Effect of Processing Method on Surface and Weathering Characteristics of Wood–Flour/HDPE Composites

Nicole M. Stark,[1] Laurent M. Matuana,[2] Craig M. Clemons[1]

[1]*U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, Wisconsin 53726-2398*
[2]*Department of Forestry, Michigan State University, East Lansing, Michigan 48824-1222*

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ABSTRACT: Wood–plastic lumber is promoted as a low-maintenance high-durability product. When exposed to accelerated weathering, however, wood–plastic composites may experience a color change and/or loss in mechanical properties. Different methods of manufacturing wood–plastic composites lead to different surface characteristics, which can influence weathering. In this study, 50% wood–flour-filled high-density polyethylene (HDPE) composite samples were injection molded, extruded, or extruded and then planed, to remove the manufacturing surface characteristics. Fourier transform infrared spectroscopy was used to chemically show the difference in surface components. The samples were weathered in a xenon-arc weathering apparatus for 1000, 2000, and 3000 h and analyzed for color fade and loss of flexural modulus of elasticity and strength. Final color (lightness) after weathering was not dependent on the manufacturing method. However, the manufacturing method was related to mechanical property loss caused by weathering. Composites with more wood component at the surface (i.e., planed samples) experienced a larger percentage of total loss in flexural modulus of elasticity and strength after weathering. © 2004 Wiley Periodicals, Inc. J Appl Polym Sci 93: 1021–1030, 2004

Key words: extrusion; FTIR; injection molding; mechanical properties; polyethylene

INTRODUCTION

Wood-derived fillers have recently made significant inroads into the thermoplastic industry, primarily as a result of the emergence of wood–plastic composites in the construction industry. Exterior nonstructural or semistructural building products, such as decking, fencing, siding, window framing, and roof tiles, are being introduced into the marketplace. For building products alone, approximately 500,000 tons of wood–plastic composites are predicted to be used in North America in 2006.[1] Construction, transportation, industrial, and consumer applications are also on the rise. Currently, nearly 70% of wood–plastic composites are polyethylene matrix composites.[1] Polypropylene and polyvinyl chloride are also common matrix materials used by the wood–plastic composites industry.

Wood–plastic lumber is being promoted as a low-maintenance, high-durability product.[2] However, the use of wood–plastic composites by the construction industry has resulted in concern about the durability of these products when exposed to outdoor environments. Ultraviolet (UV) durability is of particular concern. When exposed to accelerated weathering, wood–plastic composites experience color change[3–8] and a loss in mechanical properties.[3–6,8] Changes in mechanical properties after weathering can be due to a combination of changes, such as composite surface oxidation, matrix crystallinity changes, and interfacial degradation caused by moisture absorption.[9]

Although the effect of weathering on wood–plastic composites has been consistently reported, the rate of change has not. Samples of 50% wood–flour-filled high-density polyethylene (HDPE) have been tested for color fade after accelerated weathering. Some researchers have reported that the majority of color fade occurs in the first 700 h of 1500 h of weathering,[4] whereas others have shown that color fade continues through 2000 h of weathering.[6] Even more disparity can be found in the literature in regard to mechanical properties. Some studies have shown that for 50% wood–flour-filled HDPE, flexural modulus of elasticity (MOE) and strength decrease during the first 1000 h of 2000 h total exposure time.[3] Others have shown that for the same formulation flexural MOE and strength change very little during the first 1000 h of accelerated weathering and the majority of change occurs during the second 1000 h.[6]

Injection molding, compression molding, and extrusion are processing methods commonly used for man-

Correspondence to: N. M. Stark.

ufacturing wood–plastic composites. Parameters that are affected by processing method include temperature, pressure, and flow. Both processing methods and processing variables greatly influence the morphology and physical properties of the composite.

Injection-molded composite plaques result in a skin–core morphology. In polymeric composites made with short fibers, fibers in the core layer are oriented perpendicular to flow, while those in the skin layer are oriented parallel to flow.[10,11] Processing variables can affect the relative thickness of these layers. A low mold temperature can lead to a very thick skin.[10] Increasing barrel temperature, screw speed, and injection speed decreases skin thickness.[10] Not only does the morphology of injection-molded composites change from the skin to the core, but the volume fraction of the fiber can change as well. For injection-molded cellulose fiber-filled polypropylene, fiber volume fraction is slightly higher in the core layer than the surface layer.[11] In addition, injection-molded composites often have a polymer-rich surface layer.[12]

The extrusion of short fiber reinforced polymeric composites can also lead to a skin–core morphology. In a study of extruded polypropylene filaments filled with short glass fiber, circular profiles were analyzed for density and orientation differences.[13] The composites had higher density at the surface of the extrudate, and surface fibers were more aligned in the flow direction compared with fibers in the core.

The method of manufacturing wood–plastic composites also affects moisture absorption. Clemons and Ibach[12] studied 50% wood–flour-filled HDPE composites manufactured by extrusion, compression molding, and injection molding. The extruded composites absorbed the most moisture and injection-molded composites absorbed the least moisture. The authors presumed that this result was due to a polymer-rich surface layer and lower void content attributable to the higher density of injection-molded composites.

Mechanical properties of wood–flour-filled polymer composites are negatively affected by moisture.[12,14–18] When the composite is exposed to moisture, the hydrophilic fiber swells. Cracks may form in the polymer matrix, which can also contribute to penetration of water into the composite.[14] Exposing wood-filled polymer composites to moisture results in a drop in flexural MOE and strength by degrading the wood–polymer interfacial quality.[14–16] The amount of moisture absorbed can be influenced by wood–flour content and wood-particle size.[14,17]

Despite known effects of manufacturing methods on moisture absorption and mechanical properties of composites, research has not been extensively carried out to examine the influence of composite production methods on UV degradation. Our study had two main objectives: (1) to characterize the surface of 50% wood–flour/HDPE composites produced by using different manufacturing methods and (2) to determine how the manufacturing method affects the weathering of wood–flour/HDPE composites.

Because of its effectiveness in analyzing functional groups in a material, Fourier transform infrared (FTIR) spectroscopy was utilized to study surface characteristics of wood–flour/HDPE composites manufactured by different techniques. FTIR methods were extensively used to study weathered polyethylene.[19–24] In addition, FTIR was employed to study functional groups in wood.[25–27]

The results of the study reported here will aid in the development of an understanding of how processing methods affect color fade and mechanical properties of wood–flour/HDPE composites after weathering.

EXPERIMENTAL

Materials

The materials used in this study were wood–flour (WF) and HDPE. The WF was 40-mesh ponderosa pine supplied by American Wood Fibers (Schofield, WI). The HDPE was virgin material with a melt index of 0.72 g/10 min and density of 0.963 g/cm^3 (Fortiflex A60-70-162, Solvay Polymers, Inc., Houston, TX). A lubricant (Struktol TR016, Stow, OH; density = 0.98 g/cm^3) was also added to the extruded samples to aid processing.

Processing

Injection molded

WF was dried for 24 h at 105°C; HDPE and WF were then dry-blended at 50% WF. Compounding was accomplished by using a 32-mm Davis Standard (Pawcatuck, CT) twin-screw extruder to produce homogeneous WF/HDPE composite pellets. The melt temperature at the die was 200°C and the melt pressure was 2.96 MPa. The pellets were dried at 105°C for at least 24 h prior to injection molding into flexural bar test samples. The composites were injection molded by using a 33-ton Cincinnati Milacron (Batavia, OH) injection molder. The mold nozzle temperature was 204°C, and the injection pressure reached a peak of 12.4 MPa. The American Society for Testing and Materials (ASTM) mold cavity used for the flexural samples was 120 × 3 × 12 mm.[28]

Extruded

Extruded samples were run at the University of Maine Advanced Engineered Wood Composite Center. The composite was 49% by weight WF, 8% by weight lubricant, and the remainder HDPE. A Davis Standard 94-mm twin-screw extruder was used with a die that produced a 30 × 140-mm radius edge profile. The die

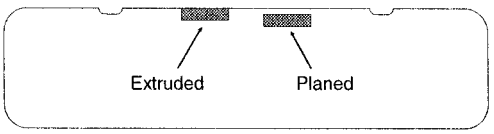

Figure 1 Extruded profile showing cutting sites for extruded and planed samples.

temperature was 180°C, and the die pressure was 2.1 MPa. Flexural samples (120 × 3 × 12 mm) were cut from deck boards for testing (Fig. 1). The extruded surface was left intact.

Planed

Less than 1 mm of the surface of the extruded samples was planed to remove any surface characteristics resulting from the extrusion processing method. Samples were cut from the deck board just below the extruded surface (Fig. 1) to minimize any difference from the extruded samples associated with the thickness of the board.

Testing and analysis

Density

Unexposed samples were dried for 24 h at 105°C before being tested for density according to ASTM D792.[28] The sample size was approximately 60 × 3 × 12 mm. Twenty replicates for each processing method were tested.

The density of wood–flour in the composites was calculated. The rule of mixtures can be written in weight fractions as

$$\frac{1}{\rho_c} = \left(\frac{w_f}{\rho_f}\right) + \left(\frac{w_m}{\rho_m}\right) + \left(\frac{w_l}{\rho_l}\right) \quad (1)$$

where ρ is density, w is weight fraction, and the subscripts c, f, m, and l refer to composite, fiber, matrix, and lubricant, respectively. Rearrangement of eq. (1) allows for calculation of fiber density in the composite (ρ_f).

Color measurement

A Minolta CR-200 Chroma Meter (Minolta Corp., Ramsey, NJ) was used to measure color by using the CIELAB color system. Lightness (L) was measured for at least five replicate samples. In the CIELAB color system, the value L can be thought of as a lightness factor. L represents reflectance of a sample. An L of 0 means the sample does not reflect light; an L of 100 means the sample reflects 100% light. An increase in L means the sample has faded or lightened ($+\Delta L$ = lightening; $-\Delta L$ = darkening).

Mechanical properties

Samples were oven dried at 105°C for 24 h before testing, to ensure the same conditioning for samples before and after weathering. Flexural tests were carried out according to ASTM D 790[28] on an MTS 810 Material Test System (MTS Systems Corp., Eden Prairie, MN). A three-point loading system was utilized with a crosshead speed of 1.3 mm/min. The exposed surface was placed away from the center load to place that part of the sample in tension. At least five replicate specimens were tested for each formulation. The MOE and maximum strength were calculated according to the standard.

Fourier transform infrared spectroscopy

FTIR spectroscopy was conducted on a Mattson Genesis II (Thermo Electron Corp., Madison, WI) spectrophotometer to provide knowledge of functional groups present at the surface of the samples. The penetration depth, which was dependent on wavelength and index of refraction of WF and HDPE, ranged from 0.5 to 3 μm. Scans were run at a resolution of 4 cm^{-1}. For each sample, 100 scans were recorded in absorbance units from 4000 to 700 cm^{-1}. Spectra were obtained by using attenuated total reflectance (ATR). The surfaces of the samples analyzed were in contact with a ZnSe crystal with a 45° angle of incidence. At least five replicate samples were analyzed.

Cellulose spectra have a strong peak as a result of hydroxyl groups at 1023 cm^{-1}.[25] A wood index was calculated by using the equation

$$\text{Wood Index} = \frac{I_{1023}}{I_{2912}} \times 100 \quad (2)$$

where I represents peak intensity. The peak intensity was normalized by using the peak at 2912 cm^{-1}, which corresponds to alkane CH stretching vibrations of methylene groups (—CH_2—).

Weathering

Composites were placed in a xenon arc-type light exposure apparatus operated according to ASTM D 2565.[29] Samples were mounted in four rows on a drum that rotated around the xenon arc bulb at 1 rpm. Each 2-h weathering cycle consisted of 108 min of UV exposure and 12 min of simultaneous water spray and UV exposure.[29] An irradiance sensor was used to measure light intensity for wavelengths from 300 to 400

TABLE I
Amount of Light Energy Between 300 and 400 nm to Which Samples Were Exposed for 500-h Increments

Time increment (h)	Dosage (kW-h/m^2)
0–500	29.4
500–1000	29.1
1000–1500	27.9
1500–2000	28.2
2000–2500	28.7
2500–3000	28.8

nm. The irradiance was monitored and voltage to the bulb was changed periodically to maintain constant irradiance. The dosage, or amount, of light energy to which samples were subjected was calculated (irradiance $\times$ time). The dosage at 500-h increments is shown in Table I. We are confident that samples were exposed to consistent energy dosages for each thousand hours of weathering. To understand the effect of time on weathering, samples were removed for analysis after 1000, 2000, and 3000 h of weathering.

Scanning electron microscopy

Molded surfaces were sputtered with gold and analyzed with a scanning electron microscope (SEM; JSM-840, JEOL USA, Inc., Peabody, MA) at a working distance of $\sim$25 mm, voltage of 15 kV, and probe current of 1×10^{-9} amp.

Statistics

To determine effects of weathering on properties, Student's two-tailed *t*-tests were carried out at $\alpha = 0.05$ for each blend, testing the data for significant differences.

RESULTS AND DISCUSSION

Unexposed samples

The WF/HDPE composites were manufactured by either injection molding or extrusion. Extruded samples were cut so that the original extruded surface remained intact or the surface was planed. Physical properties of injection-molded, extruded, and planed composites without UV weathering are summarized in Table II. Processing pressures during injection molding were much higher than those during extrusion. As a result, the density values of injection-molded samples were higher than those of extruded or planed samples. During processing, wood cells can be either compressed or filled. If HDPE is assumed to be incompressible, the density of WF in the composites can be calculated by rearranging eq. (1). Higher density was also due to the greater processing pressures experienced by the composites during injection molding. The density of wood–flour in injection-molded samples approached that of wood cell walls, ~ 1.49 g/cm^3.[30] The similar density values for the extruded and planed samples indicate that the morphologies of the two composites are similar.

Lightness (L) of the composites also varied with manufacturing method (Table II). Injection-molded samples were the darkest. Processing temperature was higher for injection-molded samples (204°C), which resulted in a darker composite as the wood, especially hemicelluloses, began to degrade. In comparison to extruded composites, planed composites were lighter. The polymeric surface layer of extruded composites effectively wet the wood–flour. When wetting occurs at a wood surface, light is transmitted deeper in the wood cell, resulting in apparent darkening of the wood.[31]

In general, flexural MOE values of the composites were similar. However, the flexural strength of injection-molded samples was greater than that of extruded and planed samples. This is most likely due to the difference in density. The higher density of injection-molded samples resulted in more intimate contact between the HDPE matrix and WF. The improvement in interfacial quality led to more efficient stress transfer between the matrix and fiber, resulting in increased strength. The addition of lubricant to the extruded and planed samples may also have affected MOE and strength.

The surface of each sample was analyzed by using FTIR spectroscopy. In Figure 2, the top spectrum is of unfilled HDPE and the bottom spectrum is of a solid piece of southern yellow pine (SYP, *Pinus* spp). The

TABLE II
Physical Properties of Unexposed 50% Wood Flour Filled HDPE Composites[a]

Sample	Composite density (ρ_c) (g/cm^3)	Wood flour density (ρ_f) (g/cm^3)	Lightness	MOE (GPa)	Strength (MPa)
Injection molded	1.135 (0.002)	1.40 (0.01)	49.0 (0.7)	3.6 (0.2)	39.6 (0.7)
Extruded	1.087 (0.008)	1.26 (0.02)	57.0 (0.8)	3.3 (0.2)	24.5 (0.9)
Planed	1.085 (0.019)	1.25 (0.05)	62.1 (1.0)	3.4 (0.2)	27.2 (0.7)
HDPE	0.953 (0.001)	NA	76.4 (0.2)	0.9 (0.1)	22.3 (0.2)

[a] Numbers in parentheses represent one standard deviation.

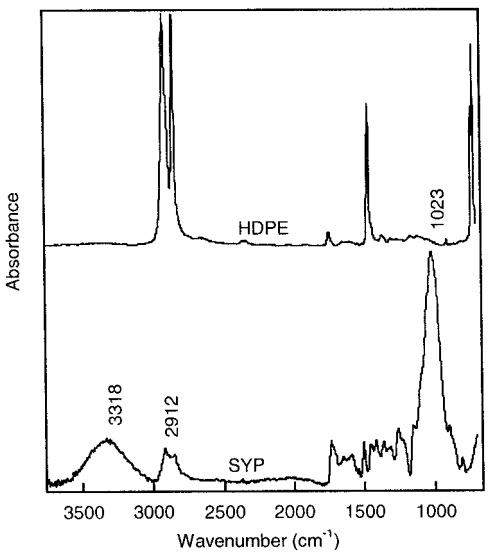

Figure 2 FTIR spectra of HDPE and southern yellow pine (SYP) samples.

broad peak at 3318 cm^{-1} is associated with mixed hydroxyl groups originating mainly from cellulose. The peak at 2912 cm^{-1} is due to CH stretching in —CH_2— groups; it appeared as a very strong peak in HDPE and a much weaker peak in SYP. Compared to SYP, a relatively large proportion of HDPE consisted of —CH_2— groups. The peak at 1023 cm^{-1} is assigned to a hydroxyl group associated with cellulose.[25]

Figure 3 shows FTIR spectra obtained for injection-molded, extruded, and planed composites. The increase in hydroxyl groups at the surface was clearly indicated as an increase in the broad peak at 3318 cm^{-1} and the strong peak at 1023 cm^{-1}. A wood index was calculated to relate the hydroxyl group peak at 1023 cm^{-1} to the methyl group peak at 2912 cm^{-1} [eq. (2)]. The results are shown in Table III. Planed samples had the highest wood index, followed by extruded and injection-molded samples. We expected that planed composites would exhibit stronger peaks corresponding with the wood component because wood particles were exposed during planing. The differences between injection-molded and extruded samples were probably due to processing differences. During processing, the higher pressures used in injection molding cause the formation of a thin layer of polymer at the surface. The increased pressure attributable to injection molding led to a composite with a thicker polymer-rich surface layer.

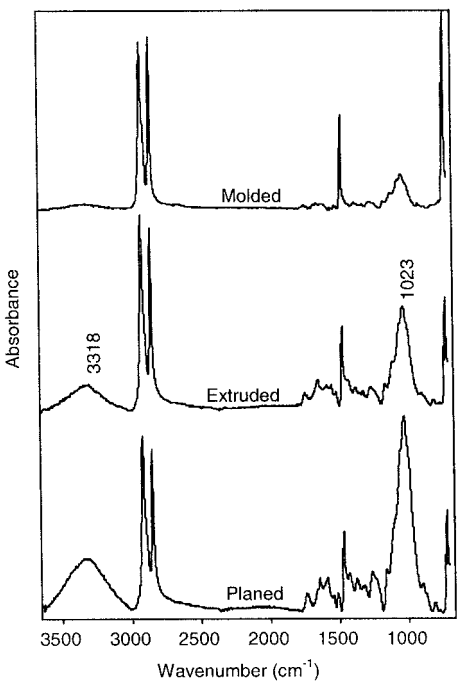

Figure 3 FTIR spectra of injection-molded, extruded, and planed WF/HDPE composites.

TABLE III
Wood Index Determined from Cellulose Peak at 1023 cm^{-1}

Sample	Wood index[a]
Injection molded	0.24 (0.02)
Extruded	0.44 (0.09)
Planed	2.74 (1.39)
Southern yellow pine	7.58

[a] Numbers in parentheses represent one standard deviation.

Micrographs of the surfaces of injection-molded, extruded, and planed composites are shown in Figures 4(a), 5(a), and 6(a), respectively. The micrographs visually confirm the FTIR data. The surface of the injection-molded sample [Fig. 4(a)] was relatively smooth, and polymer flow over wood particles was evident. The surface of the extruded sample [Fig. 5(a)] had many voids where the polymer failed to encapsulate the wood particles. The lower processing pressure and temperature did not permit the polymer to flow at the surface as well as did the processing conditions for injection-molded composites. Planed samples also had a relatively smooth surface [Fig. 6(a)]. However, it is visually apparent that wood fibers were exposed at the surface.

Exposed samples

Micrographs of unexposed and weathered surfaces are shown in Figures 4–6. Lightness, flexural MOE, and flexural strength of injection-molded, extruded, and planed composites are shown in Figures 7-9, respectively. In those figures, statistically significant differences between composites are represented by different letters. A common letter indicates that the dif-

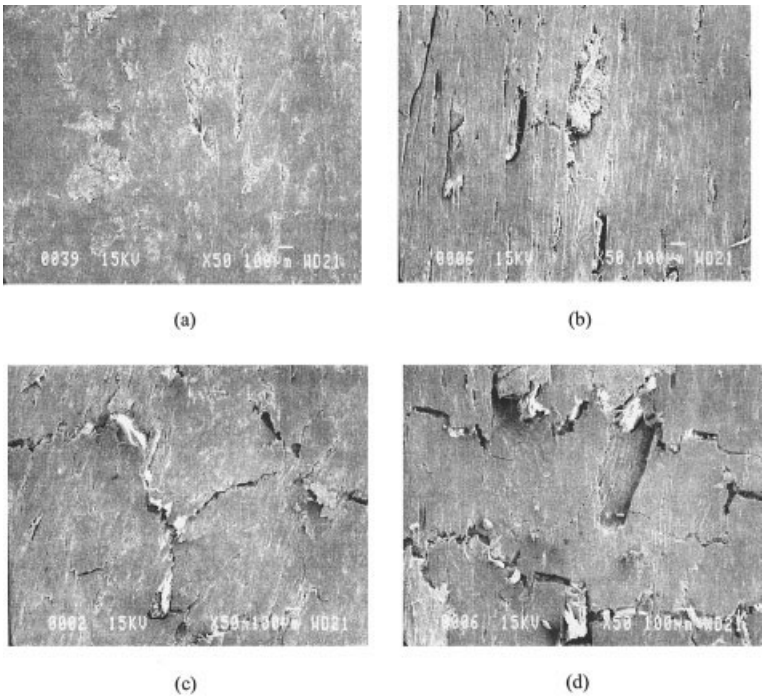

Figure 4 Micrographs of injection-molded WF/HDPE composites before weathering (a) and after 1000 h (b), 2000 h (c), and 3000 h (d) of weathering.

ference between two means is not statistically significant.

All samples showed surface cracking of the polymer matrix after weathering. In addition, swelling and shrinking of the wood particles after absorbing and desorbing moisture apparently resulted in voids at the wood–flour/HDPE interface. Surface cracking and destruction of interfacial properties continued as weath-

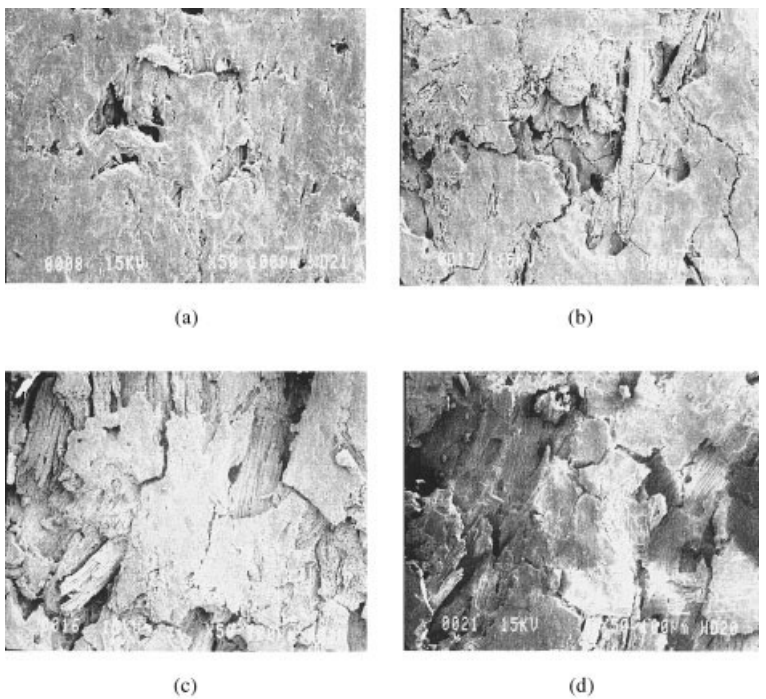

Figure 5 Micrographs of extruded WF/HDPE composites before weathering (a) and after 1000 h (b), 2000 h (c), and 3000 h (d) of weathering.

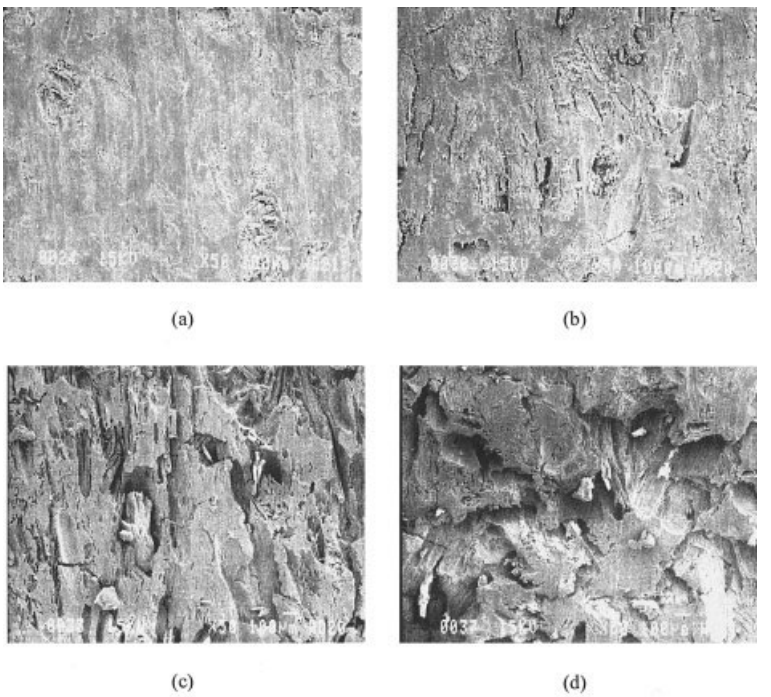

Figure 6 Micrographs of planed WF/HDPE composites before weathering (a) and after 1000 h (b), 2000 h (c), and 3000 h (d) of weathering.

ering time increased. The surface of the composite apparently began to flake off. This occurred after 3000 h of weathering for injection-molded samples [Fig. 4(d)] and after 2000 h of weathering for extruded and planed composites [Figs. 5(c) and 6(c), respectively]. Because of their high wood index, the surfaces of the extruded and planed composites were more drastically degraded after weathering than were the surfaces of injection-molded composites (Table III).

The effect of weathering on composite lightness, *L*, is shown in Figure 7. Weathering clearly resulted in lightening of the composite. For each production method, the change in *L* after each weathering period was significant. Regardless of manufacturing method, the greatest increases in *L* occurred in the first 1000 h of weathering, and all composites reached a similar lightness value after 3000 h. Lightening originates mainly from bleaching of the wood–flour and is a composite surface phenomenon. Lundin[3] found the depth of lightening of 50% wood–flour-filled HDPE to be 0.3 mm after 2000 h of weathering. Because final values of *L* were similar for all composites regardless of manufacturing method, we conclude that the lightened layer is deeper than the depth of the polymer-

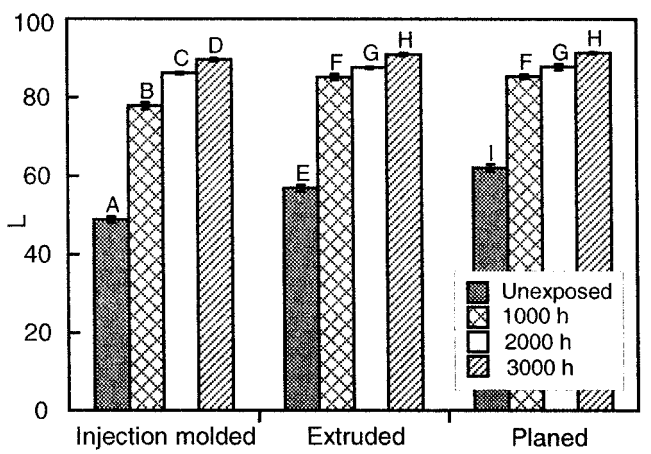

Figure 7 Lightness (*L*) as a function of processing method of WF/HDPE composites before and after weathering. A common letter indicates that the difference between two means is not statistically significant.

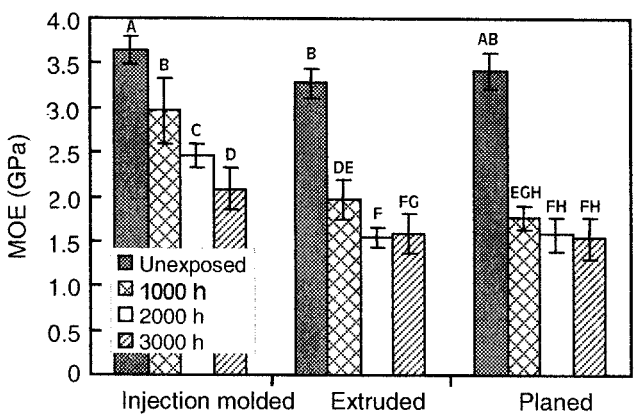

Figure 8 Flexural modulus as a function of processing method of WF/HDPE composites before and after 1000, 2000, and 3000 h of weathering.

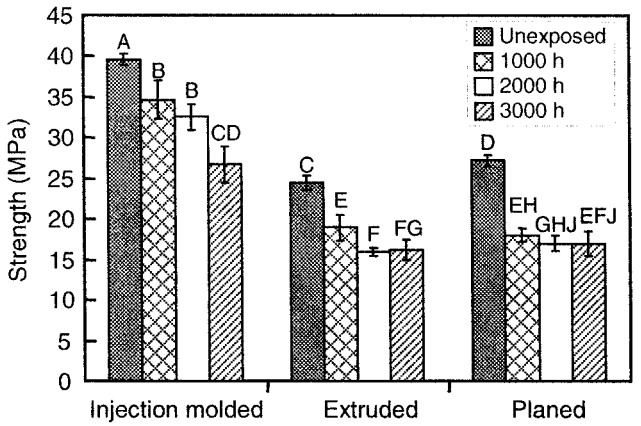

Figure 9 Flexural strength as a function of processing method of WF/HDPE composites before and after weathering.

rich layers in injection-molded and extruded samples. Therefore, production method has little effect on total lightness after 3000 h of weathering.

It is also evident that after 1000 h of weathering, planed and extruded composites were closer to their final lightness than were the injection-molded composites, with a lower wood index. After 1000 h of weathering, injection-molded samples reached 71% of total change in lightness, whereas extruded and planed samples reached 80 and 83%, respectively. This illustrates that samples with more wood component at the surface will experience a greater percentage of total lightening in the early stages of weathering.

Flexural MOE and strength generally decreased after accelerated weathering. The decrease in MOE for injection-molded samples was significant for each 1000 h of weathering (Fig. 8). For extruded samples, the decrease in MOE was not significant between 2000 and 3000 h of weathering. For planed samples, the decrease in MOE was not significant between 1000, 2000, and 3000 h of weathering.

The decrease in flexural strength for injection-molded samples was not significant between 1000 and 2000 h of weathering (Fig. 9). The same significant changes in strength after weathering were observed for extruded and planed samples as shown for MOE. After 3000 h of weathering, both MOE and strength were similar for extruded and planed samples, and lower than values for injection-molded samples. Unlike the effect on L after 3000 h of weathering, the manufacturing method did appear to affect final flexural properties; injection-molded composites had higher flexural properties after weathering compared to those of extruded and planed composites. The difference in rate of mechanical property degradation is likely due to a combination of differences in density as well as surface characteristics. However, it is expected that the mechanical properties of the injection-molded composites would reach those of the extruded and planed composites with further weathering.

Similar to the trend observed for lightness, extruded and planed samples were closer to their final MOE and strength values after 1000 h of weathering compared to injection-molded samples. After 1000 h of weathering, injection-molded, extruded, and planed samples reached 44, 77, and 88%, respectively, of total MOE loss. Similarly, injection-molded, extruded, and planed samples reached 38, 67, and 89%, respectively, of total loss in strength after 1000 h of weathering. These results imply that composites with more wood component at the surface will experience a large percentage of total property loss in initial weathering stages. Conversely, samples with a higher concentration of HDPE at the surface will experience a smaller percentage of total property loss in initial weathering.

This explains the apparently conflicting data reported by other researchers. Table IV shows the loss in MOE and loss in strength for 50% wood–flour-filled HDPE composites after weathering. Our results from tests on injection-molded, extruded, and planed samples were compared to results of two research studies in which samples were also injection molded and weathered.[3,6] In weathering 50% wood–flour/HDPE composites for 2000 h, Lundin[3] found that yield stress and bending stiffness decreased through 1000 h and then leveled off. Conversely, Stark and Matuana[6] found that MOE of 50% wood–flour-filled HDPE composites did not drop significantly after 1000 h of weathering. After 2000 h, MOE had dropped 26%. In addition to sample surface differences, the difference

TABLE IV
Loss in MOE and Strength After Accelerated Weathering for 1000, 2000, and 3000 h for 50% WF-Filled HDPE Composites Compared with Published Values

	MOE loss (%)			Strength loss (%)		
Sample [ref.]	1000 h	2000 h	3000 h	1000 h	2000 h	3000 h
Injection molded	19	33	43	12	18	32
Extruded	40	53	52	22	35	34
Planed	49	54	55	34	37	38
Injection molded [3]	29	33	—	17	20	—
Injection molded [15]	3	26	—	6	22	—

in results could be the result of comparing the effect of weathering on the basis of weathering time. The energy received by the samples also needs to be taken into consideration and may differ for each study.

The color fade of the composites was mainly due to the effect of UV exposure on wood–flour. The degradation of mechanical properties of WF/HDPE composites after weathering is thought to be primarily due to moisture effects (i.e., moisture-induced interfacial cracks resulting from wood particle swelling), although further study is needed. During weathering, the samples cycle through environments of 35°C and 100% relative humidity during the water spray cycle, and 40°C and 30% relative humidity during the dry cycle. Moisture has been shown to adversely affect properties of wood–plastic composites. Injection-molded HDPE composites filled with 40% wood fiber exposed to a water bath for 2000 h experienced 39% loss in flexural MOE.[15] Similarly, 30% WF/HDPE injection-molded samples lost approximately 25% flexural modulus after being exposed to boiling water for 50 h.[18] Processing method was also shown to influence moisture sorption properties. After soaking 50% WF/HDPE composites for 2 weeks, the more dense injection-molded composites absorbed only 4% moisture, while the less dense extruded composites absorbed 17%.[12]

CONCLUSION

FTIR can be used to examine the surface characteristics of wood–plastic composites manufactured by using different processing techniques. By following peaks associated with functional groups present in polyethylene and cellulose, differences in surface chemistry between manufacturing methods become apparent. In this study, injection-molded, extruded, and planed samples were analyzed. Injection-molded samples showed a greater polymer influence at the surface than did extruded and planed samples. Planed samples exhibited a strong wood component; wood particles were exposed when the polymer-rich surface layer was removed.

The higher processing pressures to which injection-molded samples are subjected result in a composite with higher density compared with that of extruded and planed samples. By improving interfacial quality, higher density improves the strength of injection-molded composites compared with that of extruded and planed composites.

The manufacturing method of wood–plastic composites greatly influences composite durability. Injection-molded samples show a greater polymer influence on the surface than do extruded and planed samples. Consequently, color fade is increased in injection-molded samples in the initial stages of weathering, as a result of bleaching of wood fiber. However, after sufficient weathering time, the faded degradation layer extends deeper into the composite than does the polymer-rich layer. Therefore, manufacturing method does not influence the total lightness of the composite after 3000 h of weathering.

Retention of flexural properties, however, is greatly influenced by processing method. In general, injection-molded samples retained higher flexural MOE and strength properties after 3000 h of weathering, compared with those properties of extruded and planed samples. In addition, extruded and planed samples lost a larger percentage of their total mechanical properties during the first 1000 h of exposure compared with that of injection-molded samples. This is likely the direct result of the loss in properties caused by moisture exposure. Planed samples provide a pathway for absorption of moisture as a result of the strong hydrophilic wood component at the surface.

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