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Mechanical properties and thermal stability of low-density polyethylene grafted maleic anhydride/montmorillonite nanocomposites

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ABSTRACT

Polymer layered silicate nanocomposites are very prevailing in both basic research and industrial development, among them montmorillonite (MMT) provide the most significant applied value. In this study, structures and properties of various organic/inorganic nanocomposites of low-density polyethylene (LDPE) containing MMT and LDPE grafted maleic anhydride/montmorillonite (LDPE-*g*-MA/MMT) were investigated. Mechanical properties and thermal stability of LDPE/MMT and LDPE-*g*-MA/MMT nanocomposites were examined. Samples of LDPE/MMT and LDPE-*g*-MA/MMT nanocomposites were fabricated with twin-screw extruder and injection molding machine in accordance with the standard test specimens. Furthermore, tensile, impact, bending, hardness, DSC, TGA, and SEM examinations were performed to establish the structure–properties relationships. The mechanical properties significantly improved when the proper amounts of MMT and MA-grafted materials were added to LDPE. This improvement in properties is mainly due to the compatibilizing effect of MA grafts.

Introduction

Polymer layered silicate (PLS) materials usually demonstrate unique properties superior to conventional composites. In general, they combine the characteristics of both inorganic nanofillers and organic polymers at the molecular level. These additives can be used to boost the physical properties, including thermal stability [1,2], mechanical properties [3–8] and flammability [9–11] compared with those of neat polymers. Arunvisut et al. examined LDPE/MMT nanocomposites with LDPE, organo-clay, PE-*g*-MA as the compatibilizer and observed that presence of PE-*g*-MA improves dispersion of exfoliation, tensile modulus, and yield strength as the MMT content increases [12–15].

Maleic anhydride (MA), as an organic compound, is acid anhydride of maleic acid, a dicarboxylic acid with two carboxyl groups. In industry, maleic acid is derived from maleic anhydride through hydrolysis reaction. MA is produced from benzene or butane in an oxidation process. It is soluble in water, has a melting point of 52.8 °C. Both of these properties of MA can be explained on account of the intramolecular hydrogen bonding [16,17] that takes place at the expense of intermolecular interactions.

Low-density polyethylene is a kind of PE with a density in the range of 0.910–0.940 g/cm^3. LDPE macromolecules have a high degree of short and long chain branches that prevent the chains to pack into the ordered crystal structures. It has, therefore, less strong intermolecular forces as the instantaneous-dipole induced-dipole attraction is less. This property results in a smaller tensile strength and increases ductility performance. LDPE is produced via free radical polymerization. The high degree of branching with long chains gives molten LDPE unique and desirable flow properties. It is mainly used for production of both rigid containers and plastic film used in various applications, such as plastic bags and film wrap [18].

In the field of polymer materials, the polymer layered silicate (PLS) nanocomposites are getting more attractions in both basic research and industrial products development. Among various kinds of layered silicates, MMT provides the most significant applied values [19]. Polyethylene based nanocomposites with o-MMT have been produced through various methods, including polymerization of PE in the presence of layered silicate and application of polyethylene-grafted-maleic anhydride (PE-*g*-MA) as a matrix [20,21].

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Table 1
LDPE/MMT nanocomposites designation and compositions.

Composition	LDPE (wt%)	LDPE-*g*-MA (wt%)	MMT (wt%)
LDPE	100	–	0
LDPE/MMT-1	99	–	1
LDPE/MMT-2	98	–	2
LDPE/MMT-3	97	–	3
LDPE/MMT-4	96	–	4
LDPE/MMT-5	95	–	5
LDPE-*g*-MA	–	100	0
LDPE-*g*-MA/MMT-1	–	99	1
LDPE-*g*-MA/MMT-2	–	98	2
LDPE-*g*-MA/MMT-3	–	97	3
LDPE-*g*-MA/MMT-4	–	96	4
LDPE-*g*-MA/MMT-5	–	95	5

In this study, various components of organic/inorganic nanocomposites of LDPE matrix filled with MMT nano-filler, LDPE/MMT, LDPE-*g*-MA/MMT were experimentally investigated.

Experimental

Materials and preparation method

Commercial LDPE (NA203, melting point = 108 °C, d = 0.915–0.930 g/cm^3) and PE-*g*-MA (GN1703), used as matrix, were purchased from USI Corporation in Taiwan. Montmorillonite was purchased from Long Chain International Corporation in China. In the experiments, specific amounts of LDPE, PE-*g*-MA, and MMT, according to compositions presented in Table 1 were melt mixed with twin-screw extruder machine (Sun Sing Scientific Company Hong Kong, Model SHJ-20). The compounding extruder was co-rotating and non-intermeshing type with maximum screw speed of 120 rpm, screw diameter 20 mm, L/D ratio 40, test temperature 20–400 °C, and barrel maximum volume of 200 g. An injection molding machine was used to make the samples in the standard forms for examinations. LDPE-clay composites were prepared in a twin-screw extrude machine at screw speed of 85 rpm, melt temperature at 160 °C.

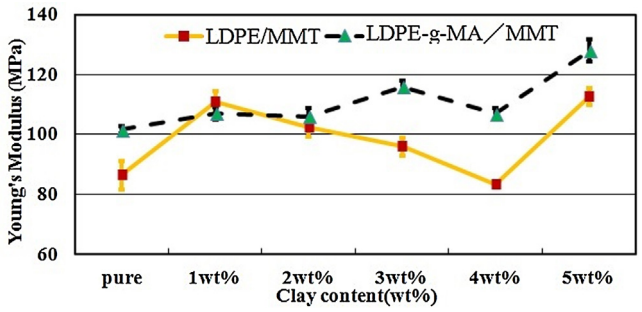

Fig. 1. Young's moduli versus filler content for (a) LDPE/MMT and (b) LDPE-*g*-MA/MMT groups.

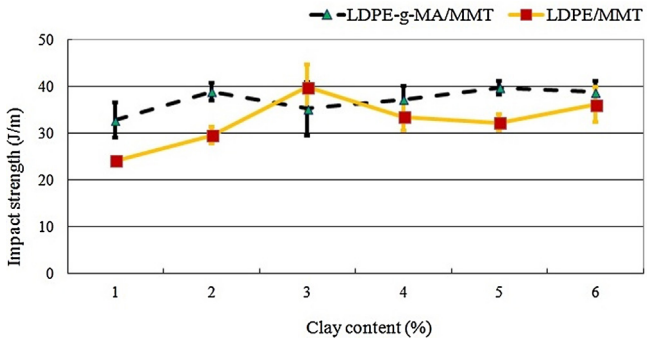

Fig. 2. Impact strengths versus filler content for (a) LDPE and (b) LDPE-*g*-MA groups.

Testing methods

Tensile examinations were performed using a mechanical testing machine at a speed of 10 mm/min with at least 3 specimens of each material according to ASTM D638 standard method [22]. Impact test was performed using Izod impact testing machine; the specimens were prepared according to ASTM D256 [23] and CNS 13334 [24] standard methods. Flexural test was conducted using a three-point bending machine at a speed of 0.5 mm/min for 200 s according to ASTM D790 standard

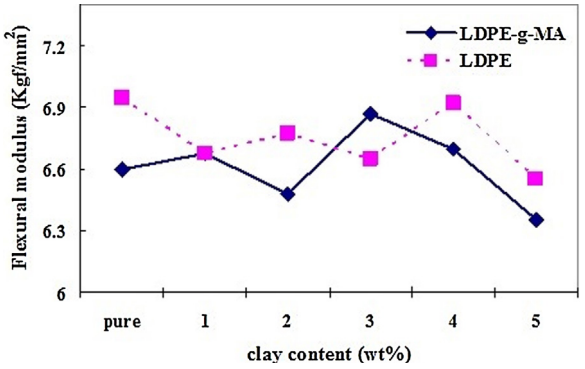

Fig. 3. The flexural moduli versus filler content for LDPE and LDPE-*g*-MA groups.

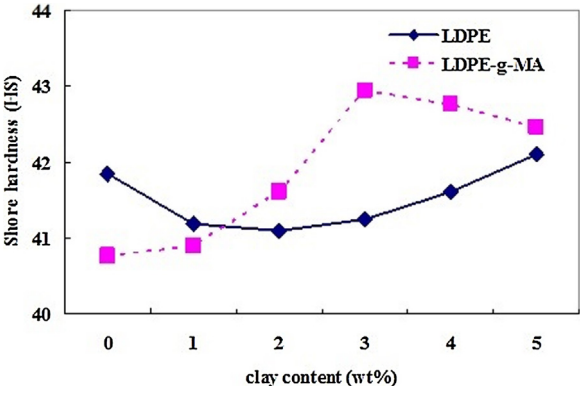

Fig. 4. Shore hardness of LDPE and LDPE-*g*-MA groups versus filler content.

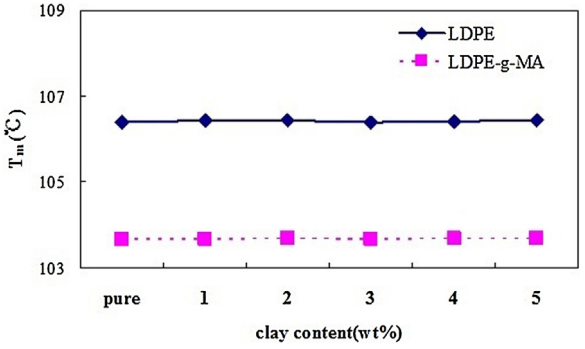

Fig. 5. Melting point in LDPE and LDPE-*g*-MA groups versus filler content obtained from DSC examinations.