Composites Part B 120 (2017) 42–53

Contents lists available at ScienceDirect

Composites Part B

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

Erosion-wear, mechanical and thermal properties of silica filled epoxy nanocomposites

J. Abenojar [a, *], J. Tutor [b], Y. Ballesteros [b], J.C. del Real [b], M.A. Martínez [a]

[a] *Materials Science and Engineering Department, IAAB, Universidad Carlos III de Madrid, Av. Universidad 30, Leganés, 28911, Spain*
[b] *Institute for Research in Technology/Mech. Eng. Dept. Universidad Pontificia Comillas, Alberto Aguilera 25, Madrid, 28015, Spain*

ARTICLE INFO

Article history:
Received 4 May 2016
Received in revised form
25 January 2017
Accepted 19 March 2017
Available online 2 April 2017

Keywords:
Polymer-matrix composites
Thermosetting resin
Nano-silica
Wear
Thermal properties
Mechanical properties
Mechanical testing
Thermal analysis

ABSTRACT

Different nano- and micro-fillers are added to modify the mechanical properties, wear resistance, thermal properties and the curing process of polymers. A very important application for epoxy resins is to be used as coating for anti-cavitation painting. Pyrogenic silica is already used in adhesives and paints, being its application related to rheology. The objective of this work is to study the effect of pyrogenic silica on epoxy resins, usually not present in their formulation. SiO_2/epoxy nanocomposites with two different loads of nano-silica, 3 and 5 wt% were manufactured. In particular, the study focuses on the influence that the addition of nano-silica has on the mechanical, wear and cavitation erosion properties as well as on the thermal properties and the curing reaction. To accomplish these goals, nanocomposite samples in bulk and as coating were prepared. Mechanical properties (hardness, bending and tensile strength), wear resistance (in bulk and coating) and cavitation erosion were evaluated. The epoxy curing process and the influence of nano-SiO_2 additions on the glass transition temperature (T_g) were studied by Differential Scanning Calorimetry (DSC).

In general, a plasticising effect was observed with nano-silica addition. Moreover, the resistance to erosion by cavitation, in terms of cumulative erosion and erosion rate, was higher for the nanocomposites than for clear resin.

1. Introduction

Epoxy resin is an engineering material used in many industrial products because of its good mechanical properties, such as a high modulus, excellent adhesion strength and low creep [1], but it is rather brittle. A very important application of epoxy resins is like anticavitation painting (i.e. coating) [2]. Cavitation erosion is the mechanical degradation of a surface as a consequence of the continuous collapsing on it of cavities or bubbles from a surrounding liquid. This degradation mechanism dramatically affects the operation of hydraulic equipment, such as hydroelectric turbines, valves, fittings, pumps, ship propellers, etc. [3].

Brittle behaviour of epoxies is the reason why different percentages of nanoparticles are used as filler. Nanoparticles, such as silica (SiO_2), can increase the fracture toughness [4]. Other fillers, such as cork micro-particles, also can decrease the brittle of epoxy resin [5] or natural fibres as jute [6,7]. Nano- and micro-fillers in the epoxy resins have been intensively investigated, as they modify the mechanical properties [8,9], wear resistance [10–12], thermal properties and the curing reaction of the epoxy resins [13,14]. Specifically, pyrogenic silica is used as filler in urethane-acrylic, which is used as coating on polycarbonate substrates to improve wear resistance [15].

Amorphous silicon dioxide, also known as silica, is the main thixotropic agent used in the formulations of anaerobic adhesives (as in many other adhesives) [16]. More recent studies have used silica to manufacture polyurethane nano-adhesives, as SiO_2 nanoparticles can increase nano-adhesives Young's modulus and tensile strength. The best results were achieved when 6 wt% of nano-SiO_2 was incorporated into the polyurethane adhesive [17]. As additives for adhesives, there are basically two types of silica: hydrated silica [18] and fumed silica preferred for its exceptional properties [19].

Fillers can also affect the viscosity. Excessive viscosity has an effect on the yield stress [20]. Viscosity also influences the dosage of the adhesive. Pseudoplasticity and thixotropy determine to which degree other denser components of the adhesive are kept in

* Corresponding author. Materials Science and Engineering Department, IAAB, Universidad Carlos III de Madrid, Av. Universidad 30, Leganés, 28911, Spain.
E-mail address: abenojar@ing.uc3m.es (J. Abenojar).

http://dx.doi.org/10.1016/j.compositesb.2017.03.047
1359-8368/

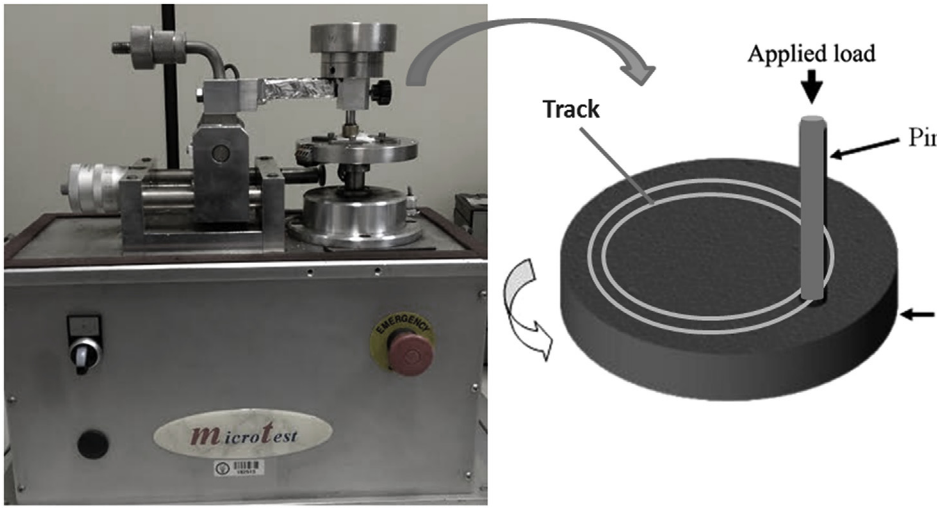

Fig. 1. Pin-on-disk' test equipment (left) and scheme of the tribology test.

suspension or they may stabilise the viscosity with temperature variations [21]. Pseudoplasticity and thixotropy can be related to the chemistry of the fumed silica surface, where the open internal structure of the particles is produced as a result of the formation process [22]. The thickening and thixotropic agents may be considered reinforcing fillers used to modify the rheology of the adhesive and they can affect the properties of the cured adhesive.

Many researchers have studied clusters of silica particles to form aggregates which, in turn, are grouped into agglomerated aggregates that bind, generating a three-dimensional skeleton [23,24]. The surface of the pyrogenic silica has siloxane and silanol groups. The siloxane groups are responsible for the inert character of the silica, while the silanol groups confer hydrophilic properties to the silica. Clusters are generated at each level due to the formation of

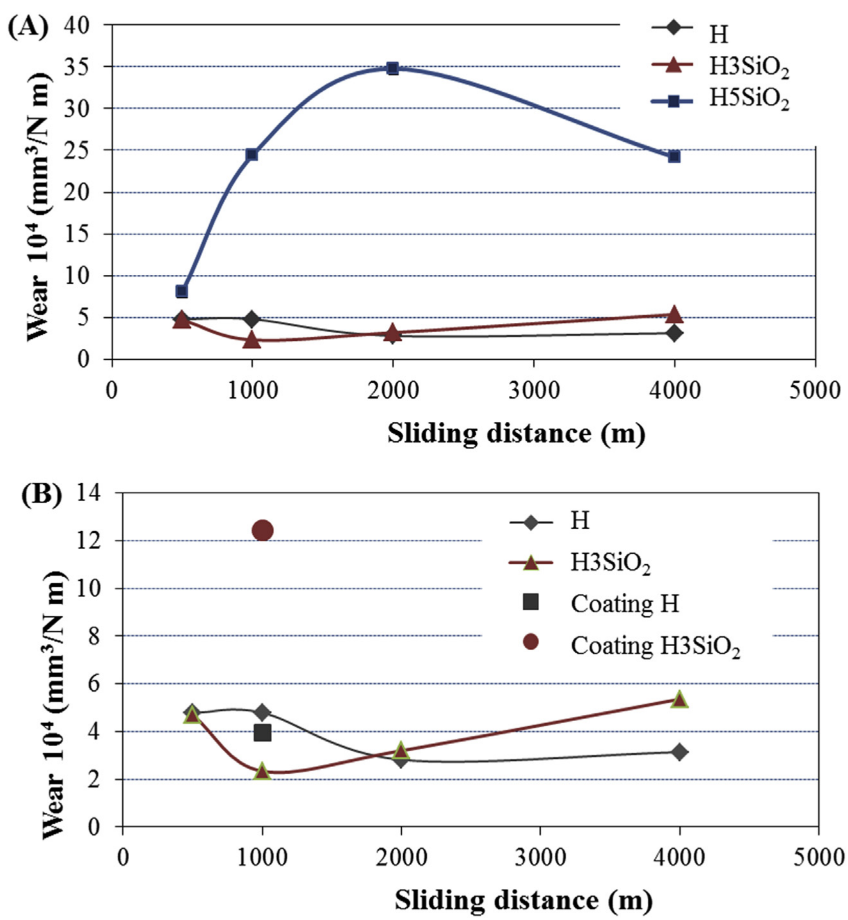

Fig. 2. A) Wear of bulk samples of clear resin (H) and with 3 and 5% SiO_2 nanocomposites (H3SiO_2 and H5SiO_2). B) Detail of clear resin (H) and with 3% SiO_2 nanocomposite.