Study of Plastic Compounds Containing Polypropylene and Wood Derived Fillers from Waste of Different Origin

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ABSTRACT: The scope of the article was to study the perspectives of the using of wood derived fillers (WDF) from waste of different origin as fillers of polypropylene. The WDF used in this study was hard wood flour (HW), birch veneer polishing dust (VD) and tetra-pack carton cellulose fiber (TC). Some mechanical strength parameters, water uptake in the static and cyclic test and resistance to fungal decay of polypropylene (PP) composites containing these three types of WDF were studied and compared with similar loading (40 wt %) talc-filled PP. Composites containing TC and VD fibers as filler showed the highest flexural strength at three test temperatures (−40, +20, and +40°C) and flexural modulus and tensile strength at plus temperatures. On the other hand talc-filled PP exhibited greatest flexural modulus at minus temperature, greatest impact strength at room temperature and best flow ability. Significant difference was observed between PP composites with HW and VD fillers regarding water uptake in cyclic tests, however flexural strength and modulus change of composites were reversible after drying. No weight loss of WDF/PP composites was observed after 6 week exposure to brown- and white-rot fungi, however, degradation of the surface of samples was detected by SEM. © 2010 Wiley Periodicals, Inc. J Appl Polym Sci 117: 368–377, 2010

Key words: Biofibers; composites; mechanical properties; fungal decay resistance

INTRODUCTION

In today's environmentally focused society natural fiber-based composites are penetrating the market of reinforced plastics and filled polymers that was previously dominated by glass fiber and different mineral fillers. According to data from the literature,[1] fibers derived from agricultural sources such as flax, hemp, sisal, kenaf etc. have been used as fillers in polymer composites. It has been shown by authors,[2,3] that strength and stiffness of such composites are better than virgin polymer and in terms of specific properties some of them are comparable with glass fiber reinforced plastics. However, the main part of prior work on lignocellulosic fibers in polyolefins has been concentrated on wood derived fillers (WDF), such as wood flour, sawdust, wood fibers and recycled newspapers.[4–6] WDF other than wood are preferable, especially if they are byproducts of different processes, because of the decreasing availability of natural wood resources. In the plastic industry, reprocessing of waste materials is a common practice. Moreover, the recovery processes comply with modern environmental guidelines that promote the reduction of waste arising from different processes.

Hence, the development of new value-added products such as WDF/polyolefin composites with the aim of utilization of the waste WDF (low cost fillers)—means there is no need for additional wood resources. Such materials otherwise would be burned or added to landfills. Application of such WDF composites includes plastic substitutes for timbers, lumbers, window-sills, floor tiles etc., therefore flexural strength and modulus, impact strength and water uptake are properties important for such products.

The mechanical strength of natural fiber-polymer composites is determined by the strength of the fibers and the polymer and the ability of the matrix to transfer stress to the fibers. This in turn, depends on the filler loading, size, aspect ratio, degree of dispersion and bonding at the interphase. In short-fiber reinforced composites, a critical length of fiber is required to develop its fully-stressed conditions in the matrix.[7] Polar natural fibers are not easily dispersed in hydrophobic polymers due to their intermolecular hydrogen bonding which leads to agglomeration. In the optimal case, the length, dispersion degree and bonding at the interface have to be adequate, then natural fibers works as reinforcement instead of being only filler. But this is not so easy to realize.

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TABLE I
Materials for Composite Formulation (WDF Loading: 40 or 50 wt %, MAH Loading: 5% of PP Weight)

Material	Origin	Grade	Description
Polypropylene (PP)	Commercial (Sabic GmbH)	Stamylan 17M10	MFI (190°C, 21.6 N) = 4.5 g/10 min T_m = 165°C
Coupling agent – maleated PP (MAH)	Commercial (Clariant GmbH)	Licomont AR 504	Acid value = 37–45 mg KOH/g viscosity = 650–950 mPa.s T_m = 150°C
Hard wood fiber (HW)	Commercial (J.Rettenmaier &Söhne GmbH)	Lignocel	Size = 0.2 – 2.0 mm aspect ratio approximately 1.5 – 5.6
Veneer polishing dust (VD)	Processing waste	–	Size $\leq$ 0.5 mm aspect ratio approximately 2.7–10
Tetra pack carton fiber (TC)	Processing waste	–	Size $\leq$ 1.0 mm aspect ratio approximately 20–70
Talc	Commercial (Salyana)	–	Size approximately 4.5 mkm polydispersity = 12.6

In order to clarify the technical viability of the two waste products of different origin: birch veneer polishing dust (VD) and tetra-pack carton (TC) cellulose fibers as a potential fillers in PP, compared to the widely used fillers, comparison was made with hard wood (HW) and traditional talc-filled PP composites. Maleated PP was used as the coupling agent.

Some mechanical properties and moisture uptake characteristics of the WDF/PP composites compared to talc-filled PP at the same loading were determined. Susceptibility of WDF/PP composites (50 wt % loading) to biodegradation was also monitored.

EXPERIMENTAL

Characteristics of the materials used are compiled in Table I. TC fibers were ground before use and sieved, the fraction which passed through a 1 mm mesh sieve was used. Other fillers were used as received and they differed between themselves by size and aspect ratio. Before mixing all WDF were dried for 24 h at 105°C. Compounding of components was done on a two-roll mill (40 wt % WDF) or twin-screw extruder (50% WDF). The mix of components was milled for 15 min in a laboratory two-roll mill (159 × 320 mm) at 0.8 mm nip setting and then sheeted out. The speed of the slow roll was 26 rpm with a gear ratio 1 : 1.23. The nip gap, speed ratio and milling time were kept the same for all blends. Composites with 50% of filler were mixed in twin-screw Haake extruder (L/D = 32, screw = 25 mm, screw rotation speed was 100 rpm).The barrel temperature ranged from 170 to 195°C, the residence time was 240 s. The extrudate was quenched inside the water bath and then were cut into granules with a pelletizer. Reason of the change of the mixer is imposibility to obtain homogeneous mixture on two-roll mill if content of filler is greater as 40%.

Tensile and flexural properties of PP composites were measured in accordance with ASTM Standards D638 M and D790 M. The Charpy un-notched impact strength was measured with impact pendulum tester Zwick 5102b according to ASTM D 256M. Injection molded samples were prepared on Kloeckner Ferromatic FM 85 molding machine, the temperature profile was: 40; 160; 170; 180; 180°C, injection pressure was 780 bar, mold temperature – 60°C. Melt flow index of composites was measured according ASTM D 1238 using load 21.6 N or 50 N at 190°C. Moisture absorption of composites were measured at relative humidity (RH = 97%) at 20°C by weighing on balance with precision of 0.00001 g. Cyclic wetting/drying test was performed with injection-molded bars for flexure. After 24 h in water at 20°C specimens were dried at 20°C for 24 h (1cycle) and measurements of water gain and change of flexural strength and modulus were recorded as a function of the numbers of cycles.

Fungal resistance of WDF/PP composites was tested according to standard EN 113. Specimens (2 × 2 × 0.5 mm) were sterilized at 100°C with water steam and placed in a sterilized bottle containing moist soil at a temperature of 22–28°C and RH = 70%. Bottles were inoculated with the brown-rot fungus *Coniophora puteana* BAM Ebw.15 or the white-rot fungus *Coriolus versicolor* CTB 863A. After 6 weeks of fungal exposure, specimens were removed from the bottles and their weight loss and moisture content were determined. Behavior of WDF/PP composites was compared with a control sample of solid pine wood.

After the fungal test surface morphology of all samples was observed using Scanning Electron Microscopy Vega Tescan (HV = 20 kV)

RESULTS AND DISCUSSION

Mechanical properties of PP composites

In randomly oriented short-fiber composites the fiber length, aspect ratio and content play an important

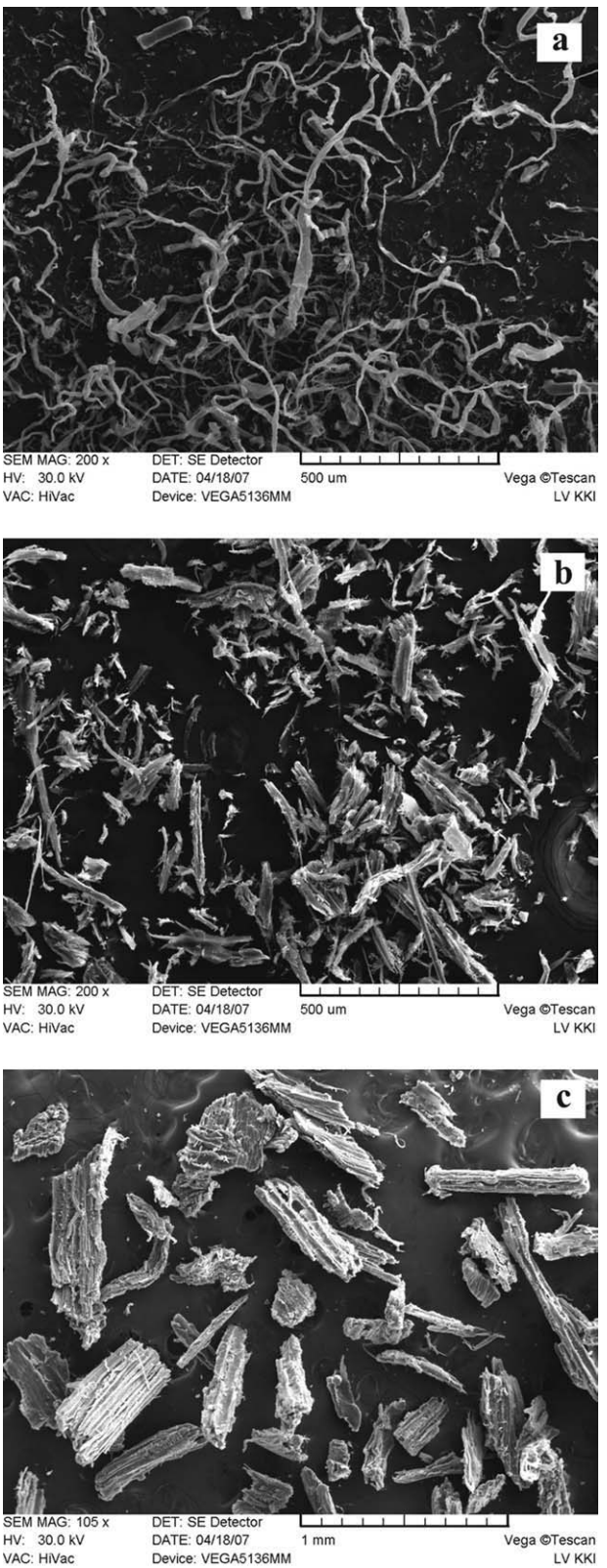

Figure 1 SEM micrographs of (a) cellulose fibers, (b) birch veneer polishing dust, and (c) wood particles. Magnification (a,b) 200× and (c) 105×.

role in determining their mechanical properties. WDF used in this study differ by the size and aspect ratio, as it is seen from Table I and SEM micrographs (Fig. 1). VD and TC are fiber-like and their aspect ratio lies around 10–80, whereas the aspect ratio of HW is approximately 2–6. The filler is particle-like, in the state of bundles with irregular shape. The bundle itself may be low in strength due to poor adhesion of fibers in the bundle, it would also reduce the strength of composite, containing such filler. WDF used in the study differ also by surface roughness (HW displayed higher roughness compared to two other WDF), which could play a significant role in mechanical interlocking of the polymer and could enhance adhesion with the PP matrix.

The flexural properties of injection molded samples depending on fiber type, loading and test temperature are presented in Figure 2. From the bar graphs it is evident that significant decrease in flexural strength and modulus occurs upon increase of temperature from −40°C to + 40°C independent of the type of filler. At similar filler loading (40%) talc-filled PP exhibited lower values of flexural modulus at plus temperatures compared with WDF composites. The exception is the modulus of talc-filled PP at −40°C, which is greater compared with WDF/PP composites. Regarding the flexural modulus of WDF composites, the highest value (3.8 GPa) was displayed by PP composite containing VD fiber, the

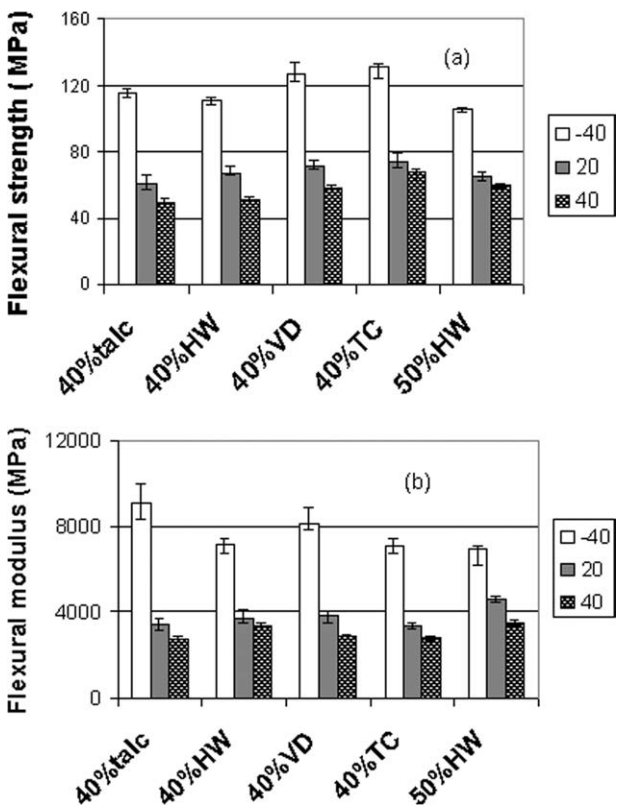

Figure 2 The flexural strength (a) and flexural modulus (b) of WDF/PP composites depending on WDF type and test temperature.

lowest – by composite containing TC fiber (3.3 GPA).

Cellulose fibers are more flexible compare with VD and HW fillers, it reduces their elastic modulus and consequently reduces modulus of the TC/PP composite. Furthermore, it should be remembered that the length of TC fibers is greater compared with VD or HW fillers, therefore, after injection molding TC fibers can be bent or curled. In short-fiber reinforced composites the fibers are not perfectly aligned in an un-axial direction and it is known that longer fibers give slightly lower orientation in molding direction. Our results are in contrast to the study of Premalal et al.,[8] which found that talc/PP composites exhibited higher flexural modulus when rice husk powder/PP composites at the same loading. However, in that case both fillers behaved as particles, while TC and VD used in our study presented fibrous structures, therefore their reinforcing effect is greater compared with rice husk filler.

The flexural strength of any reinforced composite depends on the strength properties of fibers, matrix, and fiber-polymer adhesion. The fiber strength and modulus are related to chemical composition of fiber and also its internal structure. The lower the cellulose content of a fiber, the lower will be strength of the fiber (and the strength of a composite containing such fiber). Among the WDF-s we tested, the TC fibers showed the greatest cellulose content.

All WDF composites showed better flexural strength than talc-filled PP and among the WDF fillers, TC fibers performed the best (TC composites displayed the highest flexural strength at 74.6 MPa). All over the temperature range used in this study, HW/PP composites exhibited the lowest values of flexural strength (66.4MPa). As in the case of tensile strength of WDF composites, the same trend was observed (Fig. 3). This behavior of WDF/PP composites can be attributed to the characteristics of different WDF (greater length and aspect ratio of TC compared with HW). If the surface area of fiber increases, fiber-polymer adhesion will improve resulting in composite strength increase. Influence of glass fiber length on the stiffness and strength of glass fiber-reinforced PP was reviewed by Thomason.[9] It was shown that increase of fiber length from 1 mm to 10 mm leads to increase of composite stiffness and impact strength.

Figure 3 demonstrates the correlation between flexural, tensile and impact strength of tested composites. The neat PP did not break at room temperature and introduction of fillers independent of type, as was expected, leads to a sharp decrease of σ_{imp}. It is evident that talc-filled PP exhibits lower flexural and tensile strength, but greater impact strength compared with WDF composites. This can be explained by the smaller size of talc particles compared with WDF and lack of the OH— groups on the talc surface, therefore its tendency to aggregation is smaller compared with WDF and this filler can be more homogenously dispersed in the PP matrix. It has been shown, that depending on particle size, the fracture type of talc-filled PP can be brittle (in the case of large particles) or ductile (if fine particles were used as filler).[10] Consequently, increase of impact strength was observed in the last case.

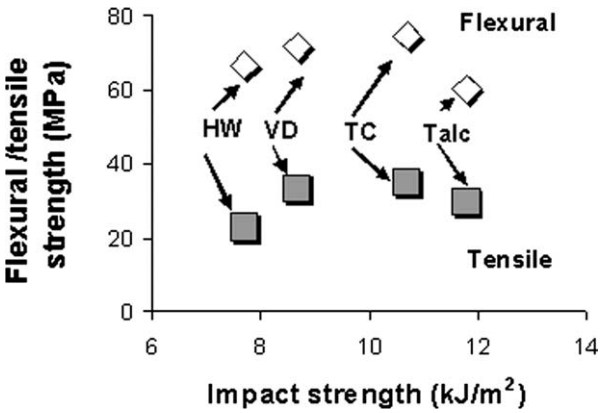

Figure 3 Correlation between flexural, tensile and impact strength of WDF/PP composites depending on WDF type. Filler content −40 wt %.

Among WDF composites the greatest value of σ_{imp} was demonstrated by TC filler. This filler has the greatest length and aspect ratio compared with the two other WDF we tested. The longer aspect ratio of the fibers inhibits their pull-out during impact event, it is also possible that the bridging provided by longer TC fibers results in better impact strength.

The correlation between fiber length of pineapple leaf and the impact strength of reinforced polyester was studied by Devi et al.,[11] who observed a lower fracture work for composites with fiber length shorter than a critical length. However, they draw the conclusion that the critical length of fiber is dependent upon which composite properties are being considered. Composite stiffness, for example, reaches 90% of maximum attainable with fiber length of only 1 mm, but to attain 90% of the maximum strength, fibers of 7 mm or longer were necessary.

The lowest value of σ_{imp} was demonstrated by PP composite containing HW. It should be remembered that large particles of that filler were in bundle state, and this would cause higher stress concentration, where cracking can be initiated more easily. As it will be seen from the SEM study [Fig. 4(b)], HW dispersion in the matrix is not homogenous, there exist zones with agglomerates, what leads to a decrease of composite mechanical strength.

It is well-known that impact energy is dissipated by debonding, fiber pull-out and fiber or matrix

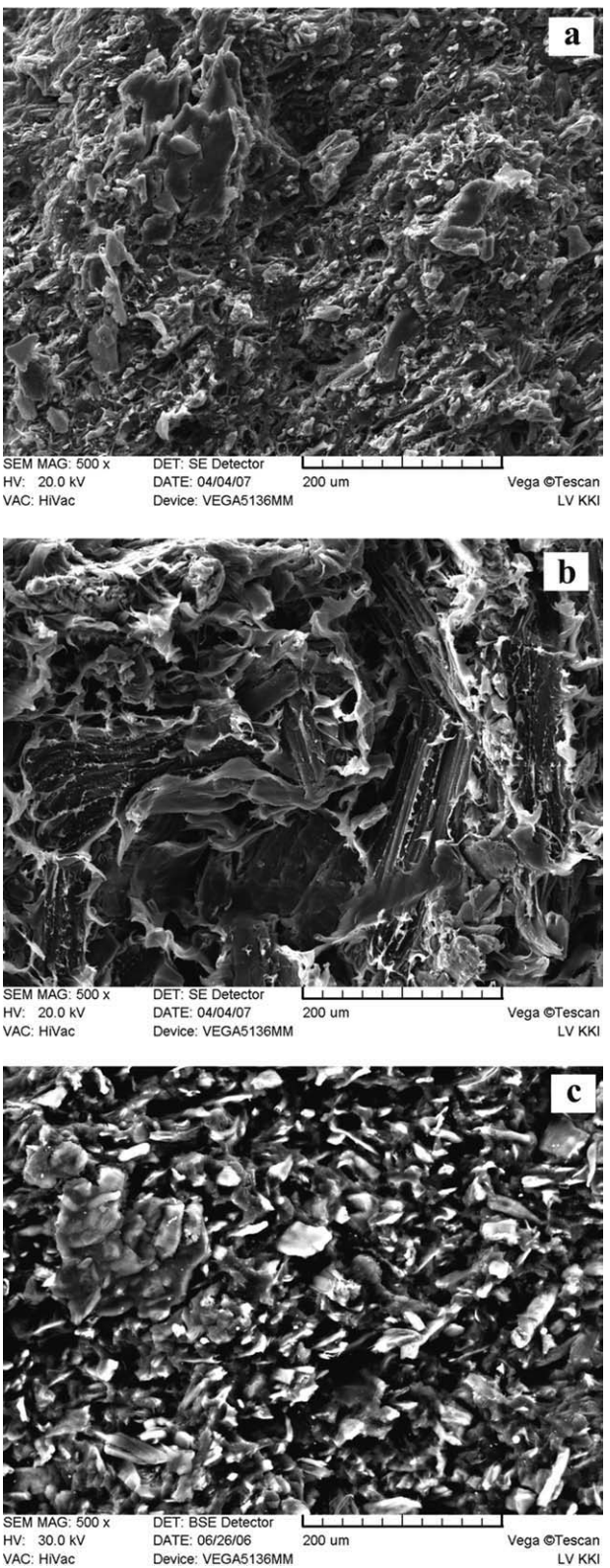

Figure 4 SEM micrographs of fractured surfaces of WDF/PP composites, which contain 40 wt % veneer polishing dust (a), wood flour (b) and cellulose fibers (c). Magnification 500×.

fracture. In the case of HW, the crack has not run through the HW/PP interface or perpendicularly through the fiber (as in the case of TC fibers), but it has split the HW bundles along their length [Fig. 4(b)].

All WDF composites displayed lower values of the impact strength compared with talc-filled PP, however in terms of specific σ_{imp} properties, WDF composites compared well with talc-filled PP (Table II).

MELT FLOW INDEX

Flow ability of PP/WDF composites prepared on two-roll mill (loading degree was 40%) was evaluated by the melt flow index (MFI).

From the bar graphs of Figure 5, it is evident that significant decrease in MFI occurs upon filling the PP with WDF compared with talc-filled PP. In the presence of filler particles the mobility of the PP macromolecule chains are restricted. It seems, that incorporation of WDF leads to greater restriction of the PP macromolecular mobility compared with talc. A similar effect of talc on the melt flow rate of PP was observed also by other authors, who showed, that the addition of 30% of talc to PP does not have a significant effect on polymer MFI.[10]

It is well-known that particles of this filler are in the form of plates, therefore, talc lubricate PP and facilitate to processing of PP composites.

Size and aspect ratio of fibers are main factors that influence melt flow of the composite independent on filler content. TC presented a larger value of aspect ratio than VD and especially HW. Consequently, the presence of TC fibers determines the greater rise of viscosity (decrease of MFI) of composite compared with HW. A similar tendency was observed by La Mantia et al.[12] for PP filled with glass fibers, sago starch and wood flour. The largest rise of the viscosity was shown by glass fiber-filled PP (glass fiber presented a larger value of aspect ratio than wood flour or starch). It was concluded that a shorter L/D ratio of fillers provoked a lower rise in the viscosity.

Incorporation of HW in PP caused the lowest decrease in composite MFI compared with the two other fillers at similar loadings. It can be assumed, that when large size HW particles were used as filler, the volume of unfilled regions within the polymer melt increases, resulting in greater flow mobility for the polymer and higher MFI of HW containing composites compared with those containing VD or TC.

SEM EXAMINATION

The SEM examination of the cross-sectional areas of impact-fractured samples revealed the fracture mode

TABLE II
Specific Mechanical Strength Properties of WDF/PP Composites (All Composites Contain 5 wt % MAH of PP Weight)

Filler	Tensile strength MPa	Flexural strength MPa	Flexural modulus MPa	Impact strength kJ/m^2
40% talc	24.2 ± 2.3	49.0 ± 2.5	2808 ± 200	9.7 ± 0.2
40% HW	22.5 ± 3.5	62.4 ± 2.7	3460 ± 270	7.2 ± 0.7
40% TC	32.0 ± 4.1	68.6 ± 7.0	3164 ± 124	9.8 ± 0.6
40% VD	31.8 ± 3.9	67.6 ± 5.0	3617 ± 280	8.2 ± 0.8

of the PP/WDF composites- they fail in the brittle way (Fig. 4). It was expected, that in the maleated composites, the impact energy absorption mechanism consists mainly of PP and WDF fracture (as far as fiber pull-out is partially suppressed due to better PP-WDF adhesion at the interface in the presence of coupling agent).

It can be seen, that HW fibers tended to cling together in bundles due to strong interfibre hydrogen bonding and they resisted dispersion of the individual fibers in PP matrix during compounding process. The failure mode observed shows fiber splitting, breakage and failure of both, fiber and PP. This explains the low value of impact strength of HW/PP composites. In wood cells there are two domains: the cell wall and the cell lumen. The lumen is a critical component of cells, it is void space available for water conduction, but also available for impregnation with polymers. Figure 6 shows open lumena of HW, however, part of the voids are filled with polymer, which is pulled- out during fracture. It is evident from Figure 4, that better dispersion of fibers within the matrix was achieved with TC or VD fibers in comparison with HW particles. The SEM micrographs displayed a VD and TC fibers embedded in the PP matrix, the fibers are connected with the PP layer. The fractured surfaces of PP/WDF composites characterized by broken PP matrix and LCF indicate that strong adhesion between VD (or TC) and PP was attained.

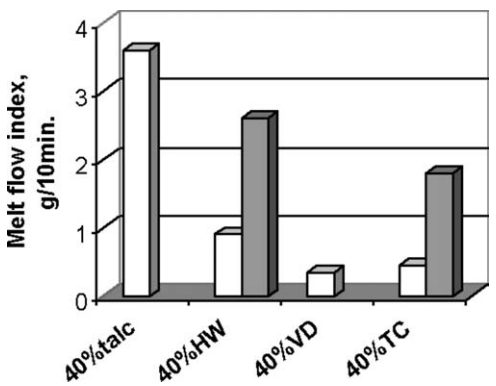

Figure 5 Melt flow index of WDF/PP composites at a load 21,6 N (dark bars) and 50 N (light bars) depending on WDF type.

The larger aspect ratio of TC tends to inhibit fiber pull-out, therefore in TC/PP composite impact energy is absorbed mainly by TC and matrix fracture. Considerable fiber rupture during the impact event seems to be the dominating failure mechanism of these composites.

MOISTURE ABSORPTION

The environmental stability of WDF composites is a key issue of concern. Strong interfacial adhesion, low moisture (water) absorption and dimensional stability are desirable properties for all WDF composites. Results of moisture absorption and cyclic wetting/drying tests respectively, for WDF/PP composites are shown in Figure 7. As it was expected, talc-filled PP exhibited the lowest moisture sorption ability, in contrast to the WDF composites.

Among WDF composites, which contain 40 wt % of filler, the greatest water absorption was exhibited by TC fiber, followed by VD and HW. A possible explanation of lower water uptake by HW/PP composite may be the fact that lumenas of that filler are impregnated by polymer and therefore less available to water. Increase of VD fiber content till 50 wt %

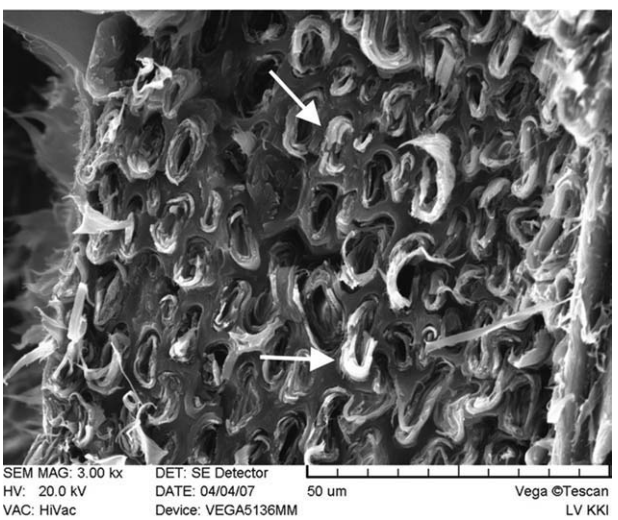

Figure 6 SEM micrograph showing PP penetration into HW lumens in PP composite containing 40 wt % HW. Magnification 3000×.

leads, as expected, to increase of moisture uptake compare to the composite with 40 wt % of VD. This could be caused by WDF agglomeration during compounding, which leads to forming of microcracks, through which water can more easily enter into the the bulk of polymer.

It is assumed that the water uptake of WDF composites is mainly a result of fillers water uptake, consequently, water absorption increase as the filler content increase. To see better difference between two filler types regarding water uptake in cyclic wetting/drying test, composites with 50 wt % filler content were prepared in twin-screw extruder and tested.

Two compounding processes were employed in this research (two-roll mill and twin-screw extruder), they differ by type and intensity of shear stress produced during mixing. Two-roll mill provides effective mixing along the tangential direction of the rolls, but lacks mixing efficiency along the longitudinal axis. It was shown by us[13] that both compounding methods (two-roll mill and twin-screw extruder) reduced wood filler size, however, greater size reduction was observed for composites compounded in extruder. On the other side – this type of mixing allowed to achieve better dispersion of filler because of the higher shear stress compare to two-roll mill. In this case filler will be less accessible to water because moisture penetration into natural filler containing composites can be conducted by: open fillers unprotected by polymer matrix and gaps between fiber and polymer in the case of weak interface adhesion. Regarding to influence of fiber size, it was shown[14] that water absorption increase with an increase of wood fiber length.

Water content changes in a 40-cycle soaking/drying test for two (HW and VD) composites are shown in Figure 7(b). It is interesting to note, that in the case of HW/PP composite most of the water uptake increase occurred in the first 15 cycles, contrary to composites with 50% VD, for which water uptake continued to increase to 36 cycles and only then were equilibrium values reached. It can be seen from Figure 7(b), that VD/PP composites displayed greater maximum water uptake than HW/PP composites.

During cyclic experiments values of flexural strength and modulus of both composites were periodically measured after the drying step. As it is seen from Figure 8, increase of cycle number does not affect these parameters during experiment time. This recovery of flexural strength and modulus indicates that the effect of water at room temperature is mainly physical interaction between hydroxyl groups of WDF and water molecules and upon their removal the properties of composites are fully restored.

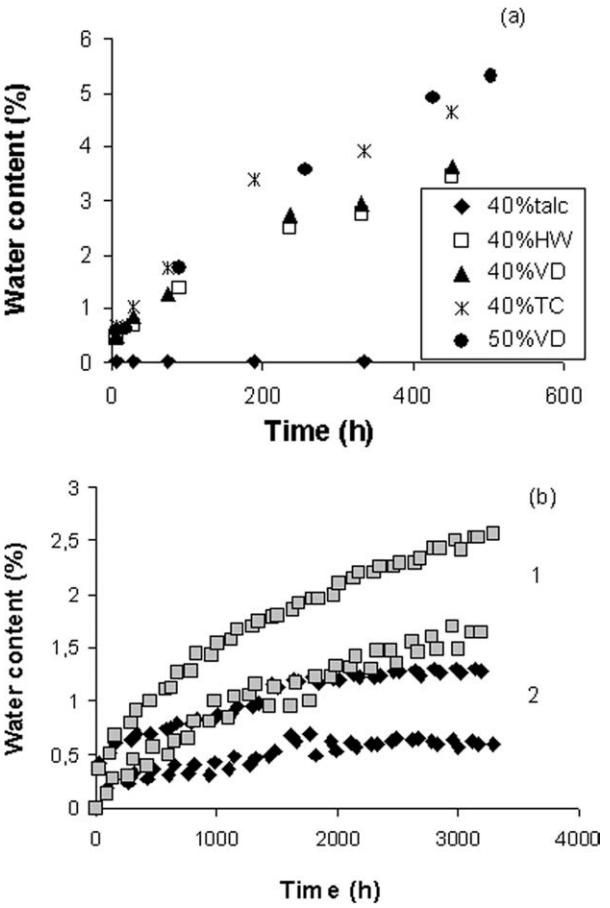

Figure 7 Water absorption of WDF/PP composites in (a) static conditions and (b) cyclic test at 20°C: 1- VD/PP composite, 2-HW/PPcomposite. Content of VD and HW—50 wt %.

FUNGAL EXPOSURE

Decay fungi are single-celled or multicellular filamentous organisms that use wood as food. Brown-, white-, and soft-rot fungi all have enzymatic systems that demethoxylate lignin and produce endocellulases.[15] Decay fungi need food (hemicellulose, cellulose, lignin), oxygen (air), optimal temperature (10–35°C) and moisture (above the fiber saturation point ~ 30%) to grow. Brown-rot fungus decomposes the carbohydrates (cellulose and hemicellulose) which leaves the lignin remaining, making the wood browner in color. Because of the attack on the cellulose, the strength properties of brown-rot decayed wood decrease quickly, even in the early stages. White-rot fungus decomposes all the structural components of wood. As the wood decays it becomes bleached. Toughness or impact strength of wood are the most sensitive parameters to decay. Decay results from the control samples and WDF/PP composites are presented in Table III. Exposure to brown-rot fungus caused the greater weight loss (14.9%) of solid wood compared with white-rot

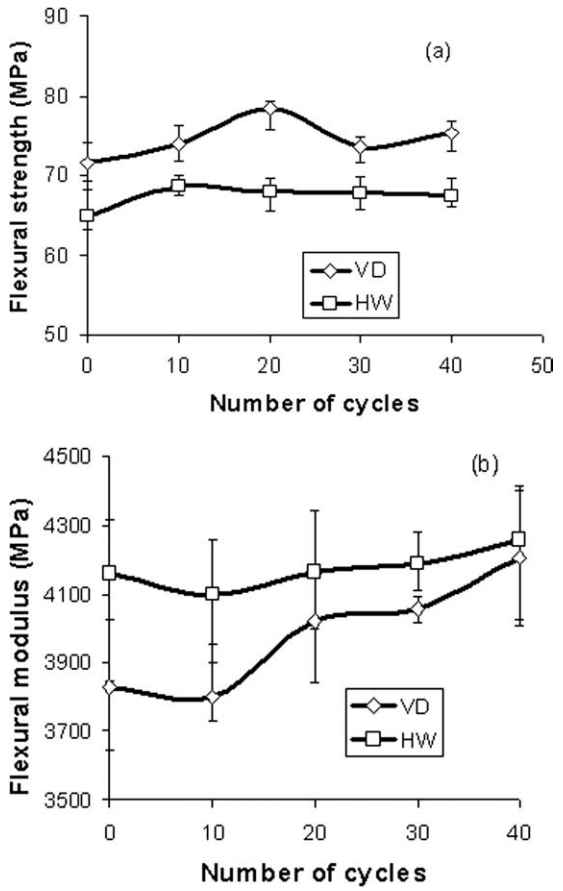

Figure 8 Influence of cyclic tests on (a) the flexural strength and (b) modulus of HW/PP and VD/PP composites. Content of VD and HW −50 wt %.

fungus (∼ 14%). These results demonstrate good fungal decay activity on solid wood.

In relation to WDF/PP composites, decay fungi did not cause weight loss in the tested samples. It seems, that encapsulation of WDF particles in polypropylene matrix prevents fungal attack. It is also possible that the encapsulated particles were prevented from attaining a moisture content, that was great enough to support decay (WDF composites absorb only ∼ 3% moisture compare with solid wood, which absorbed 76–83% moisture, if brown-rot fungus was used or ∼ 40% if white-rot fungus resistance was tested.)

The data from scanning electron microscopy, however, revealed changes in surface morphology of the samples after the fungal test (Figs. 9–11). During the fungal test two degrading factors took place: fungal attack and moisture. When HW/PP composite is exposed to moisture, large size HW particles swell significantly, and this leads to destruction of the surface layer of the sample (Fig. 9). When the protecting layer is destroyed the degrading factors have free access to the interior of composites and further degradation can be much faster. Formation of holes was observed on the surface of samples of TC/PP and to a lesser extent VD/PP composites. (Figs. 10, 11). The attack of brown-rot fungus is more damaging, when TC fibers were used as filler (Fig. 11).

TABLE III
Weight Losses and Moisture Uptake of WDF/PP Composites During Fungi Test

Sample	Test fungus	Weight loss %	Moisture content %
Solid pine	Brown-rot	14.3	76–83
Solid pine	White-rot	14.8	40.5–43.3
PP + 50% HW + 5% MAH	Brown-rot	0	2.8
PP + 50% HW + 5% MAH	White-rot	0	1.0
PP + 50% TC + 5% MAH	Brown-rot	0	2.9
PP + 50% TC + 5% MAH	White-rot	0	3.0

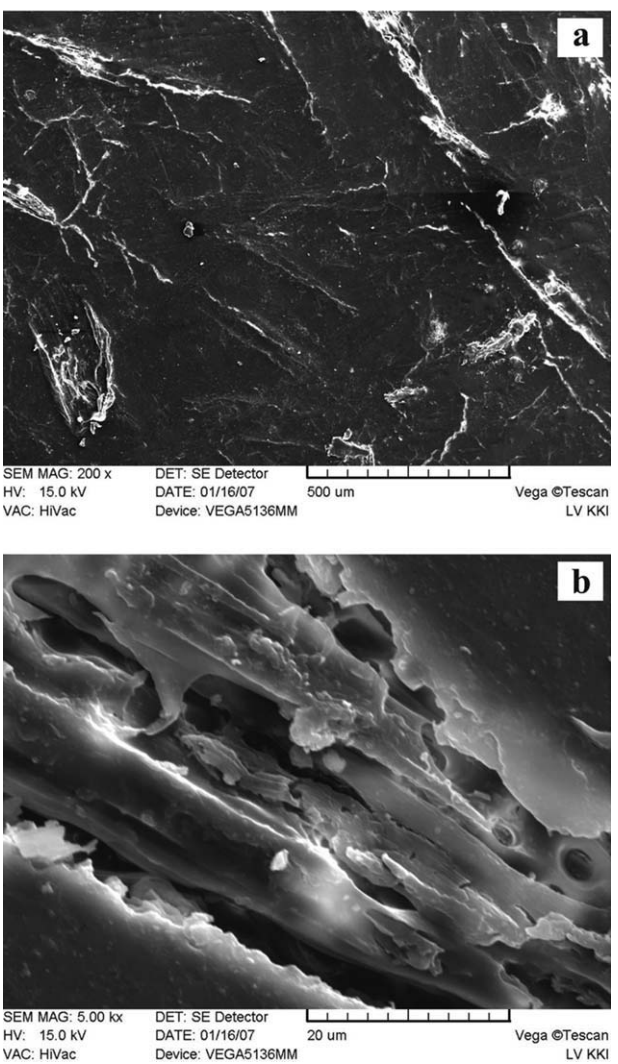

Figure 9 SEM photographs of PP/HW (50 wt %) composite surface after 6 weeks long exposure to brown-rot fungus at RH = 70%. Magnification: 200× (a), 500× (b).

Mankowski and Morrell[16] also observed, the effects of decay on wood/thermoplastic model composites through the use of SEM. However, Khavkine et al.[17] reported no significant decay of wood/thermoplastic composite containing wood content lower then 70% by mass.

Such contradictory results left a question as to how susceptible lignocellulosic fiber composites are to fungal attack. However, it is likely that such materials need to be treated with preservatives if outdoor application is expected.

CONCLUSIONS

The results of this study demonstrate the feasibility of two wood derived fillers (TC and VD) from waste of different origins as reinforcing filler for PP.

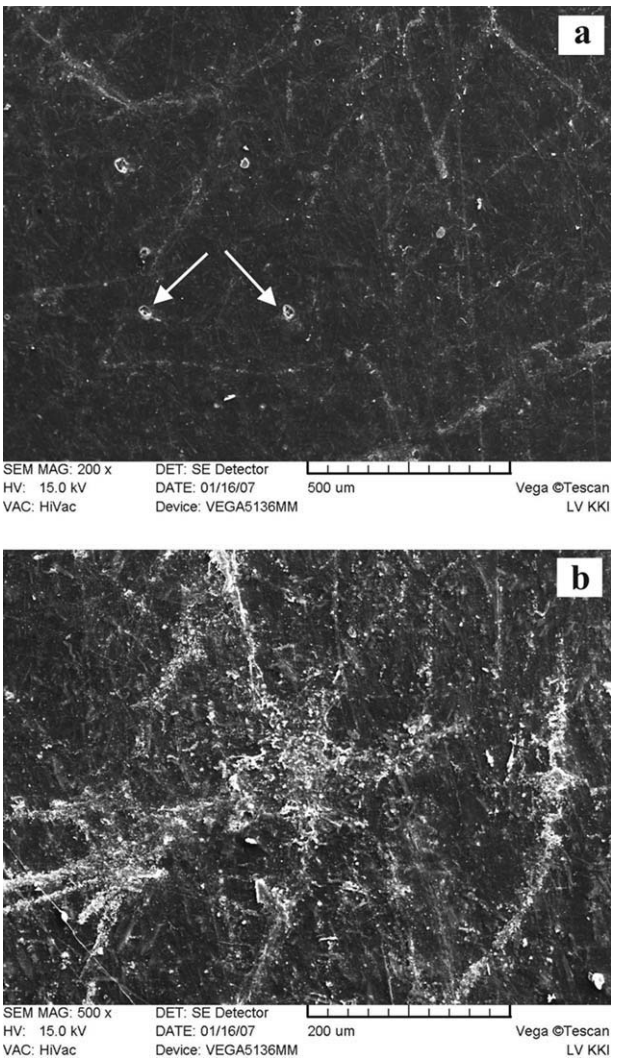

Figure 10 SEM photographs of PP/VD (50 wt %) composite surface after 6 weeks long exposure to brown-rot fungus at RH = 70%. Magnification (a) 200× and (b) 500×.

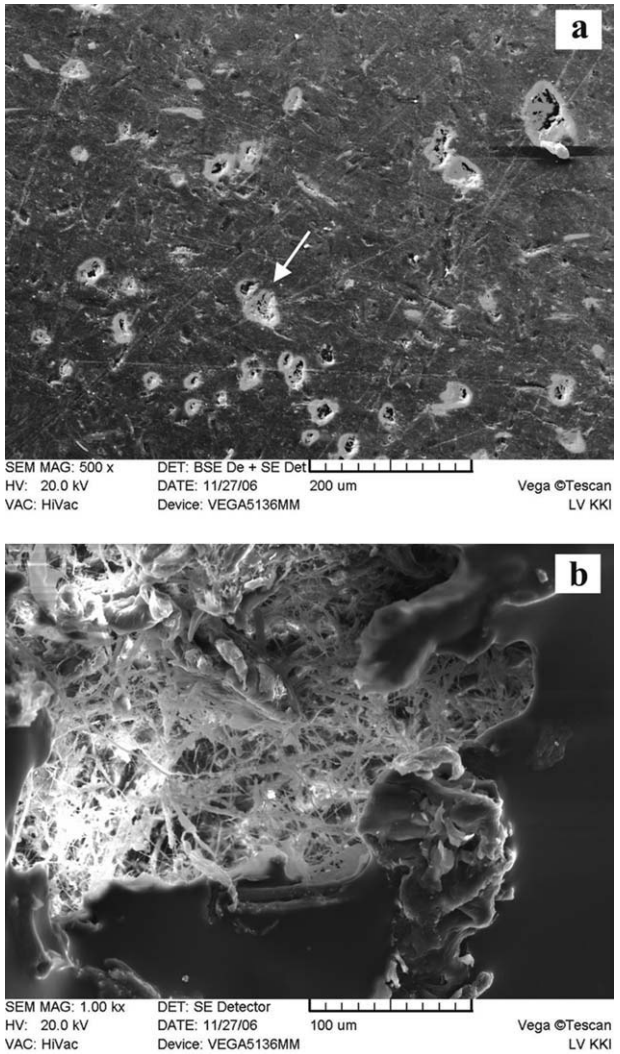

Figure 11 SEM photographs of PP/TC (50 wt %) composite surface after 6 weeks long exposure to brown-rot fungus at RH = 70%. Magnification (a) 500×, (b) 1000×.

Performance and processability of PP/WDF composites depends on the type of WDF- composites reinforced with TC and VD fibers displayed:

- greater tensile and flexural strength,
- greater impact strength,
- greater values of water uptake,
- lower values of MFI compare to composites with HW flour of similar loading.

Performance of PP/WDF and PP/talc composites at the same loading were compared. It was found, that talc composites exhibit greater flexural modulus at temperatures of less than 0°C, greater impact strength at room temperature and are easier to process than WDF composites. However, PP filled with WDF displayed higher flexural modulus at plus temperatures and tensile strength over the whole temperature range used in the study. All the specific

properties of PP/WDF composites also are greater compared with talc/PP composite.

Results of both the brown-rot and white-rot fungal decay tests demonstrated that WDF/PP composites did not show weight loss duaring test time, however, surface degradation of the samples took place.

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