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Mechanical properties modification of a thin film phenolic resin filled with nano silica particles

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ABSTRACT

The current manuscript experimentally investigates the mechanical and wears properties of three different phenolic polymer nanocomposites. Samples are made of 1, 2 and 3 wt.% of well-dispersed silica nanoparticles in a phenolic resin. Firstly, it was found that for the phenolic polymer, the Young's modulus steadily increased as the weight percent of silica nanoparticles was increased except for 3 wt.% nanoparticle filled samples. For the phenolic polymer with 1 and 2 wt.% nano silica, Young's modulus was increased 7% and 12.5%, respectively in comparison with the neat phenolic resin. However, for samples with 3% nanosilica this value showed a reduction about 13.5% and 2.7% in comparison to 2% nanoparticle filled samples and pure samples, respectively. Secondly, the presence of 2 wt.% nano silica particles increased the hardness of the phenolic polymer by 27.3% compared with the pure phenolic resin. Also, it was shown by the results of scratch tests that nano silica has almost no effect on the coefficient of the friction and wear rates.

1. Introduction

Polymeric nano-reinforced coatings have drawn considerable attention, in recent years, caused by improvements in various properties comprising scratch resistance, abrasion resistance, heat stability as well as other mechanical properties [1–4]. Traditionally, the scratch resistance of an organic coating can be improved by the addition of high content of inorganic filler. As inorganic fillers a range of different metal–oxide particles can be dispersed in the polymeric matrix [1,5–8]. The use of inorganic particles in the nano scale range is particularly attractive since it allows improving the properties of the polymers by controlling the degree of interaction between the polymer and the nano fillers [9] via a top–down approach.

Phenol resins (PF), notwithstanding the century-long history, are still attracting a great deal of research interests. They are important technical materials and irreplaceable in many fields, especially in thermal insulation, coating, aeronautic utilities, electro-optical devices and composite materials due to their thermal stability, high char yield, structural integrity and solvent resistance. Phenol resin-based friction materials usually contain a large number of reinforcing and filling constituents such as reinforcing fibers, abrasives, binders, fillers, and friction modifiers (solid lubricants). This accounts for the great dependence of their properties on the interactions and synergetic effects among the multiphase ingredients. In this sense, it is very important to correctly select and properly combine the different components so as to satisfy a number of requirements for the properties of the friction materials, such as good wear resistance, stable friction coefficient and reliable strength at a wide range of rigorous conditions.

In recent years, one of the widely used techniques for the evaluation of the mechanical and tribological properties of metals, ceramics, polymers and films at ultra-microscopic level is nano indentation and nano scratch tests using depth-sensing method [10,11]. However, up to now, few papers concerning the tribological behaviors at the micro/nano-scale of the phenolic-based nano composites have been presented [12,13].

The present paper characterizes the mechanical and tribological behaviors of phenolic films and SiO_2/phenolic nano composite coatings by using nano mechanics testing.

2. Materials and methods

2.1. Materials

Resol-type phenolic resin (IL800) and SiO_2 particles were used in the present research. The morphology of SiO_2 nanoparticle is

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Table 1
Impurities of Silicon nano-oxide [14].

Component	Cu	Zn	Fe	Mg	Na	Al	As	Sb	Pb	Hg
Content (%)	0.0	0.0005884	0.0	0.0000042	0.0	0.0	0.0	0.0000031	0.0	0.0

spherical with an average particle size of 10–15 nm, and purity of Silicon nano-oxide is 99.999% as shown in Table 1.

2.2. Sample preparation

Phenolic resin was mixed with 1 wt.%, 2 wt.% and 3 wt.% of SiO_2 for 20 min by a mixer at 600 rpm by using a two-propelled mechanical stirrer. Then, it was mixed for extra 5 min at 100 rpm. In order to obtain a full dispersion of the nanoparticles, probe sonicator of 14 mm in diameter (Hielscher UP400S) was utilized. The sonication process was performed for 30 min with 50 s cycle using ultrasonic waves set to 50 kHz. To avoid temperature rise during the ultrasonic processing, the Pyrex beaker containing resin and nano silica were cooled by an ice-bath. During the stirring, air bubbles created due to mixture also could inversely affect the quality and the properties of final product. To avoid this effect, the prepared mixture was placed in a vacuum oven for 15 min to be completely degassed. The mixture was prepared as a thin film on a metal substrate and kept for 18 h at 40 °C temperature to complete the curing process of the specimens.

It is worthy to note that to have a tendency solvent used in resin; resins were stored at room temperature to evaporate the solvent for a week which leads to smooth sample surface without any pores.

2.3. Characterization method

To investigate the mechanical and tribological performances of composite coating, nano-scale indentation and scratch tests were applied by using HysitronTribo Indenter. The indentation tests were carried out underforce-control method, where the applied load is controlled according to a programmed loading function, and the displacement was continuously monitored.

The loading function of the indentation in this research consists of five steps linear loading and five step sun loading segment together. The maximum applied load for all samples was 800 μN. The final values of hardness and modulus were taken as the average of five indentations carried out in different spots on the same material.

To calculate hardness (H) and modulus (E) the Olive and Pharr method [15] were used:

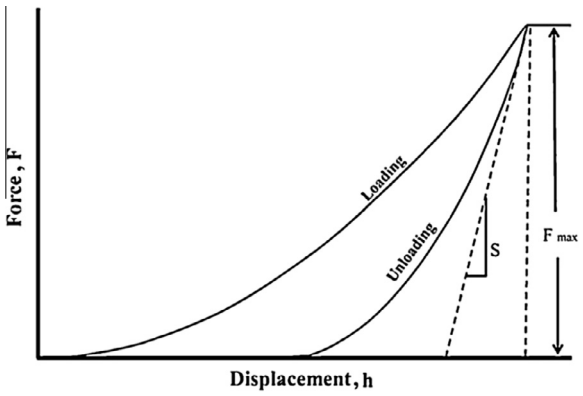

Fig. 1. A schematic representation of the load–displacement curve [15].

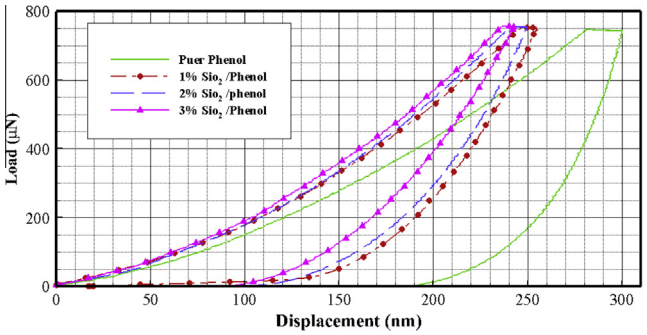

Fig. 2. Load–displacement curve for the specimens.

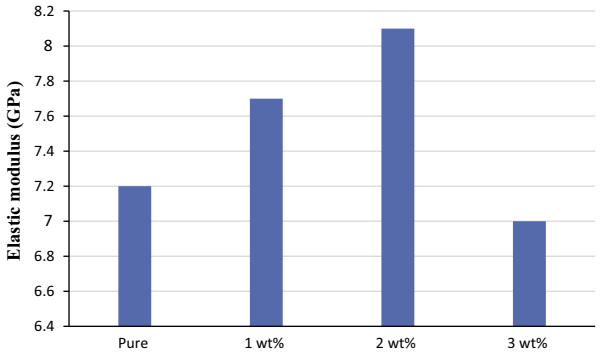

Fig. 3. Elastic modulus of the specimens.

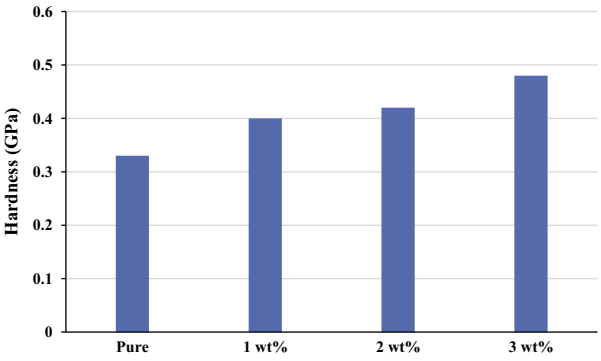

Fig. 4. Hardness of the specimens.

Table 2
Results of the indentation test.

	Young's modules (GPa)	Hardness (GPa)	Max force (μN)
Pure	7.2	0.33	748.7
1%	7.7	0.40	751.6
2%	8.1	0.42	752.8
3%	7.0	0.48	754.8