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ORIGINAL PAPER

# The synergistic effect of functionalized montmorillonite with intumescent flame retardant in EVA

**Yan Liu**

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**Abstract** An intumescent flame retardant (IFR), a Schiff-base polyphosphate ester (PAB)-functionalized montmorillonite (PAB-MMT) was combined with PAB to adopt into ethylene–vinyl acetate copolymer (EVA) by melting intercalation. The synergistic effect between PAB-MMT and PAB was evaluated by thermogravimetric analysis (TGA), transmission electron microscopy (TEM), limiting oxygen index (LOI), vertical burning test (UL-94), micro-scale combustion colorimeter (MCC) and scanning electron microscopy (SEM). The results showed that when 5.0 wt% PAB-MMT replaced the same amounts of Na-MMT in the composite, the flame retardancy of EVA/PAB composite was improved. For this composite, the LOI value was increased and the ignition time in UL-94 rating was shortened compared to pure EVA or composites containing PAB or Na-MMT/PAB. The MCC results indicated that the peak heat release rate (PHRR) and total heat release (THR) were significantly reduced in comparison with other EVA nanocomposites. Meanwhile, the TGA data showed that the EVA/PAB/PAB-MMT nanocomposite had higher char residue than the EVA/PAB and EVA/PAB/Na-MMT nanocomposites. The TEM and dispersibility measurement results showed that PAB-MMT had better dispersion than Na-MMT. The SEM results demonstrated that the minimal loading levels of PAB-MMT in EVA/PAB/PAB-MMT composite had a well-structured and strong char which had better ability to endure heat erosion. A good synergistic effect between PAB-MMT and PAB was constructed.

**Keywords** Intumescent flame retardant · Synergistic effect · Montmorillonite · Ethylene–vinyl acetate

## Introduction

Nowadays, polymers are versatile materials and are used massively in our everyday life due to their remarkable combination of properties. However, the lacking in flame retardancy is the common problem of polymers [1]. The incorporation of flame retardant additives has proved to be an effective way to reduce the flammability of polymers [2–4]. Intumescent flame retardant (IFR) materials have found a place in polymer science as a method of providing flame retardancy to polymeric materials [5]. However, IFRs also have drawbacks, for instance, low flame retardant efficiency and low thermal stability [6]. Recently, much attention has been devoted to the use of nanoparticles such as layered silicates, graphite oxide, layered double hydroxides and layered metal phosphates [7]. Among them, montmorillonite (MMT) is the most commonly used layered compound which improves polymeric materials' flame retardancy, particularly in reducing peak heat release rate (PHRR) during burning when is evaluated by cone calorimetry [8]. The most popular accepted mechanism to explain the fire retardancy of polymer–clay nanocomposites is based on barrier effects [9]. MMT has been identified as a promising synergistic agent when combined with polymer intumescent systems [10, 11].

Natural MMT has usually been modified by organic intercalation agents to obtain the good affinity of MMT with organic polymers [12]. However, organic intercalation

Y. Liu
Fundamental Science on Radioactive Geology and Exploration Technology Laboratory, East China Institute of Technology, Nanchang 330013, Jiangxi, China

Y. Liu (✉)
Department of Materials Science and Engineering, East China Institute of Technology, Nanchang 330013, China
e-mail: fzliuyan1986@163.com