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Tribological behavior of nanoclay/epoxy composites

Chun Ki Lam, Kin Tak Lau *

Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

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Abstract

This paper aims to discuss the mechanical performance of nanoclay/epoxy composites (NCs) through micro-hardness and abrasive tests. It was found that the hardness and wear resistance of NCs increased with increasing nanoclay content of up to 4 wt.%. The improvement of mechanical properties of the NCs by increasing nanoclay content is explained by the degree of agglomeration of nanoclay clusters inside the NCs through SEM and XRD investigations. A mathematical interpretation for the determination of hardness and wear resistance of the NCs at different nanoclay contents in relation to the diameter of nanoclay clusters and their inter-particle distance is given.

Keywords: Hardness; Nanocomposites; Nanomaterials; Wear

1. Introduction

In everyday engineering applications, an excellent wear resistance of engineering materials is a critical requirement for surface coating applications in severe working environment. Furthermore, the maintenance cost can be kept as low as possible for an engineering component to possess a high wear resistance. In the past decade, many researches on the applications of various types of nanocomposite coatings for different engineering components have been conducted [1–3]. Recently, researchers have showed that polymer nanocomposites can provide high mechanical and tribological performance with wide applicability in both conducting and insulating surfaces of engineering products without adding much extra loading to the main engineering bodies. TiO_2 [4], SEBS [5] and carbon nanotubes [6] were being used as nanofillers in epoxy, polystyrene and other polymers for nanocomposite coatings.

Layered montmorillonite (MMT) or nanoclays (SiO_2) are newly invented nanofillers in polymers for extraordinary improvements in mechanical behaviors of polymer matrix. Fig. 1 shows three typical forms of MMT inside polymer matrix. MMT is composed by stacks of nanoclay platelets. They can provide significant improvement to the mechanical properties of polymer matrix due to their high aspect ratio of the nanoclay platelets and thus provide large contacting interfaces for the interaction between the nanoclays and the matrix. Many researchers have begun to study the abrasive durability of nanoclay-based polymer composites in order to replace the traditional superhard nanoparticles-based surface coatings [7–9]. Nevertheless, fully exfoliated nanoclay/epoxy composites (NCs) can only exist in laboratory studies by absolute controlled experimental conditions. Lam et al. [10,11] have studied the effects of nanoclay clusters in NCs and the results showed that there was an optimum nanoclay wt.% inside NCs in order to possess the highest mechanical reinforcement. It was found that the maximum hardness can be achieved for the nanoclay content at 4 wt.%. Further increasing the amount of nanoclays resulted in decreasing the hardness of the NCs. The nanoclay clusters behaved like the novel superhard nanoparticles in conventional surface coatings. As a result, intercalated nanoclay clusters should be investigated for surface coatings that can cope with most engineering manufacturing processes instead of testing the applicability of fully exfoliated nanoclay platelets inside controlled laboratory conditions. To the best knowledge of the authors, the wear resistance of intercalated NCs has not yet been studied to date.

In this study, up to 4 wt.% of nanoclays mixed with an epoxy matrix to form NC samples were fabricated. Scanning Electron

* Corresponding author.
E-mail address: mmktlau@polyu.edu.hk (K.T. Lau).

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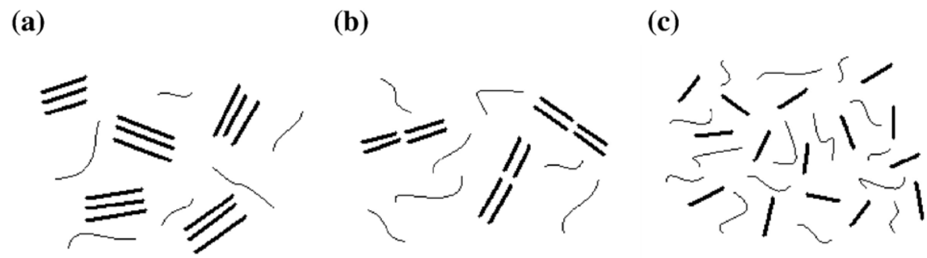

Fig. 1. Three existences of MMT inside polymer matrix. (a) Intercalated; (b) flocculated; and (c) exfoliated.

Microscopy (SEM) and X-ray spectroscopy (XRD) examination was used to verify the degree of intercalation of nanoclays inside the samples. Vickers micro-hardness test was conducted to test their hardness and twin SiC sliding wheels test was employed to visualize the wear resistance of the NC samples.

2. Experimental investigation

2.1. Materials

Nanoclay particles (SiO_2 Nanolin DK1 series from the Zhejiang Fenghong Nanoclay Chemical Technology Company) were used as nano-reinforcements for this study. The mean diameter, density and montmorillonite content of the nanoclays were 25 nm, 0.45 g/cm^3 and 95%–98% of SiO_2, respectively. The epoxy resin and hardener selected for this study were Araldite® GY 251 bisphenol-A liquid epoxy resin and Hardener HY 956 aliphatic amine from Ciba Speciality Chemicals respectively. They were mixed in a ratio of 5 to 1 parts by weight.

2.2. Sample preparation

NC samples were fabricated by using mechanical mixing process with different amounts of nanoclay, 0 wt.% (NC-0), 1 wt.% (NC-1), 2 wt.% (NC-2) and 4 wt.% (NC-4). The predetermined amounts of nanoclays were dispersed in epoxy resin. The mixtures were hand stirred for 10 min until the epoxy resin and the nanoclays were well mixed at room temperature. Ultrasound sonication was employed to further disperse the nanoclays in the resin. The sonication time was fixed at 20 min for all the samples in order to ensure their maximized mechanical performance [11]. Hardener was added into sonicated mixtures by hand stirring and followed by vacuuming for 24 h at room temperature for curing. The abrasive testing samples were prepared by curing them in same grade of surface-treated circular polypropylene discs with 4 in. in diameter.

2.3. Measurements

X-ray diffraction (XRD) of NC samples were conducted on a Philips PW 1830 X-ray Generator (Cu K_α, λ=0.154 nm) in order to visualize the degree of aggregation of the nanoclay clusters. Scanning Electron Microscopy (SEM) of the fractured surfaces of NC samples was conducted on a Leica Stereoscan 440 SEM.

Micro-hardness test of NC samples was conducted by using the micro-hardness tester (FM-7E) of the Future-Test Corporation from Tokyo, Japan. Each NC sample was indented ten times at different locations under the same indenting conditions and the average value was taken as a representing micro-hardness of the specified NC samples.

Wear resistance of the NC samples was obtained from an abrasive test performed on the circular NC samples with 4 in. in

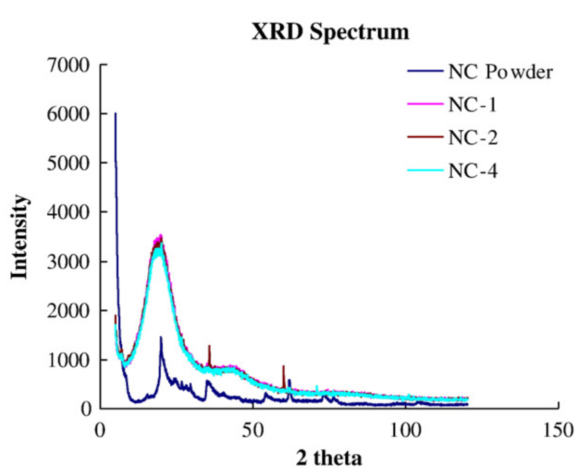

Fig. 2. XRD spectrum of different wt.% of NCs.

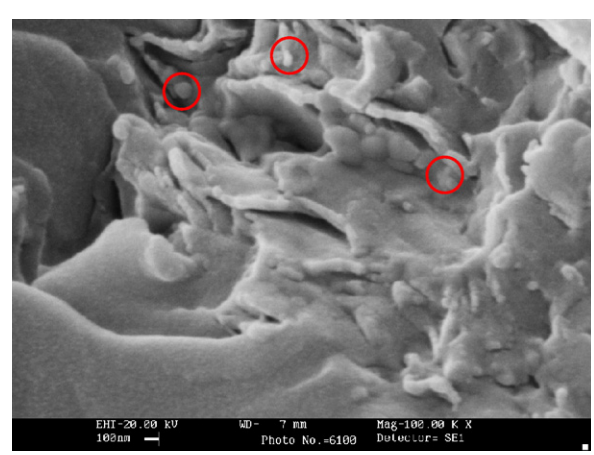

Fig. 3. SEM of the fractured surface of NCs with 4 wt.% of nanoclays.