



## TRIBOLOGICAL COMPARISON OF SOME PARTICULATE COMPOSITES

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**Abstract:** Using powders to fill a polymer some of its properties might be improved and some other properties might be damaged. The presence of filler's particles inside the polymer volume reduces and limits the polymer chains with consequences on mechanical behaviour of the final material. It is above any discussion that the nature of the powder and the dimensions of powder particles have strong effects on the final material. In the case of a thermosetting material arises another problem connected with the way in which the filled pre-polymer is realized. For this study the epoxy system EPIPHEN RE 4020 / EPIPHEN DE 4020 was used. The named epoxy allows a 45 minutes gel time, long enough to mould valuable materials and long enough to allow three different way of powders dispersion. For each powder three materials were formed (all of them with a volume ratio powder : polymer of 2:100) by dispersing the powder alternatively in the two components or epoxy system or directly into the pre-polymer solution. Mechanical properties of formed materials were investigated together with a tribological investigation performed with pin-on-disk method (with rectangular pins made of particulate composites and steel disk).

**Keywords:** epoxy, clay, talc, starch, CNT, friction, wear.

### 1. INTRODUCTION

Epoxy resins are one of the most versatile classes of polymers with diverse applications such as metal can coatings, automotive primer, printed circuit boards, semiconductor encapsulants, adhesives, and aerospace composites. Most cured epoxy resins provide amorphous thermosetting with excellent mechanical strength and toughness; outstanding chemical, moisture, and corrosion resistance; good thermal, adhesive, and electrical properties; no volatiles emission and low shrinkage upon cure; and dimensional stability - a unique combination of properties generally not found in any other plastic material. These superior performance characteristics, coupled with outstanding formulating versatility and reasonable costs, have gained epoxy resins wide acceptance as materials of choice for a multitude of bonding, structural, and protective coatings applications [1].

As a general rule the polymer composites, as well as ceramic or metal matrix composites, are imparted in particulate (filled) and reinforced or combinations of them. In each case the composite

material is formed to solve a problem, to maximize a property for a certain application [2-5]. Carbon fiber reinforced polymers, for instance, are used and formed for low weight and high strength especially for motor sports but in this case it might be done more due to the electrical properties of carbon fiber; namely it might be possible to achieve information about structure's state via electrical resistivity of carbon fibers (or tows).

Complex polymer materials (reinforced with filled matrix) may solve more than one or two problems due their components properties. In this case some problems may occur because by increasing the number of components the forming technique becomes more complicated. However, to form reinforced composites with regulated distribution of fibers is difficult and led to pre-preg solution; to form particulate composites with uniform dispersion of fillers' particles is also difficult; to form a polymer composite with a regulated distribution of fibers and uniform dispersion of fillers' particles is more complicated.

This study is just a part of a larger one regarding complex polymer composites reinforced with fibers

fabrics and with particulate matrix meant to reach more capabilities for final material. The use of fabrics ensures the fibers spatial distribution and use of fillers solves physical properties (electrical and/or thermal conductivity, dimensional stability etc). In this case it has to be known the way each filler reacts with the polymer aside the necessity of ensure the interface between fibers and polymer. Due an appropriate forming technique (layer-by-layer, for instance) it is possible to obtain laminated-like materials having other fabric in each reinforcement layer and other filler in each polymer layer but keeping the same polymer bonds into material's volume.

## 2. MATERIALS

The Epoxy system RE 4020 – DE 4020 was used as matrix to form particulate composites with Clay, Talc, Starch, CNT, Aluminum titanate and Lithium titanate. Each of the fillers is used on a certain purpose connected to the final properties of the composite.

The use o Clay is recommended by its capacity to generate nanostructures inside the matrix each nano-plate of clay acting as a crystallization germ and changing, locally, the normal polymer structure with effects on mechanical properties of the final material due to the soft transfer of the loadings between the crystalline and amorphous phases [6]. Another aspect is about the fact that Clay presence in the pre-polymer mixture allows a better dispersion of CNT's which generally tend to aggregate [7, 8]. The clay powder used to form the particulate composites is one of cosmetic application so it contains organic substance aside the mineral one.

The presence of the Talc inside a polymer matrix increases the fire resistance and contributes to better mechanical properties. The presence both of Clay and Talc leads to a material which act as a liquid with very high viscosity because the ordered zones surrounding the Clay or Talc particles are connected through typically polymer bonds. It is expected that the particulate composite to show lower mechanical properties but higher dimensional stability.

Starch is known as a good dispersant and also is known for its capability to form structures inside liquid phases. Starch also may be easily functionalized with various ions and it might be used to transport transitional metals' ions, via complex combinations, inside the polymer structure solving in reasonable limits the problem of electrical conductivity (and not only).

The use of CNT is intended for changing electric behavior [9]. As per Aluminum titanate and Lithium titanate, they are used due their capacity to

form nano-structures inside the polymer matrix. Taken separately each of the fillers may be used to obtain a benefit but the problem is to use all of them to fill the same matrix. This type of filled polymer might be also used as matrix for a reinforced composite (with long fibers or fabrics) such as, at least, one design problem to be solved in one layer of the hybrid composite. For instance the external layer has to show high electrical conductivity and good wear resistance, while the other properties of the structure might be set in the internal layers by using glass fibers – for strength, protected by aramide fibers for shock resistance. Using various polymers in various layers it is more possible to control the design of composite materials or composite structures.

For each of above mentioned fillers three types of materials were formed with a volume ratio of 2% filler/polymer. The first type (denoted as A) consists in mechanical dispersion of fillers' particles into the liquid component A of epoxy system (bisphenol A) followed by adding of right amount of B component (aliphatic amine complex). The second type (denoted as B) consists in mechanical dispersion of filler into the liquid component B of the epoxy system while the third type (denoted as P) consists in dispersion of filler into the pre-polymer mixture of right amounts of A and B components of epoxy system.

All the samples were thermally treated to reach their best properties, according to the producer's recommendations. The thermal treatment develops at relatively low temperatures such as the fillers are not affected, except the organic substance from clay powder.

The mixing rule is giving the same result regarding the specific weight for all three types of materials (A, B or P) and it is not taking into account the interactions. Table 1. shows the specific weight values for powders, epoxy and particulate composites, as well as the theoretical value as it results through application of mixing rule [10, 11]. Some differences between measured and evaluated values might be noticed.

**Table 1.** Specific Weight of Components and Materials

Component		Mixing rule	A type	B type	P type
Epoxy	1.128				
Starch	0.588	1.118	1.090	1.165	1.240
Talc	0.763	1.121	1.113	1.160	1.087
Clay	0.608	1.118	1.145	1.212	1.125
Lithium titanate	1.210	1.130	1.180	1.208	1.132
Aluminum titanate	1.913	1.144	1.231	1.180	1.068
CNT	0.047	1.107	1.146	1.163	1.125

### 3. MEASUREMENTS AND RESULTS

The tribological behaviour and the wear behaviour had been studied on the same machine *Multi-Specimen Test System - UMT from CETR* in the fixture pin-on-disk with pin made of stratified material and steel disk and with the disk covered with abrasive paper (abrasive tests) – Figure 1.



Figure 1. The Multi-Specimen Test System

Analysis was performed at different sliding speed values and different loadings but generally the friction behaviour may be placed into three categories: medium powders (starch and CNT), hard powders (Aluminium titanate and Lithium titanate) and soft powders (talc and clay) as can be noticed in figures below.

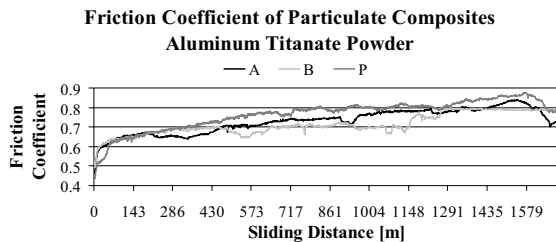


Figure 2. Friction coefficient for hard powders

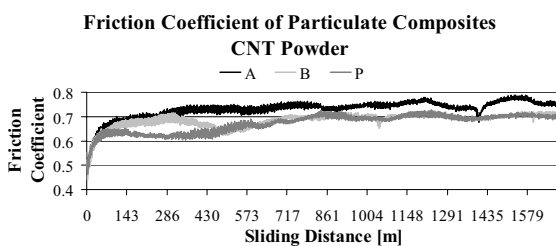


Figure 3. Friction coefficient for soft powders

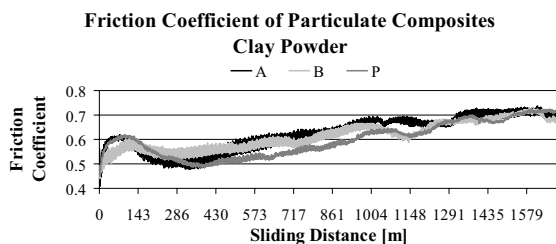


Figure 4. Friction coefficient for soft powders

The hard powders determine low variations of friction coefficient during testing while the soft powders induce large variations of friction coefficient.

The wear rates both at friction and abrasion were evaluated according [12, 13] and the results are presented in figures below. In each case the relative wear rate is presented having as reference the wear rate of epoxy resin and it might be noticed (Figure 5) that generally filling the polymer the wear resistance is increased [14-16] but the dispersion method influence the results. All the values were computed on the basis of measured specific weight. Significant improvements correspond to the clay, talc and CNT filled polymer but for clay and CNT the highest values are related to pre-polymer dispersion while in the case of talc the highest value corresponds to first dispersion method.

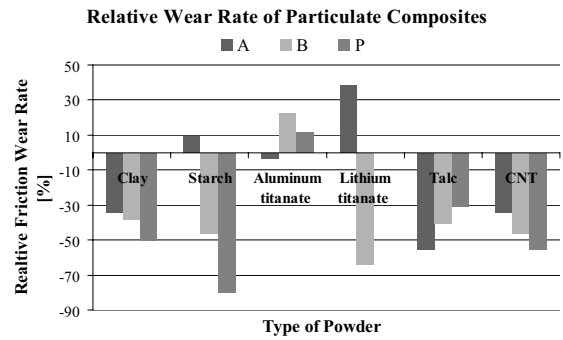


Figure 5. Relative friction wear rate of materials

The abrasive wear tests were performed on the same machine but the steel disk was covered with abrasive paper P400. Presence of clay ensures a higher abrasive wear resistance while presence of talc reduces the resistance (Figure 6).

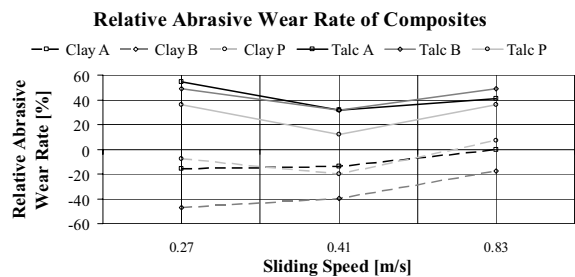


Figure 6. Relative Abrasive Wear Rates - soft powders

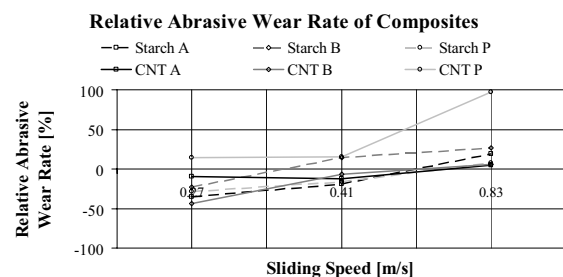
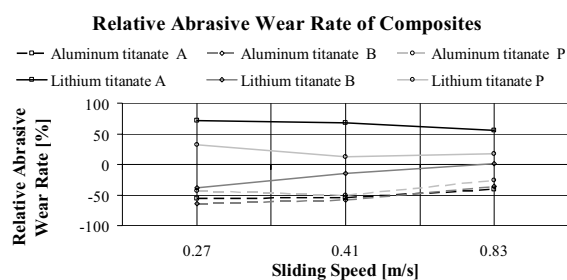


Figure 7. Relative Abrasive Wear Rates - medium powders



**Figure 8.** Relative Abrasive Wear Rates - hard powders

In the case of medium powders the benefits are not too important while in the case of hard powders the results are imparted again as in the case of soft powders with the Aluminium titanate increasing the abrasive wear resistance and with Lithium titanate lowering it.

#### 4. CONCLUSIONS

The aim of this study was to identify the effect of dispersion method on the tribological and abrasive properties of particulate composites. The entire study is centred on 2% volume ratio of filler but the analysis has to be performed for other concentrations.

In the case of use of such filled polymers as matrix to form reinforced composites it is necessary to know the way in which the forming technique (the dispersion) is influencing the final properties. Mechanical, thermal and electrical analysis has to be performed to offer accurate information about the presented filled polymers. Even the basic constituents are the same it is easy to notice that is possible to set various properties in various ways leading to the possibility to form a reinforced material based on the same polymer and same filler but having various behaviour in various matrix or reinforcement layers.

Using a layer by layer forming technique the final material will have the same polymer as matrix showing the same type of polymer bonds in all its volume so the loadings will affect the matrix as a bulk material avoiding the inter-laminar problems.

Just few aspects were presented but it is reasonable to imagine a CNT filled polymer matrix fabric reinforced composites with a certain distribution of matrix specific weight based just on the CNT's dispersion technique into the polymer. Such a material could have a better electrical conductivity at the surface combined with a high density (required by tribological behavior).

#### REFERENCES

[1] Pham, H.Q. & Marks, M.J., Epoxy resins, in Mark, H.F. (ed), *Encyclopedia of Polymer Science and*

*Technology*, John Wiley & Sons, Inc., vol. 9, pp. 678 – 804, ISBN: 978-0-471-27507-7, 2004.

- [2] Gay, D., Hoa, S. V., Tsai, S. W., *Composite Materials – Design and Applications*, CRC Press, Boca Raton, USA, ISBN: 58716-084-6, 2003
- [3] Daniel, I & Ishai, O., *Engineering Mechanics of Composite Materials*, Oxford University Press, New York, USA, ISBN: 019515097X, 2006.
- [4] Jones, R.M., *Mechanics of Composite Materials*, Taylor&Francis Inc., Philadelphia, USA, ISBN: 1-56032-712-X, 1998.
- [5] Vasiliev, V. V. & Morozov, E. V., *Mechanics and Analysis of Composite Materials*, Elsevier, ISBN: 0-08-042702-2, 2001.
- [6] Winey, I. Karen & Vaia, A. R. (ed), *Polymer Nanocomposites*, MRS Bulletin, Vol. 32, 2007.
- [7] Ciricumaru, A. et al., Thermo-mechanical and electrical properties of high filled epoxy composites, *EUROMAT 2009*, Galsgow, Scotland, 2009.
- [8] Andrei, G., Dima, D., Birsan, I., Andrei, L., Ciricumaru, A., Effect of Ferrite Particles on the Mechanical Behaviour of Glass Fibers Reinforced Polymer Composite, *Materiale Plastice*, 46, Nr. 3, 284-287. ISSN 0025-5289, 2009.
- [9] Andrei, G., et al., Selected mechanical properties of fabric reinforced composites with talc and carbon black filled matrix, in *Journal of Polish Society for Composite Materials*, Quaterly, 9, Nr.4/2009, 347-351 pp, ISSN 1641- 8611, 2009.
- [10] Torquato, S., Modeling of physical properties of composite materials, *International Journal of Solids and Structures*, 37, 2000.
- [11] Callister, W. D. Jr., *Materials Science and Engineering*, 7th ed., John Wiley & Sons, ISBN-10:0-471-73696-1, 2007.
- [12] El-Tayeb, N.S.M., Two-body abrasive behaviour of untreated SC and R-G fibers polyester composites, *Wear*, (266), pp. 220-232, 2009.
- [13] Mimaroglu, A., Sen, U., Unal, H., Abrasive Wear Volume Maps for PA6 and PA6 Composites Under Dry Working Condition, *Appl. Compos. Mater.*, (15), pp. 13-25, 2008.
- [14] Tsukizoe, T., Ohmae, N., Friction and Wear Performance of Unidirectionally Oriented Glass, Carbon, Aramid and Stainless Steel Fibre-Reinforced Plastics, in Friedrich, K. (ed.) *Friction and Wear of Polymer Composites*, Amsterdam, Elsevier, pp. 205-231, 1986.
- [15] Friedrich, K., Wear of Reinforced Polymers by Different Abrasive Counterparts, in Friedrich, K. (ed.) *Friction and Wear of Polymer Composites* Amsterdam, Elsevier, pp. 233-287, 1986.
- [16] Mathias, P. J., Wu, W., Goretta, K.C., Routbort, J.L., Groppi, D.P., Karasek, K.R., Solid Particle Erosion of a Graphite-Fibre-Reinforced Bismaleimide Polymer Composite, *Wear*, Vol. 135, pp. 161-169, 1989.