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Polymerized Lightweight Fibrous Composites

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ABSTRACT

Industrial, agricultural, and naturally occurring waste materials in conjunction with liquid epoxy resin, asbestos, and silica have been employed to make lightweight engineering composite materials. To bring down the cost of epoxy resin, phenol formaldehyde was used as a binding material. Various physicomachanical properties of these composites were investigated. This study advocates elegant, economical, and lighter alternative materials for structural applications, reducing the deadweight of the structure and thereby resulting in lighter foundations. Furthermore, an attempt has been made to find a suitable fibrous material as an alternative substitute for asbestos to meet hygienic requirements.

INTRODUCTION

Engineers, chemists, and architects are now aware of the importance of using lighter building materials of superior strength and increased durability as compared to normal cement concrete [1-4]. International interest in the successful use of polymers in concrete dates back to the early 1950s. This work expanded into large-scale research in the late 1960s and early 1970s; since then, many investigations [5] have been carried out to incorporate polymers into con-

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crete. One of the main techniques in producing such polymerized composites is to minimize void volume in the aggregate so as to reduce the quantity of relatively expensive polymer needed for binding the aggregate. Another idea was to make composites that are economical and resistant to moisture and cyclic changes in weather.

Several fibrous materials have been used as fillers [6]. It has been reported that when the fibrous materials are incorporated into the matrix, the interlaminar shear strength is decreased due to the weakness at the resin-filler interface [7]. Improving the mechanical properties therefore clearly meant that the fiber-matrix bond had to be strengthened, and this directed attention to the need for surface treatment. Coupling agents such as organofunctional silanes and titanates, which act as a bridge between inorganic reinforcing material and the organic resin matrix, have been successfully used for many years on glass fibers to improve the performance of glass-reinforced polymer composites [8-10]. Addition of fibrous fillers such as asbestos or glass wool impart further strengthening effects to the finished products.

Progress in the construction industry has resulted from the continued search of new materials in place of health hazardous asbestos. Among new materials that are under active investigation are several types of modified polymer composites. Concretes prepared from Portland cement, sand, aggregate, and water have many defects such as poor adhesion of fresh concrete to old concrete, poor resistance to the action of chemicals and water, inferior resistance to abrasion breakdown due to repeated freeze-thaw cycles, and the growth of fungus and microorganisms.

In our earlier research [11-14] on new lightweight polymer composites, several industrial, agricultural, and naturally occurring waste materials were successfully utilized. Increased use of such wastes might prove to be a beneficial factor where ecology and economy are concerned [15].

In the present investigation, polymerized lightweight fibrous composites have been investigated. The following fibrous materials have been used: sawdust (SD), fly ash (FA), cinder (CI), coke (CO), rice husk (RH), paddy husk (PH), maize cobweb (MC), jute powder (JP), coconut shell (CS), ground nut shell (PS), fuller's earth (FE), graphite (GR), asbestos (AS), vermiculite (VM), and mica (MI). Such properties as Young's modulus, tensile strength, compressive strength, thermal conductivity, unit weight, and water absorption have been studied. Furthermore, an attempt has been made to find a suitable fibrous material as a substitute for asbestos to meet hygienic requirements.

THEORETICAL

Several theories have been proposed to predict the Young's modulus of a composite system in relation to its constituents [16-21]. In most

of these theories, the increase in stiffness or elastic modulus of a composite has been attributed to the presence of rigid fillers in the matrix [30]. The following relation has been frequently considered in the analysis of data for composite systems [24]:

$$\frac{Y}{Y_1} = \left\{ \frac{1 + AB\phi_2}{1 - B\phi_2} \right\} \quad (1)$$

where the subscripts 1 and 2 refer to the continuous matrix phase and discontinuous filler phase, respectively, Y is the modulus of elasticity, and ϕ is the packing fraction of the fillers in the composite. The constants A and B are defined as

$$A = k_E - 1 \quad (2)$$

$$B = \frac{(Y_2/Y_1) - 1}{(Y_2/Y_1) + A} \quad (3)$$

k_E in Eq. (2) is called Einstein's coefficient. The function Ψ is related to the maximum packing fraction ϕ_m :

$$\Psi \approx 1 + \left\{ \frac{1 - \phi_m}{\phi_m^2} \right\} \phi_2 \quad (4)$$

The elastic moduli of a large number of composite systems have been calculated from the table values of Einstein's coefficient [22, 23]. In most cases, good agreement was observed between the experimental and theoretical predictions [24].

In another theoretical approach suggested by Guth [25], Young's modulus, Y , of a composite has been related to Young's modulus of the liquid resin, Y_0 :

$$Y = Y_0(1 + 2.5\phi_v + 14.1\phi_v^2) \quad (5)$$

where ϕ_v is the fractional volume occupied by the spherical fillers and is further related to the tensile strength σ of the composite:

$$\sigma = \sigma_0(1 - \phi_v^{2/3}) \quad (6)$$

where σ_0 represents the tensile strength of the resin present in the mix. It should be realized that Guth's relation (i.e., Eq. 5) holds good only for spherical particles. In an attempt to apply Eq. (5) to nonspherical particles, Cohan [27] introduced a shape factor, f , which is equal to the ratio of the length to the diameter of nonspherical particles. The modified Guth's relation would be

$$Y = Y_0(1 + 0.67f\phi_v + 1.62f^2\phi_v^2) \quad (7)$$

One of the essential features of Eq. (7) is that it can be applied to both rodlike and plate-like fillers such as mica and vermiculite [28].

EXPERIMENTAL PROGRAM

The mix proportioning procedures and sample preparations remained exactly the same as outlined in our earlier papers [11-13]. Phenol formaldehyde (Fig. 1) and diglycidyl ether of bisphenol A (Fig. 2) were the resins employed in this work. The liquid hardner triethylene tetramine (TETA) was used.

These resins are macroporous and have good dimensional stability. The mixture composition data for all the mixes are presented in Table 1. Samples of a 2.54 cm cube were prepared by adding varying amounts of asbestos to the waste materials. The sand and resinous mass was kept constant in all the mixes. For each composite, three sets of ex-

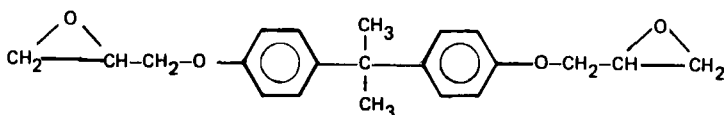


FIGURE 1.

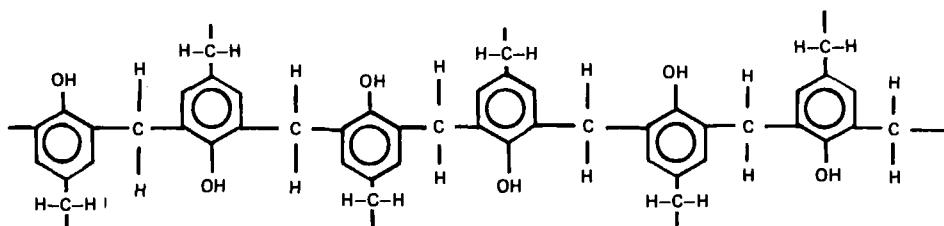


FIGURE 2.

TABLE 1. Mixture Composition Data

Series	Composition (% by weight)				
	Sand	Asbestos	Waste material	Aluminum silicate	Epoxy + hardner mixture
X-I	10	10	40	7	33
X-II	10	20	30	7	33
X-III	10	30	20	7	33

periments were performed. All the specimens were cured in air for 28 days, and the mechanical tests were performed as per standard specifications [11, 29].

RESULTS AND DISCUSSION

Physicomechanical properties of polymerized composites derived from industrial wastes are presented in Table 2. With an increase in the amount of asbestos, a decrease in unit weight was observed. However, other mechanical properties such as compressive strength, tensile strength, and modulus of elasticity were found to be in increasing order. The thermal property, namely, thermal conductivity, did not show any systematic trend. Since silica in these mixes was kept constant, we could not derive any trend in mechanical properties with silica. A similar behavior in properties was observed for composites derived from agrowastes and naturally occurring waste materials. These data are presented in Tables 3 and 4, respectively.

It should be noted that, in general, the composites derived from agricultural wastes are much lighter and their mechanical properties better than the industrial and naturally occurring waste materials. Thus, even the presence of a small amount of asbestos in the aggregate did not drastically affect the properties of the end products.

The reasons for the improvement in strength are not fully understood and are still the subject of considerable research. The polymer is distributed throughout the pores of the mix, acting as a filler to the microcracks, which tend to eliminate fracture propagating behavior, resulting in a decrease in stress. The improvement in strength can also be attributed to interfacial bonding [31]. The nature of the interface between the matrix and filler phases seems to play an important role in changing the behavior of a composite. One assumption in the discussion up to this point is that there is good adhesion between the phases, so there is no motion at the interface. Another implicit

TABLE 2. Physicomechanical Properties of Polymer Composites Derived from Industrial Wastes

No.	Composition	Unit weight (kg_f/m^3)	Compressive strength (kg_f/cm^2)	Tensile strength (kg_f/cm^2)	Young's modulus (kg_f/cm^2)	Heat conductivity ($\text{kcal} \cdot \text{cm}/\text{m}^2 \cdot \text{h} \cdot ^\circ\text{C}$)
1	X-I (SD)	1484	225.7	136.4	426	0.44
2	X-II (SD)	1451	223.6	95.6	142	0.46
3	X-III (SD)	1421	88.9	55.1	142	0.43
1	X-I (FA)	1730	282.3	175.1	492	0.59
2	X-II (FA)	1636	191.6	111.1	426	0.52
3	X-III (FA)	1599	14.1	8.7	426	0.54
1	X-I (CI)	1849	170.8	105.6	639	0.69
2	X-II (CI)	1724	169.1	101.0	562	0.59
3	X-III (CI)	1677	53.2	33.0	492	0.56
1	X-I (CO)	1677	237.1	147.3	562	0.56
2	X-II (CO)	1516	193.7	117.8	284	0.44
3	X-III (CO)	1461	10.9	6.7	284	0.47

TABLE 3. Physicomechanical Properties of Polymer Composites Derived from Agricultural Wastes

No.	Composition	Unit weight (kg_f/m^3)	Compressive strength (kg_f/cm^2)	Tensile strength (kg_f/cm^2)	Young's modulus (kg_f/cm^2)	Heat conductivity ($\text{kcal} \cdot \text{cm}/\text{m}^2 \cdot \text{h} \cdot ^\circ\text{C}$)
1	X-I (RH)	1636	172.9	107.2	284	0.48
2	X-II (RH)	1564	67.1	41.5	142	0.54
3	X-III (RH)	1528	64.1	39.6	142	0.51
1	X-I (PH)	1581	216.5	132.9	639	0.48
2	X-II (PH)	1505	161.1	100.4	211	0.38
3	X-III (PH)	1480	106.5	66.1	142	0.46
1	X-I (MC)	1325	300.9	186.6	710	0.39
2	X-II (MC)	1301	236.2	146.2	281	0.51
3	X-III (MC)	1290	85.8	53.4	142	0.38
1	X-I (JP)	1599	327.8	205.4	710	0.52
2	X-II (JP)	1575	140.6	87.2	422	0.47
3	X-III (JP)	1544	73.1	43.9	284	0.49
1	X-I (CS)	1610	357.8	175.8	710	0.52
2	X-II (CS)	1528	283.3	49.2	284	0.59
3	X-III (CS)	1520	79.1	22.8	211	0.48
1	X-I (PS)	1674	142.0	88.0	355	0.44
2	X-II (PS)	1514	92.4	59.4	284	0.47
3	X-III (PS)	1454	14.1	8.4	211	0.56

TABLE 4. Physicomechanical Properties of Polymer Composites Derived from Naturally Occurring Materials

No.	Composition	Unit weight (kg_f/m^3)	Compressive strength (kg_f/cm^2)	Tensile strength (kg_f/cm^2)	Young's modulus (kg_f/cm^2)	Heat conductivity ($\text{kcal} \cdot \text{cm}/\text{m}^2 \cdot \text{h} \cdot ^\circ\text{C}$)
1	X-I (FE)	1730	167.3	103.7	568	0.56
2	X-II (FE)	1689	138.5	85.8	422	0.59
3	X-III (FE)	1676	14.1	8.7	352	0.56
1	X-I (GR) ^a	1882	201.8	125.2	2010	0.48
2	X-II (GR) ^a	1589	173.2	107.4	1729	0.52
3	X-III (GR) ^a	1517	151.9	94.2	1455	0.70
1	X-I (AS) ^a	1634	674.9	118.5	6469	0.54
1	X-I (VM) ^a	1699	301.6	187.0	1561	0.58
1	X-I (MT) ^a	1512	146.2	89.4	970.3	0.47

^aDiglycidyl ether of bisphenol A was used as a binding resin.

TABLE 5. Properties of Some Lightweight Concretes and Other Building Materials

Material	Unit weight (kg/m ³)	Compressive strength (kg/cm ²)
Dense or gravel concrete	2400	-
No fines gravel concrete	1600-1860	49-88
No fines crushed granite concrete	1710	77
No fines crushed limestone concrete	1850	70
No fines clinker concrete	1300-1460	-
Clinker concrete	1050-1700	21-70
Foamed blast furnace slag concrete	970-1780	126-230
"Aglite" (expanded shale) concrete	1620-1750	210-350
"Leca" (lightweight expanded clay) concrete	810	-
Fly ash concrete (semi-dry mixes)	1150-1230	45-70
Fly ash concrete (fully compacted mixes)	1490-1570	105-195
"Lytag" (cellular aggregate) concrete	1050	42
Perlite concrete	320-810	8
Distomite concrete	700-1000	22-114
Sawdust concrete	640-1600	17-350

assumption is that the particles are dispersed so that there are no particle-particle interactions. By changing the nature of the interfaces, one or both of these assumptions can be made invalid. An example is to measure the mechanical damping [30]. Since mica proved to increase the damping, in this investigation we have employed mica. A further increase in damping was observed when the mica surface was treated with dichlorodimethyl silane which supposedly destroyed the polymer-mica adhesion, thus encouraging agglomeration of mica particles and thereby increasing particle-particle interactions. We assume that the increased damping comes from slippage at the interface and from particle-particle contacts.

In all cases the strength properties of our composites are much better than some of the lightweight building concrete materials [32] (see Table 5). The percent of water absorption was, however, found to be somewhat higher (data not presented in our tables) compared to

our earlier materials [11-13]. This high percent of water absorption might have been due to the presence of hydroxy groups in phenol-formaldehyde resin, thus attracting more water molecules.

CONCLUDING REMARKS

From the foregoing discussion it can be concluded that the use of health hazardous asbestos can be minimized to produce high strength and low weight concrete materials that can be of immense use not only in building technology but also in several other related applications. The fibrous materials used in the present investigation have been derived from industrial, naturally occurring, and agrowastes. The properties of these end products have been proved to be quite comparable to and in some cases somewhat better than normal cement concrete. It is also seen that even phenol-formaldehyde binds very well with the fibrous materials employed here. It has been proved that several other fibrous materials can be used successfully to replace the heavy usage of asbestos in building technology.

REFERENCES

- [1] B. H. Spratt, An Introduction to Lightweight Concrete, Cement and Concrete Association, London, 1975.
- [2] G. Rudnai, Lightweight Concrete, Hungarian Academy of Sciences, Budapest, 1963.
- [3] American Concrete Institute Committee, "Guide for Cellular Lightweight Concrete," Am. Concr. Inst. J., 72, 50 (1975).
- [4] T. M. Aminabhavi, P. E. Cassidy, and L. E. Kukacka, J. Macromol. Sci.-Rev. Macromol. Chem., C22, 1 (1982-83).
- [5] Polymers in Concrete (Report by ACI Committee 548), American Concrete Institute, 1977.
- [6] D. R. Bloss, S. J. Hubbard, and B. H. Gray, Development and Evaluation of a High Strength Polyester Synthetic Concrete, U.S. Army, Construction Engineering Research Laboratory, Champaign, Illinois, Technical Report M-2, 1970.
- [7] "Interfaces in Polymer Matrix Composites," in Composite Materials, vol. 6 (E. P. Plueddeman, ed.), Academic, New York, 1974.
- [8] C. A. Villamizer, A. M. Escalona, and E. Duran, J. Appl. Polym. Sci., 27, 2151 (1982).
- [9] Silane Adhesion Promoters in Mineral-Filled Composites, Union Carbide Technical Bulletin F-43598.
- [10] S. G. Monte and G. Sugerma, "A New Generation of Age- and Water-Resistant Reinforced Plastics," Polym. Plast. Technol. Eng., 13(2), 115 (1979).
- [11] T. M. Aminabhavi, R. C. Patel, and N. S. Biradar, Mater. Sci. Eng., 48, 199 (1981).

- [12] T. M. Aminabhavi, R. C. Patel, and N. S. Biradar, Polym. Eng. Sci., **21**, 1085 (1981).
- [13] T. M. Aminabhavi, R. C. Patel, and N. S. Biradar, Polym. Compos., **2**, 171 (1981).
- [14] N. S. Biradar, T. M. Aminabhavi, and R. M. Holennavar, Mater. Sci. Eng. Lett., Submitted for Publication.
- [15] P. E. Cassidy and T. M. Aminabhavi, J. Macromol. Sci.-Rev. Macromol. Chem., **C21(1)**, 89 (1981).
- [16] D. J. Williams, Polymer Science and Engineering, Prentice-Hall, Englewood Cliffs, New Jersey, 1971.
- [17] S. W. Tsai, U.S. Department of Commerce, Rep., AD 834851 (1968).
- [18] T. B. Lewis and L. E. Nielsen, Trans. Soc. Rheol., **12**, 421 (1968).
- [19] T. B. Lewis and L. E. Nielsen, J. Appl. Polym. Sci., **14**, 1449 (1970).
- [20] L. E. Nielsen, J. Appl. Phys., **41**, 4626 (1970).
- [21] L. E. Nielsen, Appl. Polym. Symp., **12**, 249 (1969).
- [22] J. E. Ashton, J. C. Halpin, and R. H. Petit, Primer on Composite Analysis, Technomic, Stamford, Connecticut, 1969.
- [23] J. M. Burgers, Second Report on Viscosity and Plasticity, Nordemann, New York, 1938, p. 113.
- [24] L. E. Nielsen, Chemtech, p. 486 (August 1974).
- [25] E. Guth, J. Appl. Phys., **16**, 20 (1945).
- [26] L. E. Nielsen, J. Appl. Polym. Sci., **10**, 97 (1966).
- [27] L. H. Cohan, India Rubber World, **117**, 343 (1947).
- [28] R. Seymour, Chemtech, p. 422 (July 1974).
- [29] Indian Standard Code of Practice for Plain and Reinforced Concrete, I.S. 456-1964, 1978 (Revised), Indian Standards Institution, New Delhi.
- [30] L. E. Nielsen, Mechanical Properties of Polymers, Van Nostrand Reinhold, New York, 1962.
- [31] R. N. Swamy, J. Mater. Sci., **14**, 1521 (1979).
- [32] R. M. Holennavar, PhD Thesis, Karnatak University, June 1980.

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