7th INTERNATIONAL MULTIDISCIPLINARY CONFERENCE
Baia Mare, Romania, May 17-18, 2007
ISSN-1224-3264

LONG-FIBRE COMPOSITE EXPERIMENTAL MODELLING

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Abstract: *The article deals with experimental modelling of single-layer long-fibre composite structures with a non-linear matrix and a steel reinforcement in the form of a wire or twisted wire. These specific composites are used in radial automobile tires as steel-belt layers. The article also deals with the design of the shape and geometric parameters of composite specimens taking into account the type of testing machine. The design was necessary since the shapes and parameters of the specimens for different forms of loading are not standardized. Presented as examples of experimental modelling of composite specimens are results of tensile tests of single-layer specimens with selected cord angles with respect to the loading direction simultaneously with a variety of specimen widths.*
Key words: *Composite structures, tire, long-fibre, single-layer, non-linear matrix, steel reinforcement, experimental modelling, tensile test, specimen design.*

1. INTRODUCTION

Current industrial and research needs require experimental and computational modelling of the mechanical behaviours of composite elements. Material parameters of composite structural parts are necessary input data for computational models and for subsequent comparison of computational models with experiments. Knowledge is also necessary of the behaviour of composites under mechanical load. These data are obtained by experimental modelling of composite specimens and composite structural parts (matrixes and reinforcement) by static tensile, compression, shear and bending tests.

The behaviour of such materials under mechanical loading is in many ways different from the behaviour of commonly used technical materials such as steels. In composites, compared with metals, final mechanical properties can be controlled e.g. in the direction of the orientation of fibres. Composites also have elevated fatigue life, by one order higher material damping and are resistant to failure due to their ability to stop growth or decelerate propagation of cracks on the matrix-cord interface.

This paper is a part of a long-term scientific project dealing with systemic approach to computational modelling of complex single-layer, two-layer and multilayer long-fibre composite elements. These composites are used in radial tire casing, as presented in dissertation thesis **Krmela (2004)**.

2. FORMULATION OF PROBLEM

The aim of this paper is experimental modelling of single-layer long-fibre composite structures with a non-linear (hyperelastic) matrix and steel reinforcement in the form of wire and twisted wire currently used in radial tires as steel-cord belts. Examples from the experimental modelling of composites will be represented by result of tensile tests. The shape and geometric parameters of the experimental specimens must be designed appropriately to the testing equipment, they cannot be found in any literature. The paper also deals with the assessment of tensile testing conditions.

The results of experimental modelling will serve as data for verification analyses between experiments and calculations. The design of specimens will be used as input data for computational modelling of steel-cord belts in dependence on different cord angles and varying character of load (tensile, bending, combined load, etc.).

3. REVIEW AIMED AT DESIGN OF COMPOSITE SPECIMENS

Tests of specific long-fibre composite materials with non-linear (hyperelastic) matrix are not standardized and neither are the shape and dimensions of test pieces, namely for tensile tests, which are for the observation of mechanical behaviour absolutely essential.

In composite specimens or in specimens with a certain content of composite layers of concern will be the configuration of cords with respect to the direction of loading which results in a change of the stiffness characteristics.

Paper Shiguro (2004) which deals with the mechanical characteristics of composites for tire-casing gives the geometric parameters of single-layer specimens for tensile tests.

Basically we can work with standards generally valid for tests of composite materials. In most cases the standards apply to composites denoted as laminates (or lamina). Some standards describe the testing procedure and conditions of testing, the shape and geometric parameters of the test pieces. In some cases the standards describe only the procedure and testing conditions or on the other hand are oriented only on standardization of the shape and geometric parameters of the test pieces in dependence on the type of test.

Standard ASTM D-3039-76 prescribes the width of test pieces in the form of strips 25 mm wide, 2-4 mm thick with a working length of 150 mm. This standard allows smaller widths, e.g. 10 mm. Another standard EN 2561 however in some case prescribes a different width and thickness in the measured sector of the test piece. Foreign standards, even those stated as equivalent standards, do not define the geometry of the test pieces uniformly. Publication

Daniel (2004) gives a comprehensive and well-organized comparison of shapes, geometric parameters and testing conditions of selected standards for laminated composites.

Test pieces for compression test are standardized e.g. by ASTM D 695 and ISO 8515 in the form of strips with a smaller width compared with tensile tests – e.g. 12.7 mm.

ASTM D 7901 and ASTM D 62722 standards describe bending tests for laminates. Three-point or four-point bending tests are used for measuring bending characteristics. Test pieces must have a certain length-to-thickness ratio.

4. CONCEPT OF SHAPE AND GEOMETRIC PARAMETERS OF COMPOSITE SPECIMENS WIT RESPECT TO TESTING EQUIPMENT

On the basis of verified computational models used in the original research work by **Krmela (2004)** the potential of the testing machine and new calculations performed in 2006 (also with respect to the computational time and available computer hardware) and the number of produced strips Krmela determined **test pieces in the form of strips 5, 10, 15 and 25 mm wide with a total length of 120 mm**.

Single-layer specimens were water-jet cut from plates with wire and thin wire cords (cord-angles 45°and 90°). The determined cord-angle orientations with respect to the direction of loading in tensile tests were **0°, 25°, 45°, 65°and 90°**. Instead of specimens with a 22.5° and 67.5° cord angle orientation which could not be produced due to the applied technology, specimens were produced with cord angles 25° and 65°. The former research work from 2005 dealt with cord angles 0°, 30°, 45°, 60°, 90° with thin wire (dia 0.94 mm) reinforcement. The thickness ranged from 2.25 mm (specimens with wire cord) up to 2.7 mm (specimens with a thin wire cord). The single wire cord actually comprises four wires (filaments) with an 0.28 mm diameter of each filament (cord denoted 4x0.28). The diameter of the thin wire is 0.89 mm.

From two-layer specimens with wire reinforcement specimens were prepared with a cord angle orientation of **±22.5°** (i.e. lengthwise symmetrically oriented as if a tire steel belt was cut peripherally, **Fig.1 – Specimen A**) and **±67.5°** (i.e. transverse symmetrically oriented as if a tire steel belt was cut transverse-perpendicular to ±22.5°, **Fig.1 – Specimen B**) and **±45°**. The thickness of the specimens is 4 mm.

Concerned are further two-layer **asymmetrically** oriented specimens with cord angles between the top/bottom layer **+0°/-45°** (**Fig.1 – Specimen C**) and **special asymmetrical specimens +67.5°/+22.5°** (**= +22.5°/-112.5°**, **Fig.1 – Specimen D**).

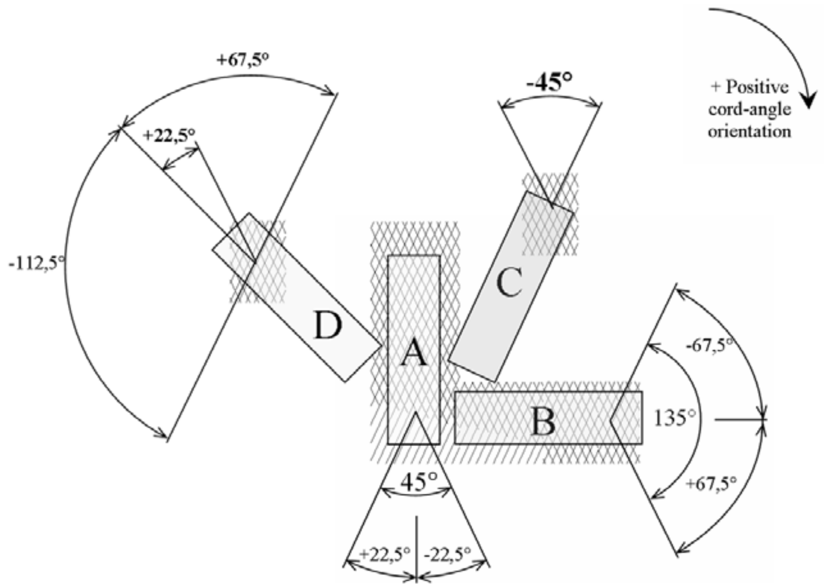

Fig.1 Two-layer specimens from plates with cord orientations 45°: A – lengthwise symmetrical specimen with ±22.5°; B – transverse symmetrical specimen with ±67.5°; C – asymmetrical specimen with +0°/-45°; D – asymmetrical specimen with +67.5°/+22.5°

The width of the strips can vary due to the applied cutting technology (water-jet) from the prescribed width within the range from ±0.5 mm (e.g. widths of 10 mm tests pieces ranged from 9.8 to 10.5 mm). A similar deviation is allowed of orientations of reinforcing materials (cord angles).

Besides the above also specimens with different dimensions or shapes were designed including specimens for biaxial tensile tests of composites, **Krmela et al. (2006)**.

5. RESULTS OF TENSILE TESTS

Structural components of composites (matrix and reinforcements) were tested by tensile tests.

It is necessary to give a concept of the conditions of the tensile tests. The initial length between the jaws of the testing machine is 92 mm. Elongation measured on the same length (with respect to the fact that the testing machine is not equipped wit an extensometer. Otherwise elongation would be measured on 50 and 25 mm in the centre of the specimen). The rate of the test was 25 mm/min.

Presented as examples of experimental modelling of composite specimens will be results of tensile tests of single-layer specimens with selected cord angles with respect to the loading direction simultaneously with a variety of specimen widths.

Fig.2 gives tensile force-elongation dependencies for 25°and 45° cord angles. At present tensile tests continue for other cord angles and widths, the results have not yet been evaluated by comparison analysis.

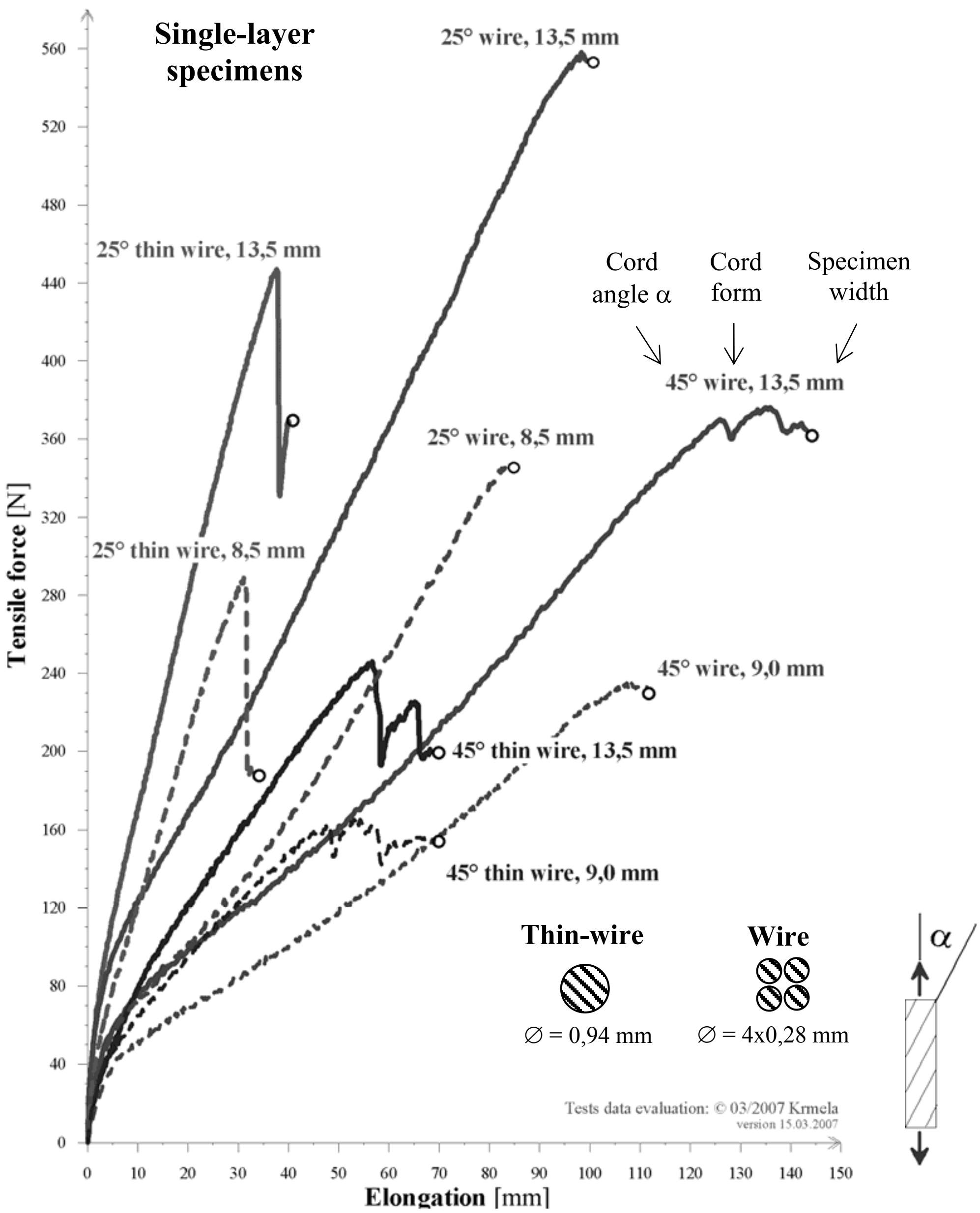

Fig.2 Tensile tests on single-layer specimens for different cord- angles configurations (α) with respect to the loading direction, different widths and different cords' forms

6. CONCLUSION

Owing to the fact that tests for long-fibre composite specimens with a non-linear matrix and steel reinforcement are not standardized the geometric parameters and shape of single-layer and two-layer test pieces with wire or thin wire reinforcement were designed by Krmela namely in view of their use for computational modelling.

The designed test pieces are strips 5, 10, 15 and 25 mm wide with a total length of 120 mm. The determined cord-angle orientations in single-layer specimens 0°**, 22.5°, 45°, 67.5° and 90°** (in some cases **30° and 60°**). Two-layer specimens are **symmetrically orientated**

between top/bottom layer **±22.5°**, **±67.5°**, **±45° and asymmetrically orientated** with cord-angles **+0°/-45° and +67.5°/+22.5°**.

At present the specimens are subject to **statical tensile, compression, shear and bending tests**. Also **testing conditions have been designed**. Tests will be performed not only at ambient temperature 20°C but also at lowered and elevated temperature.

Selected single-layer composite test pieces are subject to **corrosion tests in a corrosion chamber**. The aim of these tests is to find **the influence of the degrading process on the stiffness characteristics** of the composite structure (influence of the time behaviour of degradation on the tensile and bending stiffness).

The results obtained from experimental modelling composite elements will be applied for comparison analyses of computational models of steel-cord belts with experiments and will also be used as input data in the computational model of a tire as a whole.

ACKNOWLEDGEMENTS

This article was prepared during investigation of a postdoctoral grant of the Czech Science Foundation **Krmela: GAČR 106/08/P136„Výpočtové modelování jako prostředek pro predikci porušování složitých kompozitních materiál " – "The computational modelling as a means of failure predication of complicate composite materials".**

The authors also thank Professor Janíček Přemysl, DrSc. from the Brno University of Technology in Brno for cooperation and consultations in the experimental and computational modelling of polycomponent materials.

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