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ORIGINAL PAPER

Physical properties and shape memory behavior of thermoplastic polyurethane/poly(ethylene-*alt*-maleic anhydride) blends and graphene nanoplatelet composite

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Abstract A new thermoplastic polyurethane (TPU) was prepared from polylactide-*b*-poly(ethylene glycol)-*b*-polylactide (soft segment) and 2,4-toluene diisocyanate (hard segment). Then, TPU in various proportions (i.e., 50, 70, and 90 wt%) was blended with poly(ethylene-*alt*-maleic anhydride) (PEMA) to form samples coded as TPU/PEMA50, TPU/PEMA70, and TPU/PEMA90. The TPU and PEMA blend at ratio of 50:50 was reinforced by various graphene nanoplatelets (GNPs) contents. Three novel strategies were opted in this research, including design of novel thermoplastic polyurethane, blend of TPU with poly(ethylene-*alt*-maleic anhydride), and fabrication of graphene nanoplatelet-based nanocomposites. Hydrogen bonding between blend component and GNPs directed the formation of regular nanostructure. Consequently, unique self-assembled flower-shaped morphology was observed in blends as well as hybrid materials using the scanning electron microscopy technique. Physical interlinking between blend components and nanofiller was also responsible for rise in tensile modulus (39.3 MPa) and Young's modulus (4.04 GPa) of the TPU/PEMA/GNP 5 hybrid compared with the neat blend. The crystallization property was studied by the X-ray diffraction analysis and differential scanning calorimetry. The melting temperature of about 70 °C was preferred for the shape recovery studies. The results from heat-induced shape recovery were compared with those of electroactive shape memory effects. Electrical conductivity was increased to 0.18 S cm^{-1} using 5 wt% GNP nanofiller, which was dependent on the applied temperature, as well. The original shape of TPU/PEMA/GNP 5 sample was almost 95 % recovered using heat-induced shape memory effect, while 98 % recovery was observed in an electric field of 40 V. Electroactive shape memory results were found to be better than those induced by heat stimulation effect.

Keywords Thermoplastic polyurethane · Blend · Self-assembly · Graphene nanoplatelet · Shape memory

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Introduction

Shape memory polymers (SMPs) are recently distinguished as imperative type of self-healing polymers. Shape memory polymers demonstrate a fast response in altering impermanent shapes to original shapes when subjected to electric field, temperature, light, and pH changes. Among these, the most commonly explored systems are thermal stimulus responsive SMPs systems. Owing to superior properties, including flexibility, resilience, biocompatibility, and abrasion resistance, thermoplastic polyurethane (TPU) is a suitable material for technical applications [1, 2]. Thermoplastic polyurethanes (TPUs) exhibit a range of properties depending on the ratio of hard and soft segments [3]. In TPU elastomers, the soft segments are, essentially, copolyesters or polyethers. Consequently, the soft segment may show good compatibility with block copolymer. The block copolymers are usually miscible with the polyesters and polyethers [4, 5].

Thermo-responsive shape memory polymers are smart materials having aptitude to recuperate from a deformed/temporary shape to their original/permanent shape. The shape change phenomenon in thermo-responsive shape memory polymers is often observed when they are