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Modified epoxy coatings on mild steel: Tribology and surface energy

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ABSTRACT

A commercial epoxy diglycidylether of bisphenol-A (DGEBA) was modified by adding fluorinated poly(aryl ether ketone) fluoropolymer and in turn metal micro powders (Ni, Al, Zn, and Ag) and coated on mild steel. Two curing agents were used; triethylenetetramine (a low temperature curing agent) and hexamethylenediamine (a high temperature curing agent) for understanding the curing temperature effect on the properties. Variations in tribological properties (dynamic friction and wear) and surface energies with varying amounts of metal powders and curing agents were evaluated. When cured at 30 °C, dynamic friction and wear decrease significantly due to phase separation reaction being favored between the fluoropolymer and the epoxy. However, when cured at 80 °C, friction and wear increase; this can be explained in terms of a crosslinking reaction favored at that temperature. There is a significant decrease in surface energies with the addition of modifiers.

1. Introduction

Epoxies are noted for their versatility, high resistance to chemicals, outstanding adhesion to a variety of substrates, toughness, high electrical resistance, durability at high and low temperatures, low shrinkage upon cure, flexibility, and the ease with which they can be poured or cast without forming bubbles [1–5]. These properties make them eligible for use in various applications such as protective coatings (for appliance, automotive primers, pipes) [6], encapsulation of electrical and electronic devices, adhesives, bonding materials for dental uses, replacement of welding and riveting in aircraft and automobiles, composites materials in space industry, printed circuitry, pressure vessels and pipes, and construction uses such as flooring, paving, and airport runway repair [1,7].

One of the ways of improving the performance of polymers is by introducing a metallic dispersed phase. Metallic materials have useful properties and characteristics that are crucial for many applications; among them high electric conductivity, paramagnetism, high thermal conductivity as well as good mechanical properties. Combination of polymers with metals results in materials with electrical and magnetic properties comparable to neat metals and with a significant improvement in thermal properties of polymers. Also, the processability is the same as for neat polymers – a significant advantage for speed of production and processing costs.

Al particles added to poly(ethylene oxide) affect electric conductivity as reported by Muszynska and her colleagues [8]. Mamunya et al. used Cu and Ni powders as fillers in an epoxy resin and in poly(vinyl chloride) and studied the concentration dependence of electric and thermal conductivity [9]. Kim and coworkers added a soft Al + Fe + Si magnetic powder to a polymeric matrix to

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produce magnetic films to be used for shielding of electromagnetic waves [10]. Metal powders have been distributed in low density polyethylene (LDPE) without agglomeration [11], resulting in improvement of tribological properties [12,13]. Brito and Sanchez [14] used Zn, Cu, and Al as fillers in thermoset polymer systems composed by epoxy and amino resins at several concentrations up to 30 wt.%; they studied mechanical properties as well as thermal decomposition. They observed that the temperature of decomposition decreases when metal is added to epoxy + amine resins, this for all metals and all epoxy:amine ratios.

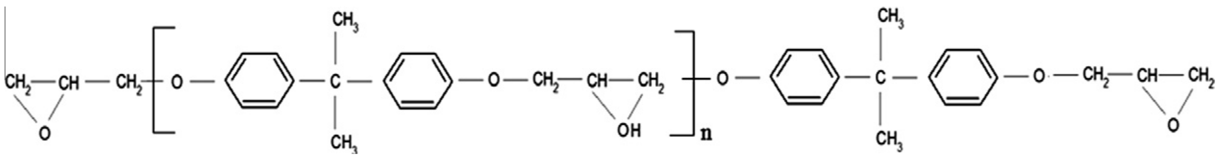
Modification of epoxies for achieving a wide range of properties including the above mentioned ones can be effective. Fluoropolymer modified epoxy provides better scratch resistance, low surface tension, better overall tribological properties and hydrophobicity [15–18]. Kumar, Alagar and Mohan developed siliconized epoxy interpenetrating coatings over mild steel wherein Zn powder was used for achieving good corrosion resistance [19]. Bazyliak, Bratychak, and one of us proposed the use of oligomers containing peroxy groups as epoxy modifiers in order to improve adhesion [20–22]. Polymer composites including carbon nanotubes (CNTs) are used for a variety of applications [23]; epoxies as corrosion protection coatings on steels have been reported [24]. Epoxy powder coatings modified using nano-$CaCO_3$, resulting in tensile and corrosion resistant properties were described by Yu and coworkers [25]. There has also been work reported on blends of thermoplastics like polysulfones and poly(methyl methacrylate) with epoxies for achieving toughness [26,27]. Kumar, Balakrishnan, Alagar and Denchev used silicone and phosphorus for modifying an epoxy to achieve anticorrosion, antifouling and flame retardant properties [28]. Fibers can also be used to alter the properties of the material [29].

In this work, modification of pure epoxy had been carried using a fluoropolymer and metal powders to achieve an advantageous combination of tribological and hydrophobic properties.

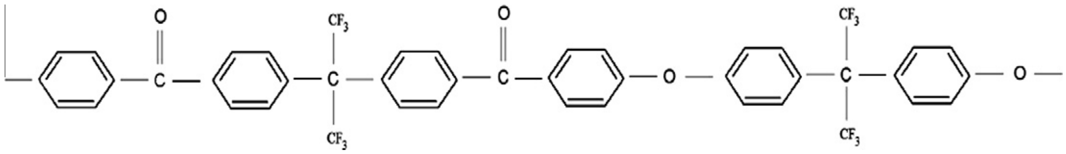
2. Experimental

2.1. Materials

Epon™ Resin 828, an undiluted clear difunctional bisphenol-A/epichlorohydrin derived liquid epoxy resin, diglycidyl ether of bisphenol-A (DGEBA), from Hexion Speciality Chemical Inc., was used as the base epoxy. The glass transition temperature T_g of the epoxy is 92 °C [16]. The epoxide equivalent weight of the epoxy is 185–192 g/eq. Its chemical formula is:



Fluorinated poly(aryl ether ketone) (FPEK) fluoropolymer was used as one of the modifiers due to its low surface energy nature which could provide hydrophobicity to the material and for its scratch resistance [19]. FPEK was synthesized in the Department of Chemistry, Texas State University, San Marcos according to a procedure reported in [30,31]. The T_g of the FPEK is 180 °C. Its chemical formula is:



The other modifier used was a metal powder. Four types of metal powders of size 1–5 μm were used: Ni, Al, Ag, and Zn. These metals powders were obtained from Atlantic Equipment Engineers (a division of Micron Metals Inc.). The Ni particles were used in flakes form whereas the Al particles were atomized particles. The shape of Ag was irregular, whereas the Zn particles were a combination of irregular and spherical particles.

Two types of curing agents were used in this work. One of them is triethylenetetramine (TETA) – a room temperature curing agent (from Hexion Speciality Chemical Inc.) and the other is hexamethylenediamine (HMDA) – a high temperature curing agent (from Sigma Aldrich). It has been reported in literature that curing temperature has a significant effect on a variety of properties – especially mechanical ones, friction, tensile bond strength, electrical resistivity, etc. of cured epoxies [16,32,33].

2.2. Epoxy modification, coating, and curing

Amount of FPEK used was 10 wt.% of the total system. Amount of curing agent used was 13 g TETA/100 g epoxy; 15 g HMDA/100 g epoxy. 25 wt.% metal powder/100 g epoxy was used.