



## Correlation between the wear resistance, and the scratch resistance, for nanocomposite coatings

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### ABSTRACT

The nanoscratch test, used in this study, quantitatively characterizes the scratch behaviour of coatings. Some of the obtained parameters are plastic and elastic deformation, critical load to start the scratch, chipping or other change in the scratch mechanism of the coating. The knowledge of the scratch mechanism allows the optimisation of the material behaviour. In the present study the scratch resistance with the wear resistance has been correlated for nanocomposite coatings. Knowledge of mechanical properties extracted from the scratch test, supports the optimization of the coating against wear. The study was applied to nanocomposite coatings with different polymer matrices, different percentages and nature of nanoparticles.

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### 1. Introduction

The development of high performance materials is finding a growing number of applications where good tribological properties are required. The natural evolution in the design of organic coatings to provide good wear resistance has been the incorporation of inorganic fillers [1].

Generally, in inorganic–organic materials, the organic component provides flexibility for the coatings whereas the inorganic component is responsible of the hardness and mechanical properties of the composites. In addition, nanosized inorganic components improve scratch and wear resistance maintaining low viscosity, gloss and transparency of the nanocomposite coatings. The key issue of preparing these coatings without modifying the workability and the properties of the developed nanocomposites, is based on the effective and uniform dispersion of the inorganic nanofillers in the polymeric matrix avoiding aggregation and phase separation.

The improvement of the tribological properties by nanocomposite coating design has been extensively illustrated in the literature [2–4]. Different wear methods could be used to characterize the behaviour of the coatings [5] but none of them provides information on the property to be modified to optimize their behaviour. The optimization of the material behaviour, using only one wear test should be done by an empirical method.

In the present work, we have studied the relation between the wear resistance and the scratch behaviour for nanocomposites with different organic matrices and different inorganic nanofillers.

### 2. Materials and methods

#### 2.1. Materials

Three acrylated resins and three acrylated monomers were supplied by Cytec Industries Inc.: acrylated polyester resin (A), acrylated epoxy resin (B), acrylated urethane resin (C), 1,6-hexanediol diacrylate (HDDA), dipropylene glycol diacrylate (DPGDA) and tripropylene glycol diacrylate (TPGDA). 2-Hydroxy-2-methyl-1-phenyl propan-1-one (Darocur 1173) was supplied by Ciba and was used as photoinitiator. The commercial nanoparticle suspensions employed were: Highlink Nano G 103-53, a 50 nm SiO<sub>2</sub> in HDDA at 50% (wt.) by Clariant; Highlink Nano G 107-53, a 50 nm SiO<sub>2</sub> in DPGDA at 50% (wt.) by Clariant; Nanocryl C 145, a 15 nm SiO<sub>2</sub> in TPGDA at 50% (wt.) by Hanse Chemie; Nanobyk 3602 a 45 nm Al<sub>2</sub>O<sub>3</sub> in HDDA at 30% (wt.) by Byk-Chemie; and Nanobyk 3601 a 40 nm Al<sub>2</sub>O<sub>3</sub> in TPGDA at 32% (wt.) by Byk-Chemie. All these products were used without further purification.

#### 2.2. Coating processing

The nanocomposites were prepared from different commercial suspensions of silica or alumina nanoparticles in acrylated monomers. Organic matrices of nanocomposites have been made to maintain a constant ratio between resin/monomer/photoinitiator

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(77/20/3). Monomer content in the commercial nanoparticle suspension was taken into account to keep the right ratios. Three types of resins were employed: an acrylated polyester resin (A), an acrylated epoxy resin (B) and an acrylated urethane resin (C).

The level of dispersion of nanoparticles in the composition was determined by controlling the nanoparticle size in suspension with a Zetasizer Nano ZS by Malvern.

The coatings were applied on a glass surface as 60  $\mu\text{m}$  thickness and polymerized by exposure to ultraviolet light. The UV irradiation source was a Superfici source (160 W/cm) equipped with an H-bulb lamp. The samples were passed under the lamp at a speed of 5 m/min.

### 2.3. Characterization

#### 2.3.1. FTIR

Fourier transform infrared spectrometer (FTIR) was carried out using the attenuated total reflectance (ATR) mode on a THERMO model NICOLET 6700 spectrophotometer, with a 64-scan per sample cycle and a resolution of 4  $\text{cm}^{-1}$ . The samples were scanned between the following wavelengths of 4000–600  $\text{cm}^{-1}$ .

#### 2.3.2. Wear test

The wear resistance of the coatings was determined by Taber abrasion test [6]. CS-10 abrasive wheels were used with a 1000 g weight in each wheel. The regeneration of the wheel was done with an abrasive paper of S-11 for 50 cycles. Before abrasion process the weight of the sample was determined with an accuracy of 1 mg. Every thousand cycles the weight of the specimen was determined again and the weight loss calculated. Successive abrasion cycles were performed, showing the wear evolution on a graph of weight loss versus the number of abrasive cycles. The specific rate of wear of the specimens was calculated from the slope of the line obtained, expressed in  $\text{kg/mN}$ .

#### 2.3.3. Scratch tester

The scratch test was performed using a Nano Indenter. A diamond indenter with conical geometry (Rockwell) and spherical tip radius of 200  $\mu\text{m}$  was used. The scratch test was carried out with progressive loading [7], which involves applying a charge on the surface at a constant rate of increase as the sample moves a certain

**Table 1**  
Compositions prepared.

Compositions <sup>a</sup>	Resin (g)	HDDA (g)	Photoinitiator (g)	Nanosilica (g)
AH1	77	20	3	0
AH2	77	20	3	5
AH3	77	20	3	20
BH1	77	20	3	0
BH2	77	20	3	5
BH3	77	20	3	20
CH1	77	20	3	0
CH2	77	20	3	5
CH3	77	20	3	20

<sup>a</sup> A: polyester matrix; B: epoxy matrix; and C: urethane matrix.

distance laterally, progressively increasing the applied load along from 0 to 2000 mN. This test allows observing the behaviour of the material in the range of loads, studying both elastic and plastic deformation, recovery and analysing the degradation mechanism.

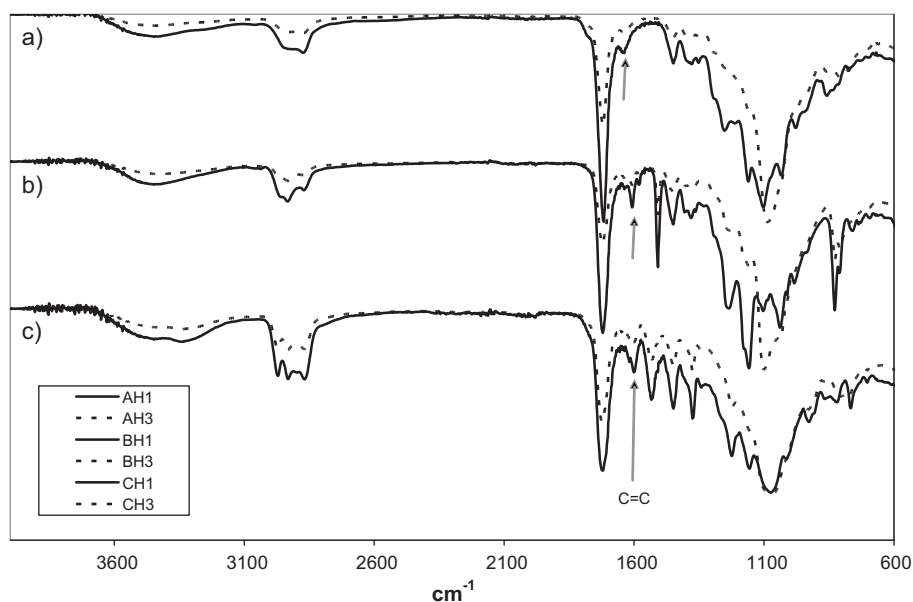
To avoid errors caused by point defects on the surface to be tested, which might influence the tests results, three stripes have been performed on each sample, each of 2 mm in length.

Before and after scratching the surface, the indenter traverses the area to test, applying a minimum load, recording the contours of the surface. Comparing the first and the last obtained profiles, changes in depth on the scratched surface can be detected. In all tests, load and length of the line were increased simultaneously at speeds of 10 mN/s and 10  $\mu\text{m/s}$ , respectively. The three surface profiles measured for each strip can be defined as follows:

- *Original profile*: profile of the surface of the coating before damage.
- *Scratching profile*: profile followed by the indenter during the scratch test.
- *Final profile*: profile of the surface of the coating after damage.

After the scratch test, with an optical profilometer, topographic maps of the damaged surface were obtained, evaluating the changes in the mechanism of scratch and the critical loads.

The adhesion of the coating to the substrate, the generation of cracks, the change in the scratch mechanism and both elastic and plastic deformations were evaluated with this test. From



**Fig. 1.** FTIR spectra of (a) polyester coatings, (b) epoxy coatings and (c) urethane coatings (continue lines show organic coatings and discontinue lines show nanocomposite coatings with nanosilica).

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