Preparation and morphological, thermal, and physicomechanical properties of polypropylene-potato peel biocomposites

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ABSTRACT: Potato peel powder (POPL), which is biodegradable, has been used as filler material in polypropylene (PP) matrix in varying concentration from 10 to 40% by weight to prepare biocomposites and investigated water absorption, physicomechanical and thermal properties. Scanning electron microscopy and X-ray diffraction has been used for morphological characterization and crystallization studies. Flexural modulus of biocomposites increased by 40% compared with neat PP at 30% loading of POPL. Flexural strength also increased with increasing filler loading. Tensile strength of biocomposites has been observed to be comparable with neat PP up to 20% filler loading and increase in tensile modulus up to 40% was seen in biocomposites with 20% filler loading. Impact strength of biocomposites up to 20% filler loading was found to be at par with neat PP. Use of MA-*g*-PP compatibilizer in the biocomposites yielded better physico-mechanical and thermal properties than biocomposites without compatibilizer. © 2015 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2015**, *132*, 42445.

INTRODUCTION

Isotactic polypropylene (PP) is one of the most popular synthetic polymers with versatile application. Recently PP based composites have gained industrial importance due to its low cost, easy process ability and excellent mechanical properties.[1] However, presently due to increasing environmental awareness, international government policy, and regulations, plant based fibers are looked upon as alternate reinforcing materials in polymers. Biocomposites based on polymer matrix and naturally occurring renewable biological reinforcements have gained much importance due to their low cost, light weight, better mechanical strength, and are environmentally friendlier than glass and other synthetic fiber reinforced plastics.[2] World-wide capacity of biobased plastics is projected to increase from 0.36 million metric ton in 2007 to 3.45 million metric ton by 2020.[3] Natural polymers derived from plants, such as starch, cellulose, and pectin are abundantly available on earth and found in cell walls of living species like plants, animal, bacteria, and algae. These polymers have been characterized for chemical and physicomechanical properties and have been extensively used in preparation of biocomposites.[4–8] However, poor interfacial adhesion between bio-reinforcement and many of synthetic polymers like PP is a factor, which lowers the ability of effective load transfer between the fibers. This drawback has also been effectively overcome by modification of the fiber surface by addition of a suitable chemical compatibilizer.[9]

Potato (Solano tuberous L) is an important food for human life all over the world.[10] Domestic preparation of food items and recent outburst of fast food industries in developing economies have increased the consumption of potato and its processed foods. Potato peeling industrially is accomplished either with steam, abrasive, or lye peeling, depending on the product to be produced. These processes have led to generation of large amount of potato peels as waste, which is prone to microbial spoilage and poses a severe disposal problem to potato industry. However, potato peels are renewable, biodegradable with considerable application in food and nonfood applications. The peels generally contains about 18% dry matter, which is made up of 3.4% pectin, 2.2% cellulose, 14.7 proteins, 66.8% starch, and 7.7% ash.[11] Recently, many efforts are been reported about use potato peel derivatives in combination with potato trim waste to produce useful industrial application like adhesives and binders in a variety of industrial and food product uses.[12] Roy *et al.*[13] has studied starch as biodegradable filler in thermoplastic polymer matrix (PP) composites with potato starch to PP ratio in the range of 5–20%. In a study to improve the

interfacial adhesion and to reduce moisture absorption in starch based thermoplastic polymer, potato starch has been derivatized with acetic acid, maleic anhydride, and octanoyl chloride.[14,15] Chemical compatibilizer are used in preparation of composites involving polymeric or biofillers to enhance adhesion between matrix and reinforcers.[16,17] Low compatibility and interfacial adhesion between the hydrophobic PP and hydrophilic biofiller inherently resulting in lowering of mechanical and thermal properties of end-product has been observed and this drawback has been effectively improved by selecting a chemical compatibilizer-Maleic anhydride grafted PP (MA-g-PP) and reported elsewhere.[18] Chen et al.[19] has derived cellulose nanocrystals (CNC) from potato peel waste and compared the physical features and reinforcement properties with CNC derived from cotton cellulose in thermoplastic starch films and polyvinyl alcohol nanocomposites films. The study showed that CNC can be derived from potato peel and the extraction time was longer in the case of potato peel compared with cotton cellulose and the longer nanoparticle of CNC from potato peel resulted in improved barrier properties in polymer matrix at low loading.

In all the above works, starch, cellulose, or nanocellulose has been isolated from potato peel and has been used as fillers in the biocomposites preparation or various methods of derivatization of starch has been employed. All these methods involve use of many chemicals and are expensive and time consuming. The yield of derivative form or nanocellulose material from potato peel is very less. No previous work has been reported for preparation of the biocomposites using potato peel powder (POPL) as reinforcement filler in PP matrix. In this work, a novel biocomposite based on POPL as filler in PP matrix has been prepared. To overcome the issues related to interfacial adhesion and water absorption in biocomposites, MA-g-PP has been added as compatibilizer. Melt flow rate (MFR), morphology, crystallization, and physic-mechanical properties such as, flexural, tensile, izod strength, and water absorption at different filler ratios has been carried out. Comparison of properties among neat PP and biocomposites prepared with and without compatibilizer has been made.

EXPERIMENTAL

Materials
Raw potato peel was obtained from food industry and was thoroughly washed to remove silica and other impurities. The peels were dried and grinded and sieved using ASTM 50 mesh (300 μm). POPL particles with < 300 μm was separated and used as fillers material.

Commercial Homo polymer PP PROPEL PP 1110MG designated as PP was obtained from M/s Indian Oil Corporation, India. Its melting point was 163°C by DSC and MFR was 12.0 g/10 min at 230°C.

Ma-g-PP (C1) from M/s Pluss Polymers, India was used as compatibilizer. The Maleic anhydride content was 1.6 to 2.5% in the compatibilizer.

Characterization of POPL
Mean Particle size of POPL powder used in preparation of biocomposites has been investigated using Malvern Particle Size

Table I. Composition of Neat and POPL/PP Biocomposites

Sample Designation	PP (% wt)	POPL (% wt)	C1 (MA-g-PP; % wt)
Neat PP	100	0	0
BIOPP-1	90	10	0
BIOPP-1C1	85	10	5
BIOPP-2	80	20	0
BIOPP-2C1	75	20	5
BIOPP-3	70	30	0
BIOPP-3C1	65	30	5
BIOPP-4	60	40	0
BIOPP-4C1	55	40	5

Analyzer. Elemental composition of POPL powder was determined by Elementar CHNS analyzer, Germany as per ASTM D 5291 method. Ash content of POPL has been determined by ASTM E 1755 standard Test Method. Presence of metals present in the ash was determined by Inductively Coupled Argon Plasma (ICAP) technique after dissolving in acid medium. The composition of POPL was estimated by NREL method for determination of structural carbohydrate and lignin in biomass.[20]

Preparation of Biocomposites
The POPL was dried in air oven at 60°C for 24 h before compounding. POPL was mixed with PP in a Batch blender at 300 rpm for 30 min for thorough mixing. The details of the biocomposites prepared are depicted in Table I.

The pre mixed batches were compounded in a Twin-screw extruder under nitrogen blanket and pelletized. (M/s Labtech, Thailand. L/D - 40 & Screw Dia 25 mm). The temperature profile in the extruder was maintained from 230 to 170°C.

Specimen Preparation
Specimens for physico-mechanical testing were prepared using injection molding machine (M/s L & T-Demag ASWA 60) with maximum injection pressure at 1766 bar as per ASTM. After molding the specimens were conditioned at 23 ± 2°C and relative humidity 50 ± 5% for 48 h according to ASTM D 618 prior to testing.

Melt Flow Rate
MFR experiments were conducted according to ASTM D1238 on Automatic Multiload Melt Flow Indexer MI4 from M/s Goetfrett, Germany.

Morphology
Scanning Electron Microscopy (SEM). Surface topography of interface and fractured surfaces of POPL/PP biocomposites, with and without Ma-g-PP were scanned with the aid of Zeiss SUPRA™ 55 Field Emission Scanning Electron Microscope. Cryofractured specimen were surface-metalized by sputter coating with evaporated gold metal (2–4 nm in thickness) before analyzing by FE-SEM at accelerating voltage of 1 KV.

Thermal Analysis
Thermogravimetric Analysis (TGA). TGA was conducted using Thermo gravimetric analyzer TGA Q50, from M/s TA

Table II. Metal Composition of POPL (<300 µm) used as Filler in Biocomposites

Al (ppm)	Ca (ppm)	Cr (ppm)	Fe (ppm)	K (%)	Mg (ppm)	Na (ppm)	P (ppm)	Zn (ppm)	Si (%)
400	3190	38	772	3.9	1850	2237	3815	116	1.8

Instruments. The samples were weighed in the range 10–20 mg and placed in the sample pan in the balance system of the equipment. The samples were heated steadily at 20°C/min from 25°C to 800°C in nitrogen medium to check thermal stability, volatile content, and residue.

Differential Scanning Calorimetry (DSC). DSC from M/s Mettler Toledo was used to characterize the thermal properties of neat and biocomposites samples. A sample size with average weight of 7–8 mg encapsulated in a sealed aluminum pan was prepared for each composite sample. The sample was heated from room temp to 200°C at heating rate of 10°C under nitrogen atmosphere to remove thermal history. The melting temperature T_m and heat of fusion (ΔH_f) of composite samples were determined from peak maximum and area under the peak, respectively. Degree of crystallization of PP/POPL biocomposites and neat PP was calculated from the following equation.

$$X_c (\% \text{ Crystallinity}) = [He/W \times \Delta H_{f100}] \times 100$$

where ΔH_f is the heat of fusion of the composite sample, ΔH_{f100} is the latent heat of fusion of the composite sample, ΔH_{f100} is the latent heat of fusion of a PP with 100% Crystallinity (207.1 J/g) and W is the weight fraction of PP in the composite.

XRD Studies. WDXRD studies were carried out in an 18 kW Wide angle X-ray diffract meter (Rigaku, Rint 2500PC, Japan). XRD patterns were recorded at 50 kV and 250 mA, at a scan rate of 2°/min with a step size of 0.01° in the angle range of 5–75° (2θ).

Physicomechanical Evaluation
Tensile Strength and Tensile Modulus. For tensile test, five replicate dumbbell shaped test specimens for each of composites as per ASTM D 638 were tested using Universal testing machine 2700 from M/s TIRA, Germany. Load range of 10 kN and cross-head speed 50 mm/min was applied for carrying out the tests.

Flexural Strength and Flexural Modulus. Flexural strength and modulus of Neat PP and biocomposites were tested as per ASTM D 790 Three point bending test was carried at load of 200N and cross-head speed of 13 mm/min. For each test five replicate test specimens were taken and from the experimental data obtained, the average data and corresponding Standard Deviation were calculated.

Notched Izod Impact Strength. Izod impact strength was carried as per ASTM D 256 A on Resil Impactor (M/s CEAST, Italy) with a notch angle of 45°C and depth of 2.54 mm. Mechanized Notch cutter from M/s Ceast, Italy was used.

Water Absorption. Water absorption was determined using ASTM 570-98 method. For each test three test specimens in the form of bar of dimension 75 × 25 ×3 mm were prepared by injection molding method. The specimens were then dried in an oven at 60°C for 24 h, cooled in desiccators and immediately weighed to nearest 0.001 × g. The specimens were then immersed in a container of distilled water at room temperature (23 ± 1°C) for 24 h to observe the water absorption capacity of the composites. After removal from water the test specimen were carefully dried using dry cloth and then weighed to nearest 0.001 × g immediately. Percentage increase in weight during water immersion was calculated as increase in weight.

$$M (\%) = \frac{[W_b - W_a]}{W_a} \times 100$$

where M is the moisture absorption (%), W_b is the weight of specimen after 24 h (g) and W_a is initial weight of oven dry specimen (g).

RESULTS AND DISCUSSION

Particle size of POPL was carried out by dispersing the powder in distilled water and the size of the particle was measured from 100 to 1000 µm. The graph shows that 50% of the particles had <125 microns and 90–95% of particles had size below 300 microns. CHNS analysis showed that the POPL contained 40.9% carbon, 5.6% hydrogen, 2.2% nitrogen, and 0.7% sulfur. Ash content in POPL was found to be 8–10%. ICAP analysis of the ash content shows the presence of following metals in POPL as shown in Table II. Composition of POPL powder was determined by NREL method[21] given in Table III. It was found that POPL contained high amount of starch and cellulose in addition to protein, lignin, and hemicellulose. The filler was used as such without any treatment in preparation of biocomposites for this study.

Melt Flow Rate
MFR value of biocomposites prepared using POPL is given in Table IV. MFR value was found to decrease with increase of POPL content in the biocomposites. This type of trend has also been reported earlier in biocomposites prepared using PP and starch.[21] The main reason for this type of behavior can be attributed to particle-particle interaction, which is stronger than particle-matrix interaction, leading in agglomeration of particles resulting in immobilization of matrix molecules. The MFR

Table III. Composition of Dried POPL

Composition (%)	Cellulose/Starch	Hemi cellulose	Proteins	Lignin	Ash content	Moisture
	59	5.5	13.8	11	1.8	6.4

Table IV. MFI of Neat and POPL/PP Biocomposites

Sample designation	MFI (without compatibilizer; g/10 min, 2.16 Kg)	Sample designation	MFI with Compatibilizer (g/10 min, 2.16 Kg)
Neat PP	14.2	Neat PP	14.2
BIOPP-1	13.5	BIOPP-1C1	13.7
BIOPP-2	11.6	BIOPP-2C1	12.1
BIOPP-3	8.4	BIOPP-3C1	10.7
BIOPP-4	7.9	BIOPP-4C1	10.0

value of neat PP was found to be 14.2 g/10 min and decreases to a value of 7.9 g/10 min for 40% filled biocomposites (BIOPP-4) without compatibilizer. However, addition of compatibilizer (C1), which is a MA-g-PP, improves the MFR value as it enhances the adhesion between filler and PP matrix.

Morphology Using Field Emission-SEM

The injection molded specimens were cryo-fractured to study the morphology of biocomposites prepared. Figure 1(a,b) represent the SEM image of POPL filler used to prepare biocomposites at different magnifications. SEM image in Figure 1(a) shows of POPL having almost uniform sized particles in round to oval shape. SEM images of Potato starch having similar structures have been reported.[22] Figure 1(b) is the SEM image at higher magnification, which shows agglomeration of POPL in some places. Figure 1(c,d) illustrates the scanning electron microphotographs of cryogenically fractured surfaces of BIOPP-1 and BIOPP-1C1 composites. From the SEM images of biocomposites, it is evident that dispersion of filler is more in 40% filler loaded biocomposites than 10% filler loaded biocomposites. SEM images of biocomposites show overall uniform dispersion of the filler in the matrix. Figure 1(e,f) represent the

SEM images of BIOPP-4 and BIOPP-4C1. The dispersion of filler is found to be more uniform and shows better adhesion in composites prepared using compatibilizer than biocomposites without compatibilizer. It is also observed that in biocomposites with compatibilizer due to improved adhesion and fiber dispersion, lesser number of filler pullouts and voids are visible than with biocomposites without compatibilizer as seen in the SEM images. However, agglomeration of filler particles were also observed in the biocomposites in the SEM images.

Thermal Evaluation

Thermogravimetric Analysis. TGA curve of Neat PP, MA-g-PP compatibilizer (C1), 10, 20, 30, and 40% POPL/PP Biocomposites shown in Figure 2(a) and TGA curve of Neat PP, MA-g-PP compatibilizer, 10, 20, 30, and 40% POPL/PP with 5% compatibilizer is illustrated in Figure 2(b). From Figure 2(a), it is evident that POPL filler showed major degradation at three major stages as observed in the TGA graph. First weight loss occurred around 150°C due to moisture and volatiles, second degradation from 120 to 350°C, may be due to starch molecules and third degradation may be due to continuous breaking down of complex cellulose, hemicelluloses, and lignin structures in filler material as explained elsewhere.[23] Weight loss of neat PP occurred in one step degradation from 371 to 470°C. The onset temperature of Neat PP was found to be 371.2°C and end point was 470°C; 100% weight loss was observed in the case of neat PP.

It has been observed from Figure 2(b) that maximum thermal stability was exhibited by MA-g-PP compatibilizer with onset at 477°C and end point at 490°C. From Figure 2(a,b), it is found that TGA curve of BIOPP-1 biocomposites was found to be similar to neat PP curve, with thermal stability slightly lesser than neat PP. BIOPP-1C1 curve was also found to be similar to neat PP and MA-g-PP, but showed better thermal stability better
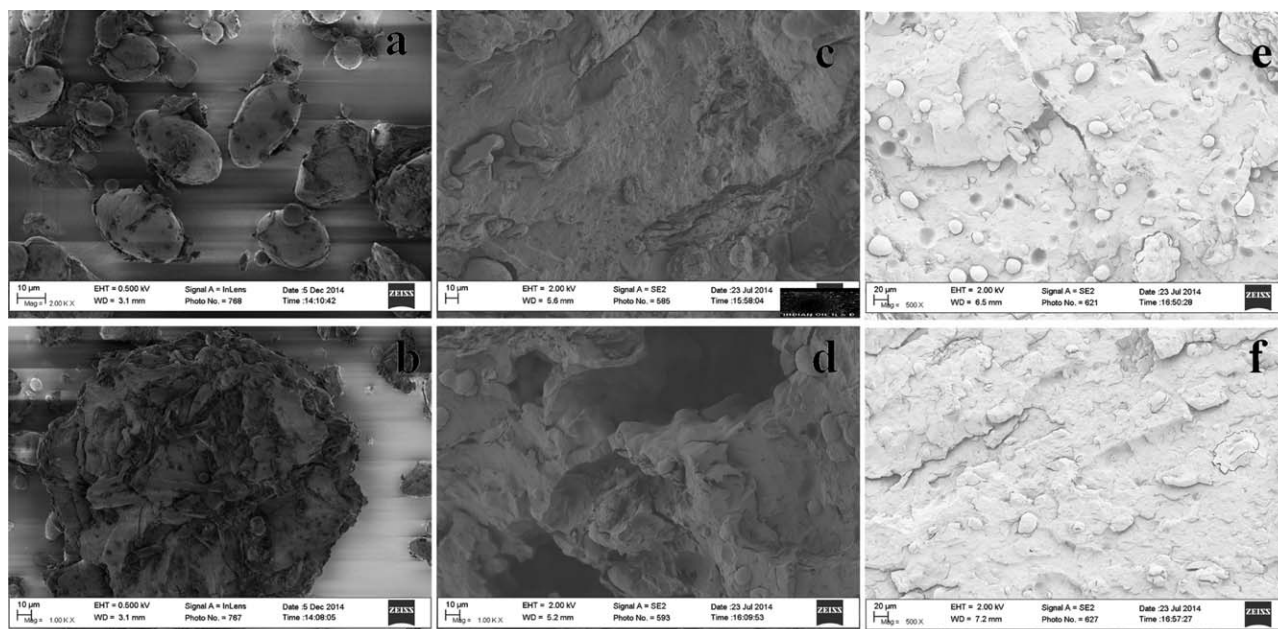
Figure 1. SEM images of (a,b) POPL, (c,d) BIOPP-1 and BIOPP-1C1, and (e,f) BIOPP-4 and BIOPP-4C1.
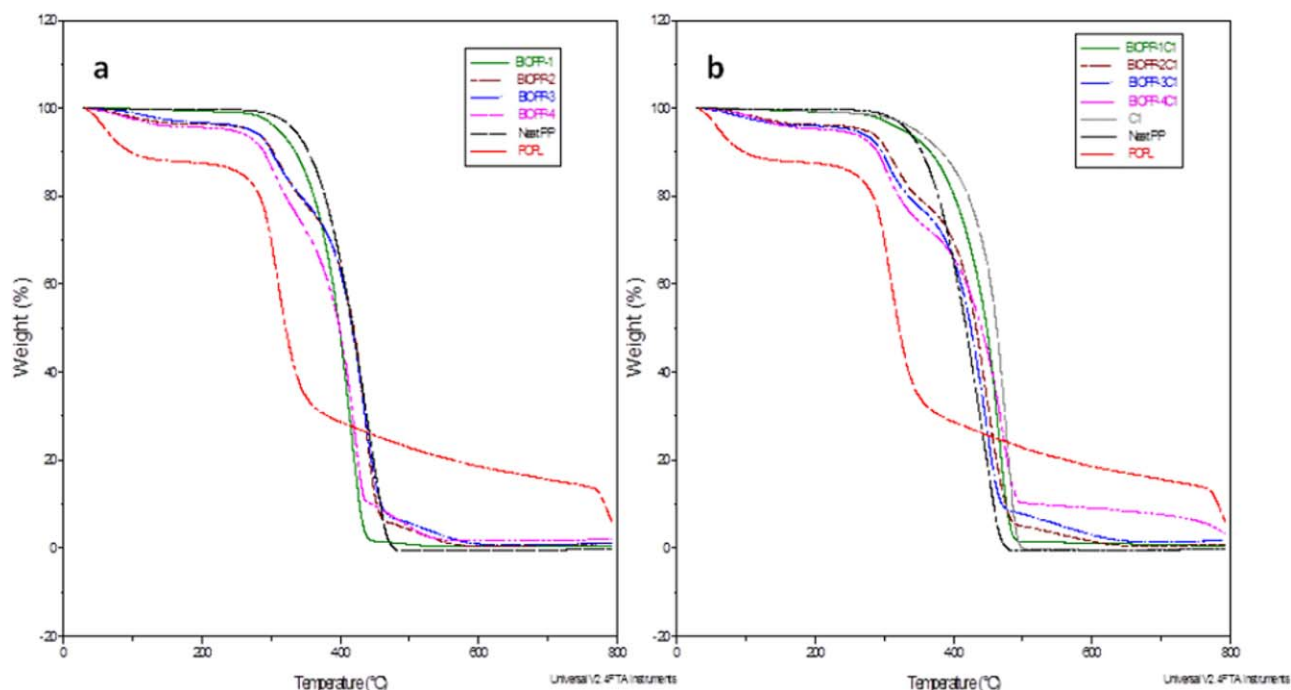
Figure 2. TGA Curve of Neat and POPL/PP Biocomposites (a) without compatibilizer (b) with compatibilizer. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

than neat PP and BIOPP-1 biocomposites, due to the addition of 5% compatibilizer, which had better thermal stability properties. TGA curve of 20, 30, and 40% POPL/PP composites showed thermal stability slightly lesser than neat PP and MAPP, but better thermal stability than POPL filler and the curve characteristics showed three degradation steps as in filler. However, the thermal stability of BIOPP-2C1, BIOPP-3C1, and BIOPP-4C1 were found to be better than corresponding biocomposites, BIOPP-2, BIOPP-3, and BIOPP-4C without compatibilizer. It was observed that curve characteristics of the biocomposites changed from neat and attained curve characteristics of filler with increase in filler loading.

It was also found that the residue percentage also increased with increase in the amount of filler in the biocomposites from 0.5% approximately in BIOPP-1 biocomposites to 1.5 in 40% POPL/PP composites. The residue content of the biocomposites was in agreement with the ash content determined by ASTM D 5630 confirming the amount of filler in the composites.

Differential Scanning Calorimetry. Table V represents the DSC results of biocomposites prepared without compatibilizer and with compatibilizer, respectively. From the table, the melting point (T_m) of biocomposites without compatibilizer was observed to be in the range 163.5–164.6°C and does not differ much from PP neat. Crystallization temperature (T_c) was observed at 122.7°C in neat and in the range of 115.2–122.7°C in the POPL/PP biocomposites. Heat of fusion (ΔH_f) value for BIOPP-1 without compatibilizer was in the same range as in neat PP, and from BIOPP-2 to BIOPP-4 was in the range of 99.8–116.6 J/g. Crystallinity (X_c) of BIOPP-1 was also found to be close to neat PP at 56%. BIOPP-2 to 4 was in the range of 48.2–49. In the case of biocomposites with compatibilizer, pres-

ence of compatibilizer (MA-g-PP) in biocomposites did not alter the DSC thermogram shape as it known that cocrystallization of MA-g-PP within the spherulitic structure of PP and formation of isomorphic crystals in composites.[24] Crystallization temperature of biocomposites with compatibilizer was also in the range of 120–121.7°C. ΔH_f value of BIOPP-1C1 was almost same as in neat PP. In the case BIOPP-2C1, decrease in ΔH_f was observed as in the case of BIOPP-2. In BIOPP-3 and 4, ΔH_f value was in the range of 51.9–57.1 J/g. Percentage crystallinity values also showed the same trend as in POPL/PP biocomposites. POPL filler in biocomposites resulted in marginal changes in heat of fusion and degree of crystallization and behaved like inert filler in most of the biocomposites.[25]

Table V. DSC Analysis

Sample	T_m (°C)	T_c (°C)	ΔH_f (J/g)	X'_c (%)
Biocomposites without compatibilizer				
Neat PP	163.5	122.7	113.9	55.0
BIOPP-1	164.6	119.6	116.0	56.0
BIOPP-2	164.1	115.9	99.8	48.2
BIOPP-3	163.9	121.5	116.6	56.3
BIOPP-4	163.7	115.2	101.7	49.1
POPL/PP biocomposites with compatibilizer				
Neat PP	163.5	121.5	113.9	55.0
C1 (Ma-g-PP)	159.9	120.8	112.0	54.1
BIOPP-1C1	163.5	121.6	113.3	54.7
BIOPP-2CI	164.8	120.7	96.4	46.5
BIOPP-3C1	162.9	121.7	107.4	51.9
BIOPP-4C1	164.5	120.0	118.2	57.1
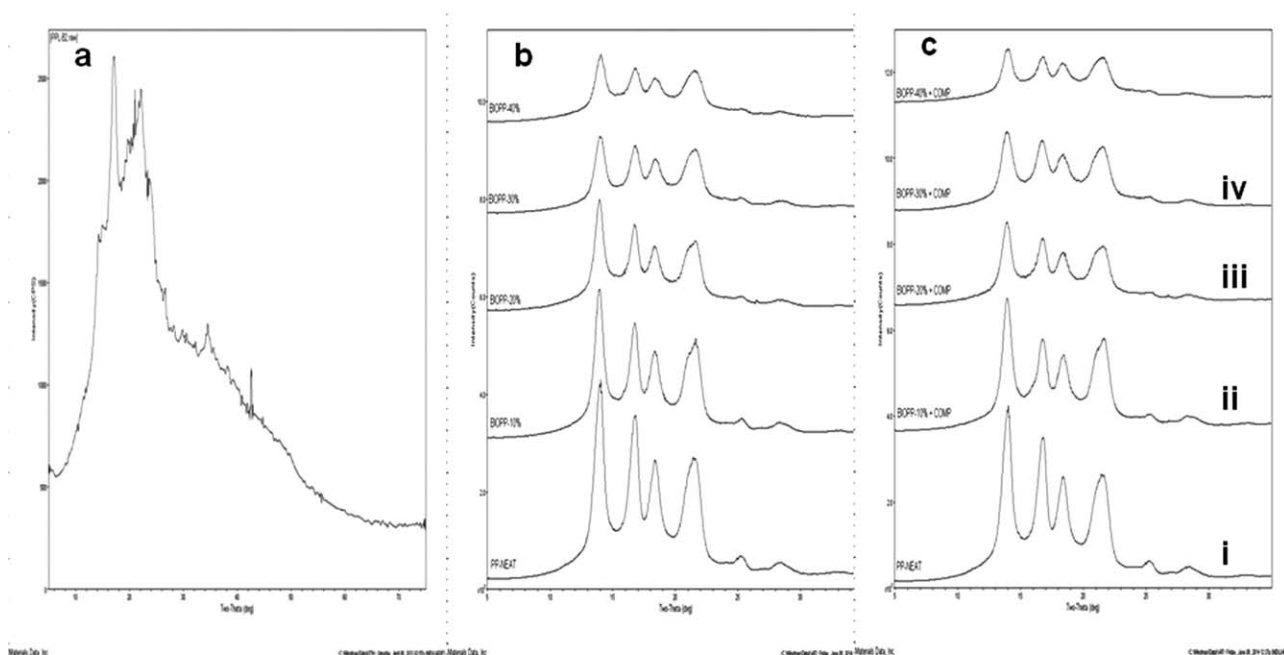
Figure 3. XRD spectrum of (a) POPL powder (<300 microns). (b) Neat 10, 20, 30, and 40% POPL/PP biocomposites without compatibilizer. (c) Neat 10, 20, 30, and 40% POPL/PP biocomposites with compatibilizer.

XRD Studies. XRD spectrum of POPL powder (<300 microns) is given in Figure 3(a). XRD spectrum of PP showed a broad hump in two theta around 20–30°, which indicates the presence of amorphous material in POPL, may be due to starch. The peaks observed around $2\theta = 15$, 17, and 20°, could be due to cellulose crystalline structure[17] overlapping with the starch peaks in the sample.

Figure 3(b) represents XRD pattern of 10, 20, 30, and 40% POPL/PP biocomposites along with neat PP. Figure 3(c) represents XRD pattern of neat PP and 10, 20, 30, and 40% POPL/ PP biocomposites with compatibilizer respectively. XRD pattern of neat PP (i) shows four distinct diffraction peaks at 2θ in Figure 3(a-i), which is assigned to PP crystalline structure.] Figure 3(ai–aiv) show the XRD pattern of BIOPP-1,-2, -3, and -4 biocomposites without compatibilizer respectively. Figure 3b(i–v) represent Neat PP and BIOPP-1C1,-2C1, -3C1 and -4C1 biocomposites with compatibilizer (C1). From the XRD pattern it is evident that there is a decrease in crystalline structure of PP with the addition of POPL powder which is more amorphous in nature. However, not much difference between the XRD patterns of biocomposites with and without compatibilizer was observed.

Mechanical Evaluation
Tensile Strength and Modulus. Figure 4(a,b) show the tensile strength and tensile modulus of the biocomposites prepared with 0–40% POPL filler loading in PP matrix. From Figure 4(a), it can be seen that in the case of biocomposites prepared without compatibilizer, and filler loading from 0 to 40%, the tensile strength was found to decrease after 20% POPL loading. Further, tensile strength dropped on increasing the POPL content and at 40% loading total tensile strength of composite reduced up to 40%. However, in the case of POPL/PP biocom-

posites compatibilizer with MA-g-PP, tensile strength was found to increase by 10% in BIOPP-2 [Figure 4(b)]. In all the POPL/ PP biocomposites prepared with and without compatibilizer, tensile modulus was observed to be higher than neat PP. This shows that there was no change in tensile strength or tensile modulus in biocomposites with filler loading above 30% weight; 20%POPL/PP showed tensile strength at par with neat and better modulus than neat and other biocomposites. This type of behavior has been observed in natural fiber reinforced biocomposites, which may be due to optimum aspect ratio, proper dispersion of filler in the polymer matrix and good adhesion between filler and polymer aided by addition of compatibilizer.[26]

Flexural Strength and Modulus. Flexural strength and flexural modulus of biocomposites is depicted in Figure 5(a,b), respectively. Flexural strength of biocomposites prepared without compatibilizer showed 14% increase with BIOPP-2 and was comparable to that of neat PP at higher loading. Further, 44.6% increase in flexural strength of compatibilizer POPL/PP biocomposites was observed for BIOPP-2C1. Further, at higher loading of 30 and 40% the flexural strength was found to increase 38 and 35%, respectively. The addition of compatibilizer was found to tremendously increase the flexural strength, which can be attributed to better adhesion of filler and matrix.

Similarly, flexural modulus results showed a slight drop in value from 1325 to 1295 in BIOPP-1 and 1262 in BIOPP-1C1, though the change is not significant and again shows a sharp increase at 1261 MPa for 20% filler loading and 1942 for 20% filler loading with compatibilizer (C1). At 30 and 40% filler loading, flexural strength did not show much variation in value. The same is observed in the case of biocomposites without compatibilizer also. From the figure, it is seen that there is overall
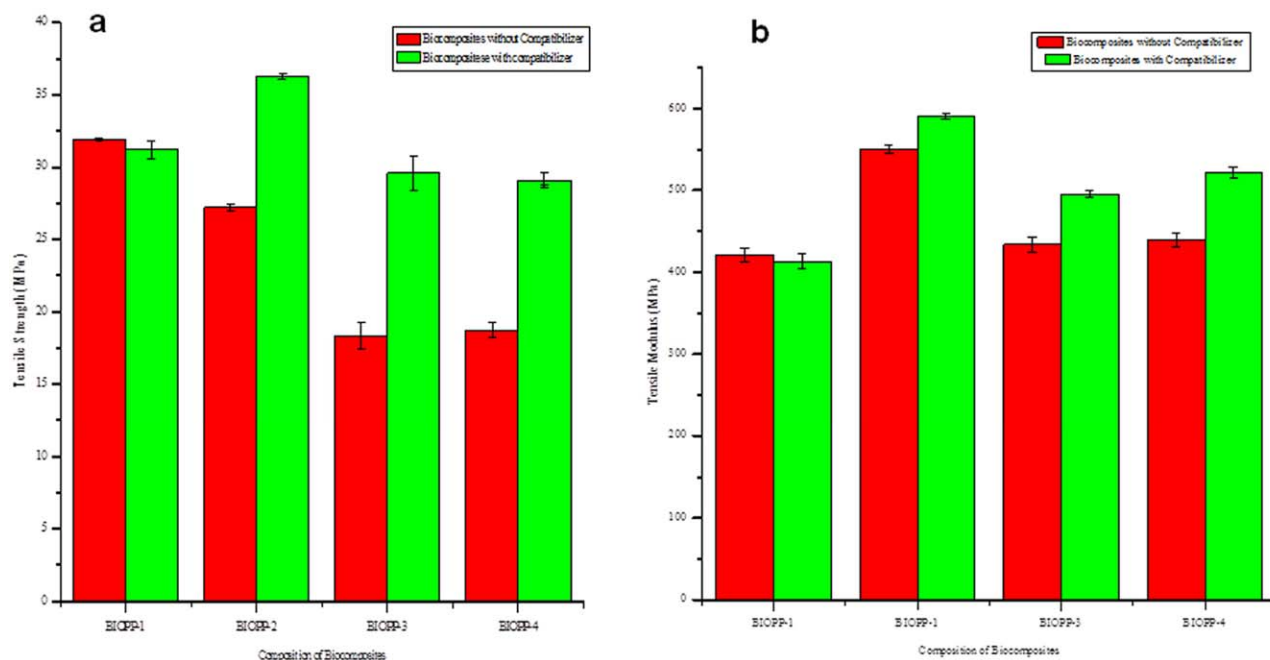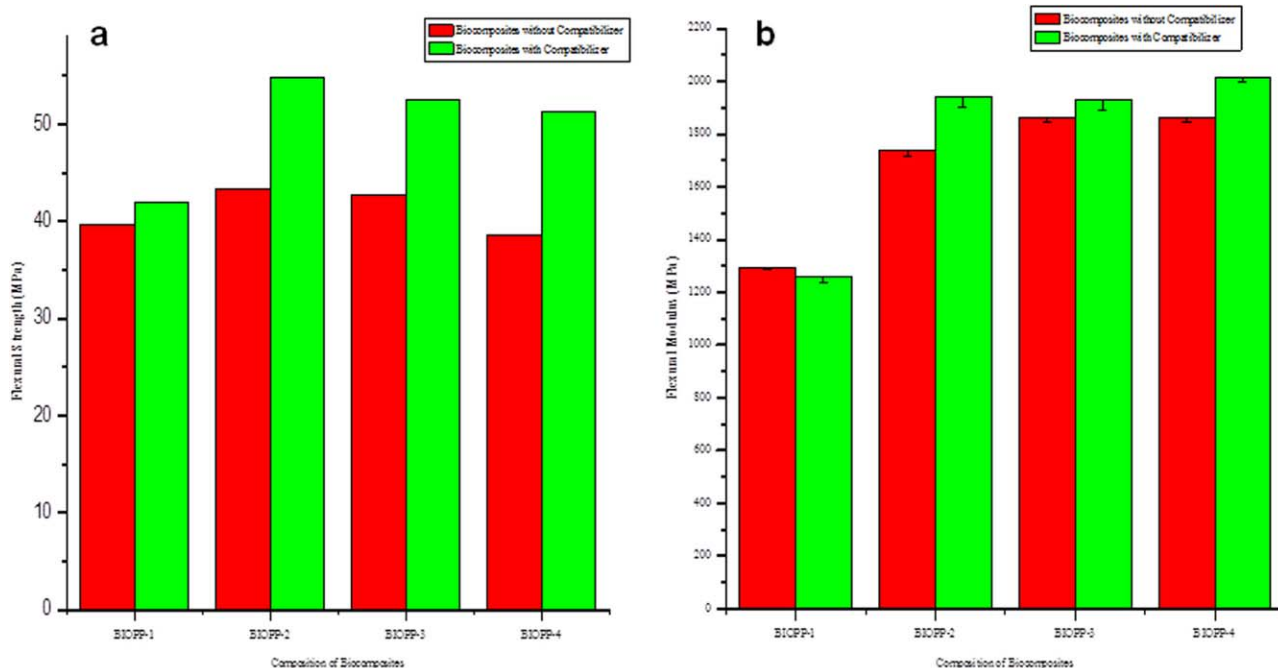
Figure 4. (a) Tensile strength and (b) tensile modulus of POPL/PP biocomposites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

increase in Flexural strength from neat to 40% filler loaded biocomposites, with and without compatibilizer compared with neat PP. Addition of 20% biofiller seems to be optimum, as flexural strength increased by 14% and flexural modulus also increased by 31% compared with neat PP. The increase in flexural strength and modulus may be due to proper dispersion of the filler in the matrix and improved adhesion qualities in the

case of biocomposites with compatibilizer. From the results, it is obvious that use of Ma-*g*-PP as a compatibilizer increased chemical bonding at the matrix-fiber interface by eliminating weak boundary layers as explained elsewhere.[27]

Table VI depicts percentage elongation of biocomposites prepared with and without compatibilizer. Both show decrease in
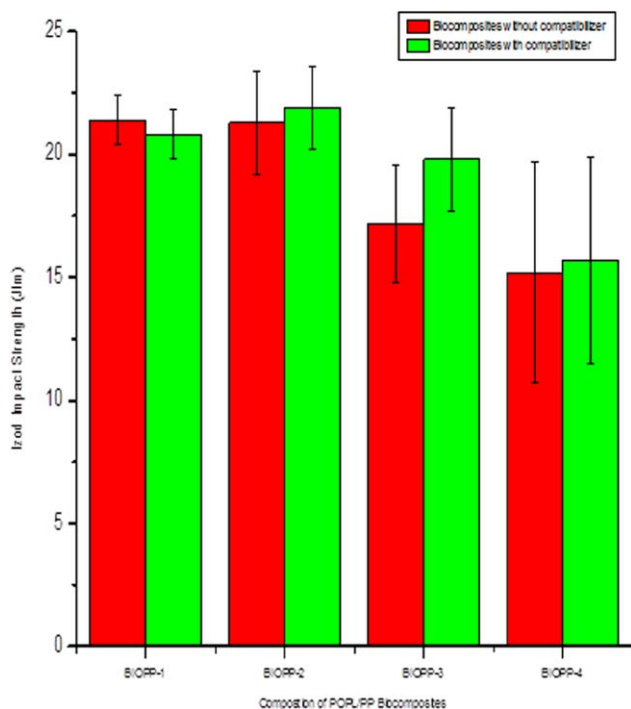

Figure 5. (a) Flexural strength and (b) flexural modulus of POPL/PP biocomposites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table VI. Percentage Elongation of POPL/PP Biocomposites

Sample designation (without compatibilizer)	Percentage elongation (%)	Sample designation (with compatibilizer)	Percentage elongation
Neat PP	21.9	Neat PP	21.9
BIOPP-1	15.6	BIOPP-1C1	16.9
BIOPP-2	11.3	BIOPP-2C1	11.3
BIOPP-3	9.4	BIOPP-3C1	9.3
BIOPP-4	8.2	BIOPP-4C1	8.4

Table VII. Percentage of Water Absorption of POPL/PP Biocomposites

Sample designation (without compatibilizer)	Water absorption (%)	Sample designation (with compatibilizer)	Water absorption (%)
Neat PP	0.02	Neat PP	14.2
BIOPP-1	0.10	BIOPP-1C1	0.09
BIOPP-2	0.19	BIOPP-2C1	0.16
BIOPP-3	0.30	BIOPP-3C1	0.26
BIOPP-4	0.60	BIOPP-4C1	0.51

elongation strength from 21.9 to 8.2%. Decrease in elasticity due to addition of POPL filler in PP matrix is observed from the graph as expected due to elasticity reduction. However, no significant change in percentage elongation is observed with addition of compatibilizer (C1).

Izod Impact Strength. Izod impact strength of the biocomposites with and without compatibilizer on notched specimens is shown in Figure 6. The impact strength of neat PP was observed to be 21.4 J/m. In the case of biocomposites without compatibilizer, the amount of filler loading did not show any change in the impact strength of the biocomposites up to 20% filler loading. Above 20% filler loading in PP matrix, impact strength of notched specimen was found to reduce from 20 to 30% in BIOPP-3 to BIOPP-4. In the case of biocomposites with compatibilizer (C1) also, it was observed that biocomposites did not show change in the impact strength with filler loading upto 20%. Above 20% loading, the biocomposites showed reduction

Figure 6. Izod impact strength of POPL/PP biocomposites. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

in impact strength only upto 8% weight in 30 to 40% filler load. Therefore, at higher filler loading poor interfacial adhesion may cause formation of more micro spaces between filler and polymer, leading to mechanical rupture and crack propagation in biocomposites with higher filler loading resulting in reduction of impact strength.[21] Therefore, it is evident that in biocomposites up to 20% filler loading no change in Izod impact strength was noticed and above 20 to 40% filler amount, reduction in impact strength of POPL/PP biocomposites was observed. However, with addition of compatibilizer, deterioration of Izod impact strength was reduced from average of 25 to 5% in biocomposites.

Physicochemical Evaluation

Water Absorption. Water absorption test results (Table VII) show that Neat PP has least water absorption capacity. The experiments showed that there was an increase in water absorption in case of biocomposites. An increment of 0.05% water absorption with increment of 10% filler content in 10–30% BIOPP composites was observed. However, in biocomposites with 40% filler content, the water absorption percentage almost double to 0.5–0.6%. Addition of 5% MAPP in the biocomposites showed very slight improvement in the hydrophobic character of the biocomposites. Reduction of water absorption due to addition of Ma-g-PP compatibilizer has been reported earlier.[28]

CONCLUSIONS

This work demonstrates the use of waste potato peel to produce a value added biocomposites by replacing PP up to 20%, without compatibilizer and possessing properties comparable to neat PP. Better properties than neat PP in potato peel based biocomposites were obtained with addition of 5% MA-g-PP compatibilizer. Uniform dispersion of filler in polymer matrix and better adhesion in biocomposites prepared with compatibilizer is evident from SEM studies. SEM observations show enhanced adhesion in biocomposites with compatibilizer, which is corroborated by the results of mechanical testing. It is observed that POPL used as filler contains cellulose, hemicelluloses in addition to starch and is present in higher amount in the range of 10–40%. This may be the reason for enhancement of mechanical properties of biocomposites, in spite of the nearly spherical morphology of filler as seen in SEM images, which needs further investigation. Our study shows that better tensile modulus and flexural properties are obtained in the biocomposites

prepared with filler amount up to 40% in PP matrix. Since potato peel is biodegradable, the usage these biocomposites has potential application in automobile, food and packaging industries.

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