Chemical Science International Journal

20(4): 1-12, 2017; Article no.CSIJ.37423
ISSN: 2456-706X
(Past name: American Chemical Science Journal, Past ISSN: 2249-0205)

Gamma-radiation-induced HDPE/Wood Composite: Studies of Morphological, Mechanical and Thermal Properties of the Composites

Babacar Niang[1], Diene Ndiaye[1*], Moustapha Lô Kholl[1], L. Y. El Hadj Babacar[1], Abdou Karim Diallo[1] and Ansou Malang Badji[1]

[1]Section Physique Appliquée, Université Gaston Berger, de Saint-Louis, Sénégal.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CSJI/2017/37423
Editor(s):
(1) Georgiy B. Shul'pin, Semenov Institute of Chemical Physics, Russian Academy of Sciences, Moscow, Russia.
Reviewers:
(1) Ahmad Adlie Shamsuri, Universiti Putra Malaysia, Malaysia.
(2) Jian Wen Wang, Chung Hwa Univ Med Technol, Taiwan.
Complete Peer review History: http://www.sciencedomain.org/review-history/21683

Original Research Article

Received 16th October 2017
Accepted 27th October 2017
Published 1st November 2017

ABSTRACT

Wood-polyethylene composites (WPEC) have been prepared with high density polyethylene (HDPE) matrix with pine wood, using maleic anhydride polyethylene (MAPE) as coupling agent and gamma irradiated. This paper discusses the behavior of the composites after exposure to various gamma irradiation doses (5 – 175 kGy) in the presence of oxygen. The dependence of mechanical properties on the integral dose for a constant dose rate of 4.8 kGy/h confirms the influence of the irradiation. The main objective of this study was also to examine the potential benefits of gamma irradiating WPEC in order to enhance some physical properties of WPC, namely morphological and thermal properties. The tensile and flexural modulus increased with dose level. The fracture surfaces of the composites show a noticeable difference with the increase in the dose rate. The fracture surfaces of composites exhibited clear difference in failure with increasing the dose rate. Meanwhile, the thermal stability was found to increase with increasing irradiation dose as shown by the percentage loss in weight at different decomposition temperatures and the temperatures of the maximum values of the rate of reaction. Examination of the fracture surfaces of composites revealed a distinct difference in failure between irradiated and non-irradiated surfaces.

**Corresponding author: E-mail: diene.ndiaye@ugb.edu.sn;*

Keywords: Gamma irradiation; composite; morphological; thermal; mechanical properties.

1. INTRODUCTION

Plastic bags are used in large numbers in Senegal both by the consumer and the retailer due to the affordability and convenience in the field of packaging. Released into the wild, these residues are a serious problem among consumers and environmentalists about the environmental impacts. Due to the lack of proper plastic waste management policy, our environment is becoming increasingly polluted. The management problem of exponential increase in plastic waste due to population growth, the deforestation due to cyclical drought consequences of global warming, the scarcity of fossils resources, all these factors make people to need materials more environmental friendly. Nowadays, plastic waste management has become a serious issue in most countries around the world. Besides of this, agricultural waste has also become a critical problem since populations tend to burn it contributing to the global warming. In our underdeveloped countries there are no concrete actions to find appropriate solutions to this problem. The burial or incineration is only temporary solutions because it is know that each of these processes had adverse effects on groundwater or on the ozone layer. WPC is a hybrid material composed of natural wood fiber /powder and plastic granulate with some coupling agents. The major drawbacks associated with the use of wood as reinforcements in a thermoplastic matrix are the inherently poor compatibility and dispersability of the hydrophilic cellulose fibers with the hydrophobic thermoplastic. Polyethylene grafted maleic anhydride (PE-MA) is used to improve the compatibility of lignocellulosic fibers with the polymer matrix. Among disadvantages, one can cite also the thermal instability of wood above 200°C. However the majority of thermoplastics exhibit melting points between 160 and 220°C. To overcome the drawbacks, surface modifications of the natural fibers using physical and chemical treatments have been carried out. Among them, physical treatment, such as ionizing radiation can introduce better cross-linking between natural fiber and matrix, and reduce its hydrophilic nature through hydrophobic matrix [1,2]. The gamma irradiation process for modification of commercial polymers is a widely applied technique to promote new physical-chemical and mechanical properties. Gamma irradiation generates free radicals which can induce chain scission or recombination, providing its annihilation, branching or crosslinking. In this work, we want to develop performing composites of wood polymer composites with gamma irradiation.

Nowadays, crosslinking is applied to a large number of synthetic polymers, which have been discovered since then, and a variety of crosslinking techniques have been developed. One of these techniques is irradiation crosslinking. The crosslinking effect of ionizing radiation was conclusively demonstrated for the first time by A. Charles by in 1952 after the irradiation of low density polyethylene in one of the research reactors at Harwell [3]. There are two main irradiation-initiated polymerization methods used to cure monomers in wood: gamma irradiation and electron beam. The objective of this work is focused on gamma irradiation; an electromagnetic wave in nature. These rays are often produced by radioactive decay, fusion, fission, interactions of atomic particles. They are the highest energy electromagnetic radiation and typically have energies greater than 100 keV, frequencies greater than 10^{19} Hz susceptible to initiate polymerization. When γ-radiation passes through a material such as wood or a vinyl monomer it leaves behind a series of ions and excited states as the energy of the γ-ray is absorbed through photoelectric, Compton, and pair production collisions. Gamma radiation, as a high energy, ionizing electromagnetic radiation, easily penetrates through wooden objects. The energy-rich gamma rays modify molecular structures and lead to unexpected function of living cells or to their death. The use of gamma radiation with composite materials offers several advantages, such as continuous operation, minimum time requirement, less atmospheric pollution, curing at ambient temperatures, increased design flexibility through process control [4]. The crystallinity increases slightly at low doses before declining gradually for doses greater than 100 kGy [5]. The same trends were established by Nasef et al. for doses up to 1200 kGy [6]. Gamma irradiation may also remove moisture from the composite, which in turn contributed to better fiber matrix adhesion. This may be the reason behind the increased mechanical properties of the composites. Because of high energy of gamma radiation, it penetrates through the entire cross section of wood. For this property, gamma rays are often used as a catalyst for polymerization of monomers in

monomer-impregnated wood as well as for chemical modification of wood to create wood-plastic composites – WPC [7] mentioned three possible uses of gamma radiation:

1. as pre-treatment in the chemical modification of cellulose;
2. as the initiator of the catalytic polymerization of monomers in the cellulose chains;
3. as pre-treatment for further chemical processing of cellulose in order to improve its solubility.

Cross-linking generally occurs in amorphous zones because of the higher mobility of polymer chains and the resulting higher probability of bonding between free radicals. Some free radicals can be stable for a certain time in crystalline zones. Gamma rays can break covalent chemical bonds, but their energies are insufficient to break the chemical bonds within the nucleus of atoms (protons and neutrons).

The gamma irradiation changes the anatomical and chemical structure of wood, but also the physical and mechanical properties. One of the interesting areas of application of gamma rays and X-rays is in non-destructive analysis of density and water content and their distribution in solid wood, and the wood based materials, i.e. wood panels used gamma irradiation in their studies for non-destructive detection of decay and other defects in logs [8].

Gamma irradiation produces three types of reactive species with polymers. Include ions, radicals and peroxides groups. These latter are produced in the case where the polymers are irradiated in the presence of air. In this same situation, cellulosic chain of wood generates radicals through hydrogen and hydroxyl groups. Gamma radiation can also break carbon -carbon bonds and produces free radicals. The chain scission can also operate by generating other radicals. Gamma irradiation may affect the polymeric structure of the wood fiber and polymer matrix, which may produce active sites that can contribute to better wood, and polymer bonding [9,10]. The main objective of this study is to experience the technique based on the gamma-irradiation in composites as an alternative of coupling or compatibilizing agents. This paper presents the results of a comparative evaluation of a PE-based WPC subjected to different gamma-radiation doses. Results are presented in terms of morphological, thermal stability and flexural strength properties to evaluate the impacts of GR on the PE-based WPCs. Thermal, hygroscopic properties and photo degradation will be followed because these products are often for external use. The present paper also addresses the effect of gamma radiation to make an efficient compact product without open pores on the surface and without agglomerates of wood filler inside the composite.

2. EXPERIMENTAL

2.1 Materials

Polyethylene has been one of the most extensively studied synthetic plastics in polymer science and engineering, principally because it is chemically simple and it has an increasing number of applications [11].

High density polyethylene (HDPE) used has a density 0.963g/cm^3 and a melt index of 0.72g/10 min was provided by Solvay Co. Polyethylene grafted with maleic anhydride (MAPE) with an approximate maleic anhydride (MA) content of 3 WT % was purchased from Aldrich Chemical, Inc. (Milwaukee, WI). This compatibilizer has been used to enhance the bonding between the wood and the polymer matrix. The wood flour particles of 425 microns (40-mesh) in size were kindly donated by American Wood Fibbers (Schofield, WI) and are constituted predominantly with pine and oak. All ingredients were used as received.

2.2 Compounding and Processing

Before compounding, the wood flour was dried in an oven for at least 48 h at 105°C to a moisture content of less than 1%.

First, the HDPE was put in the high-intensity mixer (Papenmeier, TGAHK20, Germany), and the WF was added after the HDPE had reached its melting temperature. The mixing process took 10 min on average. After blending, the compounded materials were stored in a sealed plastic container. For the mechanical property experiments, test specimens were molded in a 33-Cincinnati Milacron reciprocating screw-injection molded (Batavia, OH). The nozzle temperature was set to 204°C. The extrudate, in the form of strands, was cooled in the air and pelletized. The resulting pellets were dried at 105°C for 24 h before they were injection-molded into the ASTM test specimens for flexural, tensile

(Type I, ASTM D638) and impact strength test. The dimensions of the specimens for the flexural tests were 120 x 3 x 12 mm^3 (length x thickness x width).

Table 1. Sample composition

Sample code	HDPE (%)	Wood (%)	MAPE (%)
SP40	57.5	40	2.5

The sample formulation is indicated above in the Table 1. The percentage is based on the total weight of the sample.

2.3 Gamma-Irradiation

Prior to $\gamma - radiation$, the samples were placed in a cylindrical device made of 304 stainless steel and then irradiated at different doses within the 0-150 kGy range at 80°C. The samples were irradiated in air and to assure the most uniform dose distribution, irradiated from both the front and back of each sample. They were irradiated with γ rays at total radiation doses of 5, 25, 50, 75, 100 and 150 kGy using a dose rate of 4.8 kGy/h, at room temperature with a ^{60}Co which is the most common gamma emitter used because of its abundance in the market and the operational safety of devices that use it. The experimental measurements were taken after two days of storage under oxygen.

2.4 Scanning Electron Microscopy (SEM)

The state of dispersion of the wood inside the polymeric matrix was analyzed using optical microscopy on samples of 100–200 mm thick. The fractured samples were coated with a thin layer of gold to avoid electrostatic charging during examination. SEM was used to obtain microphotographs of the fracture surfaces of the wood composites. These fractures have been performed in liquid nitrogen to avoid any deformation. SEM has been performed using a Fei Quanta 400 microscope working at 30 kV. The polymer surface was examined with Leica optical microscope working in a transmission mode. Samples were thin enough that no special preparation was needed for their observations with the optical microscope.

2.5 WAXD Analysis

Wide-angle X-ray scattering (WAXS) analysis of neat HDPE and irradiated samples with different gamma dose was performed with a Bruker General Area Detector Diffraction System that recorded the intensity of the X-rays diffracted by the sample as a function of the Bragg angle using Bruker computer software. A $CuK\alpha$ radiation (wavelength $\lambda = 1.5406\ A°$) operated at 40 kV and 30 mA was used with a nickel filter. The 2θ range was from 5° to 40° with a scanning speed of 4°/min.

2.6 Thermal Stability Characterization

The thermogravimetric analysis (TGA) is the most popular method for characterizing the thermal stability of polymers and wood polymers composites. TGA decomposition information can be used to predict the useful product lifetimes of some polymeric materials. This analysis consists to record the weight of sample in dynamic conditions at a heating rate of 10°C/min between 30 and 700°C under nitrogen atmosphere at the heating rate of 20°C/min and was performed using Perkin equipment Elmer Pyris-1 TGA. The sample (mass of $10 \pm 1 mg$) was placed in a little cup made of aluminum hanging from a microbalance. The variation of the mass of the sample allows drawing the TG (variation of the mass in function of the temperature) and DTG thermograms (derivative of loss of mass versus the time) measure the change of heat. The combination of these two data gave a clear indication of number of stages of the thermal degradation. This method allows determining the degradation temperature of the materials and thus the thermal stability of the composite.

2.7 Mechanical Tests

The most important single indication of strength in a material is the tensile test. In this test, the most properties can be represented by tensile strength and Young's modulus.

Flexural Test is the capacity of a material to withstand bending forces which is applied perpendicular to its longitudinal axis. Tensile tests (tensile strength and tensile strain) and three-point flexural tests (flexural modulus and flexural strength) were carried out on an Instron 5585H testing machine (Norwood, MA) with crosshead rates of 12.5 and 13.5 mm/min according to the procedures outlined in ASTM standards D 638 and D 790, respectively. Eight

replicates were run to obtain an average value for each formulation.

The impact strength is defined as the ability of a material to resist the fracture under stress applied at a high speed. The impact properties of composite materials are directly related to their overall toughness. The notched impact strength test is the total energy required to break a notched sample. Before each test, the films were conditioned in a 50% relative humidity chamber at 23°C for 48 h.

3. RESULTS AND DISCUSSION

3.1 Scanning Electron Microscopy

Fig. 1 shows a comparison of the SEM microphotographs of the fracture of the composites with different gamma doses. Gamma irradiation leads to significant color changes of wood HDPE composites. With increasing radiation dose the darkening of the specimens increased as can be seen from the samples. At the interface between HDPE and fibers, the cavities were clearly seen in the none-irradiated sample Fig. 1.a, indicating poor interfacial bonding between wood fibers and polymer matrix. Conversely, less cavities were observed in the polymer matrix and wood fiber inter-phase structure in the irradiated ones (Fig. 1.b (SP40 gamma irradiated 25kGy), Fig. 1.c (SP40 gamma irradiated 75kGy) and Fig. 1.d (SP40 gamma irradiated 100kGy)). The wood particles appeared to densely contact with the HDPE matrix, indicating better interfacial adhesion between wood and polymer matrix. In the irradiated samples, it can be seen that the effects of radiation depend on the dose applied to the sample. Moreover, for these samples, a loss of weight (less than 1% after 75 kGy irradiation and about 1.25% after the 100 kGy dose) was observed and a visible yellowing appeared already after 50 kGy [12]. These phenomena were most probably signs of degradation. Smirnov and Deyun [13] showed that the average molecular weight of PP, when subjected to gamma radiation, did not show significant variations when the radiation dose was under 10 kGy. The irradiated samples exhibited a slight improvement with more smooth surfaces than the none-irradiated sample, probably due to a reorganization of the matrix chains during irradiation. This variation has been attributed to an increase in the mechanical strength of the material due to radiation crosslinking. The 150 kGy irradiated PE blend presents a mixed mode of fracture, being more brittle, with smooth areas associated to localized plastic strain regions.

3.2 Wide-angle X-ray Scattering

Fig. 2 shows the results of X-ray diffraction analysis for the neat HDPE (Fig. 2a in the left) and the irradiated composites obtained for this study (Fig. 2b in the right). The curves for irradiated samples were translated, by addition of fixed amounts, for better visualization. The XRD patterns, having 2θ range of 5°- 40°, for neat HDPE, wood and composites (SP40) gamma irradiated with 50, 75, 100 and 175 kGy are shown in Fig. 2b. In our previous studies [14], we have demonstrated that the main feature of these results is the decrease of the peaks in length (from 50, 75, 100 and 175kGy) accompanied by a reduction of its width by increasing the amount of wood and other agents incorporated. So we judge not necessary to study here the effect of gamma radiation on

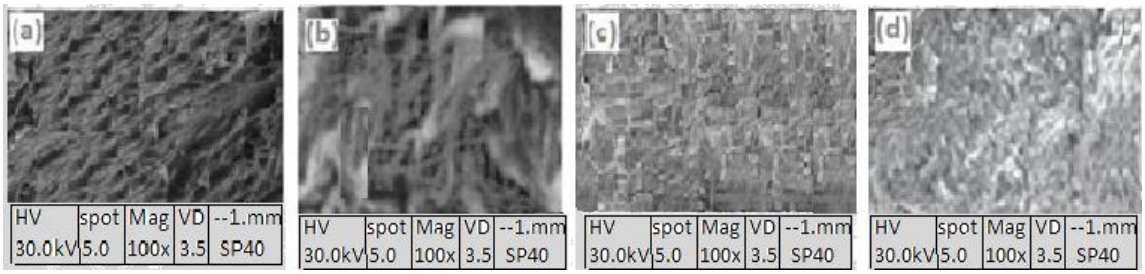

Fig. 1. Scanning electron micrographs of Wood HDPE composites of irradiated and no irradiated composites with varying gamma doses: (a) no irradiated, (b) 25 kGy, (c) 75 kGy and (d) 100kGy

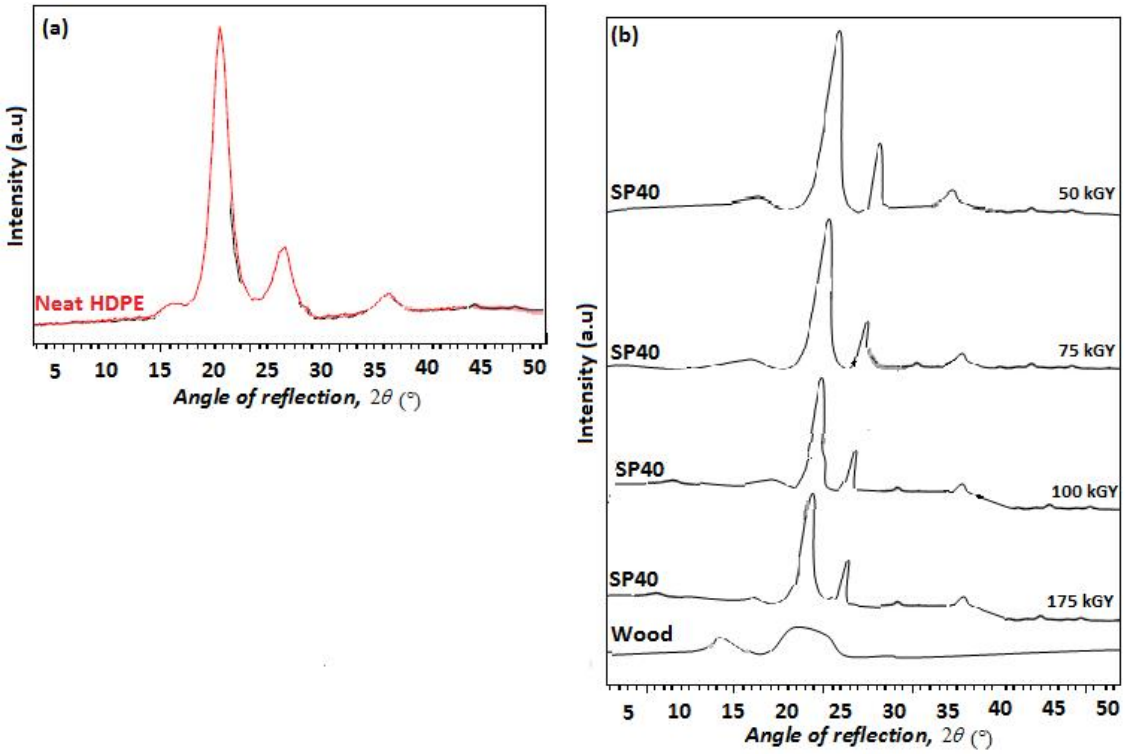

Fig. 2. XRD analysis of neat HDPE (a), and irradiated composites with varying gamma doses (b)

various samples with different wood content. We consider here one sample SP40 (HDPE 57.5%, wood 40%, MAPE 2.5%) with different gamma irradiation doses. In all these composites, the profiles show one higher crystalline diffraction peak appearing at 21.8 and two weak peaks at 24.2 and 36.5° corresponding approximately to the 110, 200, 020 lattice planes of the crystalline form of polyethylene. These results refer to an orthorhombic structure of the used HDPE [15]. The peaks were weakened after gamma irradiation. The scattering peak at 2θ of 19.8° corresponds to an amorphous phase. The amorphous parts of the polymer are represented by a shoulder in Fig. 2 (scattering peak at 2θ of 19.8°). The characteristic peaks of the irradiated composite (SP40) at different doses are similar to those of neat HDPE, as shown in the figure. In all the cases, the peak position does not change, while the intensity and width decrease with increasing dose. These phenomena demonstrate a change of crystallinity and crystallite size in the samples. The XRD trace recorded on the WF is characteristic for the cellulose form and it does not change during compounding. The main feature of these results is the decrease of the peaks accompanied by a reduction of its width by increasing gamma irradiation dose.

3.3 Thermal Stability

In Fig. 3, the values corresponding to thermal analysis are shown in Table 3.

Fig. 3 presents, the TGA curves of neat HDPE, irradiated and non-irradiated samples of composites. The first one below 100°C is attributed to the gradual evaporation of absorbed moisture. Between ambient temperature and 140°C, other volatile particles evaporate; generating a weight loss around 10 to 30%. The important degradation process of wood starts at around 200 – 220°C and it concerns the three major constituents of wood (cellulose, hemicellulose and lignin) [12]. As the gamma dose increased, the thermal stability of the composites decreased and at the same time, the decomposition temperatures of the composites decreased slightly by increasing the gamma doses. High irradiation doses generate chains scissions into the material in turn contribute to the decrease in thermal stability of composites.

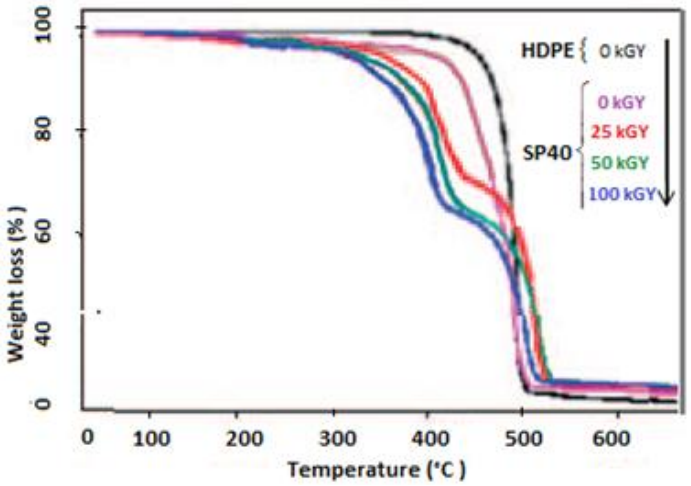

Fig. 3. TGA thermograms of neat HDPE and irradiated composites with varying gamma does

Table 2. Thermal behavior of neat HDPE and irradiated composites with varying gamma doses

Gamma dose (kgy)	Crystallisation temperature (°C)		Melting temperature (°C)		Crystallinity (%)	
	HDPE	SP40	HDPE	SP40	HDPE	SP40
0	112.5	114.5	168	164	82	55
25	113	113.5	165	164	76.5	50
50	113.5	113.25	165	163	73.25	47.5
100	113.5	113.0	161	161.5	72	48.25

For the irradiated composites, it was verified that the maximum degradation rate was shifted to a lower temperature. Radiation dose is the only variable against weight loss, wood composition is constant - hence we correlated this phenomenon with the effect of radiation dose. Degradation of all polymer composites first decomposition temperature peak started at around 225ºC, which is similar to the degradation temperature of lignocellulosic materials, hemicellulose, cellulose and lignin. Greater mass loss is happening between 450-500°C.

It is known that HDPE degrades at around this [16].

In Fig. 3, the values corresponding to thermal analysis are shown in Table 3.

The melting temperature of SP40 (in all cases) is lower than that of neat HDPE and crystallization temperature of SP40 is higher, indicating that the incorporation of wood significantly accelerates the decomposition of the composite sample. This phenomenon is pronounced with increasing gamma radiation dose.

Increasing gamma irradiation dose in the polymer causes breakage of covalent bonds which is accompanied by the creation of free radicals. This division is also responsible for a decrease in molecular weight; these chains can bind to the initial share point or rearrange by covalent cross-links with neighboring chains, leading to cross-links. Gamma irradiation can also eliminate moisture of the composite, which in turn contributes to better fiber matrix adhesion.

3.4 Mechanical Results

In the table 3 below, at lower gamma doses (< 75 kGy) it is observed that the tensile strength increases with the increase of gamma radiation dose. However, the tensile modulus increases steadily with the increase of gamma radiation dose. This increase in the tensile strength is attributed to increase of fiber/matrix adhesion leading to an efficient stress transfer from the matrix to the fiber. Tensile strength (TS) of SP40 (50 kGy) increases up to 54% as compared to virgin HDPE or non-irradiated SP40, but this property falls for doses up to 100 kGY. This drop in tensile strength at higher gamma dose is a

Table 3. Effect of gamma irradiation on tensile, flexural and notched Impact strength (IS) properties of neat HDPE and irradiated composites with varying gamma doses

Sample code	TS (MPa)	TM (GPa)	FS (MPa)	FM (GPa)	Impact (kJ/m^2)	Gamma irradiation (kGy)
HDPE	21.5	0.45	19.5	0.75	32.5	0
SP40	22.5	0.75	22.5	1.05	18.25	0
SP40	23.5	1.5	25.75	1.25	15.75	5
SP40	27.25	2	30.25	1.5	13.5	25
SP40	35	2.5	34.5	1.75	12.5	50
SP40	34.5	2.75	34.25	2	12	75
SP40	32.25	2.5	32.25	1.85	11.5	100

In Fig. 3, the values corresponding to thermal analysis are shown in Table 3.

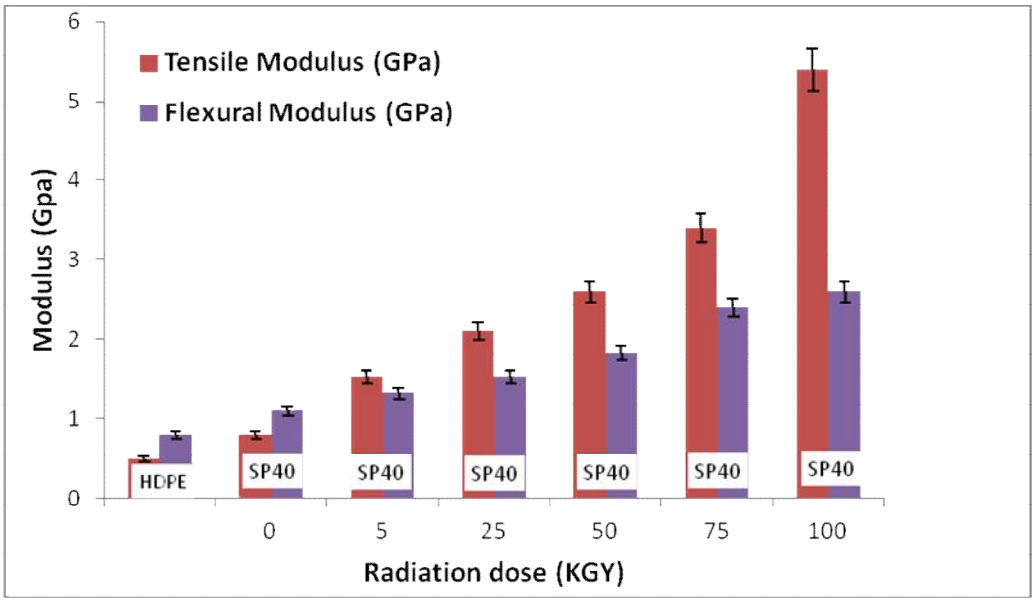

Fig. 4. Tensile and Flexural modulus of neat HDPE and irradiated composites with varying gamma doses

direct consequence of weak fiber/matrix adhesion which leads to micro-crack formation at the interface under loading and non-uniform stress transfer due to the fiber agglomeration in the matrix. Higher gamma doses (up to 175 kGy) also lead to an increase in fiber–fiber interaction which results in difficulties in dispersion of the fibers within the polymer matrix. The micrographs show good dispersion of the fiber in the polymeric matrix [17]. Ismail et al. [18] showed mechanical properties improvement with the strong adhesion between fiber and matrix. In presence of MAPE, the tensile strength is also enhanced by forming more chemical bonding between the migration of maleated HDPE and wood fibers since enough fibers provide more active sites on surface for esterification that is hydroxyl groups [12]. By ionizing, the hydrophobicity of the wood flour increase. This phenomenon produces better compatibility which generates a significant improvement of flexural properties of the irradiated composites. This property increases around 75 kGy and a slight fall begins to manifest towards 100 kGy. Cross-linking generally occurs in amorphous zones because of the higher mobility of polymer chains and the resulting higher probability of bonding between free radicals. It is stable up to 75 kGy and then it begins to decrease. Beyond this dose (75 kGy), irradiation of the polymer causes the breaking of covalent bonds of the latter which is accompanied by the creation of free radicals. This division is also responsible for a decrease in

molecular weight; these chains can bind to the initial split point or rearrange by covalent cross-links with neighboring chains, leading to cross-linking. However, at higher doses, the competition between cross-linking and degradation in particular are prominent, and hence, there is no significant increase in the properties of the hybrid composites between 75 and 100 kGy. Gamma radiation is used as an ionizing radiation source to generate free radicals on the polymer. The recombination of some free radicals form the crosslinks, which reduce the chain stretch of the material, and consequently, the plastic deformation is significantly reduced. However, a high radiation dose accelerates the oxidation, which increases the failure of the material [19]. This is because excessive free radicals migrate to the interface (crystalline/amorphous) and react with diffused oxygen, causing oxidation and brittleness. Gamma irradiation may also remove moisture from the composite, which in turn contributes to better fiber matrix adhesion. When gamma irradiation is increased, degradation through the formation of peroxy and hydroperoxy radicals in the amorphous regions appears to be the primary cause of physical property loss. When sufficient numbers of tie molecules between crystallites are cut through this chain scission process increases the local stress concentration on the crystals. Therefore, these mechanical properties (tensile strength and bending strength) are reduced drastically [20]. With moderate gamma irradiation, the micrographs show good dispersion of the fiber in the polymeric matrix. The impact test machine used in this study did not provide enough energy to break the neat HDPE because of the high flexibility of the HDPE matrix. By contrast, all the composites broke completely. The impact energy decreased with increasing gamma dose. Reinforcing wood flour in the composite led to an increased stress concentration because of the poor bonding between the wood flour and the polymer. Although crack propagation became difficult in the polymeric matrix reinforced with wood, the decrease in the impact energy observed was ascribed to fiber ends, at which micro cracks formed and fibers debonded from the matrix. These micro cracks are a potential point of composite fractures.

The fig. 5 exhibits tensile and Flexural Strength of neat HDPE and irradiated composites with varying gamma radiation doses. Many studies [21,22] in the literature showed that for HDPE, the tensile strength increased with the radiation dose. The explanation of this increase can be attributed to the two main processes: increase in the crystallinity and formation of crosslinking in the crystalline and amorphous regions. The ionizing radiation increases the resistance of the composite containing wood and MAPE until dose of 75 kGy and it decreases around 100 kGy.

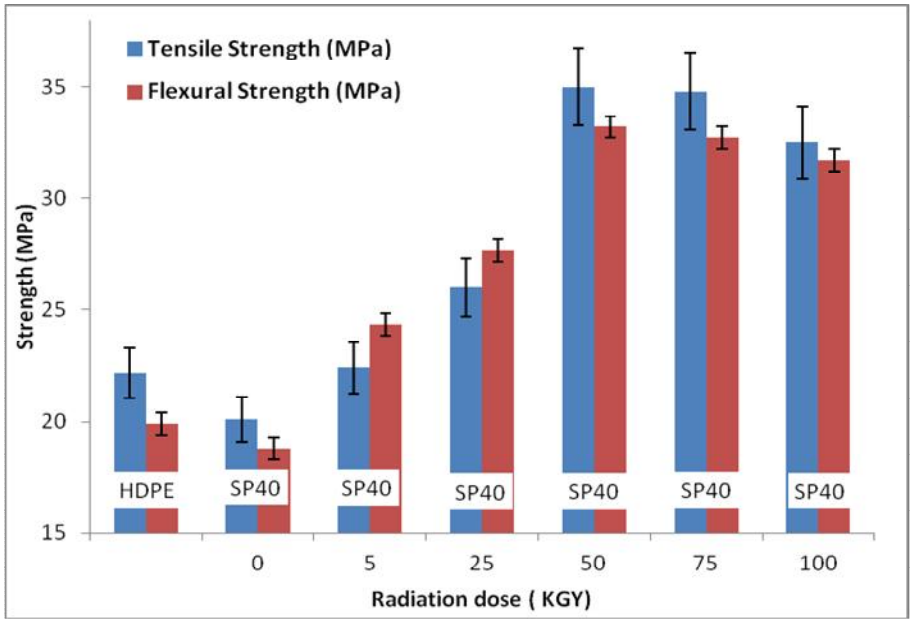

Fig. 5. Tensile and Flexural Strength of neat HDPE and irradiated composites with varying gamma radiation doses

Furthermore, the composites irradiated by 50 kGy exhibited higher flexural strength. This phenomenon is due to the increase in interfacial adhesion between the wood and the HDPE with this gamma dose. Stronger adhesion between the fibers and matrix interface produced a better stress transfer from the matrix to the fibers, leading to a higher flexural strength [23]. Despite the fact that irradiation was carried out in the presence of air, the improvement in composite mechanical strength properties for certain conditions shows the predominance of cross-linking over oxidative degradation. It is found that the Impact strength of all the irradiated composites decreased remarkably with increasing gamma dose. As the radiation dose increases from 5 kGy, the value of the impact strength reduces on exposure to intense gamma radiation dose due to chain scission phenomenon. Possible reasons for the decline in impact strength at high gamma dose are:

* Poor interfacial adhesion, which promotes micro crack formation at the interface as well as non-uniform stress transfer because of wood agglomeration (wood-wood contact which results in wood damage) within the HDPE matrix, and;
* An increase in the number of voids in the composites that serve as local areas for crack initiation. Incorporating wood in the polymer matrix reduced the stress on the polymer matrix and generated a successful bridging role as the wood fiber restricted further extension of a crack in the polymer matrix under stress from wet-dry cycles.

The mechanical properties of the composite are highly dependent on the adhesion and the compatibility of the mixture elements. In the impact test, material fracture is attributed to the failure of adhesion between the matrix and the dispersed phase which leads to a stress concentration around defects and inhomogeneities in the material structure. The incorporation of filler into the polymer matrix disrupted the homogeneity of the matrix [24]. Too much wood reinforcement involves a more difficult adhesion leading to a drop in performance. These phenomena are well known in the field of WPC (wood plastic composite). It is quite uncommon to find in the literature of composites WPC containing a percentage of wood greater than 50% (the material becomes rough and the surface cracks). At this level, appear major difficulties in molding and difficulties. When the weight ratio of the polymer (75%) is higher than that of wood (25%), there is less wood in the sample and the molten polymer can quite well encapsulate the particles of wood flour. In the other ones, it appears a poor interfacial adhesion between the filler and the matrix when the rate of wood increases [25].

A significant adhesion is required to obtain good impact strength in composites. Elements which are tightly linked together resist to deformation during an impact, which generates crack propagation from the matrix, through the fiber and a round trip to the matrix. When the fibers are not too bonded to the polymer, they dislocate from the matrix when impact occurs with energy absorption. This degree of adhesion, fiber pullout, and the mechanism involved in the absorption of energy is what determines the impact strength of the composite.

4. CONCLUSION

With gamma irradiation, the micrographs show good dispersion of the fiber in the polymeric matrix. It is clear from the figure that the pure HDPE shows the presence of a semi-crystalline phase with the characteristic diffraction peak located at 21.8°. This peak becomes less intense and more broadening as the gamma irradiation dose is increased due to transference of polymer from semi crystalline to amorphous structure. Mechanical properties such as tensile and flexural strength are promoted with increasing gamma radiation dose until 100 kGy, consequently a decrease in the impact strength of the system was observed. It was also demonstrated that it is possible to use low irradiation doses to modify the characteristics of polymer and filler, which means a number of advantages: no chemical reagents are required and there are no residual polluting by-products or tedious post-treatment. With gamma radiation, the scanning electron microscopy (SEM) of the micrographs became smoother and we can notice an improvement of interaction between polymer and wood fibers. Gamma-irradiation, therefore, is a promising technology to modify these composites in industry.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Khan MA, Hinrichen G, Drzal LT. Influence of noble coupling agents on mechanical properties of jute reinforced polypropylene composite. J. Mater. Sci. Lett. 2001;20: 1711-1713.
2. Khan MA, Khan RA, Haydaruzzaman, Ghoshal S. Study on the physico mechanical properties of starch treated jute yarn reinforced polypropylene composites: Effect of gamma radiation. J. Polym. Plast. Tech. Eng. 2008;48:542-548.
3. Charlesby A. Mathematical, physical and engineering sciences. cross-linking of polythene by pile radiation. Published 25 November 1952.
   DOI: 10.1098/rspa. Proceeding of the royal society 1952; A 215: 187.
4. IAEA-TECDOC-834. Advanced radiation chemistry research: Curing status. International Atomic Energy Agency, Vienna, Austria; 1995.
5. Ludovic Dumas. Post-modification par irradiation γ de polymères `a base de fluorure de vinylidiene: Applications aux membranes separatrices de supercapacite. These INSA de Lyon, 2012. Available:http://theses.insa-lyon.fr/publication/2012ISAL0016/these.pdf
6. Nasef MM, Dahlan KZM. Electron irradiation effects on partially fluorinated polymer films: Structure-property relationships. Nuclear instruments & methods in physics research. Section B, Beam Interactions with Materials and Atoms. 2003;201(4):604–614.
7. Bakraji EH, Itlas M, Abdulrahman A, Issa H, Abboud R. X-ray fluorescence analysis for the study of fragments pottery excavated at Tell Jendares site, Syria, employing multivariate statistical analysis. J Radioanal Nucl Chem. 2010;285:455–460.
   DOI: 10.1007/s10967-010-0595-
8. Karsulovic JT, Dinator MI, Morales R. Nondestructive gamma radiation methods for detection of central rot in loges of lenga (Nothogagus pumilo). Forest Prod J. 2002;52(11/12):87-93.
9. Khan F, Ahmad SR. Graft copolymerization reaction of water-emulsified methyl methacrylate with preirradiated jute fiber. J. Appl. Polym. Sci. 1997;65:459-468.
10. Khalil MMI, Naeem ME, Gamil AE. Gamma-irradiation effects on the thermal and structural characteristics of modified, grafted polypropylene. J. Appl. Polym. Sci 2006;102:506-515.
11. Lin Y, Du W, Tu D, Zhong W, Du Q. Space charge distribution and crystalline structure in low density polyethylene (LDPE) blended with high density polyethylene (HDPE). Polym. Int. 2005;54:465-470.
12. Diène Ndiaye, Ansou Malang Badji, Adams Tidjani. Physical changes associated with gamma doses on wood/polypropylene composites. J Compos Mat. 2014;48(25): 3063–3071.
13. Smirnov LP, Deyun EV. Evolution of the molecular mass distribution parameters during gamma radiolysis. Polym Sci Serv A. 1999;41(5):506–511.
14. Diene Ndiaye, Adams Tidjani. Effects of coupling agents on thermal behavior and mechanical properties of wood flour/polypropylene composites. J Compos Mat. 2012;46(24):3067–3075.
15. Yijian, Lin, Weichuan Du, Demin Tu, Wei Zhong, Qiangguo Du. Space charge distribution and crystalline structure in low density polyethylene (LDPE) blended with high density polyethylene (HDPE). Polym. Int. 2005;54:465-470.
16. Tasçioglu C, Tufan M, Yalcin M, Şen S. Determination of biological performance, dimensional stability, mechanical and thermal properties of wood plastic composites produced from recycled chromated copper arsenate treated wood. J Thermopl Compos Mat. 2014;1-19.
   DOI: 10.1177/0892705714565704.
17. Inamura PY, Kasawa CTS, Colombo MA, Moura EAB, Mastro NL. Del changes in gelatin/brazil nut shell fiber composite treated by electron beam radiation. In: 3rd Asia Pacific Symposium on Radiation Chemistry (APSRC- 2010). Treasure Island Resorts. Lonavala, India. 2010;14–17 September.
18. Ismail H, Nurdin HI. Tensile properties and scanning electron microscopy examination of the fracture surface of oil palm wood flour/natural rubber composites. Iran Polym. J. 1998;7(1):53–58.
19. Jahan MS. Chapter 29—ESR insights into macroradicals in uhmwpe. In Uhmwpe Biomaterials Handbook, 2nd ed.; Kurtz, S.M., Ed.; Academic Press: Boston, MA, USA. 2009;433–450.
20. Albanoa C, Reyes J, Ichazo M, et al. Analysis of the mechanical, thermal and

morphological behavior of polypropylene compounds with sisal fiber and wood flour, irradiated with gamma rays. Polym Degrad Stab. 2002;76:191–203.
21. Premnath V, Bellare A, Merrill EW, Jasty M, Harris WH. Molecular rearrangements in ultrahigh molecular weight polyethylene after irradiation and long- term storage in Airî. Polym. 1999;40:2215-2229.
22. Costa Neto CA, Ferreira M, Leal VS, Soares MC, Ajdelsztajn L. Efeito da radiaÁ„o gama sobre a resistÍncia mec‚nica de polietileno de alta densidade. In: IV Encontro TÈcnico de Materiais e QuÌmica, Rio de Janeiro; 2001.
23. Diène Ndiaye, Mamadou Gueye, Ansou Malang Badji, Coumba Thiandoume, Anicet Dasylva, and Adams Tidjani. Effects of Reinforcing Fillers and Coupling Agents on Performances of Wood–Polymer Composites; chap.7 in the book "Bio-Based Composites for High-Performance Materials: From Strategy to Industrial Application" 2014; October 24.
24. Diène Ndiaye, Laurent M. Matuana, Sandrine Morlat-Therias, Loïc Vidal, Adams Tidjani, Jean-Luc Gardette. Thermal and mechanical properties of polypropylene/wood-flour composites. J Appl Polym Sci. 2011;119(6):3321–3328.
25. Diene Ndiaye, Vincent Verney, Haroutioun Askanaian, Sophie Commereuc, Adams Tidjani. Morphology, thermal behavior and dynamic rheological properties of wood polypropylene composites. Mat Sci & Appl. 2013;4:730-738.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/21683