A study of wood-plastic combinations based on low-density woods

A. MUÑOZ-ESCALONA, P. BOLSAITIS
Instituto Venezolano de Investigaciones Científicas, Caracas, Venezuela

J. E. VIELA
Laboratorio Nacional de Productos Forestales, Mérida, Venezuela

Six low-density tropical woods were impregnated with various vinyl monomers and polymerized by irradiation with a $^{60}$Co source. The wood—plastic combinations were subjected to standard tests of mechanical properties, and their fracture surfaces were studied by scanning electron microscopy. It was found that, even though most mechanical properties are enhanced by addition of plastics, the properties of wood—plastic combinations fall below those of high-density natural woods on a per unit weight basis. The direct observation of fracture surfaces gave indications of non-uniform penetration of the plastic and little bonding between the polymer and cellulose fibres. Although the wood—plastic combinations produced by the present methods may not be recommendable for applications where increased strength is desired on the basis of cost/quality considerations, they may be suitable for uses where increased abrasion resistance, dimensional stability and lower anisotropy of compressional properties are primary considerations.

1. Introduction
The advent of composite materials as a solution to the relentless need for ever stronger and better materials has led to the study of multitudinous combinations of different fibres and matrix materials. One such combination that has drawn the attention of numerous researchers over the past decade is plastic impregnated wood, where it is hoped to combine the tensile strength of cellulose fibres with the hardness, abrasion resistance, and incompressibility of the polymeric materials used. These materials also offer the particular advantage of greater dimensional stability (i.e. resistance to swelling).

A great deal of the accumulated research effort has gone into the study of permeability and conditioning of wood and the formulation of optimum irradiation conditions for the monomers used in impregnation. Although a large number of wood—plastic materials have been tested for their mechanical and physical properties, such data have generally not been analysed past the stage of establishing an improvement or deterioration of properties. Since wood—plastic combinations are proposed not only as “erstaz” type materials for natural woods but also as improved materials, a more careful cost—quality relationship seems necessary. As has been pointed out by Tarkow [1], cost considerations have severely impaired the development of modified (plasticized, plastic-impregnated, and compressed) woods.

An interesting comparison of the effect of plastics on the properties of wood is the comparison of resin-treated and compressed wood (staypack) [1, 2]. This comparison shows a superior quality, at the same density, for the compressed material, indicating that “wood substance” is a superior quality filler. Unfortunately, compressed woods are as costly to produce as wood—polymer composites.

Tropical woods, because of their broad range of densities (0.26 to 1.18 g cm$^{-3}$ among 144 species of the Venezuelan Guayana [3]) offer a particularly interesting base for comparison of natural
and plastic-impregnated woods. For this reason it was deemed interesting to compare, on a per unit incremental density basis, the increment in mechanical properties produced by filling density woods with various polymeric materials, and to compare the properties of these wood–polymer combinations to high-density woods. Also, direct examination of fracture surfaces by SEM was made in an attempt to correlate the strength of the materials tested to the morphology of the fracture surfaces.

2. Experimental

The following six woods, based on their availability and low density, were selected for impregnation studies (common name in parentheses):

- *Erisma uncinatum* (muriello) \( \rho = 0.59 \text{ g cm}^{-3} \)
- *Hieronyma laxiflora* (sangrón) \( \rho = 0.63 \text{ g cm}^{-3} \)
- *Jacaranda superba* (girasol) \( \rho = 0.35 \text{ g cm}^{-3} \)
- *Pithecellobium jupunba* (saman) \( \rho = 0.62 \text{ g cm}^{-3} \)
- *Pterocarpus vernalis* (sangre de drago) \( \rho = 0.71 \text{ g cm}^{-3} \)
- *Tabebuia rosea* (apamate) \( \rho = 0.63 \text{ g cm}^{-3} \)

The densities quoted above refer to air-dried specimens.

The following monomers were used for impregnation of samples of each of the above woods:

- Methylmethacrylate (MMA) commercial grade of the Aldrich Chemical Co.
- Methylmethacrylate (80%) and unsaturated polyester (20%) (MMA-AR). The unsaturated polyester used was AROPOL 2731 of Ashland Chemical Co.
- Styrene (60%) and acrylonitrile (40%) (ST-AN) commercial grade of Aldrich Chemical Co.
- Styrene (48%), acrylonitrile (32%) and polyester (20%) (ST-AN-AR).

The impregnation was carried out in a steel tank of 50 cm \( \times \) 52 cm \( \times \) 13.5 cm. Sixteen samples of 6 cm \( \times \) 6 cm \( \times \) 50 cm were placed simultaneously in the tank, which was then evacuated to a pressure of 2 to 3 mm Hg and held at this pressure for 2 to 3 h. Monomer was then introduced maintaining the vacuum during this time. Subsequently a pressure of 2 atm was introduced on the monomer solution holding the immersed wood samples. This pressure, supplied from a nitrogen tank, was maintained for 14 h after which time the tank was depressurized and the impregnated samples removed. A schematic drawing of the impregnation apparatus is shown in Fig. 1.

The samples were subsequently irradiated from a \( ^{60} \text{Co} \) source of 7000 Ci activity. The samples were placed in an aluminium irradiation tank in a position where the average radiation intensity was of 0.045 Mrad h\(^{-1}\). The total radiation doses used for the four monomers were the following: MMA-0.46 Mrad, MMA-AR-0.60 Mrad, ST-AN-1.10 Mrad and ST-AN-AR-0.35 Mrad.

Using the following values for the densities \( \rho_M \) of the polymerized plastic materials: MMA-0.95 g cm\(^{-3}\), MMA-AR-1.01 g cm\(^{-3}\), ST-AN-0.87 g cm\(^{-3}\) and ST-AN-AR-0.94 g cm\(^{-3}\) and a value of the density of the wood substance \( \rho_w \) of about 1.5 g cm\(^{-3}\), the impregnation efficiency (ratio between the absorbed volume of monomer and the free pore volume of the wood, in percent) was calculated as \( \text{imp. eff.} = 100 \frac{M}{(\rho_M \cdot V_f)^\%} \), where

---

**Figure 1.** Schematic drawing of impregnation apparatus.

---