# Interfacial and Thermal Characteristics of Natural Fiber Composites Reinforced with Henequen Surface-Treated with EBI

Yansong Pang*·한성옥**·조동환*·Lawrence T. Drzal***

Yansong Pang*, Seong Ok Han**, Donghwan Cho*, and Lawrence T. Drzal***

**Abstract**

In this study, a number of natural fiber henequen reinforced polymer matrix composites were successfully fabricated by means of a compression molding technique using chopped henequen fibers surface-treated with different electron beam irradiation (EBI) dosages, thermoplastic poly(butylene succinate), thermosetting unsaturated polyester and phenolic resins. Their interfacial and thermal characteristics were studied in terms of interfacial shear strength, fracture surface, dynamic mechanical properties, dimensional stability, and thermal stability using single fiber microbonding test, SEM, DMA, TMA, and TGA. The results show that their interfacial and thermal properties significantly depend on the intensity of EBI treatment on the natural fiber surface.

**Key Words:** Natural fiber composites, Henequen, EBI, Interfacial properties, Thermal properties.

## 1. INTRODUCTION

Natural fiber composites or biocomposites have increasingly attracted attention because they may be a promising material not only as a novel material for natural resource, eco-friendliness, sustainability, lightness and cost-effectiveness, but also as an alternative to conventional glass fiber polymer composites.[1-2] Natural fiber composites have potential for uses, especially in automotive, building, commodity, and other applications.

Henequen(*Agave fourcroydes*)[3] is one of plant-based natural fibers like sisal, flax, jute, and hemp. It is long, hard, and strong fiber obtained from the 2~4 foot long leaves of agave plants, which is native to Yucatan, Mexico. Poly(butylene succinate), PBS is biodegradable, thermoplastic, and aliphatic polyester.[4] Thermosetting resins are often used as matrix in natural fiber composites although they are not biodegradable. This is because they have easy proccessibility, low cost, and better properties in comparison with thermoplastic biodegradable polymers.

The adhesion between hydrophilic natural fiber and hydrophobic polymer surfaces has often been issued in many different natural fiber composite systems. A number of studies have been devoted to understand and improve the interfacial characteristics. Electron beam irradiation (EBI) techniques have been increasingly utilized for surface-modification and property enhancement of various polymer materials.

In this study, the interfacial and thermal properties of natural fiber composites fabricated with henequen surface-treated with different EBI doses and PBS, unsaturated polyester (UP), phenolic (PH) resins have been explored. The effect of EBI surface treatment on the interfacial shear strength, dynamic mechanical and thermal properties, and fracture

* Dept. of Polymer Science Engineering, Kumoh National Institute of Technology
** Functional Materials Research Center, Korea Institute of Energy Research
*** CMSC, Michigan State Univ., USA

surface of each natural fiber composites will be presented.

## 2. EXPERIMENTAL

### 2.1 Materials

Henequen fibers (HQ), originated from Mexico and supplied from Michigan State University in 30-40 cm long filament form, were used as reinforcement throughout this work. PBS (EnPol G-5100) was kindly supplied from IRe Chemical Co. It has a melting point of about 115℃, the specific gravity of 1.22, and the melt index (g/10 min at 190℃) of 15-25. UP resin (UP-GR235) is supplied from Sewon Chem. Co. It has the styrene content of 35 wt%. Methyl ethyl ketone peroxide (MEKP) was used as catalyst. Phenolic resin (KC4100) used was of resol-type, supplied from Kangnam Chem. Co. The chemical structure of each compound is shown in Fig. 1.

### 2.2 Composite Fabrication

The fiber contents and chopped fiber lengths were 40 wt% and 1/2 inch for PBS biocomposites, 10 wt% and 1/4 inch for UP biocomposites, and 20 wt% and 1/4 inch for phenolic biocomposites, respectively. The HQ fibers were irradiated with different EBI dosages of 0, 10, 30, 50, 70, 100, 150, 200, and 500 kGy prior to composite processing (EB Tech Co.). All natural fiber composites used here were fabricated using a compression molding technique. After mechanical mixing HQ and PBS powder pulverized with a mixer, the molding compounds were melted at 130 ℃ for 15 min, holding at 1000 psi for 15 min. After mechanical mixing HQ and UP resin, the chopped molding compounds were cured at 25℃ for 15h and then 70℃ for 1h without applied pressure. The HQ/phenolic chopped molding compounds were stepwise cured at 70℃ for 1h, 110℃ for 1h, and then 140℃ for 30min, holding at 1000 psi at 110℃. Then, the molded composites were naturally cooled down to ambient temperature.

### 2.3 Characterization

A single fiber microbonding test method was performed using a tailor-made test apparatus equipped with a universal testing machine (Instron 4467). A load cell of 100N was used and the crosshead speed was 2 mm/min. Fig. 2 illustrates the test method using a resin microdroplet. A microdroplet of each matrix resin was uniformly made on the HQ fiber. The photos obtained before and after the test are presented in Fig. 3. Scanning electron microscopic (SEM, Hitachi S-570) observations were done for examining the composite fracture surfaces. Dynamic mechanical analysis (DMA 983, TA Instruments) was performed to investigate the storage modulus, loss modulus, and tan delta of each natural fiber composites. Thermomechanical analysis (TMA 2940, TA Instruments) was also used to dimensional stability and the coefficient of thermal expansion of composites. Their thermal stability was also observed using TGA (DuPont 951).

## 3. RESULTS AND DISCUSSION

### 3.1 Interfacial Properties

Fig. 4 shows the single fiber microbonding test result obtained for HQ/PBS biocomposites reinforced with henequen surface-treated with 8 different EBI doses. The IFSS value of raw HQ/PBS biocomposite increases with an introduction of a low intensity (10kGy) of EBI on the HQ surface. However, it gradually decreases with increasing EBI dosage up to 100kGy. And then, it significantly increases again up to 200kGy. With an excess irradiation of EB, the IFSS drops down to the raw HQ/PBS case. Such a change of IFSS value, which reflects the change of the fiber surface and the natural fiber-matrix interfacial adhesion, has been explained by studying the morphological change of the HQ fiber surface by EBI treatment and the fractograph of the composites. The IFSS results obtained for HQ/UP and HQ/Phenolic biocomposites are

relatively comparable with that for HQ/PBS biocomposites, at the corresponding intensity of EBI treatment on the HQ.

### 3.2 Thermal Properties

As seen in Fig. 5, the storage modulus (E′) of PBS matrix has the lowest value of 173 MPa at 50℃. The E′ of HQ/PBS biocomposite at 50℃ dramatically increases from 450MPa up to 740MPa not only by incorporating HQ reinforcement but also by EBI treatment on the HQ depending on the EBI dosage. The enhanced property is also observed near the glass transition region. The E′ value increases with an EBI treatment of 10kGy, more or less decreases with increasing EBI does to 100kGy, increases to 200kGy, and finally decreases at 500kGy, showing a similar pattern of the EBI dependence with the result found in Fig. 4. Therefore it is noted that the DMA result quite agrees with the single fiber microbonding test result.

Fig. 6 shows the storage modulus as a function of temperature for various HQ/UP biocomposites with different EBI treatments. The result shows a high E′ of 631MPa at 50℃ for UP matrix resin. As found in the HQ/PBS case, the E′ value at 50℃ significantly increases with EBI treatments of 10kGy (864MPa) and 50kGy (973MPa). The EBI treatment of 150kGy exhibits the lowest E′.

Fig. 7 presents the variation of the storage modulus as a function of temperature for various HQ/Phenolic biocomposite with different EBI treatments. The phenolic matrix resin exhibits the highest E′ value (938MPa at 50℃) among the resins used. As similarly found in other cases, the E′ obviously increases with the incorporation of HQ into phenolic resin over the temperature range measured. Also, the E′ depends on the EBI treatment showing a similar effect, as expected. Such the dependence of EBI treatment on the thermal properties may be explained by understanding the effect of the EBI on the interfacial properties between the fiber and the matrix in a biocomposite system and also on the internal and external structures of cellulosic henequen.

## 4. CONCLUSIONS

The interfacial and thermal properties of HQ/PBS, HQ/UP, and HQ/Phenolic biocomposites strongly depend on the EBI treatment done on the henequen fiber surface. The result suggests that one must use an optimal intensity of EBI to maximize the interfacial bonding and the dynamic mechanical and thermal properties. The dependence of the EBI treatment on the interfacial and thermal properties of natural fiber composites agrees well each other.

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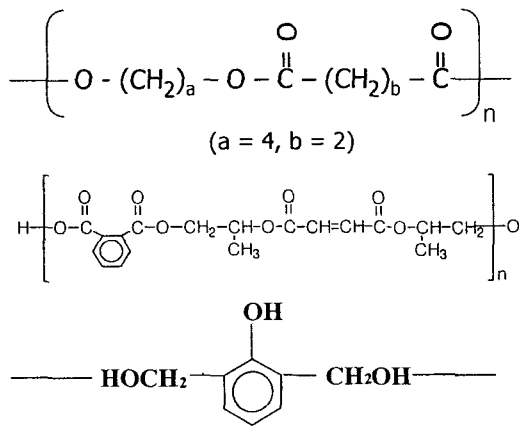


Fig. 1. Chemical structures of poly(butylene succinate), unsaturated polyester, and phenolic resins.

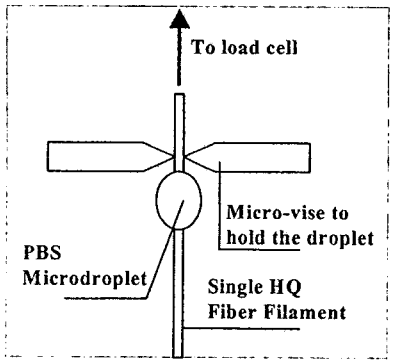


Fig. 2. Schematic of single fiber microboding test.

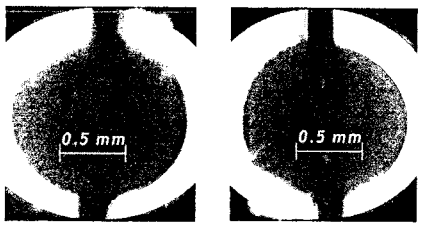


Fig. 3. PBS Microdroplets formed on a single fiber of henequen before and after the test.

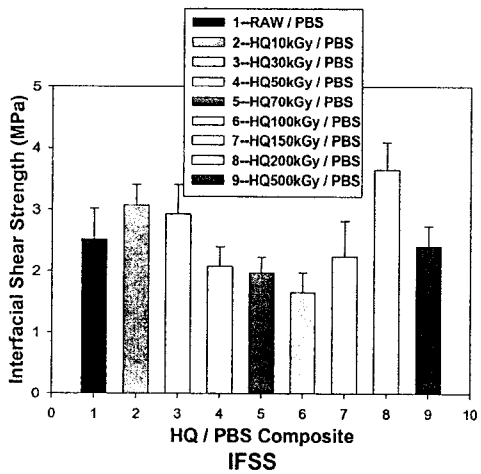


Fig. 4. Comparison of the interfacial shear strength measured for various HQ/PBS composites with different EBI treatments on the HQ surface.

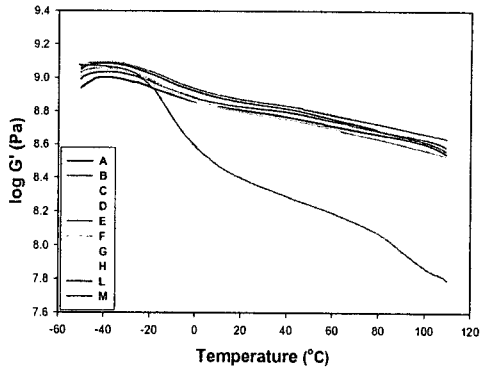


Fig. 5. Variation of the storage modulus as a function of temperature for various HQ/PBS biocomposites with different EBI treatments.

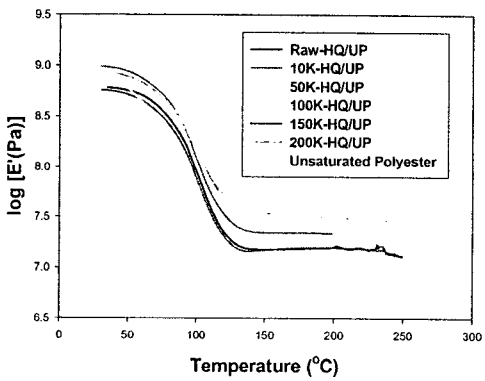


Fig. 6. Variation of the storage modulus as a function of temperature for various HQ/UP biocomposites with different EBI treatments.

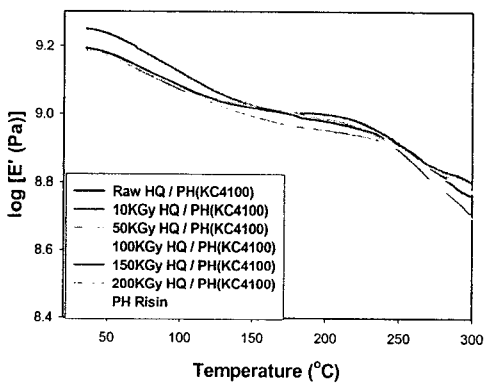


Fig. 7. Variation of the storage modulus as a function of temperature for various HQ/Phenolic biocomposites with different EBI treatments.