Pergamon

Cement and Concrete Research, Vol. 27, No. 8, pp. 1135–1139, 1997

0008-8846/97 $17.00 + .00

PII S0008-8846(97)00115-4

COMMUNICATED PAPERS

ANALYSIS OF RUBBERIZED CONCRETE AS A COMPOSITE MATERIAL

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(Communicated by F.W. Locher)
(Received March 6, 1997; in final form June 23, 1997)

ABSTRACT

In this study, an analysis of rubberized concrete was done according to composite material rules. The rubberized concrete analyzed was created using various proportions of normal C 16 concrete with bits of scrap automobile tires. Being composed of mortar, aggregate and rubber, the concrete was treated as a three-phase composite. In determining equations for elastic constants, it was observed that experimental results complied conclusively with equations used for composite material rules. An equation was solved to determine the elasticity moduli. Then it was observed that the validity of equation proposed. © *1997 Elsevier Science Ltd*

Introduction

New areas of use for concrete can be created by increasing its ductility and durability. The inclusion of rubber into concrete results in higher resilience, durability and elasticity (1-5). The use of rubberized concrete in constructions that are subject to impact effects will be beneficial due to the altered state of these properties. The unique qualities of rubberized concrete will find new areas of usage in highway constructions as a shock absorber, in sound barriers as a sound absorber and also in buildings as an earthquake shock-wave absorber. In determining the elastic constants and mechanical properties of rubberized concretes that were produced by adding rubber in different volume proportions and in different forms such as fiber chips etc., it was thought that rules for composite materials could be used.

One of the considerations that was made according to the rules of composite material was to examine the material in terms of properties of the individual phases and their proportions. In examining the concrete as a two-phase material, it is accepted that mortar is the matrix and coarse aggregate is the distributed phase (6). Once, a "unit cell" model, composed of mortar and aggregate, is assumed to reflect all properties of the material, then effort is given to find mathematical relations. In this study, rubberized concrete is accepted as being a three-phase composite material composed of mortar, aggregate and rubber. First, several samples were produced using various mixtures of aggregate and rubber. Then, physical property values for each sample were discovered through several experiments. Finally, formulas for the composition for each sample were expressed as equations, based on their physical properties.

Unit Cell Models

Parallel phase model:

$$E_c = E_m V_m + E_a V_a \qquad \text{(Upper Boundary)} \qquad (1)$$

Series phase model:

$$\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_a}{E_a} \qquad \text{(Lower Boundary)} \qquad (2)$$

Distributed phase model:

$$E_c = E_m \frac{1 + 2V_a\left(\frac{\alpha - 1}{\alpha + 2}\right)}{1 - V_a\left(\frac{\alpha - 1}{\alpha + 2}\right)} \qquad \alpha = \frac{E_a}{E_m} \qquad (3)$$

Where E_c, E_m and E_a are the elasticity moduli of composite, matrix and aggregate, respectively. V_m and V_a are designated for the volume proportions of the matrix and aggregate. Unit cell models shown in Fig. 1, represent four different phases of concrete. Given above are the analytical explanations for the "parallel phase" (same strain), "series phase" (same stress) and "distributed phase" models (6). In order to determine an equation for rubberized concretes, we accepted that aggregate and rubber behave as series phase composites until they are mixed with mortar, at which time they behave according to the laws of distributed phase composites. In determining the elasticity modulus of rubberized concrete composite, the elasticity constants of rubberized concrete were used in an equation based on the format of Eq. 2.

$$\frac{1}{E_{ar}} = \frac{V_r}{E_r} + \frac{V_a}{E_a}$$

By finding a common denominator we arrive at:

$$E_r E_a = E_{ar} E_a V_r + E_{ar} E_r V_a$$

$$E_{ar} = \frac{E_a E_r}{E_r V_a + E_a V_r} \qquad (4)$$

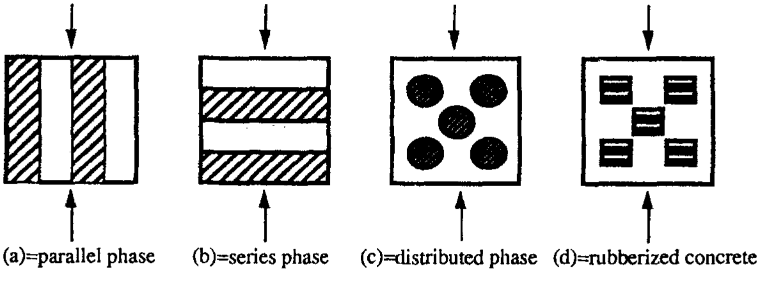

FIG. 1.
Unit cell models

The equation above is the elasticity modulus of the series phase composite, which was obtained from the aggregate and rubber in Fig. 1d. Where a represents aggregate and represents rubber. By inserting the value of the elasticity modulus of the series phase composite into Equation 3, we arrive at the elasticity modulus for rubberized concrete composite.

$$E_c = E_m \frac{1+2V_{ar}(\frac{\alpha-1}{\alpha+2})}{1-V_{ar}(\frac{\alpha-1}{\alpha+2})} \qquad \alpha = \frac{E_{ar}}{E_m} \tag{5}$$

Where c, m, and ar represent rubberized concrete composite, mortar, and series phase composite of aggregate and rubber. Finally, the equation is modified by the coefficient k' in order to compensate for normal discrepancies by defining a range of validity, derived from the rate of change between the actual and theoretical results:

$$E_c^1 = k^1 E_m \frac{1+2V_{ar}(\frac{\alpha-1}{\alpha+2})}{1-V_{ar}(\frac{\alpha-1}{\alpha+2})} \qquad \alpha = \frac{E_{ar}}{E_m} \tag{6}$$

Experimental Studies

In order to test the validity of the equations, various rubberized concrete specimens were prepared in a laboratory. These specimens were made with 15, 30, and 45% proportions of either coarse or fine particles of rubber. In addition, half of these samples were mixed with fine ground limestone (Fig. 2), while the other half were mixed with coarse ground limestone (Fig. 3). The physical properties and measured values of each sample were then determined, according to calculations from Equation 6, using their various proportions of aggregate and rubber. The elasticity moduli and appropriate k' values for equation 6 are listed in Tables 1 and 2. FRC and CRC represent fine and coarse rubberized concrete, respectively.

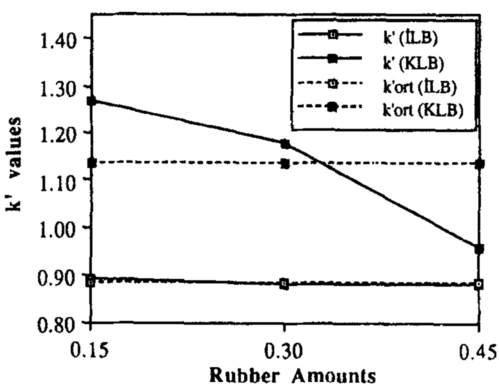

FIG. 2.
For rubberized concrete with fine ground limestone.

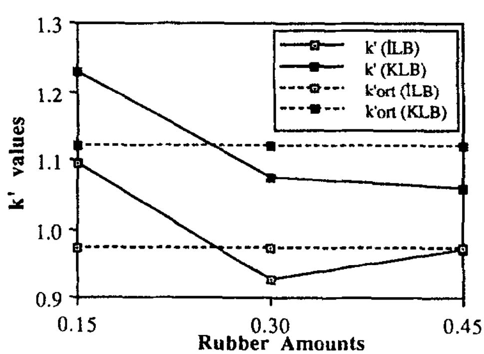

FIG. 3.
For rubberized concrete with coarse ground limestone.

TABLE 1

The Experimental Results and Elasticity Moduli

Sample Code	Fine ground limestone				Coarse ground limestone			
	V_a	V_r	E'_c	E_c	V_a	V_r	E'_c	E_c
FRC 15	0.625	0.048	12.787	11.413	0.683	0.031	11.808	12.923
FRC 30	0.592	0.092	12.300	10.825	0.659	0.061	11.336	10.500
FRC 45	0.561	0.133	11.937	10.500	0.637	0.090	11.022	9.941
CRC 15	0.596	0.095	12.194	15.441	0.651	0.072	11.197	13.770
CRC 30	0.542	0.168	11.425	13.462	0.601	0.136	10.639	11.429
CRC 45	0.496	0.235	10.784	10.294	0.556	0.194	10.183	10.769

Evaluation of the Results

k' values were calculated by applying the elasticity modulus to the equations developed. The graphics given below aid in understanding both the relationship between k' values and the quantity of rubber as well as the range of validity for the equations. The intersection between k values and k' value averages were found in order to determine ranges of validity for both fine ground and coarse ground limestone. The graphics show the range of validity for rubberized concrete with fine ground limestone being between 0.35 and 0.40. The range of validity for rubberized concrete with course ground limestone is also shown being between 0.25 and 0.30.

Conclusion

Rubberized concretes made with both fine and coarse rubber were accepted as three phase materials, and an equation was sought to determine the elasticity moduli. The equation was

TABLE 2

k' Values of Rubberized Concretes

Sample Code	Coarse	Fine
	k'	k'
FRC 15	1.094	0.893
FRC 30	0.926	0.880
FRC 45	0.902	0.880
Average	0.974	0.884
CRC 15	1.230	1.266
CRC 30	1.074	1.178
CRC 45	1.058	0.955
Average	1.121	1.133

then tested by comparing its results with the experimental results, thereby confirming its validity. When determining the elasticity moduli for rubberized concretes with fine ground limestone, the lower and upper boundaries for the range of k' values are 0.880 and 1.067. The k' values range of validity when using coarse ground limestone is between 0.954 and 1.100.

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