

## THERMAL BEHAVIOR OF ELECTRON BEAM IRRADIATED CARBON FIBER COMPOSITE

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### ABSTRACT

Carbon fibers are used as reinforcement material in epoxy matrices in advanced composites, which are used for different applications including nuclear technology. The aim of this paper was to evaluate the effects of electron beam irradiation on the thermal behavior of a carbon fiber/epoxy composite. The overall applied doses were 100, 300, 400, 500, 600, 800 and 1000 kGy. The thermal behavior of non-irradiated and irradiated samples was studied by thermogravimetric analysis and differential scanning calorimetry. The results obtained showed that samples irradiated with doses higher than 500 kGy start their decomposition at lower temperatures. The values of glass transition temperature also decrease from 92°C for non-irradiated sample to 85°C for sample irradiated with 1000 kGy. This behavior shows that the irradiation process promotes degradation or scission of polymer chains, which breaks its molecular structure and, consequently, increases its decomposition, reducing the glass transition temperature. The degradation of polymeric chains can lead to changes in mechanical properties of carbon fiber/epoxy composite, making this material unable to be used under high loads.

### 1. INTRODUCTION

Composite materials are systems composed of two or more macro constituents differing in form and/or material composition that are essentially insoluble in each other [1]. Polymeric composites are made of an organic matrix and fibers as a reinforcement material. This kind of material has been studied due to its important characteristics, such as: low weight, high mechanical performance and good resistance to corrosion [2]. Carbon fibers are used as reinforcement material associated to an epoxy matrix in advanced composites, which are used for different applications including nuclear technology [3].

The interaction of electron beam (EB) radiation with polymeric materials induces mainly two processes: (a) cross-linking, that is the formation of chemical links between molecular chains, and (b) degradation or scission of polymer chains, which breaks its molecular structure. This chemical transformation can produce changes in the physical-chemical and mechanical properties of the polymers. Although these effects occur simultaneously, one plays a dominating role depending on the chemical structure of the polymer, radiation dose and overall experimental conditions. In general, cross-linking improves mechanical properties whereas scission leads to a deterioration of the irradiated material [4].

The aim of this paper was to evaluate the effects of electron beam irradiation on the thermal behavior of a carbon fiber/epoxy composite.

## 2. EXPERIMENTAL

### 2.1. Samples

The composite studied was made by a high strength carbon fiber and a polymeric matrix based on epoxy resin thermally cured. Samples were taken from cylinders manufactured by filament winding process.

### 2.2 EB irradiations

EB irradiations were carried out at the IPEN-CTR facilities using a 1.5 MeV and 37.5 kW Dynamitron Electron Accelerator model JOB-188. Irradiation conditions were: energy 1.174 MeV, electron-current 4.89 mA and dose rate  $22.42 \text{ kGy s}^{-1}$  to reach overall doses of 100, 300, 400, 500, 600, 800 and 1000 kGy. Prior to the irradiation, the samples were wrapped with low-density polyethylene films, in order to protect them against oxygen reactive specimens, such as ozone, which are produced in the atmosphere during the EB irradiations.

### 2.3. Thermogravimetry (TG)

TG curves were obtained using a TG/SDTA851<sup>o</sup> thermobalance from Mettler-Toledo. Sample masses of about 10 mg were set in alumina open crucible and then heated from 30°C to 900°C at a heating rate of  $10^\circ\text{C min}^{-1}$  under dynamic nitrogen atmosphere ( $50 \text{ mL min}^{-1}$ ).

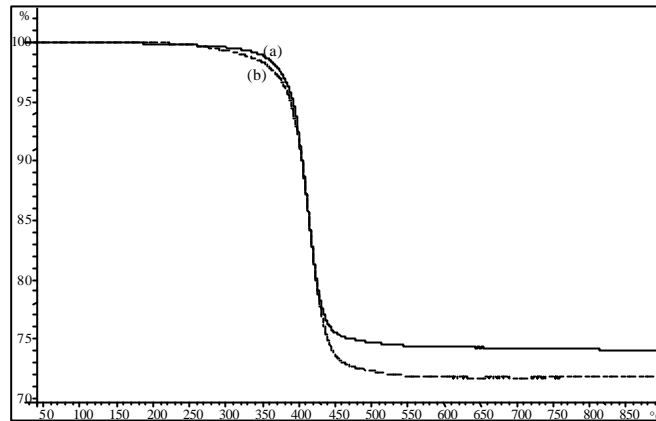
### 2.4. Differential Scanning Calorimetry (DSC)

DSC measurements were carried out using DSC823<sup>o</sup> equipment from Mettler-Toledo. Sample masses of about 40 mg were set in aluminum crucible with lid pierced and then heated from 30°C to 150°C at a heating rate of  $10^\circ\text{C min}^{-1}$  under dynamic nitrogen atmosphere ( $50 \text{ mL min}^{-1}$ ).

## 3. RESULTS AND DISCUSSION

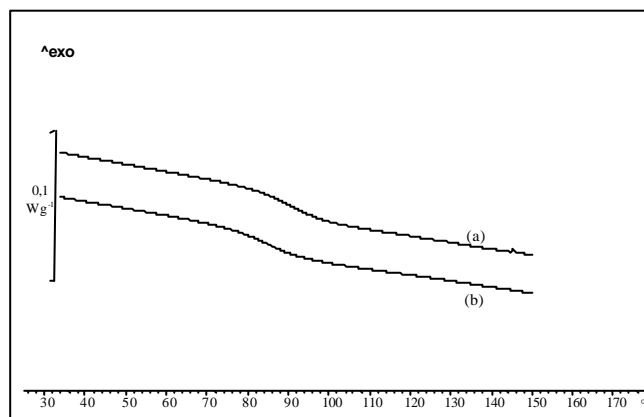
Figure 1 shows representative TG curves for the studied samples. In these curves, it can be observed that the polymeric matrix, under nitrogen atmosphere, decomposes between 300°C and 500°C, remaining the carbon fiber as residue. Although the obtained curves, within the range of doses applied, are almost alike, it is possible to observe that the sample irradiated with 1000 kGy presents an initial decomposition temperature at about 70°C lower than the temperatures registered for the other studied samples. This fact shows that high doses of electron beam radiation induce degradation of the polymeric matrix resulting in a material with lower thermal stability. Figure 1 also shows that there is about 3% of difference in the residue amount among the studied samples. The sample irradiated with 1000 kGy presents a

minor residue amount, indicating a higher decomposition degree as a function of temperature for irradiated samples.



**Figure 1. TG curves of carbon fiber composite in  $N_2$  atmosphere ( $50 \text{ mL min}^{-1}$ ),  $b = 10^\circ\text{C min}^{-1}$  and sample mass = 10 mg for: (a) non-irradiated sample and (b) irradiated with 1000 kGy sample.**

DSC representative curves for the studied samples are shown in Figure 2. The samples present a glass transition at about  $90^\circ\text{C}$ . However, it is also possible to observe that there is a slight decrease in the glass transition temperatures ( $T_g$ ) as the applied dose increases. These  $T_g$  values are shown in Table 1, it varies from  $92^\circ\text{C}$  for non-irradiated sample to  $85^\circ\text{C}$  for irradiated with 1000 kGy sample.



**Figure 2. DSC curves of carbon fiber composite in  $N_2$  atmosphere ( $50 \text{ mL min}^{-1}$ ),  $b = 10^\circ\text{C min}^{-1}$  and sample mass = 40 mg for: (a) non-irradiated sample and (b) irradiated with 1000 kGy sample.**

**Table 1. Glass transition temperatures for studied samples.**

Sample	T <sub>g</sub> (°C)
non-irradiated	92
100 kGy	92
300 kGy	91
400 kGy	88
500 kGy	88
600 kGy	88
800 kGy	86
1000 kGy	85

### 3. CONCLUSIONS

The thermal behavior observed for the studied samples indicates that, for doses higher than 500 kGy, electron beam irradiation induces degradation or scission of polymer chains of the matrix, breaking its molecular structure and, consequently, reducing the thermal stability of the composite material and its glass transition temperature. The degradation of polymeric chains can lead also to changes in mechanical properties of carbon fiber/epoxy composite, making this material unable to be used under high loads.

### ACKNOWLEDGMENTS

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