Flexural properties of copper-filled carbon fiber reinforced polymers

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Abstract. The paper demonstrates the results of flexural tests of carbon fiber reinforced polymers with the addition of copper microfillers with content varying from 2.5 to 10 wt%. It is shown that the implemented dispersive reinforcement leads to the increase of flexural strength on composites by 9%, while the elastic modulus remains the same. The reasons for the advancement in mechanical properties are discussed.

1. Introduction

Composite materials become a very important and widely used material in various fields, including but not limited to aerospace, automotive, marine, sport equipment, etc. Structural application of composites is connected to the possibility of adjusting their physical and mechanical properties to the particular area and operational conditions. Nowadays, special attention is paid for the polymers and one of the composites combining high specific strength and good fatigue resistance – carbon fiber reinforced polymers (CFRP). CFRPs due to their superior mechanical properties find their niche in aircrafts structural elements as fuselage, wings and tail. However, the application is limited due to sensitivity to impact damage and delamination. One of the possible ways to increase the desired properties is additional reinforcement of the laminated composite by dispersive nano- or microparticles. In case of aircraft industry, it not only could provide advancement in mechanical characteristics, but potentially could increase the important functional features such as electrical and thermal conductivity.

Addition of carbon fillers are widely reported in different papers and contain some information on mechanical and physical properties. For example, in the published paper [1] it has been shown that composite reinforced by dispersive fillers has higher mechanical properties under tension, compression, bending and fatigue. In the few other articles [2,3], the increase of fracture strength under impact loading has been reported.

The results on metals fillers are less studied – in the following papers the composites were filled with silver [4-5], copper metal spheres [6] and metal coatings [7], which significantly improve functional properties. In [4], silver is used as a coating of carbon fibers which then reinforce the epoxy binder leading to an increase in electrical conductivity by 4 times. In [5], the addition of silver powder increased the thermal conductivity of polypropylene composites by 4 times with 5 vol% powder content and also reduced the coefficient of thermal expansion linearly.

In [7], four coating methods were investigated: (1) hybrid coating based on silver nanoparticles dispersed in a conducting polymer PEDOT: PSS; (2) hybrid coating in the form of silver-coated nanotubes, which was applied to the surface of the composite; (3) A solid metallic coating of the composite with silver and (4) a metallic coating of tin with 10% copper. To test the materials obtained, damage to the substrate during the course of electrical discharges (similar to a lightning strike) was evaluated. Conventional carbon and carbon plastic with foamed copper foil on the surface were taken as base materials. According to the test results, it was found that the foamed copper foil showed the highest protective ability, and the metal coatings (3) and (4) exceeded the hybrid ones (1) and (2).

The most papers describe the effect of metals addition to the electrical properties, while only limited amount of them is devoted to mechanical characteristics. The present paper study the flexural properties of CFRP modified by copper micropowder.

2. Materials and testing technique

The specimens were carbon fiber reinforced polymers (CFRP) with addition of copper microparticles. The lay-up was balanced, symmetric and pseudosotropic: $[0/90;+45/-45]_{4S}$. CFRP components:

- CBX300 biaxial fabrics made of PAN carbon fiber (Mitsubishi Pyrofil TR50S 12K);
- R&G Epoxy L with GL2 hardener;
- copper micropowder with a mean diameter of 50-100 µm.

The resulting thickness of the plates was ~4 mm and the specimens were cut using milling machine. The content of the fillers was varied resulting in the formation of 4 concentration of uCu in the blanks. The compositions tested are summarized in Table 1. The additive concentration is calculated for the total epoxy weight, not for the resulting CFRP.

Two types of 3-point bending tests were utilized in the paper. The first was done according to ASTM D2344 which is aimed at the evaluation of interlaminar shear strength by flexural loading of short-beam specimen. The size of the specimen was 24×8×4 mm and a span length was 16 mm. The second type 3-point bending test was arranged according to ASTM D7264. Five specimens having the sizes of 154×13×4 mm were tested for each composition. The span length of 128 mm resulted in a span-to-thickness ratio of 32:1. The loading rate was equal to 5 mm/min. Flexural strength and modulus were measured after the tests.

The resulted CFRP plates and long-beam bending specimens are presented in Figure 1. The addition of copper slightly changes the color of the originally black epoxy emerging light ochre tint. The higher uCu content the more saturated the tint.

Table 1. Overview of the tested compositions

Additive	Content, wt%	Designation
Non-modified CFRP	0	NM CFRP
uCu	2.5	uCu-2.5
	5	uCu-5.0
	7.5	uCu-7.5
	10	uCu-10

3. Experimental results and discussion

The summary of the results on short-beam flexural tests are demonstrated in Table 2. This test type do not implies the determination of the elastic modulus or strain at break, so the main characteristic being obtained is the interlaminar shear strength. Non-modified epoxy has strength of 50.7 MPa which is common for such composites. The addition of 2.5 and 5 wt% of micro copper powder slightly increases the property up to 51.9 MPa and 51.8 MPa – the percentage growth is +2.5% and +2.3% respectively. The improvement of the interlaminar strength for low copper content is mostly connected with scatter rather than with any physical processes affecting the results. While 7.5 wt% gives some potential and demonstrates the advancement in mechanical characteristic to 55.8 MPa (+8.5%). However, the further increase of the content leads to the reduction of the strength (53.7 MPa and +5.9% compared to the NM CFRP).

a b

Figure 1. Images of the uCu-7.5 blank (a) and
uCu-100 specimens for ASTM D7264 testing (b)

Of course, the changes are minor but they obviously take place. The authors attribute the increase in the interlaminar properties to the addition of the cooper micropowder. The micro particles are involved in the epoxy deformation process as obstacles which strength the matrix and increase its properties. At the same time the adhesion between epoxy and copper could not be high enough because it is mostly mechanical, so it could not provide the great increase and after some additive concentration the lack of chemical adhesion will become a major effect which results in decrease of the mechanical characteristics.

Table 2. Results of short-beam bending test

Material	Interlaminar shear strength, MPa
NM CFRP	50.7±4.1
uCu-2.5	51.9±3.6 (**+2.5%**)
uCu-5	51.8±3.6 (**+2.3%**)
uCu-7.5	55.8±3.6 (**+8.5%**)
uCu-10	53.7±2.8 (**+5.9%**)

The results of for the second type of bending test – long-beam flexural – are presented in the form of plot in figure 2. At the upper part of the diagram the changes in elastic modulus of CFRP versus uCu content is demonstrated, the lower part is for combined graph on flexural strength and strain at break.

The elastic modulus of non-modified CFRP is 53.7 GPa and addition of copper micropowder do not change it so much. The moduli have values of 54.3, 53.1, 52.5 and 53.0 GPa for 2.5, 5, 7.5 and 10 wt% of micro Cu. So the elastic modulus is not affected by the addition of copper powder in long-beam flexural tests. However, the strength and elongation at break were increased. The first changed from 650 MPa to 710 MPa, which is approximately 9% of the increase. Subsequently, the strain at break become higher: simply the specimen could withstand higher deformation due to higher strength while the modulus is the same.

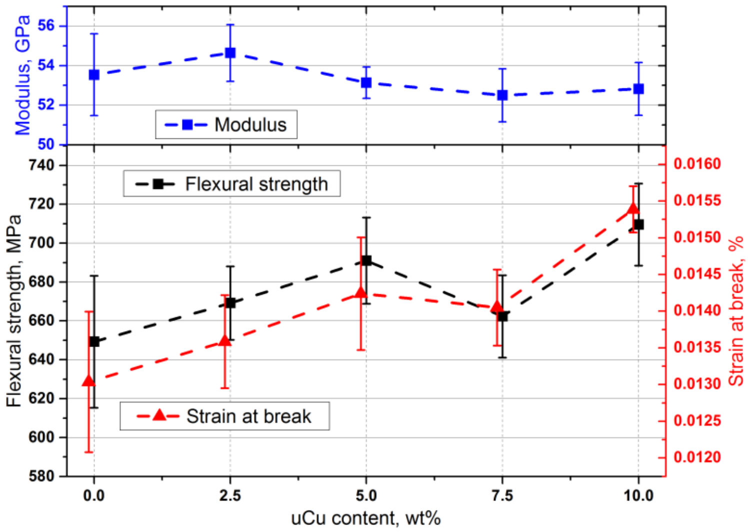

Figure 2. Flexural properties obtained in long-beam bending test

4. Conclusion

The experimental results obtained on the effect of copper micropowder addition into epoxy-based CFRP lead to the following conclusions:

- Copper microfiller increase the strength of the CFRP in case of short-beam and long-beam flexural tests – the approximate enhance reach 9% for both test types.
- The flexural modulus remains the same and it is not affected by the addition of copper powder.
- The assumed reason for the observed effects is the analogous to doping strengthening in metals when the copper particles play a role of obstacles to the development of failure at low content. For higher amount of copper due to the lack of chemical adhesion between powder and epoxy the filler become a concentrator for the crack initiation and mechanical properties reduce.

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