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Study of the modulus of elasticity of polymer concrete compounds and comparative assessment of polymer concrete and portland cement concrete

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Abstract

The main aim of this study is to assess the modulus of elasticity of polymer concrete (PC) compounds produced using two types of binders: orthophtalic or isophtalic polyester. The compositions used were selected from a previous study that identified cost-effective PC compositions. Based on those data, the concentrations of polymer used were 12% of orthophtalic polyester and 13% of isophtalic polyester by weight of the dry materials. Fly ash was used as a filler and compositions with 8%, 12%, 16% and 20% of ash by weight of aggregate were studied. Results indicate that all compositions assessed in this study display high modulus of elasticity values. Statistical analysis of the data reveals that the type of resin and the concentration of fly ash, both in isolation and in combination, have a significant effect on the modulus of elasticity of these compounds.

Keywords: Polymer concrete; Polyester resin; Fly ash; Modulus of elasticity

1. Introduction

The development of new composite materials possessing increased strength and durability when compared with conventional types is a major requirement of applications in repairs and in the improvement of infrastructure materials used in the civil construction industry. Polymer concrete (PC) is an example of a relatively new material with such high performance. Its excellent mechanical strength and durability reduce the need for maintenance and frequent repairs required by conventional concrete. An additional advantage of PC is its fast curing time, which is an asset in the production of precasts as parts can be demolded a few hours only after the concrete placement. In applications with coatings and repairs, the original structure can be in use again after a single day only [1,2]. These characteristics of PC are the result of the substitution of a polymeric material for the cement binder [3].

PC is produced by using dry aggregates and monomers (binders) which undergo polymerization (hardening) after the addition of additives, catalysts and accelerators. Its composition will depend on its intended application.

However, the growing need for durable materials to replace portland concrete, particularly with regards to chemical strength properties, has not been translated into widespread usage of PC. The most likely reasons behind this are a lack of information on the properties of PC, the technology employed in its production and its higher cost. The major cost component in these materials is the resin used in their production. To address this issue, this study investigated both isophtalic and orthophtalic polyesters, because the latter has a much lower cost than the former, which is the traditional material used in the production of PC. The compositions used in the present study also derive from a previous study which investigated a large number of compositions using different concentrations of resin and filler so as to determine their optimal cost/performance ratio [4].

The importance in assessing the modulus of elasticity of the PC compositions in this study stems from the fact that this property is one of the most important characteristics of these materials. There are also polymers with low modulus of elasticity values (classified as thermoplastics) which, if used in PC compositions, can result in low modulus of elasticity values in the final product.

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However, as the polyester resins used in the production of PC are dissolved in a styrene monomer, cross-linking occurs during polymerization and a tridimensional reticulate structure (a thermoset) results. This thermosetting polymer is insoluble, infusible and displays improved mechanical properties when compared with thermoplastics. These characteristics require the use of different technologies in the mode of application of these polymers [5].

The compositions selected in this study were intended for use in precast materials, which have gained increasing acceptance in the civil construction industry over the last decade. One of the key strands in PC research aims at lowering binder concentrations through the optimization of the concentration of aggregate materials. With this, the lowest feasible concentration of polymers can be used and costs are reduced in the final product [6,7]. The four compositions in this study used fixed concentrations of 12% of orthophtalic polyester and 13% of isophtalic polyester and fly ash as a filler. This filler is used at the maximum compacity between aggregate and ash and also in different concentrations, above and below maximum compacity, to provide a more comprehensive assessment of the effect of fly ash on the elasticity modulus of PC compounds.

2. Experimental program

2.1. Materials

2.1.1. Resins

Unsaturated polyester resins were chosen as binders. Their superior chemical and mechanical properties, combined with their lower cost when compared with epoxy materials, as well as their wide commercial availability, make polyester resins the most widely used polymer in PC compositions [2]. This study investigated PC manufactured with isophtalic and orthophtalic polyesters dissolved in styrene.

These two polyester varieties (isophtalic and orthophtalic) show basic differences in their reagents. Polyesters are the product of polycondensation reactions of dicarboxylic acids with dihidroxy alcohols. Isophtalic polyester (isopolyester) is produced from isophtalic acid while orthophtalic polyester is the result of a reaction with phtalic acid. Because of the constraints involved in obtaining high molecular weight orthophtalic polyester, the properties of this material when used in isolation are inferior to those of isophtalic polyester [7].

2.1.2. Filler

Fly ash is a by-product of the burning of coal in power plants and was chosen as a filler because it is readily available locally. Its proven efficiency in PC also supports this choice. The use of fly ash as a fine aggregate in PC yields improved mechanical properties and reduced water absorption by the concrete. In addition, there is good compatibility between ash and sand [8] and the fly ash also improves the workability of the fresh PC mix and the mechanical strength of the hardened material, resulting in products with excellent surface finish [9]. A recent study showed that the use of fly ash also improves the chemical strength of PC compositions because of its small particle size and its roundness. This reduces the mean pore size of PC and blocks the penetration of aggressive agents [3].

The specific mass of fly ash is 2.16 g/cm^3 according to the Brazilian Standard NBR 6474 [10].

2.1.3. Aggregate

Medium-size river sand with a regular particle size distribution and specific mass 2.65 g/cm^3 according to the Brazilian Standard NBR 9776 [11] was used.

2.2. Methods

The compressive strength test was performed according to ASTM ASTM C 39/C 39M-01 [12]. Three cylindrical test specimens measuring 5 × 10 cm were cast for each composition and the results represent the mean of the individual values for each TS.

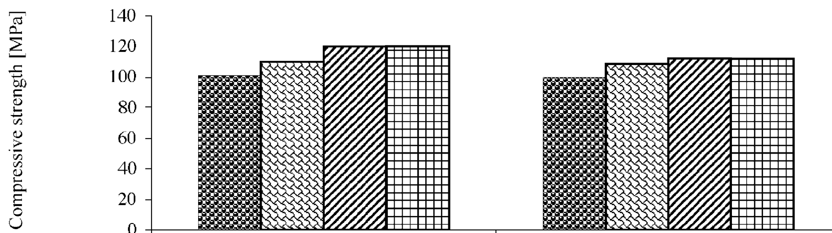
The test of static modulus of elasticity was performed using ASTM C 469-94 [13].

The tests were conducted in a Shimadzu UH-2000 kNA press with a scale of 400 kN, at a loading rate of 40 kN/min. The data (creep and load) were recorded each second until the point of failure. The secant modulus of elasticity was determined.

Table 1
PC compositions used in this study

Polymer matrix components	Composition	% Mass
(a) Polyester		
Resin 1	Unsaturated isophtalic polyester 33411 (Reichhold)	12[a]
Resin 2	Unsaturated orthophtalic polyester 10228 (Reichhold)	13[a]
Catalyst	Cobalt naphthenate 3%	1.0[b]
Initiator	Methyl ethyl ketone peroxide (MEKP)	1.0[b]
(b) Aggregates		
Sand	River sand, medium particle size	(70.4–81.0)[c] for 12% resin (69.6–80.0)[c] for 13% resin
Filler	Fly ash	(8%, 12%, 16% and 20%)[d] (7.0–17.6)[c] for 12% resin (7.0–17.4)[c] for 13% resin

[a] Percentages by weight of ash + sand.
[b] Percentages by weight of binder.
[c] Range (g) for each 100 g of PC.
[d] Percentages by weight of sand.



	PC isophtalic resin	PC orthophtalic resin
fly ash 8%	101	99,7
12%	110	108,8
16%	120	112,3
20%	120,1	112

Type of resin / fly ash concentration [%]

Fig. 1. Effect of the type of resin and fly ash concentration on axial compressive strength.

All data underwent statistical analysis using the SPSS statistical software application with the Tukey HSD method for the analysis of variance (ANOVA), which is a statistical comparison of the influence of each factor studied in the test while checking for any interaction among the variables. For the present study, a level of significance of α=.05 was chosen.

2.3. PC compositions

The optimized PC compositions used in the present study are listed in Table 1.

3. Results and discussion

The results obtained in the compressive strength and elasticity modulus tests of isophtalic polyester PC and orthophtalic polyester PC using 8%, 12%, 16% and 20% of fly ash are presented and discussed in this section.

The following acronyms were used:

I = samples prepared with unsaturated isophtalic polyester.
O = samples prepared with unsaturated orthophtalic polyester.
Figures (8, 12, 16, 20) = percentage of fly ash by weight of sand.

3.1. Axial compressive strength

Fig. 1 shows the effect of the type of resin and the concentration of fly ash on axial compressive strength.

The results summarized in Fig. 1 show that high compressive strength values were obtained. This is in agreement with the values expected for PC. Obviously, these values depend on the specific composition of each PC formulation. Abdel-azim and Atta produced concrete samples with strength values ranging from 92 to 112 MPa using high molecular weight polyester resins and concentrations of 15% of polymer by weight of the aggregate [14]. Oshima and Koyanagi [15] found values in excess of 120 MPa using polyester concentrations of up to 20% resin, coarse and fine aggregates and calcium carbonate as filler.

These results show that the concentration of fly ash in the PC composition produce changes in compressive strength. It was observed that higher fly ash concentrations increase the strength of PC, with previous SEM studies showing that the addition of fly ash to PC results in reduced voids [3]. Due to the regular spherical shape of the fly ash, better packing of the aggregate–ash mixture is achieved and this results in increased strength.

It was also observed that all compositions displayed higher strength values than those found in portland concrete (including high strength compositions prepared with silica fume or rice husk ash). Sensale [16] studied different composition of cement concrete with concentrations of up to 20% of rice husk ash and obtained maximum compressive strength values of 81.76 MPa after 63 days of cure using w/b ratio 0.28 and 5% rice husk ash. A comparative study of different dosage methods of high strength concrete with 10% silica fume yielded values of 80 and 84 MPa using the IPT[1] and Mehta[2] methods, respectively [17].

Another important point is that the concrete produced with isophtalic polyester resulted in slightly higher strength values when compared to that produced with orthophtalic polyester, showing that the intrinsic characteristics of the binder are indeed transferred to the PC.

3.2. Modulus of elasticity

Table 2 lists individual and mean values of the elasticity modulus in PC samples prepared with isophtalic and orthophtalic polyesters.

The statistical analysis used the individual values listed in Table 2, which shows the elasticity modulus (GPa) of the

[1] São Paolo State Technological Research Institute, Brazil.
[2] After Prof. Mehta, UC Berkeley, USA.

Table 2
Modulus of elasticity of PC with isophtalic or orthophtalic polyester with 8, 12, 16 and 20% fly ash

Test specimen	Elasticity modulus (GPa)				S (GPa)	CV (%)
Resin–ash (%)	Individual values			Mean		
I-8	23.94	25.00	25.05	24.66	0.62	2.51
I-12	26.42	28.69	26.72	27.28	1.23	4.50
I-16	31.70	29.73	29.69	30.37	1.15	3.78
I-20	28.20	28.59	28.40	28.40	0.20	0.69
O-8	22.70	22.31	26.13	23.71	2.10	8.86
O-12	25.30	23.59	23.80	24.23	0.93	3.84
O-16	27.16	28.35	26.62	27.38	0.88	3.21
O-20	28.77	28.70	29.38	28.95	0.37	1.25

PC samples prepared with four different concentrations of fly ash and two types of binders (isophtalic and orthophtalic polyesters). This part of the study checks for the existence of any significant influence of the concentration of fly ash and the resin type as well as any interactions between these two. The results of this analysis are shown in Table 3. Table 4 summarizes the homogeneous subsets resulting from the multiple comparisons of the mean values in relation to the concentration of fly ash.

The following acronyms are used in the ANOVA table:

SQ = square sum
GDL = degrees of freedom
MQ = square mean = SQ/GDL;
F = MQ/MQError
F_{AB} = MQAB/MQError (effect of interaction between any factors A and B)
S = significance

The values listed in Table 2 show that PC has high modulus of elasticity values, comparable to those obtained in high strength concrete. Sensale [16], in his study, after 91 days of cure, obtained mean values of 27.09 and 32.37 GPa for concrete with a 10% addition of American rice husk ash and w/b ratios 0.5 and 0.32, respectively. Silveira et al. [18] also produced high-performance concrete by using silica fume and w/b ratio 0.27 with modulus values in excess of 30 GPa.

The modulus results observed are in agreement with the values described in PC literature. Oshima and Koyanagi used polyester resins to obtain modulus of elasticity of approximately 20 GPa using 20% of resin by weight of the aggregates, of over 25 GPa using 13% of resin and 30 GPa with 10% of resin [15]. Using low shrinkage polyester resin, they found approximately 35 GPa. Bhutta et al. [19] produced polyester PC compounds for use as counter-weights and obtained modulus of elasticity values in the range of 23.7 and 25.1 GPa.

Table 3
ANOVA in the modulus of elasticity test

Source	SQ (10^4)	GLD	MQ (10^4)	F_{cal}	S	Significance
Resin type (A)	1169.47	1	1694.77	8.015	0.012	S
Fly ash concentration (B)	8582.68	3	2860.89	19.607	0.000	S
Interaction AB	2006.55	3	688.51	19.607	0.017	S
Error	2334.63	16	145.91			
Total	14,093.34	23				

Table 4
Homogeneous subgroups derived from the multiple comparison of the mean values of the modulus of elasticity of PC prepared with 8%, 12%, 16% and 20% fly ash

Concentration of ash	*n*	Subgroups_modulus (GPa)	
		1	2
8.00	6	24.2	
12.00	6	25.8	
16.00	6		28.9
20.00	6		28.7
Significance		0.154	0.804

The modulus of elasticity tends to increase as fly ash concentrations also increase. This is probably related to the increase in the stiffness of PC resulting from the increase in filler concentration.

The statistical analysis presented in Table 3 (ANOVA) shows that the type of resin and the concentration of fly ash, in isolation, have a significant effect on modulus of elasticity values. An interaction between these factors is also observed; that is, together, they have a significant effect on this property. The concentration of fly ash shows different effects for each resin type. This is attested by the fact that isophtalic polyester PC shows the highest modulus with 16% of fly ash, while orthophtalic polyester PC displays the highest value with 20% of fly ash in its composition.

The values in Table 4 are generated by multiple comparisons of means. They show no significant difference between the concentrations of 8% and 12% of fly ash, but these are significantly different from those obtained with 16% and 20% of filler. Results indicate that the concrete produced with isophtalic polyester and 16% of fly ash has a higher modulus than that produced with 20% of this addition. However, the multiple comparison of means shows that the differences are not statistically significant between the concentrations of 16% and 20% of ash.

4. Conclusions

- There was an increase in axial compressive strength as concentrations of fly ash increased. However, all compositions resulted in high-strength concrete.
- High modulus of elasticity values were obtained and the peak value was 29 GPa. These values are comparable to those observed in high-strength portland concrete.

- ♦ There was an overall increase in the modulus of elasticity as the concentration of fly ash increased. Isophtalic polyester PC reached values from 25 to 28 GPa while orthophtalic polyester PC reached values in the range of 24 to 29 GPa.
- ♦ The statistical analyses showed that the factors investigated, namely, resin type and fly ash concentration, and the interactions between them were significant.

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