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Mechanical and morphological properties of fly ash/epoxy composites using conventional thermal and microwave curing methods

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Abstract

Conventional thermal and microwave curing methods were utilized to cure fly ash/epoxy composites, and the mechanical and morphological properties of the composites were evaluated. The conventional thermal curing was performed at 70 °C for 80 min while microwave curing was carried out at 240 W for 18 min in order to achieve the optimum cure of the composites, determined using Differential Scanning Calorimeter. The results suggested that the tensile and flexural moduli of the composites increased with increasing fly ash content while the effect became opposite for tensile, flexural and impact strengths, and tensile strain at break. Improved mechanical properties of the composite could be obtained by addition of *N*-2(aminoethyl)-3-aminopropyltrimethoxysilane coupling agent, the contents of 0.5 wt% being recommended for the optimum mechanical properties. Beyond these recommended contents, the mechanical properties greatly reduced, except for the flexural modulus. The comparative results indicated that the composites by the microwave cure consumed shorter cure time and had higher ultimate strengths (especially impact strength), and strain at break than those by the conventional thermal cure. The composites with higher tensile and flexural moduli could be obtained by the conventional thermal cure.

Keywords: A. Coupling agents; B. Mechanical properties; B. Curing; Fly ash; A. Polymer–matrix composites

1. Introduction

Ash residues are wastes of coal-fired power plants and they are produced at the boiler outlet of the plants, these including fly ashes and bottom ashes [1]. The demand for lightweight materials, such as for concrete construction applications, with high strength and stiffness has led to the development of fly ash based thermosetting resins. There have been a small number of material technologists having interests in using of the fly ash (FA) as filler in polymer materials [2–6]. Chand [2] studied the effect of volume fraction of fly ash on the mechanical properties of unsaturated polyester composites, and found that increasing the volume fraction of fly ash reduced the tensile and impact strengths of the composites, this corresponding to the work by Kishore et al. [3] for epoxy composite system. In fibre-epoxy composites, the addition of fly ash led to a reduction of the density and an increase in modulus of the composites, the latter effect being caused by an improved dispersion of the fiber in the matrix [4]. The use of fly ash particles as filler in rubber materials has expanded the usefulness of the fly ash particles. Garde et al. [5] indicated that the mechanical properties of polyisoprene rubber loaded with ash particles were still inferior to that filled with silica. Sombatsompop et al. [6] suggested that fly ash (FA) particles contained 30–40% of silica which could be used as reinforcing or extending filler in natural rubber (NR) compound. Further work by Thongsang and Sombatsompop [7] suggested that the fly ash particles could become a reinforcing filler to improve the mechanical properties of FA/NR composites, after surface treatment by bis-(3-triethoxysilylpropyl) tetrasulfane (Si69) at 2.0–4.0% wt.

At present, epoxy resins are widely used in various engineering and structural applications such as electrical

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industries, and commercial and military aircrafts industries. In order to improve their processing and product performances, and to reduce cost, various fillers are introduced into the resins during processing [8]. Most fillers used in the epoxy resins include inorganic [9,10], organic [11,12] and ceramic materials [13,14]. It is accepted that the properties of epoxy composites can be altered by the characteristics of the fillers including shape, size, volume fraction in the resin, as well as the modification of the filler surfaces. It can be expected that composites between hydrophobic thermosetting materials and hydrophilic fly ash particles are incompatible and led to poor interfacial bonding and inferior mechanical properties [15–19]. Hydroxyl groups on the fly ash surfaces usually cause cluster or agglomerate between themselves and lead to strong filler–filler interaction in the polymer matrices [20]. Therefore, many silane coupling agents are applied to promote adhesions between the thermosetting matrices and the fly ash [16–18]. The mechanism of the polymer-ash interaction involves formation of siloxane bonding [15,21].

Curing of thermosetting resins is usually carried out by conventional heating oven which involves a direct application of thermal energy from heaters to the resins. It has been evidenced that this thermal curing introduces a number of processing related problems such as long curing times and large temperature gradients [22–24]. A microwave curing has been referred to as efficient alternative energy source for curing thermosetting resins and their composites because curing by the microwave can reduce the cure time and increase the crosslink rate [25–30]. In addition, the microwave irradiation allows more efficient curing, more uniform cure and improved physical/mechanical properties of the materials [31–34].

According to literature, there have been a number of published papers on using the microwave irradiation for curing the epoxy composites [26–30,35–38], but none of these have published on the microwave curing of fly ash filled epoxy composites. In this work, fly ash particles were chemically treated and introduced in epoxy resin, and the composites were cured by conventional thermal and microwave cures. The effect of fly ash contents, chemical surface treatment and curing systems were discussed based on the changes in mechanical and morphological properties of the composites.

2. Experimental

2.1. Raw materials

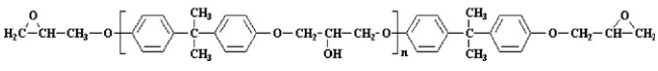
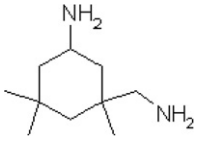
The epoxy prepolymer used was a diglycidyl ether of bisphenol-A-(DGEBA) and the hardener was 3-aminomethyl-3,5,5-trimethylcyclohexyl-amine (isophorone diamine). The epoxy prepolymer and the hardener were supplied by I-Chem Co., Ltd. (Bangkok, Thailand). Table 1 shows the chemical structures and descriptions of both prepolymers. The resin and the hardener were mixed in a ratio of 100:60 by weight as recommended by the supplier.

The fly ash (FA) particles were suppiled by Mae Moh Power Station of KNR Group Co., Ltd. (Lampang, Thailand). The dimensions and shape of the FA particles were examined using a JEOL JSM-6301F SEM machine (Tokyo, Japan), and found that FA was made of round-shaped particles with relatively smooth surfaces. The average particle size and pH of the FA used were 50–100 μm and 9.5, respectively. An X-Ray Fluorescence Spectrometer (XRF Model MESA-500 W, Horiba Ltd., Japan) was used for analyzing the chemical compositions of the FA. It was found that the major component of FA was SiO_2, this being about 46%. In this work, the FA content was varied from 0 to 80 phr.

2.2. Surface treatment of the fly ash particles by silane coupling agent

N-2(Aminoethyl)-3-aminopropyltrimethoxysilane (KBM-603), supplied by Shin-Etsu Co., Ltd. (Japan), was used as a chemical coupling agent for FA surface treatment. The FA particles were carefully dried before use in an oven

Table 1
The chemical structures and descriptions of the epoxy, isophorone diamine and KBM603

Chemical description	Chemical structure
DGEBA	
Isophorone diamine	
KBM603