THE TESTS OF LOW CYCLIC LOADING OF COMPOSITES WITH TEXTILE STRUCTURE ON TEST MACHINE WITH VIDEO-EXTENSOMETER

Jan Krmela and Vladimira Krmelova

Alexander Dubček University of Trenčín, Faculty of Industrial Technologies, I. Krasku 491/30, 020 01 Púchov, Slovakia jan.krmela@fpt.tnuni.sk, jan2.krmela@post.cz

Abstract: In this contribution, the composites with textile reinforcement and rubber matrix are studied experimentally. The reinforcement is in the form of fibre and material is PA66. These composite with textile structure are applied in tire casings for passenger cars and conveyor belts. The aim of research work of authors is propose and evaluate the experimental procedures for tests cyclic loading of selected composites, which consist of textile reinforcement with a different cord angle. The image analysis is applied for obtaining of information about geometry parameters of cords for specimen design for tests. The test machine Autograph AG-X plus 5kN – Schimadzu with a video-extensometer is used for the tests of low cyclic loading in tensile with cycle loops. The results of tests and geometry parameters are needed for creation of computational models of composites such as parts of tire casing.

Keywords: composite, textile fibre, PA66, tire, low cyclic loading, video-extensometer, cycle loop.

1 INTRODUCTION

For computational modeling of parts of tire casings and tires, the material parameters of matrixes and reinforcements are necessary as input data for the computational model and the experimental data of composite structures can be used as the verification criteria for the comparison of computational outputs with test results [1]. The static tests are not able to provide the information about the operational behavior. For computational modeling of a tire casing, the results from experimental data from cycle tests are needed.

It is necessary to deal with cyclic tensile tests of longfiber composites with textile and steel reinforcement together as tire casings or conveyor belts. Therefore, the aim is also to propose and evaluate the experimental procedures for cyclic loading tests of selected composites, which consist of textile reinforcement with different cord а angle. The optimization of an angle of textile reinforcement in composites is possible on the basis of the results from the test of cyclic loading. A standard automobile radial tire casing consists of elastomer parts and parts with textile-cords (Table 1) and steel-cords in a tire tread as reinforcements.

The structure parts applied into passenger car radial tire casings are: textile carcass plies, a textile cap ply (called an overlap belt) and steel-cord belts [2, 3].

These structures of tire have got different cord material, angle and numbers of layers. The behavior of such materials as tire belts under mechanical loading is in many ways different from the behavior of commonly used technical materials [4, 5].

Material	Labeling of construction [tex]	Application
Polyester	PES 144x1x2 PES 167x1x3	Carcass plies
Polyamide 6	PA6 94x1x2 PA6 94x1	Cap ply
Polyamide 66	PA66 140x1x2	Cap ply
Rayon (viscose)	VS 184x1x2 VS 244x1x2	Carcass plies
Aramid	Aramid 110x1x2	Carcass plies for sport tire casings

 Table 1 Materials of textile-cords for tires [3]

The PA66 and PES textile fibers are used for passenger tires, especially for common purposes. The aramid fibers, especially Kevlar, are used for tires of sport and high-speed cars. Kevlar has a high strength (up to 2750 MPa), a low modulus of elasticity, low elongation and dimensional stability [3].

The sidewall also shows the material of cords and number of plies in the sidewall and under the tread of tire casing. The sidewall of a tire for passenger cars consists of one polyester carcass ply with a cord angle of 90° and in the tread, there are four plies: one polyester ply, two steel plies with a cord angle approx. $21-27^{\circ}$ in ply and one polyamide cap ply with a cord angle approx. 0° , see Figure 1.

A tire with the symbol Extra load (XL) may have two polyester- or two polyamide plies. The textile carcass density (it is a number of ends per one meter of width, marked as EPM) is from 700 to 1150 m^{-1} . The EPM of a textile cap ply is 1100–1200 m^{-1} .



Figure 1 The structure of tire casing – cord angles

Tests of specific long-fiber composite materials with an elastomer are not standardized. The paper [5] describes the geometric parameters of single-layer specimens of tire casings with different cord-angles $(0^{\circ}, 25^{\circ}, 45^{\circ}, 60^{\circ} \text{ and } 90^{\circ})$ for tensile tests. Some standards describe the testing procedure and conditions of testing, the shape and geometric parameters of the test specimens for static tensile tests [12, 13]. E.g., the standard ASTM D-3039-76 [14] describes the width of test specimens of fiberresin composites in the form of strips 25 mm wide, 2-4 mm thick with the working length of 150 mm. Therefore, for tests of cyclic loading the shape of single-layer specimens with textile cords and an elastomer must be designed.

dynamic-mechanical properties of The such composites can also be described by an elastic, viscous modulus and a loss factor [6]. For computational modeling, the modulus of elasticity and Poisson ratio are used as material input parameters of textile reinforcements. The LASE modulus from the producer of a textile cord is used [7]. LASE is a modulus of elasticity for elongation 5% (LASE is an acronym of Load At Specific Elongation 5%). Another option is the determination of modulus as stress necessary for elongation by 100% obtained by extrapolation for elongation by 2%. After the vulcanization process and during the industrial process of a tire casing, the modulus can be changed (the influence of heat during vulcanization). The conditions of tire's vulcanization process are the temperature of 193°C, the pressure of 1534 kPa and time 10 min.

The static tensile modulus of elasticity of PA66 is from 900 to 3450 MPa or from 9 to 50 cN/dtex [3, 8, 9]. It is a broad range. In case of rayon, the modulus is from 600 MPa to 11 GPa or 8–120 cN/dtex. Typically values of modulus of elasticity are in Table 2. Usually the test conditions are a temperature of $20\pm2^{\circ}$ C, humidity of $65\pm5\%$ and an initial length between clamps of a test machine (gauge length) 500 mm [10]. The Poisson ration of PA66 is approx. 0.4.

Table 2 Modulus of	of elasticity of textile	cords [11]
--------------------	--------------------------	------------

Material	Labeling of construction [tex]	Modulus of elasticity [GPa]
Polyester	PES 110x1x2	4
Polyamide 66	PA66 94x1x2	3.4
Rayon (viscose)	VS 184x1x3	11
Aramid	Aramid 167x1x2	25

The low-cyclic loading of composites is still actual and has been discussed increasingly, because the obtained experimental can be really good information in relation to the composite behavior and they can be used as input parameters for computational modeling. Therefore the aim of research work of authors is propose and evaluate the experimental procedures for tests cyclic loading of selected composites.

2 EXPERIMENTAL METHODS

2.1 Image analysis of cross-section of tire casing

The geometric configuration of reinforcements is the main factor for the specification of material parameters, which would be used for the description of the whole area of casing under the tread. The photo camera Canon EOS 600 D and a standard light microscope were used to obtain the images. The software IMPOR 5.0 with plug-in Object Measuring is used for the image analysis.

The cord structure of the selected tire casing Continental 245/40 R18 97Y XL is represented in Figures 2 and 3. The tire has polyamide cords in cap ply, the detail of polyamide cord is in Figure 3 bellow. The cord structure for different tire casing Dunlop 215/40 R17 87V XL is in paper [15].



Figure 2 The structure of tire casing 245/40 R18 by photo camera

The image analysis is applied for obtaining the information about geometric parameters of cords such as distances between cords and ply thickness for specimen design for tests of low cyclic loading.



Figure 3 The detail of structure by light microscope with polyamide cord in cap ply of tire casing 245/40 R18 by light microscope

2.2 Specimen design

Before carrying out the mechanical tests. the geometric parameters of test specimens had been proposed and test conditions with respect to had the test apparatus been determined. The composite specimens with an angle of the textile reinforcement 0° (textile reinforcement is perpendicular to the direction of loading), 45° and 60° are used for the cyclic tests. The composite specimens are consisted of one layer. The PA66 is used as textile reinforcement and elastomer for production of radial tire carcass is used as matrix.

The geometric parameters of rectangle shape specimens are a length of 195 mm, a width of 35 mm, initial length between clamps of a test machine 100 mm and a thickness of the specimen of 1.05 mm. The cord diameter is 0.5 mm. The EPM is 870 m^{-1} . The specimens were produced by the authors. The initial length between the points for a video-extensometer is 50 mm, see Figure 4.



Figure 4 Specimens with geometric parameters (in mm)

2.3 Methods of cyclic loading

The tests of cyclic loading of these composites are requested for the verification analyses between tests and computational modeling of tires. Standards and a methodology of optimal testing of composites with the textile structure have not been determined yet but the determination can be based on the behavior of elastomers under the cyclic loading [16]. For elastomers under the first cycle, there is the occurrence of Mullins effect. This effect is characterized by a big hysteresis. In the second cycle, there is a typical stress drop, which decreases in each following cycle. In case of the cyclic deformation with constant amplitude, the stresselongation characteristics are stabilized over several cycles (usually up to 10 cycles). For textile materials, the DIN 53835-13 standard is defined [17] and according to the mentioned standard, the conditions are taken into consideration during the first 5 cycles.

The design of method for cycle loading tests of composites with a textile fiber and an elastomer matrix on a test machine with a video-extensometer has these conditions: the loading speed 250 mm/min for cycles and 50 mm/min for a pre-test by force value 2 N [17]. Five cycle loops are applied. Every cycle loop consists of five cycles. Every cycle is defined as loading to a certain percentage of elongation between clamps of a test machine and unloading to a certain percentage of elongation between clamps of a test machine and between clamps of a test machine.

For angles 0° and 45°, the first cycle loop consists of cycles with loading to 30% and unloading to 3% of elongation (not 0% because the negative force is not possible during tensile testing for certain composite specimens with the textile reinforcement). The second loop consists of cycles with elongation higher by 10%: loading to 40% and unloading to 10% of elongation. The third loop consists of five cycles that have loading to 50% and unloading to 20% of elongation, the fourth loop with cycles has loading to 60% and unloading to 30% of elongation. The fifth loop has cycles with different elongations, the loading to 60% is the same as fourth loop and unloading is 5% of elongation. The final step is loading to 100% of elongation. The specimens with a cord angle of more than 45° have a higher rigidity, so the method is different for an angle of 60°: all values of elongations are multiple 0.4 of values of elongations for angles of 0°, 30° and 45°.

2.4 Experimental apparatus

The test machine Autograph AG-X plus 5kN – Schimadzu with a video-extensometer for large strain as tensile tests of composite materials with elastomer and viscoelastic materials with the test mode Control of software Trapenzium X version 1.4.5 is used for the tests of cyclic loading in tensile with cycle loops. Before the tests, calibration of the video-extensometer is required.

The software Matlab was used for separation of data for every cycle for obtain graphic curves.

3 RESULTS AND DISCUSSION

3.1 Geometrical parameters of cords

The geometric parameters of the reinforcements of tire casing 245/40 R18 in place end of steel-cord belts are showed on the Figure 5 and schematic structure in the center of the tread is on the Figure 6.



Figure 5 The image analysis of part of tire casing 245/40 R18

The EPM of the textile cap ply is approx. 850 m^{-1} . The diameter of cords is 0.69 mm and the thickness of the cap ply is approx. 1.2 mm. The textile carcass has 0.5 mm diameter of cords and the thickness is 0.92 mm. The steel cord belts consist of two plies with a density of 920–960 m⁻¹ and the cord construction is 2x0.30 mm. The thickness of the steel

cord belt (two plies altogether) is 1.94 mm. The thickness of layers of elastomer under tread is visible on the Figure 6.



Figure 6 Geometrical parameters of cords in cross-section

The geometric parameters (Figure 6), which were obtained by an image analysis of the cross-section (the accuracy of the parameters is 95%), will be used as necessary geometric input data in order to create a computational model with a real configuration of cords.

The obtained information about the geometric arrangement of reinforcements can be used also for an optimization of arrangement of cords in a tire casing in order to gain better stiffness parameters in individual directions.

3.2 Composite after tests of cycle loading

Deformations of specimens are shown in Figure 7. The geometrical change of the specimen shape is not symmetrical for an angle of 45°, a part of the specimen was pulled from jaws of the testing machine during the test. White lines on a side of the surface of the sample are signs of better representation of deformation during the test.



Figure 7 Photos of specimens by a video-extensimeter for the deformation 100 mm (photos obtained by a video-extensimeter)

Raw data from Trapezium X have over 46 000 rows for every angle. The further data processing is difficult because of a large number of data fields in Microsoft Excel. Therefore the software Matlab was used for searching of cycle maximum and minimum from raw data.

Dependences of true stress on elongation between points for a video-extensometer (marking as elongation ex.) are:

- the Figures 8 and 9 (in Figure 8 dependences of engineering stress on elongation between clamps of the test machine are only for comparison with true stress - elongation ex.) for a cord angle of 45°;
- the Figure 10 for a cord angle of 0°;
- and the Figure 11 for a cord angle of 60° (a different method).

The behavior of specimens during the tests is very different.

The fifth cycle in every cycle loop can be considered as a stable cycle because difference between fourth and fifth cycle is about to 5%. Therefore the dependences of fifth cycle of every cycle loop are important for the comparison between the cord angles. The comparisons of the fifth cycles are given in Figure 12 as dependences of true stress on elongation ex.

The approximate the dependences for a cord angle of 0° (Figure 12) can be used as input material parameters of an elastomer matrix.

The envelope curve for a cord angle of 45° is in Figure 13. This curve can be used as input material data, which describes a textile cap ply as a whole, for computational modeling of a specific tire carcass e.g. a sport bike tire [18].

The computation modeling and calculations of longfiber composites are very difficult because the accurate materials characteristics of matrixes [19] and reinforcement are needed but these accurate materials characteristics have to be obtained from the tests of cycle loading.



Figure 8 Dependences of engineering stress on elongation between clamps for a cord angle of 45°



Figure 9 Dependences of true stress on elongation between points for a video-extensometer for a cord angle of 45°



Figure 10 Dependences of true stress on elongation between points for a video-extensometer for a cord angle of 0°



Figure 12 Comparison of the fifth cycle of cord angles 0° and 45°

4 CONCLUSSIONS

The geometric parameters, which were obtained by the image analysis of cross-section, will be used as necessary geometric input data in order to create the computational model with real configuration of cords. The geometric parameters, which were obtained by an image analysis of the cross-section (the accuracy of the parameters is 95%), will be used as necessary geometric input data in order to create a computational model with a real configuration



Figure 11 Dependences of true stress on elongation between points for a video-extensometer for a cord angle of 60°



Figure 13 The final envelope curve for a cord angle of 45°

of cords. The results can be used for an optimization of the deposition angle of textile reinforcement in composites.

In this study, methods for testing of textile composites with five cycle loops for different elongation with five cycles in every cycle loop have been designed with following finding:

• The fifth cycle in every cycle loop can be considered as a stable cycle, because difference between fourth and fifth cycle is small.

- The values of true stress for a cord angle of 45° are approximately 20–25% higher than values for a cord angle of 0° (reinforcement has right angle to loading force).
- Suggestion for the second option of the method: unloading for the next cycle loop only to the maximum elongation from the previous cycle loop.

A mathematical description of the envelope curve from the fifth cycles (Figure 13) is search. The curve can be replaced by polynomial of 9^{th} degree.

The results from tests of low cyclic loading can be used for the optimization of the deposition angle of textile reinforcement in composites.

For the specimens with steel-cord, different (lower) elongations for definition of cycle loops must be used because the specimens of steel-cord belt have higher stiffness than the specimens of composite with textile reinforcement such as a tire carcass.

The test machine Autograph AG-X plus 5 kN – Schimadzu has a hybrid temperature-humidity chamber allowing the tests from -70 to 180° C and from 20 to 80° C, it is possible to change the humidity from 30 to 95%. Future research is needed for the tests of cyclic loading of composites, which will be realized at different temperatures.

ACKNOWLEDGEMENT: The contribution was supported by the Cultural and Educational Grant Agency of the Slovak Republic (KEGA), grant No. KEGA 005TnUAD-4/2016 and the project "Centrum pre testovanie kvality a diagnostiku materiálov" ITMS code 26210120046 of the Operational Program Research and Development funded from European Fund of Regional Development.

5 REFERENCES

- 1. Barbero E.J.: Introduction to composite materials design, Taylor and Francis, 2010, ISBN 978-1-4200-7915-9
- Koštial P., Krmela J., Frydrýšek K., Ružiak I.: The Chosen Aspects of Materials and Construction Influence on the Tire Safety, Composites and Their Properties, Chapter 13, InTech, Rijeka, 2012, pp. 265-298, ISBN: 978-953-51-0711-8. doi: 10.5772/48181
- 3. Composite authors: Rubber Technology, GC Tech Peter Gerši, Trenčín, 2006, ISBN 80-969189-5-8
- Nideröst K.J., Walters M.H.: Cord reinforced elastomers, In: Comprehensive Composite Materials, New York, Elsevier, 2000, pp. 77-105. ISBN: 978-0-08-042993-9
- Shiguo R. et al.: Mechanical Properties and Failure Behaviour of Cord/Rubber Composites, Applied Composite Materials 11(6), 2004, pp. 353-357, doi: 10.1023/B:ACMA.0000045312.61921.1f

- Ferry J.D.: Viscoelastic properties of Polymers, New York, John Wiley & Sons, 1980, 117, ISBN: 978-0471048947
- Jambrich M.: Štruktúra a vlastnosti výstužných technických vlákien (Structure and properties of reinforcing technical fibers), Proceedings of SRC (Slovak Rubber Conference), Púchov, 2001, (in Slovak)
- Tanner J.A.: Computational methods for frictional contact with applications to the space shuttle orbiter nose-gear tire, Hampton, Virginia, NASA Langley Research Center, 1996, 58 p., NASA-TP-3573
- 9. The Pneumatic Tire, Gent A.N., Walter J.D. (Eds.), NHTSA, 2006, 705 p., US DOT HS 810 561
- ISO 2062:2009, Textiles Yarns from packages Determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester
- Marcín J., Zítek P. :Gumárenské výroby I Pneumatiky (Rubber Manufacturing I – Tires), SNTL, Prague, 1985, 490 p., ISBN 04-626-85 (in Czech)
- Krmela J., Dvořák Z., Pešlová F.: Long-Fibre Composite Experimental Modelling, Scientific Bulletin – 7th International Multidisciplinary Conference, Baia Mare, North University of Baia Mare 21, 2007, pp. 369-374, ISSN 1224-3264, Access mode: <u>http://www.nordtech.ubm.ro/issues/</u> 2007/2007.01.57.pdf
- 13. Eric Greene Associates: Marine Composites, 1999, Access mode: <u>http://www.ericgreeneassociates.com/</u> <u>images/MARINE COMPOSITES.pdf</u>
- 14. ASTM D-3039-76:1985, Standard Test Method for Tensile Properties of Fiber-Resin Composites
- Krmela J., Krmelová V.: Tire casing and their material characteristics for computational modeling of tires, Proceedings of 16th International Scientific Conference Engineering for Rural Development, Jelgava, 2011, pp. 206-211, doi: 10.22616/ ERDev2017.16.N043, ISSN 1691-5976
- Le Cam J.B., Toussaint E.: Cyclic volume changes in rubber, Mechanics of Materials 41(7), 2009, pp. 898-901, doi: 10.1016/j.mechmat.2009.02.004
- 17. DIN 53835-13:1983, Testing of textiles; determination of the elastic behaviour of textile fabrics by a single application of tensile load between constant extension limits
- Krmela J., Vančo M.: Bike tire with textile reinforcement experiment and computational modelling, Vlakna a Textil (Fibres and Textiles) 21(3), 2014, pp. 31-34
- Krmela J.: Tire Casings and Their Material Characteristics for Computational Modeling, Scientific monograph. Czestochowa, Poland: Oficyna Wydawnicza Stowarzyszenia Menadżerów Jakości i Produkcji (Printing House The Managers of Quality and Production Association), 2017, 109 p., ISBN 978-83-63978-62-4