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Key words: cement-based composite, aggregate, elastic moduli, concrete, micromechanics.

ABSTRACT

The elastic moduli of cement-based composite materials with different types of aggregates were investigated in this study. Twelve mixes with various volume fractions (10%, 20%, and 30%) were selected. Cylindrical specimens with a dimension of ϕ 10 x 20 cm were cast and tested. Electric strain gages were used and elastic moduli were obtained from the stress-strain curves. Theoretical moduli were calculated based on H-S bounds and micromechanics. Test results show that the types and volume fractions of aggregates significantly affect the elastic moduli of concrete composite materials and the theoretical predictions fairly agree with the experimental data.

INTRODUCTION

Cement-based composite material is one of the popular artificial materials because it is energy-conserving, cost-efficient, easy to cast into any shape, and highly resistant to marine environments. In reinforced and prestressed concrete design, the elastic moduli of structural materials are very important parameters, particularly in designing structural elements based on the stiffness. With the rapid development of composite materials technology, high strength and high performance concrete has been applied to civil structures.

It is noted that the overall elastic behavior of cement-based composite materials is affected by the elastic modulus and proportional ratio of the aggregate and matrix. Hirsch [1] derived an equation to express the elastic modulus of concrete using an empirical constant. Several experimental programs have been conducted using different types of aggregate such as steel, sand, crushed glass, gravel, crushed limestone, and lead. Baalbaki et al. [2] demonstrated that the elastic moduli of concrete composite materials is influenced by the elastic properties and volume fractions of aggregates. Stock et al. [3] also obtained some experimental results for the elastic moduli of mortar and concrete with different aggregate volume fractions.

The overall mechanical behavior of composite materials has been studied for many years. The Voigt's [4] approximation gave the upper bound and the Reuss's [5] approximation gave the lower bound of the average elastic moduli. Hashin and Shtrikman [6] applied variational principle to find bounds of the average elastic moduli of composite materials. Mori and Tanaka [7] has utilized the concept of average field to analyze macroscopic properties of composite materials. In addition, Yang et al. [8] proposed a model for approximating elastic modulus of concrete by employing Mori-Tanaka Theory and Eshelby's Method [9]. In this study, based on Hashin and Shtrikman bounds (H-S) and Yang's model the elastic moduli of cement-based materials were computed and compared with experimental results.

THEORETICAL APPROACH

The Micromechanics method are calculated for the experimental results according to the following equation [8]:

$$\overline{\underset{\sim}{C}}=\{\underset{\sim}{C}^{-1}+f[\{(1-f)(\underset{\sim}{C}^{*}-\underset{\sim}{C})\underset{\sim}{S}-f(\underset{\sim}{C}-\underset{\sim}{C}^{*})+\underset{\sim}{C}\}]^{-1}(\underset{\sim}{C}-\underset{\sim}{C}^{*})\underset{\sim}{C}^{-1}\}^{-1}, \qquad (1)$$

where:

$\overline{\underset{\sim}{C}}$: the average elastic moduli tensor of concrete;
$\underset{\sim}{C}$: the elastic moduli tensor of mortar;
$\underset{\sim}{C}^{*}$: the elastic moduli tensor of aggregate;
$\underset{\sim}{S}$: Eshelby's tensor for sphere aggregate;
f: the volume fraction of aggregate.

H-S bounds are calculated for the experimental results according to the following equations [6]:

$$K_m=\frac{E_m}{3(1-2\nu_m)} \qquad (2)$$

$$G_m=\frac{E_m}{2(1+\nu_m)} \qquad (3)$$

$$K_a=\frac{E_a}{3(1-2\nu_a)} \qquad (4)$$

$$G_a=\frac{E_a}{2(1+\nu_a)} \qquad (5)$$

$$K_c^-=K_m+\frac{f_a}{\frac{1}{K_a-K_m}+\frac{3f_m}{3K_m+4G_m}} \qquad (6)$$

$$K_c^+=K_a+\frac{f_m}{\frac{1}{K_m-K_a}+\frac{3f_a}{3K_a+4G_a}} \qquad (7)$$

$$G_c^-=G_m+\frac{f_a}{\frac{1}{G_a-G_m}+\frac{6f_m(K_m+2G_m)}{5G_m(3K_m+4G_m)}} \qquad (8)$$

$$G_c^+=G_a+\frac{f_m}{\frac{1}{G_m-G_a}+\frac{6f_a(K_a+2G_a)}{5G_a(3K_a+4G_a)}} \qquad (9)$$

$$E_c^-=\frac{9K_c^-G_c^-}{3K_c^-+G_c^-} \qquad (10)$$

$$E_c^+=\frac{9K_c^+G_c^+}{3K_c^++G_c^+} \qquad (11)$$

where:

E : Young's modulus;
K : bulk modulus;
G : shear modulus;
ν : Poisson's ratio;
f: relative volume of the phase;
m: mortar;
a : aggregate;
c : concrete;
- : value for lower H-S bound;
+ : value for upper H-S bound.

EXPERIMENTAL PROGRAM

In the experimental program, several aggregates were selected for concrete composite materials. Various water/cement ratios (W/C = 0.286, 0.294, 0.315) and volume fractions (A/T = 0.1, 0.2, and 0.3) were considered in the mix proportions. The mix design of this investigation is given in Table 1. The cement-based matrix includes type I portland cement, river sand and silica fume. The concrete composite materials is made of matrix and different types of aggregates. The quantities of aggregates were adjusted for each mix in order to obtain different volume fractions (aggregate volume/ total composite volume). The selected aggregates include steel, glass, gravel, and crushed stone. The Young's moduli of aggregate ranges from 38.0 GPa to 205.8 GPa. The geometric shape and elastic properties of aggregates are listed in Table 2.

Cylindrical specimens with various W/C ratios and different aggregates were cast and cured in the research laboratory. For determining the elastic moduli of concrete composite materials, two electric strain gages were mounted on opposing sides of each specimen to measure the compressive strains. Continuous measurements were recorded to obtain the stress/strain curves and compressive strengths. A typical stress-strain curve for cement-based composite material is shown in Fig. 1.

RESULTS AND DISCUSSIONS

The moduli of elasticity of cement-based composite materials were obtained directly from the stress/strain curves. The Poisson's ratios of cement-based matrixes (composite materials without aggregate) were also measured and recorded by use of lateral strain gages. The elastic moduli and Poisson's ratios of the matrixes are presented in Table 3. The moduli and Poisson's ratio decreases as water/cement ratio increases.

The computed and tested elastic moduli of the cement-based composite materials are given in Table 4. It includes the theoretical results from micromechanics theory and H-S bounds. The parameters used in the

Table 1. Mix Design ($^{Kg}/_{m^3}$)

Batch designation	W/C	Super plasticizer	Water	Cement	Silica Fume	Sand	Coarse Aggregate		
							Glass Crushed Gravel Steel (1/2")	(5/8")	(3/4")
A0	0.286	15.9	228.5	805	48.3	1259	0	0	0
GA1							252		
RA1	0.286	13.76	205.7	724	43.5	1133	266		
OA1							284		
SA1							143	317	257
GA2							505		
RA2	0.286	12.23	182.8	644	38.6	1007	532		
OA2							568		
SA2							286	634	514
GA3							757		
RA3	0.286	10.7	160	563	33.8	881	798		
OA3							852		
SA3							429	951	771
B0	0.294	17.08	234.3	786	68	1243	0	0	0
GB1							252		
RB1	0.294	15.37	210.9	708	61.2	1119	266		
OB1							284		
SB1							143	317	257
GB2							505		
RB2	0.294	13.66	187	629	54.4	995	532		
OB2							568		
SB2							286	634	514
GB3							757		
RB3	0.294	11.96	164	550	47.6	870	798		
OB3							852		
SB3							429	951	771
C0	0.315	14.95	246.2	782	45.3	1225	0	0	0
GC1							252		
RC1	0.315	13.46	221.5	704	40.8	1103	266		
OC1							284		
SC1							143	317	257
GC2							505		
RC2	0.315	11.96	196.9	626	36.2	980	532		
OC2							568		
SC2							286	634	514
GC3							757		
RC3	0.315	10.47	172.3	548	31.7	858	798		
OC3							852		
SC3							429	951	771

model predictions are given in Tables 2 and 3. The spherical aggregates were considered in computing the Eshelby's tensor $\underset{\sim}{S}$ [10]. Fig. 2 illustrates the relationships between volume fraction and elastic modulus for the composite with steel aggregate and various W/C ratios. It shows that the elastic modulus increases as long as the matrix strength increases (the W/C ratio decreases) for different volume fractions. Fig. 3 through Fig. 5 are the elastic modulus vs. volume fraction curves for the composites with various W/C ratios It seems that the aggregate properties and volume fractions have significant effect on the elastic moduli of the com-

Table 2. The Properties of Coarse Aggregates

Coarse Aggregate	Shape	Poisson Ratio	Elastic Modulus (GPa)
Steel	Spherical	0.33	205.8
Glass	Spherical	0.28	72.2
Gravel	Round	0.23	54.0
Crushed Stone	Angular	0.23	38.0

Table 3. The properties of Matrix

Batch	W/C	*Elastic modulus (GPa)	*Poisson Ratio
A	0.286	32.11	0.228
B	0.294	28.46	0.217
C	0.315	23.83	0.208

*Average of three specimens

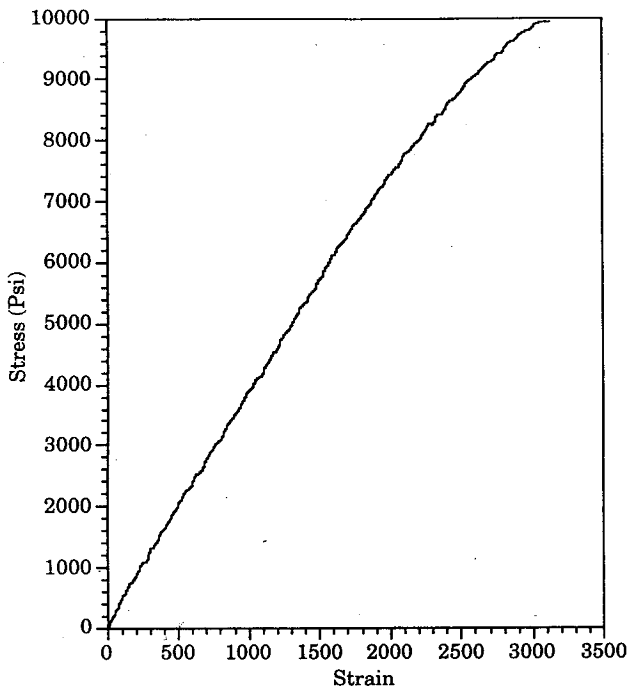

Fig. 1. A typical stress-strain curve for high strength concrete.

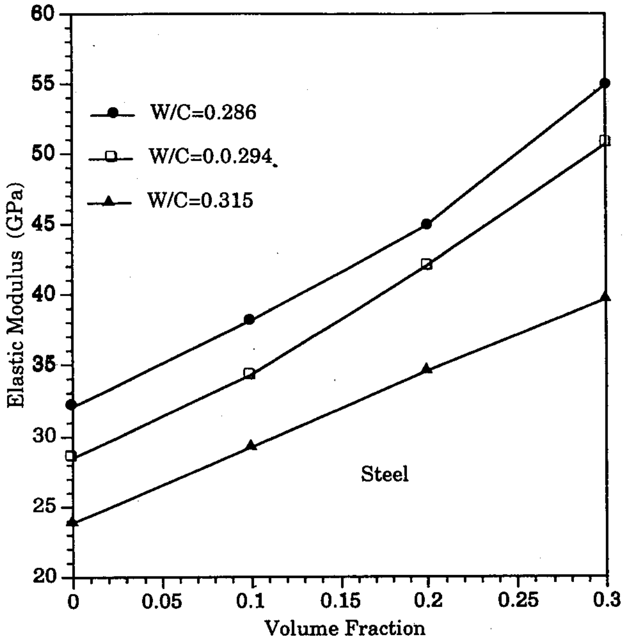

Fig. 2. Volume fraction vs. elastic moduli curves for steel aggregate composites with various W/C ration.

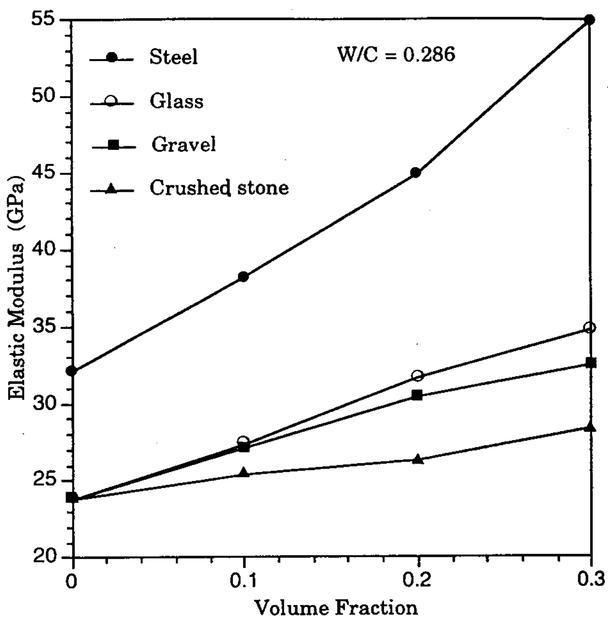

Fig. 3. Volume-fraction vs. elastic modulus curves for composites at W/C=0.286.

posite. Test results show that elastic modulus and volume ratio of aggregate increases the elastic modulus of the composite improves. Except for composites with crushed stone aggregate, the difference between experimental results and the computed values are less than 10%. The improper prediction for composite with crushed stone aggregate is because the shape does not conforms to the spherical shape assumption in the theoretical model.

CONCLUSIONS

The elastic moduli of cement-based composite are influenced by the elastic properties and the volume fraction of the matrixes and aggregates. The elastic modulus of the composite increases with increasing

Table 4. Esperimental and Theoretical of Elasticity Moduli

Batch designation	Aggregate Type	Volume Ratio	*Measured Elastic Moduli (GPa)	Micro-mechanics Method (GPa)	Upper H-S Bound (GPa)	Lower H-S Bound (GPa)
A-0		0.0	32.11	32.11	32.11	32.11
SA-1		0.1	38.13	37.16	42.62	37.16
SA-2	Steel	0.2	44.86	43.08	54.08	43.08
SA-3		0.3	54.85	50.10	66.64	50.10
GA-1		0.1	34.79	34.68	35.09	34.68
GA-2	Glass	0.2	36.60	37.46	38.25	37.46
GA-3		0.3	31.28	40.49	41.06	40.49
RA-1		0.1	28.12	32.65	32.66	32.65
RA-2	Grushed	0.2	27.32	33.21	33.21	33.21
RA-3	Stone	0.3	31.90	33.77	33.78	33.77
OA-1		0.1	33.16	33.78	33.89	33.78
OA-2	Gravel	0.2	33.57	35.55	35.75	35.55
OA-3		0.3	36.75	37.41	37.68	37.41
B-0		0.0	28.46	28.46	28.46	28.46
SB-1		0.1	34.27	33.12	39.05	33.12
SB-2	Steel	0.2	42.01	38.61	50.61	38.61
SB-3		0.3	50.70	45.17	63.31	45.17
GB-1		0.1	32.19	31.05	31.61	31.05
GB-2	Glass	0.2	35.89	33.88	34.97	33.88
GB-3		0.3	37.24	37.00	38.54	37.00
RB-1		0.1	25.86	29.29	29.30	29.29
RB-2	Grushed	0.2	27.80	30.14	30.17	30.14
RB-3	Stone	0.3	28.30	31.02	31.06	31.02
OB-1		0.1	29.58	30.28	30.46	30.28
OB-2	Gravel	0.2	31.78	32.22	32.55	32.22
OB-3		0.3	33.87	34.29	34.75	34.29
C-0		0.0	23.83	23.83	23.83	23.83
SC-1		0.1	29.20	27.93	34.51	27.93
SC-2	Steel	0.2	34.59	32.80	46.18	32.80
SC-3		0.3	39.68	38.69	59.03	38.69
GC-1		0.1	27.34	26.36	27.17	26.36
GC-2	Glass	0.2	31.62	29.18	30.74	29.18
GC-3		0.3	34.69	32.33	34.58	32.33
RC-1		0.1	25.45	24.95	25.01	24.95
RC-2	Grushed	0.2	26.27	26.12	26.23	26.12
RC-3	Stone	0.3	28.33	27.35	27.50	27.35
OC-1		0.1	27.10	25.75.	26.07	25.75
OC-2	Gravel	0.2	30.38	27.84	28.43	27.84
OC-3		0.3	32.42	30.10	30.95	30.10

*Average of three specimens

volume fraction and elastic modulus of aggregate. In this study, two-phase material can be modeled for the composites to predict the material elastic properties using micrmechanics theory with acceptable accuracy.

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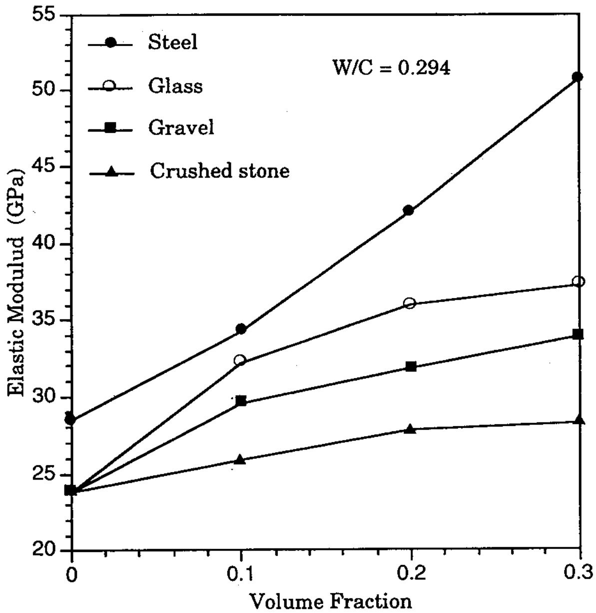

Fig. 4. Volume-fraction vs. elastic modulus curves for composites at W/C=0.294.

REFERENCES

1. Hirsch, T.J., "Modulus of Elasticity of Concrete Affected by Elastic Moduli of Cement Paste Matrix and Aggregate," J. ACI, pp. 427-451 (1962).
2. Baalbaki, W., Benmokrane, B., Chaallal, O., and Aitcin, P.C., "Influence of Coarse Aggregate on Elastic Properties of High-performance Concrete," ACI Materials Journal, Vol. 88, No. 5, pp. 499-503 (1991).
3. Stock, A.F., Hannant, D.J., and Wiliams, R.I.T., "The Effect of Aggregate Concentration upon the Strength and Modulus of Elasticity of Concrete," Magazine of Concrete Research, Vol. 31, No. 109, pp. 225-234 (1979).
4. Voigt, W., "Über die B eziehung zwischen den beiden ElastizitätskonstAnten Isotroper KÖrper," Wied. Ann., Vol. 38 pp. 573-587 (1889).
5. Reuss, A., "Berechnung der Fliessgrenze von Mischkristallen auf Grund der Plastizität Sbedingung für Einkristalle," Z. angew. Math. Mech., Vol. 9, pp. 49-58 (1929).
6. Hashin, Z. and Shtrikman, S., "On Some Variational Principles in Anisotropic and Nonhomogeneous Elasticity," J. Mech. Phys. Solids, Vol. 10, pp. 335-343 (1962).
7. Mori, T. and Tanaka, K., "Average Stress in Matrix and Average Energy of Materials with Misfitting Inclusions," Acta Metall., Vol. 21, pp. 571-574 (1973).
8. Yang, C.C., Huang, R., Yeih, W. and Chang J.J. "Theoretical Approximate Elastic Moduli of Concrete Material," The Chi. J. of Mechanics, Accepted.
9. Eshelby, J.D., "The Determination of the Elastic Field of an Ellipsoidal Inclusion, and Related Problems," Proc. Roy. Soc., A241, pp. 376-396 (1957).