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ORIGINAL PAPER

Effect of gamma irradiation on thermal, mechanical and water absorption behavior of LLDPE hybrid composites reinforced with date pit (*Phoenix dactylifera*) and glass fiber

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Abstract

Date pit/ glass fiber reinforced LLDPE hybrid composites were compounded by single screw extruder and injection molded into dumbbell specimens. The composites were subjected to thermal gravimetric analysis (TGA), tensile testing, flexural study and water absorption analysis. TGA study confirmed the positive hybrid effects of reinforcements on the thermal stability of LLDPE composites. The decrease in weight loss percentage with the addition of glass fiber authenticated the increase in thermal stability. The maximum tensile strength 20.2 ± 0.8 MPa was obtained with 10% date pit and 20% glass fiber. The water-resistant property of hybrid composites reinforced with high percentage of glass fiber was found to be improved in comparison with virgin. The resulting composites were also exposed to different gamma doses (75 and 150 kGy) and the effect is characterized in terms of thermal and mechanical properties. Irradiation of gamma rays under 75 kGy improved the thermal stability and tensile strength than unirradiated and irradiated samples at higher dose (150 kGy).

Keywords Thermal · Tensile · Hybrid · Date pit · Glass fiber · Gamma irradiation

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Introduction

Through the last few years, there has been tremendous growth in the formulation of thermoplastic as well as thermosetting polymer composites using natural fibers as reinforcements [1]. In addition to their recyclability, thermoplastic polymer composites are preferred over the thermosetting-based composites as they easily undergo the process of extrusion and injection molding [2]. Thermoplastic polymers include the examples of PVA, polyethers, polypropylene (PP), low, linear low and high density polyethylenes (HDPE), etc. Among these linear low density polyethylene (LLDPE) being less dense, flexible, extra linear and possessing more tensile strength is an eminent commodity copolymer of ethylene and another longer α-olefin such as butane, hexene and octene. Due to the absence of long chain branching, LLDPE possesses an ease of processability in fields of commodity, pipe industry, agricultural film, cable containers, covers, packaging, etc.[3]. On the other hand, incorporating the cost-effective natural fibers as fillers in polymer matrices provides environmental advantages such as renewability and biodegradability [4, 5]. Natural fibers or biomasses in the form of some agricultural wastes such as jute [6], sisal [7], wood fibers [8], walnut shells [9], date pits [10, 11] and rice husk [12] present environmentally benign fillers for polymer matrices. The reinforcement of bamboo [13], wood [14] or Kevlar [15] fiber in LLDPE matrix are some examples of LLDPE-based polymer composites. Despite the attractiveness of natural fibers, their lower strength and modulus as well as poor moisture resistance limits its applications [16]. Also, the hydrophilic nature of fibers is responsible for the low compatibility with hydrophobic polymer matrices which leads to poor dispersion of fiber in the matrix. In order to improve the compatibility between cellulosic material and polymer matrices, various coupling agents or compatibilizers are used to formulate efficient biocomposites. Maleated polyolefins such as maleic anhydride polyethylene (m-PE), maleic anhydride linear low density polyethylene (MALLDPE) and maleic anhydride polypropylene (MAPP) copolymer were found to be very efficient compatibilizers for lignocellulosic polyethylene and polypropylene composites, respectively [5, 6, 17, 18]. Also, the irradiation of composites seems to be an alternative to compatibilizing agents. Gamma irradiation of polymer composite samples has been studied by many researchers [19, 20]. The positive effects of gamma irradiation can be easily seen in the recycled polyethylene terephthalate and low density polyethylene (R-PET/LDPE) blends. Increase in γ dose up to 100 kGy was found to increase the cross-linking of R-PET/LDPE blends cross-linked by ethylene vinyl acetate (EVA) [21].

Hybridization of natural fiber with some stronger and more corrosion-resistant synthetic fiber such as glass fiber or carbon fiber can be another effective approach to improve the strength as well as moisture-repellent properties of composites [15, 22]. Producing hybrid composites, we are adding the environmental advantages of natural fibers with high mechanical performances of glass fibers. LLDPE composites reinforced with Kevlar fibers/ short glass fibers present an example of this type of hybridization [15]. There have been other numerous

studies on the hybridization of natural and glass fibers, but only a few references are, however, available on using date pit and glass fiber as reinforcements. Date pits generally do not have significant use, but these are used as feed for various livestock and also used as soil organic additives [23–25]. These ground date pits containing about 78% carbohydrates, 10% oil, 5.5% protein, 1.5% ash and 5% moisture [26] make their use as fillers in thermoplastics [10]. With high availability and no specific use of date pits, it seems quite reasonable to use the date pit flour as reinforcing filler in thermoplastic-based composites.

In the present study, linear low density polyethylene (LLDPE) hybrid composites reinforced with date pits and glass fiber were synthesized by single screw extruder and casted into shape by injection molding technique. The resulting films were also exposed to gamma radiations and the effect is characterized in terms of thermal and mechanical study.

Materials and method

Materials

LLDPE (M26500) with melt flow index (190 °C/2.16 kg) of 50 g/10 min was procured from Reliance Polymers Delhi, India. Maleated anhydride grafted linear low density polyethylene (MALLDPE) with brand name of Optim E-119 was used as compatibilizer to improve the interfacial adhesion between matrix and fillers, obtained from PLUSS Advanced Technologies, Pvt. Ltd., Bawal, India. Stearic acid (SA) was used as a lubricant to ease the passage of material during the process of extrusion, obtained from Himedia, India. Dates were purchased, deseeded, washed with deionized water and oven-dried at 80 °C for 48 h. It was powdered by using ball mill (Insmart Systems) sieved to 75 mesh size and placed in desiccator to avoid moisture. E-glass fiber (initial length: 3 mm) was obtained from Ashoo Model Arts, Delhi, India.

Specimen fabrication

Compounding of the materials was carried out on laboratory-scale single screw extruder (designed and developed in house and manufactured by Quality Engineers, Ambala Cantt. Haryana, India) with following specifications: Screw diameter: 22 mm, Screw length (L/D): 20 mm, PID controller: 0–400 °C and AC motor: 0.25 HP.

The different components were kept in vacuum oven at 100 °C for 12 h to remove all the moisture content and initially mixed before transferring into extruder. The extrusion was carried out at screw speed of 35 rpm and temperature range of 135, 140 and 150 °C between the feeding to the die zone. The resultant material coming out of the extruder was cooled in water and pelletized. The extrudates were fed into molding machine (barrel length 400 mm) to process the samples into shape. The sample index and composition of different components is listed in Table 1.

Table 1 Sample coding and composition of LLDPE hybrid composites

Sample index	LLDPE (g)	MALLDPE (g)	Stearic acid (g)	Date pit (g)	Glass fiber (g)
D0G0	100	3	2	–	–
D30G0	70	3	2	30	0
D25G5	70	3	2	25	5
D20G10	70	3	2	20	10
D15G15	70	3	2	15	15
D10G20	70	3	2	10	20
D5G25	70	3	2	5	25
D0G30	70	3	2	0	30

Characterizations

Thermal properties

Thermal analysis (TGA/DTA) of the samples was conducted under flowing nitrogen atmosphere at the heating rate of 10 °C min^{-1} from ambient temperature to 700 °C on STAH instrument. The alumina powder as reference material and ceramic crucible as sample holders were used.

Mechanical study

The tensile and flexural samples of neat LLDPE and composites were conditioned at 25 °C and relative humidity of 50%. Specimens were tested on Animatex Universal Testing Machine in accordance with ASTM D638 for tensile samples and ASTM D790 for flexural samples standards. Three independent samples corresponding to each composition were tested in each category, and an average value is reported.

Water absorption

The specimens were immersed in water for up to 30 days (720 h). Mass change of all the samples was recorded at regular time intervals. The moisture absorption in terms of weight gain percentage ($\Delta M\,(t)$) was calculated as:

$$\Delta M\,(t) = \frac{M_t - M_o}{M_o} \times 100 \tag{1}$$

where M_o and M_t are the masses of specimen before and during aging, respectively. Three samples of each composition were tested for water absorption study. The tensile strength of the samples was also measured after the end of water absorption process.

FTIR

FTIR spectra scanned on MB-3000 ABB spectrophotometer over the frequency range of 4000–600 cm^{-1} was used for depicting any changes in LLDPE composites on gamma irradiation.

Scanning electron microscopy (SEM)

SEM analyzer, JEOL JSM-6390LV, was used to analyze the morphology of composites. Prior to testing, the samples were coated with thin layer of gold particles to make the sample conductive.

X-Ray diffraction (XRD)

A Panalytical's X'Pert Pro X-ray diffractometer was used to observe the diffraction pattern of some selected samples of the films with nickel-filtered Cu-Kα radiation. Diffraction patterns were in the range of 2θ between 5° and 60° by step of 0.017°.

Gamma irradiation

The gamma irradiation on polymer samples to required doses of 75 kGy and 150 kGy was carried out using ^{60}Co γ cell at Inter University Accelerator Centre, Delhi, India. The process was performed under atmosphere (air) with a dose rate of 2.798 kGy/h.

Results and discussion

Thermal properties

Thermal study

The weight loss (TGA) curves of composites are presented in Fig. 1. TGA of unirradiated and irradiated samples of composites, viz., D0G0, D30G0, D15G15 and D0G30 was carried out in order to assess their thermal stability and degradation temperatures. The weight loss in all the samples at around 120 °C was related to the loss of water/moisture attached to the surface. Figure 1 (I) shows that weight loss occurs in a single step from 365–495 °C in case of virgin LLDPE film (D0G0), which corresponds to the decomposition of C–C bonds in the chain of LLDPE [14]. The weight loss in the temperature range 242–342 °C occurs due to the degradation of cellulosic and hemicellulosic components of date pit fiber present in D30G0 and D15G15, respectively [27]. In D30G0, weight loss in region 384–504 °C ascribed to the decomposition of LLDPE component. For instance, it is shown in Table 2 that addition of cellulosic fiber improved the onset degradation temperature (T_0) of LLDPE in D30G0. In composite film

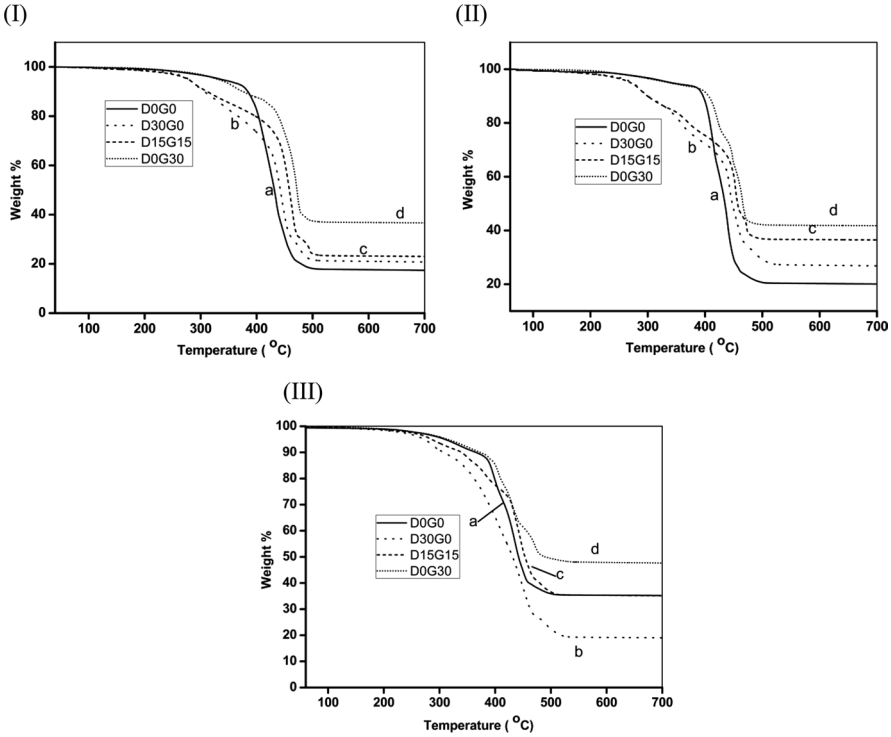

Fig. 1 TGA thermograms of **a** D0G0, **b** D30G0 **c** D15G15 and **d** D0G30 of unirradiated (I) and irradiated samples, (II) 75 kGy and (III) 150 kGy gamma dose

D15G15, the reinforcement of both date pit and glass fiber enhanced the T_0 of LLDPE component. The maximum T_0 (427 °C) obtained in D0G30 shows that incorporation of thermally stable glass fiber improves the overall thermal stability of LLDPE composite. Temperatures corresponding to the weight loss of 50% (T_{50}) and 75% (T_{75}) are also summarized in Table 3 along with weight loss percentage at 700 °C. It is evident from Table 3 that incorporation of both date pits and/or glass fiber shifts the temperature of degradation toward higher values in case of all unirradiated samples, affirming the increase in thermal stability. The reinforcement of glass fiber decreased the percentage of weight loss continuously which again confirms the enhancement in thermal stability [28]. This is attributed to the addition of highly thermally stable glass fiber [2] which presents a kind of hindrance to the specimen to get degrade.

Irradiation of gamma dose at 75 kGy and 150 kGy increased the T_{50} (Table 3) for D0G0 and D0G30 (without date pit fiber). Also, the percentage of weight loss at 700 °C was found to be decreased at 150 kGy in comparison with unirradiated sample, which is supporting factor for increasing thermal stability of these composites with increase in gamma dose. On the other hand, the composites reinforced with date pit fiber (D30G0 and D15G15) the increase in gamma dose from

Table 2 Characteristic thermal decomposition data of LLDPE composites

Sample index	Degradation stage	Gamma dose								
		0 kGy			75 kGy			150 kGy		
		T_0	T_{max}	T_{end}	T_0	T_{max}	T_{end}	T_0	T_{max}	T_{end}
D0G0	First	–	–	–	–	–	–	–	–	–
	Second	365.13	434.05	495.13	388.15	434.05	498.95	386.01	437.37	496.88
D30G0	First	242.34	290.18	342.01	254.03	353.10	374.90	261.15	285.58	331.96
	Second	384.96	439.20	504.90	419.04	441.60	519.98	380.13	451.90	530.99
D15G15	First	249.15	285.03	329.55	282.15	369.48	342.91	277.03	379.23	397.89
	Second	408.05	463.12	508.97	426.05	451.90	496.97	417.05	446.93	527.95
D0G30	First	–	–	–	–	–	–	–	–	–
	Second	427.05	471.77	507.95	435.10	461.47	495.94	390.12	469.56	520.98

Table 3 Weight loss percentage at different decomposition temperature for unirradiated and irradiated samples at different irradiation doses (kGy)

Sample index	T_{50} (°C)			T_{75} (°C)			Weight loss % at 700 °C		
	0 kGy	75 kGy	150 kGy	0 kGy	75 kGy	150 kGy	0 kGy	75 kGy	150 kGy
D0G0	431.03	434.11	444.77	457.90	458.36	–	82.62	79.93	64.26
D30G0	441.62	446.62	429.49	477.31	–	482.48	79.24	73.18	80.99
D15G15	456.15	457.86	452.06	494.33	–	–	76.99	63.54	64.87
D0G30	471.46	472.08	477.38	–	–	–	63.37	58.22	52.38

75 to 150 kGy led to decrease in T_{50} and at the same time, percentage of weight loss was found to be increase at high gamma dose (150 kGy). This finding shows that low irradiation of 75 kGy presents the optimum dose for increasing the number of active sites in the polymer backbone incorporated with date pit fiber [29].

However, at high radiation (150 kGy) the composite reinforced with any amount of date pit fiber led to the chain scissioning of material and decreased the thermal stability of the composites. The results are in good agreement with the observations of Khan et al. [29] and Ndiaye et al. [30] where high dose led to decrease in thermal stability of composites.

Mechanical study

Tensile and flexural properties

The behavior of tensile strength and Young's modulus of the irradiated and unirradiated LLDPE composites are shown in Fig. 2.

LLDPE exhibited a tensile strength of 10.63 ± 0.67 MPa. The results were in close agreement as observed by Harishchandra et al. [31]. It can be noticed that LLDPE composites with reinforcement of 30% date pit (D30G0) and 30% glass fiber (D0G30) showed tensile strength of 8.12 ± 0.22 and 17.57 ± 1.99 MPa, respectively. The high percentages of any kind of reinforcement led to the decline in its value which could be attributed to the poor fiber/ matrix adhesion and fiber agglomeration [27] in polymer matrix clearly visible in their SEM micrographs also (Fig. 7). However, in case of hybrid composites it was observed that replacement of less stiff date pit fiber with more stronger and stiffer glass fiber resulted in an increase in tensile strength with maximum obtained in D10G20.

As a result, LLDPE composite with 10% date pit and 20% glass fiber presented an optimum tensile strength of 20.28 ± 0.88 MPa; owing to the enhanced adhesion among the reinforcing fillers and matrix resulting in the efficient transfer of load along the fiber/matrix interface which is shown in the form of minimum fiber pull out and compact surface of D10G20 in its SEM image (Fig. 7e). However, at further loading of glass fiber there was a net negative effect of glass fiber in hybrid composites due to increase in more brittle nature of composite with the addition of glass fiber, thereby reducing the tensile strength. Young's modulus of LLDPE showed a

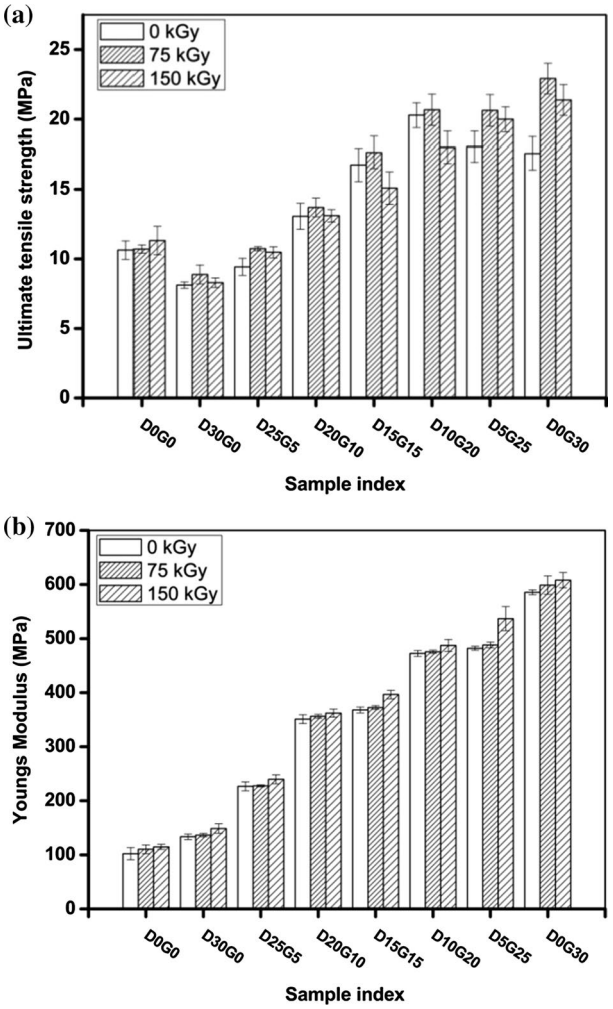

Fig. 2 Effect of gamma irradiation on **a** Tensile strength and **b** Young's modulus of LLDPE composites

continuous increase in its value with the incorporation of fiber due to the shifting of maximum tensile load to the fiber(s) rather than matrix alone (Fig. 2b). Unlike the tensile strength, the maximum value of modulus was observed at higher glass fiber content (D0G30) as observed by Panthapulakkal et al. [2] for the synthesis of hemp/glass fiber reinforced polypropylene hybrid composites. Also, the tensile strain % was found to be continuously decreased with the increasing content of glass fiber in hybrid composites (Table 4).

The results of flexural strength and modulus of composites are shown in Fig. 3. The flexural strength and modulus of LLDPE is 3.94 ± 0.40 and 53.06 ± 5.78 MPa, respectively. The incorporation of 30% date pit fiber and 30% glass fiber resulted in an increase in flexural strength to 5.19 ± 1.00 and 24.2 ± 0.57 MPa, respectively.

Table 4 Elongation % of irradiated and unirradiated LLDPE composites

Sample index	Tensile strain %		
	0 kGy	75 kGy	150 kGy
D0G0	23.5 ± 0.8	21.3 ± 0.2	21.3 ± 0.7
D30GO	22.7 ± 0.3	20.3 ± 0.4	21.3 ± 0.8
D25G5	21.2 ± 0.3	19.4 ± 0.5	20.6 ± 0.9
D20G10	21.0 ± 0.3	19.1 ± 0.1	20.1 ± 0.9
D15G15	19.5 ± 0.3	18.9 ± 0.5	19.5 ± 0.9
D10G20	19.1 ± 1.2	18.7 ± 0.1	19.9 ± 0.7
D5G25	18.8 ± 0.6	17.6 ± 0.7	18.1 ± 0.9
D0G30	18.0 ± 1.2	17.3 ± 0.3	18.0 ± 0.2

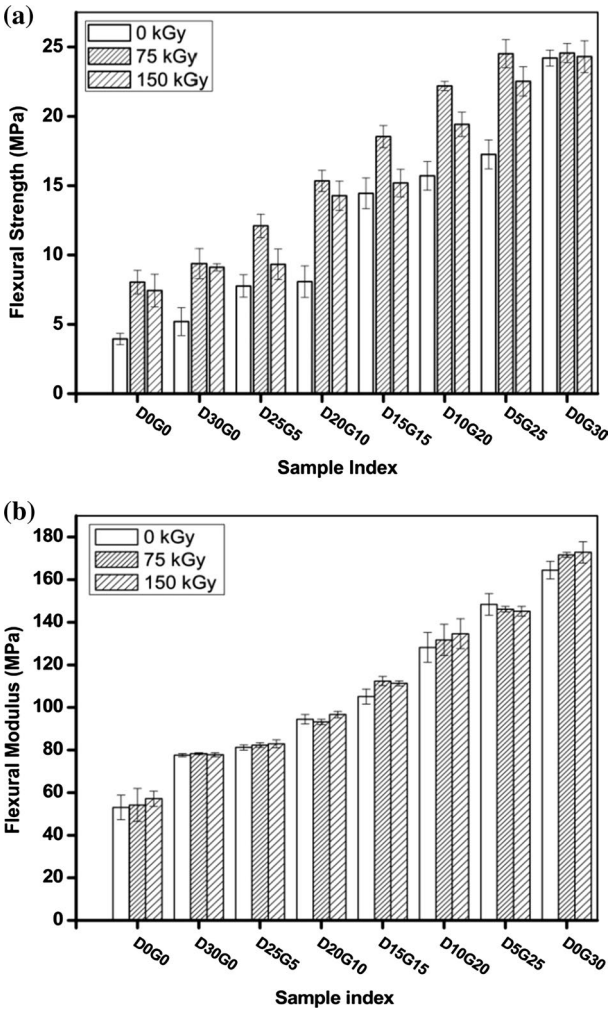

Fig. 3 Effect of gamma irradiation on **a** flexural strength and **b** flexural modulus of LLDPE composites

In case of hybrid composites, reinforcement of any kind of fiber continuously found to increase the flexural modulus in comparison with virgin LLDPE. This enhancement can be attributed to the reinforcement of high modulus components, viz., lignocellulosic date pit and glass fiber in plastic composites [32]. The results are in close agreement with the study of Jarukumjorn et al. where the addition of highly stiffer and stronger glass fiber led to an overall increase in flexural properties of PP/ sisal-glass fiber hybrid composites [33].

Effect of gamma irradiation on tensile and flexural properties

The effect of different doses of gamma radiation (75 and 150 kGy) on LLDPE composites was also studied in terms of tensile and flexural properties, and the results are shown in Figs. 2 and 3, respectively. The exposure of gamma radiations results in the scission (degradation) and cross-linking in irradiated polymer. At lower dose, the process of degradation leads to the increasing concentration of polar carbonyl groups as compared to the unirradiated apolar LLDPE. These active sites thus generated on polymer substrate induce the formation of network structure and cross-linking occurs in polymer chain [29, 34]. On the other hand, continuous exposure of gamma radiation of higher dose causes the breakdown of main polymer chain and its degradation into the small fragments. As a result, tensile strength reduces after certain gamma dose [35]. An intense gamma exposure to polymer blends result in declination of tensile strength and reduced degree of polymerization, as also observed by Marcovich et al. [36] However, the irradiation produces fluctuating behavior for Young's modulus, being the values for some irradiation doses higher than unirradiated or low gamma irradiated samples [32, 37] irrespective of the value of tensile strength obtained for the specimen. In our study, it was found that there was an enhancement in tensile as well as flexural strength of LLDPE composites at gamma dose of 75 kGy and further exposure led to the deterioration of these properties. The process of chain scissioning results in the removal of the sufficient number of crystallites and increases the local stress concentration on crystals and hence responsible for decrease in tensile strength after certain gamma dose [37]. ANOVA analysis also revealed that the reinforcement of both the fibers as well as effect of gamma irradiation affected the tensile and flexural strength significantly ($P < 0.05$). Young's modulus on the other hand was found to show an unexpected increase in its value at high gamma dose and thus show variable nature of this property as also observed by other researchers [32, 37]. The effect of gamma radiation in range from 0 to 150 kGy on LLDPE/wood flour is reported in our previous study also where the increasing gamma dose enhanced the thermal stability up to 50 kGy with maximum value of Young's modulus obtained at 75 kGy [38]. Reyes et al. [39] have also observed the increase of Young's modulus with increase in gamma dose up to 6 Mrads irrespective of the trend of tensile strength which showed its high value at 2.5 Mrads in PP/HDPE/wood flour composites. The similar trend of Young's modulus was also reported by Rimdusit et al. [40] who studied the effect of gamma irradiation on mechanical properties of PP/wood flour composites.

Sorption behavior

The sorption curves of LLDPE and composites at room temperature are shown in Fig. 4, where percentage of mass change is plotted against the square root of time. The virgin film D0G0 without any fiber content showed the lowest percentage of water uptake (0.66 ± 0.01). A rapid moisture uptake was observed for all the films loaded with any amount of date pit fiber within the initial days of immersion. The maximum percentage of water absorption 4.97 ± 0.02 was obtained in composite with 30% date pit fiber (D30G0). This was attributed to the presence of maximum content of hydrophilic hydroxyl groups in D30G0. However, saturation level has not been attained for any composite film within the aging period. It was also found that replacement of date pit by glass fiber in composites reduced the moisture absorption in hybrid composites. This is because glass fiber due to negligible moisture absorption capacity acted as a barrier to date pit fiber by preventing the direct contact between hydrophilic date pit fiber and water [27]. Among the hybrid composites, D10G20 presented an unusual trend and showed minimum sorption percentage (1.23 ± 0.06) as was expected for D5G25 (3.17 ± 0.01). The reduction in absorption capacity of D10G20 is believed to be attributed to strong interfacial adhesion, cohesiveness and hence resulting minimum interfacial voids (Fig. 7) which prevented the accumulation of water in composite.

Effect of aging on tensile strength

It is well-known fact that decrease in interfacial adhesion between matrix and fiber deteriorates the mechanical properties of the composites [41]. The polymer matrix dissolution, debonding of fiber/matrix interface and leaching of fiber during aging in

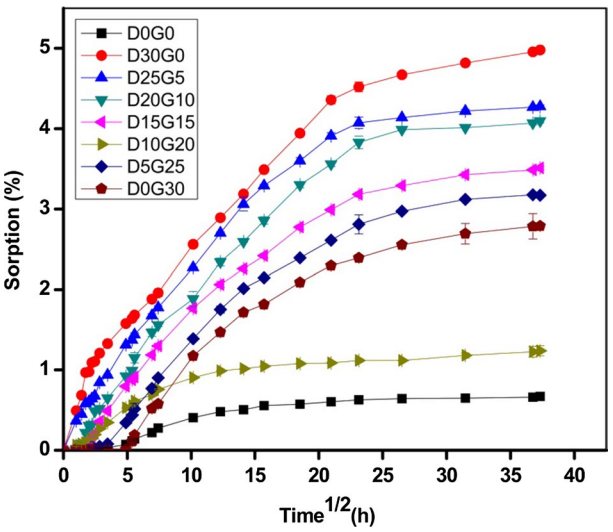

Fig. 4 Sorption behavior of LLDPE composites as a function of time ($h^{1/2}$)

water are the other factors responsible for reduction in mechanical properties. Tensile strength of all the composites after aging in water is presented in Fig. 5. The results indicate that virgin LLDPE without any fiber reinforcement retained its tensile strength and did not show any significant change. An overall reduction of 4–17% was observed in tensile strength of LLDPE composites. It was found that composites with high glass fiber content (D0G30, D5G25 and D10G20) showed moderate reduction in tensile strength. On the other hand, incorporation of maximum amount of date pit fiber led to the deterioration in tensile strength (D30G0). This loss was believed to be failure of date pit fiber in terms of stress transferred from the polymer matrix through the disrupted interface as a result of the water absorption.

FTIR Spectra

Figure 6 shows the FTIR spectra of unirradiated and irradiated LLDPE composite reinforced with 10% date pit and 20% glass fiber (D10G20) which displayed bands at 2930 and 2844 cm^{-1} (C–H aliphatic stretching), typical characteristics of lignocellulosic date pit fiber [42, 43]. The band at 1469 cm^{-1} (CH_2 rocking) corresponds to the presence of octane as side chain and 712 cm^{-1} ($-(CH_2)_2$ wagging) attributing to the band of polyethylene chain. The band at 1725 cm^{-1} is attributed to the –C = O stretching of MALLDPE grafted polyethylene [44]. The results of spectral bands of composite were in good agreement with the results of other researchers [45–47]. The irradiated composites exhibited the aforementioned peaks with some noticeable changes. It is noteworthy that at 75 kGy dose, the band attributed to the carbonyl group was found to be disappeared, instead a broad region was observed which might be caused by the conversion of maleic anhydride group into other carbonyl groups or acid derivatives. Additionally, irradiation at 75 kGy dose caused the

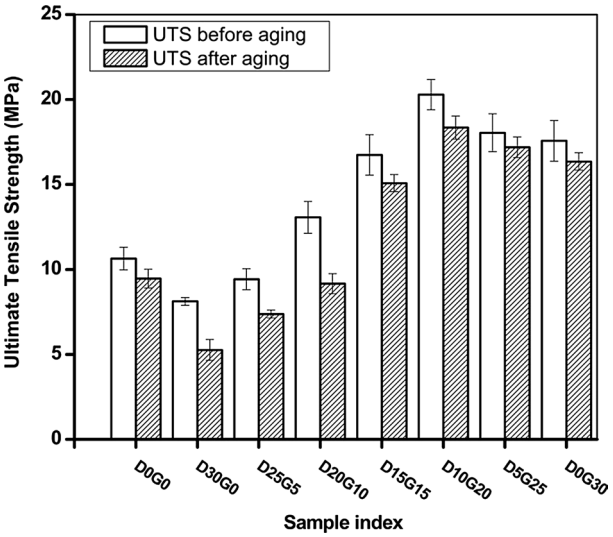

Fig. 5 Effect of aging on tensile strength of LLDPE composites

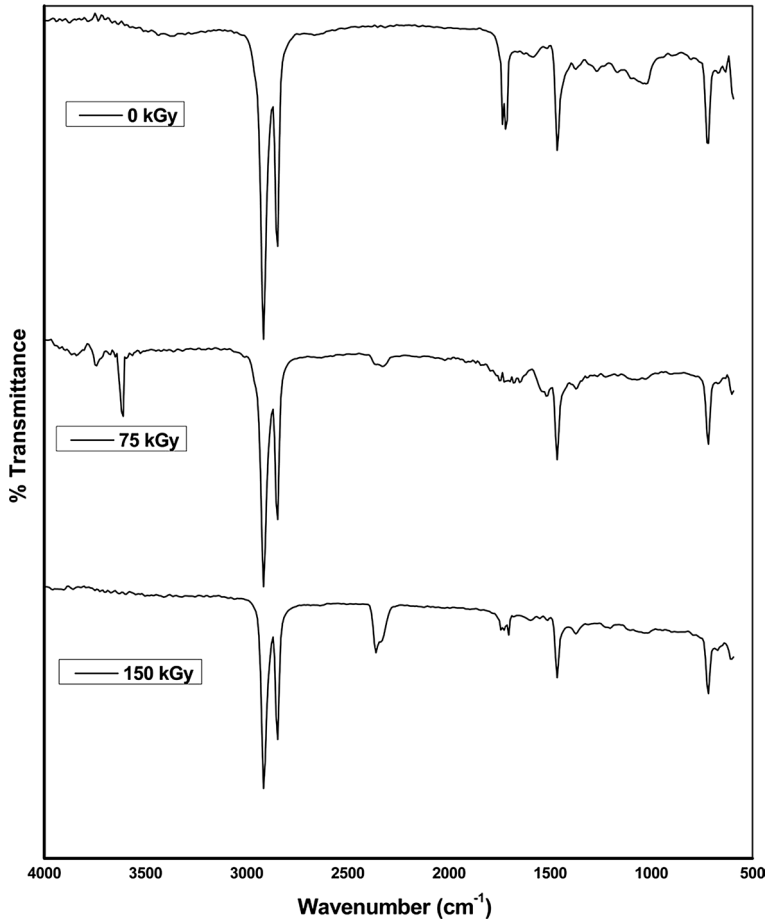

Fig. 6 FTIR spectra of unirradiated and irradiated LLDE composite D10G20

hydroxyl radicals in the blend to increase which is shown in the form of increasing intensity of band at 3622 cm^{-1}. The formation of these groups/radicals are responsible for changing the polarity as well as enhancing the polymer filler interactions [48].

SEM analysis

The evidence of effective compatibility between matrix and fiber with different ratios of hybrid fiber is depicted in SEM photographs of specimens in Fig. 7. Figure 7a clearly indicates that surface of LLDPE film without any fiber loading was regular. At high loading of any kind of fiber whether date pit or glass (Fig. 7b and f) aggregation of fiber at one side of surface could be easily seen showing that with such high amount of fiber, the nature of resulting adhesion was poor

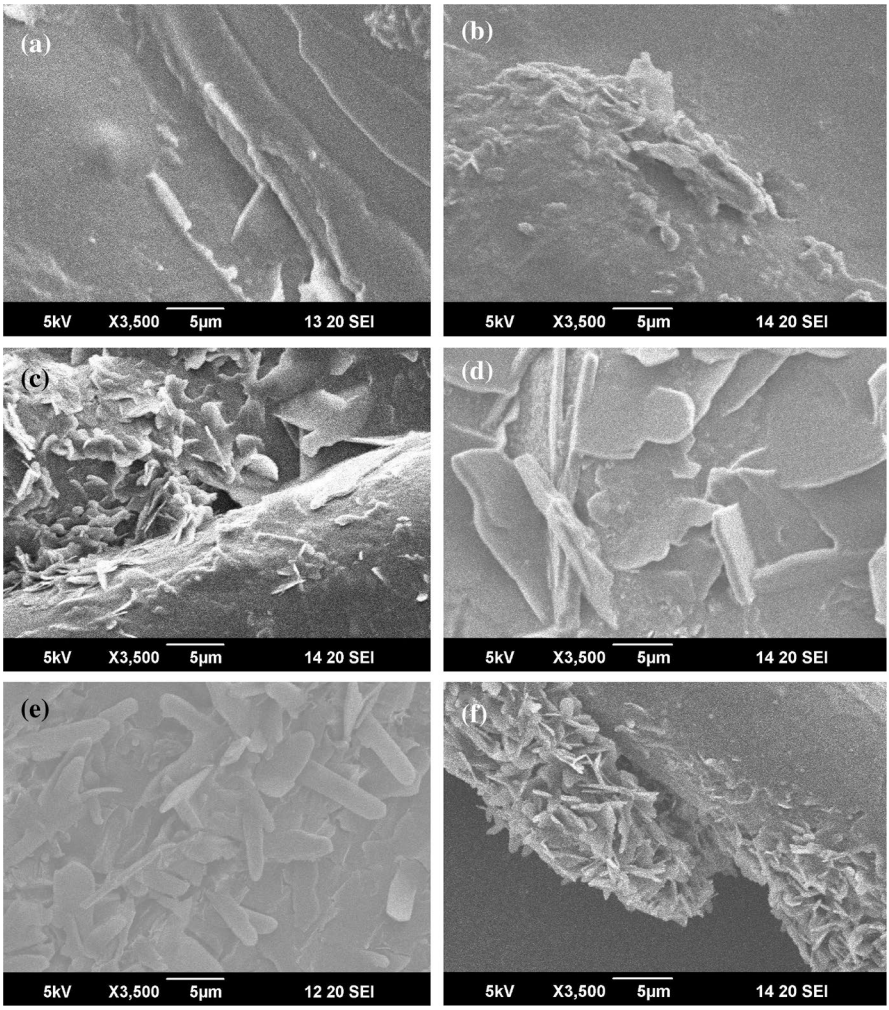

Fig. 7 SEM micrographs of: **a** D0G0, **b** D30G0, **c** D20G10, **d** D15G15, **e** D10G20 and **f** D0G30

between fiber and matrix. The high number of debonding particles, clusters, voids and fiber pull out are also observed in Fig. 7c and d. However, in Fig. 7e with 10% date pit and 20% glass fiber content the more compact surface and minimum fiber pull out were observed. The homogeneity, cohesiveness, strong adhesion and absence of voids give an idea about this ratio of hybrid fiber as an optimum loading of reinforcement in the matrix.

On the other hand, the maximum tensile strength obtained in D10G20 again confirms the existence of the strongest adhesion obtained with this particular loading of hybrid fiber (Fig. 2a). The reason for this adhesion might be due to the fact that anhydride group of MALLDPE was responsible for making good compatibility between –OH group of cellulosic date pit fiber and SiO group of glass

fiber only with this ratio as reinforcement in comparison with other specimens [22].

X-Ray diffraction

X-ray diffractogram of unirradiated and irradiated composites is presented in Fig. 8. In the diffraction pattern of D0G0 (Fig. 8a), LLDPE showed three main crystalline diffraction peaks at diffraction angle 2θ of 21.52°, 23.88° and 36.21° corresponding to 110, 200 and 020 lattice planes of orthorhombic crystal lattice [14, 49]. In composite specimen D10G20 peaks were obtained at 2θ of 21.51°, 23.71° and 36.20°. The clear presence of characteristic peaks of LLDPE in D10G20 indicates that there were not any significant changes in the crystalline structure of LLDPE on reinforcement. However, the intensity of peaks did change toward decrease connected to the decrease in crystalline structure of composites can be related to the amorphous nature of glass fiber. The findings of the experimental results carried out by Hao. et al. [50] showed that reinforcement of glass fiber does not produce any observable peak which is in agreement with other reported works also [51–53]. The exposure of gamma radiations did not change the position of diffraction peak as well as no peak was emerged on increasing the radiation dose. This observation suggests the presence of same crystalline structure of polyethylene on gamma exposure [48].

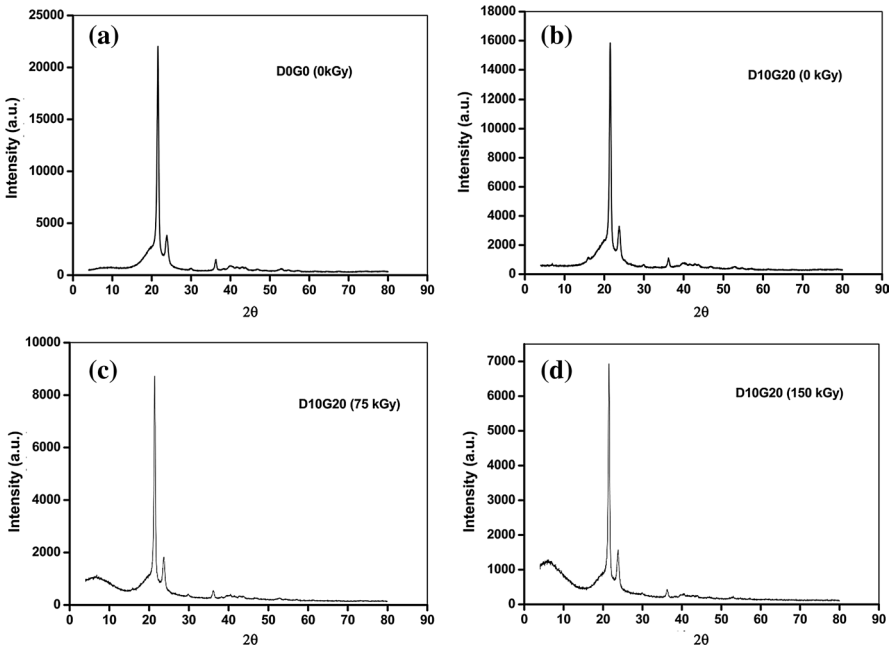

Fig. 8 X-ray diffraction patterns of unirradiated and irradiated composites

Conclusions

This article reports the thermal, mechanical, water absorption and XRD analysis of date pit/glass fiber reinforced hybrid LLDPE composites synthesized by the injection molding. A positive hybrid effect of reinforcement was observed on the thermal stability of LLDPE composites on the basis of TGA analysis. Incorporation of reinforcement found to improve the tensile as well as flexural properties of composites. The maximum tensile strength of 20.2 ± 0.8 MPa was obtained with 10% date pit and 20% glass fiber. Water-resistant property was found to be better with high percentages of glass fiber. The composites were also exposed to the gamma radiations (75 and 150 kGy), and the effect is characterized in terms of thermal and mechanical properties. Weight loss percentage was found to be decreased at gamma dose of 75 kGy in comparison with the unirradiated samples. The irradiated composites at low dose showed the significant improvement in tensile properties also. The improved adhesion on gamma exposure was also observed on the basis of SEM micrographs.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Human or animal rights The Research work is not involving any human participants and/or animals.

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