

# A study of friction wear behaviour of nano-ferrite modified epoxy resins

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**Abstract.** Ferrites are generally used to obtain soft magnets for domestic or industrial applications but their use in this direction had generated an increasing interest in modifying the polymer properties by dispersing in their volume certain amounts of these ceramic compounds. The current study focused friction wear behaviour induced by the presence of nano-sized strontium ferrite and barium ferrite in an epoxy matrix. The wear behaviour of nanoferrite modified epoxy resins tests were conducted on a pin-on-disc geometry. Three types of epoxy resins had been used with 5% weight ratio of each type of ferrite and 10% weight ratio when both ferrites were used.

## 1. Introduction

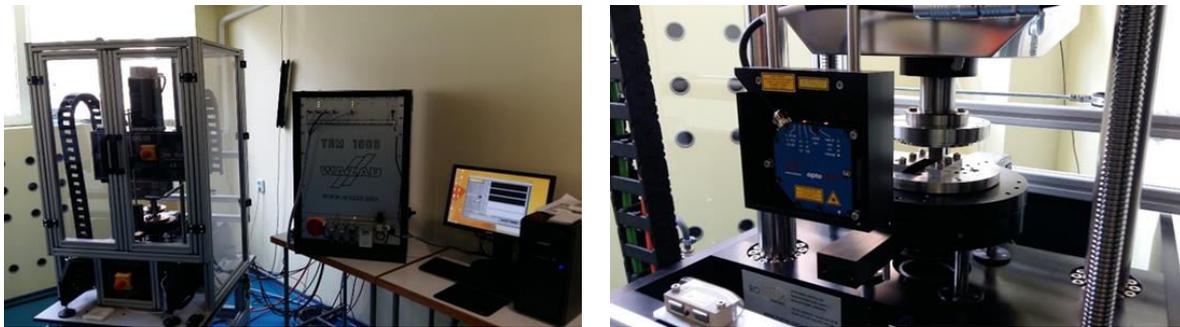
In recent years one of the main classes of high performance engineering materials, next to metals and alloys, ceramics and polymeric materials are composite materials. These engineering materials are prepared from minimum two separate substances [1]. Composite materials, one of the most rapidly growing classes of materials, are being used increasingly for tribological applications [2]. However, because the polymer matrix must withstand high mechanical and tribological loads, it is usually reinforced with fillers. Nano-scale materials have attracted much attention recently due to many unusual predicted properties [3]. Magnetite and ferrite materials have been widely used as magnetic layers on polyethylene terephthalate (PET) film, paper or metallic substrate [4]. Ferrites have high dielectric constants which makes them very useful for microwave applications. They remain the best magnetic material and cannot be replaced by any other magnetic element because they are inexpensive, more stable and have a wide range of technological applications in transformer cores, high quality filters, radio wave circuits and operating devices [5]. Strontium ferrite ( $\text{SrFe}_{12}\text{O}_{19}$ ), as an important member of hexaferrites, has higher saturation magnetization, coercivity and the Curie temperature because of high magnetocrystalline anisotropy compared to barium ferrite ( $\text{BaFe}_{12}\text{O}_{19}$ ) [6], [7], [8].

Wear is defined [9] as the damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and contacting substance or substances [10]. In this work, an attempt has been made to obtain the friction wear behaviour of nanoferrite modified epoxy resins under various conditions such as external load and sliding distances of 1000 m. In a review of some of the literature concerning friction wear behaviour of nanoferrite modified epoxy resins have not been found. Therefore, an evaluation of the tribological characteristics of nanoferrite modified epoxy resins under various sliding conditions is needed.



## 2. Experimental procedure

Polymer matrix consisting of epoxy resin bisphenol A diglycidyl ether-based were used (code H representing resin epoxy - 50% bisphenol A diglycidyl ether, code C representing resin epoxy - 75% bisphenol A diglycidyl ether and code E (Epiphen DE 4020) representing resin epoxy - 78% bisphenol A diglycidyl ether). Strontium ferrite and barium ferrite obtained from Sigma-Aldrich producer and they have been used as additives. All these systems were modified by mixing the main component (the resin) with 5% weight ratio of each type of ferrite and 10% for the materials using both ferrites. Then the mixture of nano-ferrite modified epoxy resins was mechanically mixed at 200 rotations /min for 15 min, at room temperature. After the mixtures were uniformed the right amount of hardener was stirred for ten minutes to ensure the homogeneity. The pre-polymer mixtures were moulded in cylindrical moulds 8 mm diameter and 200 mm height. After 24 hours of polymerization, all the samples were extracted from moulds and the recommended thermal treatment was applied for 8 h at 60°C.



**Figure 1.** Testing device, tribometer TRM 1000 (Wazau®, Germany)

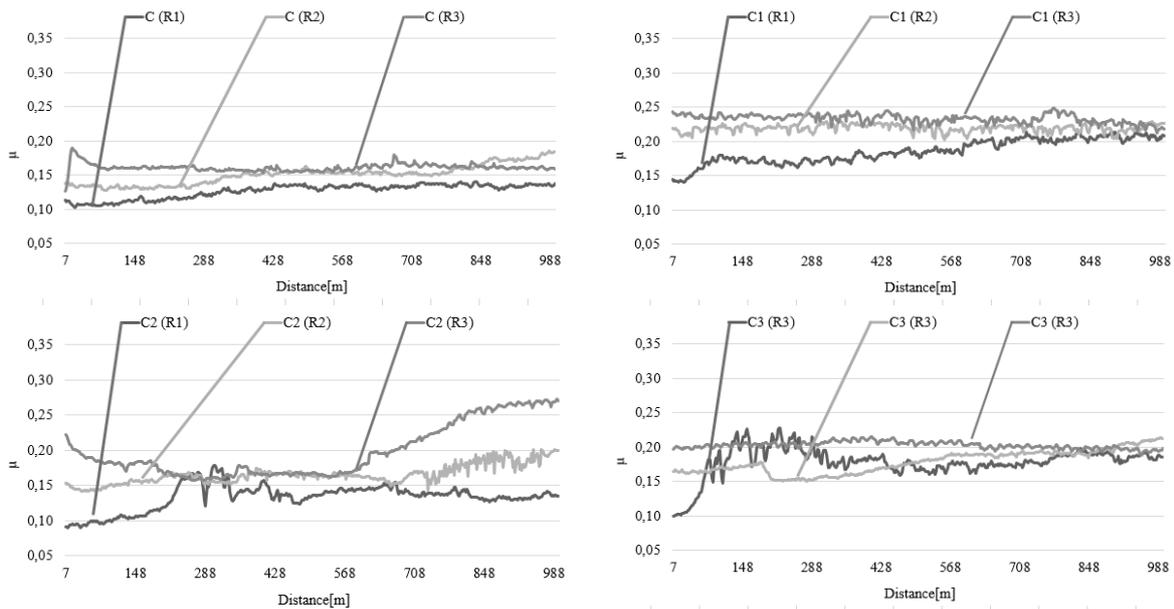
Tribological characterization was performed using TRM 1000 tribometer (Wazau®, Germany) on tribological test module dedicated to block-on-disk tests that allows setting and viewing of control and measured parameters: test rotational speed, loading force, friction and wear coefficients. The block is made of the material to be analyzed and is secured in the support of the machine, positioned perpendicularly to the disk (figure 1). Tribological tests for all types of composite were performed under dry conditions on a disk made of steel with outside diameter of 110 mm and 10 mm thickness. The length was set at 1000 meters and speed test between 0.66 [m/s] and 2 [m/s]. Testing regimes have been established as follows:

- R1: speed testing of 0.66 [m / s], load of 15N, distance 1000 meters.
- R2: speed testing of 1 [m / s], load of 10N, distance of 1000 meters.
- R3: speed testing of 2 [m / s], load of 5N, distance of 1000 meters.

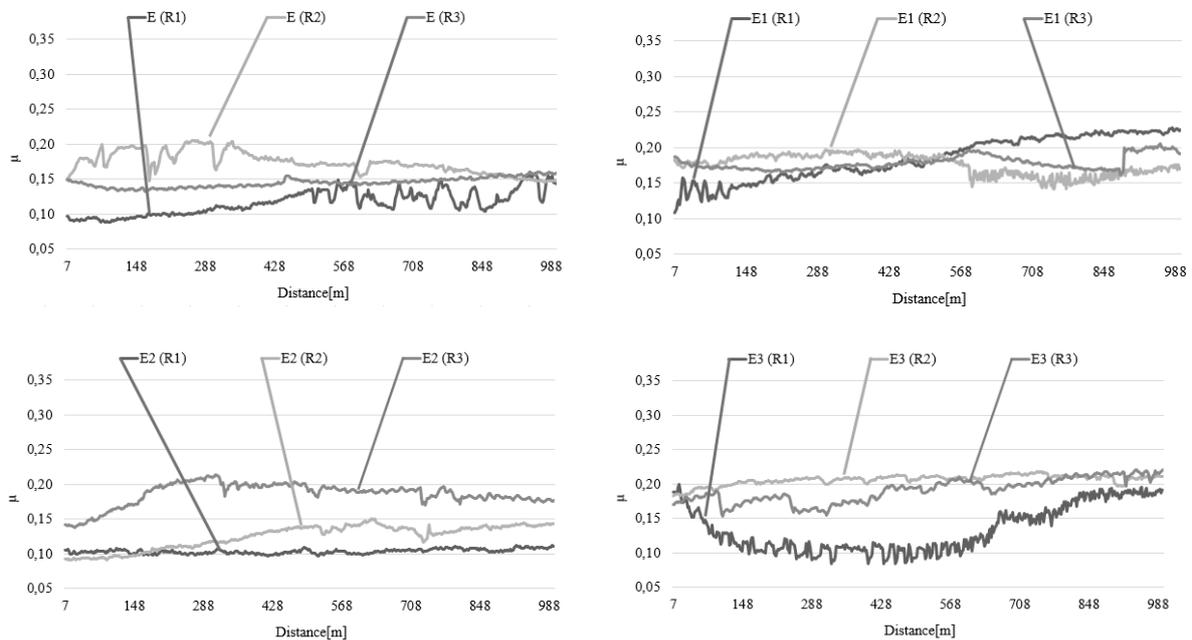
## 3. Results and discussion

The resins and the code designation for the test materials made from them are as follows: C1, E1, H1- epoxy resin with 5g barium ferrite; C2, E2, H2- epoxy resin with 5g strontium ferrite; C3, E3, H3- epoxy resin with 5g strontium and 5g barium ferrite.

Figure 2 shows friction coefficient of all samples containing C epoxy resin and the three mentioned amounts of ferrites for all three applied forces during sliding distance. The results indicate that for the same concentration of barium ferrite the friction coefficient it remains nearly constant for any tested forces. At low concentrations of strontium ferrites materials, the behavior is completely atypical to those that contain barium ferrites. At initiation stage of the process achieved friction coefficient values are different for the three regimens studied. The lowest friction coefficient for the initiation stage of the process (running-in period) are observed in the case of the R1. This value increases with decreasing the applied force because the friction coefficient is inversely proportional to normal force applied. A very unstable behavior of friction is for C2 material who present some oscillations during the tribological test. They are more pronounced in the case of R1 and available until around 500 m of sliding distance. After this distance stable friction coefficient is available until the end of the test.



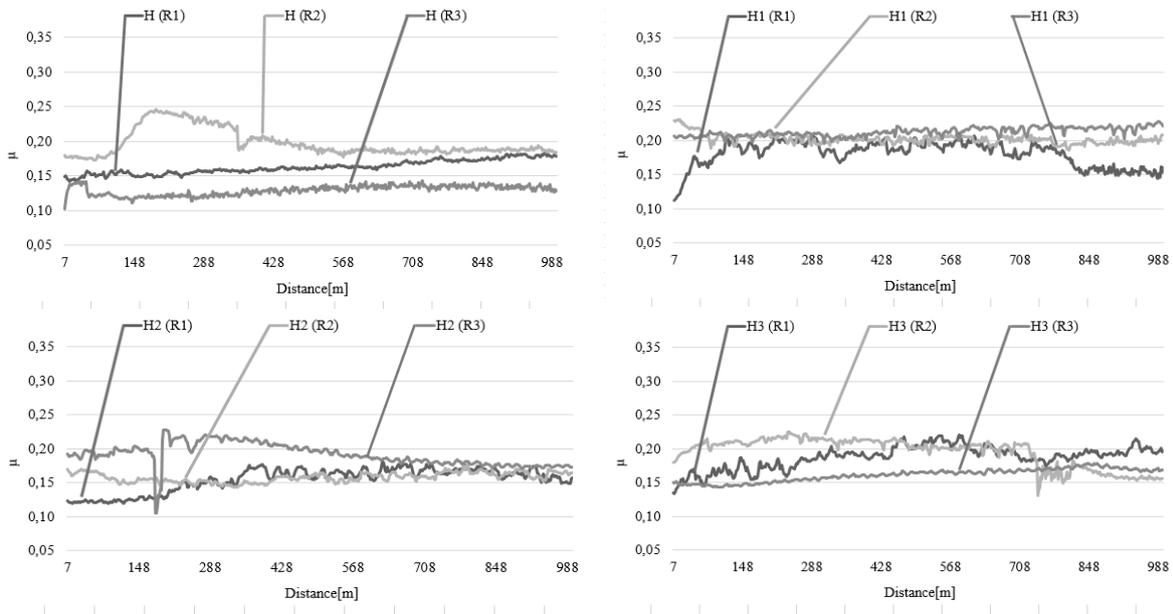
**Figure 2.** Variation with friction coefficient slide distance for C materials.



**Figure 3.** Variation with friction coefficient slide distance for E materials.

For E3 material which contain the two types of additives, can notice a significant decrease in the friction coefficient value in the first part of the test, compared to unmodified epoxy system. Small concentration of barium ferrite and strontium ferrite in E epoxy resin leads to significant increase of friction coefficient see (figure 3). The same as C type materials, the lowest values of friction coefficient for E type materials is for R1 working regime. The friction coefficient increases with decreasing the applied force. The highest value of the friction coefficient is registered for R2 regime. To some extent the evolution of friction coefficient over the entire sliding distance is relatively stable,

except E3 material for R1 regime, where a noticeable decrease of friction coefficient over the entire distance is notice due to pulling phenomenon on the contact surface of an amount of material. Oscillations of friction coefficient appear at all materials but they are less obvious for materials containing small amounts of ferrite nanoparticles. These oscillations are caused by the fact that some additives show a higher hardness resulting in easy removal of nanoparticles of contact surface.



**Figure 4.** Variation with friction coefficient slide distance for H materials.

For H epoxy resin (figure 4) we can say that the friction coefficients are almost the same throughout the range 0.10 – 0.20. The modified materials behave identically, except H1 material friction coefficient values which remain almost constant throughout the test. The lowest values of the friction coefficient in the first phase are observed in R1 regime, after which they showed a slight upward trend, followed by stabilization until the end of the test.

Table 1 shows the degree of wear values calculated for each component. These values were determined using the following formula:

$$W_s = \frac{\Delta m}{F \cdot L}$$

where  $\Delta m$  weight loss; F applied force; L sliding distance of 1000 m.

C-type materials testing regime had a significant influence on the wear behavior (table 1). The lowest rate of wear was obtained for C1 and C2 materials. The amount of additive has a significant influence on the tribological behavior. C3 material wear rate was similar in the case of R2 without additives and increased for R1 and R3. By adding an amount of 5% additive to improve the tribological properties of the C1 and C2 materials, while the amount of additive up to 10% resulted in degradation of the wear properties.

E-type materials testing regime had a significant influence on the wear behavior. The lowest rate of wear was obtained for E1 and E2 materials. The amount of additive has a significant influence on the wear behavior. By adding an amount of 5% additive, the tribological properties of E1 and E2 materials improves while the amount of additive up to 10% resulted in degradation of the wear properties of the E3 material.

For H-type materials the highest wear rate is for H3 material for R2 regime. For the others materials wear rate was very low, which makes the conclusion that regardless of the amount and type of used additive tribological properties are improved.

**Table 1.** Wear rate of epoxy matrix materials

Wear rate x 10 <sup>-6</sup> [g/N·m]					
Materials	Values	Materials	Values	Materials	Values
C (R1)	4.340	E (R1)	1.080	HT (R1)	4.200
C (R2)	1.510	E (R2)	0.450	HT (R2)	1.770
C (R3)	1.380	E (R3)	0.340	HT (R3)	1.080
C1 (R1)	0.580	E1 (R1)	6.800	HT1 (R1)	2.440
C1 (R2)	0.100	E1 (R2)	3.000	HT1 (R2)	1.300
C1 (R3)	0.140	E1 (R3)	2.000	HT1 (R3)	0.880
C2 (R1)	0,300	E2 (R1)	0.400	HT2 (R1)	5.000
C2 (R2)	0,270	E2 (R2)	0.200	HT2 (R2)	3.700
C2 (R3)	0,207	E2 (R3)	0.127	HT2 (R3)	1.270
C3 (R1)	2.520	E3 (R1)	5.000	HT3 (R1)	1.200
C3 (R2)	1.590	E3 (R2)	3.700	HT3 (R2)	0.800
C3 (R3)	0.867	E3 (R3)	1.270	HT3 (R3)	0.487

#### 4. Conclusion

The key step of the present research and of materials formation was to choose the fillers that could be used to modify the resin basic properties. The decision regarding the use of the two above mentioned ferrites was imposed by their flexible way of use and the novelty of their usage to form epoxy composites. As a conclusion we can say that the best used filler is strontium ferrite, but this is only for C resin. This significantly influences the friction coefficient of C resin by the fact that it maintains it nearly constant for the whole distance for all tested forces.

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