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THE BEHAVIOUR OF SOME ADDITIVATED COMPOSITE MATERIALS AT SLIDING INDENTATION TEST

Constantin Spanu[1], Sorin Ciortan[1], Vasile Bria[1], Igor Roman[1]
[1]"Dunarea de Jos" University of Galati, Romania
constantin.spanu@ugal.ro; sorin.ciortan@ugal.ro; vasile.bria@ugal.ro; igor.roman@ugal.ro

Abstract: *The polymeric composite materials with epoxidic resin base and multi-walled carbon nano-tubes (MWCNT) can be used, due their electrical properties, as covering layers for parts subjected to electrical fields, in order to avoid electrostatic charges.These materials also present a brittle behaviour, being subjected to surface cracks development if the loading overcome certain levels. The material's surface response to dynamic loadings has a deirect influence on its tribological properties. A method for characterization of brittle behaviour is the sliding indentation. The paper presents the results obtained by performing indentation and sliding indentation tests on a epoxidic resin based composite, additivated with MWCNT. The tests show that the mixing order of the components have an influence on mechanical properties of the composite.*

Keywords: *MWCNT composite, sliding indentation, mechanical properties.*

1. INTRODUCTION

The composites, as macro-level combination of several materials in order to obtain a new material, with different properties [1], are new opportunities for designers allowing the optimization of products by better matching with technical requirements. By proper choosing of the components, the physical and mechanical properties of the composite can be predicted and obtained, accordingly with the requirements.

Even the composites properties are predicted from the mixing stage, a complete set of tests are required in order to establish the full applications possibilities. Among other classical tests for mechanical properties assessment, the indentation and the sliding indentation can provide useful information about the material behaviour under high loadings rising up until the plastic deformation appear.

Indentation is a mechanical testing method much easier than others (traction, for example), requiring simple samples and providing with satisfactory precision values of specific material's stresses (like ultimate tensile stress and yield tensile stress) [2,3].

The sliding indentation method, [4,5], where to the normal indentation force a tangential one is added, is more difficult to put in practice but provide a more complex state of stress in the sample than simple indentation [6,7].

The present paper is focused on the investigation of the behaviour of some composites based on epoxidic resin with 2% multi-walled carbon nano-tubes (MWCNT), taking into account the obtaining method. Both indentation methods are used for the establishing of cracking force and corresponding pressure values.

2. EXPERIMENTAL SETUP

The tests were performed on several flat samples of a composite with the same ingredients but obtained through different mixing technologies.

2.1 Studied materials

The subject of investigation was a composite based on bi-component epoxidic resin (component A - Ephiphen RE 4020 and component B - Ephiphen DE 4020) with additivated 2% MWCNT. This material should be used as covering layer for parts subjected to electrical fields, in order to avoid static charges. As consequence, some properties like: light weight, good mechanical resistance and electrical conductivity are required.

The system RE 4020/DE 4020 was chosen based on its properties: polymerization at room temperature, high thermal, UV and humidity resistance, transparency and low toxicity.

The added MWCNT should provide the required electrical conductivity and mechanical strength.

The obtaining technologies for composites based on epoxidic resins require the mixing of the additive with the resin's components. This can be done in several ways:

- first mixing all the additive quantity only with component A. The obtained mixture is then mixed with component B and polymerized;
- first mixing all the additive quantity only with component B. The obtained mixture is then mixed with component A and polymerized;
- first component A and B are mixed and all the additive quantity is before polymerization.

The performed tests try to determine which mixing method (Table 1) is most appropriate in order to obtain a composite material showing, beside required electrical properties, the best mechanical ones.

Table 1. Tested samples

Code	Mixing order
CNT-A	MWCNT additive mixed with component A
CNT-B	MWCNT additive mixed with component B
CNT-AB	MWCNT additive mixed with A-B mixture

2.2 Sliding indentation test rig

The tests were performed on a dedicated test rig [8,9,10,11], Figure 1, with a sliding speed v=0.172 mm/s. For simple indentation, a null speed was imposed.

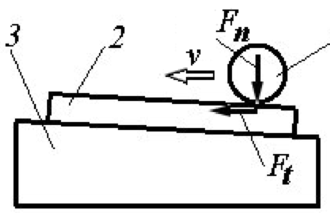

Figure1. The test rig: 1- indenter, 2 - sample, 3- inclined plane, v- horizontal sliding speed, F_t - tangential force, F_n - indentation force

As indenter, a 12.675 mm diameter ball was used. The ball material is hardened Romanian steel RUL-1 (SREN ISO 683-17:2002). The holder doesn't allow the ball rotation and for each test, a new ball was used.

In sliding indentation method case, the normal force value's increasing is obtained by mounting the sample on an inclined plane with angle value 2° (Figure 1), associated with a horizontal sliding speed of the indenter. This mounting leads to increasing rate of normal force (indentation force) depending on both plane angle and sample toughness. Keeping the same angle value for all tested samples, the only one dependency is with sample toughness. Both normal force and tangential force values were monitored and recorded using stress gauges and corresponding electronic amplifier connected to a personal computer.

3. TESTING RESULTS

The results of performed tests allowed analyzing of the composite mechanical behaviour. Several samples from every mixing method were tested and the corresponding results values were averaged.

3.1 Simple indentation

The average normal forces values, leading to samples' cracking are presented in Table 2.

Table 2. Numerical results

Average normal cracking force [N]		
CNT-A	CNT-B	CNT-AB
3039.20	2761.00	2295.64
Average indenter impression diameter [mm]		
CNT-A	CNT-B	CNT-AB
2.484	2.049	2.214
Average cracking pressure [MPa]		
CNT-A	CNT-B	CNT-AB
156.779	209.242	149.20

In order to evaluate the corresponding cracking pressure values, the indenter impression on the sample were measured (Figure 2) using a dedicated image analysis software package.

Figure 2. Indenter impression with lateral cracks

Due to radial cracks and material plastic deformation, aberration from circular shape of the impression was observed, requiring a measurement strategy: circle generation through three points placed on the largest un-cracked arc.

Averaged values of impressions' diameters for each sample category are presented in Table1.

Based on normal force values and measured diameters the corresponding average cracking pressure values can be computed, Table1.

The average calculi for all categories were checked with Grubbs statistical test.

In Figure 3 is presented a graphical comparison between average cracking pressure values.

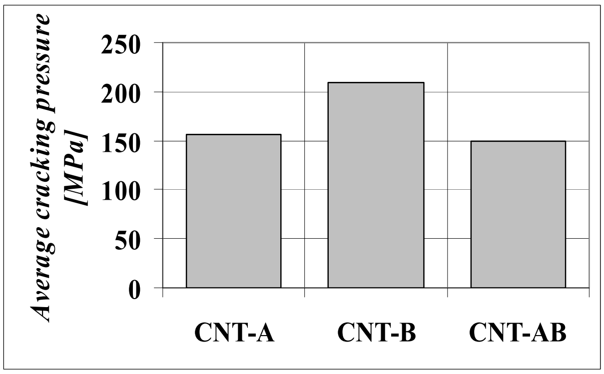

Figure 3. Comparison between average cracking pressure values.

The presented data shows that CNT-B mixing method leads to the highest cracking resistance, comparing to CNT-A and CNT-AB methods.

3.2 Sliding indentation

During sliding indentation process, due to constant normal force increasing, the indenter leaves on the sample surface tracks with a characteristic shape, Figure 4. At beginning and at the ending of the sliding track, areas with higher deformation can be observed. In these areas, due to the sample and indenter manipulation time, a simple indentation effect occurs.

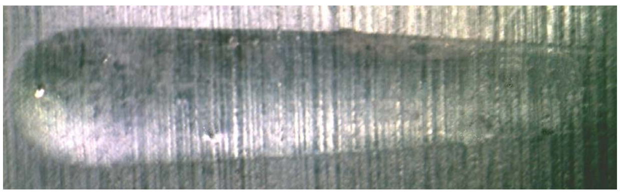

Figure 4. Characteristic tracks during sliding indentation.

The tests want to establish the increasing rate of normal force, as an indicator of material's hardness. As higher is the rate, as harder the material is. With this aim of the normal force variation was monitored and recorded.

In Figure 5 is presented, as an example, the corresponding variation for sample CNT-A.

In order to avoid erroneous results, the recorded data corresponding to areas of sliding beginning and ending are removed.

It can be observed that the graph is stepped shaped; this can be explained by appearance of oscillatory phenomenon due to accumulating-releasing of elastic deformation during sliding process.

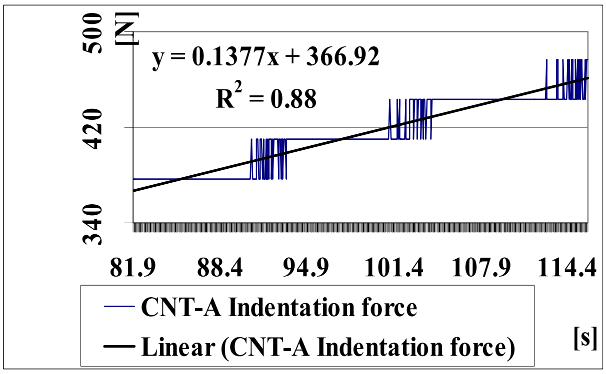

Figure 5. The increasing rate of indentation force for CTA-A sample

Regarding to the increasing rate of the indentation force $\mathbf{F_n}$, the obtained curves was approximate with a straight line, using Trendline facility in MS Excel. Even the R-squared coefficient presents relatively low values, indicating that there is another better approximation; this was preferred, allowing a more facile comparison between the samples. On the chart can be seen also the line equation and the corresponding R-squared coefficient values.

The values for normal force increasing rate obtained from regressing lines that correspond to all materials are presented in Table 3.

Table 3. Normal force increasing rate

Increasing rate [N/s]		
CNT-A	CNT-B	CNT-AB
0.1377	0.1448	0.0965

In Figure 6 is presented a comparison between all three regression lines.

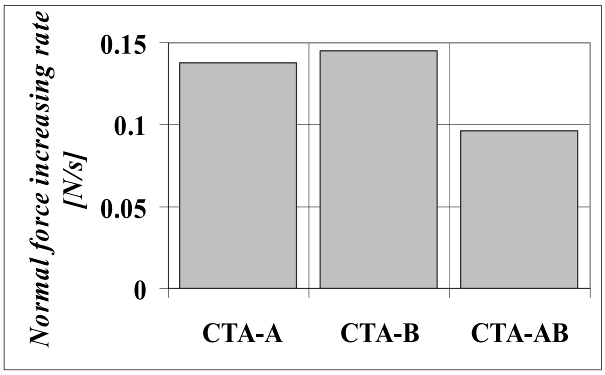

Figure 6. Comparison of normal force increasing rates for tested samples

It can be observed that normal force increasing rate, is biggest in CNT-B case. This observation is coherent with simple indentation results, Figure 3.

4. CONCLUSIONS

The paper presents the results obtained after indentation and sliding indentation tests performed on an epoxidic resin – MWCNT composite. Three mixing methods were sampled, in order to establish the best one from mechanical resistance point of view.

The results show that:

- simple indentation test can stand as a affordable and easy method to establish the toughest material, as being the one which require the biggest cracking pressure value;
- with sliding indentation method, as complementary test, the validation of simple indentation results can be done;
- composites based on epoxidic resin with added MWCNT show, beside the electrical properties, good mechanical properties, making these materials appropriate for using as cover layers.

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