Mechanical and thermal properties of horn fibre reinforced polypropylene composites

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Abstract

A new particle-reinforced composite has been developed using defatted horn fibre (HF) and polypropylene (PP). Physical, mechanical, thermal and micro-structural properties of HF/PP composites with varying fibre wt% (5%, 10%, 15% and 20%) have been characterized and compared with the properties of pure PP and pure HF. Mechanical properties of pure HF are found to be very high compared to pure PP and HF/PP composites. Compared to pure PP, HF/PP composites show an increase in tensile yield strength slightly, tensile modulus by 15.74%, flexural strength by 16.95% and flexural modulus by 59.69% and decrease in ultimate tensile strength by 15.03%, percentage elongation at break and impact strength to a considerable amount. Melt flow index for HF/PP composites decreases with increase in fibre content. Thermogravimetric analysis reveals that there is an increase in thermal stability of HF/PP composites with increase in fibre content. SEM micrograph shows that there is good compatibility between HF particles and PP. Among the HF/PP composites, composite with 15 wt% of HF particles has optimum results. The horn and HF/PP composites with low density and good properties can find application in fields like automobile, computers, construction, house ware, etc.

1. Introduction

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Horns are pointed projections found in the heads of oxen, buffalo, sheep, goat, etc. They are never branched and are usually found in pairs. Oxen horn consists of a core, for the support of the horn arising in the dermis of the skin and is fused with the skull. These cores are of elongated conical form and vary greatly in size, length, curvature and direction. Horn is formed as a hollow cone-shaped sheath around this core [1]. Animals use horns for protecting themselves from predators and fighting with their own species for territory dominance or mating priority. These horns are composed of a structural protein called keratin.

In fact, keratins are components of tissues that act as an interface between the internal and external environment of a living organism and serve as a barrier to environmental stresses. Rigidity and strength of keratin are mainly due to sulphur-sulphur intramolecular cross links between cysteine amino acid residues and to extensive intramolecular hydrogen bonding. Based on the amount of sulphur/cysteine content, keratins are distinguished as soft and hard keratins. Soft keratins have lower sulphur content and are found in epidermis and calluses. Hard keratins have higher sulphur content and are generally classified into two groups, hard α-keratin found in mammalian epidermal attachments like hairs, quills, horn, nails, etc. and β-keratin found in avian and reptilian tissues. α-keratin has α-helical coiled coil structure while β-keratin has twisted β-sheet structure [2].

Horn keratin belongs to α-keratin that consists of an amorphous matrix phase and a crystalline fibre phase. The amorphous phase has non-helical fraction of microfibrils with a high content of cysteine while the crystalline phase has α-helical fraction of microfibrils with a low content of cysteine. Hard α-keratin fibre is a hierarchically structured material that is fibrous in structure measuring from nanometre to micrometre scale. The matrix adheres to the filaments by means of secondary bonds like van der Waals forces, hydrogen bonds and ionic interaction. Thus keratins form a biological representation for polymeric nanostructured composite materials [2].

One of the by-products of the slaughter house is oxen horn. As per the regulations framed by certain countries these horns are allowed for the production of ‘technical products’ intended for purposes other than human or animal consumption, including organic fertilizers and soil. Very small percentage of horn is used for the manufacture of useful items from the central core of the horn. In such cases the central core of raw horn is turned into cylindrical form by removing the outer layers of the horn in the form of chips. These chips and the horns that cannot be used for production of useful items become landfill and pose huge problem causing environmental pollution. These horns with high strength, high rigidity and low density and with fibrous structure can be used as reinforcing fibre for the manufacture of composite materials.

PP is a tough and flexible thermoplastic material used mainly in the manufacture of automobile parts. Its glass transition temperature (T_g) is much below the room temperature and its crystalline melting temperature (T_m) is much above the room temperature. At room temperature it is semicrystalline in structure. Decrease in crystallinity increases transparency of PP. The melt flow behaviour of PP makes it easy to manufacture using any one of the moulding processes. At room temperature, the crystalline portion bears the load and amorphous portion makes it to move and thus improves toughness. Properties of PP can be enhanced by fibre reinforcement. But, it is possible only when there is a strong bonding between fibre and PP. Compatibilizers can be used to increase bonding between fibre and PP. Recyclability, high strength-to-weight ratio and toughness of PP makes it to be selected as matrix material.

A number of research works have been carried out on composites with various plant based natural fibres and animal based keratin fibres reinforced with polymer matrices. Structure of horn has been briefed by Septimus Sisson [1]. Frequency and temperature dependence of dielectric constant and loss factor in cow horn keratin have been investigated by Tasneem Zahra Rizvi and Muhammad Abdullah Khan [2]. Structure and mechanical properties of proteins have been discussed by Marc Andre Meyers et al. [3]. Tensile properties of various plant-based natural fibre reinforced polymer composites have been reviewed by H. Ku et al. [4]. Properties of plant and animal based natural fibre reinforced composites have been investigated by several authors [5-16]. Effects of particle size, particle/matrix interface adhesion and particle loading on the stiffness, strength and toughness of particulate–polymer composites have been reviewed by Shao-Yun Fu et al. [17]. Very few literatures exist on composites using keratin fibres obtained from oxen horns.
The objective of the present work is to use bio-waste horn fibre for the manufacture of useful composite materials. This reduces environmental pollution, replaces synthetic fibres and is cost effective. In this work particle-reinforced composites were manufactured using defatted oxen horn particles as fibre, PP as matrix and maleic anhydride grafted polypropylene (MAPP) as compatibilizer for four different weight proportions. Physical, mechanical, thermal and micro-structural properties of these composites are characterised and compared with the properties of pure PP and pure HF.

2. Experimental work

2.1. Materials

Particles of HF less than 500 μm obtained using double bladed kitchen grinder and sieve shaker, defatted using distilled water, 0.1 N sodium chloride solution, ethanol and diethyl ether were used as particles for reinforcement. Polypropylene (PPH110MA) of homopolymer grade (6287) with density of 0.911 g/cc and MFI of 18 g/10 min measured at 230°C under 2.16 kg load obtained from Reliance Industries Ltd., India was used as matrix material. Maleic anhydride grafted polypropylene (MAPP) obtained from Exxon Mobile India Ltd., India under the trade name Exxlor PO 1020 with melt flow index of 125 g/10 min was used as compatibilizer between ground HF and PP.

2.2. Composite preparation

Four proportions of compounding materials i.e., HF, MAPP and PP in the corresponding ratios of 5:5:90 (B), 10:5:85 (C), 15:5:80 (D) and 20:5:75 (E) were weighed and compounded using twin screw extruder (Plasticolor, Woywod-Plastore, West Germany) with barrel l/d ratio of 40:1. The materials were extruded at a screw speed of 150 r/min. The extruded material was cooled in water bath followed by pulverising in a pulverising unit (Inventa Technologies Pvt. Ltd., India). The pulverised material was dried at 100°C for 6 h in a vacuum oven. Pure PP, 0:0:100 (A) was not compounded. Five test specimens from each composition A, B, C, D and E were injection moulded using injection moulding machine [Model: SP 130, R. H. Windsor (India) Ltd.] with a clamping force of 800 kN. The specimens for tensile, flexural and impact tests were injection moulded according to ASTM test standards. The composite specimens were allowed to sit in ambient conditions for one week before testing. The specimens of pure HF, 100:0:0 (F) were prepared by milling raw horn into flat shape.

2.3. Composite testing

Specimens of A, B, C, D, E and F of dimensions 165 mm x 12.7 mm x 3 mm were subjected to tensile test as per ASTM D638 using Shimadzu universal testing machine (Model: AG-50kNISD MS, Shimadzu Corporation, Japan). Gauge length of 115 mm and cross head speed of 50 mm/min was used for carrying out this test. Specimens of A, B, C, D, E and F of dimensions 127 mm x 12.7 mm x 6 mm were subjected to three point bend type flexural test as per ASTM D790 using Instron universal testing machine (Model: 3382, USA). A cross head speed of 2.6 mm/min and a span length of 100 mm were used for this test. Izod impact test was conducted as per ASTM D256 on specimens A, B, C, D, E and F of dimensions of 63.5 mm x 12.7 mm x 3 mm with a “V” notch depth of 2.54 mm and notch angle of 45°. Tinius Olsen impact testing machine (Model: IT 504 Plastic Impact, Tinius Olsen, USA) was used for this purpose. Densities of all six specimens were determined as per ASTM D792 using Mettler Toledo density measuring equipment (Model: XS 204, India). Densities were computed by measuring the weights of the specimens in air and after immersing in 2-propanol having a density of 0.786 g/cc. Melt flow index (MFI) values for specimens A, B, C, D and E were determined by adding the pellets of pulverised material into the barrel and die of Lloyd melt flow indexer (Lloyd Instruments, London) following ASTM D1238 standard. The test was conducted at 230°C with a load of 2.16 kg. Values were obtained by taking the average of five extrudates. This test was not carried on specimen F as it is not a plastic. Thermogravimetric analysis (TGA) test was conducted on all six specimens A, B, C, D, E and F by adding the pulverised material in the platinum crucible of Perkin Elmer thermogravimetric analyzer (Model:
Pyris 1 TGAC, Pyris Diamond DSC, USA). The test was conducted at a temperature range of 50°C to 800°C with 20°C/min rate of increase in a controlled atmosphere of nitrogen supplied at a rate of 20 ml/min to avoid oxidation. A Zeiss scanning electron microscope (Model: EVO MA 15, Zeiss Carl Pvt. Ltd., UK) was used for imaging the impact fractured surfaces of all six specimens. Prior to the observation, the specimens were sputter coated with Gold Palladium by electroplating process to eliminate electron charging. The specimens were attached by double sided electrically conductive adhesive carbon tape to a stub. All specimens were examined using an accelerating voltage of 20 kV power supply. SEM with EDX test was conducted using high resolution scanning electron microscope (Model: Quanta 200F) for imaging the impact fractured surface of pure horn specimen and to find its elemental composition. Before the observation the specimen was sputter coated with Gold Palladium by electroplating process to eliminate electron charging. The specimen was attached by double sided electrically conductive adhesive carbon tape to a stub. The specimen was examined using an accelerating voltage of 30 kV power supply. Five replicate specimens were used for each test and the data reported are the average of five tests.

3. Results and discussion

3.1. Elemental composition of horn fibre using SEM with EDX

Figure 1(a) shows photograph of an oxen horn. Figure 1(b) shows photograph of horn chips thrown as landfill. Figure 1(c) shows photograph of horn chips ground into particles and segregated to the desired size. SEM with EDX test was conducted to find the elemental composition of specimen F. Weight% and atomic% of the elements contained in specimen F are listed in Table 1. It is found that the major elements present are Carbon, Oxygen, Nitrogen and Molybdenum with a maximum Carbon wt% of 59.03. Other elements present in smaller amounts are Iron, Sodium, Chlorine and Calcium. Figure 2(a) shows the SEM micrographs of the impact fractured surface of specimen F. Fibre bundles in the order of nanometre scale can be noticed from it. Figure 2(b) shows the energy dispersive X-ray spectrometry result of impact fractured surface of specimen F.

Table 1. Weight % and atomic % of elements present in pure HF.

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt%</th>
<th>At%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CK</td>
<td>59.03</td>
<td>69.38</td>
</tr>
<tr>
<td>OK</td>
<td>17.04</td>
<td>15.04</td>
</tr>
<tr>
<td>NK</td>
<td>13.56</td>
<td>13.67</td>
</tr>
<tr>
<td>MoL</td>
<td>08.75</td>
<td>01.29</td>
</tr>
<tr>
<td>FeK</td>
<td>00.66</td>
<td>00.17</td>
</tr>
<tr>
<td>NaK</td>
<td>00.41</td>
<td>00.25</td>
</tr>
<tr>
<td>CIK</td>
<td>00.29</td>
<td>00.12</td>
</tr>
<tr>
<td>CaK</td>
<td>00.25</td>
<td>00.09</td>
</tr>
<tr>
<td>Matrix</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Photograph of (a) an oxen horn, (b) horn chips thrown as landfill and (c) horn chips ground and segregated to the desired size.
3.2. Mechanical and physical properties

Tensile, flexural, impact tests and density determination were conducted on specimens of pure PP, HF/PP composites and pure HF. The test results are listed in Table 2 in the mean ± standard deviation format with 99% confidence level.

Table 2. Mechanical and physical properties of pure PP, HF/PP composites and pure HF.

<table>
<thead>
<tr>
<th>Specimen (HF: MAPP : PP) (wt%)</th>
<th>Ultimate Tensile Strength (MPa)</th>
<th>Tensile Modulus (MPa)</th>
<th>Elongation at Break (%)</th>
<th>Flexural Strength (MPa)</th>
<th>Flexural Modulus (MPa)</th>
<th>Impact Strength (J/m)</th>
<th>Density (g/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (0:0:100)</td>
<td>32.63±0.17</td>
<td>464.43±12.39</td>
<td>88.59±60.14</td>
<td>34.51±0.62</td>
<td>459.34±10.41</td>
<td>35.97±6.86</td>
<td>0.911</td>
</tr>
<tr>
<td>B (05:5:90)</td>
<td>32.48±0.13</td>
<td>500.19±40.00</td>
<td>21.79±0.92</td>
<td>37.14±0.40</td>
<td>513.75±05.21</td>
<td>20.61±3.68</td>
<td>0.928</td>
</tr>
<tr>
<td>C (10:5:85)</td>
<td>31.32±0.29</td>
<td>504.30±39.69</td>
<td>17.67±1.99</td>
<td>40.36±1.09</td>
<td>597.49±25.91</td>
<td>22.12±3.57</td>
<td>0.939</td>
</tr>
<tr>
<td>D (15:5:80)</td>
<td>27.68±0.45</td>
<td>537.52±27.43</td>
<td>13.58±0.87</td>
<td>40.28±0.91</td>
<td>625.29±16.59</td>
<td>15.99±3.42</td>
<td>0.955</td>
</tr>
<tr>
<td>E (20:5:75)</td>
<td>25.14±0.28</td>
<td>523.26±18.31</td>
<td>11.85±0.74</td>
<td>40.10±1.97</td>
<td>733.52±63.80</td>
<td>21.80±3.52</td>
<td>0.960</td>
</tr>
<tr>
<td>F (100:0:0)</td>
<td>41.86</td>
<td>2031.20</td>
<td>5.04</td>
<td>122.9</td>
<td>4515.30</td>
<td>136.70</td>
<td>1.304</td>
</tr>
</tbody>
</table>

3.2.1. Properties of pure PP and pure HF

From Table 2 it is found that the ultimate tensile strength of specimen A is 32.63 MPa and for specimen F it is 41.86 MPa which is 28.28% greater. Tensile modulus for specimen A is 464.43 MPa and for specimen F it is 2031.2 MPa which is 4.37 times greater. Elongation at break for specimen A is 88.59% and for specimen F it is 5.04%, which is 17.58 times lesser. Flexural strength of specimen A is 34.51 MPa and for specimen F it is 122.9 MPa, which is 3.56 times greater. Flexural modulus for specimen A is 459.34 MPa and for specimen F it is 4515.3 MPa, which is 9.83 times greater. Impact strength of specimen A is 35.97 J/m and for specimen F it is 136.7 J/m which is 3.8 times greater. From the values of elongation % at break and from the stress-strain diagram, Figure 3a, it is found that specimen A is ductile and specimen F is brittle. Density of specimen A is 0.911 g/cc and for specimen F it is 1.304 g/cc. From Table 3 it is found that pure HF decomposes at higher temperature than pure PP. As the mechanical and thermal properties of pure HF are greater than pure PP, except the elongation % at break, reinforcing of HF particles with PP will enhance the properties.
3.2.2. Tensile test

The tensile strength of a particle-reinforced polymer matrix composite is based on the effective load transfer between the matrix and the particles. Factors like bonding strength between particle and matrix, size of the particle and particle loading affects the strength. Good bonding strength increases the strength while less bonding reduces it. The bonding can also be increased by the use of compatibilizers. Small sized particles have high surface area with the matrix and thus increase the strength. Fibre loading up to certain range increases the strength, beyond which the strength decreases due to clustering of particles. Stress-strain graphs and bar charts are drawn using the tensile test results. Figure 3 shows the effect of fibre content on the tensile properties of HF/PP composites. Figure 3(a) shows the stress-strain graphs of tensile test. It shows that specimen F is brittle, specimen A is ductile and specimens B, C, D and E have both ductile and brittle behaviour. From the stress-strain graph it is noticed that the tensile yield strength of HF/PP composites increases up to 15 wt% and decreases for higher fibre loading due to clustering effect of the particles. But the tensile yield strength of all the HF/PP composites is greater than that of pure PP showing good bonding between them. Figure 3(b) shows the bar chart drawn between ultimate tensile strength and fibre content. From the chart, ultimate tensile strength of specimen F is found to be highest with 41.86 MPa. For other specimens, it decreases from specimens A to B, C, D and E with increase in wt% of HF particles. Hard particles of HF act as the stress concentration points and thus the addition of HF particles weakens the composite instead of reinforcing it at high loading conditions. Increase in fibre loading increases the stress concentration points and thus the ultimate tensile strength of the HF/PP composites continuously decreases with increase in fibre loading.

Figure 3. Effect of fibre content on tensile properties of HF/PP composites (a) stress-strain graphs of tensile test specimens, (b) ultimate tensile strength vs. fibre content, (c) tensile modulus vs. fibre content and (d) breaking strain vs. fibre content.

Tensile modulus is measured at low deformation; hence there is no space to make interface separation. In a
particle-reinforced polymer matrix composite, modulus is increased by adding high stiffness particles to polymer matrices. Tensile modulus is independent of particle size and interfacial adhesion but depends on the fibre loading. Clustering of particles at high fibre loading and debonding is another factor that decides the tensile modulus. Tensile moduli for the above specimens are calculated using the stress and strain values. Figure 3(c) shows the bar chart drawn between tensile modulus and fibre content. Tensile modulus for specimen F is found to be 2031.2 MPa and is very high compared to other specimens. Compared to specimen A, tensile modulus of specimens B, C and D increases with increase in fibre wt% and decreases for specimen E. Rigidity of HF particles is greater than PP. Addition of HF particles offer resistance to the movement and deformation of the matrix. Hence the tensile modulus of HF/PP composites increases with increase in the fibre weight up to 15 wt% and starts decreasing thereafter due to clustering effect of the particles.

Figure 3(d) shows the bar chart drawn between breaking strain and fibre content. The percentage elongation at break for specimen A is higher with 88.6% and it decreases from specimen B to C, D and E. This implies that increase of fibre content in HF/PP composites increases brittleness and reduces plastic deformation. Specimen F has the lowest elongation percentage at break with 5.04% as it is brittle.

The decrease in the ultimate tensile strength between specimen A and specimen C is within 4.9 MPa that is by 15.03%, but the tensile modulus of this set of specimen has increased up to 73.09 MPa that is by 15.74%.

3.2.3. Flexural test

Factors like good bonding strength between particle and matrix, smaller sized particles and particle loading up to certain level affects the flexural strength of a particle-reinforced polymer matrix composites. Bar charts are drawn using the flexural test results. Figure 4 shows the effect of fibre content on various mechanical and physical properties of HF/PP composites. Figure 4(a) shows the bar chart drawn between flexural strength and fibre content. From the data, flexural strength of specimen F is found to be highest with 122.9 MPa. For other specimens, it increases from specimen A to B and C and almost remains constant for specimens D and E. This is because there is good adhesion between HF particles and PP up to 15 wt% of fibre loading and starts clustering thereafter.

Flexural modulus of a particle-reinforced polymer matrix composite is not affected by particle size and interfacial adhesion but depends on the fibre loading. Fibre loading of high stiffness particles increases flexural modulus. Figure 4(b) shows the bar chart drawn between flexural modulus and fibre content. For specimen F it is found to be 4515.30 MPa and is very high compared to other specimens. Flexural modulus of specimens B, C, D and E increases with increase in wt% of fibre particles and are found to be higher than specimen A.

The increase in the flexural strength of specimens B, C, D and E compared to specimen A is 5.85 MPa that is by 16.95% and the flexural modulus has increased up to 274.18 MPa that is by 59.69%.

3.2.4. Impact test

Factors like, size of the particle, particle loading and mainly bonding strength between particle and matrix affects impact strength of a particle-reinforced polymer composite. Figure 4(c) shows the effect of fibre content on the impact strength of HF/PP composites. It shows that impact strength of specimen F is highest with 136.7 J/m as it is completely fibrous and for specimen A it is 35.97 J/m. Impact strength of HF/PP composites falls below the impact strength of pure PP due to the continuous increase in conversion from ductile to brittle nature with increase in fibre loading.

3.2.5. Density

Figure 4(d) shows the bar chart drawn between density and fibre content. It shows that the density of specimen F
is 1.3 g/cc and is more than 0.9 g/cc, the density of specimen A. The densities of the specimens B, C, D and E increases with increase in fibre loading and are between the densities of specimen A and specimen F.

![Graphs showing various properties of HF/PP composites](image)

**Figure 4.** Effect of fibre content on various properties of HF/PP composites (a) flexural strength vs. fibre content, (b) flexural modulus vs. fibre content, (c) impact strength vs. fibre content and (d) density vs. fibre content.

3.3. Thermal properties

3.3.1. Melt flow index (MFI)

Melt flow index is a measure of the ability of the material in molten condition to flow under pressure through a die. It is also an indirect measure of the molecular weight of the material. Material with low MFI value will have high molecular weight. MFI tests were conducted on specimens and the test results are listed in Table 3. Figure 5(a) shows the bar chart drawn between MFI and fibre content. It shows that melt flow index for specimen A is highest with 18.226 g/10 min and for specimens B, C, D and E it decreases with the increase in fibre content. This is because the addition of HF particles offers resistance to flow. This test was not carried on specimen F as it is not a plastic.

3.3.2. Thermogravimetric analysis (TGA)

Thermogravimetric tests were conducted to understand the stability of the material under high temperature applications. It is conducted by heating the sample slowly, in a controlled atmosphere and monitoring the mass of the sample with respect to temperature. The extrapolated onset temperature (T_o), indicates the temperature at which the weight loss begins. The first derivative peak temperature (T_p), indicates the temperature at which higher weight loss occurs. Thermogravimetric tests were conducted on all samples and the test results are listed in Table 3. Figure 5(b) shows the bar chart drawn between first derivative peak temperature (T_p) and fibre content.
Table 3. Thermal properties of pure PP, HF/PP composites and pure HF.

<table>
<thead>
<tr>
<th>Specimen (HF: MAPP : PP) (wt%)</th>
<th>Melt Flow Index (MFI) (g/10 min)</th>
<th>TGA Temperature, To (°C)</th>
<th>DTG Temperature, Tp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (0:0:100)</td>
<td>18.226</td>
<td>371.38</td>
<td>424.85</td>
</tr>
<tr>
<td>B (5:5:90)</td>
<td>16.003</td>
<td>305.59</td>
<td>409.90</td>
</tr>
<tr>
<td>C (10:5:85)</td>
<td>15.236</td>
<td>359.90</td>
<td>426.77</td>
</tr>
<tr>
<td>D (15:5:80)</td>
<td>13.172</td>
<td>340.32</td>
<td>429.15</td>
</tr>
<tr>
<td>E (20:5:75)</td>
<td>12.437</td>
<td>391.01</td>
<td>436.50</td>
</tr>
<tr>
<td>F (100:0:0)</td>
<td>-</td>
<td>225.39</td>
<td>507.08</td>
</tr>
</tbody>
</table>

Figure 5. Effect of fibre content on thermal properties of HF/PP composites (a) MFI vs. fibre content (b) first derivative peak temperature (Tp) vs. fibre content.

Figure 6 shows the thermogravimetric (TG) curve drawn between weight % and temperature and first derivative thermogravimetric (DTG) curve drawn between first derivative weight % and temperature for all samples. The first derivative peak temperature (Tp) for specimen A is 424.85°C and it decreases slightly for specimen B and increases continuously for specimens C, D and E with increase in fibre loading and is highest for specimen F with 507.08°C. This is because the HF particles decompose at higher temperature than pure PP and offer restriction to the movement of the polymer matrix. Thus there is an increase in thermal stability with increase in fibre content.
Figure 6. Thermogravimetric (TG) and first derivative thermogravimetric (DTG) curves of samples (a) pure PP (A), (b) HF/PP composite (B), (c) HF/PP composite (C), (d) HF/PP composite (D), (e) HF/PP composite (E) and (f) pure HF (F).

3.4. Scanning electron microscopy

Figure 7 shows the scanning electron microscope (SEM) images of the impact-fractured surfaces of one specimen from each composition. Figure 7(a) shows the image of specimen A with elongated structure of PP, as it takes the entire load. Figure 7(b) to (d) shows the images of specimens B, C and D with even distribution of fibre particles and stretched PP matrix. Good compatibility between fibre particles and PP can also be noticed for these composites. Figure 7(e) shows the image of specimen E with clustering of fibre particles and void spaces. Figure 7(f) shows the image of specimen F with complete fibre bundles.
Figure 7. SEM micrographs of the impact fractured surfaces of samples (a) pure PP (A) at 1 k magnification, scale = 10 μm, (b) HF/PP composite (B) at 5 k magnification, scale = 2 μm, (c) HF/PP composite (C) at 4 k magnification, scale = 10 μm, (d) HF/PP composite (D) at 4 k magnification, scale = 10 μm, (e) HF/PP composite (E) at 3 k magnification, scale = 10 μm and (f) pure HF (F) at 4 k magnification, scale = 10 μm.

4. Conclusion

A new functional composite has been developed using particles of defatted horn fibre and polypropylene. Physical, mechanical, thermal and micro-structural properties of the composite with varying wt% of fibre have been characterised and compared with the properties of pure PP and pure HF. The horn and HF/PP composites can be used in fields like automotive, computers, construction, house ware, etc.

Pure HF consists of Carbon, Oxygen, Nitrogen and Molybdenum with maximum Carbon wt%. Iron, Sodium, Chlorine and Calcium are also present in smaller amounts. Pure HF is light weight, brittle and has excellent mechanical properties than pure PP and HF/PP composites. Melt flow index of HF/PP composites decreases with increase in HF content. HF decomposes at a higher temperature than pure PP and also offers restriction to the movement of the polymer matrix at the interface and thus increases thermal stability of HF/PP composites.

Compared to pure PP, increase in tensile yield strength, tensile modulus, flexural strength, flexural modulus and decrease in ultimate tensile strength and impact strengths of HF/PP composites is noticed. The decrease in ultimate tensile strength and impact strength is due to increase in stress concentration points of hard HF particles and clustering of fibre particles with increase in fibre loading. Good compatibility between the fibre particles and PP has been noticed up to 15 wt% of HF/PP composites. No void spaces have been noticed for this group of composites.
This work is innovative in respect to the source of fibre as it is derived from bio-waste. The use of bio-waste fibre for composite manufacturing reduces environmental pollution, replaces synthetic fibres and is cost effective. This work will set a new direction for the researchers to carryout research using many such bio-wastes from animals.

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