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COMPARISON OF BENDING PROPERTIES FOR WINDED AND WRAPPED COMPOSITES

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Abstract
The aim of presented work is by using the three point bending test compare two kind of theoretically identical composite rods manufactured by different ways. In technical practice we could find applications of pre-impregnated fibres so called "prepreg" especially by the wrapping technology, which is generally helical layering of one wide tape. The main disadvantage is limitation of using this technology only for straight shapes. Therefore a simultaneous deposition of larger number of thinner fiber filaments, called winding has been used to enhance this technology also for curved shapes and parts with various cross-sections. The aim of this work is to experimentally compare flexural strength of two almost identical composite rods, one wrapped and second winded. Subsequently in the ACP module of ANSYS their models as a tool for verification of the obtained data were created. Significant differences in the behavior of those rods created by two manufacturing methods have been found.

Key words: *composite; winding; wrapping; bending; prepregs.*

INTRODUCTION

Reduction of costs, improving quality and using of modern CAD technologies are the key points in the future of composite parts. Composite materials are used especially because of their low weight, very high strength and offer also solution for applications subjected to fatigue loadings. By changing the material from metal to composite It is possible to reduce the weight of vehicles with 40 to 60 per cent (*Harry, 2012*). The most effective replacement of conventional materials by composites is possible with the appropriate combination of manufacturing technologies, stack up of individual layers, dispersion and matrix. Plastics materials reinforced by long fibers are widely used because of their high strength and modulus to density ratio (*Suganuma, 2007*). Compared to metallic structures, composite laminates offer some unique engineering properties while presenting interesting but challenging problems for analysts and designers (*Kherredine, 2012*). During the creation of a composite part we have to consider lot of aspects (grease, pressure, temperature, imperfect vacuum, real thickness of plies) and this all significantly affect the final mechanical parameters. Instead of using classical dry fibres, this work describes using presaturated material so called prepreg. The main benefit of using pre-impregnated fibers instead of filaments is the simplification (or even elimination) of consequent technologies like saturation and curing in form. The aim of this article is to compare behavior of theoretically identical parts created from preimpregnated fibres by two different methods.

MATERIALS AND METHODS

Nowadays technologies like winding of fibers, tape wrapping, laminating of fabric layers and some other operations are often used for manufacturing the so called advanced composites (*Allen, 2004*). Methods based on epicyclic winding or helical wrapping (Fig. 1) are generally used for manufacturing of thin-walled composite parts with circular or oval profiles. Those methods are usually used for so-called "wet" case, when a bundle of dry placed fibers is subsequently impregnated with resin. Another way is to use of the pre impregnated materials. Because of their significantly different behavior (sticky, such as double-sided tape), their use is generally limited primarily to manufacturing straight bars. One of used technologies is wrapping. It means a helical layering of one wide tape on a straight or eventually conical mandrels (Fig. 2). Winding is a manufacturing process that should keep the fibers continuous and aligned throughout entire part, offers a high degree of automation and a relatively high processing speeds (*Harry, 2012*). The process of winding fibers is known for a long time. However, until recently this technology was concerned especially to field of textile engineering (braiding of ropes, fluid – air hoses) and parts usually from some atypical sectors. Due to a big progress in using composite materials instead of conventional, we could met the winded composite parts in many industries.

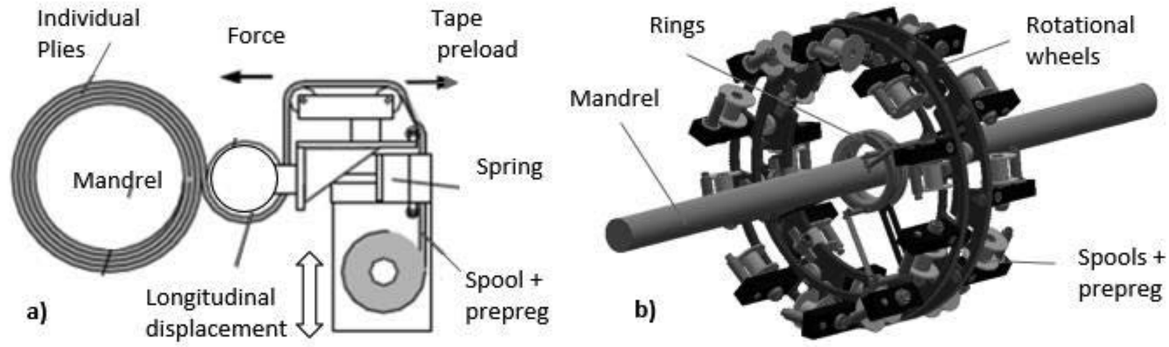

Fig. 1 The used manufacturing methods a) Wrapping b) Winding

The fundamental idea of this winding method is based on a registered patent (*Sevcik, 2013*), which was developed at the Technical University of Liberec. The head is formed by a base frame and two rotary wheels, which carry spools with material used for winding. During the process of prepregs winding the mandrel is pulled through the center of the rotational head. Compared to a conventional winding of dry fibers there is significantly bigger axial force caused by the dragging fibers over aluminum rings, some passive resistances and a braking moment in the spool mechanism. As mentioned (*Zhang, 2015*) for ensuring the best properties is necessary to preload the tape with a quite big and invariable force to improve alignment of individual fibers and to prevent warping and premature sticking of the winded tape.

Through the fibers, the force comes to the rotary wheel (*Kovar, 2016*). To assure the most optimal properties of the basic material (Tab. 1) should the semi-finished pre-impregnated fibers come from the manufacturers in frozen state with the individual plies protected by a foil of silicone paper. Tensile strength in the direction perpendicular to the direction of longitudinal fibers is for uni-directional materials even lower than the ultimate strength of the matrix itself, which is caused by the concentration of local stress on their interface (*Kherredine, 2012*).

Tab. 1 material properties of used UD prepreg materials

	E1 [MPa]	E2 [MPa]	ρ [g/cm^3]	μ [-]	Ductility [%]
Carbon	101 000	9 000	1,9	0,25	lim -> 0

The stiffness could be described by a set of five parameters: young-moduli ($E_{11}$and E_{22}), Poisson's ratios (ν_{12} and ν_{23}) and a shear-modulus (G_{12}). With using of homogenization techniques these five parameters describing the stiffness behavior of the composite can be derived. It is necessary to mention that this idea is valid only with an assumption of a really perfect alignment of fibres. Then the compliance matrix e.g. in (Kaw, 2006), can be rewritten in terms of the engineering constants.

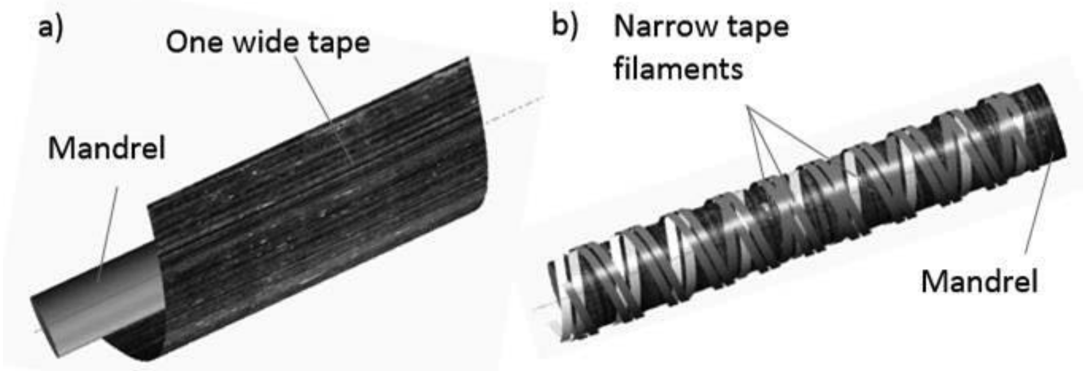

Fig. 2 The two principles how the fiber material is layered a) Wrapped b) Winded

With the optimal settings the resulting layer should have the same angle of the fibers, the thickness, the weight and theoretically almost identical mechanical properties. During the production of the sample, attention was paid to the aims that composition, number of layers, weight and curing parameters mutually correspond as much as possible, but as could be seen in the Fig. 3 it is possible to find fist visual differences immediately after the curing. In the winding process arising a lot of seemingly small unimportant defects in the fiber aligning and also sticking of the tape's edges.

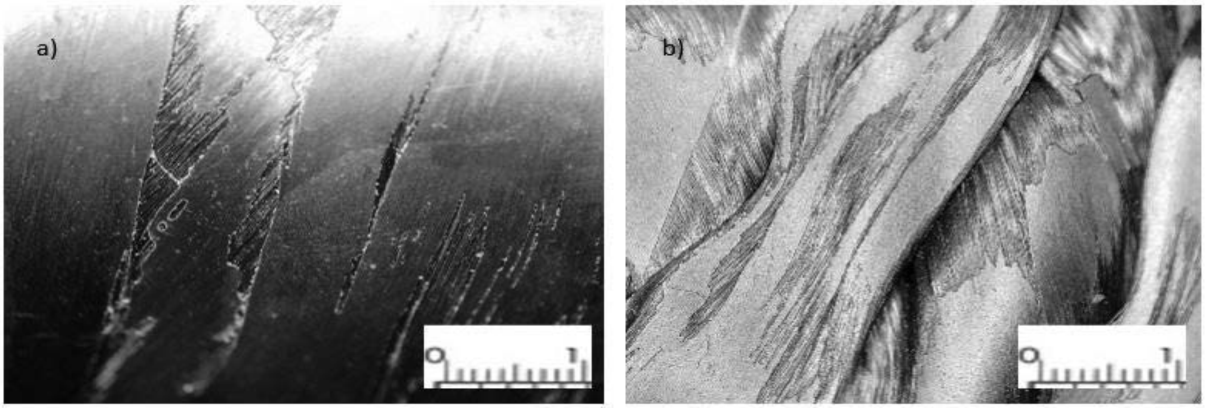

Fig. 3 The surface of the a) wrapped b) winded, parts from carbon prepreg (added scale 1 cm)

The prediction of composite mechanical behavior is a very complex problem, because the process induces whole spectrum of attributes like the fibres orientation, interface properties, cohesive forces and failure criteria. Advanced methods could describe the entire damage process from its initiation to a complete failure of a composite structure (*Ullah, 2012*). An unanswered question is, how accurate the simulation should be to be suitable: the mesh relevance, chosen formulations, failure criteria etc., when we consider the initial error caused by the material model and boundaries. Because the modeling of contact like in our case the between layered shell and solid element is very problematic. It is possible to find various simplifications, e.g. (*Gruber, 2013*) created and simplified static model of the part alone without using any contact.

In our case, the model was solved as a fully contact task, Fig. 4b. The tested part was laid on two fixed supports. For combination of solid and shell elements the pure penalty formulation with nodal-normal detection of integration points was used. The chosen basic normal stiffness 1e-002 could be additionally adjusted by program. The simplest way of handling an initially unconstrained model was to add weak springs. The spring constant can be made dependent on the load parameter, so that the spring has effect only in the beginning of the simulation (*Ansys, 2010*). Kirstein even described thesis that during the test could be the boundary of the plate considered to be free as the plate is supported at interior points, and no special treatment is required (*Kirstein, 1966*).

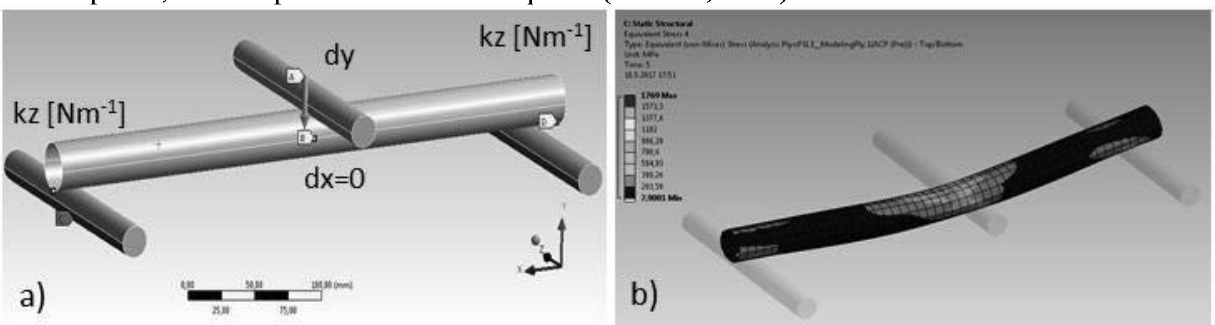

Fig. 4 The numerical model of shell composite bending test a) scheme with the boundary conditions b) An example of resulting stress in one ply

In our case the problem of numerical simulation of composite materials is an assumption of a homogeneous system with perfectly aligned fibers and their uniform distribution throughout the cross section. This idea is commonly applied to the simulation of laminated and wrapped parts. However, how much the results differ for the winding, (i.e. method with large randomness in the fiber alignment and even overlapping of filaments) is a question for comparing individual results in next chapter.

The flexural strength is the maximum stress that material subjected to bending load could resist before failure (*Chung, 2004*). In the conducted test the samples of almost identical wrapped and winded rods were tested and mutually compared. The distance *l* between the cylindrical supports was in our case equal to 380 mm. The applied quasi static loading had increased with step 0. 5 mm /s until caused the final displacement of used indenter 80 mm.

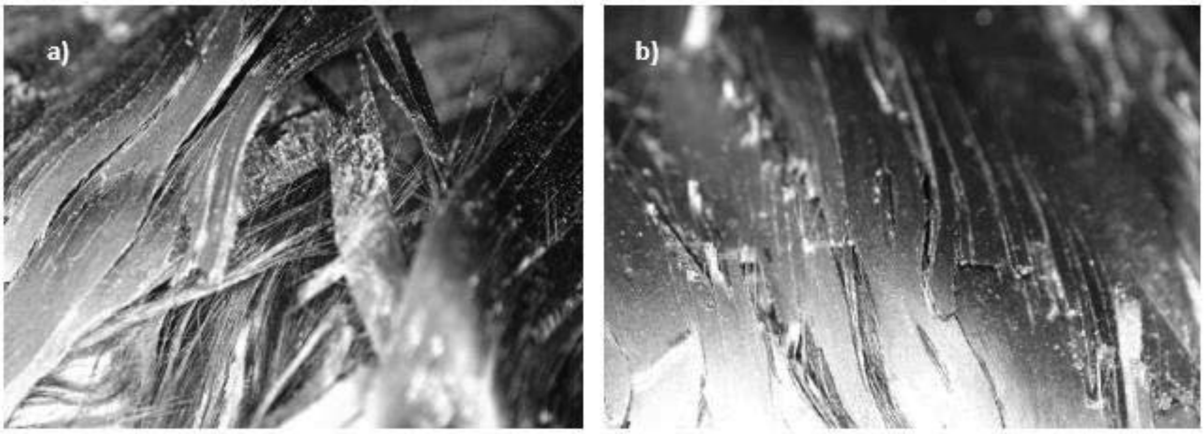

Fig. 5 The found typical failures of parts in bending test explored for the a) wrapped b) winded, parts

RESULTS AND DISCUSSION

The resulting flexural strength obtained for the two groups of tested parts were significantly different as could be seen in Table 2 and in Fig 6. There are differences not only in the maximum stress level, but also in the value of displacement and it is possible to see that the place of material ruptures looks differently (Fig. 5). In one case there were mainly delamination and the filament ruptures in the other. The carried model (Fig. 4) was in the beginning (i.e. until 25 mm of displacement) in a good agreement with the wrapped parts. Then, in the real part some first ruptures and delamination arose, while the force in the model still increased up to the deformation of 35 mm, where was not possible to reach the convergence of solution anymore.
When assessing the second test case, winded parts (not the one wide tape but 10 segments of relatively narrow filaments) the obtained values were significantly different.

Tab. 2 Resultant values from experiment compared with the numerical model

	Displacement	**F_{max}**	
	at Fmax	Experiment	Model
Wrapp	41 mm	840 N	~1600 N
Wind	16 mm	1300 N	360 N

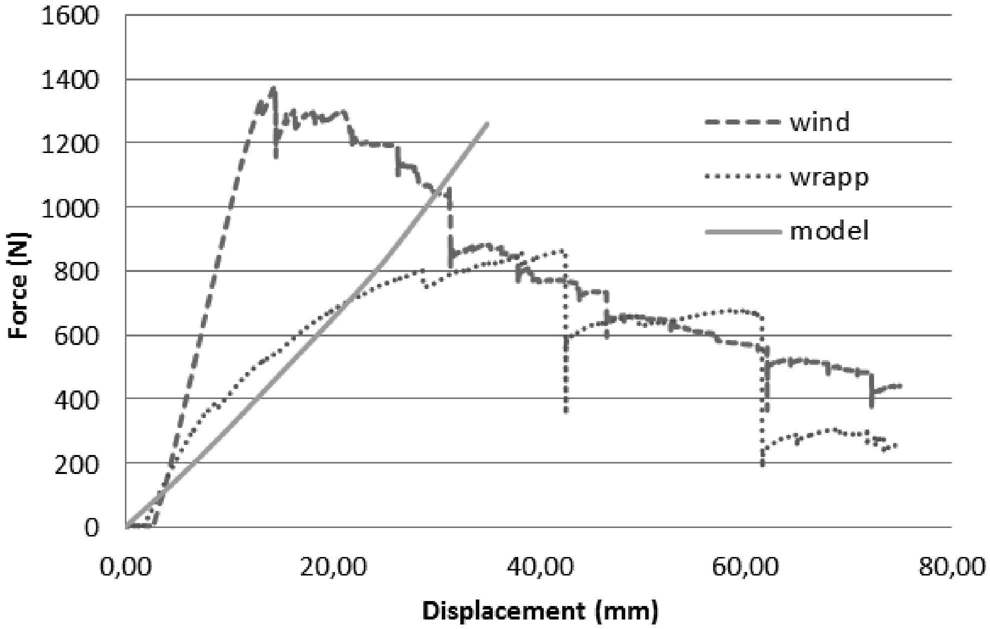

Fig. 6 The comparison of the tested parts (arithmetic mean of values for the tested sets)

CONCLUSIONS

Two sets of samples, one made by winding and second by wrapping of UD prepreg carbon material, were tested. Method one wrapping of a wide tape had a very good surface quality and homogeneity of material characteristics. In the second case we tried to use non-conventional method of winding combined with pre-impregnated materials. This method utilizes instead of one wide tape the segmentation, when each layer consists of 10 narrow strips. This method is suitable for straight shapes and with appropriate setting of the winding angle and can also create curved or closed shapes. A disadvantage is that the fibers are often not ideally aligned as in the case of one wide tape and there are many places of their mutual overlapping which cause the resulting structure forming characteristic warp defects. What could be important, is that the fibres are evidently more fastened. During the experiment we have obtained significantly different behavior of the two theoretically identical parts. There was not only different value of the maximal flexure strength, but also fundamentally different fracture mechanisms, delamination and the deformation of the entire test rods.

The found results have been evaluated also by using numerical model, created in ACP preprocessor. Good conformity with the wrapped part was obtained in the beginning of loading. Then it the composite materials arose some issues like delamination or fractures. With a standard material model it is not possible to consider all this phenomenas like it is usual for the conventional materials. In our next work will be necessary implement into the model also the cohesive interface layers and damage mechanisms that could describe the arising material failures. In the term of numerical simulation of the winded parts the entire approach to the model should be modified. In the first step is possible try to change the definition of input materials. It means do not use the verified material model of the ideal UD tape but homogenize the new tape by taking account the all occurring defects, pores and overlapping. However, it is also possible that the usual shell methods using stacked plies with different stiffness matrix will not be appropriate.

The main benefit of using prepreg instead of filaments is the simplification of consequent technologies like saturation and curing in form. As disadvantages are the considerably higher price of presaturated fibers and big, ideally constant preloading in the fibers throughout the entire process. The winding technology has also a big potential to replace the classical but for today using insufficient wrapping method. However, it will be necessary to spend a long time by optimizing the final structure and also find a way, how to correctly simulate the material model and mechanical behavior of this structure and also how to improve the technology to minimize all the imperfect places in the material structure.

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