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Short Communication

Influence of Nickel Electrodeposition on Tensile Strength of Carbon Fibre Tow Material

Boguslaw Pierozynski[*], *Tomasz Mikolajczyk and Marcin Turemko*

Department of Chemistry, Faculty of Environmental Management and Agriculture, University of Warmia and Mazury in Olsztyn, Plac Lodzki 4, 10-957 Olsztyn, Poland
[*]E-mail: bogpierozynski@yahoo.ca

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Carbon fibre (CF) and nickel-coated carbon fibre (NiCCF) materials find numerous applications within modern industry, including: telecommunication, automotive and military sectors. These materials are typically used as electrically conductive fillers in various thermoplastics to enhance both mechanical and electrical properties of such-produced thermoplastic composites. This paper reports on the problem of tensile strength reduction, a result of nickel electrodeposition (at various Ni loading levels) onto a 12K carbon fibre tow substrate.

Keywords: carbon fibre; nickel-coated carbon fibre; CF; NiCCF; nickel electrodeposition; tensile strength.

1. INTRODUCTION

One of the key applications for carbon fibre (CF) and nickel-coated carbon fibre (NiCCF) materials is their utilization in electrostatic dissipation (ESD) and electromagnetic interference (EMI) shielding techniques. These technologies are especially important for automotive, telecommunication and military industry markets [1-6]. Numerous EMI/ESD technologies utilize conductive thermoplastic composites, which may contain a variety of electrically conductive fillers, including: carbon fibre, metal fibre and metal-coated carbon fibre materials. Electrically conductive thermoplastics are typically produced through an injection-moulding process, where a conductive filler is directly introduced to the moulding machine, usually in a chopped form. Apparently, both electrical and mechanical properties of such fillers are of significant importance for such-produced thermoplastic composites. This work is primarily concerned with significant reduction of tensile strength parameter for nickel-coated carbon fibre composites, as compared to that of their 12K substrate CF tow material.

2. EXPERIMENTAL

A single-filament tensile strength testing method, based on ISO 11566 standard [7] was used to carry-out tensile strength measurements in this work. The above method requires the fibre strand to be secured to a piece of squared paper using resin-based glue, with the center of the paper being cut-out to form a 1.3 cm gap (see Fig. 1 below). After mounting the paper with the fibre into the tensile machine, the paper is cut into two halves and equipment is zeroed for the total weight of the paper and the CF filament. Then, tensile equipment pulls the sample, until it breaks, while the load (N) is being continuously measured.

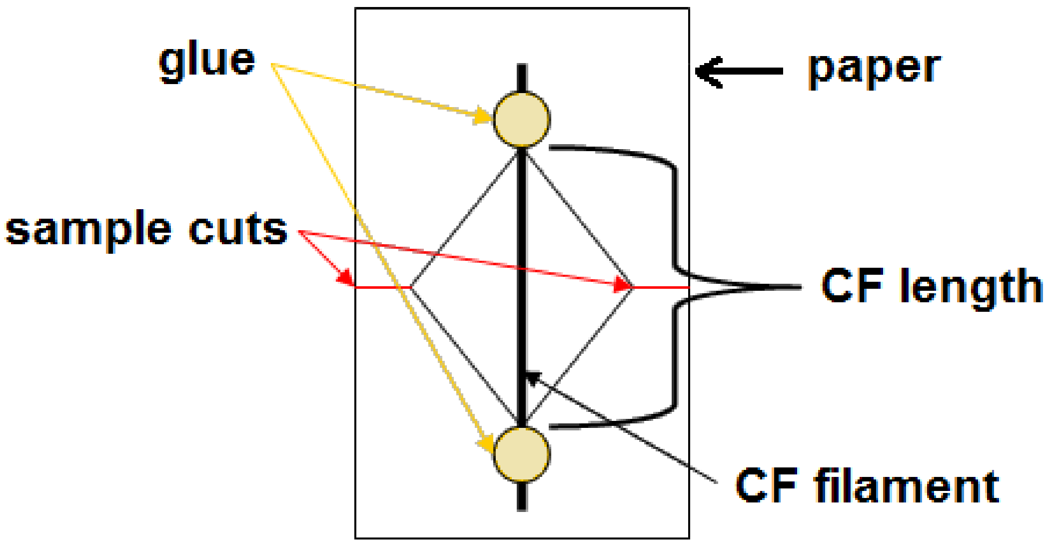

Figure 1. Arrangement of single-filament CF sample for tensile strength measurements.

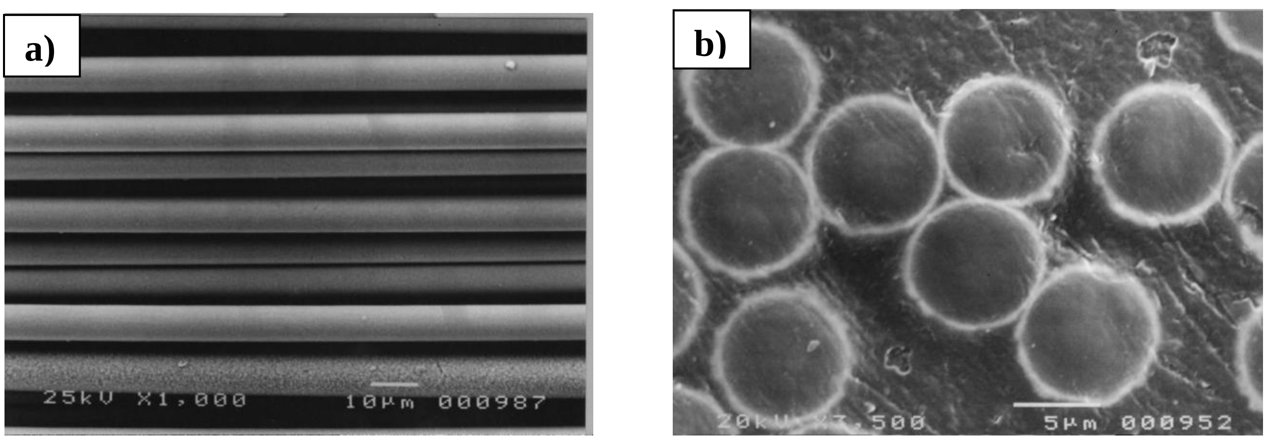

Figure 2. a) SEM micrograph picture of laboratory-electrodeposited 12K50 NiCCF sample (48 wt.% Ni), taken at 1,000× magnification [9]; b) As above, but cross-sectional sample view, taken at 3,500× magnification [9].

Initially, tensile strength testing was performed on Hexcel 12K AS4C carbon fibre tow samples [8], which then followed examination of laboratory-produced (via electro-deposition) nickel-coated carbon fibre specimens, at *ca*. 20 and 50 wt.% Ni (see Fig. 2 [9] above). All obtained results were presented as averages, based on tests conducted on 20 individual filaments, each time performed for three tow sections with a confidence interval of 0.001 N. Single filaments were randomly selected from 12,000-filament tow samples.

3. RESULTS AND DISCUSSION

Table 1. Comparison of breaking loads for single-filament tensile strength measurements (usually ±10% within each tow section), carried-out on Hexcel 12K AS4C CF, 12K20 and 12K50 NiCCF specimens.

Tow section	Average breaking load [N]
Hexcel 12K AS4C CF	
1	0.163
2	0.175
3	0.180
Average:	0.173
12K20 NiCCF	
1	0.125
2	0.140
3	0.145
Average:	0.137
12K50 NiCCF	
1	0.120
2	0.115
3	0.132
Average:	0.122

Table 1 above presents comparison of breaking loads, each time recorded and averaged for 20 single-filament measurements, selected independently at three tow sections for the following fibre specimens: Hexcel 12K AS4C CF (“as received”), laboratory-produced 12K20 and 12K50 NiCCF samples. It could be observed in Table 1 that different sections (see sections 1 through 3 in Table 1) of the same carbon fibre tow produced somewhat different, averaged values of the breaking load. The above proves the existence of surface inhomogeneities (local defects and/or structural imperfections) that might exist along the carbon fibre tow. Please note that all examined fibre sections were 20 cm apart from each other within the tow. Thus, the calculated average of the breaking load (0.173 N) for Hexcel AS4C carbon fibre tow yielded the tensile strength of 4,495 MPa (see Table 2), which is only some 2.5% higher than that reported by Hexcel Corporation in Ref. 8.

Table 2. Comparison of tensile strength parameter for Hexcel 12K AS4C CF, laboratory-produced 12K20 and 12K50 NiCCFs, and Toho-Tenax 12K50 NiCCF material samples.

Fibre type	Ni [wt.%]	Ni_{thick} [μm]	Tensile strength [MPa]
Hexcel 12K AS4C CF	0	0	4,385 [8]
Hexcel 12K AS4C CF	0	0	4,495
12K20 NiCCF	20 ± 2	0.10	3,365
12K50 NiCCF	50 ± 5	0.25	2,761
Toho-Tenax 12K50 NiCCF	45 ± 3	0.25	2,744 [10]

On the other hand, electrodeposition of nickel onto Hexcel AS4C CF tow substrate resulted in a substantial reduction of the recorded, averaged values of the breaking load, which came to 0.137 and 0.122 N for 12K20 and 12K50 nickel-coated carbon fibre composites, correspondingly. The above clearly indicates that metal deposition process itself could have some detrimental effects on the mechanical properties of carbon fibre filaments. These are most likely related to significant resistive heating phenomenon that carbon filaments experience upon initial voltage imposition (typically in excess of 5 V for a bach-type Ni electrodeposition process). In addition, microscopic attractive interactions between the surface of carbon filament and nickel deposit could have some adverse effect on the tensile properties of carbon fibre itself. As a consequence, the recorded tensile strength values for the nickel-coated carbon fibre composites considerably declined, as compared to that of "as received" 12K CF tow. Hence, the calculated tensile strength parameter exhibited Ni-loading dependent behaviour, where its values came to 3,365 and 2,761 MPa for the 12K20 and the 12K50 NiCCF materials, respectively (see Table 2 again). Interestingly, the latter value came very close to that reported for a commercially available 12K50 NiCCF product by Toho-Tenax Company [10].

Furthermore, it should be understood that a relative (and significant) increase of the filament's cross-sectional surface area (*ca*. 15% from the substrate CF to the 12K50 NiCCF composite, with single-fibre diameters of 7.0 and 7.5 μm, respectively) cannot be responsible for a dramatic reduction of the tensile strength (by about 1.6×), derived between these two fibre tow materials.

4. CONCLUSIONS

Individual carbon fibre filaments within 12K carbon fibre tow could become locally damaged during nickel electroplating process, which results in a dramatic reduction of the tensile strength parameter for nickel-coated carbon fibre composites, as compared to that observed for a substrate, "as received" CF tow material. The above effect is partly caused by a relative increase of the cross-sectional surface area for nickel-coated fibre filaments, in reference to that exhibited by the substrate CF filaments. Also, it is believed that contribution to the tensile strength from Ni coating itself is rather insignificant.

Single-filament tensile strength measuring method seems fairly accurate for determination of the tensile strength parameter for fibre type materials. The above is especially important for the production of thermoplastic composites with fibre fillers, where application of various pre and post treatments to fibre or fibre composite materials (having strong impact on their mechanical properties) usually makes an essential production step.

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