MICRO- AND NANOCELLULOSE COMPOSITES FOR AUTOMOTIVE APPLICATIONS

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Abstract

Carmakers and their suppliers push cellulose-based material use for a variety of reasons depending on regulatory, economic, company policy-related and product-specific purposes. In spite of being the most abundant natural polymer on earth, the processing of cellulose into different types of micro- and nano structures has only recently received considerable attention. Using cellulose-based materials as reinforcement in thermoplastic composites is a novel application of nature-derived materials and it has numerous advantages for the environment, such as reducing CO2 emissions into atmosphere during their cycle of production, processing and use. However, incorporating cellulose as reinforcement in thermoplastic polymers also has challenges including: (1) the issue of compatibility between hydrophilic cellulose and hydrophobic polymers, (2) moisture sensitivity because of its hydrophilic nature, (3) uniform dispersion and extreme agglomeration, and (4) low thermal stability, limiting its applications in thermoplastics with high melting points. These challenges may be the reason of limited application of cellulose composites in automotive applications compared to glass fiber-based composites. This review of recent work discusses the opportunities, challenges, innovations and properties of micro- and nanocellulose-based technological developments reported by University of Maine researchers, related to micro- and nanocellulose fiber-filled thermoplastic composites especially engineering thermoplastic composites (melting point above 220 °C) and hydrophobic polymer composites (PP and PE based). It is believed that the knowledge gained from this work and future studies will result in micro- and nanocellulose replacing glass and mineral fillers in the automobile industry.

Background

Nanotechnology and nanomaterials are of great importance to the automotive industry to improve the performance of automobiles as well as meet both consumer needs and regulatory requirements. According to a recent estimate, nanotechnology and nanomaterials enabled products utilized in the automobile industry for 2010 was around $246 million and by 2015, estimates are up to $888 million (conservative) and $1.852 billion (optimistic) [1]. In spite of being the most abundant natural polymer on earth, the processing of cellulose into different types of micro- and nano structures has only recently received considerable attention. Cellulose micro- and nanobased materials have also received great attention in the automobile industry because of their broad availability, renewability, low density, environmentally benign nature (non-toxicity) and outstanding mechanical properties [2-10]. To meet the new 2025 Corporate Average Fuel Economy (CAFE) standards of 54.5 mpg. set by the Federal Government, automakers will need to be more creative and innovative. Figure 1 shows fuel economy progress in selected counties/regions [11]. Automakers are also looking for new materials and techniques to make cars safe, but much lighter [12]. According to the estimation of the CAFE, a 10% reduction in weight of a car can decrease fuel usage by 6–8% [13].
The higher volume fraction of lower density cellulose-based micro-and nano based fillers in plastic composites can address lighter weight materials that meet or surpass the performance requirements of the automotive industry. The automotive industry’s adoption of cellulose-based materials has been gradually accelerating over last several years and adoption of cellulose-based materials in the automotive industry is mainly driven by regulatory, economic, company policy-related and product-specific concerns [14]. Several Asian governments and European Union in requiring automakers to use cellulose-based materials, promoting recyclability of vehicle components, or requiring automakers to take responsibility for vehicle disposal at the end of a vehicle’s service life [14-15]. The increase in prices of plastics, both engineering (e.g., polyamides and polyesters) and commodity (e.g., polylefins) over the past few years has been the main economic driver of the adoption of cellulose-based materials in the automotive industry [3, 9]. Many automakers (Ford is researching formulation using up to 30% cellulose based fillers, which would typically replace talc or glass fiber composites in traditional automotive plastic compounds) have adopted company-wide sustainability policies that highlight the firm’s environmental responsibilities to both its employees and the public [14-15]. Cellulose-based products have specific advantages (specific strength and modulus) over their conventional counterparts (glass and talc fibers) that make them preferable for automotive applications [3].

The example below shows the importance of using cellulose fibers for the automobile industry. The Ford biomaterials research team has been working with wood and pulp giant leader, Weyerhaeuser, to investigate the use of plastic composite materials utilizing cellulose fibers from trees in place of fiberglass or mineral reinforcements. Weyerhaeuser, figured out how to make a thermoplastic composite called THRIVE™ using engineered cellulose fiber from trees, instead of the short glass fibers usually used for reinforcement. THRIVE composites are economical and currently available as cellulose blended with polypropylene with both high and low melt flow indices, and require less energy to produce and can reduce wear and tear on processing equipment when compared with those containing abrasive short glass fibers. Ford’s research has found that Weyerhaeuser’s cellulose-based plastic composite materials meet the automaker’s stringent requirements for stiffness, durability and temperature resistance. Further, components weigh about 10 percent less and can be produced 20 to 40 percent faster and with less energy when made with cellulose-based materials compared with fiberglass-based
materials. These weight and process savings can enable equivalent or reduced component costs and these substantial benefits create significant advantages for companies such as Ford Motor Company looking to reduce their carbon footprints while enhancing performance and productivity [16-17].

Besides Ford, many automakers (General Motors, Daimler, Toyota, Fiat, Volkswagen and BMW) use cellulose-based fibers such as flax, sisal, abaca, hemp, jute, wood, coconut, banana and wheat straw as reinforcement in plastic composites. These fibers have been used in many different parts and components including spare-wheel compartment covers, underbody panels, seat backrests, headliners, engine and transmission covers, under-the-hood radiator end tanks, rear panel shelves, door trim panels, dashboard components and interior components such as the luggage compartment, speakers, carpeting, package shelves, luggage-trim upholstery, cowl-side trim, door scuff plate, tool box area, floor finish plate, and seat cushions [14, 18-19]. In spite of the fastest growing reinforcement in plastic composites and advancements, there are still challenges which prevent cellulose-based materials' wider application in the automotive industry [14, 18-19]. Cellulose-based materials have unique negative characteristics such as cost (high energy consumption needed produce cellulose in micro and nanoscale), odor issues, increased susceptibility to moisture, degradation issues at higher processing temperatures and lack of compatibility between cellulose-based materials and hydrophobic polymers (polyolefins), as well as not being sufficiently flame-retardant [2-10, 14, 19].

This review of recent work discusses the opportunities, challenges, innovations and properties of cellulose micro- and nanobased technological developments reported by University of Maine researchers, related to micro- and nanocellulose-filled thermoplastic composites especially engineering thermoplastic composites (melting point above 220 °C) and hydrophobic polymer composites (PP and PE based). The studies in this section were selected because they were high profile and demonstrate a range of pathways to commercialize automotive components made from cellulose-based micro-and nanomaterials. The section will include information on 1) Microcrystalline Cellulose-Filled Engineering Thermoplastic Composites, 2) Green Composites: From Under Foot to under the Hood, and 3) Cellulose Nanofibrils-Polyethylene Nanocomposites Modified by Polyvinyl Alcohol.

**Microcrystalline Cellulose-Filled Engineering Thermoplastic Composites**

The automobile and construction markets need high specific strength and modulus, low density and inexpensive reinforcements for engineering thermoplastics (polyamide 6 and 66, polyethylene terephthalate (PET) and polytrimethylene terephthalate (PTT)). MCC is a naturally occurring substance obtained from purified, partially depolymerized cellulose, prepared by treating alpha cellulose, obtained as a pulp from fibrous material with mineral acids [10]. According to TGA results, MCC is thermally stable until 300°C which is much higher than melting temperature of nylon 6 (225 °C) and polyethylene terephthalate (270°C). Because of the high specific strength and modulus, low density and thermally stable structure of microcrystalline cellulose (MCC), it could be a good candidate as reinforcement for engineering thermoplastics. Although recent efforts have demonstrated the feasibility of producing cellulose-filled engineering thermoplastic composites, there are only a few studies because of the difficulties in producing the composites without considerable thermal degradation of the cellulose and high cost of engineering thermoplastics compared to commodity plastics [20-23]. Most were also concerned with mechanical properties and there is not enough information related to thermal and rheological properties and crystallization behaviour of engineering thermoplastics/cellulose composites in the literature.
In terms of the analysis and design of processing operations as well as understanding the relationship between structures and polymer properties of polymer composites, the flow or rheological behavior of the polymer composites is of great importance [24-25]. The rheological properties of cellulose reinforced composites are related to the materials’ microstructure, the state of cellulose dispersion in the matrix, as well as the interactions between cellulose and polymer chains [25]. In spite of its importance, the rheological properties of cellulose-filled engineering thermoplastic composites have rarely been investigated and still remain much less explored to date. The most important phase transition for processing semi-crystalline polymers is crystallization, which can be analyzed by both isothermal and non-isothermal methods. Addition of fillers to a polymer matrix may disturb the crystal structure and change its material properties such as the degree of crystallinity, size, distribution of the crystallites and spherulites which eventually affect the material properties [26]. Extensive studies have been carried out to understand the crystallization behavior of cellulose-filled thermoplastic composites; however, to the best of our knowledge, only one report found in the literature addresses the effect of cellulose on the crystallization behavior of engineering thermoplastic based composites.

The objective of this study was to prepare composites to investigate the influence of added MCC on the mechanical thermal and rheological properties and crystallization behavior for engineering thermoplastic composites. In this study, compatibilizers or coupling agents were not used because of the complicated rheological data by the fact that such composites contain several types of materials (coupling agents, MCC, etc.). This study is starting point for future research, which will help to understand relationship between structures and polymer properties of cellulose-filled engineering thermoplastic composites and easily compare the various properties of initial composites with compatibilizers or other additives.

In this study, engineering thermoplastic composites were fabricated that were reinforced with MCC at up to 30 percent MCC to PA 6 and polyethylene terephthalate (PET)/polytrimethylene terephthalate (PTT) blend weight ratios. Composites were prepared by melt mixing and injection molding. Overall, mechanical properties of the resulting composites showed comparable or better properties compared to the neat PET-PTT blend and neat PA 6. Thermal analysis of the composites indicated that rapid thermal degradation decreased with increasing MCC content. Thermal analysis also indicated that the MCC did not show significant initial degradation under 300°C, which implies thermal stability so that MCC-filled composites could be used for high temperature circumstances, like in under-the-hood applications in the automobile industry [4-7].

Rheological properties of PA6 and MCC composites were measured on a stress-controlled Bohlin Gemini rheometer (25 mm diameter, 1.0 mm gap) at a temperature of 235°C. The storage moduli of composites are higher than the pure matrix, especially for the highest MCC content in Figure 2. The slope of the storage modulus curves with frequency decreased a small amount with increasing amounts of MCC. The decrease in the slopes of storage modulus for the composites compared to PA6 can be explained by the microstructural changes of the polymer matrix because of the incorporation of MCC [25]. The MCC-MCC and strong PA6–MCC (interfacial) interactions increase with increasing MCC content [2].
It was found that the PA6-MCC composites behave as pseudoplastic fluids in Figure 3. The higher the MCC content of the composite, the higher the shear viscosity. This behavior is attributed to the hindering of the movement of the macromolecular chains of the matrix by the MCC [27]. The importance of the pseudoplastic behavior is larger as the MCC content in the composite increases [2].
To analyze crystallization kinetics, DSC analysis was carried out with a sample weight of 8–10 mg. All samples were held at 5°C for 5 min, heated at a rate of 5°C/min to 250°C, subsequently held for 5 min to erase thermal history, then cooled at a rate of 5°C/min to −10°C. The addition of MCC shifts the melt crystallization onset \( (T_{co}) \) and peak \( (T_{cp}) \) temperatures of PA 6 to larger values. The composite samples had lower percentage crystallinity \( (X_c) \) compared to neat PA 6, indicating the possibility that polymer chains had restricted movement in the composites microstructure. The Avrami and Tobin equations fit the empirical data well. There is also no significant change in crystallization parameters by adding MCC to PA 6 reflecting the poor nucleating effect of MCC [2].

**Green Composites: From Under Foot to under the Hood**

According to U.S. carpet industry statistics, the rate of carpet disposal is about 2-3 million tons per year in the US and about 4-6 million tons per year worldwide. Only less than 5% of this amount is being recycled and less than 1% is reused [28-32]. Nearly all the rest of the waste, approximately 95%, is disposed of in landfills [28]. Total carpet waste accounts for approximately 1 wt% and 2 vol% of the municipal solid-waste stream in the U.S. and is increasing every year because of the average life expectancy of a carpet. About 70% of the carpet produced replaces old carpet, which typically is between 8-11 years old [28, 30]. The landfilling of carpet waste has become a growing environmental problem because carpet waste is nonbiodegradable and diminishes the availability of landfills for other uses [28, 33-34].

Because of its versatility, moldability and resistance to high temperatures and harsh chemicals, nylon 6, 6 is the most frequently used engineering thermoplastic in the automotive industry today. It is forecast that the demand for nylon 6, 6 will be 1.1 million metric tons in 2012 and expand at a 4% rate. Demands for nylon 6, 6 will increase for the major sectors served. To expand demand, producers of engineering polymers must replace traditional materials like metal and glass with nylon 6, 6. Overall, worldwide automotive industry demand for nylon is expected to grow. Nylon 6, 6 from carpet waste could potentially fill this demand. Ford Motor utilizes Wellman Engineering Resins’ EcoLon material, a nylon comprised of 100% recycled carpet diverting 4.1 million lb of carpet that would have gone to landfills in 2010. In addition to their recycled content, the cylinder head covers are environmentally friendly and show great fuel economy because of weight savings of almost 20% when compared to aluminum die-cast cylinder head covers [35].

The lack of available landfill spaces, demands for resource conservation, environmental issues, the need for relief from foreign oil dependence and demands for nylon 6, 6 establish the importance of recycling carpet. There has also been increased interest in the use of natural fibers in numerous automotive interior and exterior parts recently. In this context, cellulose fibers (microcrystalline cellulose (MCC)) filled engineering thermoplastic (carpet waste (nylon 6, 6)) composites produced in this research for certain under-the-hood applications in the automobile industry where conditions are too severe for commodity plastics to withstand [8].

In this study, engineering thermoplastic composites were fabricated that were reinforced with MCC at up to 30 percent MCC to RPA 6, 6 weight ratios. Dynamic mechanical thermal analysis (DMTA) and thermogravimetric analysis (TGA) were used to determine thermal properties of the composites. Tensile, flexural and impact tests were used to evaluate the mechanical properties of the composites as well as determining the composite densities [8].
The tensile strength, tensile modulus of elasticity and elongation at break were determined from the stress and strain curves and the results are presented in Table 1. Tensile strength increased by 109% with 20% MCC addition. After 20 wt% MCC addition, the tensile strength decreased but it was greater than recycled nylon 6, 6. Elongation at break of composites was greater (reaching values of 1.98% with addition of 20 wt% MCC). Tensile modulus of elasticity increased by 36% with 20% MCC addition. The composite reinforced with MCC displayed comparable or higher flexural strength in comparison with the recycled nylon 6, 6. The flexural modulus of elasticity increased with increasing MCC loading. Flexural modulus of elasticity increased by 70% with 30% MCC addition [8].

Table 1: Summary of mechanical properties of recycled Nylon 6, 6 and MCC filled composites.

<table>
<thead>
<tr>
<th>Properties</th>
<th>RPA66</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>30</th>
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</thead>
<tbody>
<tr>
<td>Tensile Strength (MPa)</td>
<td>C, 26.2</td>
<td>C, 34.6 (NC)</td>
<td>B, 44.2 (68.4%)</td>
<td>A, 54.9 (109.3%)</td>
<td>A, 53.9 (105.6%)</td>
</tr>
<tr>
<td>TMOE (GPa)</td>
<td>D, 3.2</td>
<td>CD, 3.4 (NC)</td>
<td>C, 3.5 (7.6%)</td>
<td>B, 3.9 (19.4%)</td>
<td>A, 4.4 (35.8%)</td>
</tr>
<tr>
<td>EAB (%)</td>
<td>D, 0.8</td>
<td>CD, 1.1 (NC %)</td>
<td>BC, 1.3 (59.1%)</td>
<td>A, 1.9 (140.4%)</td>
<td>B, 1.5 (81.1%)</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>C, 84.3</td>
<td>B, 89.6 (6.3%)</td>
<td>A, 95.9 (13.9%)</td>
<td>B, 91.9 (9.1%)</td>
<td>C, 84.2 (NC)</td>
</tr>
<tr>
<td>FMOE (GPa)</td>
<td>E, 2.2</td>
<td>D, 2.5 (15.4%)</td>
<td>C, 2.8 (28.3%)</td>
<td>B, 3.30 (50.3%)</td>
<td>A, 3.7 (70.0%)</td>
</tr>
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</table>

The same letters indicate no statistical difference between properties of composites and those around it. NC is no significant change upon the addition of natural fiber blends (α=0.05) and parenthesis show the effect of natural fiber blends loading on the mechanical properties of composites in comparison with the neat Nylon 6. FMOE: Flexural modulus of elasticity, TMOE: Tensile modulus of elasticity and EAB: Elongation at break [8].

Figure 4 shows the temperature dependence of the storage modulus of recycled nylon 6, 6 and MCC-filled composites. The recycled nylon 6, 6 shows a typical behavior of semi-crystalline polymer. MCC-filled composites show a similar behavior and have a higher modulus for all temperature ranges especially temperature ranges for under-the-hood application compared to the unfilled composites [8].

![Temperature range for under-hood application (from -40°C to 125°C)](image)

Figure 4: Storage modulus of recycled nylon 6, 6 and MCC filled composites from -50 to 150°C as a function of temperature [8].
The thermal expansion of the composites decreased with increasing MCC content. Thus, MCC filler is a suitable material for preventing the thermal expansion of the composite materials caused by cold and warm atmospheric changes. The thermal expansion of the recycled nylon 6, 6 and MCC-filled composites increased with increasing temperature because of the increased polymer chain mobility at higher temperature. The creep compliance decreased with the incorporation of MCC at all test temperatures. The magnitude of creep compliance undergoes a large reduction with the increase in MCC content. This fact can be observed, for example, from the drop in creep compliance at 60°C by about 61 % and 68 % for the composites with 20 and 30 wt.-% of MCC content, respectively, compared to recycled nylon 6,6, which indicates enhanced creep resistance. The results show that as the filler loading increased, the thermal stability of the composites slightly decreased as the MCC content increased because of the lower thermal stability of MCC compared to the recycled nylon 6, 6. The TGA results also demonstrated thermal stability decreased slightly with the addition of MCC but still within temperature ranges for the automobile industry [8].

**Cellulose Nanofibrils-Polyethylene Nanocomposites Modified by Polyvinyl Alcohol**

A broad range of potential applications of CNF to high-performance bio/nanocomposites have been developed and these applications are expected to open up opportunities that would allow the replacement of conventional petroleum based-composites with new and better composites properties such as greener, cheaper, lighter and materials with higher resistance [36-38]. However, despite these active research activities and their attractive properties, there are several obstacles for the use of CNFs, that is, cost-effective methods for producing CNFs, enhancing their dispersion property in matrix systems especially difficulty of using CNFs in systems which are not water-based and polar and improving their interfacial adhesion properties [37, 39]. Several routes were adopted to improve compatibility at the fiber-matrix interface and to enhance dispersion of CNFs, which include the use of surfactants, use of functionalized CNFs and use of coupling agents. However, these routes are expensive, time consuming and hardly compatible for industrial applications [36, 40-41]. Thus, the most important barriers is the achievement of desired degree of dispersion in CNFs reinforced polymer nanocomposites using industrial techniques without using solvent methods and surface functionalization for CNFs.

A possible approach to get better dispersion is to use a water soluble polymer as a carrier system for the CNF suspension in the hydrophobic polymer matrices. This water soluble polymer is expected to encapsulate the single CNF fibers and provide better dispersion in the polymer matrix and formation of strong hydrogen bonds as the water is evaporated [42]. Poly(vinyl alcohol) (PVA), water soluble with high strength is a large volume produced polymer and should be a great candidate as a carrier system for CNF suspensions for hydrophobic polymers because the hydroxyl groups on partial hydrolyzed PVA are expected to interact with the hydrophilic surfaces of cellulose and the residual vinyl acetate groups with hydrophobic PE [42].
The objective of this study was to develop a novel carrier system using PVA to create compatibility between the CNF suspension and a conventional PE matrix and to increase the mechanical properties of PE using CNF with PVA. In this study, the PE composites were prepared by first melt blending and then followed by injection molding. Mechanical properties, thermal stability, melt rheology and morphological behavior of PE and composites with various CNF loadings with carrier system were studied in this work. The advantages of the carrier system include: the use of wet, high solid CNF suspension in combination with a conventional melt blending process that has been optimized to produce enhanced PE-based nanocomposites. No pre-drying of the CNF is required which can save process time and money. The commercial application for this method would be in glass fiber and inorganic-filled PE composites such as in packaging, automobile applications (side panels, dashboard, etc) and related consumer goods.

The results of mechanical properties of composites are presented in Table 5. The TMOE of the composites continuously increased with increasing CNF loading (reaching values 1.1 GPa with the addition of 5% CNF-PVA). The tensile strength increased by 25% with 5% CNF-PVA addition compared to neat PE. The FMOE increased by 45% up to 10 wt. % CNF, where it reached a maximum value of 0.7 GPa. The flexure strength of neat PE is 16.2 MPa and incorporation of CNF significantly increased flexural strength (10 wt. % CNF content, increase 20%). Izod impact strength reduced 60% for 10 wt. % CNF composite compared to neat PE. Table 2 also shows the MFI values for the PE and PE+PVA and CNF composites. The MFI also decreased with increasing treated CNF loading and the MFI value of the neat PE was 4.7 g/10 min and decreased to 3.9 g/10 min (10 wt. % CNF content, decreased 17%)

Table 2: Mechanical properties and MFI of PE, PE+PVA and CNF composites.

<table>
<thead>
<tr>
<th>Samples</th>
<th>PE (MPa)</th>
<th>PE+PVA (MPa)</th>
<th>1%CNF (MPa)</th>
<th>2.5% CNF (MPa)</th>
<th>5% CNF (MPa)</th>
<th>10% CNF (MPa)</th>
</tr>
</thead>
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<tr>
<td>TS (MPa)</td>
<td>13.9 (0.3) D</td>
<td>14.6 (0.2) C</td>
<td>14.7 (0.2) BC</td>
<td>15.3 (0.8) B</td>
<td>17.4 (2.4) A</td>
<td>16.8 (0.3) A</td>
</tr>
<tr>
<td>TMOE (GPa)</td>
<td>0.8 (0.02) D</td>
<td>0.9 (0.04) C</td>
<td>1.0 (0.05) BC</td>
<td>1.1 (0.07) AB</td>
<td>1.1 (0.09) A</td>
<td>1.1 (0.03) A</td>
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<tr>
<td>IS (J/m)</td>
<td>149 (18) A</td>
<td>136 (16) A</td>
<td>104 (7) B</td>
<td>85 (11) C</td>
<td>73 (4) CD</td>
<td>60 (4) D</td>
</tr>
<tr>
<td>FS (MPa)</td>
<td>16.2 (0.3) E</td>
<td>16.8 (0.5) DE</td>
<td>17.2 (0.9) CD</td>
<td>17.7 (3.3) BC</td>
<td>18.2 (3.7) B</td>
<td>19.5 (0.6) A</td>
</tr>
<tr>
<td>FMOE (GPa)</td>
<td>0.5 (0.06) E</td>
<td>0.5 (0.02) C</td>
<td>0.5 (0.04) C</td>
<td>0.6 (0.02) BC</td>
<td>0.6 (0.02) AB</td>
<td>0.7 (0.04) A</td>
</tr>
<tr>
<td>MFI (g/10 min)</td>
<td>4.7 (0.1) A</td>
<td>4.6 (0.1) A</td>
<td>4.7 (0.1) A</td>
<td>4.6 (0.3) A</td>
<td>4.1 (0.1) B</td>
<td>3.9 (0.1) B</td>
</tr>
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</table>


The thermal stability of the composites decreased slightly as CNF content increased because of the lower thermal stability of CNF compared to the neat PE. The higher the CNF content of the composite, the higher the shear viscosity. The shear viscosities at shear rate 0.01 (\(\eta_{0.01}\)) for PE-5% CNF with PVA carrier system and PE-10% CNF are on 35% and 95% higher than that of the matrix PE respectively. For comparison, at \(\omega= 0.1\), the elastic modulus of PE-5%CNF with PVA carrier system and PE-10% CNF are up to 68% and 190% higher than that of neat PE respectively. The melt creep compliance decreased with the incorporation of CNF. The addition of CNF to the system, it also increases the melt recoverable structure of the composites. It seems that the micrograph of 5% CNF with PVA carrier system and 10% CNF showed evidence of aggregation of CNF fibers and generally poor adhesion between the CNF surface and the PE matrix in Figure 5. The cavities and agglomerates are much smaller in the 5% CNF with PVA carrier system than in the 10% CNF because partial hydrolyzed PVA interacted with the hydrophilic surfaces of cellulose and the residual vinyl acetate groups with hydrophobic PE.
Conclusions

Cellulose-based micro- and nano-material breakthroughs can come from green, sustainable, fuel efficient, stronger and lighter cars: results from intensive research and development efforts driven by regulatory, economic, company policy-related and product-specific concerns. It is possible to produce composites of cellulose fiber in high melting engineering thermoplastics with melt compounding followed by injection molding without compatibilizers and surface treatment. The use of wet, high solid CNF suspension in combination with a conventional melt blending processes that have been optimized to produce enhanced PE-based nanocomposites. No pre-drying of the CNF is required which can save process time and money. Higher specific properties with lower prices of cellulose-based materials are making it attractive for different parts and components in the automotive industry such as side and back door and other panels, dashboard components and under-the-hood radiator end tanks. Knowledge gained from this work and future studies are important for the automotive industry because of awareness towards green products and increasing acceptability, need of light weight, cost effective products, reduced global warming effects. Performance improvement of cellulose-based micro- and nano fillers (surface modification, new compounding techniques and the use of new engineering thermoplastics) will help cater to more applications and industries in the near future.

Figure 5: Over-view of fractured composite surfaces: (a) neat PE, (b) PE+PVA (c) 5%CNF with PVA carrier system and (d) 10 % CNF filler loading.
References


