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Material Properties

Fracture studies of polypropylene/nanoclay composite. Part I: Effect of loading rates on essential work of fracture

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Abstract

Polypropylene (PP)/Montmorillonite (MMT) nanoclay based composite was prepared by melt compounding with maleic anhydride grafted polypropylene (MA-g-PP) as a compatibilizer in a twin-screw extruder, and the test specimens were injection molded. Mechanical properties such as tensile modulus, flexural modulus, yield strength and maximum percent strains were measured for pure PP and PP based nanocomposite to establish the effect of clay platelet reinforcement. The fracture properties were measured by using the essential work of fracture (EWF) method. PP/clay nanocomposite shows 25% improvement in specific EWF compared to pure PP. The variation of EWF parameters with loading rate is discussed, whilst the mechanisms of fracture are considered in a subsequent paper.

Keywords: Polypropylene; Nanocomposite; Essential work of fracture; Shear yielding

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1. Introduction

In recent years, polymer/layered silicate nanocomposites have attracted general interest, both in industry and in academia, as they can often exhibit remarkable improvement in material properties when compared to virgin polymer or conventional micro or macro-composites. These improvements can include higher moduli, increased strength and heat resistance, decreased permeability and flammability, and increased biodegradability of biodegradable polymers [1]. Conventional composites usually require as much as 10–50% by weight of filler loading in order to impart the desired mechanical or thermal properties to the virgin polymer, but organically modified layered silicates (organoclay) can achieve the same properties with typically 2–5% by weight of filler, thereby producing materials of lower density and better processability [2].

It has been reported that the dispersion of such minerals at the level of a few nanometers induces a significant improvement in mechanical properties, flame resistance and barrier properties, compared with pure polymer [1]. There are several techniques used for dispersing organoclay at a nanoscopic scale, including the addition of organoclay during polymerization (in situ method), or to a solvent swollen polymer (solution blending), or to a polymer melt (melt intercalation method), as described in recent reviews [1,3].

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Polypropylene (PP) is one of the most widely used commodity thermoplastic. To upgrade its properties to match the profile of a typical engineering thermoplastic, it has been considered widely as a suitable polymer matrix for polymer/clay nanocomposites development. A few systematic studies have been done on the preparation and characterization of PP/clay nanocomposites, for instance, Deenadayalan et al. [2], Lertwimolnum et al. [4], Gopinath et al. [5], Huaili et al. [6] and Svoboda et al. [7] prepared PP/clay nanocomposites via melt mixing processes. In all of these studies, the importance of a compatibilizer in the development of nanocomposites was stressed.

Nowadays, the essential work of fracture (EWF) method is gaining more attention and acceptance for the toughness description of ductile polymers, toughened polymer blends and composites, especially for fracture tests of sheets and films, due to the simplicity of the experimental process and data manipulation [8–17]. The EWF test is a means of separating the work associated with the fracture of a specimen into components: one, designated as the EWF, that is intrinsic to the fracture of the material and the other designated as non-EWF, i.e. related to plastic work dissipation in the process zone, and it depends upon the geometry of the specimen and process zone [9,14,15]. Recently, researchers have focused on the fracture behaviour of polymer/clay nanocomposites, for instance, Martin et al. [9], Yang et al. [10], Qiao et al. [11] and Bureau et al. [12] studied the fracture behaviour of polymer/clay nanocomposites by means of the EWF method. In most of the above research, the dependency of fracture properties and failure mechanism on loading rate was not investigated.

Hence, the present study focuses on the dependency of fracture properties and failure mechanism of PP/clay nanocomposite on loading rate. The first part of the two-part study, reported here, deals with effect of loading rate on EWF. The second part, to be published subsequently, reveals the failure mechanism under fracture loads.

2. Theory

2.1. The concept of EWF

The EWF method has become popular, particularly in the evaluation of the toughness of polymer sheets. This is because it is the only test for thin materials which can provide a fundamental fracture parameter. The EWF is the energy per unit area dissipated locally in forming the fracture surfaces. This is, of course, similar to the true fracture toughness and can be compared to J_c (critical value of J-integral) [15].

According to the EWF theory by Kocsis [16], the total work of fracture (W_f) can be divided into essential work (W_e) required to fracture the polymer in its inner fracture process zone, and the plastic work (W_p) consumed by various deformation mechanisms in the outer plastic zone. Therefore, the total work of fracture can be written as

$$W_f = W_e + W_p, \quad (1)$$

where W_e depends on the surface area under fracture and W_p is volume related.

EWF test is a simple tensile test using double edge notched test specimens (DENT) as shown in Fig. 1, where D is the width of the specimen, H the length of the specimen, L the gauge length, l the ligament length, t the thickness of the specimen.

The total work of fracture is calculated by the area of the load vs. displacement diagram as shown in Fig. 2, where P is the load, d the displacement, W_f the total work of fracture

The necessary equation can be further written in the form of

$$W_f = w_e tl + \beta w_p tl^2 \quad (2)$$

and after normalizing by ligament area $A = l \times t$, the specific total work of fracture is obtained as

$$w_f = w_e + \beta w_p l, \quad (3)$$

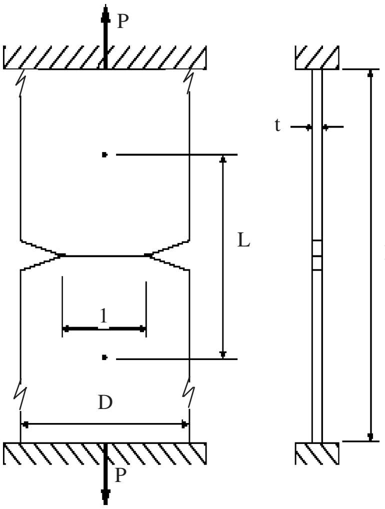

Fig. 1. Tensile testing of DENT specimen.