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Polymer nanocomposite foams

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Abstract

Polymer nanocomposite foams have received increasingly attention in both scientific and industrial communities. The combination of functional nanoparticles and supercritical fluid foaming technology has a high potential to generate a new class of materials that are lightweight, high strength and multifunctional. A small amount of well-dispersed nanoparticles in the polymer domain may serve as the nucleation sites to facilitate the bubble nucleation process. Moreover, the nano-scaled particles are suitable for micro-scaled reinforcement, thus achieving the macroscopic mechanical enhancement. In this paper, we will first briefly review the synthesis and processing techniques of nanocomposites based on polymers that are important in the foam industry. Both thermoplastic and thermoset nanocomposite foams will be addressed. This is followed by an introduction of various foaming techniques. The effect of nanoparticles on the foam morphology and properties is then discussed. We conclude with the current and future trends of nanocomposite foams in both industrial and biomedical applications.

Keywords: Polymer nanocomposite; Nanocomposite foam; Nucleation; Bubble growth; Cell size; Cell density

1. Introduction

Polymer nanocomposites have drawn a great deal of interest in recent years because these materials possess high potential to achieve great property improvement by adding a small amount of nanoparticles in the polymer matrices. Plastic foams, on the other hand, represent a group of lightweight materials that have been widely used in a variety of industries with a market value of US $2 billion in 2000. However, the foam applications are limited by their inferior mechanical strength, poor surface quality, and low thermal and dimensional stability. Furthermore, the most widely used chlorofluorocarbon (CFC) blowing agents have been found to cause ozone depletion in the upper atmosphere and will be banned by 2010, according to the Montreal Protocol. Environmentally benign gases such as supercritical carbon dioxide ($ScCO_2$) are attractive alternatives for CFCs as blowing agents. But low solubility and high diffusivity of CO_2 in polymers make it more difficult to control the foam morphology. A small amount of well-dispersed nanoparticles in the polymer may serve as nucleation sites to facilitate the bubble nucleation process. Plate-like nanoparticles can also reduce gas diffusivity in the polymer matrix. In addition, the presence of nanoparticles may enhance mechanical and physical properties, the heat distortion temperature, and fire resistance of polymer foams. Novel nanocomposite foams based on the combination of functional nanoparticles and supercritical fluid foaming technology may lead to a new class of materials that are ligh weight, high strength and multifunctional. In this article, we review the recent progress in this area.

Polymer nanocomposites cover a vast array of different polymer matrices and nanoparticles. A detailed survey on this topic is beyond the scope of this paper. The readers are referred to dedicated reviews for details [1–6]. We will first briefly review the synthesis and processing techniques

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of nanocomposites based on polymers that are important in the foam industry. Both thermoplastic and thermoset nanocomposite foams will be addressed. This is followed by an introduction of foaming processing methods. The effect of nanoparticles on the foam morphology and properties is then discussed. We conclude with current and future trends of nanocomposite foams in both industrial and biomedical applications.

1.1. Polymer nanocomposites

Polymer composites are widely used in automotive, aerospace, construction, and electronic industries because they provide improved mechanical properties (e.g., stiffness, strength) and physical properties over pure polymers. Micron-sized particulates and long fibers are most widely used in traditional polymer composites. Nanocomposites are a new class of materials providing superior properties when compared to their microcomposite counterparts. An addition of a small amount of nanoparticles can significantly improve a variety of properties without sacrificing the lightweight of polymer matrices.

Nanocomposites usually refer to composites in which at least one phase (the filler phase) possesses ultrafine dimensions (on the order of a few nanometers). They include the use of three different types of nanoparticles as shown in Fig. 1. The first type of nanoparticles only has one dimension in the nanometer scale. They possess a platelet-like structure. The lateral dimension may be in the range of several hundred nanometers to microns, while the thickness is usually less than a few nanometers. Clay is a good example of this type of nanoparticle. Layered nanographites are another example. If two dimensions of the nanoparticles are at the nanometer scale while the third is larger, these particles possess an elongated structure. Nanotubes and nanofibers belong to this group. The third type of nanoparticle has all three dimensions at the nanometer scale; for example, spherical silica particles, nanocrystals, gold and other metal nanoparticles, and block copolymers. A variant of this type of particle is the nanoporous microparticles. While the diameter of the particle may be in the order of microns, the pore sizes are in the order of nanometers. While all three types of nanoparticles have been used in nanocomposite synthesis and processing, plate-like clay nanoparticles and fiber/tube like carbon nanofibers (CNFs) and carbon nanotubes (CNTs) have attracted the most attention. The nanocomposites and nanocomposite foams discussed in this article are mainly based on these nanoparticles.

1.2. Polymer foams

Foams are defined as materials containing gaseous voids surrounded by a denser matrix, which is usually a liquid or solid. Foams have been widely used in a variety of applications: e.g., insulation, cushion, absorbents and weight-bearing structures [7]. Foams of high porosity with interconnected pores have also been used as tissue engineering scaffolds for cell attachment and growth [8]. Various polymers have been used for foam applications, e.g., polyurethane (PU), polystyrene (PS), polyolefin (polyethylene (PE) and polypropylene (PP)), poly(vinyl chloride) (PVC), polycarbonate (PC), just name a few. Table 1 [9] displays the US market for polymer foams by resin family in 2001 and 2006, and the projected growth rate for each resin family.

In 2001, the US use of polymer foam products was 7.42 billion pounds and that transfers into a $16.2 billion market [10]. PU occupies the largest market share (53%) in terms of the amount consumed, while PS is the second (26%).

Depending on the composition, cell morphology and physical properties, polymer foams can be categorized as rigid or flexible foams. Rigid foams are widely used in applications such as building insulation, appliances, transportation, packaging, furniture, flotation and cush-

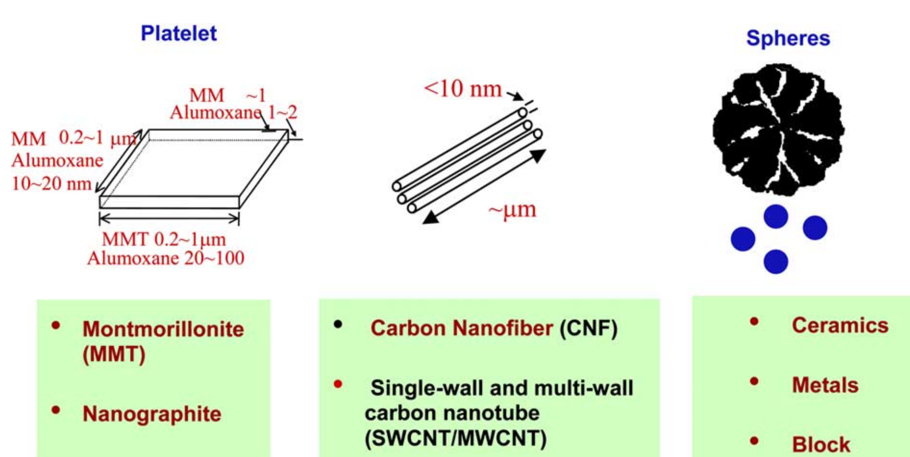

Fig. 1. Different nanoparticles.