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New Plastic Scintillators for future Light-based detectors

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Abstract.
Polyethylene naphthalate (PEN) and polyethylene teraphthalate (PET) are cheap and common polyester plastics used throughout the world in various applications such as packaging industry. These plastics are also known organic scintillators with very good scintillation properties. As particle physics experiments increase in energy and particle flux density, so does radiation exposure to detector materials. It is crucial to search for scintillators with competitive light yield, and radiation-resistant and PEN and PET may respond to these requirements. We produced several samples with different shapes of PEN, PET and PEN/PET blends by extrusion and injection-moulding. Subsequently, we subjected the samples through an optical characterisation process in which was used a radioactive source of Sr-90. Results showed a good light output behavior of PEN whereas PET has 7x less light output than PEN.

Keywords: Plastic scintillators, Polyethylene Naphthalate, Polyethylene Terephthalate, Extrusion, Injection-Moulding

1 Introduction

Scintillators are transparent materials that emit light upon excitation by energetic ionising particles. They are widely used in particle physics in order to detect energetic particles and measure their properties. One of the applications of these materials is the ATLAS detetor TileCal [1]. However they tend to degrade with radiation which means it is important not only to comprehend the light output of these plastic scintillators, but also the effect of the radiation on the material components.
PEN and PET are both thermoplastics polyesters and unlike specialized organic scintillators, both are readily available worldwide because of its common use in everyday objects such as dinner sets or water bottles [2]. Recent works proved the possibility of using these common low-cost plastic polymers as scintillators for radiation-sensing applications. PEN offers excellent scintillation properties such as high density (1.33 g/cm3), a peak emission wavelength at 425 nm, and a light yield of roughly 10^4 photons/MeV [2], making PEN a good candidate for new scintillators due to its competitive light yield. On the other hand, PET has good recovery properties for higher ionising doses and has a faster light signal [3]. The aim of this research is to try to give answers to the feasibility of PET and PEN as new candidates for future scintillators, studying their properties and test if they blend synergistically.

2 Manufacturing and method

We produced several PEN, PET and PEN/PET blends samples using two manufacturing processes employed by plastic manufacturers: extrusion and injection moulding. The production phase took place in the Institute for Polymers and Composites (IPC) at University of Minho.

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2.1 Extrusion

Firstly we extruded 5 tape samples of PEN and PET with different percentages: PEN (pure tape sample), PET (pure tape sample), PEN/PET (90:10), PEN/PET (50:50) and PEN/PET (10:90). This phase turned out to be crucial because enabled us to establish the operating parameters and ensure that the samples scintillate. Tables 1 to 5 show the set and measured temperatures for each zone of the extrusion machine.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Temperature Set (ºC)	273.2	280.0	280.0	280.0	300.0	295.0
Temperature (ºC)	271.0	280.1	280.1	280.0	300.1	295.0

Table 1. Temperatures used to extrude the first PEN pure tape sample.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Temperature Set (ºC)	272.8	280.0	280.0	280.0	280.0	275.0
Temperature (ºC)	264.9	279.9	280.0	279.9	279.9	275.0

Table 2. Temperatures used to extrude the first PET pure tape sample.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Temperature Set (ºC)	262.2	280.0	280.0	280.0	275.0	275.0
Temperature (ºC)	257.5	280.0	280.0	280.0	274.9	275.0

Table 3. Temperatures used to extrude the first PET:PEN (90:10) tape sample.

In order to evaluate PET and PEN performance as an organic scintillator, 30 mm × 30 mm × 2 mm butterfly samples were produced in march by using the injection moulding machine (BOY 12A shown in Fig. 1) and then in july we optimised the parameters of injection, increasing both transparency and sharpness of the samples (Fig. 2).

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Temperature Set (ºC)	262.2	280.0	279.8	280.0	304.9	295.0
Temperature (ºC)	264.9	280.1	280.0	280.0	305.0	295.0

Table 4. Temperatures used to extrude the first PET:PEN (50:50) tape sample.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Temperature Set (ºC)	273.2	280.0	290.0	300.0	310.0	310.0
Temperature (ºC)	259.6	280.1	290.1	300.0	309.9	310.0

Table 5. Temperatures used to extrude the first PET:PEN (10:90) tape sample.

A picture of the samples scintillating to UV light can be shown in Fig. 3.

Figure 1. Injection moulding machine BOY 12A.

Figure 2. Optimised butterfly samples.

PET and PEN samples were injected based on several parameters such as dosing, Cooling Time, Injection Speed, Melting Temperature and etc.

Figure 3. Scintillating PEN sample with UV light source.

3 Optical Characterisation and Results

We subjected the samples through a characterisation process in which the emission spectrum and light response were evaluated.
First of all, we measure the emission spectra of the UV light source using a spectrometer inside a light tight box. The instrument used was a Hamamatsu mini-spectrometer C10082MD, with polychromators integrated with optical elements, an image sensor and a driver circuit. The peak wavelength emitted by the UV light LED measured was around 365 nm (Fig. 4).

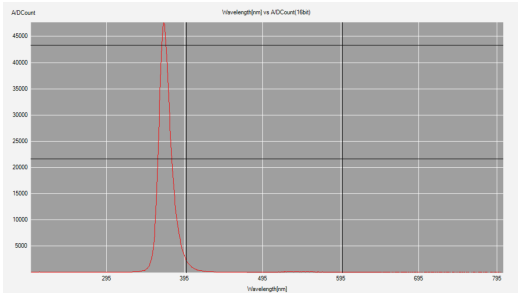

Figure 4. Emission spectra of light source.

Then we pointed the light source to the PEN sample and obtained the sample emission spectra, shown in Fig. 5. The measured peak emission wavelength was 425 nm. The obtained emission spectrum of PEN and its peak wavelength is similar to that found in the literature (Fig. 7).

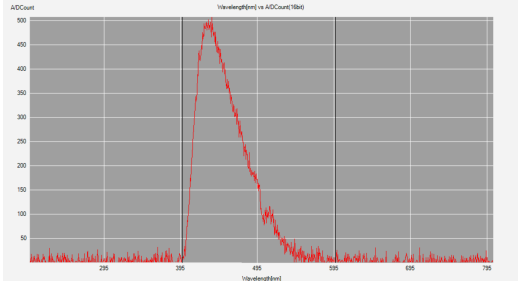

Figure 5. Emission spectra of PEN sample produced in july.

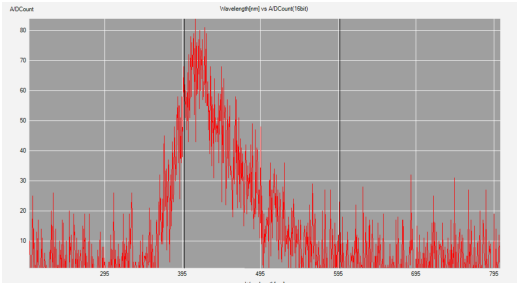

Figure 6. Emission spectra of PET sample produced in july.

We did the same procedure for the PET sample obtaining an emission spectrum with its peak wavelength emission measured at 410 nm (Fig. 6) which was not expected according to figure 7. The reason for the disagreement is that the light source does not have a short enough wavelength to excite the left-side of the emission PET spectrum (see Fig. 4).

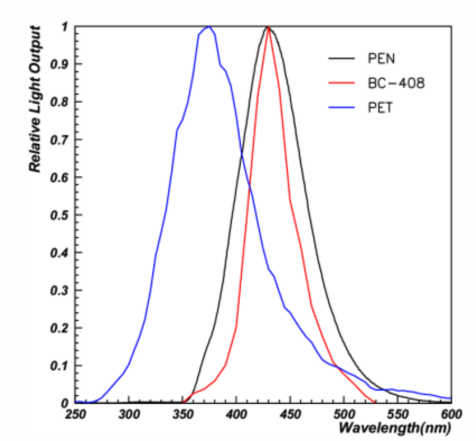

Figure 7. Emission spectra of polyethylene naphthalate (PEN; black line), commercial organic scintillator (BC-408; red line) and a plastic bottle (PET; blue line).[2]

In order to measure the light yield response, we used an experimental setup consisting of a Sr-90 source scan of the samples. Here, one of the side borders of the sample was optically connected to a photomultiplier tube (Hamamatsu with photocathode covered, maintaining HV power supply) and to a scintillating tile from TileCal/ATLAS through an optical fiber. The Sr-90 radiation source was placed under the 30x30mm^2 face the sample in study, and the light output of each sample was measured for different source positions, as shows Fig. 8.

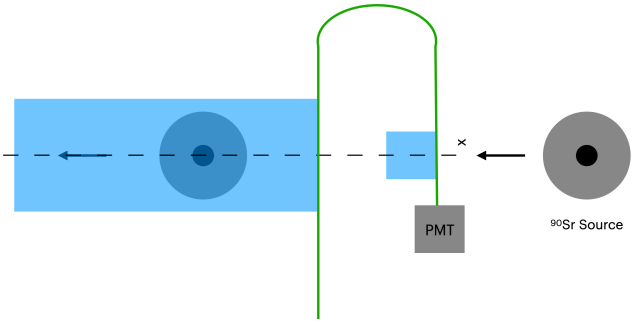

Figure 8. Experimental setup.

We measured the light response of both PEN and PET samples before (march samples) and after (july samples) the optimisation of the injection process relative to a scintillating tile from TileCal/ATLAS. The obtained results are exhibited in Figure 9 and Figure 10.

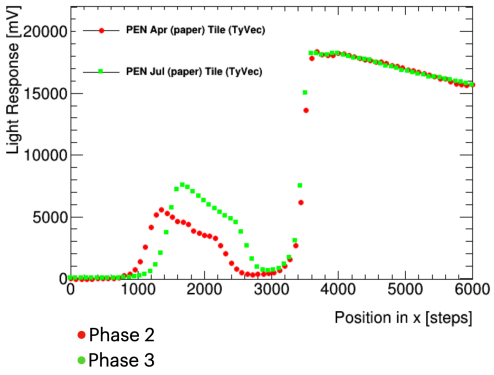

Figure 9. Samples produced in march vs july (optimised) of PEN.

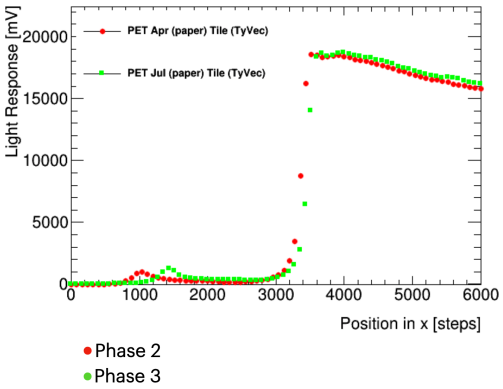

Figure 10. Samples produced in march vs july (optimised) of PET.

4 Conclusions

With the data obtained, the measurement of PEN has got a significant increase of 28% in light output between march and july. The observed ratio between PEN and PET light output is 7 (as we were expecting, PEN emits a higher number of photons per incident radiation event than PET). Further studies are needed in order to increase the light output of PEN and PET.

References

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