Structural behaviour of concrete combined with synthetic monomers

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1 SUMMARY

A combination of concrete with monomers forms a remarkable method for the improvement of the physical, chemical and mechanical properties of this material. In the above combination the synthetic monomer could be added to the composite in the mixture during the mixing phase of fresh concrete, which is a well known method. The combination of hardened concrete with monomer synthetic resins by impregnation forms another less known method which offers entirely different advantages to those offered by the first method, and for this reason it has a special interest from a scientific and practical point of view. In this program it is our intention to present this method together with the experimental results available.

The experimental work associated with this research involves cement and concrete mixtures with light or heavy aggregates. The experiments are carried out in the Radiation Laboratory of the National Nuclear Research Center "DEMOCRITUS", Athens, and the University of Patras. The casting of specimens and the standard strength tests are performed in the Materials Laboratory of the Ministry of Public Works, and the Laboratories of "TITAN" Cements. The analysis of the problem relating to the concrete polymer composites and the needs for producing such composite materials is carried out first, followed by a comparison between the two combinations: a) concrete-synthetic polymers (C-SP) and b) concrete-synthetic monomers (C-SM). The present study will be finally confined only to the C-SM combination and the experimental results available to-date, will be presented. A thorough reference to the method of solidification of monomer synthetic resins in the mass of concrete will be made, with special emphasis to the method of radiopolymerization with gamma-rays. Radiopolymerization is used for the experimental work in this project.

Light and heavy weight concrete specimens will be tested. The materials produced from a combination of perlite-polymer concrete, have small specific weight and

prevent moisture movements. They are durable to radiation cross linking and could be shaped to form pipes, slabs, and blocks and other structural members suitable for precasting. In the heavy concretes these combinations have the advantage of being able to combine with heavy aggregates such as lead or steel shots, to produce members that could be used as biological shields in areas of high radiation levels. A presentation of the experimental procedures of all phases starting from materials proportioning, mixing, casting, curing, monomer impregnations, gama-radiation, and the final preparations of the test specimens will be made for the C-SM combination. Test results available will also be presented, followed by a discussion on the conclusions made and the practical applications of the proposed method to industry.

2 INTRODUCTION

Composite materials have a technology that has recently expanded to structural concrete. Concrete-polymer materials are composites of concrete and polymers. A composite material is a combination of two or more selected materials that has the best properties of each component and could sometimes have superior properties to those of any constituent alone. Concrete-polymer composites (C-PC) produce, in general, better properties to either single component (1-9). Normal portland cement concrete (PCC) can offer very little resistance to chemical attack, deterioration due to rapid freeze-thaw, law mechanical properties, ie., tensile, shear and bond strengths. It has also microstructural defects such as air voids and shrinkage cracking (7,8,10). The use of polymers in concrete began in the early 1950's and research started in the 1960's and early 1970's as an application for radiation purposes(9,11,12). It has since developed into a full scale materials development program with the purpose to modify concrete mainly in three different aspects: a) adjust the rheology of the fresh mix, b) develop the strength during setting process and c) improve the properties of hardened concretes.

Polymer-concretes have developed due to the availability of various kinds of monomer and to polymerization techniques (1). The cost-benefit ratio of concrete structures is comparable to conventional material even with high material expenses. Concrete-composite materials are being made to obtain and improve mechanical, chemical, electrical and thermal properties. Attempts have been made to substitute cement, partly or fully by developing new lightweight polymer-concrete. Such concretes may cost more per unit valume, than normal weight concretes, and yet result in a structure of reduced cost due to lower dead load, quality of concrete and forming costs.

From the two types of polymerization techniques employed in polymer-concrete development,ie., catalytic and radiation polymerization. Utilization of isotopic radiation energy for polymerization purposes is relatively expensive. Reactions forming polymers from monomers by polymerization areparticularly suited to being promoted by high energy gamma radiation. An economically attractive process for polymerization is that with Cobalt-60 gamma radiation.

Gamma radiation can penetrate materials of an open cell structure and bring about changes within them. Concrete has an open cell structure and could be easily penetrated by gammas. Radiopolymerization, which is initiated by free radicals or ions, has two significant advantages: a) free radicals can be performed at any temperature and b) no chemical catalist is required. The disadvantages are a) the cost of radiation and b) the limited dimensions of specimens to be irradiated.

Three classes of concrete-polymer composites (C-PC) exist. a) polymer-impregnated concrete (P-IC) b) polymer-concrete (P-C) and c) polymer portland cement concrete (PPCC). Distinctions between the three classes are very important for the selection of materials and design. P-IC has been investigated in this program. The P-IC is formed by allowing monomeric systems to penetrate hardened portland cement concrete, normally precast (12,13). The monomers are subsequently polymerized within the structure and the polymer adds properties to those characteristics of the original concrete.

The resultant properties of the concrete composites produced depent on the type of monomer, the selected method of polymerization, and on the porosity of the material. The improvement in the properties of concrete occurs because water and air filled pores are replaced by a load-bearing polymer phase. Moreover, micro-fractures are healed and the bond between the cement paste and aggregate is improved. It could, therefore, besaid, that the final properties of P-IC are dictated by the following factors: a) the extend of impregnation and filling of the pores, b) the type of polymer ability to carry stress, c) the degree of conversion of monomer to polymer and d) the type of concrete and methods of precasting. Techniques for producing light-weight insulating type concrete composites have been developed (14,15). Such composites have been produced with polyester-styrene mixtures.

3 MATERIALS AND EQUIPMENT FOR FABRICATION AND POLYMERIZATION OF TEST SPECIMENS

The materials used in this program for fabrication of test specimens and the laboratory equipment used for the application of impregnation and polymerization techniques are named in this section. These are: a) ordinary portland cement, b) standard French sand type AFNOR/NF P 15 403, c) perlite of grade 0-4mm, d) styrene and polyester mixture of mixing proportions 30% and 70% respectively. The source producing gamma radiation is a Cobalt-60 source consisting of five tubes each containing two Co-60 rods. The tubes are fixed in a circle of 30cm diameter on an aluminium plate. The system is kept at the bottom of a concrete pool filled with filtered water to a depth of 5.0m. A steel impregnation chamber is required to impregnate the polyester-styrene monomer mixture to the specimens.

The original power of the radiation source was 2.5×10^4K. Curies and the average dose rate ranged upto 0.4Megarads/hour. This provided the required radiation of 2.0 to 2.5 Megarads induced to the test specimens. Loading machines for evaluation of compressive and flexural strengths were also provided in the laboratory.

4 TYPES OF TESTS PERFORMED

The experimental results reported herein form only a small part of a major research program conducted by the authors. Two composite materials have so far been designed for the tests, a concrete-polymer and a perlite-cement-polymer composite. A series of compressive and flexural tests have been performed to evaluate these composites. Three series of tests have been completed and tested. The test results on each series including precast concrete and perlite specimens are presented in a later section. The tests performed to-date could be summarized in the following list: a) compressive strength, b) flexural strength, c) effects of radiation on the strength of composites, and d) monomer absorption.

5 PRESENTATION OF TEST PROCEDURES

The test procedures for evaluating concrete and perlite-cêment polymers are briefly presented and discussed here. a) compressive strength: all tests were performed on a 4x4x4cm and 4x4x8cm specimens. Control specimens ie., non-polymer impregnated of the same dimensions have also been tested. b) flexural strength: all tests were performed on a 4x4x16cm specimens. The specimens were loaded at mid-span. c) compressive and flexural tests were performed on irradiated specimens as described in (a) and (b). The specimens were exposed to a Cobalt-60 gamma radiation source for the same periods of time amounting to 18 hours and comparisons were made. d) moisture content: the specimens were kept in the oven at a temperature of 50°C and weighed before impregnation. They were then placed under vacuum at room temperatures and soaked in styrene-polymer mixtures. The percentage of polymer absorptions were evaluated.

6 PRESENTATION OF CONCRETE AND PERLITE-POLYMER TEST SPECIMENS

6.1 First series of tests. Non-impregnated concrete specimens.

Ordinary portland cement non-impregnated concrete specimens were cast for the series. The materials used for the concrete mix were: ordinary portland cement with an additive of 3% of lignite ash. Standard French sand AFNOR/NF P 15 403 and water. The characteristics of sand are shown in Table 1. Prismatic specimens 4x4x16cm were cast and cured for 28 days in water. Some of the prisms were tested for flexure and others were cut to produce 4x4x4cm cubes and

Sieve net(mm)	% age retain	Classif. of sand
0.08	48±2	Fine
0.15	88±2	
0.50	67±5	Medium
1.00	33±5	Coarse
1.70	5±5	
2.00	0.0	

Table 1. Proportions of standard French sand AFNOR/ NP P 15 403.

4x4x8cm prisms. The samples of these specimens were first produced in a series of preliminary experiments whose purpose was to determine whether concrete could be impregnated by using methods that have been used previously, and to obtain as many characteristics as possible. Before monomer impregnation and irradiation stages began, the following tests took place: Compressive strength of non-impregnated control specimens. The results shown in Table 2.

No	Comp.Str. N/mm^2
1	58.2
2	58.2
3	61.3
4	61.3
Mean Value	59.9

Table 2. Compressive strength of 4x4x4cm control specimens.

6.2. Second series of tests. Impregnated and irradiated concrete specimens.

Specimens of radiation polymerized concrete-polymer composite were produced with the same materials and proportions to those of first series. Two sub-series of tests 2-A, and 2-B, were performed, but only the results of sub-series 2-A are included in this report. Concrete cubes 4x4x4cm were cast and tested for compression at impregnation pressures ranging from 0 to 10Atm. Percentages of monomer absorption weight are smaller than 2%. This %age is too low to consider for having an important improvement in the properties of polymer composites studied. For this reason we focused our attention to more porus materials such as perlite-cement composites. The work that follows is exclusively concerned with the above material.

6.3. Third series of test impregnated and radiated perlite-cement specimens.

Specimens of ordinary portland cement, perlite of grade 0-4mm and water, were prepared and tested for compressive and flexural strengths. Three perlite-cement mixes were designed M_1, M_2, M_3, having the proportions shown in Table 3. Before casting, the apparent mean value of density d_m and the yield coefficient n_p, of perlite were measured and were found to be d_m=108·6gr/dm, and n_p=56 ~ 80% respectively. Mixing proportions for dry materials were as follows:

Mixes	Cement kg/m^3	Water kg/m^3	Perlite m^3/m^3
M1	430	367	1.78
M2	345	446	2.05
M3	308	447	2.08

Table 3. Mix proportions.

Cement:Perlite:water =0.9(840gr):3:0.9dm^3. The apparent weight of perlite-cement is =1195gr/dm^3, Real weight =1933gr/dm^3, and the yield coefficient of perlite n_p=1195: 1933=66%.

Fifteen 4x4x16cm prismatic specimens were cast and tested. The percentages of monomer absorption during impregnation for pressures at 0, 5, and 10Atm, and the three mixes are shown in Table 4.

Sub.Series.	No.	Pressure (Atm) 0	5	10
2-A	A_1 A_2 A_3 A_4 A_6	4. 4%	10.5%	24.03%
2-B	B_1 B_2 B_3 B_4 B_6	7.53%	24.7%	68.04%
2-C	C_1 C_2 C_3 C_4 C_6	10.91%	39.1%	87.64%

Table 4. Percentage monomer absorption during impregnation of specimens.

Compressive and tensile strengths are shown in Table 5.

Series	No.of Spec.	%Monomer Absorption	Impregnation pressure (Atm) 0	5	10
3-A	A1 A2	4. 4%	36.2/8.33 38.0/8.33		
	A3 A4	10. 5%		38.0/9. 2 36.2/9. 2	
	A6	24.03%			29.2/11.6
3-B	B1 B2	7.53%	26.9/5.71 33.3/5.71		
	B3 B4	24. 7%		44.4/5.71 33.3/5.71	
	B6	68.04%			89.5/20.8
3-C	C1 C2	10.91%	26.9/4. 7 28.0/4. 7		
	C3 C4	39.10%		43.8/6. 3 44.4/6. 3	
	C6	87.64%			88.9/33.1

Table 5. Compressive/tensile strength of five 4x4x16cm specimens for the three design mixes. (425,345,308,kg/m3.). Mean value of compressive strength for control specimens as follows: Series A:29.68, B:15,68, C:11.17.N/mm^2.

The percentage of monomer absorption per impregnation pressure for the three series is shown in Fig. 1. Changes of tensile and compressive strengths of specimens with impregnation pressure are shown in Figs. 2 and 3 respectively.

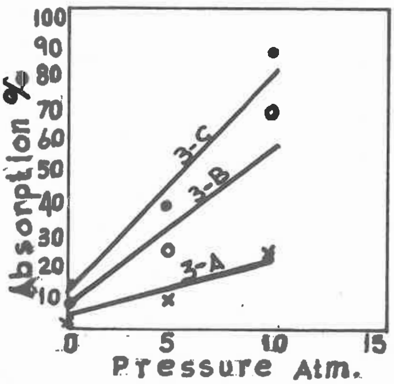

Fig.1.%absorption-
impregnation pressure Atm.

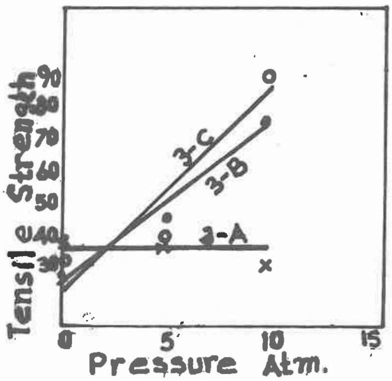

Fig.2.Tensile strength-
impregnation pressure Atm.

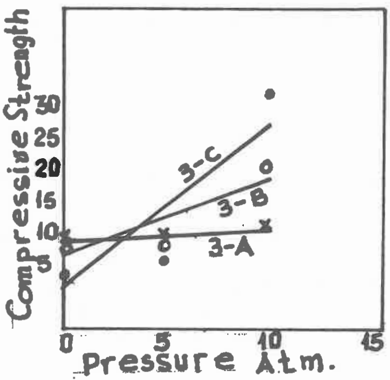

Fig.3.Compressive strength-
impregnation pressure Atm.

7 CORRILATION OF STRUCTURAL PROPERTIES

As reported in the paragraphs of section (6) the tests included compressive and flexural strengths. The change of monomer impregnation with respect to the induced pressure was measured similarly. The improvement of compressive and tensile strengths with respect to monomer impregnation were recorded. Compressive strengths: the effects of the above variables on compressive strength is shown in Figs. 1, 2, and 3. Flexural strength: the flexural strengths of non-improgranted and impregnated specimens were also plotted in the same figures as the compressive strengths and tabulated in the Tables. The results indicate trends similar to those of compressive strengths.

8 COMPARISON OF PROPERTIES OF CONCRETE AND PERLITE-POLYMERS WITH OTHER MATERIALS.

It is intended to compare the strength of concrete and perlite-polymer composites with those of conventional concrete and other structural materials and to obtain some comparisons: The test results available to-date are not considered sufficient to make meaningful comparisons.

According to the theory of composite structures (16) the polymer may be considered as the continuous material. However, the concrete is a composite material in itself, containing cement and aggregate. Perlite concrete may also be considered as having a similar structure. The concrete and perlite polymer composites are actually three-phase materials, cement-aggregate-polymer and cement-perlite polymer. The polymer may therefore act to strengthen the cement-aggregate and the perlite-cement bond. The compressive strength of concrete-polymer falls between that of the concrete and the polymer alone. The tensile strength appears to be an additive property based on the valume fraction of the concrete and polymer phases. This would indicate that the polymer acts as a reinforcing member in the concrete. Concrete-polymer composites should be most useful when compressive force is dominating. Advantages other than strength properties should make concrete-polymer compoties still more competitive.

9 APPLICATIONS

Prestressed concrete pressure vessels are constructed of concrete as they have the advantage in that they are cheaper to construct, provide structural safety and serve as giological shields. There is a possibility of using concrete polymer for improved strength, with a saving in materials. The radiation level in the outer section of the vessels are not very high. However, if any further biological shielding would be required, it could be provided by pre-cast P-IC members with heavy aggregates fixed outside the vessel. For experimental reactors, movable biological shielding parapets could be provided by precast P-IC members in areas where irradiation experiments are in progress. Protective biological curtains could also be provided by precast P-IC members during transportation of radioactive elements. P-IC materials may have some application in the building industry for low-cost housing construction. In sea water desalination plants P-IC could possibly provide adequate corrosion resistance. Also, in ocean technology for both commercial and scientific purposes P-IC could be used for the same purpose.

10 DISCUSSION

The work to-date has indicated that precast heavy&lightweight concrete can be impregnated with monomers and polymerized by radiation techniques. The resultant P-IC material has been found to have improved structural properties compared with conventional concrete. The experimental results available to-date show of course, considerable statistical variations which are mainly due to inhomogeneity and porosity of the material. It follows, there, fore, that variation in strength should be expected. A considerable number of test specimens are required in order to obtain more reliable results. Further research is required to different types of composites to obtain foundamental understanding of the nature of the bonding between the polymer, concrete, perlite and aggregate.

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