

CHARACTERISTICS STUDY OF POLYETHYLENE TEREPHTHALATE (PET) USED FOR COMMERCIAL DRINKING BOTTLES UNDER ULTRAVIOLET (UV) RADIATION

MOHD FAIRUZ AFFANDI AZIZ* AND WEE NEE ANGELINE

Department of Physical Sciences, Faculty of Science & Technology, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia.

**Corresponding author: fandy@umt.edu.my*

Abstract: The characteristics of polyethylene terephthalate (PET), used for commercial drinking bottles of different brands and colours after photodegradation process under three different ultraviolet (UV) sources: sunlight, UV lamp with wavelength of 365 nm and UV lamp with wavelength of 254 nm, were studied. The tests that were carried out included tensile tests, Fourier Transform Infrared (FTIR) Spectroscopy and Scanning Electron Microscopy (SEM). After 250 hours of exposure to sunlight, the force at break and Young's Modulus were found to decrease up to 36.5% and 47.9% respectively. For samples exposed to 365 nm UV light radiation, the force at break and Young's Modulus were also found to decrease up to 52.7% and 54.9% respectively, which is higher than the effect of sunlight radiation. After 250 hours of exposure to 254 nm UV light, the force at break decreased up to 34.7% and the Young's Modulus decreased up to 17.5%. FTIR spectroscopy showed that the absorbance for samples exposed to the three UV sources decreased with increasing exposure time, especially at peak 1716.42 cm^{-1} , which signifies the carbonyl, C=O group with the highest decrease in absorbance is 62.33%. The decrease in absorbance values showed that photodegradation of PET caused the C=O bonds to break. The longer the exposure time towards the UV source, the ability to absorb infrared by these bonds decreases. SEM images obtained after tensile tests showed the fractured surfaces having suction cups.

KEYWORDS: *Polyethylene terephthalate, UV radiation, photodegradation, FTIR spectroscopy, force at break*

Introduction

Polyethylene terephthalate (PET) is a polymer with the molecular formula $C_{10}H_8O_2$ as its repeating unit. Its monomer is formed by the esterification of terephthalic acid and ethylene glycol. The polymer is then formed from the polycondensation reaction of the monomers. PET is known as one of the toughest plastics since it has excellent tear and fatigue strength. Its thermoplastic property allows it to be moulded and shaped to be used in many applications, such as containers in the food and beverage industry, storage, clothing and even in tires (Callister, 2007). PET is a thermoplastic polymer of the polyester family. Besides having excellent tear and fatigue strength, it is also resistant towards humidity, acids, oils, grease and solvents such as acetone and therefore it is suitable to be used in many applications (Callister, 2007). PET is used in the production of commercial drinking bottles such as Coca-cola, Ice Cream Soda, Sprite and other carbonated drinks, and also mineral and drinking-water bottles such as Spritzer and Borneo.

PET is used in the production of commercial drinking bottles because it is visibly clear (Westerhoff *et al.*, 2007). It is known that consumers have a natural tendency to repeat the usage of the bottles frequently since it does not require much hassle in cleaning and storing. Although there should be no concerns when it comes to frequent reuse of the PET bottles as long as proper cleaning steps are taken (Westerhoff *et al.*, 2007), the degradation of PET under UV radiation however may

render it unsuitable to be used frequently since exposure to sunlight will cause chain degradation and loss of strength in PET (Andrady, 2007).

The objective of this study is to study the effects of UV radiation from different types of sources on PET used for commercial drinking bottles, namely Coca-cola (CC), Ice Cream Soda (AKS) and Sprite (SP). The characteristics studied were mechanical properties, namely force at break and Young's Modulus; absorbance spectra by FTIR spectroscopy and SEM images.

Experimental Method

Sample Preparation

Three 1,500 ml brands of commercial drinking bottles were obtained from Giant Hypermarket, Kuala Terengganu: CC, AKS and SP carbonated drinks. All bottles were made of PET and the CC bottles were colourless, AKS bottles had bluish tint while SP bottles had greenish tints. All the caps and the brand labels of the bottles were removed. The bottles were rinsed with tap water before being cut into rectangular samples of dimensions of 10 cm × 5 cm. The rectangular samples were then washed with Sunlight dishwashing liquid and rinsed with distilled water. After that, the samples were wiped with paper towels and placed under ceiling fan for drying. After drying, the samples were numbered and grouped into nine groups according to their brands and exposure type. Table 1 shows the grouping of the sample according to their brands and exposure type. Sample S01, S02 and S03 are control samples, whereby they did not undergo any type of radiation and served as references for comparison.

Table 1: The grouping of samples according to brands and exposure.

Groups	Brand	UV Exposure
S01	CC	None
S02	AKS	None
S03	SP	None
S10	CC	Sunlight
S20	AKS	Sunlight
S30	SP	Sunlight
S11	CC	UV lamp (365 nm)
S21	AKS	UV lamp (365 nm)
S31	SP	UV lamp (365 nm)
S12	CC	UV lamp (254 nm)
S22	AKS	UV lamp (254 nm)
S32	SP	UV lamp (254 nm)

Exposure to UV sources

The samples were exposed to the respective UV sources according to Table 1. The samples were exposed from 1000 hrs to 1500 hrs, a time period where the highest intensity of UV radiation exists (WHO, 2002) with the maximum time of exposure of 250 hrs. The UV lamp used in this study was the MINERALIGHT® Lamp Model UVGL-58. The distance between the lamp and samples was ≈ 30 cm.

Tensile tests

After the exposure, all the samples were cut into rectangles of 1 cm × 10 cm. The cut samples were individually tested using the materials-testing machine M350-10CT by Testometric. The samples were individually attached and clamped by the grips of the testing machine. The upper and lower parts of the samples were wrapped using cardboard sheets to protect the samples and also to tighten the grips (Sell & Marquez, 1993). The machine was made to pull each sample at a crosshead speed of 10 mm min⁻¹ until it broke apart.

FTIR Spectroscopy

FTIR spectrometer was used to study the extent of photodegradation on PET towards the absorbance of infra-red to PET (Allen *et al.*, 1993, Fehine *et al.*, 2004, Sell & Marquez, 1993, Smith *et al.*, 1989). The samples were scanned using the Thermo Nicolet Avatar 360 Spectrometer to obtain the transmission spectra.

Scanning electron microscopy (SEM)

The fractured samples which went through tensile tests were viewed under the scanning electron microscope model JEOL JSM-6360LA which is located at the SEM laboratory, Institute of Oceanography, Universiti Malaysia Terengganu.

Results and Discussion

Samples exposed to sunlight

After 250 hrs, the decrease in force at break values is shown in Figure 1(a) where it is shown that the CC samples had the lowest decrease in the value of force at break at 17.91%, followed by AKS samples at 35.87% and SP samples at 36.54%. Figure 1(b) shows the graph of Young's Modulus against the time of exposure for the samples exposed to sunlight. It is shown in the graph that the Young's Modulus for all the samples decreased with increasing time of exposure to sunlight.

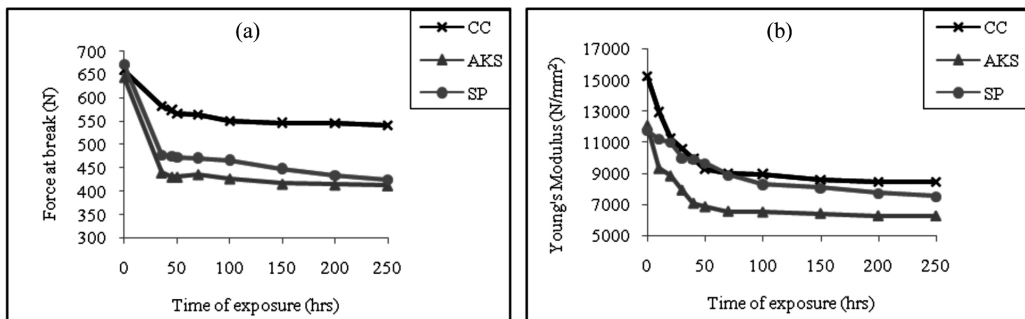


Figure 1: The results showing (a) the decrease in force at break and (b) the decrease in Young's Modulus after 250 hrs of exposure to sunlight.

Samples exposed to 365 nm UV light

After 250 hrs, the samples showed a decrease in force at break values as shown in Figure 2(a). AKS samples showed the highest decrease in force at break at 52.65%, followed by SP samples at 43.92% and CC samples at 30.58%. Figure 2(b) shows the graph of Young's Modulus

against the time of exposure for the samples irradiated under UV lamp of wavelength 365 nm. It is shown in the graph that the Young's Modulus for all the samples decreased with the increasing exposure time to the UV source. SP samples had the highest decrease in Young's Modulus after 250 hrs of exposure at 63.78%, followed by CC samples with 54.86% and AKS samples with 48.90%.

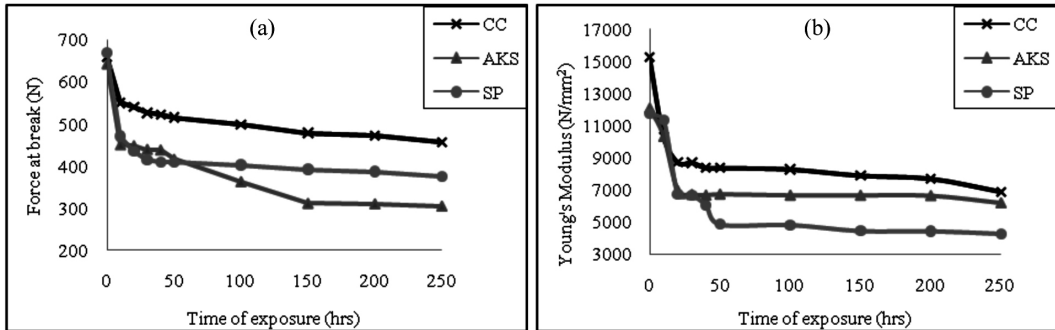


Figure 2: The results showing (a) the decrease in force at break and (b) the decrease in Young's Modulus after 250 hrs of exposure to 365 nm UV light.

Samples exposed to 254nm UV light

It was found that, after 250 hrs of exposure to 254 nm UV light, the percentage decrease in force at break for SP samples was the highest at 34.67%, followed by AKS samples with 32.43% and CC samples with 24.30% decrease from the values of force at break at 0 hrs of radiation. Figure 3(b) shows the graph of Young's Modulus against time of exposure for samples exposed to the same type of radiation. It was found that the decrease in Young's Modulus was lower than the ones found for samples exposed to sunlight and radiation under 365 nm UV light. The decrease in Young's Modulus might be due to the higher elongation of the samples before it breaks.

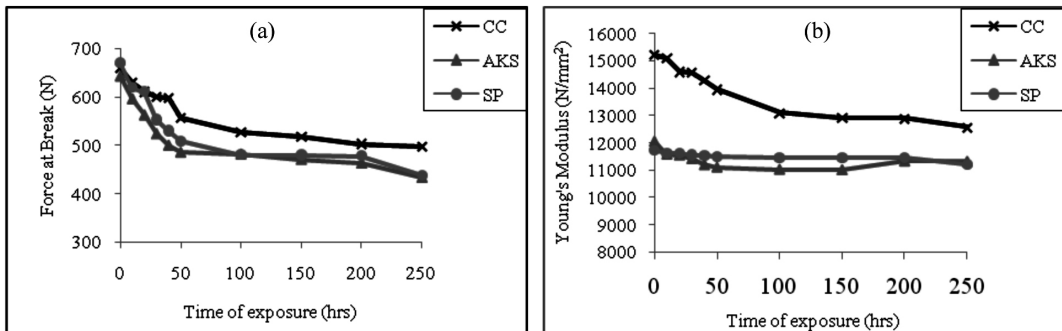


Figure 3: The results showing (a) the decrease in force at break and (b) the decrease in Young's Modulus after 250 hrs of exposure to 254 nm UV light.

FTIR spectroscopy

The carbonyl, C=O region in the IR spectrum is located between 1500 cm⁻¹ and 1900 cm⁻¹. From the results obtained, an obvious peak was found at wavenumber 1716.42 cm⁻¹. Generally, there was a decrease in the absorbance of the C=O group towards IR for all the exposures towards different types of UV sources. This shows that C=O bonds are unable to absorb IR since they were weakened by the attack of UV light. Figures 4 – 6 show the graph of absorbance for C=O band against the time of exposure to sunlight, 365 nm UV light and 254 nm UV light respectively.

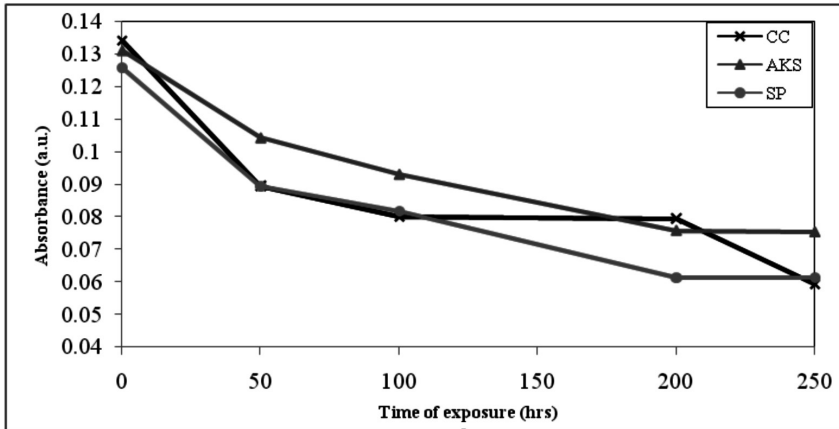


Figure 4: The graph of absorbance for C=O band versus time of exposure for samples exposed to sunlight.

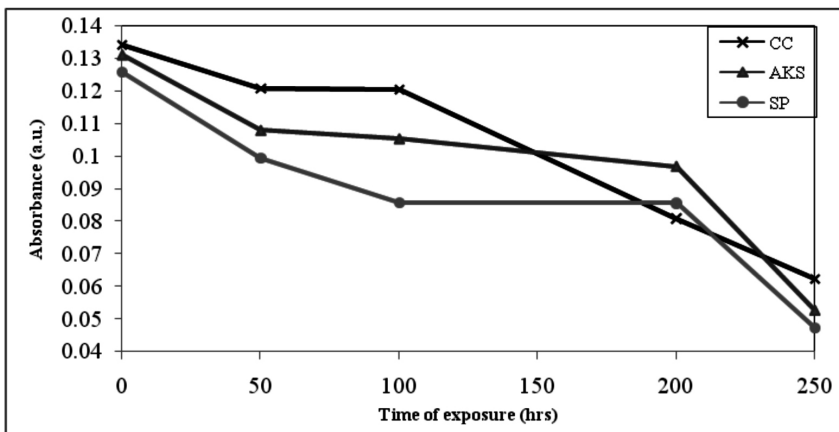


Figure 5: The graph of absorbance for C=O band versus time of exposure for samples irradiated with 365 nm UV light.

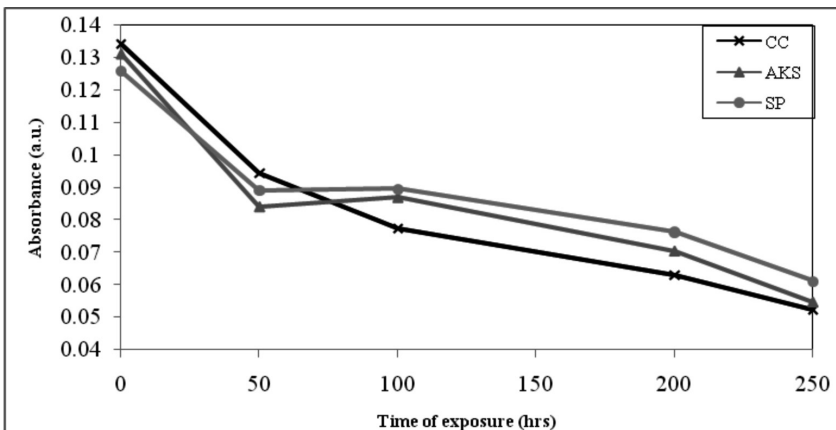


Figure 6: The graph of absorbance for C=O band versus time of exposure for samples irradiated with 254 nm UV light.

SEM images

Figure 7 shows the images of fractured samples which were unexposed to any UV radiation. Figure 7(a) shows that the fractured sample appears to have arranged lines of suction cups resulting from the ductility property of the samples. However, Figures 7(b) and 7(c) show the samples have a clean-like surface after the fracture. This could be caused by unavoidable exposure to other factors (i.e. heat or humidity) during sample preparation.

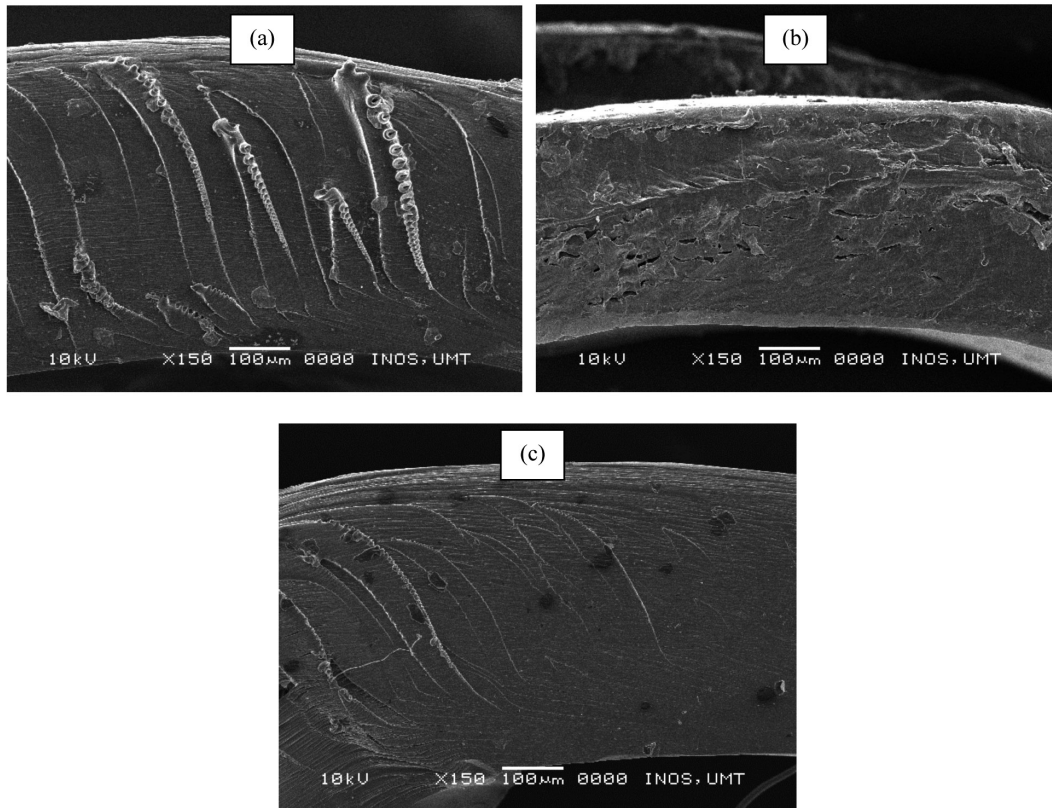


Figure 7: The SEM images for unexposed (a) CC sample, (b) AKS sample and (c) SP sample after tensile tests.

Figure 8 shows the fractured samples which were exposed to sunlight. Comparing Figure 7(b) and Figure 8(b), it can be seen that suction cups are starting to appear after the sample was exposed to sunlight for 250 hrs and the same goes for SP sample.

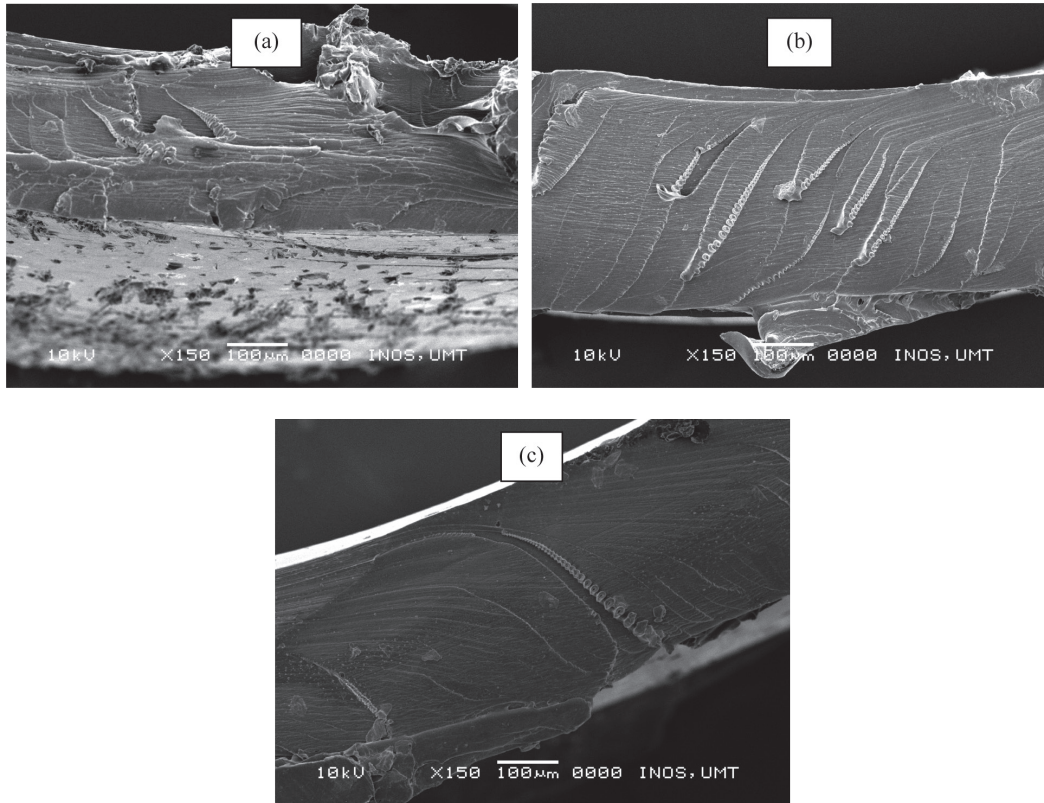
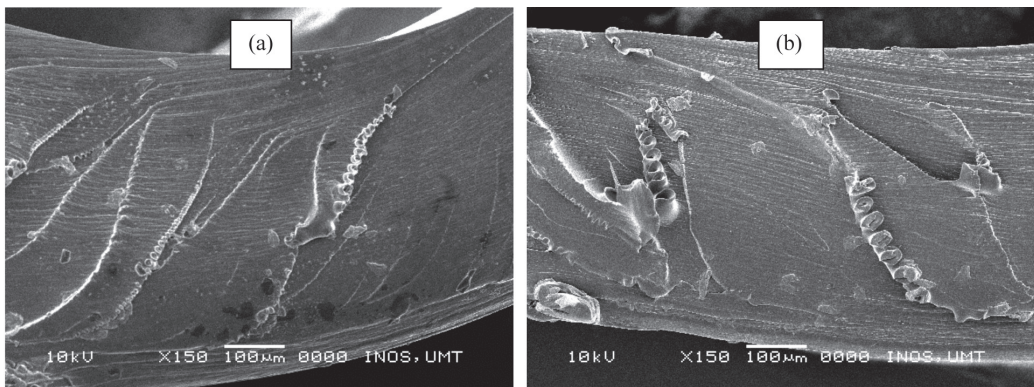


Figure 8: The SEM images for (a) CC sample, (b) AKS sample and (c) SP sample which were exposed to sunlight after tensile tests.

In Figure 9, the fractures of the samples irradiated under 365 nm UV light seem more obvious than the ones being exposed to sunlight although they have the same time exposure. This is because the distance of the samples exposed to sunlight is further than the distance of the samples being irradiated under the lamp.



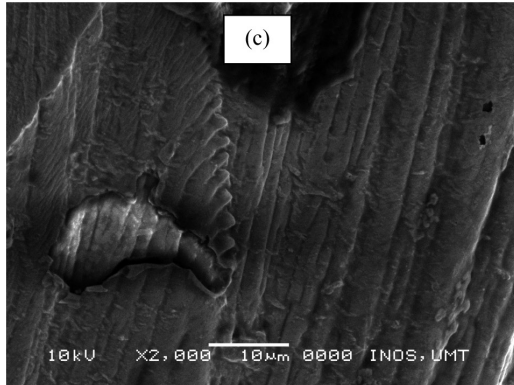


Figure 9: The SEM images for (a) CC sample, (b) AKS sample and (c) SP sample which were irradiated under 365 nm UV light after tensile tests.

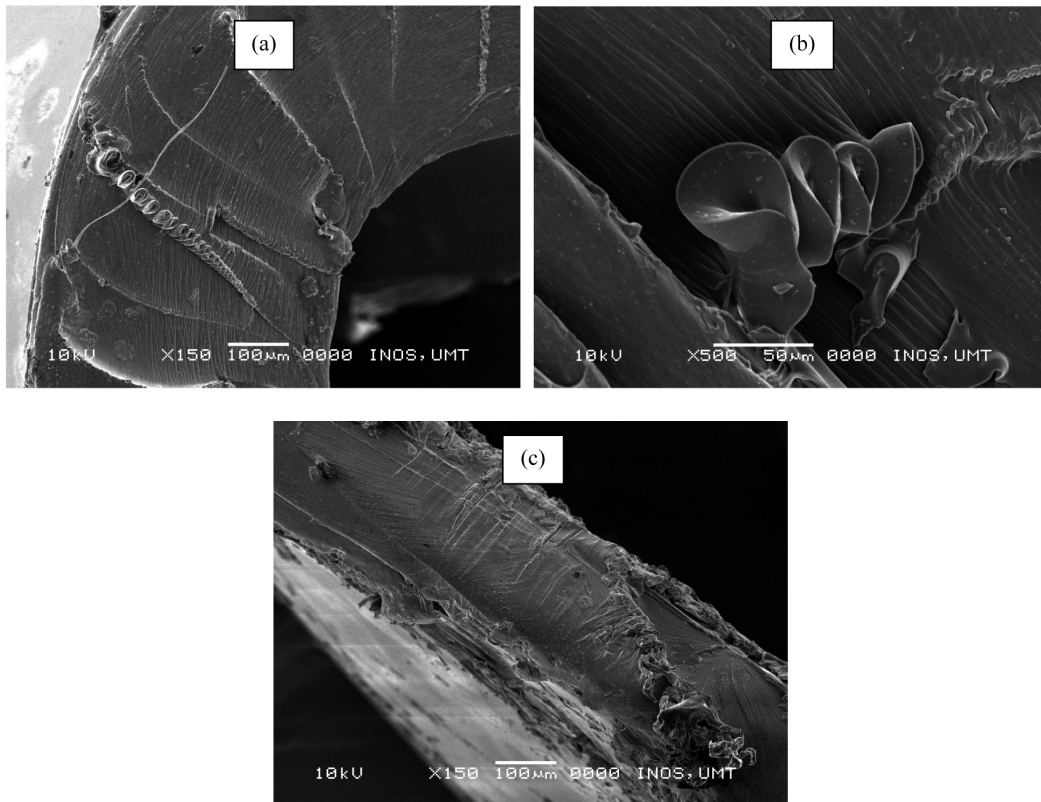


Figure 10: The SEM images for (a) CC sample, (b) AKS sample and (c) SP sample which were irradiated under 254 nm UV light after tensile tests.

In summary, when tension was applied to the sample, it was stretched before breaking, showing that the bonds within the samples were still strong. However, after a series of radiation, the lines of suction cups distanced themselves from one another, showing the decrease in ductility in

the sample. The higher magnification chosen for samples exposed to 254 nm UV light also shows that the size of the suction cups appear to decrease; it is obvious that the fractured surface appears slightly smoother than usual.

Conclusion

In conclusion, UV radiation was found to cause the photodegradation of PET used for commercial drinking bottles with various colours using different UV sources with the highest wavelength at 365 nm. It was found that, with the increase of exposure time towards the UV sources, mechanical properties such as force at break and Young's Modulus decreases. The samples which were exposed to UV light of 365 nm experienced the higher decrease in force at break values; with the highest decrease of 52.651%. For the changes in Young's Modulus, it was found that the parameter decreased with increasing time of UV exposure. The samples which were exposed to UV light of 365 nm had the higher decrease in the values with the highest decrease of 63.776%. These results show that, overall, the UV light of 365 nm caused more severe damage on the samples compared to sunlight or UV light of 254 nm.

Furthermore, UV exposure on PET was shown to weaken the carbonyl, C=O bonds in this polyester as shown by the FTIR spectroscopy results. At wavenumber 1716.42 cm^{-1} , the absorbance of PET decreased with increasing time of exposure towards UV. Generally, the values of absorbance had percentages of decrease more than 40% of initial values with the highest decrease of 62.33% and this sample was exposed to 365 nm UV light. As the time of exposure towards UV increased, the C=O bonds suffered damage and were prone to destruction since they were unable to absorb and transmit IR wave.

SEM images also showed that there were differences in the cross-section where the PET breaks due to tension. The type of fracture before any exposure showed that PET exhibit ductility. However, after a series of exposures, the polyester becomes brittle.

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