Electrical Conductivity of Fabric Based Filled Epoxy Composites

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One major disadvantage of polymeric composites is their low electrical conductivity. This is a trail-and-error study regarding PMC's conductivity modification by filling the polymer matrix with various powders. Clay, CNT and Ferrites were used as fillers, Epoxy Epiphen RE 4020 with Epiphen DE 4020 as hardener was used as matrix and simple type fabric of alternate kevlar and carbon untwisted tows was used as reinforcement. The mechanical properties of a PMC are improved by using reinforcements so it is naturally to ask what is happening when a reinforced composite is formed with filled polymer matrix. Plate samples were formed and their electrical conductivity was evaluated. The filler's concentration was considered and information was used in order to form the reinforced composite with the highest conductivity.

Keywords: CNT, Ferrite, Clay, Epoxy, Fiber Fabric Reinforcement

The most important feature of a composite material is given by the fact that such a material shows properties which are not characteristic for components. Many properties of polymeric composites are results of forming technique and sometimes consequences of hazard. However the most important aim of nowadays researches is to find a way to change the basic properties of polymeric composites to make them more and more reliable in their competition against metals. Fact is that, generally, it is accepted that the properties of formed composites depend on nature and quality of interface [1, 2] (in the case of bi-component composites such as filled or fiber-reinforced composites). In the case of multi-component composites the problem becomes more complicated [3]. It is obvious that using filled polymer instead of polymer as composite's matrix there will be necessary to take into account, at least, two interfaces. As it is possible to use two or more types of fibers to control mechanical properties of a reinforced PMC it is possible also to fill the matrix with two or more fillers to improve its thermal or electrical properties. The scientists are looking for both new techniques of testing and mathematical models able to describe the properties of composites [4-8]. Since the mechanical properties of a PMC can be deigned through design of the reinforcement it is interesting to investigate the ways of changing the basic properties of the polymer by filling it with two or more powders. Such a type of attempt is also the cheapest, of course, the main role is played by filler particles dimensions but the nature of the powder is important [9]. Usually the electrical conductivity (as well as dielectric permittivity, magnetic permeability, thermal conductivity, specific heat and coefficient of thermal expansion) for a bicomponent composite are given by mixing rule. In the case of a multi-component composite the mixing rule has to be used many times. It is very difficult to describe what really happens when the measurement signal is applied but is possible to measure the macroscopic effect. That is why this study is taking into account the evaluation of electrical conductivity for different values of fillers concentrations in order to form, at least, a reinforced composite with better conductivity.

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Experimental part

Materials and methods

One of the most used fillers in last studies is the clay because by adding this ingredient to the polymer it can be obtained a better material from the point of view of fire resistance, thermal conductivity, strength etc. Also adding clay to epoxy it could be noticed that other fillers behavior is improved i.e. the particles do not aggregate such as in the pure epoxy resin when the filler concentration is above 1% and the dispersion is more uniform and mechanical properties are improved. As the shape and dimensions of filler particles are important [10-12] combination of CNT and ferrite were proved as fillers. Samples of epoxy resin, clay added resin, clay added CNT filled epoxy and clay added ferrite were formed as basics composites (for each one three samples with different thickness were obtained). Other samples were formed using the three fillers and varying the third one's concentration. On the basis of evaluated best conductivity reinforced materials were formed.

Reinforced materials are formed through a hybrid technique consisting in layer by layer setting of filled resin imbued sheets of fabric in a glass mould followed by extraction of gases using the rubber bag method. Because of its instability during the molding the fabric was prepared by spraying a thin film of carbon black and clay added rubber and a thin film of carbon black and clay filled resin. The treatment had three aims: ensuring the stability of fabric during cutting and manipulation, ensuring an elastic interface between fibers and matrix (to enable a smooth stress transfer between the two components) and ensuring a relative conducting interface between fibers and matrix.

The reinforcement is made of 15 sheets of fabric consisting of alternate untwisted tows of kevlar and carbon fibers as fill and yarn. This kind of fabric was chosen due to carbon fiber's mechanical and electrical properties and kevlar fiber's mechanical and thermal properties. The laminar structure of the reinforced composite is $[0^\circ, 45^\circ]_S$ [13] with odd sheets 0° oriented relatively and even sheets 45° oriented relatively to the sample's edges. Each reinforced sample has a fiber volume ratio above 60%. The reinforced material is not really a laminate because of the forming technique. In the case of a laminate the plies are bonded using an adhesive while in above mentioned technique the filled polymer is filling the spaces between fill and yarn tows and polymerize in the entire volume at once. From this point of view the matrix of such material is acting as rigid foam.

The conductivity evaluation is based on method of electrical resistance measurement using an RLC-meter [14, 15] and the four wire technique. Taking into account the electrical properties frequency dependence of such particulate materials the electrical resistance has been measured for two different frequencies of measuring signals. The dimensions and geometry of measuring cell are fitting the technical specifications for a valuable determination. Being measured the electrical resistance the bulk resistivity of the material can be evaluated and, subsequently, the electrical conductivity. All the measurements were performed at the ambient temperature of 25°C and the electrical resistance used values are averaged values of more than 100 determinations. One problem noticed during the measurement is the low instability of reinforced samples due to the fact that inside such a sample there appear lots of small capacitors each one having a certain electric capacity.

Results and discussions

Electrical conductivity of reinforcement was evaluated and its frequency dependence is showed in figure 1. It must be noticed that changing the relative position of the fabric sheets the conductivity may differ because in the most advantageous case there may be obtained carbon fiber bridges between upper and lower faces of the material fact that is leading to a better bulk conductivity of the formed material. The electrical conductivity filled epoxy samples are shown in figure 2 - the highest value corresponds to 0.40% Clay, 0.20% CNT, 0.15% Ferrites filled epoxy (weight ratios), the measurement had been done at 100 kHz. and figure 3 – the highest value corresponds to 0.40% Clay, 0.20% Ferrites, 0.15% CNT filled epoxy (weight ratios), the measurement had been done at 100 kHz. The filled polymer having the best value of electric conductivity was used in order to form reinforced materials and the results are showed in figure 4 - the highest value corresponds to 0.40% Clay, 0.20% Ferrites, 0.20% CNT filled epoxy (weight ratios), the measurement had been done at 100 kHz. In figure 5 are shown the electrical conductivities of the reinforced materials in which instead of clay, talc has been used, in the same concentration - the highest value corresponds to 0.40% Talc, 0.20% Ferrites, 0.20% CNT filled epoxy (weight ratios), the measurement had been done at 100 kHz. Measurements had been carried out for multi-filled epoxy composite and the results are shown in figure 6 (without

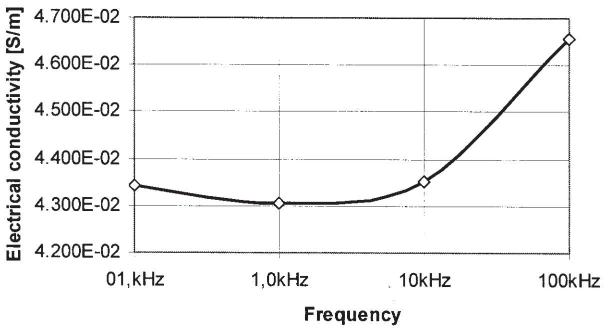

Fig. 1. Electrical conductivity of the reinforcement. The fiber fabric was treated as it is described

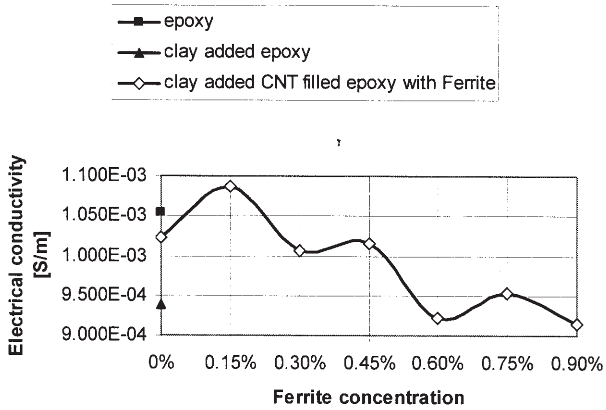

Fig. 2. Electrical conductivity of multi-filled epoxy

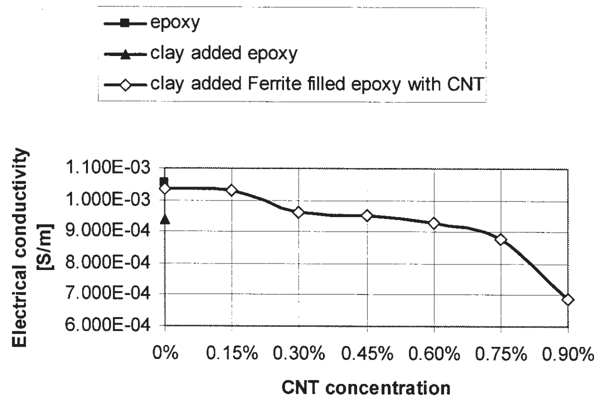

Fig. 3. Electrical conductivity of multi-filled epoxy

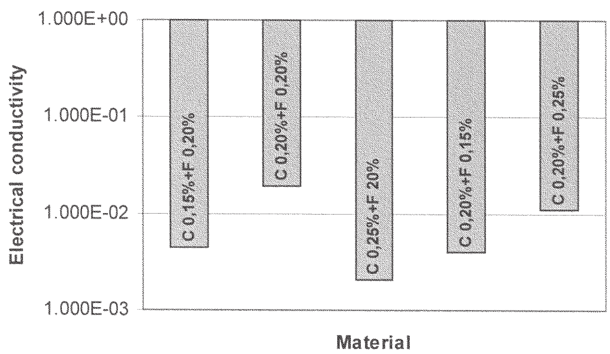

Fig. 4. Electrical conductivity of multi-filled reinforced epoxy (clay)

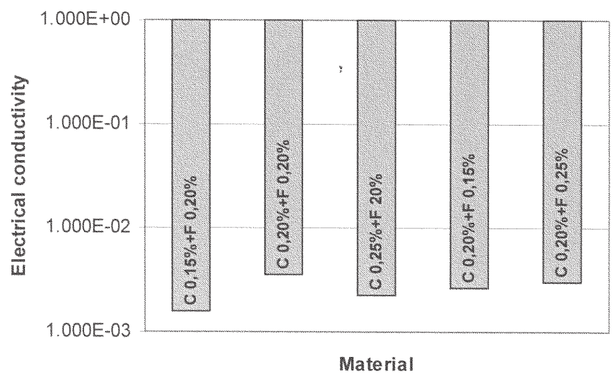

Fig. 5. Electrical conductivity of multi-filled reinforced epoxy (talc)

clay - each filler has a 0.20% weight ratio in the formed material.) and figure 7 (with clay - the clay weight ratio is 0.20% and each filler has the same ratio; for the last material the powder amount is of 0.80%) and for reinforced composites having multi-filled polymer matrix figure 8 (the reinforced materials were formed using a matrix as

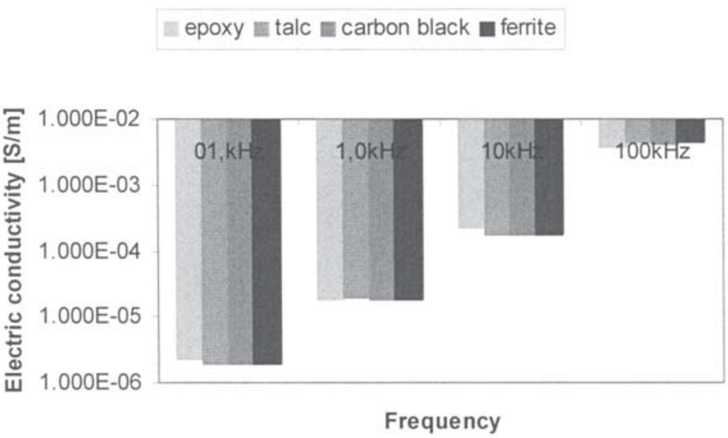

Fig. 6. Electrical conductivity of pure and filled epoxy

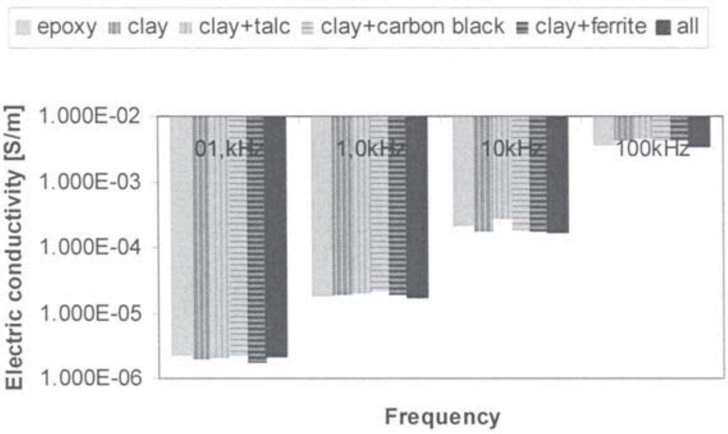

Fig. 7. Electrical conductivity for pure epoxy, clay added epoxy and clay added filled epoxy.

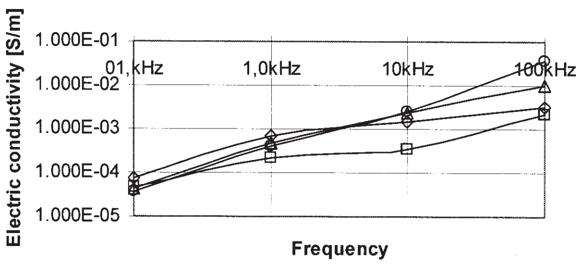

Fig. 8. Electrical conductivity of reinforced pure and filled epoxy

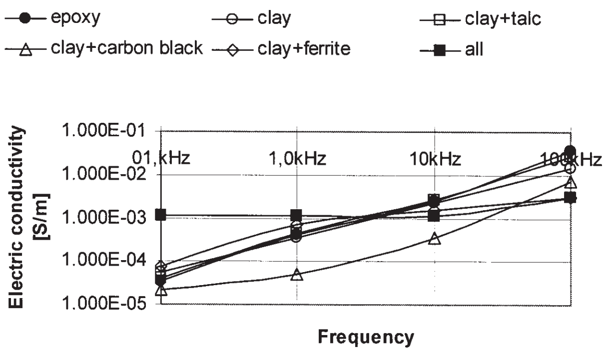

Fig. 9. Electrical conductivity of reinforced multi-filled epoxy

the ones presented in fig. 6.), figure 9 (for each material the matrix is the one show in figure 7.). In the case of filed epoxy due the small amounts of fillers it can be noticed that all the materials have a matrix dominated electro-magnetic behavior while in the case of reinforced filled epoxy the influence of reinforcement is important.

It seems that filling the epoxy resin with small amounts of various powders it is possible to change the electrical conductivity of the matrix. Forming reinforced materials with this type of matrix the electric conductivity may be higher. It is possible that using clay or talc added epoxy the amounts of CNT and Ferrites could be higher and as consequence the electrical conductivity could be also higher.

Conclusions

Using the above described forming method and combinations of fillers it can be obtained pseudo-laminate composites with the external layers having high conductivity and core layers having, for example, high magnetic properties. Also seems to be possible to create a stratified material having depth depending properties on the basis of the same polymer.

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