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Experimental Tests of Braided Composite Tubes with Kapton Tape

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Abstract. This paper focuses on experimental investigation of mechanical properties of composite tubes with separated layers and Kapton tape inclusions. The tubes are made by braiding of glass fiber bundles on a cylindrical mandrel and application of epoxy resin. The standard configuration is compared with two other configurations. First, the layers are simply separated along the circumference, thus the reinforcing fibers are no longer continuous. Second, the Kapton tape is inserted between separated layers. This configuration should have special electrical insulating properties. The tubes are subjected to four-point bending test. The variation of stiffness and load-carrying capacity of the tested configurations are analyzed.

Introduction

Kapton is a material developed by DuPont company. It is commonly used for insulation of electric and electronic devices. It offers excellent, physical, electrical, thermal and chemical resistant characteristics. It is a polyimide and it is usually available in a form of a homogeneous film wound onto a drum. In this work the Kapton tape is used within the layup of glass-epoxy (Letoxit LH198 resin, Letoxit EM231 hardener) braided composite tubes in order to increase the electrical insulation capability in case of high-voltage applications.

The goal is to investigate the mechanical properties of three configurations of the braided tubes using four-point bending test and to mutually compare their stiffness and strength. The stiffness is defined here as the ratio of force vs. deflection and the strength means the load-carrying capacity (i.e. the maximum force reached) during the bending test.

Material and Apparatus

The first configuration (V1) of the tested structures is represented by purely composite tube having 6 layers of glass-epoxy braided textile reinforcement (approx. ±45°). The second type (V2) has layer which were separated along the whole circumference (two separation per layer). The third type (V3) has layers that are separated in the same was as V2 but there is a 20 mm wide ring of Kapton tape inserted along the circumference between each separated textile parts. The layer separation is shown in Fig. 1 and the scheme of its placement along the tubes's length is shown in Fig. 2. The analysis of mechanical properties of various polyimide films (Kapton) from the anisotropy point of view was performed previously [1]. The tubes were manufactured by Technofiber s.r.o. company. The dimensions were as follows: outer diameter 100 mm, inner diameter 89 mm, length approx. 1000 mm. The bending tests were performed using Zwick/Roell Z050 machine with custom 3D-printed supports and cork layer (see Fig. 3). The internal structure of the tubes was investigated using CT scans and subsequent segmentation analysis (see Fig. 6).

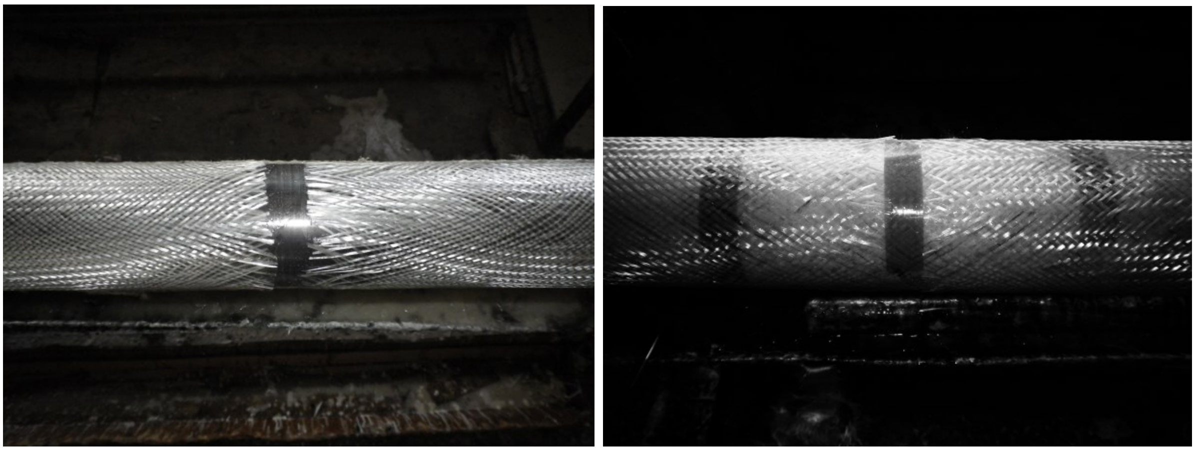

Fig. 1 Example of Kapton tape applied in the first layer (left) and in three different layers (right).

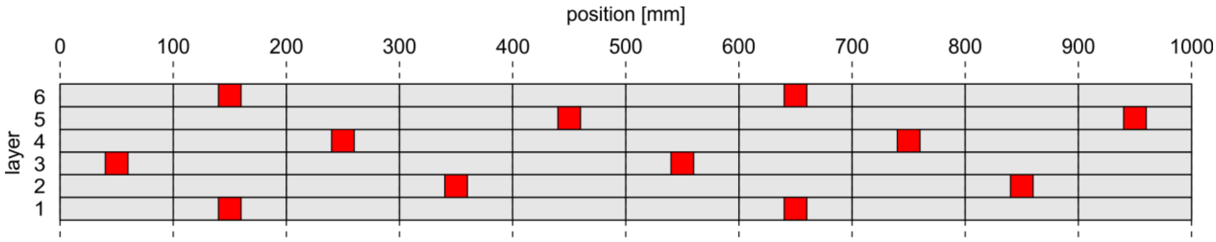

Fig. 2 Scheme of locations of layer separations indicated by red marks. Layer 1 is at the inner diameter and layer 6 is at the outer diameter.

Results and Conclusions

Five tubes for each configuration V1, V2 and V3 were tested. The dependencies between the loading force F and the displacement of the upper support u were measured. The obtained curves are shown in Fig. 4. Examples of ruptured tubes are shown in Fig. 5. The values of the maximum measured force at tube rupture (the load capacity) are summarized in Tab. 1 for the three configurations. The tube stiffness calculated as $dF/\mathrm{d}u$ on the interval $u \in (5; 15)$ mm (linear regression on the dominantly linear part of the curves) is summarized in Tab. 2.

It can be concluded that both the layer separation and the presence of the inserted Kapton tape have certain influence on both the bending stiffness (curve slope) and the load-carrying capacity (maximum force), as could be expected. The mean load capacity of tubes with continuous reinforcement was notably larger than that of the tubes with separated layers. However, the differences between configurations V2 and V3 were smaller than those within these configuration. Therefore, it cannot be concluded which type of separation has which influence on the load capacity. It will be necessary to test larger set of tubes for each configuration and to avoid undesirable geometrical imperfections of the tubes (such as variable thickness or the reinforcement orientation).

Similar conclusion can be drawn from the stiffness point of view. The tubes with continuous reinforcement have the largest mean stiffness and the smallest deviation. The separation causes decrease in the stiffness and increase in the deviation. The effect is even more significant in the case of tubes with Kapton tape.

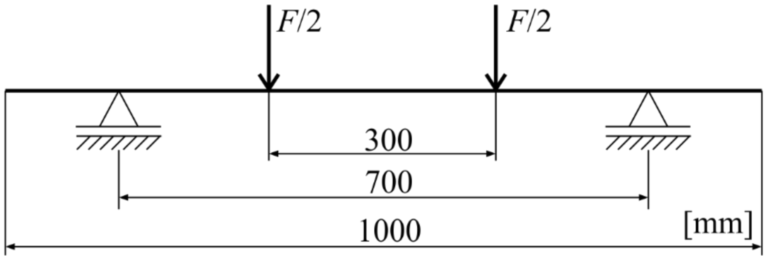

Fig. 3 Scheme of the four-point bending test.

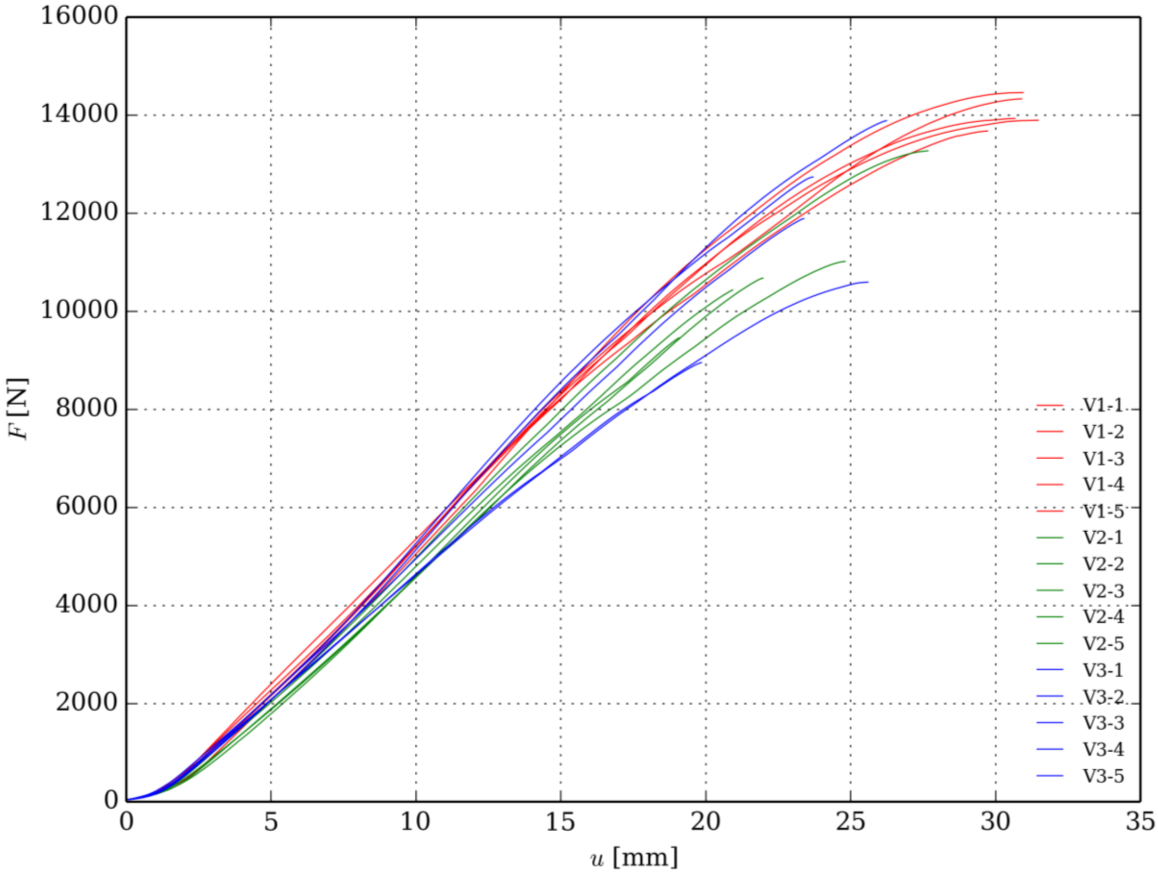

Fig. 4 Measured force–displacement dependencies for all tested tubes.

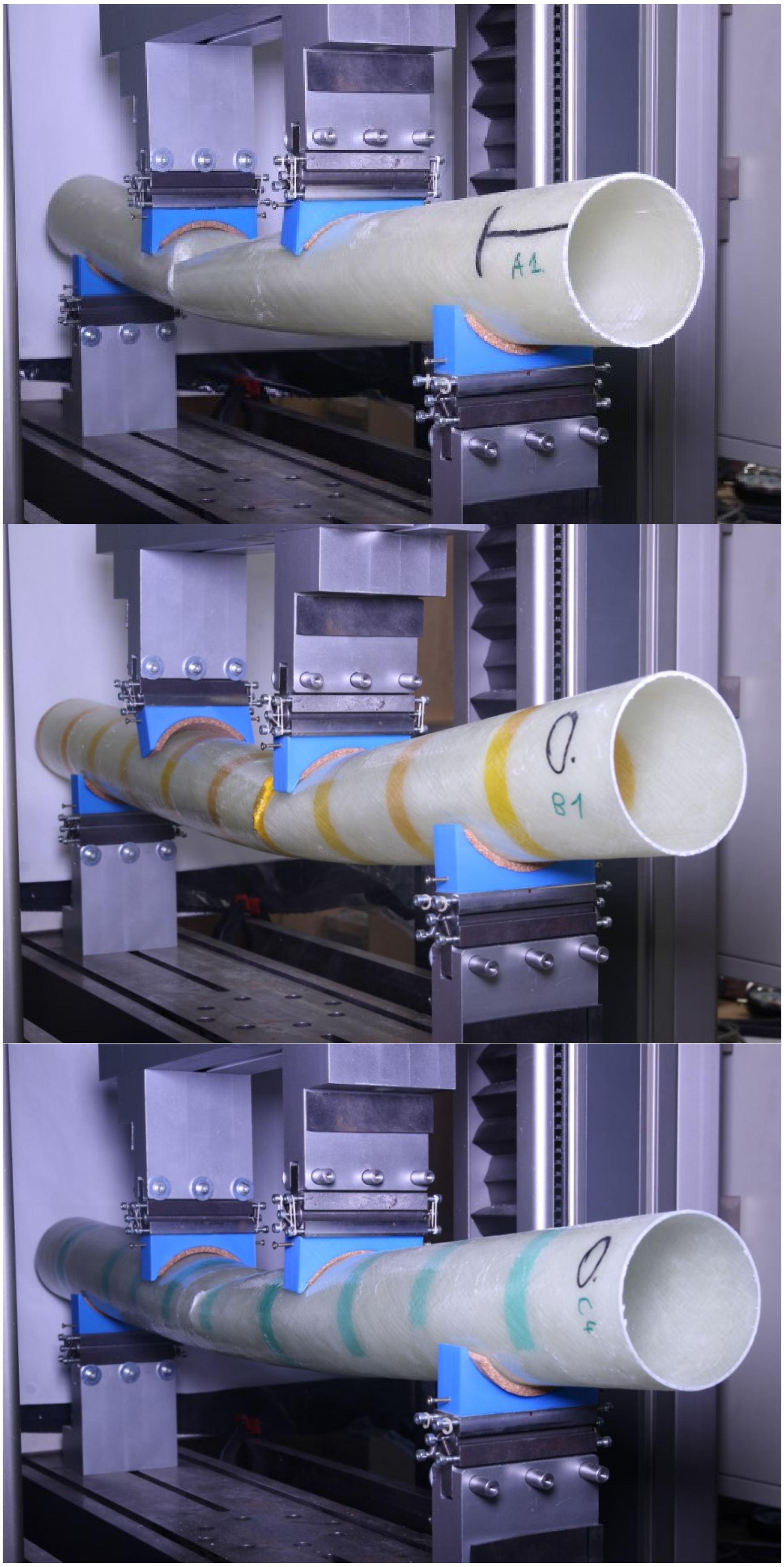

Fig. 5 Photographs of used apparatus and examples of ruptured tubes (top – V1, middle – V2, bottom – V3).

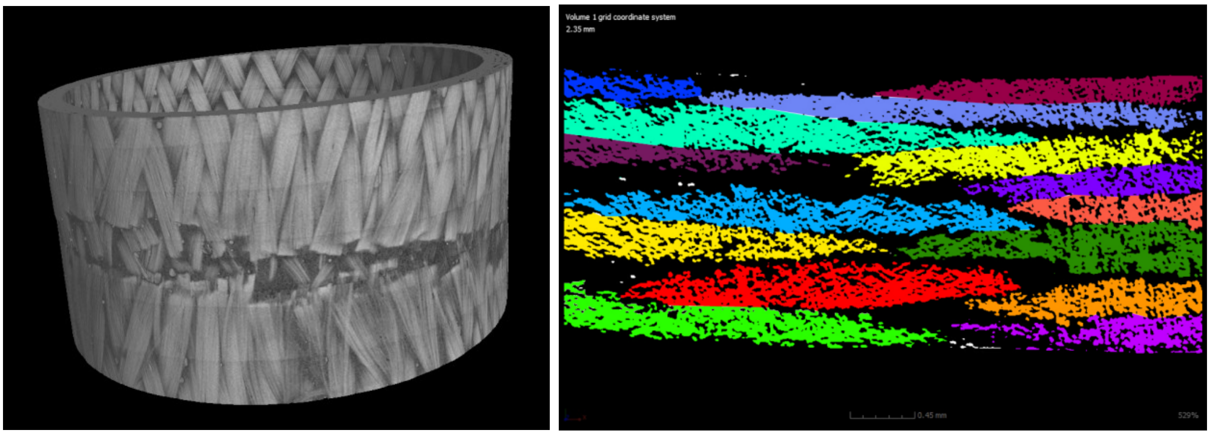

Fig. 6 CT scan of separated reinforcement (left). Segmentation result across thickness (right).

Table 1: Numerical comparison of measured load-carrying capacity values.

Maximum force F [kN]	Configuration V1	Configuration V2	Configuration V3
Tube 1	13.678	13.274	10.595
Tube 2	13.897	10.677	11.891
Tube 3	14.461	9.459	8.957
Tube 4	13.933	11.017	12.739
Tube 5	14.333	10.437	13.888
Mean	14.061	10.973	11.615
Median	13.934	10.677	11.892
Standard deviation	0.325	1.411	1.911
Minimum	13.678	9.460	8.958
Maximum	14.461	13.274	13.888

Table 2: Numerical comparison of measured stiffness values.

Tube stiffness [kN/m]	Configuration V1	Configuration V2	Configuration V3
Tube 1	590.09	587.71	507.30
Tube 2	607.40	538.16	562.28
Tube 3	608.43	572.50	511.32
Tube 4	599.57	541.07	629.06
Tube 5	622.66	553.44	623.94
Mean	605.63	558.57	566.78
Median	607.40	553.44	562.28
Standard deviation	12.03	21.17	58.69
Minimum	590.09	538.16	507.30
Maximum	622.66	587.71	629.06

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