Studies of Physico–Mechanical Properties of Wood and Wood Plastic Composite (WPC)

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SYNOPSIS

An attempt has been made to improve the quality of low grade wood through radiation induced wood plastic composite (WPC) formation in order to use these low grade woods as substitutes for high grade wood. Six kinds of local woods of Bangladesh (simul, korai, mango, jack fruit, teak, and garjon) were investigated. Both soft and hard wood varieties of these were selected. Ten vinyl monomers were used for the WPC. Improvement in the quality of wood was ascertained by determining change in physico–mechanical properties of wood. These properties were tensile strength, Young's modulus, and dimensional stability. Among all the woods investigated, simuls exhibited the best performance for WPC formation. It was found that the tensile strength and Young's modulus of WPC increased about 1.6 and 1.5 times, respectively, as compared with the strength and modulus those of untreated wood.

INTRODUCTION

Wood plastic composite (WPC) is composed of radiation or thermally induced polymerization of certain chemicals, usually called a monomer, with wood fibers. A monomer is normally injected into a void space in the wood by pressure technique, and then it is polymerized in the space by the application of radiation or heat. Monomer impregnation depends on the nature of monomer and the binding capacity of wood fibers with the monomer units. The latter is also dependent upon the structure of the wood and the distribution pattern of its porosity. In addition to cellulose, wood contains lignin and other compounds that may hinder the polymerization and grafting process to some extent, because these compounds may act like free radical scavengers. Therefore, wood, which contains more cellulose and less of other constituents, is better for grafting. Among all the constituents of wood, cellulose is most sensitive to radiation. Radiation creates sites on cellulose bone as free radicals, which initiate the grafting process. Wood plastic composite work has been carried out in many parts of the world for many years; it was industrialized in USA two decades ago.[1–3] Though impregnation of wood is normally carried out using vinyl type monomers, application of the acrylates with polyfunctional groups, isocyanate, allyl phthalet, reactive oligomers, etc., is also being performed.[4–8] An attempt, therefore, has been made to carry out the WPC work in Bangladesh using local woods in order to improve the quality of the woods.

EXPERIMENTAL

Wood

Six varieties of wood having different physical and mechanical properties (Table I) were used. Samples (4 in. × 0.5 in. × 0.25 in.) were made by cutting from a long flat grained plank, uniformly polished with sandpaper, and in vacuum 50 mm of Hg at 70°C for over 24 h to remove free water.

Monomers

All the ten vinyl type monomers were procured from E. Merck (West Germany). These are Styrene

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Journal of Applied Polymer Science, Vol. 45, 167–172 (1992)
 CCC 0021-8995/92/010167-06$04.00

Table I Physical and Mechanical Properties of Wood

Local Name	Abbreviation	Botanical Name	d gm/cm^3	YM Ksi	TS Ksi	V_{fs} cm
Simul	S	*Salmalia mamabarica*	0.40	146	2.43	0.74
Korai	K	*Samanea samane*	0.44	155	2.84	0.71
Mango	M	*Mangifera indica*	0.51	170	3.43	0.67
Jack Fruit	JF	*Arotocarpus integrifolia*	0.54	183	3.67	0.65
Teak	T	*Tectona grandis*	0.60	192	4.27	0.61
Garjon	G	*Dipterocarpus pilosus*	0.74	223	5.75	0.52

(ST), Butylmethacrylate (BMA), Methylacrylate (MA), Vinyl acetate (VA), Butylacrylate (BA), Diphenyl phthalate (DP), Methylmethacrylate (MMA), Acrylonitrile (AN), Methacrylonitrile (MAN), and Acrylic acid (Ac.A). Monomers were used as received, without removing added stabilizers. It was not necessary to remove the stabilizers beforehand, since the total dose used for experimental purposes was much higher than 1 Mrad, below which the additives may have inhibited the results.

Impregnation

Monomers were injected into the void space (free pore volume) of oven dried wood samples under pressure (50 mm Hg). The swelling agent methanol was used with monomer at a ratio of 1 : 9 v/v. Free pore volume of a wood sample can be calculated using the following formula.[1]

$$V_f = V(1 - d/d_w)$$

Where, V_f = Free pore volume in cm^3, V = Total volume of specimen in cm^3, d = Density of specimen in g/cm^3, and d_w = Density of solid material of wood (1.54 g/cm^3).

Densities of the six different wood species vary from 0.4 to 0.74 g/cm^3 (Table I). Specific free pore volumes (V_f/V), calculated on the basis of the above relation for all the six wood species, were observed to decrease with the increase of their densities (Fig. 1). This is a reciprocal relationship. Void spaces in a wood sample can be easily estimated from the above plot, if the density of the sample is known.

Irradiation

Samples encapsulated with polyethene were irradiated at room temperature by a Co-60 source (5 kCi) at a dose rate of 800 krad/h for the total dose ranging from 1 Mrad to 4 Mrad. Unreacted monomer, sensed by its characteristic odor, was completely removed from the irradiated samples by heating them at 60°C under vacuum (50 mm Hg).

Property Measurement

The six wood samples were used for studying various physical properties, such as Polymer loading (PL), tensile strength (TS), Young's modulus (YM), and dimensional stability (antishrinking efficiency). Methods for measuring polymer loading and dimensional stability were the same as reported earlier.[9] The Young's modulus and tensile strength were directly measured by the tensile strength machine of INSTRON, (model 1011, U.K.), integrated with a personal computer (Amstrad PC 1640 HD20, U.K.). The Young's modulus of untreated wood samples seems to increase as the density of the wood species increases (Fig. 2). This relation is in conformity with the expected phenomenon, which is that the Young's modulus should be enhanced as the wood material becomes stronger.

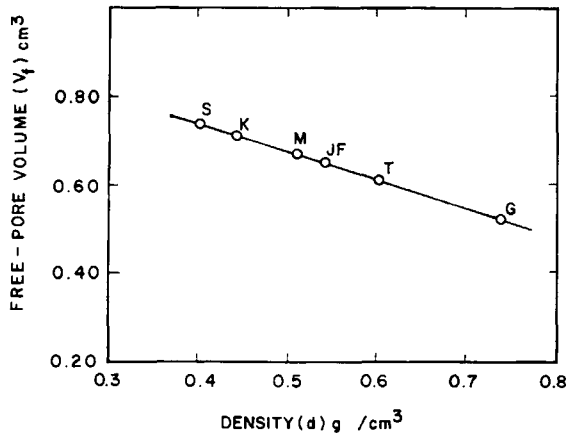

Figure 1 Density and free-pore volume relation of wood species.

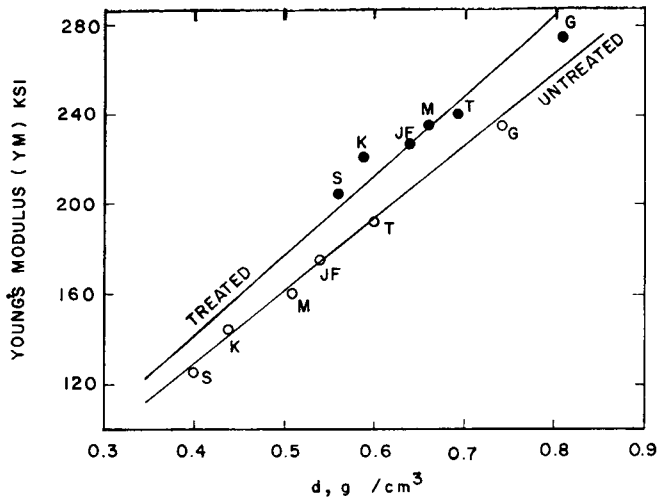

Figure 2 Young's modulus vs. densities of treated and untreated wood (styrene).

RESULTS AND DISCUSSION

Of the six species of wood selected for WPC, two were soft woods (density < 0.5 gm/cm^3) and three were hard woods (density > 0.5 gm/cm^3). As the wood species becomes harder, its free pore volume, that is, its void space, becomes smaller; in fact, this volume decreases linearly with increase of hardness (density) (Fig. 1). Polymer loading (PL) into the void spaces has been also observed to increase exponentially with softness (density) of wood species (Fig. 3). The PL of each of the ten monomers was determined as reported earlier,[9] and is given in Table II. The highest PL is observed with the soft wood, simul, with a 3 Mrad dose, followed by korai, mango, etc. Total dose used for WPC was up to 4 Mrad. Most of the wood species showed the maximum PL at about 3 Mrad. Though acrylic acid showed the maximum PL among the ten monomers, there was no binding of the polymer with the wood fibers because it was found that after soaking them in water, the polymer fraction came out from the wood fibers. Whether the quality of wood has been improved by WPC treatment can be ascertained by determining the extent of the improvements of tensile strength (TS) and Young's modulus (YM) and the reduction of water absorption ability (WA). TS, YM, and WA are three vital properties for qualitative identification of wood.

Young's modulus linearly increases with compactness (hardness) of wood material (Fig. 2). A similar trend is observed with the WPC samples. A typical plot for styrene is given in Figure 2. Density of a wood sample increases upon WPC treatment

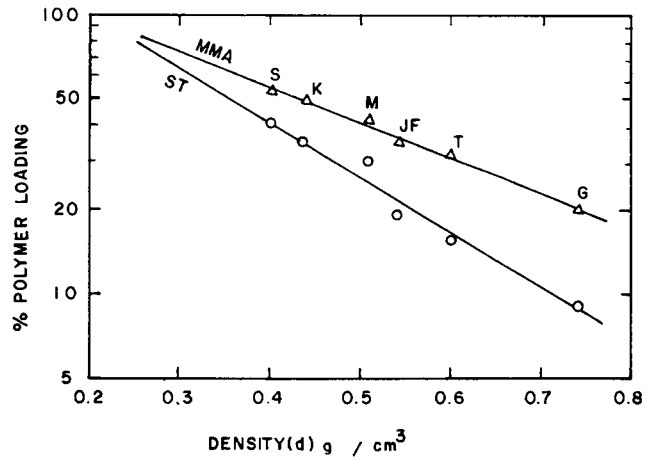

Figure 3 Relationship of polymer loading with compactness (density) of wood.

Table II Percentage of the Highest Polymer Loading of Woods Shown against the Total Dose

Monomer	Simul	Korai	Mango	J. Fruit	Teak	Garjon
ST	41 (3)	35 (4)	30 (4)	18 (4)	15 (4)	9 (4)
BMA	75 (4)	56 (2)	53 (2)	19 (3)	60 (4)	52 (3)
MA	85 (3)	55 (3)	51 (3)	43 (2)	47 (4)	33 (4)
VA	65 (4)	39 (3)	58 (4)	28 (4)	60 (4)	13 (4)
BA	114 (4)	72 (3)	27 (3)	40 (2)	44 (4)	35 (3)
DP	66 (3)	65 (2)	54 (2)	41 (2)	20 (2)	29 (2)
MMA	53 (3)	48 (3)	49 (3)	35 (3)	32 (4)	20 (3)
AN	26 (3)	18 (2)	32 (2)	21 (3)	12 (3)	11 (3)
MAN	18 (3)	15 (4)	18 (4)	16 (3)	17 (4)	10 (3)
Ac. A.	160 (2)	94 (3)	103 (3)	89 (3)	67 (4)	40 (3)

Total dose at which the highest polymer loading is obtained is given within the parenthesis.

and so also the Young's modulus increases after the treatment; however, the extent of the increment of Young's modulus (ΔYM) per unit increase of density (Δd) can be determined by plotting ΔYM vs. Δd. A typical plot is shown in Figure 4 for MMA and styrene. Though garjon is the hardest wood among the six varieties, its relative modulus change is near the lowest, whereas mango has exhibited the maximum change in modulus of elasticity as well as in density for the MMA system; these changes are followed by simul, korai, etc. However, for the styrene system, simul has produced the highest ΔYM, followed by mango, korai, etc. This observation indicates that though the MMA system has produced more poly-

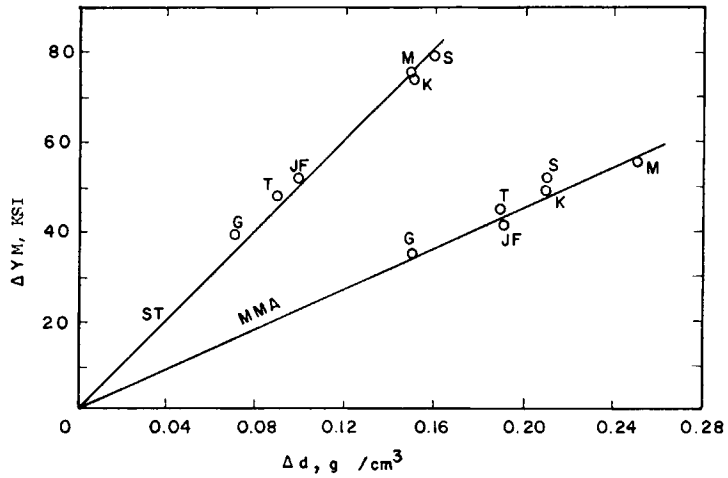

Figure 4 Modulus of elasticity change (ΔYM) against change of density (Δd).

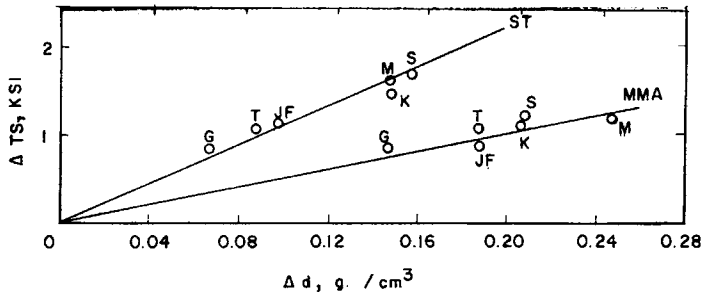

Figure 5 Change of tensile strength (ΔTS) against density change (Δd).

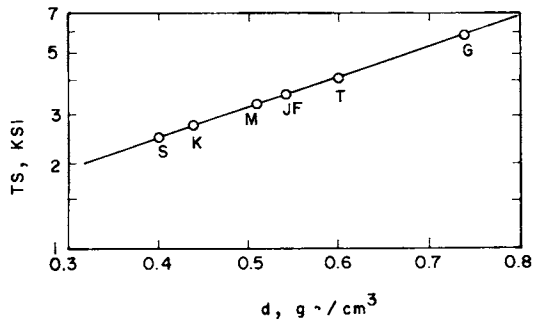

Figure 6 Relation of tensile strength change with densities of wood.

mer loading, that is, more Δd than the corresponding styrene system, the overall change in Young's modulus is higher with the latter system (ST).

An identical observation is made with ΔTS against Δd (Fig. 5). It should be noted that the change of modulus is linear with respect to the compactness of wood species (Fig. 2) and the change of tensile strength is exponential by virtue of the wood species' respective definitions; the relationship of tensile strength with change of density is shown in Figure 6.

The extent of polymer loading is not commensurate with the increase of TS after WPC treatment with monomers. Sometimes a particular monomer may induce the highest PL, but not necessarily the highest TS. For example, simul has shown 114% PL and a 27% TS increase with BA, but the same wood, having 41% PL with styrene, has exhibited 41% TS increase (Fig. 7); values of TS and PL for the other eight monomers remain somewhere between the values obtained for the BA and ST systems. The results of the other five wood species are shown in Figure 7. For every wood, the lowest and highest TS values, corresponding to its respective PL values, are shown for the monomer indicated in the plot; values for the remaining monomers for a particular wood species are also observed somewhere between these extreme values. As mentioned earlier, the highest PL does not necessarily indicate the highest TS and YM values; polymer loading may be, in some cases, a simple homopolymer without any linkage between wood fibers and monomer unit. Thus, when grafting (polymerization of a monomer with wood fibers) alone is taken into consideration, other properties like TS and YM are expected to be commensurate with the (grafting). WPC treatment is expected to reduce the water absorption ability of wood; thus it will reduce the shrinking and bending tendency of wood. Wood samples, both treated and untreated, were soaked in distilled water for a long period of time until they showed maximum water absorption. Antishrinking efficiency (ASE) is a property used to measure the water absorption ability of wood and can be calculated as,

$$\text{ASE} = 100(W_c - W_t)/W_c$$

where, W_c = Maximum weight of untreated sample and W_t = Maximum weight of treated sample.

The ASE values have been plotted against % PL in Figure 8. Teak has shown the maximum ASE per unit change of PL; however, mango is next, followed

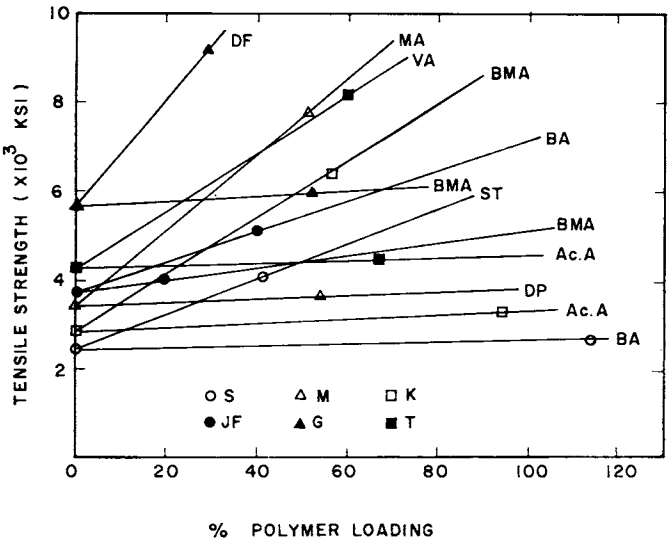

Figure 7 Tensile strengths of different wood species before and after polymer loading with various monomers.

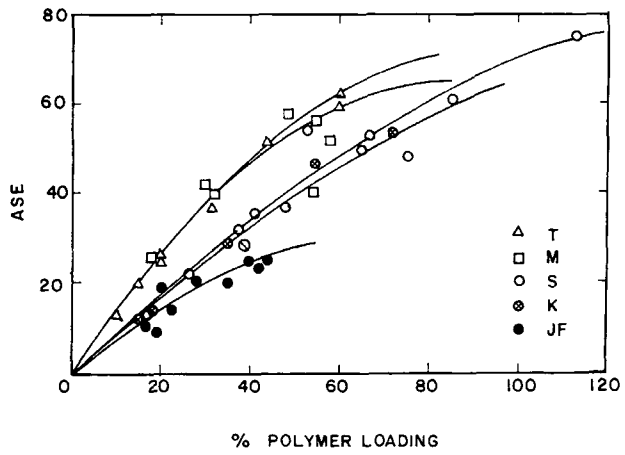

Figure 8 Antishrinking efficiency shown against the highest polymer loading of wood material with each monomer.

by simul, korai, and jack fruit. The trend of ASE is similar to the trend of change with TS and YM (Fig. 4), except for teak in the case of ASE. This exception can be attributed to the inherent character of teak, in that it has a high dimensional stability as compared to other woods. It has been found that acrylic acid did not form a copolymer with the woods under the present experimental conditions; possibly it formed only a homopolymer, which separated out from the wood bulk upon soaking in water. Thus, it was not possible to determine the reproducible ASE values of the acrylic acid system.

From the above studies, it is evident that the soft wood has exhibited better improvement upon WPC. Among the six woods, simul has shown the highest TS and YM when compared to other varieties.

We are indebted to the International Atomic Energy Agency (IAEA) for its partial financial support under research contract no. 4223/RB and technical assistance program, BGD/8/008. The authors express their thanks to the members of the Nuclear Chemistry Division and to the staff of the Institute of Food and Radiation Biology (IFRB) in charge of the Co-60 gamma source.

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Received March 25, 1991
Accepted July 24, 1991