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Preparation and Properties of Some Wood-Plastic Combinations Involving Some Tropical Commercial Woods

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ABSTRACT

Radiation-induced wood-polymer composites have been prepared using some tropical commercial woods. These included Kapur (*Dryobalanop sp.*), Kempas (*Koompassia sp.*), Red Seraya (Shorea sp.), White Seraya (Parashorea sp.), and Jelutong (Dyera sp.). The wood specimens were modified by impregnation with monomers and followed by exposure to gamma radiation. Monomer systems used were methyl methacrylate, methyl methacrylate with 5% dioxane, acrylonitrile, 60:40 styrene-acrylonitrile comonomer, vinyl acetate, and vinylidene chloride. The resulting composite specimens exhibited significant increases in hardness and compressive strength, the extent of which appeared to depend on the amount and type of polymer present. Dimensional stability increased when the woods were impregnated with polymethyl methacrylate and improved further to about 35% on addition of a swelling agent, dioxane. Wood-polyvinylidene chloride composites gave high fire resistance as opposed to wood-polymethyl methacrylate which showed increased flammability. A 4-fold decrease in weight loss was observed in the fire-tube and crib tests conducted. The impregnated polymers were not totally resistant to termites. The polymers, not being nutrients, reduced the number of survivals after a 90-d test period. Polystyrene-acrylonitrile appeared toxic to the termites.

INTRODUCTION

The development of new polymer materials not only provides direct competition to natural materials but they can also be used to improve the properties of natural macromolecules. Wood, one of the many natural macromolecules, has many excellent properties but it cannot be regarded as ideal for all purposes. With the availability of competitive materials, deficiencies inherent in wood are being progressively recognized. Research could thus lead to minimizing or connecting these unfavorable properties.

Impregnation of wood with a suitable monomer, followed by polymerization, could give a product composite of the wood and polymer. The heterogeneous composition and structure of wood together with the many parameters involved in the formation and characters of polymers could give rise to an intricate piece of composite. This paper deals with the study of the properties of these combinations in relation to the original wood.

EXPERIMENT

Five woods, based on their availability and commercial popularity, were selected for this study. They are listed in Table 1.

The monomer systems used for impregnation of samples of each of the five woods are listed in Table 2.

The impregnation was carried out in a glass vessel into which samples of 2.5 × 2.5 × 5.0 cm were placed. The vessel was then evacuated to a pressure of less than 5 mmHg and held at this pressure for a minimum of 15 min depending on the number of samples present. The appropriate monomer was then introduced, and nitrogen gas was admitted till atmospheric pressure was obtained. The vessel was kept at room temperature for about 24 h to obtain complete

TABLE 1

Wood	Density (kg/m^3)
Kapur (Dryobalanop sp.)	753
Kempas (Koompassia sp.)	881
Red Seraya (Shorea sp.)	545
White Seraya (Parashorea sp.)	673
Jelutong (Dyera sp.)	464

TABLE 2

100% methyl methacrylate (MMA)
100% acrylonitrile (AN)
95% MMA-5% dioxane (MD)
60% styrene-40% AN (STAN)
100% vinyl acetate (VA)
100% vinylidene chloride (VDC)

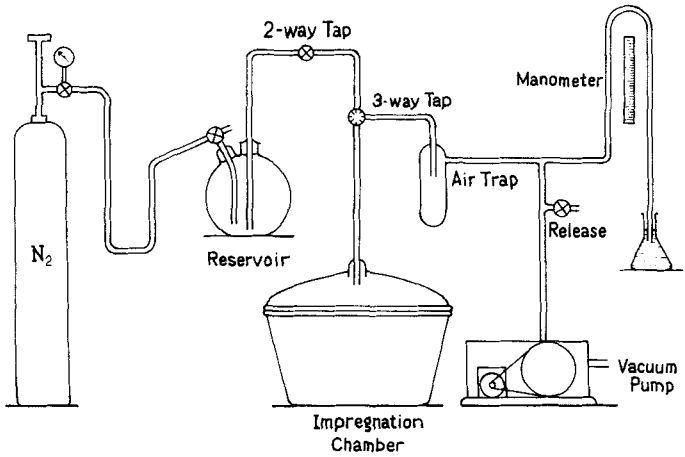

FIG. 1. The impregnation system.

impregnation. A schematic drawing of the impregnation apparatus is shown in Fig. 1.

The impregnated specimens were subsequently removed from the vessel and individually wrapped in aluminum foil and sealed. They were then placed in an aluminum container and irradiated from a ^{60}Co source of 5800 Ci activity where the average radiation was 0.3 Mrad/h. The optimum dosage for each monomer system with the complementary wood type was first determined and subsequently the production of composites for testing purposes was done with the optimum dosage obtained. After irradiation, the composites were recovered through extensive drying to remove the excess monomers. The amount of polymer in the composite, determined by the percent polymer loading in terms of weight, was made for each sample as follows:

$$\text{Polymer loading} = \frac{\text{WPC} - \text{W}}{\text{W}} \times 100\%$$

where WPC = weight of wood-polymer composite and W = weight of oven-dried specimen.

The resulting composite specimens and the unmodified wood specimens were tested for their physical, fire, and termite-resistant properties. These tests were conducted at the facilities of the Chemistry and the Building Science Departments of the University of Singapore and the Forest Research Institute at Kepong in Malaysia.

RESULTS

Mechanical Properties

The results of the hardness and compressive strength parallel to the grain tests performed on the composite materials and their corresponding control samples are listed in Tables 3 and 4. The measured values shown in these tables are the mean values. The hardness and the compressive strength results both indicated consistent improvement over the control samples.

The hardness test was performed with a Monsanto-Houndsfield tensometer with a test ball size of 5 mm in diameter while the compressive strength parallel to the grain was measured using a Shimadzu 50,000 kg universal testing machine.

The presence of polymethyl methacrylate and polystyrene-acrylonitrile in the wood increased the hardness by an average factor of 2. One of the monomers, vinyl acetate, showed rather irregular behavior with regards to improvement of hardness of composites, and one cannot predict whether it really contributes to hardness.

The maximum crushing strength values are fairly high for some of the composites, and the main cause may be attributed to the high polymer loadings of the composites. The untreated wood probably fails in compression owing to the distortion and buckling of the relatively thin cell walls which possesses a long-column type of instability. It is difficult to determine whether the increase in strength is derived from the fraction of polymer introduced into the wood since the cell wall material by itself is of a much greater strength than the polymer. Thus the increase in strength may likely be the result of the presence of a coating of the polymer on the walls. This coating could have thickened the cell walls and greatly improved their lateral stability.

TABLE 3. Hardness of Natural Woods and Wood-Plastic Combinations

Wood	Impregnation	Average polymer loading (%)	Hardness			
			Side		End	
			kN	Ratio to untreated wood	kN	Ratio to untreated wood
Kapur	Oven-dried	-	1.15	-	1.70	-
	PMMA	40	2.90	2.5	3.30	1.9
	PMD	41	2.37	2.1	2.44	1.4
	PSTAN	41	2.40	2.1	3.41	2.0
	PAR	37	2.14	1.9	2.01	1.2
	PVA	41	1.79	1.6	1.56	0.9
Kempas	Oven-dried	-	1.89	-	2.31	1
	PMMA	37	4.50	2.4	4.43	1.9
	PMD	37	3.70	2.0	3.94	1.7
	PSTAN	40	4.27	2.3	4.32	1.9
	PAR	36	3.63	1.9	3.75	1.6
	PVA	36	3.25	1.7	3.34	1.5
Red Seraya	Oven-dried	-	1.05	-	1.53	-
	PMMA	64	3.08	2.9	3.32	2.2
	PMD	64	3.20	3.0	3.50	2.3
	PSTAN	67	3.35	3.2	3.62	2.4
	PAR	49	2.67	2.5	2.86	1.9
	PVA	67	2.40	2.3	2.65	1.7
White Seraya	Oven-dried	-	0.68	-	1.08	-
	PMMA	54	1.51	2.2	2.24	2.1
	PMD	50	1.26	1.9	1.77	1.6
	PSTAN	55	1.34	2.0	1.95	1.8
	PAR	25	1.08	1.6	1.39	1.3
	PVA	28	0.76	1.1	0.98	0.9

TABLE 4. Results of Compression Tests on Natural Woods and Wood-Plastic Combinations

Wood	Impregnation	Average polymer loading (%)	Maximum crushing strength (kg/cm^2)	Ratio to untreated wood	Modulus of elasticity ($\times 10^5$) (kg/cm^2)	Ratio to untreated wood
Kapur	Oven-dried	-	809	-	1.902	-
	PMMA	44	980	1.2	2.355	1.24
	PAR	42	946	1.2	2.041	1.07
	PSTAN	29	1001	1.2	2.147	1.13
	PVA	39	763	0.9	1.582	0.83
Kempas	Oven-dried	-	846	-	1.419	-
	PMMA	38	1298	1.5	1.968	1.38
	PAR	69	1140	1.3	1.784	1.26

	PSTAN	40	1258	1.5	1.894	1.33
	PVA	37	956	1.1	1.163	0.82
Red Seraya	Oven-dried	-	687	-	1.718	-
	PMMA	67	1199	1.8	2.308	1.34
	PAR	40	1031	1.5	1.906	1.11
	PSTAN	72	1288	1.9	2.557	1.49
	PVA	65	704	1.0	1.336	0.78
White Seraya	Oven-dried	-	533	-	1.143	-
	PMMA	66	772	1.5	1.797	1.57
	PAR	31	563	1.1	1.425	1.26
	PSTAN	44	661	1.2	1.696	1.48
	PVA	33	508	1.0	1.213	1.06

TABLE 5. Summary of Dimensional Stability and Water Absorption Data

Material	Average polymer loading (%)	Maximum volumetric swell			Maximum weight increase		
		Average value (%)	Coefficient of variation (%)	Average ASE (%)	Average value (%)	Coefficient of variation (%)	Average AAE (%)
Kapur							
KA-OD[a]		18.8	12.8		61.6	12.7	
KA-PMMA	55	13.6	4.2	29.8	23.8	25.3	69.5
KA-PMD	35	13.2	5.7	30.2	27.4	9.7	55.5
Kempas							
KM-OD		19.7	4.4		52.9	4.3	
KM-PMMA	39	16.2	6.8	17.7	18.6	2.3	64.9
KM-PMD	42	11.6	8.5	41.0	17.9	9.2	66.2
Red Seraya							
RS-OD		16.7	12.3		71.5	18.3	
RS-PMMA	69	13.5	4.1	19.2	20.7	2.6	71.1
RS-PMD	64	10.8	6.5	35.5	15.0	3.9	79.0
White Seraya							
WS-OD		12.5	5.5		74.7	4.7	
WS-PMMA	47	10.4	4.9	17.2	36.9	14.7	50.7
WS-PMD	47	8.3	3.8	34.2	35.5	21.1	52.5

[a]OD = oven-dried untreated.

Dimensional Stability

Improvement in dimensional stability is the most important advantage of wood-plastic combinations over natural wood. This was taken in account by measuring the swelling behavior of the combinations produced. Volumetric swelling (Table 5) is definitely the lowest for composites containing MMA and MD.

Dimensional stability is often measured in terms of antishrink efficiency (ASE) as defined in

$$ASE = \frac{S - S_c}{S} \times 100\%$$

where S = fractional volumetric swell of wood and S_c = fractional volumetric swell of composite.

There is a clear indication from the results that the dimensional stability is greater when a swelling agent, dioxane, is present. Figure 2 shows that water continues to be absorbed by the composites as well as by the untreated wood even though the dimensional change has leveled off. This may be due to water seeping into cell cavities previously prevented by the presence of either the polymer or the cell wall. It is thus felt appropriate to define an equation in a fashion similar to ASE to quantify the permanent weight reduction quality of the polymer in wood. It was expressed as the antiabsorption efficiency (AAE) in

$$AAE = \frac{WI - WI_c}{WI} \times 100\%$$

where WI = percent weight increase of wood and WI_c = percent weight increase of composite.

In previous experiments the degree of grafting had been measured by the amount of impregnant remaining in the extracted product or the reprecipitated residue obtained after exhaustive extraction with a solvent. Results in Table 6 show that grafting may have occurred for the Kapur-methyl methacrylate dioxane composites, judging from the lower amount of polymer extracted by toluene.

Termite Resistance

Termites' role in the destruction has been the cause of concern for many wood users. Various preservatives such as creosote, insecticides, diesel fuel, and salts have been impregnated into wood by vacuum-pressure methods to safeguard against termite and other

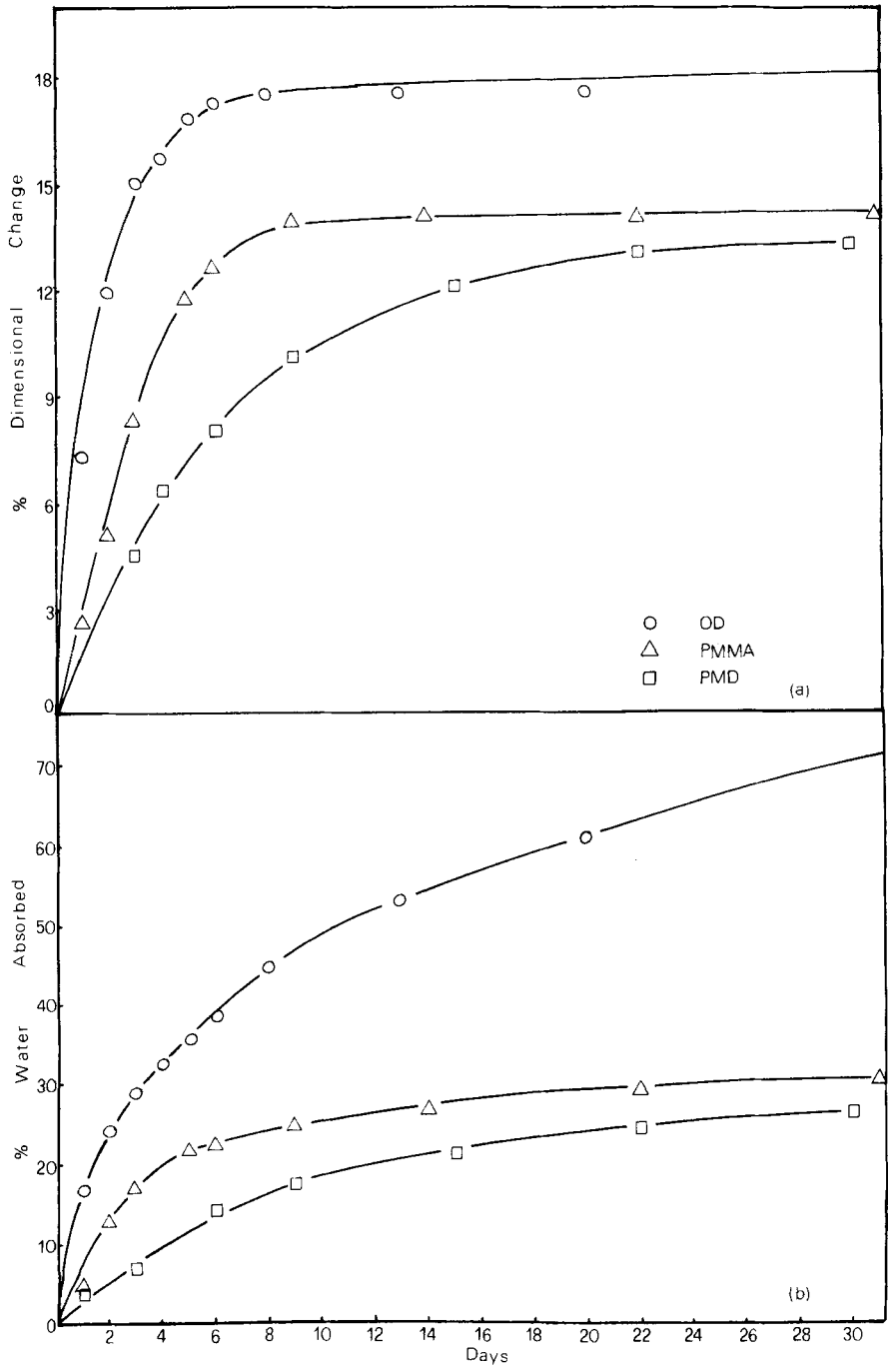

FIG. 2. Dimensional stability and water absorption: Kapur.

TABLE 6. Data on Soxhlet Extraction of Homopolymer Toluene Extraction of Methyl Methacrylate

Specimen material	Polymer loading (%)	Polymer weight (g)	Soxhlet extraction			Weight of precipitate recovered (g)	Polymer extracted[a] (%)
			Weight before extraction (g)	Weight after extraction (g)	Weight loss (g)		
Kapur-oven dried							
KA-O-205			22.5945	22.0330	0.5615		
KA-O-206			23.0976	22.7372	0.3604		
Kapur-PMMA							
KA-M-205	43.9	9.9784	36.5121	27.4908	9.0213	8.3220	83.5
KA-M-206	37.6	9.9482	32.6296	24.0361	8.5935	7.8392	78.8
Kapur-PMD							
KA-D-205	33.2	8.6191	33.0156	26.7597	6.2559	5.4817	63.6
KA-D-206	31.8	8.1525	32.1811	26.8146	5.3665	4.8181	59.1

[a] $\%\ \text{polymer extracted} = \dfrac{\text{weight of precipitate recovered}}{\text{weight of polymer present}} \times 100\%$

TABLE 7. Results of Termite Resistance Test[a]

Wood	Impregnation	Average polymer loading (%)	Survival		Total weight of sample (g)	Loss in weight	
			No.	%		g	%
Kapur	OD		56	46.7	98.1894	3.6500	3.72
	PMMA	55	39	32.5	134.6280	4.2724	3.17
	PAR	32	12	10.0	119.5334	3.0944	2.59
	PSTAN	55	0	0.0	127.1519	2.1821	1.72
	PVA	49	51	42.5	126.3170	5.3312	4.22
	PVDC	17	39	32.5	105.4145	2.9006	2.75
Kempas	OD		74	61.7	107.4690	2.0505	1.91
	PMMA	37	53	44.2	145.7604	0.7754	0.53
Red Seraya	OD		80	66.7	99.7309	2.0901	2.10
	PMMA	71	4	3.3	151.5614	0.7472	0.49
White Seraya	OD		42	35.0	73.2498	1.5006	2.05
	PMMA	45	19	15.8	103.0798	3.3517	3.25
Jelutong	OD		70	58.3	27.0062	0.4529	1.68
	PMMA	148	12	10.0	69.0076	0.3616	0.52

[a]Total possible survival = 120.

TABLE 8. Results of Fire Resistance Tests

Wood	Impregnation	Average moisture content (%)	Average polymer loading (%)	Fire-tube test		Crib test	
				Average weight loss (%)	Flaming time (s)	Average weight loss (%)	Flaming time (s)
Kapur	OD	7.59		77.36	276	79.70	162
	PMMA	6.63	45.8	81.21	356	86.70	390
	PVDC	5.73	34.9	20.52	21	56.21	130
Kempas	OD	8.08		79.57	224	81.25	173
	PMMA	6.27	39.3	83.38	284	88.53	513
	PVDC	7.13	21.7	24.81	4	38.08	87
Red Seraya	OD	9.31		87.04	229	87.48	142
	PMMA	4.95	66.5	87.13	326	88.98	562
	PVDC	6.15	32.8	18.08	5	50.89	109
White Seraya	OD	8.08		77.65	176	82.14	133
	PMMA	5.04	54.0	83.18	311	86.44	490
	PVDC	5.63	28.3	20.36	7	51.78	126

boring insects. Impregnation of high density plastics and polymers containing inherent insect-repellent properties are thus of great importance.

Wood blocks measuring 2.5 × 2.5 × 5.0 cm were each placed in a glass container specially constructed with glass slides to effect a compulsory feeding test. Thirty termites were introduced into each container and the termites were exposed to the wood surface for about 90 d. After the test period the number of surviving termites was recorded and the wood was reweighed after being vacuum-dried to constant weight.

The results (Table 7) show that the number of surviving termites in the composites are significantly lower than for the untreated wood. This shows that the presence of polymers effectively resisted termite attack though not absolutely. Termites are also known to be able to damage plastic, lead, and even underground cables, and this is probably due to their primitive mouth parts.

Fire Resistance

The fire tests conducted are adapted from the fire-tube test (ASTM, E69-50; Reapproved 1975) and the crib test (ASTM, E160-50; Reapproved 1975). These two methods cover fire test procedures for combustible properties of wood treated to reduce flammability.

Polyvinylidene chloride composites (PVDC) showed remarkable fire-proofing properties whereas the polymethyl methacrylate composities (PMMA) supported combustion. The difference in the type of wood used in the composite formation and the polymer loading did not seem to affect the fire resistance appreciably. The duration of continued flaming and continued glow can also provide an indication of flammability. The wood-PMMA composite took a relatively longer period for the flame to be completely extinguished after the removal of the igniting flame, showing that it supported combustion. The results are shown in Table 8.

CONCLUSION

The results obtained in this study indicate that generally the composites show improvement over the original wood in the various properties tested. However, their improvements are not always equal or superior to the sum of the constituent materials. It appears to be the result of the nonuniformity of penetration of plastic into the wood structure and, possibly, a weak bonding between the polymer and the cellulose cell wall.

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