G Model
JIEC 4051 No. of Pages 11

ARTICLE IN PRESS

Journal of Industrial and Engineering Chemistry xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

Review

A review on thermomechanical properties of polymers and fibers reinforced polymer composites

N. Saba*, M. Jawaid*

Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Selangor, Malaysia

A R T I C L E I N F O

Article history:
Received 19 May 2018
Received in revised form 17 June 2018
Accepted 18 June 2018
Available online xxx

Keywords:
Polymer composites
Thermal stability
Thermomechanical analysis
Coefficient of thermal expansion

A B S T R A C T

Polymer composites offered broad engineered applications, however their diversity get restricted owing to fluctuations in thermomechanical properties during heating or cooling hence great concern required prior their applications through thermomechanical analysis (TMA). Traditionally, TMA or dilatometry found to be simple, ideal, reliable, sensitive, excellent and basic thermal analytical technique. TMA provides valuable information on thermal expansion, glass transitions temperature (Tg), softening points, composition and phase changes on material of having different geometries simply by applying a constant force as a function of temperature.

This compilation highlights the basics and experimental of TMA for both research and technical applications and also provide literature on TMA of polymers, hybrid composites, nanocomposites and their diverse applications.

Contents

Introduction

Polymers and nanocomposites

Polymers possess high specific strength, excellent chemical stability, electrical insulating properties, better processability and low cost [1]. Polymers are widely been applied in the fields of electronics, biomedical, energy and manufacturing industries from

* Corresponding author at: Biocomposite Technology Laboratory, INTROP, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
E-mail addresses: jawaid@upm.edu.my, naheedchem@gmail.com (M. Jawaid).

https://doi.org/10.1016/j.jiec.2018.06.018

past decades. However, the intrinsic low thermally conductive coefficient and insufficient thermal stability of polymeric matrix restricted its broader application in the field where good heat dissipation and low thermal expansion are required [1]. Linear thermoplastics and thermosets are two major types of polymers used in advanced polymer composite industries, although they are quite different from each other. Thermoplastics are ductile, poor creep resistant, tougher and usually exists in semi-crystalline or in amorphous phase and on heating beyond the Tm or Tg, they lose their structure to more deformable and flexible structure [2,3]. Thermoplastics show reshaping and reforming prospects by simply cooling or heating. While, thermosets are less susceptible to solvent than thermoplastics, highly flammable, combustible and crosslinked polymer, hence remain in the solid state such as phenol formaldehyde, epoxy, polyester or vinyl ester resins [3,4]. Thermosets high crosslinking reactions are usually accompanied by a sharp change in the material's mechanical properties such as, an increase in tensile modulus accompanied by the shrinkage [5].

Polymer composites are the advanced materials alternative to traditional materials such as metals or ceramics and consist of at least two constituents of different phase, one of them being continuous polymeric matrix phase and other is reinforcements (fibers, filler). Polymer composites possess improved properties such as tensile/impact strength, stiffness, wear resistance, thermal conductivity, thermal insulation, corrosion resistance, weight/temperature dependent behavior and fatigue life. Polymer composites can be categorized in three sub-classes, including particles, fibers and structural based composites, displayed in Fig. 1 [3].

Nanocomposites belong to the groups called nano materials, where a nanoparticle is dispersed into a polymeric matrix [6] Nanocomposites structure is usually more complicated and its properties are determined by the same factors as in traditional composites [7]. They are defined as a multiphase, high-performance dense heterogeneous solid material of 21st century, where one of the phases has dimensions in the nanometers (10^{-9} m) ranges and have extremely large specific surface area and aspect ratio with respect to microcomposites [8]. Nanocomposites are characterized by unique characteristic including no fiber rupture, homogenous structure, optical transparency, better clarity and unchanged processability [9]. They offer diverse applications in the cosmetics, medical sciences, food packaging, construction, domestic goods, automotive and many other advanced polymer composite based industries in contrast to traditional materials.

Thermosetting polymers have several advantages over thermoplastic polymers such as higher strength/stiffness, lighter weight as well as creep and thermal resistance behavior [10]. Though, thermal expansion is another important physical property for polymers that governs their processing and applications, critically based on the chemical structures [11]. Remarkably, thermomechanical behavior and thermal stability of thermosetting polymers and their composites are quite adequate to be used for varied applications ranging from coatings, electronics, packaging, adhesives fiber reinforced composites, structural components in aircraft and aerospace industries [10]. These properties depend on various factors, including the polymer chemistry, molecular structures, cross-linking, curing tendency, thermal stability and degree of polymerization [11].

Thermal analysis (TA) and thermal stability

TA is an important key laboratory technique for industries based on inorganic and organic chemicals, pharmaceuticals, foods, petroleum, polymers, polymeric composites and many others. TA typically used to measure weight loss, heat flow and dimensions change/mechanical properties as a function of temperature [9,12,13]. It also characterized the properties including decomposition, crystallization, melting, molecular structure, viscoelastic behavior, Tg, cross-linking, oxidation, volatilization, coefficient of thermal expansion (CTE), tensile modulus, composition, processing, stability and mobility (http://www.tainstruments.com/products/thermal-analysis/#ffs-tabbed-11). Currently wide TA techniques are being known that are widely established including, thermogravimetric analysis (TGA), differential thermal analysis (DTA), differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), thermomechanical analysis (TMA) and pyrolysis combustion flow calorimetry. Their properties and unit are tabulated in Table 1.

Furthermore, thermal resistance, durability and heat resistance often been described by thermal stability. In current scenario polymer based industries shows a growing interest to obtain polymers with increased thermal stability [14,15]. Polymers of higher thermal stability are usually characterized by higher softening/melting temperatures (Tm), higher thermal decomposition, high residual mass content and minimal considerable changes in physical, mechanical and chemical properties besides higher heat deflection temperature under load, during short or long exposure to elevated temperature.

Thermomechanical analysis (TMA)

Emergence of modern TMAs brings a renaissance in the last few years of thermal analytical techniques and is found ideal for teaching, research and quality control applications, with incomparable performance. Commercial application of TMA on polymers in 1948 grew from hardness to penetration and become a key

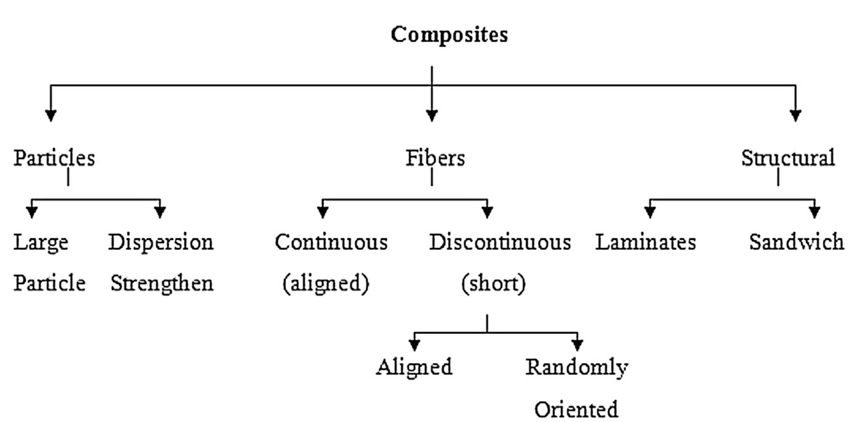

Fig. 1. Classification of polymer composites [3].