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Influence of polyamide–imide concentration on the cellular structure and thermo-mechanical properties of polyetherimide/polyamide–imide blend foams

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ABSTRACT

The present work considers the preparation of medium-density polyetherimide (PEI)/polyamide–imide (PAI) blend foams by means of water vapor-induced phase separation (WVIPS) and their characterization. While pure polymer foams showed homogeneous cellular structures with average cell sizes of 10–12 μm, PEI/PAI blend foams presented two distinctive closed-cell structures depending on the composition of the blend. At the lowest concentration of PAI (25 wt%) foams showed a very fine homogeneous microcellular structure with an average cell size of 1.4 μm, consequence of good miscibility between both polymers, while at the highest studied concentration of PAI (50 wt%) foams presented a dual cellular structure formed by small cells (around 1 μm in size) within the walls of considerably bigger ones (22 μm in size) due to polymer phase separation. The blend foams presented a thermal decomposition behavior similar to that of pure unfoamed polymers, with the foam with 25 wt% PAI showing a slightly higher thermal stability. Furthermore, this particular foam presented an improved specific storage modulus compared to pure PEI foam and to the one with 50 wt% PAI. X-ray diffraction (XRD) analysis indicated that no polymer crystallization was induced by foaming.

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1. Introduction

Current industrial trends have focused in the development of more efficient materials in order to reduce manufacturing costs and save energy. In this sense, lightweight materials with improved specific mechanical properties and functionalities are attracting considerable attention, with polymer foams appearing as promising candidates with possibility of customization for specific purposes by controlling their composition [1–4].

Among thermoplastic polymers, polyetherimide (PEI) and polyamide–imide (PAI) are classified as high-performance polymers thought for advanced applications, such as in the electrical, aerospace and energy fields, related to their combination of high toughness, high thermal stability, high glass transition temperature and enhanced chemical resistance. Particularly, polyimide-based blends could show enhanced properties suitable to the increasingly more demanding requirements of current applications, while considering polymer miscibility and phase morphology as some of the key factors [5].

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One of the most common methods for the preparation of PEI foams considers the use of supercritical CO_2 ($scCO_2$) [6–9]. However, this method leads to quite heterogeneous cellular structures across the material thickness. Another method used for PEI foam preparation has been shown to be effective in generating homogeneous cellular structures [10–11]. This method is the so-called water vapor-induced phase separation (WVIPS). In this method, a proper solvent is first chosen in order to obtain a homogeneous solution, which finally results in a cellular structure due to the nucleation of cells associated with the occurrence of phase separation promoted by the induction of water vapor from the humid atmosphere. Additionally, the addition of nanofillers such as graphene [10,11], graphene/Fe_3O_4 [12] or nickel nanoparticles [13], has been shown to lead to foams prepared using this method with multifunctional properties.

Although PEI-based blends have vastly been considered in the literature, as for instance PEI with poly ether ether ketone (PEEK) [14–16], polycarbonate (PC) [17,18], amorphous polyamide (a-PA) [19], liquid crystalline polymer (LCP) [20–23], polyethylene terephthalate (PET) [24–26] or polytrimethylene terephthalate (PTT) [27], no researches have been carried out so far regarding foams made of PEI blends using the WVIPS method.

On the other hand, the thermal and mechanical performance of PEI can be enhanced with the addition of a certain amount of a polyamide–imide (PAI) while maintaining its intrinsically high chemical resistance. However, the preparation of PEI/PAI blend foams has not received any attention in the literature. In recent works, it has been shown that PAI may be fully miscible in polyimides, such as in Matrimid® 5218 [28], or partially miscible, as in the case of cPIM-1, in which it shows a partial miscibility up to 5 wt% [29]. PEI/PAI blends prepared using melt processing at a temperature above PEI's glass transition temperature (T_g), with PEI acting as a solvent for PAI, result in molecular composites with a single glass transition temperature intermediate between that of PEI and PAI [30]. However, it has to be mentioned that the miscibility of PAI, which acts as a rigid polymer within a flexible PEI matrix, is composition-dependent [31].

With the above precedents in mind and due to potential enhancement of properties that could be induced by the addition of PAI into PEI, the present work aims to prepare PEI/PAI blend foams using WVIPS and characterize their cellular morphology, thermal stability and dynamic-mechanical properties, with the final goal of developing multifunctional lightweight materials for advanced applications.

2. Experimental

2.1. Materials

Polyetherimide (PEI), with the commercial name of Ultem 1000, was provided by Sabic (Sittard, The Netherlands) in the form of transparent amber color solid bars with a diameter of 19 mm. PEI Ultem 1000 has a density of 1.27 g/cm^3 and a glass transition temperature (T_g) of 217 °C. The repeating unit of Ultem 1000 is displayed in Fig. 1(a).

Polyamide–imide (PAI), with the commercial name of Torlon 4203, was provided by Sabic (Sittard, The Netherlands) in the form of yellow color solid bars with a diameter of 6.5 mm. PAI Torlon 4203 has a density of 1.42 g/cm^3 and a T_g of 275 °C. Additionally, it contains a small amount of TiO_2 (2.5 wt%), added as pigment. The repeating unit of Torlon 4203 is displayed in Fig. 1(b).

N-methyl pyrrolidone (NMP) was acquired from Panreac Co. (Barcelona, Spain) with a purity of 99% (boiling point: 202 °C).

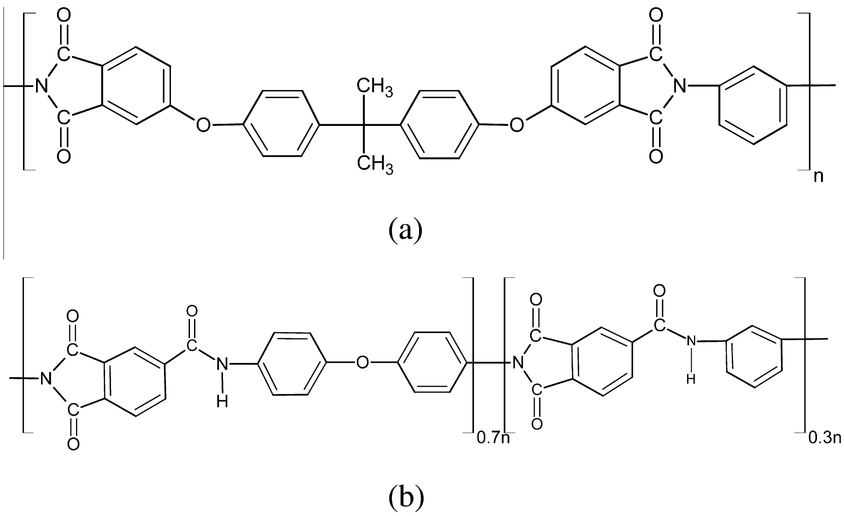

Fig. 1. (a) PEI Ultem 1000 repetitive unit and (b) PAI Torlon 4203 repetitive unit.

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