamental understanding of this material and to provide the knowledge required for its broad utilization.
In this experimental program, two types of resins (vinylester and epoxy resin) combined with fly ash and sand were used to make polymer concrete mortar. The weight percentages used in the mix designs were selected after analyzing volumetric properties of sand. This paper presents and discusses the results from an investigation of uniaxial compressive stress-strain relationship of polymer based concrete. The effect of resin (binder), and fly ash contents on the compressive strength, flexural strength, split tensile strength and modulus of elasticity of vinylester and epoxy resin based polymer filler is reported. It has been found that epoxy resin based polymer concrete and vinylester based polymer concrete can achieve compressive strengths of 75MPa and 113MPa respectively. Vinylester polymer concrete showed 4% ultimate strain, while that for epoxy polymer concrete was 8%. Tensile strengths were as high as 15MPa for both types of polymer concrete. The results show that the polymer based filler materials are suitable for both compression and tensile loading situations.

1 INTRODUCTION

Polymer concrete (PC), also known as synthetic resin concrete and plastic resin concrete is described as a composite material of fine and coarse aggregate, mineral filler and polymer binder, with no cement (Blagga & Beaudoin, 1985). 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 (Garas & Vipulanandan, 2003, Jo et al. 2008b). It has high strength properties, rapid setting times, freeze-thaw resistance and ability to withstand corrosive environments (Rebeiz et al, 1995). Polymer concrete is lighter and stronger than Ordinary Portland Cement (OPC) concrete (Zijlstra 2007) which is a major advantage, particularly in structural applications. Research work related to polymer concrete was initiated decades ago (Vipulanandan & Paul, 1993, Fattah & Hawary, 1999).

Blagga & Beaudoin (1985) reported that the amount of binder used is generally small, but depends on the size of the filler. If coarse filler is used, typically 5 to 15 percent of binder is required, however if fine filler is used, up to but not limited to 30 percent of binder can be needed. In order to develop the most economical PC, it is necessary to use minimum amount of polymer and best method of curing. Several researchers used slightly different percentages of resin and aggregate. Vipulanandan & Paul (1993) used weight of resin to be 10-20% and weight of aggregate to be 80-90% whereas Barbuta et al (2010) used 12.8-18.8% of resin. Rebeiz & Craft (2002) suggested maximum weight of aggregate to resin ratio should be 9 to 1.

It is reported in the past that different filler materials such as fly ash and silica fume gave different properties. PC with fly ash gave better compressive strength than PC with silica fume (Barbuta et al. 2010, Rebeiz et al. 2004). Further, it is documented that PC with fly ash gives better flexural strength and split tensile strength (Barbuta et al, 2010).

1.1 *Vinylester resin*

Vinylester in comparison to polyester and epoxy resin holds the middle of the performance spectrum and although not as cheap as polyester, vinylester still provides a lower cost than epoxy resin. Peters

(1998) reported that unlike other thermosets, vinylester does not have to sacrifice heat and chemical resistance to achieve a high resiliency and toughness. As vinylester possesses a low ester content and low saturation in comparison to polyester, it exhibits a greater resistance to hydrolysis, low peak exotherms during cure and less shrinkage during cure (Peters, 1998). Sirivivatnanon (2003) stated that vinylester polymer concrete has a better chemical resistance, is tougher and more resilient than most polyesters. Additionally, a higher full cure time of seven days is typically required compared to four to seven days for polyesters. The author further mentioned that with respect to polyester and epoxy polymer concretes, the compressive strength range and coefficient of thermal expansion of vinylester is lower.

Vinylester polymer concrete is also used as an overlay on concrete bridge decks. However compared to polyester overlays, the vinylester polymer concrete is more costly, harder to handle, exhibits deterioration due to thermally-induced cracks and bond failure between the concrete and overlay.

1.2 *Epoxy resins*

Epoxy resin is typically used in applications such as the aerospace industry, motor racing and racing yachts and takes the higher end of the performance spectrum. Note that the aerospace industry uses the highest performance epoxy resin, where curing temperatures of the resin are at approximately 180^{o}C. Some epoxies are cured at ambient temperatures, thus giving a reduction in production costs. Such epoxy resins are of particular interest in structural engineering applications, due to their structural performance and durability.

Epoxy polymer concrete has superior chemical resistance, excellent structural properties, good adhesion to a variety of surfaces and exhibits a minimal degree of shrinkage during curing. Blagga & Beaudoin (1985) stated that in addition to the abovementioned properties, epoxy based polymer concrete also inherits good creep and fatigue resistance and low water absorption. It is reported that epoxy polymer concrete showcases a flexural strength up to ten times greater than that in cement concrete, superb for structural engineering applications.

Blagga & Beaudoin (1985) stated that epoxy polymer concretes are mainly used in special applications, including skid-resistant overlays in highways, industrial flooring, resurfacing of deteriorated structures and epoxy plaster for exterior walls.

Having identified the importance of vinylester and epoxy based PC in structural applications, this research program aimed at investigating the mechanical properties of PC further.

2 EXPERIMENTAL PROGRAM

An experimental program was designed to investigate the several engineering properties of vinylester and epoxy based polymer concrete.

2.1 *Materials*

2.1.1 *Resin*

The 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 into a polymer concrete. It was important that the catalyst and resin were fully mixed together to ensure that the molecular structure of the mixture was uniform and that the resin would cure properly. For epoxy polymer concrete, a volume percentage of 20% catalyst to resin was used. For vinylester polymer concrete, a volume percentage of 1.73% catalyst to resin was used. Properties of the two types of resin used in this study are reported in Table 1.

Table 1. Properties of resin

Property	Vinylester	Epoxy
Viscosity (mPas @25^{0}C)	420-580	900-1100
Gel time (minutes)	35-45	40
	1% Norox 925H	Kinetix H160 hardener

2.1.2 *Sand*

Fine dry sand was obtained from Wagners in Queensland, Australia with a bulk density of 1494 kg/m3 and particle size smaller than 425 µm. The sand was dried in an oven at 110^{o}C for approximately 24 hours before used in the mix.

2.1.3 *Fly ash*

Unprocessed concrete grade fly ash with d50 of approximately 15µm was obtained from Wagners in Queensland, Australia. Chemical composition of fly ash is given in Table 2. Preparation work of the fly ash included breaking down large clumps into a fine powder and ensuring that there were no impurities in the storage drum.

Table 2: Chemical composition of fly ash (by mass%).

$Si0_2$	$A1_20_3$	Fe_20_3	Ca0	Mg0	Na_2O	K_20	$S0_3$
51.8	24.4	9.62	4.37	1.5	0.34	1.41	0.26

Mix proportions

Mix design procedure is not well documented for PC in the literature. Different researchers used different methods in doing this. Many researchers adopted design of experiments (Barbuta et al, 2010, Muthukumar & Mohan, 2004) while others select mix designs randomly (Jo et al. 2008b). Therefore there is no common agreement among the research community for mix design procedure for PC. A different approach to address the same problem was initiated by a team of researchers at University of Southern Queensland (Lokuge et al. 2011). Polymer concrete mix design was based on the air voids in sand. Using the bulk specific gravity, saturated surface dry (SSD) specific gravity, apparent specific gravity, it was found out that the industrial sand used in this study has 43% of air voids. The objective of this research is to fill this 43% of voids using different proportions of either vinylester or epoxy resin and fly ash.

Table 3 and Table 4 show the details of the specimens for vinylester and epoxy polymer concrete respectively. They are identified using the volume percentages of sand, resin and fly ash. For example S57R40F3 specimen had 57% sand, 40% resin and 3% fly ash (all are volume percentages).

Table 3. Mix proportions for Vinylester concrete (by volume).

Sample	Sand	Resin	Fly ash
S57R43	64.9	35.1	0
S57R40F3	64.4	33.6	2.0
S57R30F13	65.6	25.6	8.8
S57R22F21	66.6	19.0	14.4
S57R20F23	66.8	17.4	15.8

These volume percentages were converted to weight percentages in order to get the mix proportions.

Table 4. Mix proportions for Epoxy concrete (by weight).

Sample	Sand	Resin	Fly ash
S57R43	64.9	35.1	0
S57R40F3	65.2	32.8	2.0
S57R30F13	66.2	25.0	8.8
S57R22F21	67.0	18.5	14.5
S57R20F23	67.2	16.9	15.9

The mix design batches were cast into the correctly labeled 50mm diameter and 100mm high moulds and allowed to cure in a temperature controlled room of 24^{o}C.

2.2 *Testing*

Compressive testing was undertaken in accordance with the technical requirements outlined in standard ASTM D 695 M-91. Avery testing machine with 500kN capacity was used with a loading rate (crosshead speed rate) of 2mm/min (Figure 1). Specimens were tested for compressive strength at 7, 21 and 28 days. Stress-strain relationships for PC were obtained using platen to platen method.

Figure 1. Compressive strength testing.

Flexural tests were performed in accordance with ISO 178:1993 using specimens with a width of 16mm, height of 9mm and a length of 160mm.

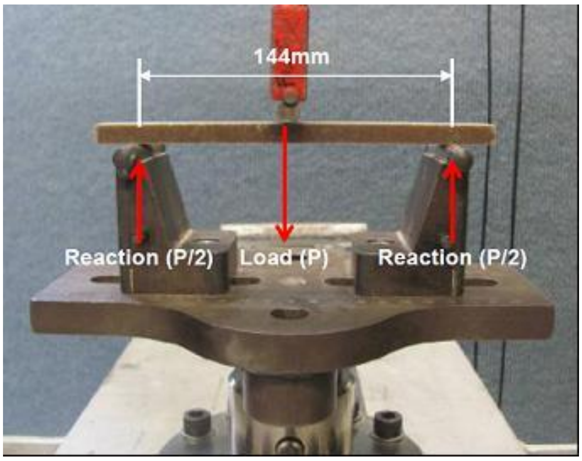

Figure 2. Flexural strength testing.

Specimens were simply supported at a 144mm span and were tested under three point loading. They were tested using a loading rate of 1mm/min in a 10kN MTS testing machine (Figure 2). The load and mid span deflection were recorded up to failure to determine the strength and elastic properties of PC.

Figure 3. Split tensile testing.

Specimens were tested for tensile strength at 7 days using 500kN capacity Avery testing machine (Figure 3).

3 RESULTS AND DISCUSSION

3.1 *Compressive strength*

Compressive strength gain with respect to age is shown in Figure 4.

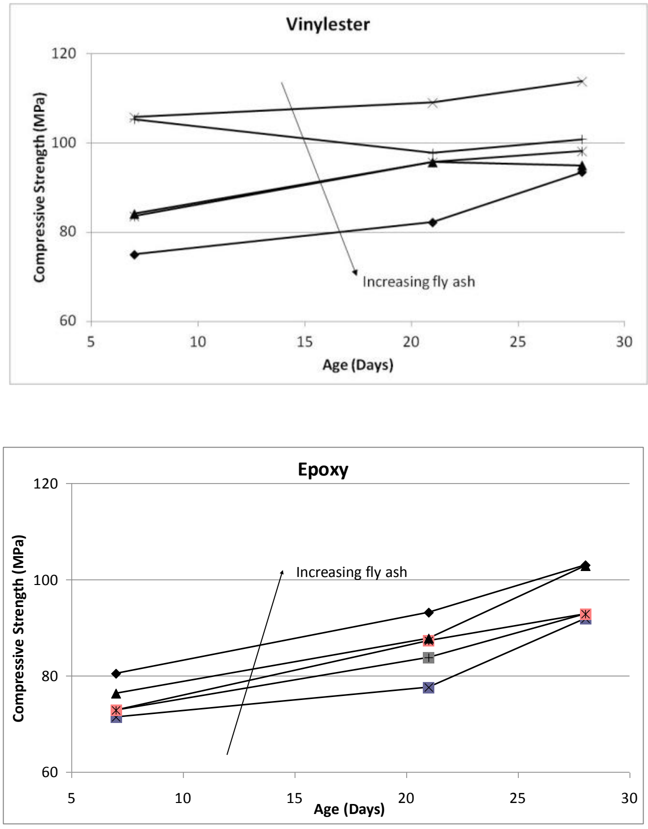

Figure 4. Strength development with age.

All the batches gain their maximum strength around the age of 28 days. At the age of 7 days all the batches reached at least 80% of the 28-day compressive strength under the adopted curing method.

It is interesting to note that from Figure 5 that compressive strength is reduced when the fly ash percentage is increased and the resin percentage is reduced for vinylester polymer concrete. On the contrary, epoxy polymer concrete shows an increasing trend in the compressive strength with the increasing fly ash percentage which is consistent with the findings of Barbuta et al. (2010) for epoxy resin mortar with fly ash. Past researchers reported fly ash percentages from 6% to 20% (Barbuta et al. 2010, Gorninski et al. 2004, Gorninski et al. 2007). Gorninski et al. (2007) reported that increasing fly ash content reduced the voids and increased the compressive strength for polymer concrete. Nevertheless they argued that the strength level of the resin itself will contribute to the overall compressive strength of polymer concrete. Epoxy resin has the greater degree of toughness and bond strength compared to vinylester resin. Therefore, with increasing fly ash epoxy based polymer concrete shows increasing strength while vinylester based polymer concrete shows decreasing strength.

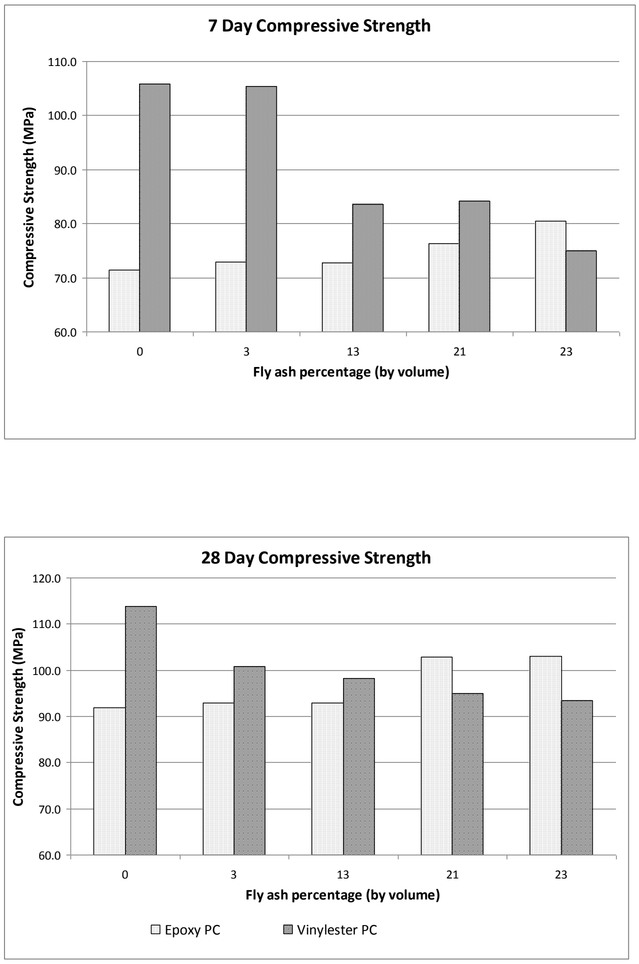

Figure 5. Compressive strength variation with fly ash.

3.2 *Stress-strain relationship*

It can be seen from Figure 6 that the higher the resin percentage is the higher the ultimate strain of the material. It has been found that epoxy resin based polymer concrete and vinylester based polymer concrete can achieve compressive strengths of 75MPa and 113MPa respectively. Vinylester polymer concrete showed 4% ultimate strain, while that for epoxy polymer concrete was 8%.

The strain corresponding to peak axial stress increases with increasing resin content in the mix for both the types of PC (Figure 6). A similar trend is reported for recycled PET polymer concrete (Jo et al, 2008a). The strain corresponding to the peak stress has a range of 0.02 to 0.04 which is much higher than that for the normal strength concrete. It can be concluded from Figure 6 that the ductility of polymer concrete increases with increasing resin content.

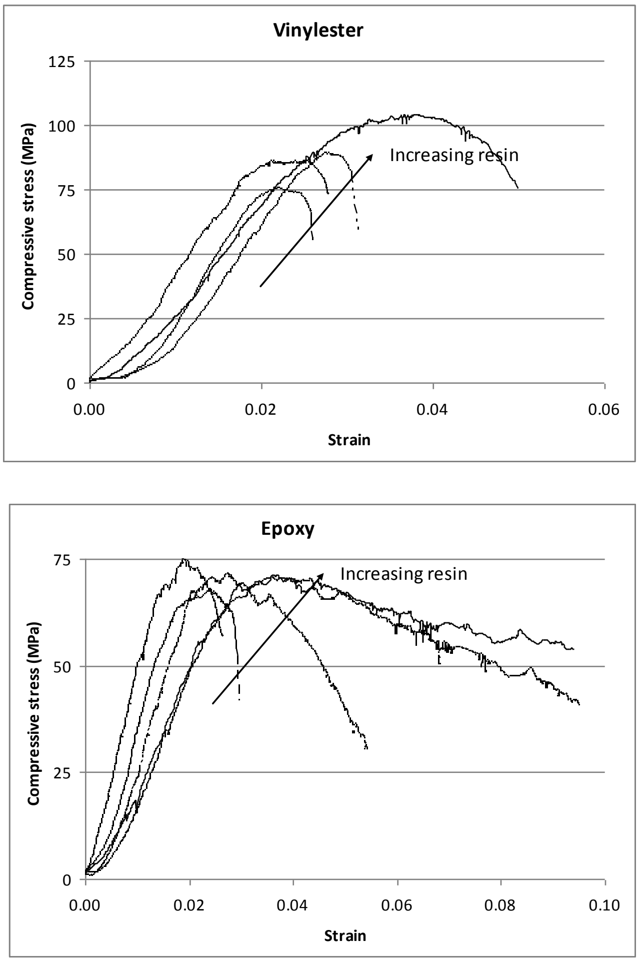

Figure 6. Stress-strain relationships

3.3 *Modulus of elasticity*

The modulus of elasticity of each specimen was calculated using the stress-strain relationship reported in Figure 6. Linear regression analysis was performed for the data set in the elastic region of each curve and the results thus obtained are shown in Figure 7.

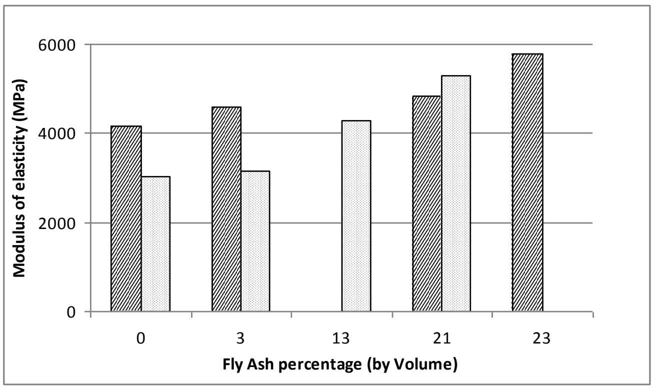

Figure 7. Modulus of elasticity

As opposed to normal strength concrete, polymer concrete has about 10 times lower modulus of elasticity. However it increases with increasing fly ash content. A similar observation was reported by Gorninski et al (2004) for polyester PC.

3.4 *Tensile strength*

The split tensile strengths for vinylester and epoxy polymer concretes are very similar.

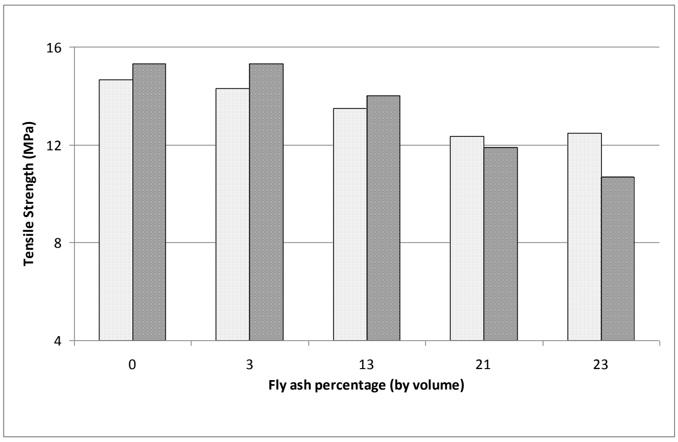

Figure 8. Tensile strength.

It can be seen from Figure 8 that both types of PC show a decrease in split tensile strength when fly ash is increased and subsequently resin is decreased. When the fly ash content is more, the bond between the resin and fly ash must be lower and hence the tensile strength is lower. The maximum tensile strength for vinylester polymer concrete is approximately 15.2MPa and decreases to approximately 10.8MPa, equating to a decrease of 29%. The maximum tensile strength for epoxy polymer concrete is approximately 14.8MPa and decreases to approximately 12.5MPa, equating to a decrease of 15%.

Epoxy polymer concrete shows a greater tensile strength than that for vinylester polymer concrete with an increase in fly ash. .

3.5 *Flexural strength*

Figure 9 shows that the flexural strength is decreasing with increasing fly ash content for both types of polymer concrete. This is consistent with the findings of Barbuta et al. (2010) for epoxy based polymer concrete.

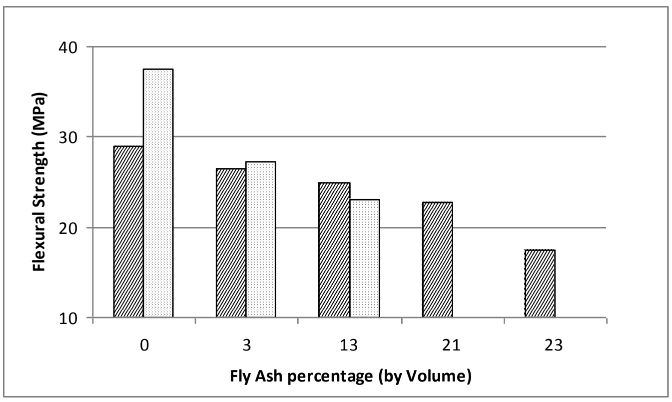

Figure 9. Flexural strength

4 CONCLUSIONS

In this research paper, the influence of various parameters such as resin type (vinylester and epoxy), resin content, fly ash content on mechanical properties of polymer concrete is investigated. The experimental investigation is based on tests conducted for compressive, tensile and flexural strengths and stress-strain relationships of the polymer concrete samples. The following conclusions are derived from this study.

- The addition of fly ash as filler material in both vinylester and epoxy PC, results in an economical mixture, while a marginal reduction in compressive strength and ultimate strain. However, the ductility can be improved with increasing resin content.
- On the other hand, modulus of elasticity increases with increasing fly ash content while the flexural strength decreases with increasing fly ash content. There is only marginal difference in the tensile strength when the fly ash content is changed.
- Vinylester PC performs better than epoxy PC in compressive strength. Nevertheless, it can be concluded that epoxy PC out-performs by showing a marginal difference in the compressive strength with increasing fly ash content.

With a combination of excellent mechanical properties, low water absorption, ability to withstand environmental conditions, chemical attack and freeze-thaw degradation and ability to adhere to other materials, polymer concrete with a mix of sand, fly ash and resin (vinylester and epoxy) provides an excellent material for many structural engineering applications.

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