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Thermal behavior of E-glass fiber-reinforced unsaturated polyester composites

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ABSTRACT

The aim of this work is to study the behavior of E-glass fiber unsaturated polyester composites, subjected to moderate and high temperatures. The obtained results show that the chemical, physical and mechanical properties of the resin and the composite change with the rise of the temperature. A thermogravimetric analysis (TGA) revealed that the thermal degradation of the composite occurs in two steps: the first between 130 and 200 °C and the second between 250 and 440 °C.

The characterization of the resin and the composite, after heating, revealed that at moderate temperatures (lower than 100 °C) an improvement of the properties of materials is observed. For high temperatures but lower than the temperature of decomposition (Td), the mechanical strength of the resin does seem to be very affected, even improved for certain cases. For these temperatures, the composite presents some fractures of the fiber–matrix interfaces, which causes losses in strength and ductility.

When the temperature reaches the temperature of decomposition (Td), a fall of the mechanical properties was recorded for both resin and composite.

1. Introduction

The industrial naval sector is increasingly calling for organic matrix composites in order to decrease the weight of the structures. Indeed, these materials combine excellent mechanical properties with a low density. However, in service conditions, these materials are exposed to various stresses, thermal, chemical and mechanical, which can involve significant losses of properties and compromise the integrity of the structures.

In the case of a thermal stress, Mouritz et al. [1] have reported that decomposition of the polyester resin starts at about 350 °C. Above this temperature the resin decomposes rapidly following an endothermic process that is dominated by a random-chain scission of the main polymer chain. The reactions of the decomposition proceed with major weight loss at about 480 °C, and the polyester loses less than 5% of its initial mass as char. This demonstrates that this resin undergoes substantial volatilization with most of the formed gases are of a low molecular weight (combustible hydrocarbons). Furthermore, Manfredi et al. [2] have reported that polyester resin degrades by a statistical chain rupture in which styrene is the primary product.

In literature [3–5], several mechanisms of the resin thermal degradation were proposed. The one proposed by Anderson and Freeman [4] is represented in Fig. 1. This reaction is considered as prevalent during degradation by thermo-oxidation. The oxygen attacks the styryl group and forms a hydroperoxide group.

These same authors [4] supposed that the hydroperoxydes groups formed, can also form the hydroxyester as illustrated in Fig. 2.

Another mechanism proposed by Anderson and Freeman [4] is represented in Fig. 3. Under the heat effect, either carbon dioxide and propylene or carboxylic acid are formed.

In literature [7], it has been reported on behavior of polyester composites under fire that the thermal decomposition process of all unsaturated polyesters is probably produced between 130 °C and 400 °C by scission of highly strained portions of the polystyrene cross-links, with the formation of free radicals that then go to imply further decomposition. This results in a variety of low molecular weight volatiles, including CO, CO_2, methane, ethylene, propylene, butadiene, naphthalene, benzene end toluene.

For post fire mechanical properties of composites, Mouritz [1] found that stiffness and failure load of GRP composite with a polyester matrix decreased rapidly with increasing heat flux or time mainly due to the thermal degradation of the resin matrix.

In addition, Samanta et al. [6] reported that the rise in temperature reduces the proof strength of the material; most of the

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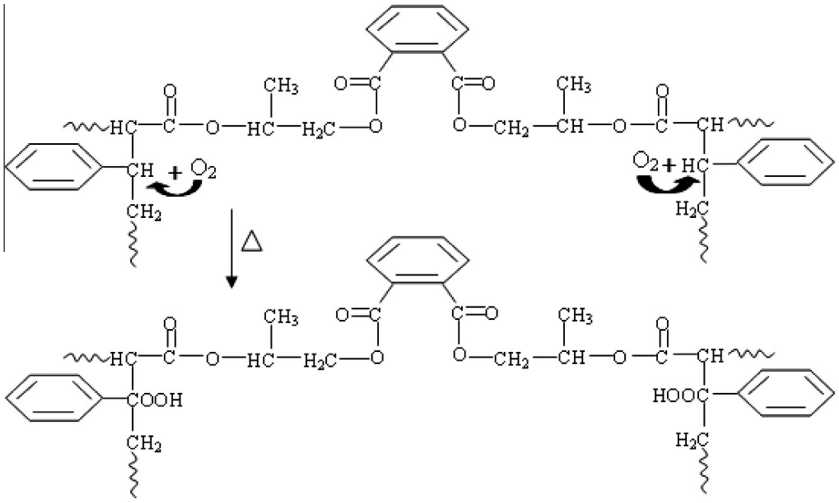

Fig. 1. Formation of the hydroperoxides groups during the thermo-oxidation of the resin [4].

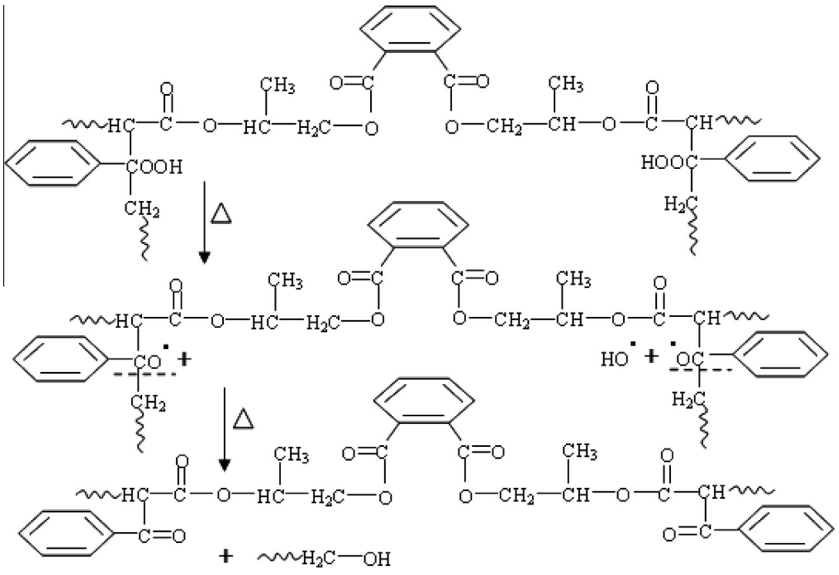

Fig. 2. Thermo-oxidation mechanism of the resin [4].

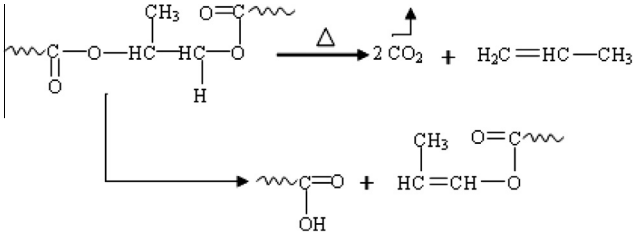

Fig. 3. Thermal decomposition mechanism of the resin [4].

strength is regained on cooling if the temperature is below 200–300 °C depending on composition and heating rate.

In order to fight the problems that could result from fire in marine industry, the regulations requires that the composite material should resist at high temperatures, at least, during the first few minutes (30–60 min) so that the crew can determine the principal source of fire [6]. Therefore, the knowledge of the thermal degradation in organic matrix composites and their residual properties becomes more than necessary.

Furthermore, when a fire occurs, the heating rate differs from a cellulosic fire to a hydrocarbon fire. The temperature can reach 1000 °C in less than 20 min in a hydrocarbon fire, while it takes about 2 h for a cellulosic fire. This temperature is recorded in materials in contact with fire like covering elements. Like the structural elements, when they are covered, they receive a temperature lower than 1000 °C; it depends on thermal and geometrical characteristics of covering materials, on the type of their assembly and the duration of exposure.

That's why the study of the behavior of structural elements made on glass/polestar composite and subjected to moderate to high temperatures was chosen in this work.

2. Materials and experimental techniques

2.1. Materials

The studied materials are polyester resin and a glass/polyester laminated composite. The resin used is a pre-accelerated unsaturated polyester (REICHHOLD) based on orthophtalic acid. As for