The Effects of Gamma Radiation on Bioplastics

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Abstract Bioplastics have been gaining traction in these few years and but still need to achieve the level of physical properties found in petrochemical plastics for wider use in applications involving radiation techniques. This study aimed to investigate the synthesis of starch bioplastic from plant sources such as starch and understand how radiation affects such a material relative to petrochemical plastic. The starch bioplastic samples were synthesised from corn flour and irradiated with a low dose along with PET and PE for comparison. Analysis was done on surface morphology, Vickers hardness test and FTIR for comparison between samples without irradiation and with irradiation. This study found almost no changes in PET, PE and starch bioplastic when exposed to 13.05 mGy of absorbed dose. Comparison between samples of the same material without and with irradiation found no observable changes in the surface morphology. After undergoing irradiation, the Vickers hardness value was found to have changed, for PET a decrease of 1.2 HV from 21.9 HV to 20.7 HV; for PE an increase of 1.57 HV from 5.49 HV to 7.06 HV; for starch bioplastic a slight increase of 0.28 HV from 1.74 HV to 2.02 HV. As for FTIR spectroscopy, the irradiated PET sample displayed slight decreased absorption for overall absorption spectra and significant decreased absorption of peaks at 1700 cm⁻¹, 1250 cm⁻¹, 1000 cm⁻¹ and 720 cm⁻¹ compared to non-irradiated sample. For PE, decreased absorption was found in the overall absorption spectra for sample with irradiation. For starch bioplastic however, no difference was found in the absorption spectra for both samples without and with irradiation. With these findings along with identified issues involved in the synthesis process of the starch bioplastic, this study would help to increase the favourability of bioplastics over conventional petrochemical plastics used in disposable consumer products.

Keywords Bioplastics, Effects, Gamma Radiation

1. Introduction

Recently, due to rising public awareness about environmental protection, more and more companies are showing a keen interest in eco- friendly products for the sake of appealing to consumer conscience. This has given rise to the manufacturing of bioplastics from renewable sources such as plant-based like corn, tapioca and sugarcane. Industrial bioplastics are in general made from polylactic acid (also polylactide or PLA), a material that is compostable and breaks down much easier than plastics derived from petroleum. Starch plastic on the other hand usually involves ingredients easily found in the kitchen and can be made in the kitchen but is significantly less resistant to solvents or heat than industrial PLA plastic. Instead starch is commonly used as a filler in bioplastics to cut down on cost [1]. The most important facet used for promoting the use of bioplastic is the fact that bioplastic is essentially a near zero carbon emission product, since its constituents are absorbed from the atmosphere during cultivation.

Given how widespread the usage of plastic is in an average consumer's daily life, it is inevitable for plastic products to come into contact with radiation, let it be purposeful or unknowing, before arriving at the consumers' end. While various studies have been done on petroleum-based plastics since the last century, studies on bioplastics focus on synthesis and are still somewhat lacking in interaction with radiation. Hence, there is an increased need to study the effects of radiation on bioplastic materials which are primarily derived from plant sources to enhance the durability and versatility of bioplastics against radioactive conditions.

2. Materials and Methods

2.1. Bioplastic Making

A recipe of 60 ml of distilled water, 5 ml of acetic acid, 5

ml of glycerine and 9 g of corn flour was used to produce the first batch of hard bioplastic. The ratio was retained and scaled up to 540 ml of distilled water, 45 ml of acetic acid, 45 ml of glycerine and 81 g of corn flour to produce a second batch which resulted in soft bioplastics later used for analysis. A third batch was produced based on the recipe of the second batch but with 35 ml of glycerine instead which resulted in hard bioplastic slightly more pliable than the first hard bioplastic.

2.2. Sample Preparation

PET and PE were obtained from commercial products of beverage bottles. The second batch of soft starch bioplastic was chosen for ease of preparation and consistent thickness. 6 samples were prepared for each material. 3 samples for non-irradiated analysis, 3 for irradiated analysis. The samples were cut into 1 cm x 1 cm with thickness of approximately 2 mm or less.

2.3. Irradiation Method

The samples were irradiated with Cs-137 (18.5 Mbq per rem) gamma source in a shielded setup at the same exposure rate of 20 mR/hr for the same duration of 75 hours. With a rate of 20 mR/hr, the resultant exposure is 1500 mR. Given that 1 roentgen of air kerma (kinetic energy released per unit mass) deposits 0.0087 J/kg which equals to 0.0087 Gy, 1500 mR of exposure that is equivalent to 13.05 mGy of absorbed dose [8]. Controlling samples of starch bioplastic was left outside of the irradiation area in the same room to check for any (a) degradation with time.

2.4. Analysis

After the irradiation period, analysis was done on both groups of non-irradiated and irradiated samples using Shimadzu HMV-FA Vickers Micro Hardness Tester for surface morphology plus hardness test and Perkin Elmer Spectrum FTIR for bonding properties.

3. Results and Discussion

3.1. Surface Morphology

The surface morphology analysis did not yield (Figure 1) any observable changes between non-irradiated samples and irradiated samples. The images obtained however helped to differentiate the surface morphology between materials and provide hints at the moulding process used.

Figure 1. PET (a) without irradiation (b) with irradiation, PE (c) without irradiation (d) with irradiation, starch (e) without irradiation (f) with irradiation

3.2. Hardness Test

The Vickers hardness test yielded minor differences between samples with and without irradiation. Out of all materials, PET had the highest hardness, followed by PE and finally starch bioplastic (Table 1). The test for starch bioplastic in particular was very challenging as it was very soft and may be unsuitable for Vickers hardness test. About three to four attempts were required for each measurement. A Knoop hardness test might be more suitable instead, but would yield Knoop Hardness Value (HK) which is incompatible for comparison with Vickers Hardness Value (HV).

Table 1. Test force of hardness test for each material

Material	Test Force (mN)	Duration (s)
PET	245.2	5
PE	98.07	5
Starch Bioplastic	98.07	15

Figure 2. Hardness value for PET, PE and Starch

For PET, the hardness value was 20.7 HV for sample with irradiation which is 1.2 HV lower than 21.9 HV for sample without irradiation. Relative to the high hardness value of PET, the difference was insignificant enough to be considered as change in hardness. For PE, the hardness value was 7.06 HV for sample with irradiation which is 1.57 HV higher than 5.49 HV for sample without irradiation (Fig. 2). This was quite the difference and may indicate an effect of irradiation which causes plastics to experience an increase in crystallinity and become harder [2-4]. For starch bioplastic, the hardness value was 2.02 HV for sample with irradiation which was 0.28 HV higher than 1.74 HV for sample without irradiation. This difference was small enough to be considered as sample variance and not a change in hardness.

3.3. Fourier Transform Infrared (FTIR)

The band ranging $3700 - 3000 \text{ cm}^{-1}$ present for all materials (Fig. 3) indicated the presence of $-\text{OH}$ groups found in phenols and alcohols, being particularly high content in starch bioplastic. The peaks found in between $3000 - 2800 \text{ cm}^{-1}$ indicated the absorption by saturated carbon bonds of CH_2-CH_2 [5]. The peak at 720 cm^{-1} for both PET and PE cannot be determined but may suggest unexpected presence of sulphated groups, likely from contamination [6]. The same goes for starch bioplastic which has an absorption band approaching 500 cm^{-1} instead.

A small peak found in PET at 1700 cm^{-1} was due to the absorption of ketone group in PET's chemical composition [7]. Peaks at 1250 cm^{-1} and 1100 cm^{-1} were due to ester groups involved in the polymerisation process of PET.

Overall, the FTIR spectrograph revealed a lot of information on the distinctive chemical composition for each material. For PET, the irradiated sample displayed slight decreased absorption for overall absorption spectra and significant decreased absorption of peaks at 1700 cm^{-1} , 1250 cm^{-1} , 1000 cm^{-1} and 720 cm^{-1} . The analysis for PE after receiving irradiation, showed the same spectrum profile and peaks, but with decreased absorbance for the entire spectrum. No explanation can be offered to properly describe the decreased absorption for the overall spectra of PET and PE after undergoing irradiation except probable contamination due to improper sample handling which may result in different optical properties. Absorption spectra for non-irradiated and irradiated starch bioplastic samples revealed no change as no new peak was formed and there was almost no changes to existing peaks.

Figure 3. FTIR spectra for all tested sample

4. Conclusions

This study had found little to no changes in the samples receiving low absorbed dose of gamma radiation which was 13.05 mGy. The sample preparation stage had yielded multiple findings about the synthesis process of starch bioplastic with the curing part being the most troublesome yet heavily influencing the properties of the final cured product. The tested starch bioplastic experienced degradation shortly after production, but the weakened degradation present in irradiated samples compared to the control samples suggested that radiation treatment can help improve the physical properties of bioplastic materials. The conclusion represents as below:

Material	Analysis	Comparison
PET	Surface Morphology	No visible changes.
	Hardness	A decrease of 1.2 HV from 21.9 HV to 20.7 HV.
	FTIR	Irradiated sample displayed slight decreased absorption for overall absorption spectra and significant decreased absorption of peaks at 1700 cm ⁻¹ , 1250 cm ⁻¹ , 1000 cm ⁻¹ and 720 cm ⁻¹ .
PE	Surface Morphology	No visible changes.
	Hardness	An increase of 1.57 HV from 5.49 HV to 7.06 HV.
	FTIR	Decreased absorption for overall absorption spectra for sample with irradiation.
Starch Bioplastic	Surface Morphology	No visible changes.
	Hardness	Slight increase of 0.28 HV from 1.74 HV to 2.02 HV.
	FTIR	No difference in absorption spectra.

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Acknowledgements

The authors would like to thank the Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia for facilities provided and gratefully acknowledged the financial support a research grant (H074 and H417) that makes the research possible.

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