V. BRIA, D. DIMA, G. ANDREI, I.-G. BIRSAN, A. CIRCIUMARU

RESEARCH

Tribological and Wear Properties of Multi-Layered Materials

The usage of fabrics as reinforcements in composites is spreading due to fabrics' properties. The use of fabrics allows obtaining of sinuous surfaces, for instance, unlike the use of pre-pregs. Using fabrics as reinforcements it is also possible to obtain laminate-like materials having the same matrix in all their volume. In the case of pre-pregs usage always it is necessary to discuss about the bonding between individual plies. For this study eight materials were formed. The forming method consisted in placing the pre-polymer imbued fabric pieces into a mould to obtain plates of composites. Two types of fabric were used: one simple type of untwisted tows of carbon fibres and the second one simple type of alternated untwisted tows of carbon and aramide fibres. Both fabrics were prepared in order to ensure the matrix adherence. The polymer matrix is realised from epoxy system EPIPHEN RE 4020 / EPIPHEN DE 4020 filled with clay and talc in equal amounts of 5% (weight ratio). The use of clay and talc were meant to improve the thermal dimensional stability of final materials. Tribological properties of formed materials were studied using pin-on-disk method with steel disk and pins made of materials. Both orientation of reinforcement fibres relative to friction direction were taken into account. Results are encouraging further studies in order to identify the best solution of forming a multi-component material with more than one designable property.

Keywords: *fiber fabrics, epoxy, clay, talc, wear.*

1. INTRODUCTION

Powders are used as fillers in order to obtain bi-components composites [1, 2, 3]. There is no structural order in such a filled composite, the most important aim being the uniform distribution of particles in matrix. If the fillers' particles are arranged into the polymer volume is possible to change the electro-magnetic behavior of the obtained composite making this one to act as a meta-material [4, 5]. The powders can be dielectric as talc, clay or ferrite can be magnetic active as ferrite, or electric active as CNT or carbon nano-fibers. All these powders, added to the polymeric matrix, have effects on the electro-magnetic, thermal and mechanical properties of the composite [6, 7]. What about using all of them, based on partially changes induced by each one? There exist many models regarding the mathematic description of electromagnetic properties of the bi-component composites. Also there are studies regarding the bounds of models. Taking into account that not only the electromagnetic properties are important but also the mechanical and thermal properties the design problem becomes almost impossible.

The use of fabrics as reinforcements for polymer matrix composites is recommended by their ability to form sinuous and complicated surfaces keeping the regulated distribution of the fibers. The lay-up method of forming allows materials with the same matrix in all the volume unlike the laminated composites where the bonds between layers are very important. Stratified materials with the same polymer in all the volume responds different from laminated at all the external solicitations – thermal, electrical, mechanical etc. For this study epoxy resin was used as matrix and two types of fabrics as reinforcement to form layered materials with various orientations of fabric layers and with different distributions of the two fabrics inside the material.

The aim of this study is to identify the tribological changes induced by fillers when they are used to form a stratified fabric reinforced material with different fillers in different layers.

Vasile Bria, Dumitru Dima, Gabriel Andrei,
Iulian-Gabriel Birsan, Adrian Circiumaru
Dunarea de Jos" University Galati, Romania,
web adress: www.ugal.ro

2. MATERIALS

Two types of fabric were used during this study; first type is simple fabric made of untwisted tows of carbon fibers while the second is a simple fabric made of alternating untwisted tows of carbon and aramide fibers. From the beginning the two fabrics were choose because of the intrinsic properties of fibers (electromagnetic and mechanical in the case of carbon fiber, shock and thermal in the case of aramide fiber). Two problems had to be solved before forming the multi-component composites: the fabrics' stability – because during the cutting the tows are slipping one on each other leading to structural defects of fabric with consequences in mechanical properties of the composite; the second problem is about the low epoxy adhesion to the two types of fiber which leads to discontinuities at the interface level with consequences in all the composite's properties. The two fabrics were specially prepared before they had been used as reinforcements.

The fabrics treatment has two phases: a chemical one meant to increase the specific area of fibers and to ensure the matrix adhesion consists in treatment with 50% hypochlorite aqueous solution and then with 20% NaOH aqueous solution; the second phase meant to stabilize the tows consists in covering the fabrics with o thin film of PNB rubber and then with a thin film of epoxy. Both the rubber solution and polymer's components solutions were filled with small amounts of clay and carbon black in order to enlarge the specific area of the fabrics and to improve the electrical behavior of materials.

The matrix is realized from the mentioned epoxy with: clay (5%), talc (5%), CNT (0,5%) for first two reinforcement layers; clay (5%), talc (5%), CNT (1%) and ferrite (5%) for next two layers; clay (5%), talc (5%), CNT (0,5%), ferrite (5%) for other two layers; clay (5%), talc (5%), CNT (0,5%), ferrite (2%) and Wolfram carbide (5%) for last two layers (respecting the molding order) – all the ratios are expressed in weight terms. This type of matrix will be denoted as s for all the information below. The other matrix, denoted with h, represents a homogeneous matrix filled with 5% clay and 5% talc for all the reinforcement sheets. All the powders were mechanically mixed and then dispersed into the right amount of A component of the epoxy system, the amount of B component was added and the fabrics were imbued with the filled pre-polymer mixture.

The presence of both clay and talc leads to a material which acts 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. The use of Ferrite is intended to change the magnetic properties of the final composite while the use of CNT for changing its electric behavior [8]. As per Wolfram carbide, despite its high specific weight, it can be used to change the tribological properties of the composite. It is taken into account not the frictional behavior but the wear resistance under the action of a flux of abrasive particles (as sand) in order to increase the lifetime of components exposed to such factors.

For this study materials were formed in order to point out the influence of reinforcements and matrix on final properties of formed materials. For each formed material the reinforcement consist in eight sheets of fabric. The reinforcement sheets were cut parallel to weft and yarn of the fabric (0) or at 45 reported to the warp and yarn of the fabric (45). The two types of fabrics are denoted as C, for carbon fiber fabric or K for mixed fabric such as each reinforcement's sheet may be described as C(0), C(45), K(0) or K(45). The reinforcement's structure of each material is presented in Table 1 and Table 2.The Epoxy system RE 4020 – DE 4020 was used as matrix and clay, talc, CNT, ferrite and Wolfram carbide as fillers. Each of the fillers is used on a certain purpose connected to the final properties of the composite.

Table 1. Stratified materials' structure - A

	Reinforcement structure - A
1	C(0^o) C(45^o) K(0^o) K(45^o) K(45^o) K(0^o) C(45^o) C(0^o)
2	C(0^o) C(45^o) C(45^o) K(0^o) K(45^o) K(0^o) C(45^o) C(0^o)
3	C(0^o) C(45^o) C(0^o) K(45^o) K(0^o) C(45^o) K(45^o) C(0^o)
4	C(0^o) C(45^o) C(45^o) C(0^o) C(0^o) C(45^o) C(45^o) C(0^o)
5	C(0^o) K(45^o) C(0^o) K(45^o) C(0^o) K(45^o) C(0^o) K(45^o)

Table 2. Stratified materials' structure - B

	Reinforcement structure - B
1	K(0^o) K(45^o) C(0^o) C(45^o) C(45^o) C(0^o) K(45^o) K(0^o)
2	K(0^o) K(45^o) K(45^o) C(0^o) C(45^o) C(0^o) K(45^o) K(0^o)
3	K(0^o) K(45^o) K(0^o) C(45^o) C(0^o) K(45^o) C(45^o) K(0^o)
4	K(0^o) K(45^o) K(45^o) K(0^o) K(0^o) K(45^o) K(45^o) K(0^o)
5	K(0^o) C(45^o) K(0^o) C(45^o) K(0^o) C(45^o) K(0^o) C(45^o)

3. MEASUREMENTS AND RESULTS

The tribological behavior and the wear behavior 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).

In both cases two situations were taken into account: parallel sliding counter-face with the sliding velocity parallel with the yarn tows of materials' first layer and perpendicular sliding counter-face with the sliding velocity perpendicular on yarn tows of materials' first layer.

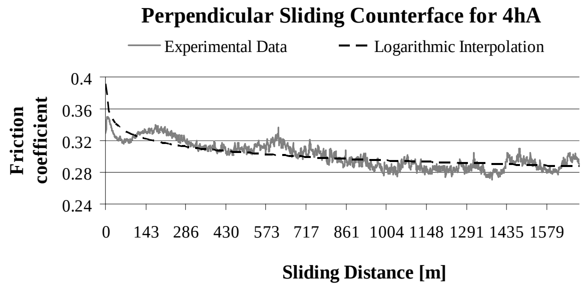

Figure 1. Friction coefficient of 4hA material

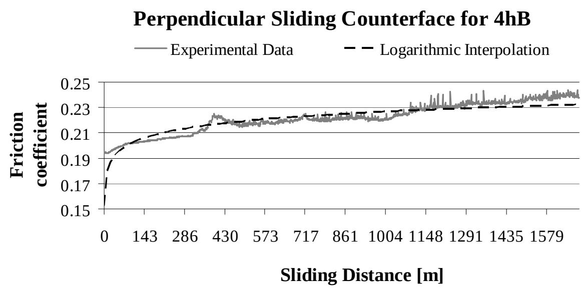

Figure 2. Friction coefficient of 4hB material

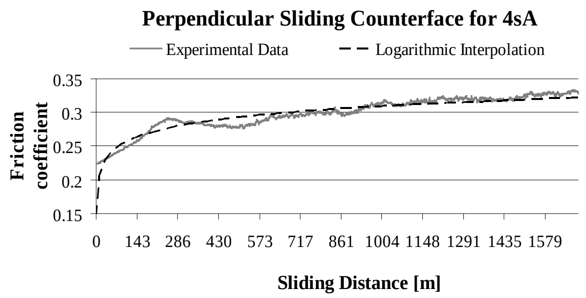

Figure 3. Friction coefficient of 4sA material

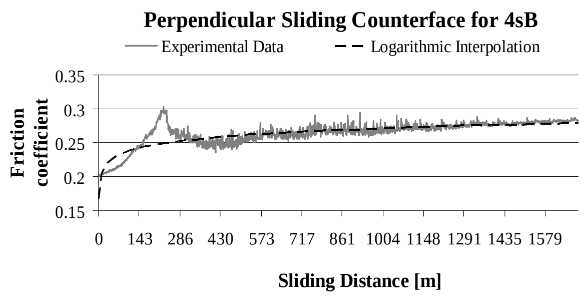

Figure 4. Friction coefficient of 4sB material

From fiber concentration point of view all the materials lie between 100% carbon fiber (4_A) and 50% carbon fiber and 50% aramide fiber (4_B) while from fiber orientation point of view all the materials are identical having 50% fibers perpendicular on the disk and 50% fibers oriented at $\pm 45^{o}$ reported to the disk surface. Materials tribological behavior lies between 4_A and 4_B behavior. In Fig. 1, 3, 5, 7 friction coefficient for 4_A on steel disk with smooth variation during test due to the small fragments of carbon fiber which are acting as dry lubricant. The 4_A represents an extreme being realized only from carbon fiber fabric as reinforcement (100% carbon fiber).

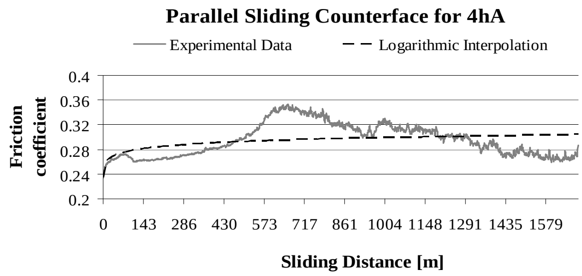

Figure 5. Friction coefficient of 4hA material

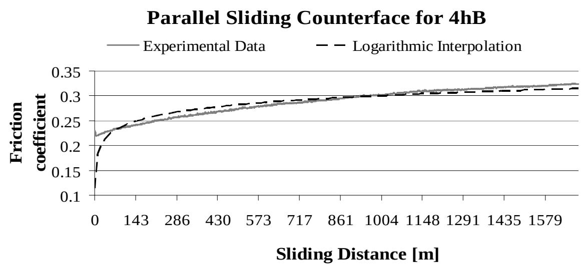

Figure 6. Friction coefficient of 4hB material

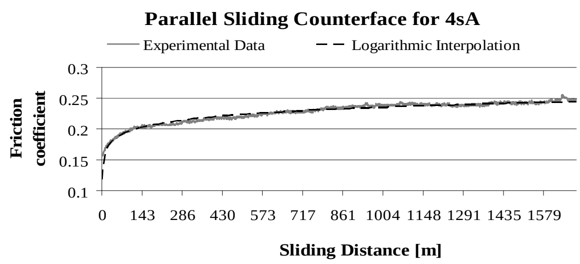

Figure 7. Friction coefficient of 4sA material

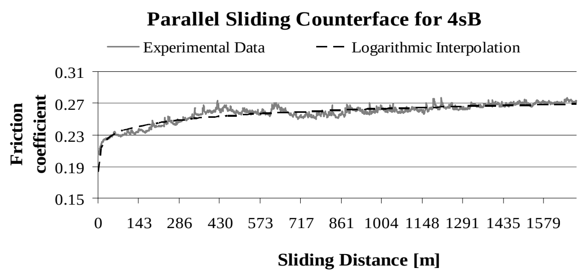

Figure 8. Friction coefficient of 4sB material

In the same figures it might be noticed that the curve realized from data acquisition shows relative flat peaks corresponding to matrix and fibers breaking. The small pieces of matrix are cutting the carbon fibers easier than aramide fibers which are more resistant leading to sharp peaks as it might be noticed in Fig. 2, 4, 6, 8. The 4_B materials are reinforced with 50% carbon fibers and 50% aramide fibers and show the lowest value of friction coefficient both on perpendicular sliding and parallel sliding due to the properties of aramide fibers. Also it is noticeable that in all the data curves these materials show sharp peaks corresponding to aramide fibers extraction from tows.

All the tested sample were extracted from initial plates of materials such as their edges are parallel with warp tows (the length of friction sample) and weft tows (the width of friction sample) of the first fabric layer (Table 1 and Table 2) such as at the contact with the disk – in the case of perpendicular sliding tests – there are 25% fibers from yarn tows of first layer and from the ones with the same orientation (0^o) - both perpendicular on disk and on sliding direction; 25% fibers from fill tows of first layer and from the ones with the same orientation - parallel with the disk and perpendicular on sliding direction); 50% fibers from yarn and fill tows of fabric layers oriented at (45^o) - being oriented at ($+45^o$) or ($–45^o$) relatively to disk and perpendicular on sliding direction. The last ones are ensuring the dry lubricant. Due their position they are breaking first unlike the fill tow fibers which are taking the interaction on their length. In the case of 4_B material the amount of each fiber is the same so in above described positions there will exist both carbon and aramide fibers with the last ones more resistant and leading to a lower friction coefficient. The aramide fibers are not chopped during the tests but they are separated from tows and remain on the disk (the ones from fill tows) or are pulled out from matrix.

In case of parallel sliding tests (Fig. 5-8) once again the behavior might be explained by fibers' positions relative to the disk and to sliding direction [8 – 11].

The three positions of tows in this case are: warp tows perpendicular on disk and perpendicular on sliding direction (but in this situation their width is parallel with sliding velocity while in previous case their width was perpendicular on sliding velocity); weft tows are parallel to the disk and parallel to sliding direction (their length is on sliding direction); inclined tows are oriented at ($\pm 45^o$) relative to disk and ($\pm 45^o$) relative to sliding direction. In the perpendicular sliding case all the fibers are exposed to interaction leading to a significant amount of chopped fibers acting as lubricant (in the case of perpendicular sliding the friction coefficient is decreasing for carbon fiber 100% and is increasing for 50% carbon fiber – 50% aramide fiber due to the resistance of last ones). In the case of parallel sliding there are fibers which are not affected (the warp tows) and their friction with the disk is lubricated by carbon fiber small pieces and frictional behavior of materials might be identical.

Regarding the friction wear rate it might be noticed that highest values for perpendicular sliding are reached for 4hA and 5sB in the first case due to the carbon fibers which are fragile and are cut by the matrix pieces becoming the dry lubricant while in the case of 5sB material the behavior might be explained by the fact that having all the mixed fabric layers at 0^o and all the carbon fibers layers at 45^o the amount of dry lubricant is low the friction involves a large number of aramide fibers which are milled by the abrasive particles (ferrite, Wolfram carbide) from matrix pieces.

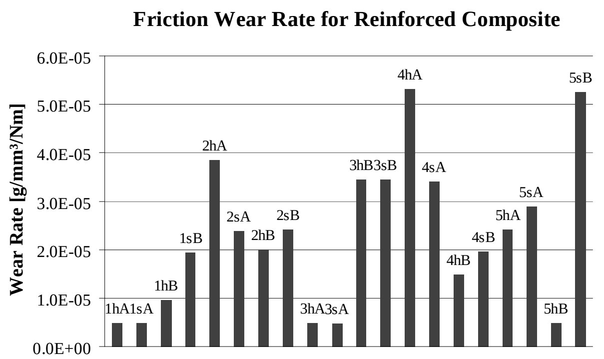

Figure 9. Friction wear rate – perpendicular sliding

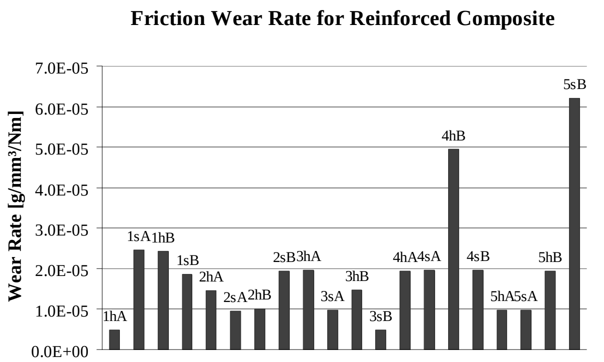

Figure 10. Friction wear rate – parallel sliding

Another aspect might be noticed analyzing both above figures namely: the materials having compact structures (sequences of two or three layers of same fabric) have almost the same behavior both for homogenous matrix and for stratified matrix in both sliding positions.

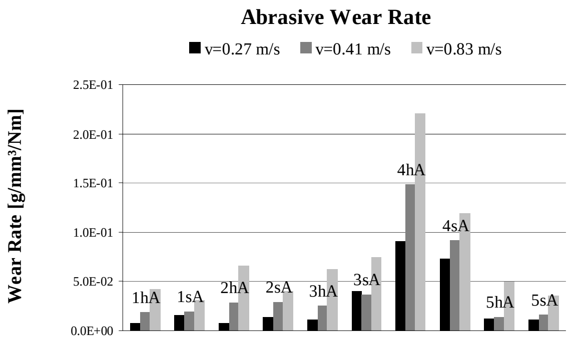

Figure 11. Abrasive wear rate, A materials - perpendicular

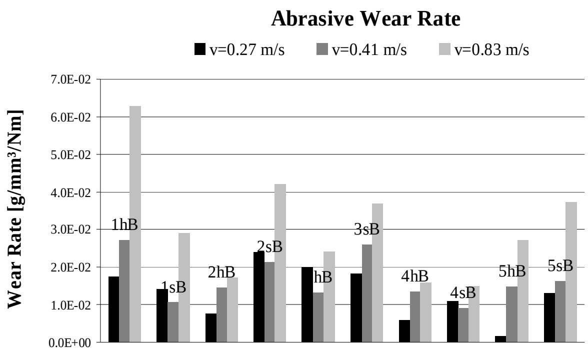

Figure 12. Abrasive wear rate, B materials - perpendicular

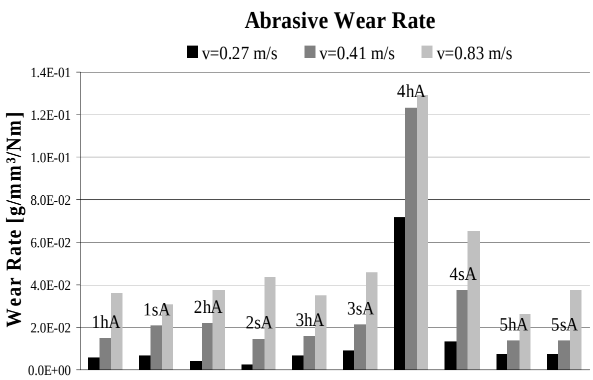

Figure 13. Abrasive wear rate, A materials - parallel

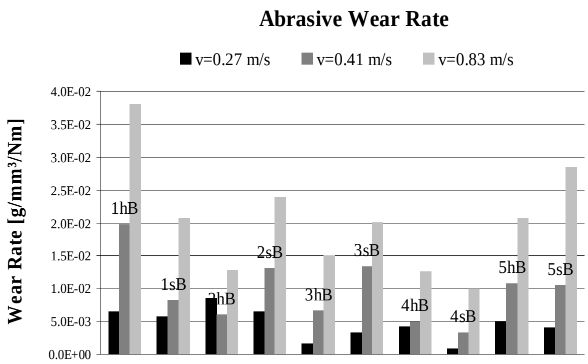

Figure 14. Abrasive wear rate, B materials – parallel

In the case of abrasive tests (Figures 11 – 14) the wear rate measurements were realized at three different values of sliding speed and as expected the wear rate directly depends on the sliding speed.

As in the case of friction wear rate the position of fibers relative to the disk are important to explain the behavior of materials. The aramide fibers are not milled at the abrasive contact but they are pulled out from matrix together with attached pieces of matrix leading to a high weight loss and as consequence to a higher wear rate.

For all the materials it seems that for stratified matrix ensures a lower wear rate both for perpendicular and parallel sliding but the B materials still show lower values.

4. CONCLUSIONS

The friction and abrasive behavior of stratified composites had been analyzed in the geometry of pin-on-disk with pin made of studied material and with steel disk or abrasive disk. The results emphasize the role of aramide fibers on increasing the wear resistance of materials while the graphite particles appearing from carbon fibers breaking acts as dry lubricant. The most balanced materials regarding friction coefficient, friction wear rate and abrasive wear rate seems to be the ones with 75% carbon fibers and 25% aramide fibers with symmetrical distribution of fabric layers.

Further studies have to be carried out to investigate the third direction of sliding – the one in which the fabric layer is parallel with the disk in order to get valuable information to design a stratified structure with improved tribological and wear properties on all the directions.

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] Tsou, A.H., Waddell, W.H., Fillers, in Mark, H.F. (ed), *Encyclopedia of Polymer Science and Technology*, John Wiley & Sons, Inc., vol. 10, pp. 1 – 20, ISBN: 978-0-471-27507-7, 2004.

[3] Lu, D., Luo, S., Wong, C.P., Conductive Polymer Composites, in Mark, H.F. (ed), *Encyclopedia of Polymer Science and Technology*, John Wiley & Sons, Inc., vol. 5, pp. 653 – 697, ISBN: 978-0-471-27507-7, 2004.

[4] Lau, A.K.T., Lu, J., Varadan, V.K., Chang, F.K., Tu, J.P., Lam, P.M.: *Multi-functional Materials and Structures*, Advanced Materials Research, vol. 47-50, at http://www.ttp.net/0-87849-378-6.html, 2008.

[5] Winey, I. Karen, Vaia, A. R. (eds): *Polymer Nanocomposites*, MRS Bulletin, Vol. 32. pp. 314 – 322, 2007.

[6] Ciricumaru, A. *et al*.: *Thermo-mechanical and electrical properties of high filled epoxy composites*, EUROMAT Galsgow, Scotland, 2009.

[7] Circiumaru, A., Birsan I.-G, Bria, V.: *Postolache*, I., Clay/Epoxy Composites, in The Annals of „Dunarea de Jos” University of Galati, Fascicle VIII, Tribology, year XV, ISSN 1221-4590, 2009

[8] 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.

[9] 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.

[10] 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.