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Study Effective Compressive Strength of Polymer Composite by Ultrasonic Wave Test at 35 KHz

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Abstract: ***Polymer concrete is a composite material realized with resin and aggregates. In this study, the unsaturated polyester composite resin was used for binding the silica sand aggregates, silica foam as filler and glass fibers. Some mechanical properties of polymer concrete have been investigated using destructive and non-destructive methods. The experimental results of non-destructive method were correlated with compressive strength. The fiber percentage and silica foam was constant, the unsaturated polyester resin and the silica sand dosages were varied. This research was conducted at 35 KHz.***

Keywords: Destructive test; Polymer Concrete; Fiber, Ultrasonic wave, 35KHz.

1. Introduction

This investigation was carried out so as to obtain further information about the effect of adding silica sand to the unsaturated polyester resin on the some mechanical properties of polymer concrete. Polymer concrete has been used for decades in engineering construction like machine foundations in the building industry for facade products and sanitary parts, parts in electrical engineering for isolation devices and especially in the chemical industry for all types of ducts due to favorable properties, especially its corrosion resistance as well as its strength and elasticity [Lang G.2005].PC is a composite material in which resin is used as binder for aggregates such as sand or gravel instead of portland cement [CastelloX,Estefen S.2008].PC is an inert product that can be cast in almost any shape [ZouG.P,Taheri F.2006].Due to its rapid setting, high strength properties and ability to withstand a corrosive environment, it is increasingly being used as an alternative to concrete cement in many applications, construction and repair of structures, highway pavements, bridge decks, waste water pipes and decorative construction panels [Garas Victor Y,Vipulanandan C.1998].Typical properties of polystyrene are given in Table 1:

Table 1: Physical properties of Polymer concrete

Property	Value		Test method
Compressive Strength	~13,000 psi	90 N/mm^2	ASTM C 579, Method B
Flexural Modulus of Elasticity	~4.0 x 10^6 psi	28,000 N/mm^2	ASTM D 790
Tensile Strength	870 psi	6.0 N/mm^2	ASTM D 638
Ring bending tensile strength	2,900 psi	16.0 N/mm^2	ASTM D 790
Coefficient of linear thermal Expansion	10 to 20x10-6 in/C°		DIN 53752

The evaluation of mechanical properties of polymer concrete by non-destructive techniques is one of the most challenging tasks in modern civil engineering. Several techniques that meet this demand are currently in use. Some of them are based on propagation of ultrasonic waves. Others are focused on measuring the thermal history or certain mechanical quantities such as penetration depth or pullout force of concrete. Further techniques deal with microwaves, electrical impedances and acoustic emissions [Akkaya, T.Voigt2, K.V. Subramaniam and S. P. Shah, 2003].Ultrasonic methods are among the most common non-destructive techniques used in material science and industry. Ultrasonic methods are well-known and standardized towards traditional building materials: metals, concrete cement and rocks. In the case of polymer concrete composites, ultrasonic methods are at the introductory stage [Garbacz and Edward J.Garboczi,2003].

2. Methods used in the Ultrasonic Measurement Technique

The most often applied methods of ultrasonic testing are the pulse velocity method, the echo method and the resonance method. One of the methods of ultrasonic wave is the ultrasonic pulse velocity method (also known as transmission method);it is one of the oldest and simplest methods of materials testing. The method consists in the determination of travel time over a known path length of the longitudinal ultrasonic wave after its transmission through the tested medium (Figure 1).Both the emitting and receiving transducers are usually placed on the opposite sides of the tested sample (coaxially if possible).Other transducer arrangements are also used in concrete testing (Figure 1b, c). They can be placed on the perpendicular surfaces (Figure 2b) or on the same side of the tested member (Figure 1c).

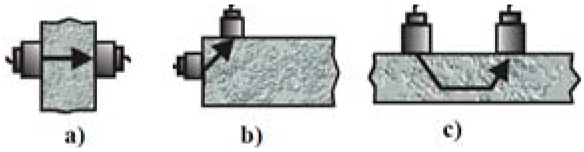


Figure 1: Ultrasonic pulse velocity method: (a) direct method, (b) semi-direct method, (c) indirect(surface) method

The ultrasonic echo method is often used for defect detection in metal members. The method consists in generation of a short impulse of the ultrasonic wave by the transmitting transducer (Figure 2).

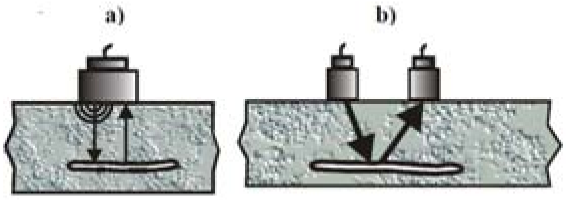


Figure 2: Testing the concrete by ultrasonic echo method: (a) transmitting-receiving transducer, (b) double transducer

The resonance method consists in the introduction of an ultrasonic wave into the tested medium which is of constant thickness *g,* in such a way that a resonant standing wave, of wavelength λ, will be formed under the condition:

$$g = n\,(\lambda/2) \quad \text{.............................(1)}$$

where n = an integer that defines the harmonic number

3. Application of Ultrasonic Methods for Concrete Testing

At present, two ultrasonic methods are used for concrete testing: the pulse velocity method and the echo method. These methods enable the evaluation of concrete strength and homogeneity. In a limited range, the ultrasonic pulse velocity method is also applied for determination of the elasticity constants [Russian Standard GOST 17624-87], detection of crack geometry [J.Kaszyński,2000],and evaluation of the degree of concrete degradation. From Figure 2,it is evident that the common procedure for evaluation of cement concrete properties with the pulse velocity method consists in regression analysis of the experimental relationship between the pulse velocity and selected technical properties (mainly compressive strength).In general, three methods of reference curve development can be recognized:

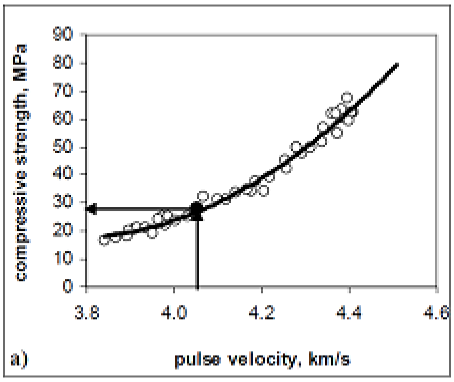
*(a) **Calibration curve:*** Developed for cube concrete specimens with the same composition and cured in the same way as the concrete in the investigated structure (Figure 3a).The number of specimens needed to develop the curve depends on its universality range of strength variability; as the universality of the reference curve increases, the number of samples necessary to develop it increases. To develop reference curves for a wide range of strength variability it is recommended to change the quantity of mixing water, the degree of compaction, age of the concrete, the curing or storage conditions and if necessary, the proportion of fine material and cement content.

*(b) **Calibration curve:*** This was experimentally established from samples taken from the structures from zones of different pulse velocity (Figure 3a); at least three individual transit time measurements should be carried out in each location and cores should be taken from the same location to obtain the compressive strength, the number of cores depends on the concrete volume.

*(c) **Calibration curve:*** This was established with inversion procedure (Figure 3b) using the reference curve for the concrete with similar composition and specimens taken from structures (number of specimens lower than in case (b) and depends on the concrete volume - at least three).This procedure is often used in practice for structures with unknown concrete composition or high age concrete and for structures where possibility of coring is limited. To obtain a recalculated reference curve the inverse coefficient should be determined. The compressive strength is calculated from the following equation:

$$fc^{ef} = Ci^{exp} fc^{ref} \quad \text{...........................(2)}$$

where: fc^{ef}= the effective compressive strength of tested concrete, fc^{ref}= the compressive strength determined from a reference curve on the base of the ultrasonic measurements, Ci^{exp}=the total coefficient of influence obtained from the tests on the cores.



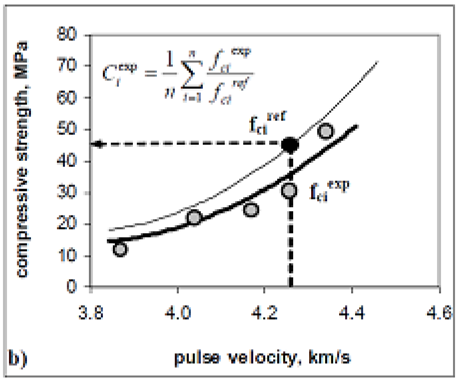


Figure 3 shows scheme of reference curve development for (a) ultrasonic evaluation of concrete compressive strength on the base of investigation of concrete cube samples with the same composition as that in the structure or on the basis of the investigation of cores taken from the structure; (b) ultrasonic evaluation of concrete compressive strength with inverse procedure using reference curve for similar concrete, where Ci^{exp} = the coefficient of influence, $f_{c,i}^{ref}$ = the strength determined from the reference curve from the ultrasonic measurements on specimen i, $f_{c,i}^{exp}$ = the measured strength of specimen i, and n = the number of specimens tested.

Most standards and guidelines recommend two regression equations for description of the relationship between pulse velocity and concrete strength [AndrzejGarbacz and Edward J. Garboczi,2003]:

$$\text{Linear}: f_c = a_o + a_1 c_p \quad (3)$$

$$\text{Exponential}: f_c = a_o \exp(a_1 c_p) \quad (4)$$

where: f_c = compressive strength, c_p = longitudinal pulse velocity, and a_0 a_1 are regression coefficients.

4. Experiment

This section describes the materials used in the production of the specimens, mix proportion and the methods of testing. The specimens were cast and cured for one hour at100°C.

4.1 Matrix Material

Unsaturated polyester resin (UPS) was used as the matrix in the preparation of composite material polymeric and manufactured by the (Industrial Chemical of resins Co.LTD) in Saudi Arabia. This resin transforms from liquid to solid state by adding (Hardener) and this hardener is manufactured by the company itself. It is a (Methyl EthylKeton Peroxide) coded (MEKP) and in form of a transparent liquid. It is added to the unsaturated polyester resin 1% percent at room temperature. In order to increase the speed of hardening, catalyzer materials on interaction are used as catalyst (Catalyst) called accelerators. Cobalt Napthenate are mixed directly with the resin.

4.1.1 Types of strengthening phases used

(a) Fibers

Glass fibers were used from type (E-Glass) as strengthening phase in the form of choppy glass fibers, average diameter of filament for this choppy glass fibers is (4–6 µm) and with length is (10-15 mm).These fibers were provided by (Mowding LTD.UK) an English company.

(b) Aggregate

Aggregate used in PC with gradation of 0-2mm, 2-8mm and 8-16mm.Itwas used between 0-2mm. Silica sand is the main component of the polymer concrete used in this study. It was brought from (General Company for Mechanical Industries in Al-Eskandria).

(c)Fillers

Silica foam is used as filler in order to achieve chemical resistance, impact and erosion strength and to increase bonding between matrix and reinforcement phase. Silica foam was brought from "Nippon AEROSIL CO. LTD JAPAN, NFPA, NO.77-1984".

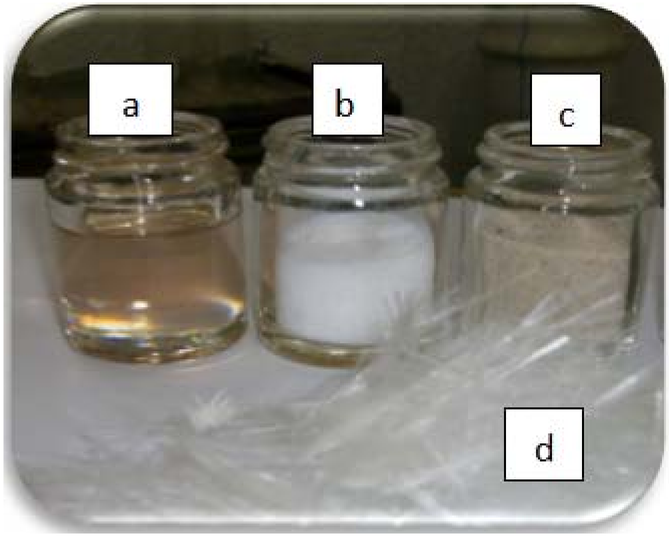


Figure 4: Shows the principal materials used in the work; (a) polyester resin (b) silica foam (c) silica sand and (d) Fiber glass.

4.2 Mix Design

By rule of mixture, design of mixtures for all groups is showed in the following manner:

GROUP 1. Samples for studying the effect of silica sand particles volume fraction with particle size rang (300µm ≥ p.s> 74µm), as in table 2.

Table 2: GROUP-1 samples

Material / NO	Silica sand (%W)	UPS (%W)
11	15	85
22	30	65
33	45	55
44	60	40
55	75	25

GROUP2. The effect of particle size and volume fraction for silica sand particles on UPS matrix with added 4% silica foam (0.02-0.5 µm).All samples are displayed in tables 2 and 3.

Table 3: GROUP-2 samples

Material / NO	Silica sand+4% Silica foam (%W)	UPS (%W)
11	11	85
22	26	65
33	41	55
44	56	40
55	71	25

GROUP3. Samples with different volume fractions of silica sand with the addition of silica foam of 4% at (0.02-0.5 µm), fiber glass is 1% (Table 4).

Table 4: GROUP-3 samples

Material / NO	Silica sand+4% Silica foam +1%fiber glass (%W)	UPS (%W)
11	10	85
22	25	65
33	40	55
44	55	40
55	70	25

4.3 Moulds for Plate

The moulds used for casting of the specimens comprised of a square steel frame measuring 50*50*50 mm by ASTM C579-01 method B.

4.4 Testing Procedures

The compression cubes samples were tested first using non-destructive methods namely ultrasonic pulse velocity test. After completion of non-destructive test, the specimens were tested in machines until failure.

4.5 Tests conducted

(a) Non–Destructive Test(Ultrasonic Pulse Velocity test)
Ultrasonic pulse velocity was used to monitor the variations in compressive strength. The Ultrasonic pulse velocity was measured by an ultrasonic concrete tester (CSI) at 35 KHz.

(b) Destructive Test (Compressive strength test)
Compressive strength was carried out and tested according to ASTM C579-01 Method B.A total number of 15 standard cubes were tested by using a compression testing machine of 2000 kN maximum capacity.

4.6 Testing specimens

For compression tests, cubic specimens (50x50x50mm) are used (Figure 1),the loading rate is 2.2 KN/sec.

Figure 5: cubic specimen of polymer concrete

5. Results and Discussion

Destructive and non-destructive test results on compression specimen are presented in table 5.

Table 5: Destructive (C.S) and non-destructive (f_c) test results in MPa unit.

Group / NO	1		2		3	
	C.S	f_c	C.S	f_c	C.S	f_c
1	106.8	104.6	101.6	140.3	102.4	98
2	114.4	124.8	125.2	106.4	122.4	97.8
3	110.8	94.3	113.6	91.6	111.2	126
4	114.4	121.8	109.2	106.4	107.6	97.8
5	98.4	90.4	82	98.3	69.8	95.8

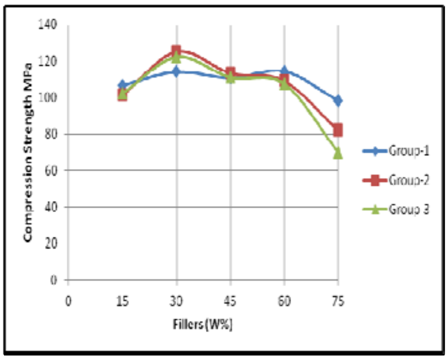


Figure 6: Variation of compression strength with fillers (W%) for all groups.

Figure 6 shows the effect of fillers on axial compressive strength for all groups. The results show that high compressive strength values were obtained and the concentration of the silica sand in PC composition produces changes in compressive strength.

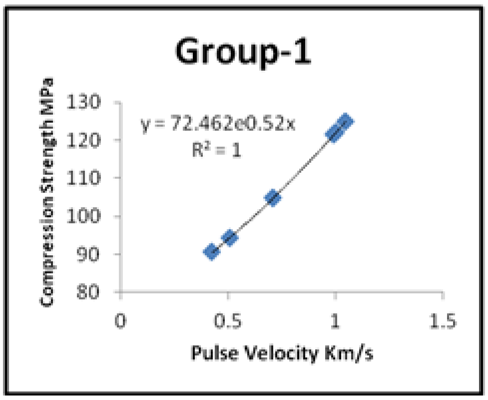


Figure 7: Variation of compression strength with Pulse velocity for group-1

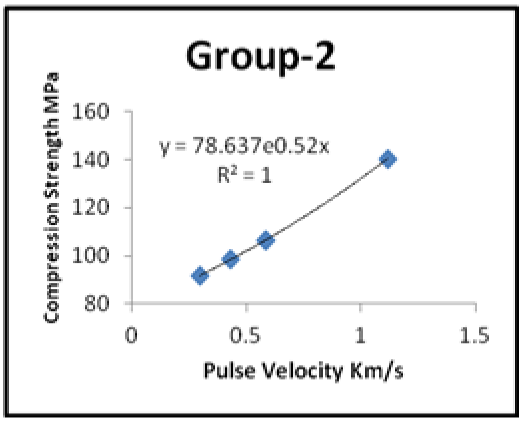


Figure 8: Variation of compression strength with Pulse. Velocity for group-2

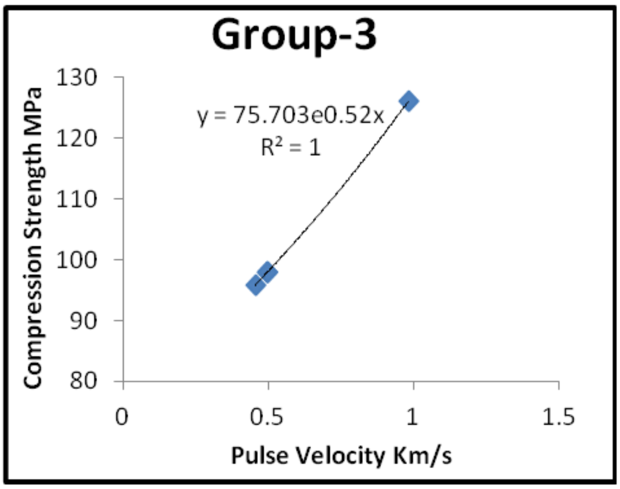


Figure 9: Variation of compression strength with Pulse velocity for group-3.

Figures 7, 8 and 9 shows variation of compression strength with Pulse velocity for all groups where exponential behavior between them is obtained. Each group has equation representing behavior and as a result we know compressive strength by knowing value of pulse velocity.

6. Conclusions

Compression strength values increase with increasing of fillers at 75%.Group-2 showed maximum compression strength value 140MPa nearly. Pulse velocity values increase with increasing of compression strength for all groups. Each group has equation representing its behavior. Equations are $y=72.462e^{0.52x}$ for group-1,$y=78.637e^{0.52x}$ for group-2 and $y=75.703e^{0.52x}$ for group-3.

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