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27th Polish -Slovak Scientific Conference on
MACHINE MODELLING AND SIMULATIONS
Rydzyna, 5.9.2022

POLYMER COMPOSITES

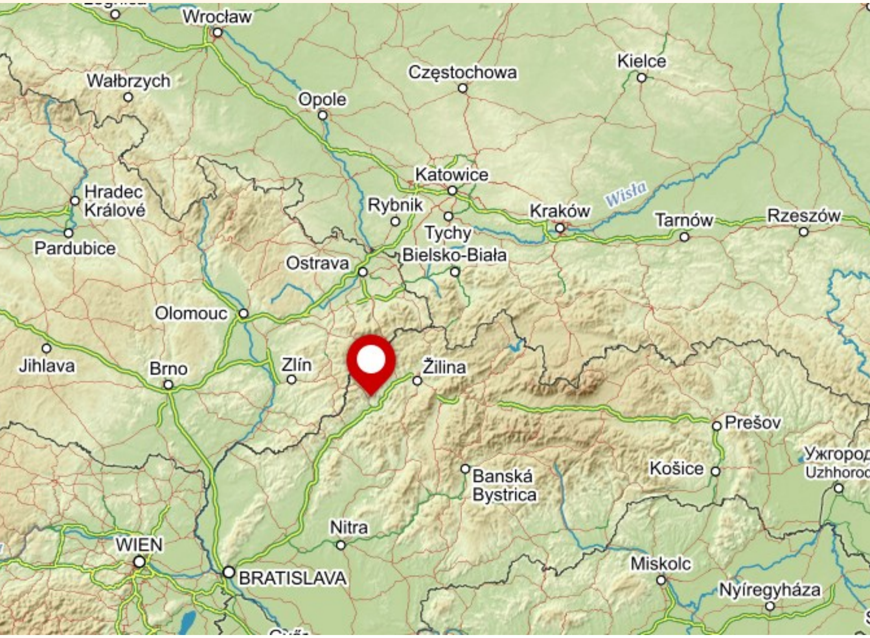
INTERACTION BETWEEN TESTING AND COMPUTATIONAL SIMULATIONS

Jan KRMELA

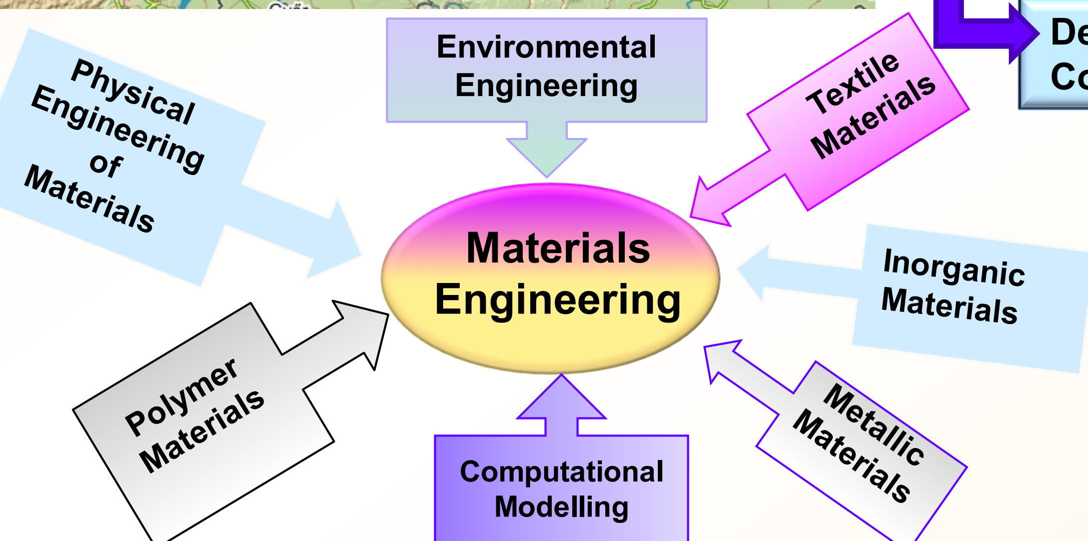
50 slides

www.fpt.tnuni.sk

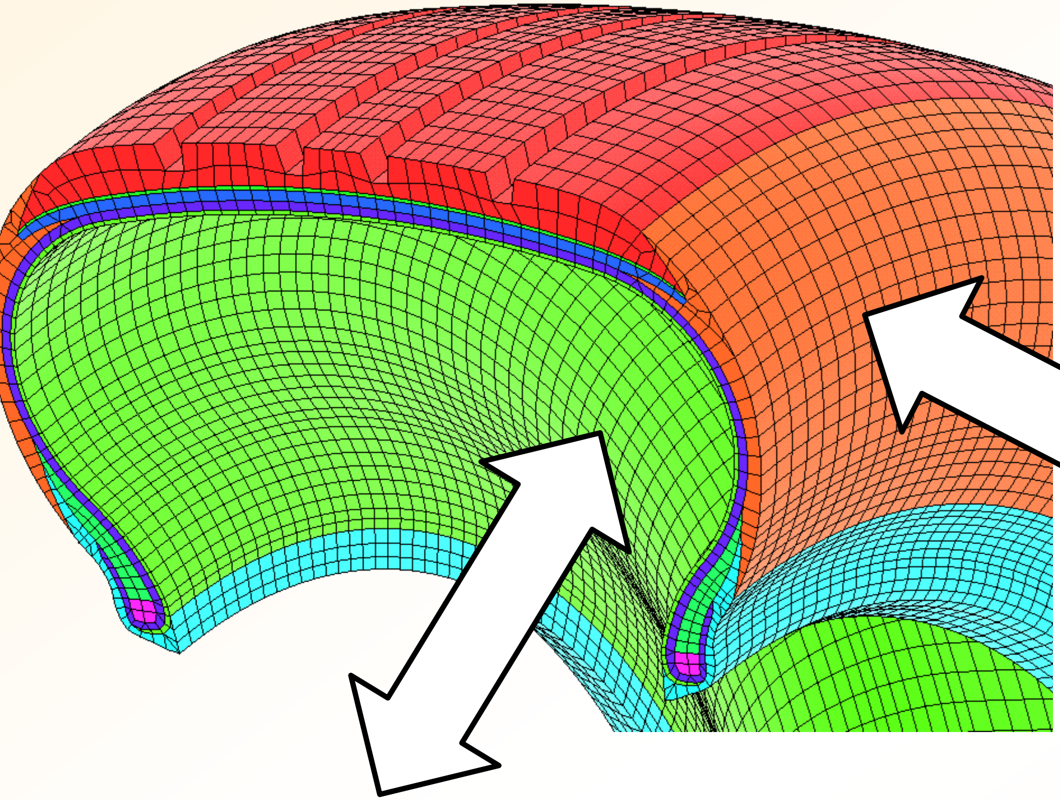
Faculty of Industrial Technologies in Púchov

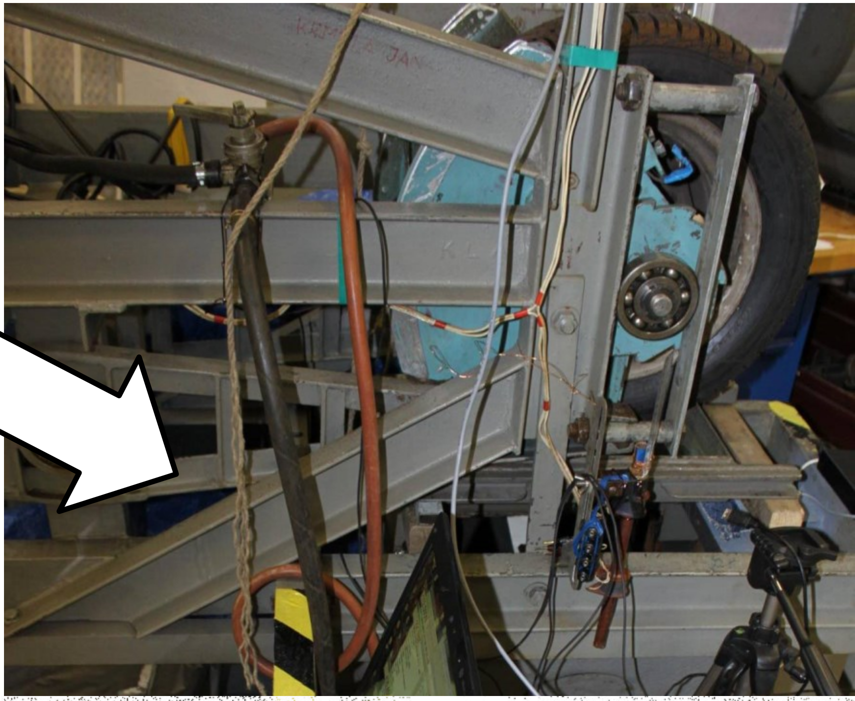


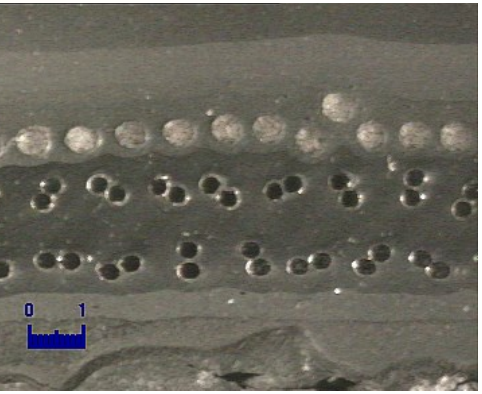
- Department of Materials Technologies and Environment
- Department of Materials Engineering
- Department of Numerical Methods and Computational Modelling

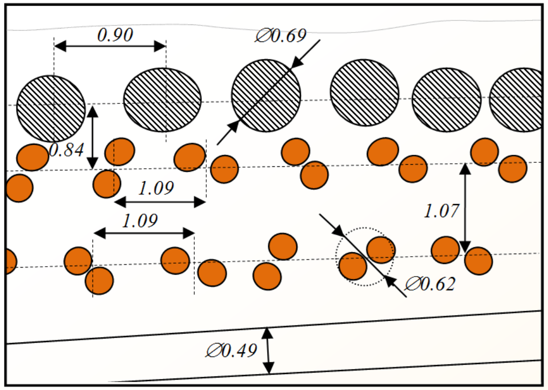


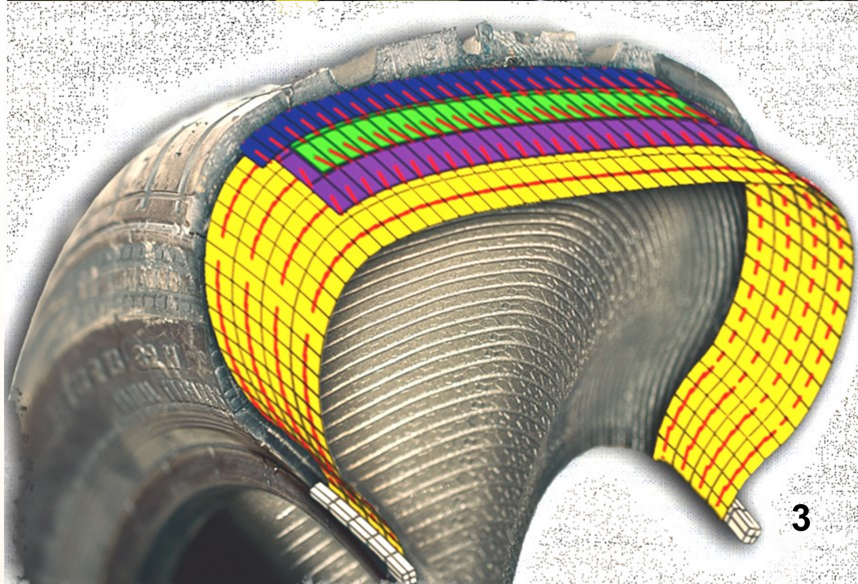
INTRODUCTION











INTRODUCTION

1. Material and geometrical parameters are necessary as input data for tire computational models for stress-strain analysis, modal analysis etc.
2. The test data of composites are used as the verification parameters for the comparison of simulation outputs with test results.

The research work deals with **computational simulation of basic and specific tests** of polymer composites with textile and steel cords, which are used as reinforcement for the composites.

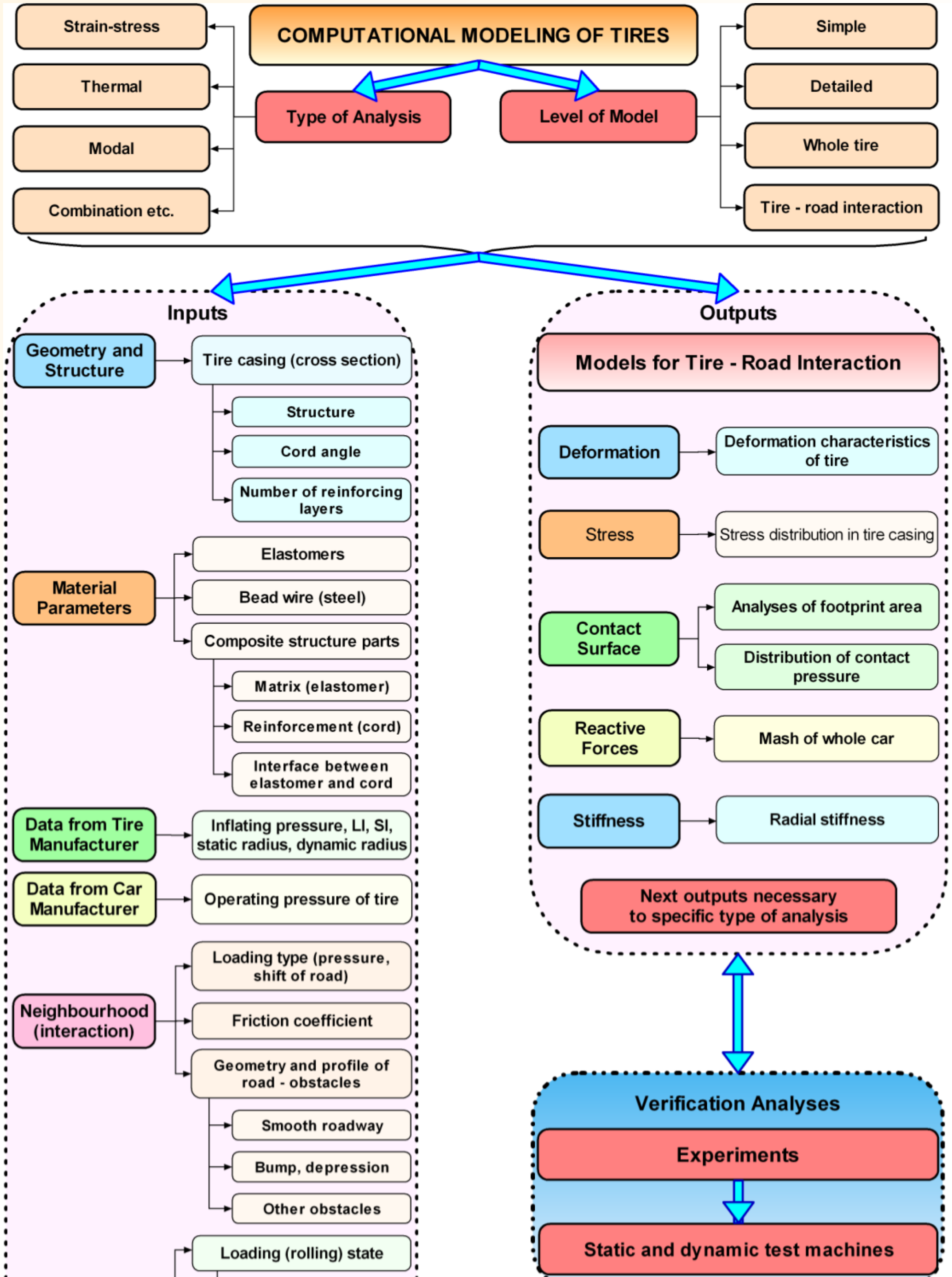
RESEARCH AIMS

The aims of this research work are:

1). Design of computational models which can be used for simulation of tests of composites based on experimental data which were obtained by test machine with video-extensometer and temperature chamber.

2). Design of computational models of tires.

3). Design of methods for specific cyclic testing of composites.

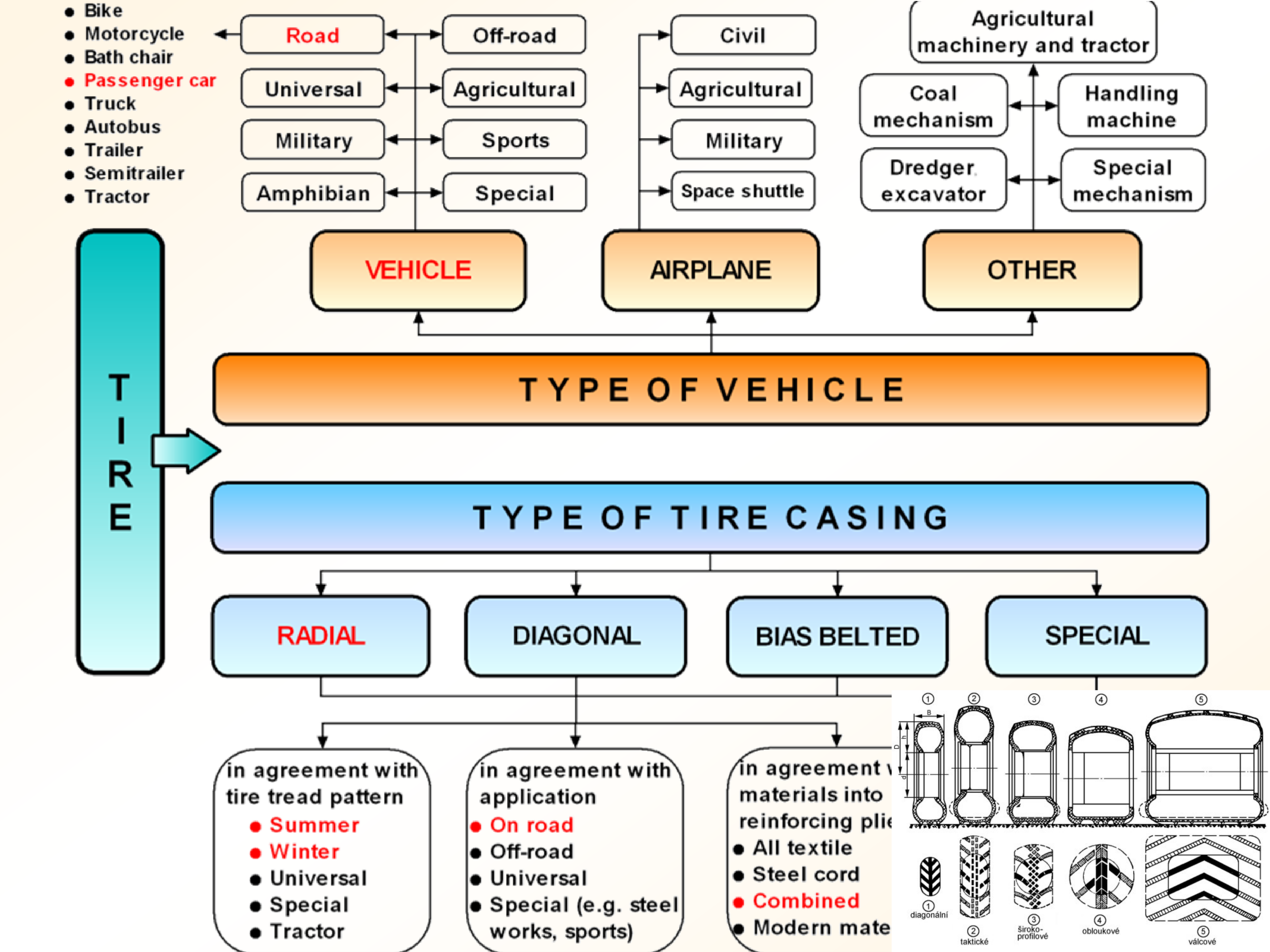

COMPUTATIONAL MODELING OF TIRES
Type of Analysis
Level of Model
Strain-stress
Thermal
Modal
Combination etc.
Simple
Detailed
Whole tire
Tire - road interaction
Inputs
Geometry and Structure
Tire casing (cross section)
Structure
Cord angle
Number of reinforcing layers
Material Parameters
Elastomers
Bead wire (steel)
Composite structure parts
Matrix (elastomer)
Reinforcement (cord)
Interface between elastomer and cord
Data from Tire Manufacturer
Inflating pressure, LI, SI, static radius, dynamic radius
Data from Car Manufacturer
Operating pressure of tire
Neighbourhood (interaction)
Loading type (pressure, shift of road)
Friction coefficient
Geometry and profile of road - obstacles
Smooth roadway
Bump, depression
Other obstacles
Loading (rolling) state
Outputs
Models for Tire - Road Interaction
Deformation
Deformation characteristics of tire
Stress
Stress distribution in tire casing
Contact Surface
Analyses of footprint area
Distribution of contact pressure
Reactive Forces
Mash of whole car
Stiffness
Radial stiffness
Next outputs necessary to specific type of analysis
Verification Analyses
Experiments
Static and dynamic test machines

APPROACH

<u>COMPUTATIONAL MODELING</u> (analyses: stress-strain, modal, temperature field, combine, dynamic) via FEA program ANSYS

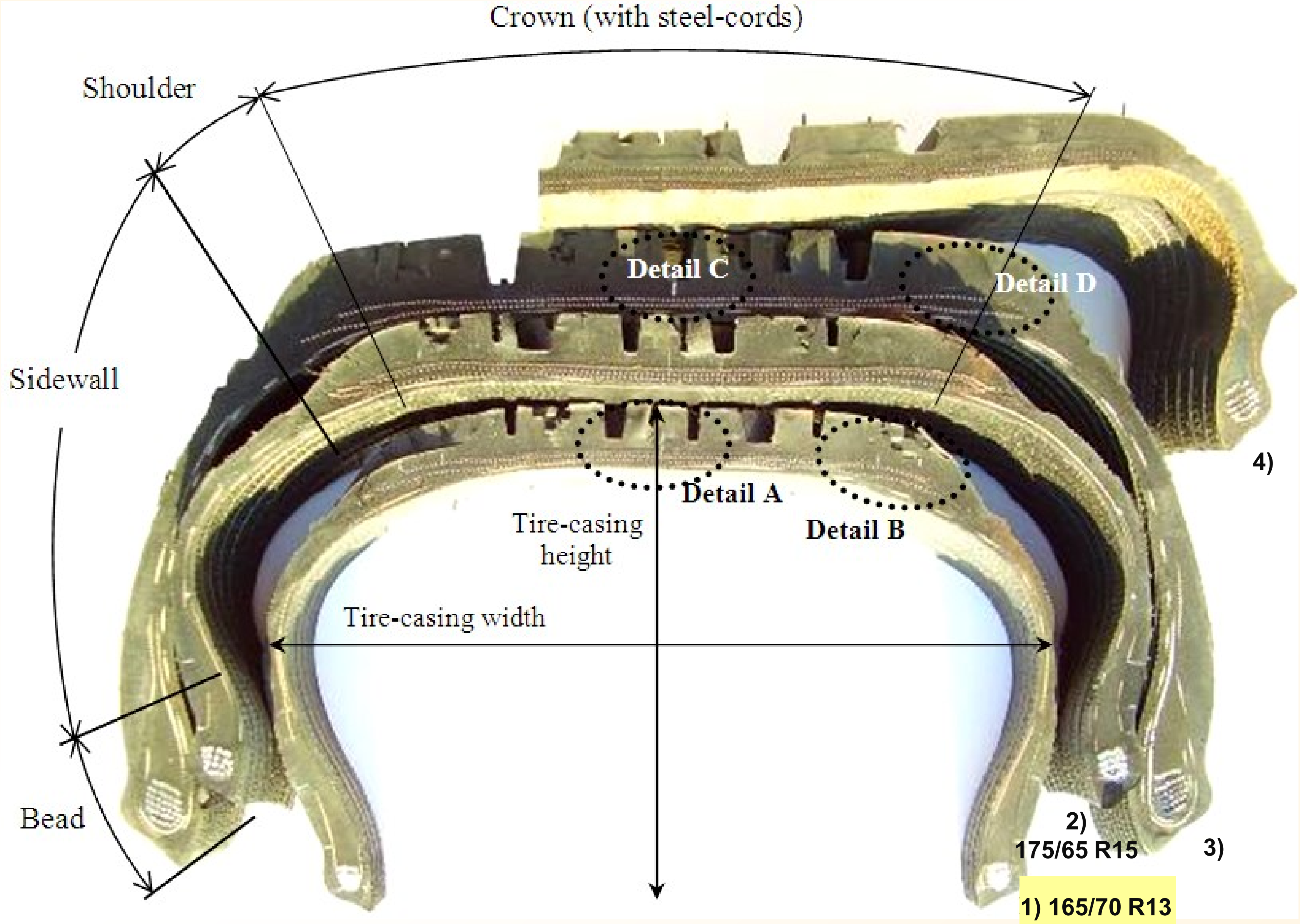
- ✓ <u>EXPERIMENTS</u> OF MATERIAL PARAMETERS
- ✓ EXPERIMENTS OF TIRES ON „ADHESOR“
- ✓ PRESSURE FOOTPRINT <u>ANALYSES</u>

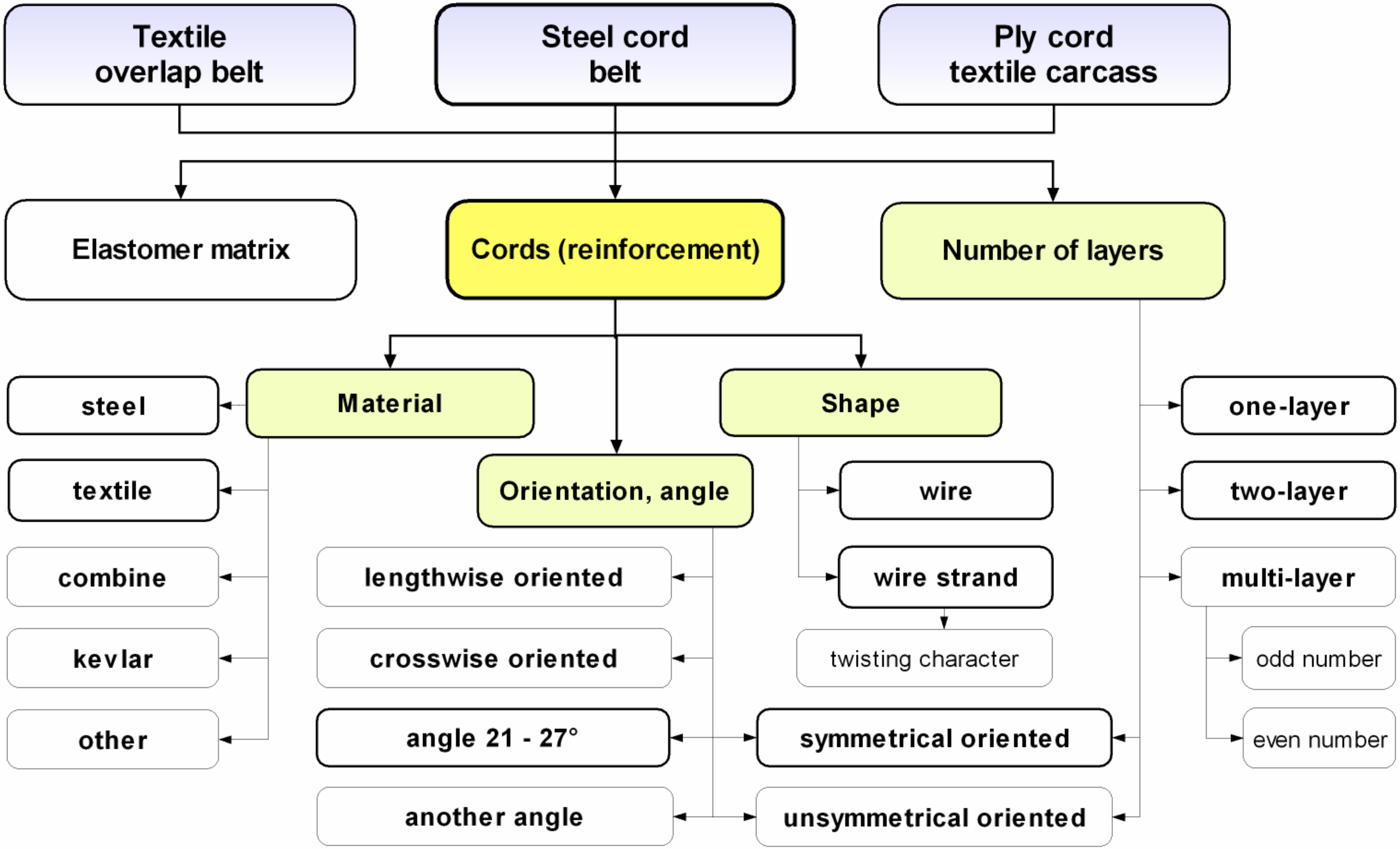
<u>VERIFICATION APPROACH</u> TO COMPUTATIONAL MODEL OF RADIAL TIRE



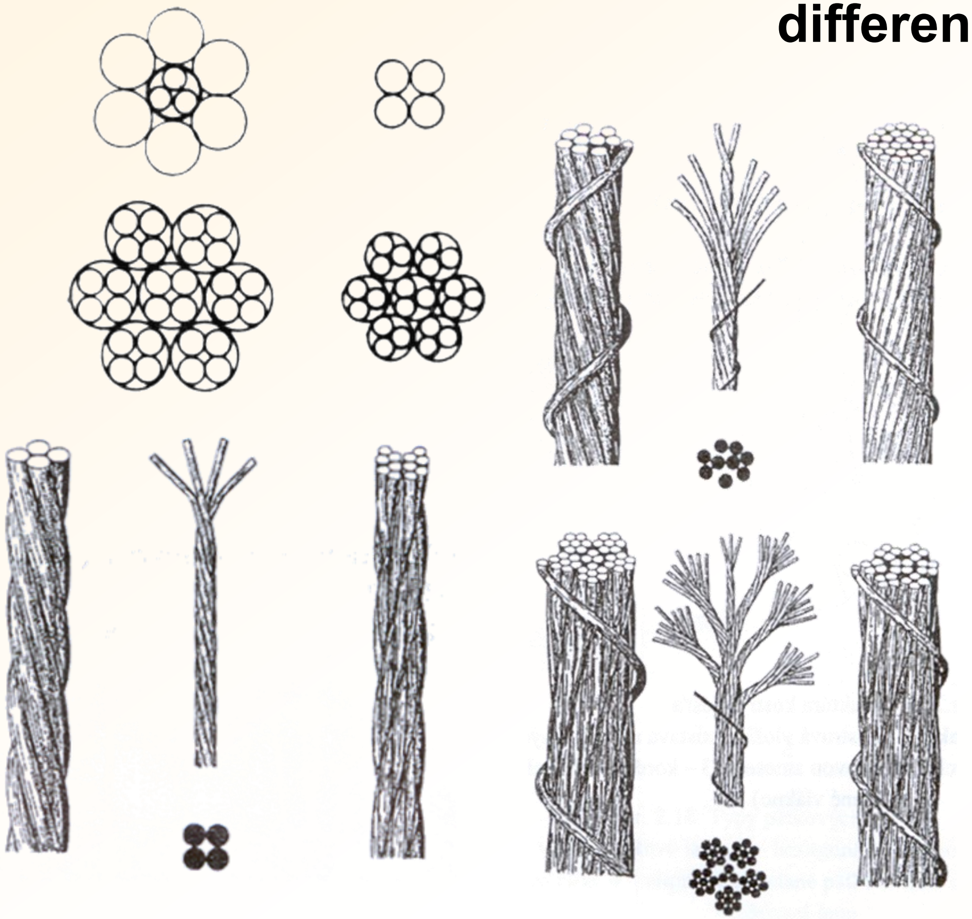
Bike
Motorcycle
Bath chair
Passenger car
Truck
Autobus
Trailer
Semitrailer
Tractor
Road
Off-road
Universal
Agricultural
Military
Sports
Amphibian
Special
Civil
Agricultural
Military
Space shuttle
Agricultural machinery and tractor
Coal mechanism
Handling machine
Dredger excavator
Special mechanism
VEHICLE
AIRPLANE
OTHER
TIRE
TYPE OF VEHICLE
TYPE OF TIRE CASING
RADIAL
DIAGONAL
BIAS BELTED
SPECIAL
in agreement with tire tread pattern
Summer
Winter
Universal
Special
Tractor
in agreement with application
On road
Off-road
Universal
Special (e.g. steel works, sports)
in agreement w
materials into
reinforcing plie
All textile
Steel cord
Combined
Modern mate
diagonální
taktické
široko-profilové
obloukové
válcové

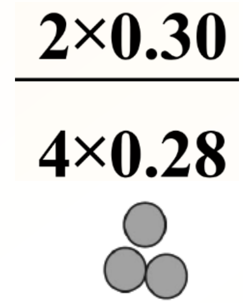
TIRE STRUCTURE



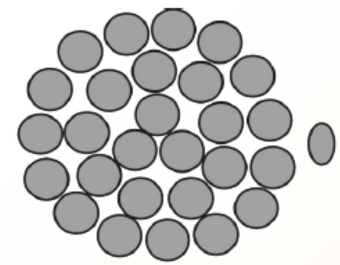

Textile overlap belt
Steel cord belt
Ply cord textile carcass
Elastomer matrix
Cords (reinforcement)
Number of layers
steel
Material
Shape
one-layer
textile
Orientation, angle
wire
two-layer
combine
lengthwise oriented
wire strand
multi-layer
kevlar
crosswise oriented
twisting character
odd number
other
angle 21 - 27°
symmetrical oriented
even number
another angle
unsymmetrical oriented

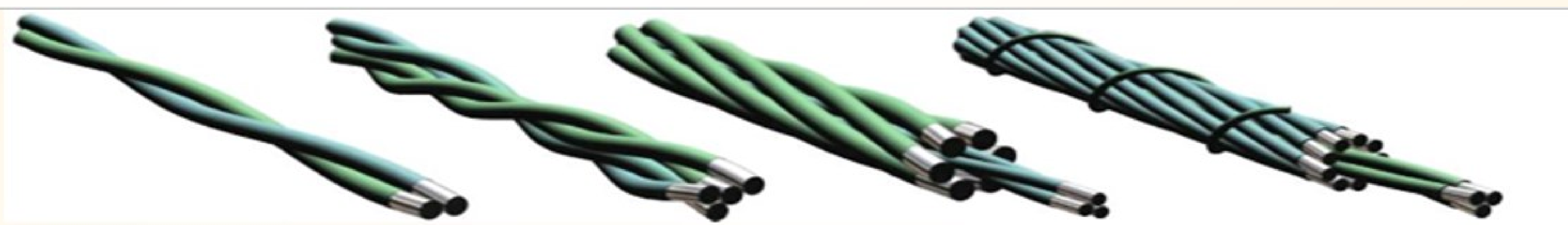
Steel-cords can be in form of thin wire or wire strand with different constructions





Tire for passenger car


Truck tire


2 x 0,30 2 + 2 x 0,30 3 x 0,20 + 6 x 0,35 3 + 9 x 0,22 + 1 x 0,15

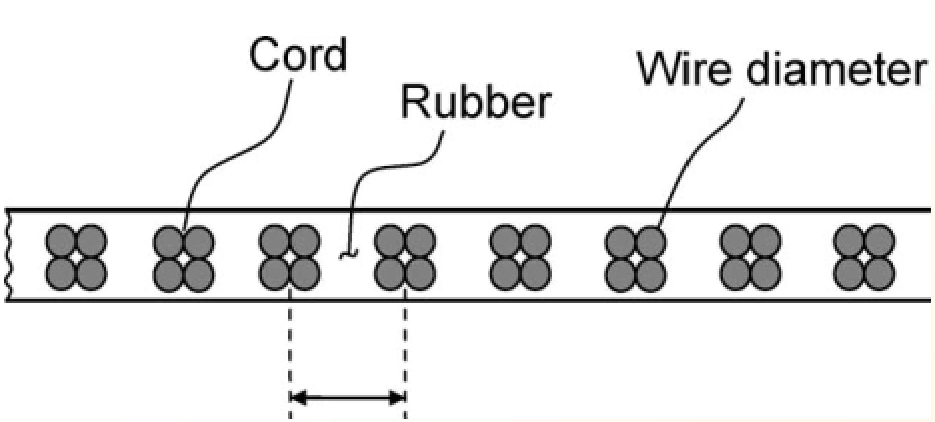
Tire cord types (by MATADOR Púchov and producer e.g. DRÔTOVŇA Hlohovec, BEKAERT):

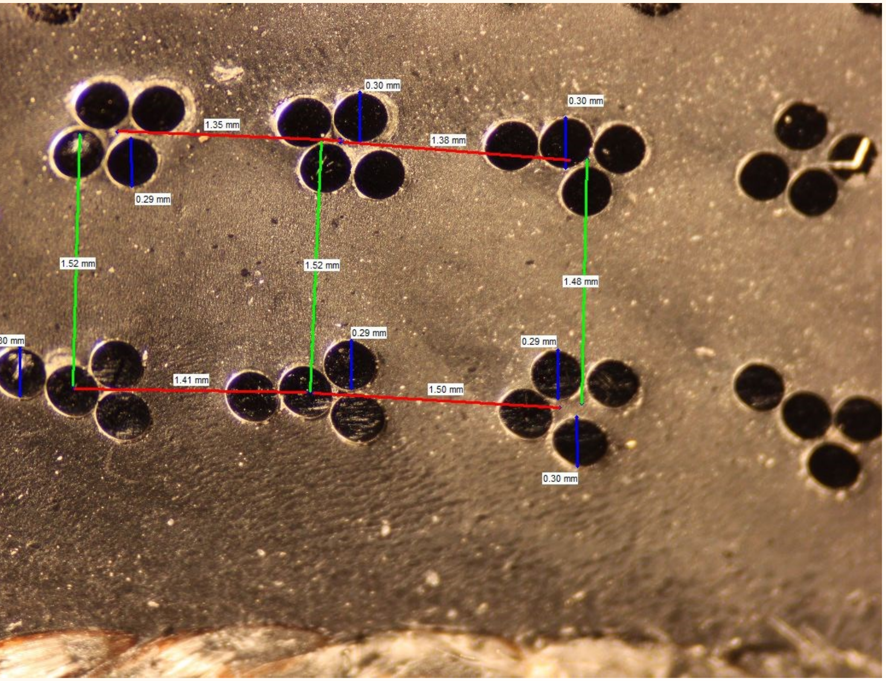
- **HT high tensile,**

- **NT normal tensile,**

- **HE HIGH ELONGATION CORD = e.g. 3x7x0,22 HE (= 3x7x0,22 SS) – overlap belt with angle 0°. Elongation up to 7.5 %. Expensive production.**

Modern cords: hybrid with polymer inside, carbon C 0,60-1,15%, manganate Mn 0,10-1,10%, silicon Si max. 0,90% + Cr, Ni, Cu, Co, V.

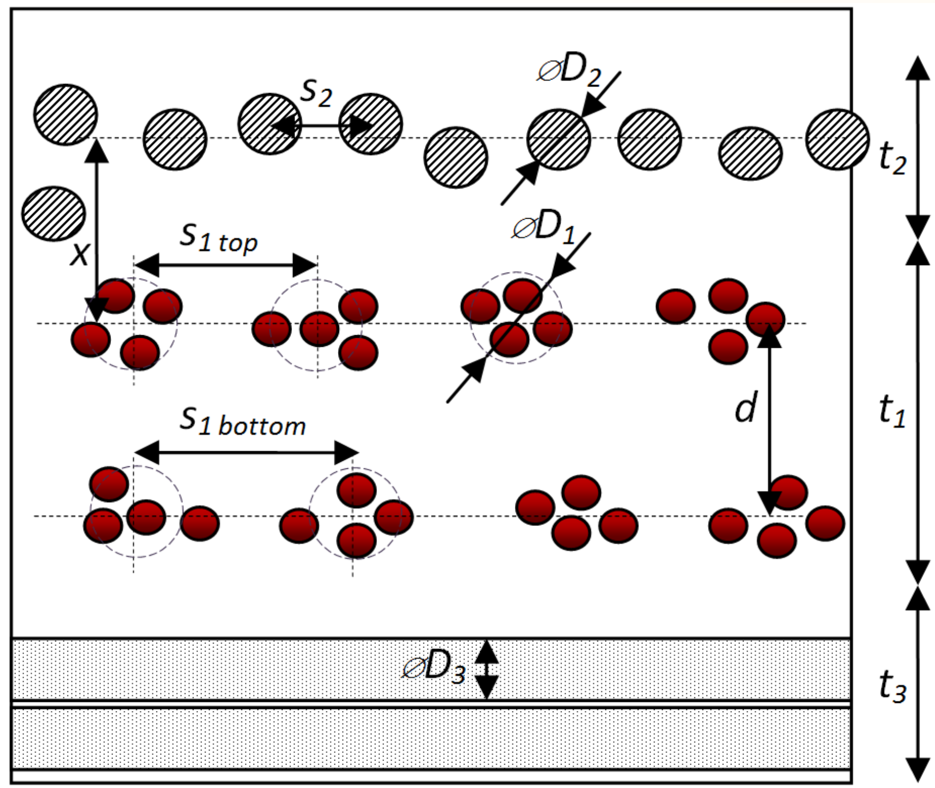


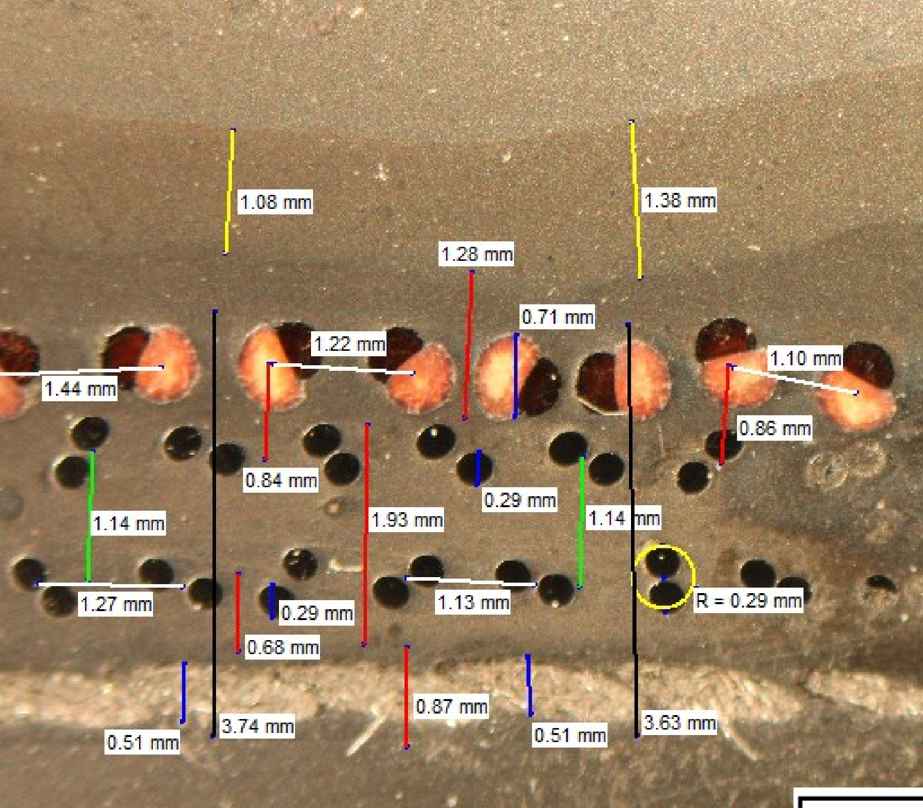


PHOTOGRAPHS ANALYSES

The image analysis is applied for obtaining the information about geometric parameters of cords such as distances between cords, ply thickness, cord diameters, etc.

Thickness of layers *t* [mm]
Diameter of cords *D* [mm]
Construction of steel-cords
Number of steel-cords per decimeter width of one steel-cord belt layer (plumb on cords) [$10cm^{-1}$] (EPDM) ……

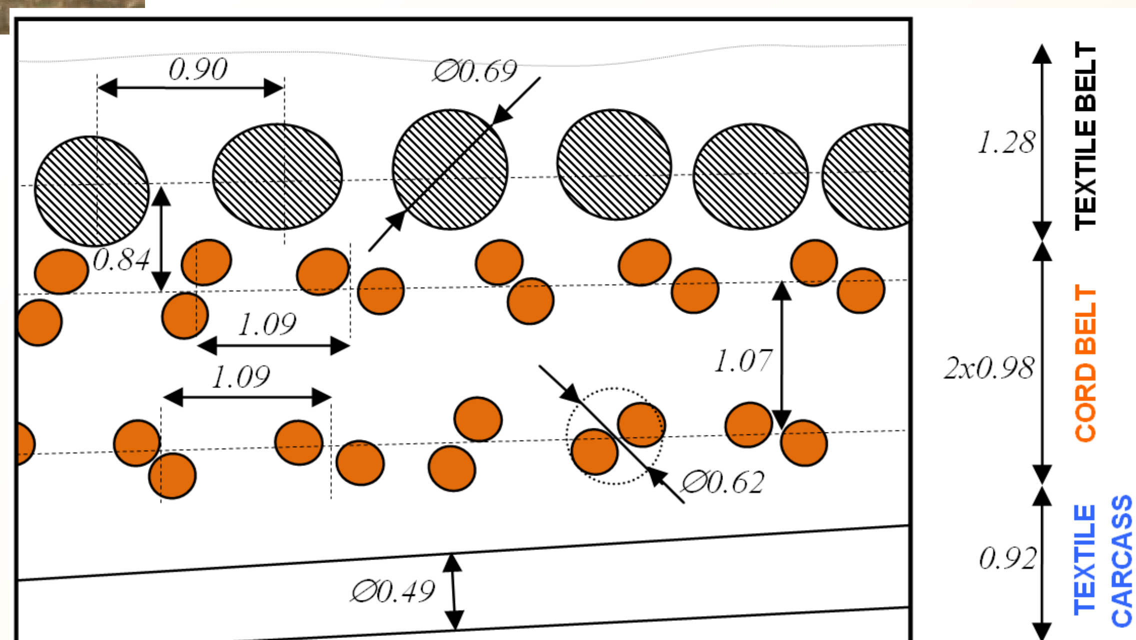


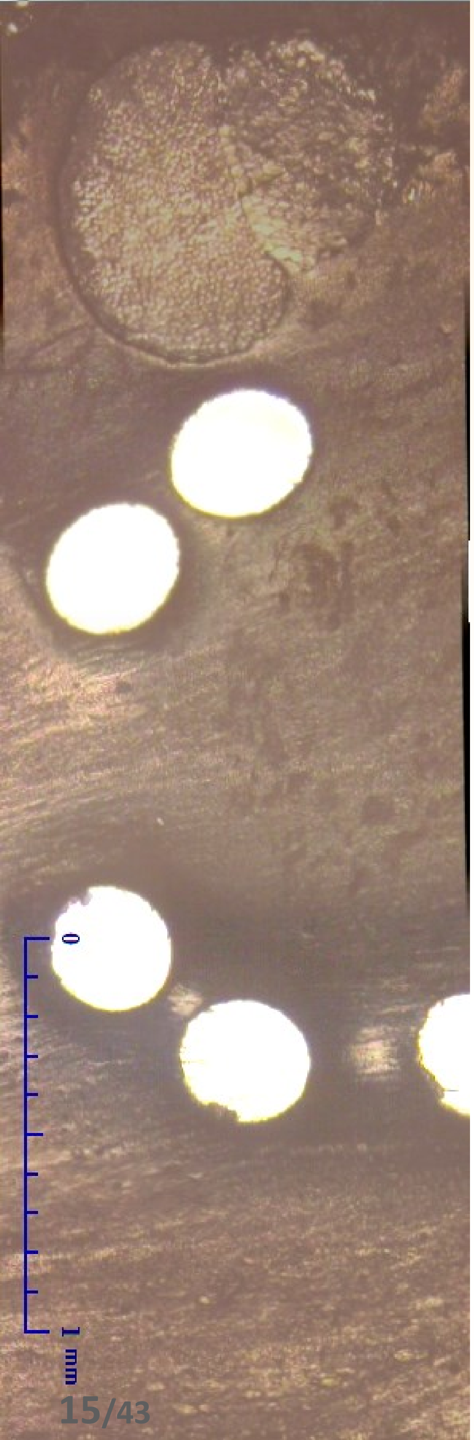


Data about cross-sections, construction-reinforcing plies, etc. are a necessary input for the creation of computational models of tires.

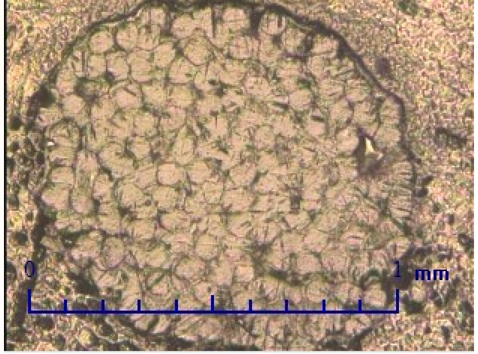
Thickness of layers *t* [mm]
Diameter of cords *D* [mm]
Construction of steel-cords
Number of steel-cords per decimeter width of one steel-cord belt layer (plumb on cords) [10cm^{-1}] (EPDM) ……

Structure of GEOMETRY in the tire-crown



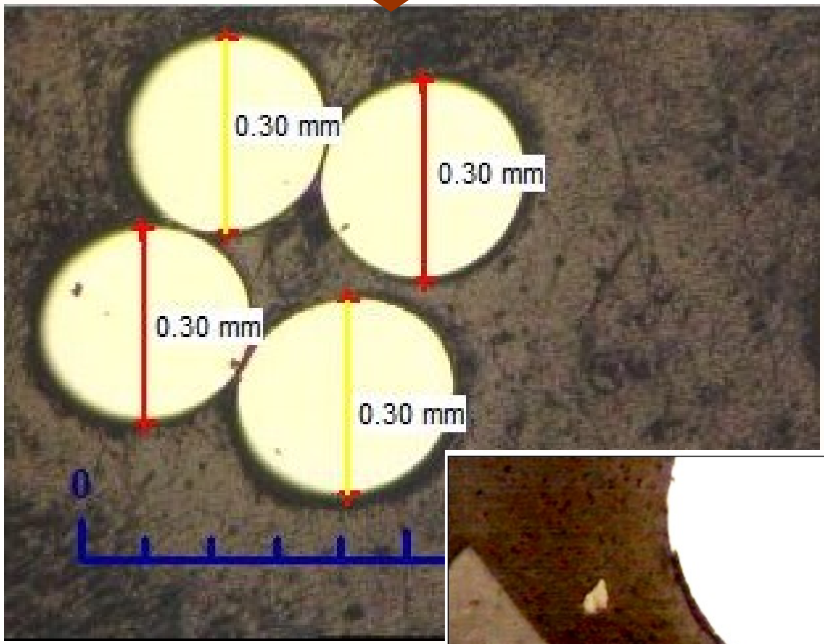


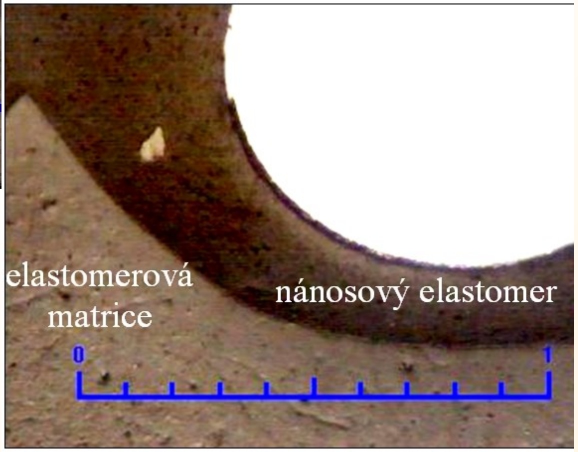
textile cord

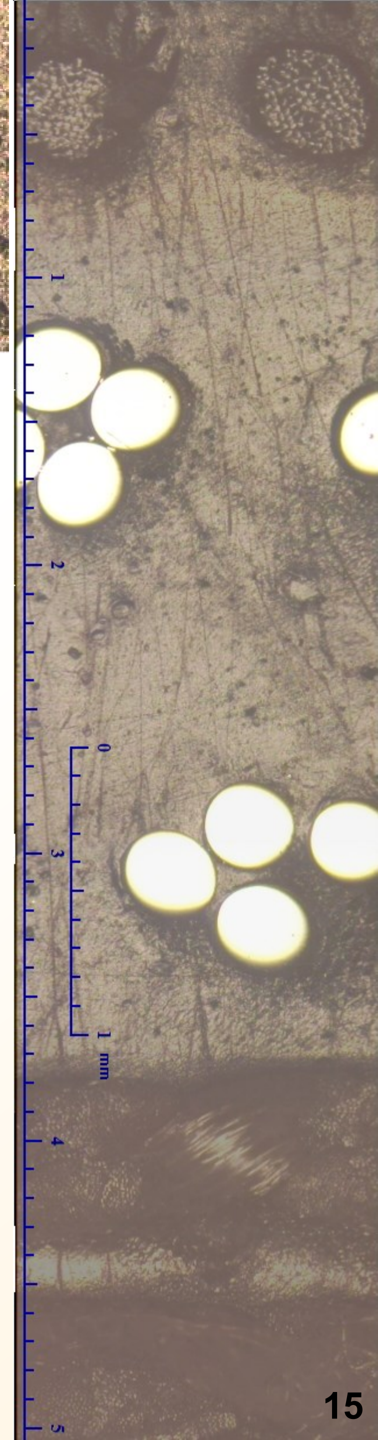


MICROSCOPY OBSERVATION

steel cord



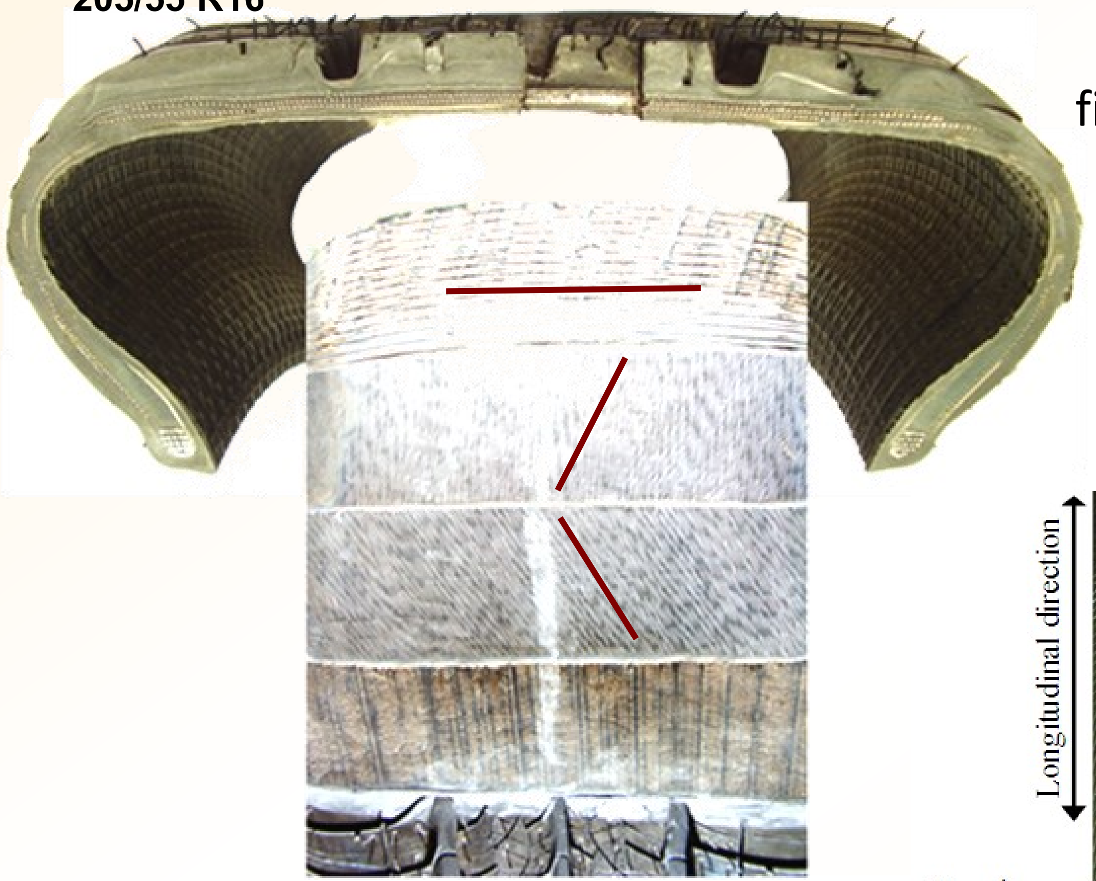




Truck tire casings or agricultural tire casings have different structures

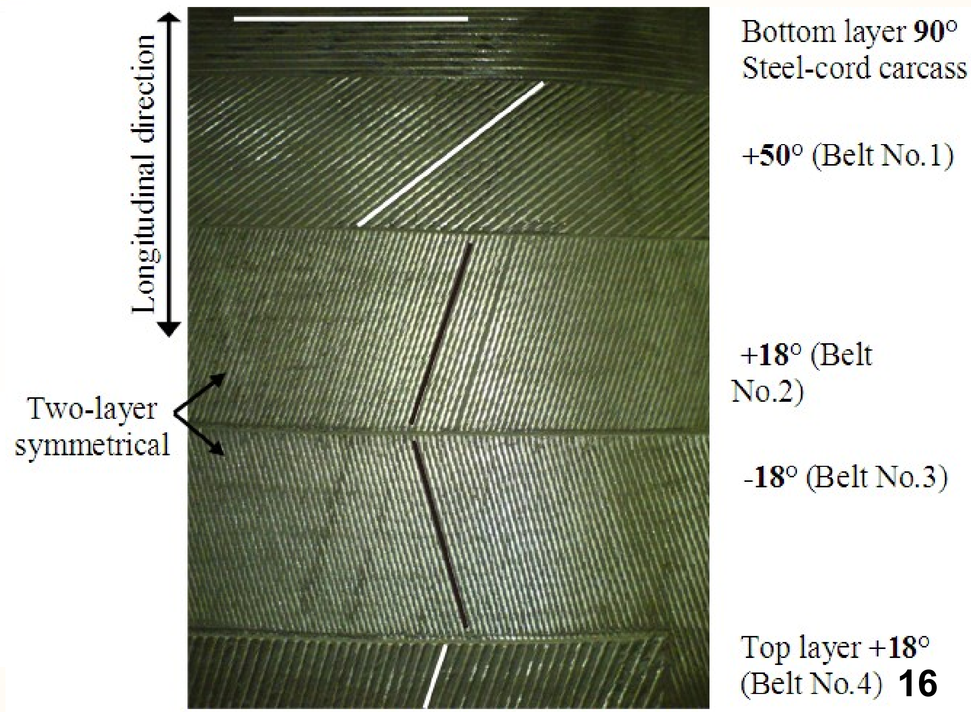
five layers in the middle of tire crown

205/55 R16



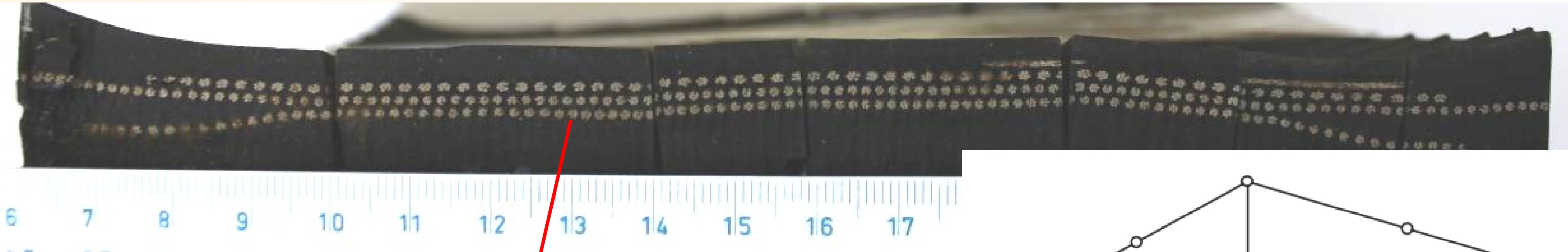
TRUCK radial tire – structure of belts of tire crown

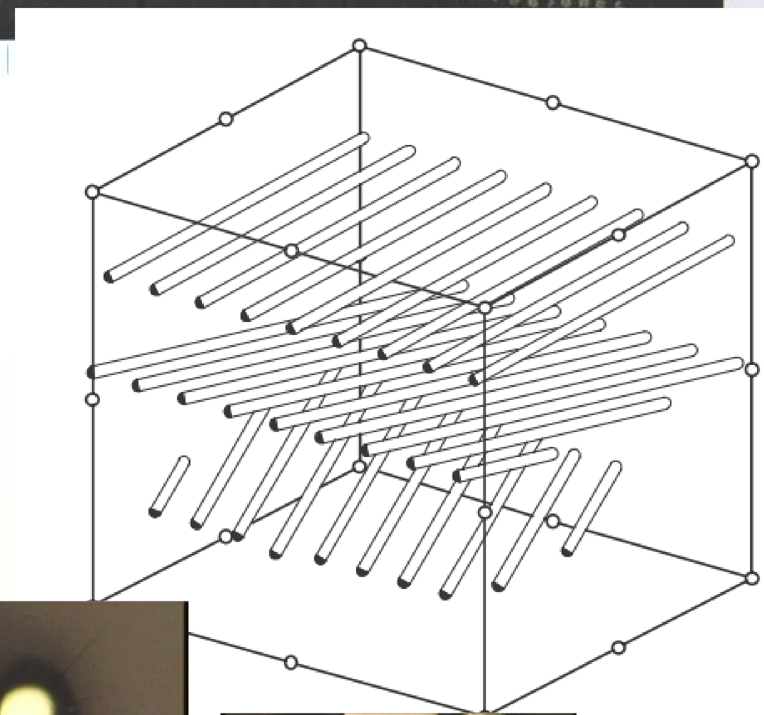
Matador 22.5”

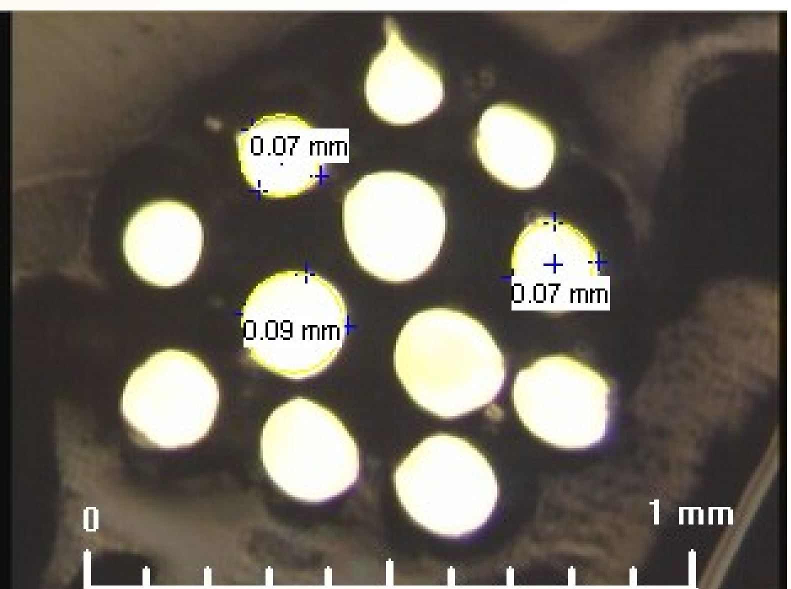


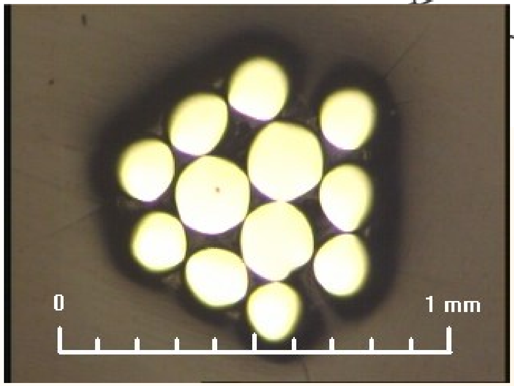
Structure of truck tire in the middle of tire crown

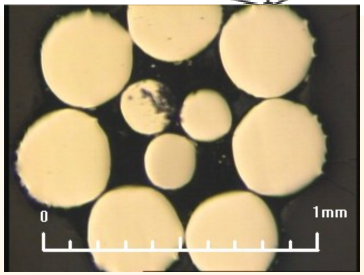
The cords have complicated constructions,
cord details from the microscopic observation











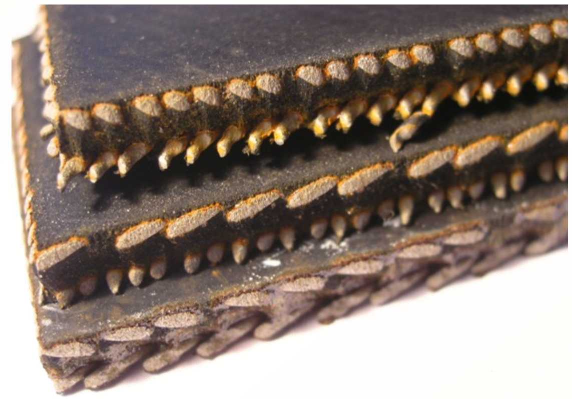
EXPERIMENTS

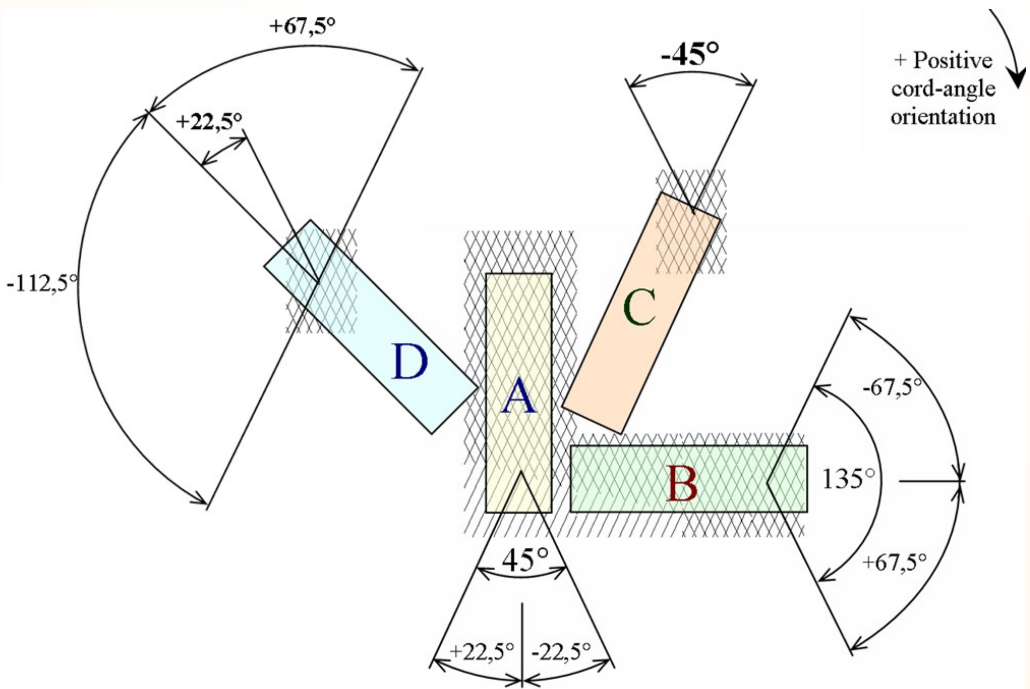
For computational modeling of parts of tire casings and tires, the material parameters of matrixes and reinforcements are necessary as input data for the computational model and the experimental data of composite structures can be used as the verification criteria for the comparison of computational outputs with test results. Therefore, **the results from tests of parts of tires are important**.

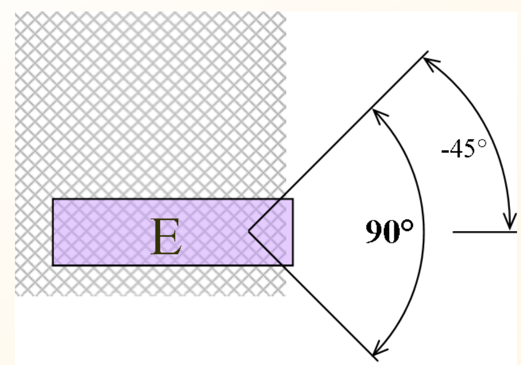
EXPERIMENTS OF PART OF TIRE CASING

The tire casing was cut by water jet cutter in longitudinal and transverse direction in order to obtain the specimens from the whole under-tread reinforcing area of the casing. The specimens were prepared with different width and it was 10, 15 and 20 mm.

steel cord belt ply of tire

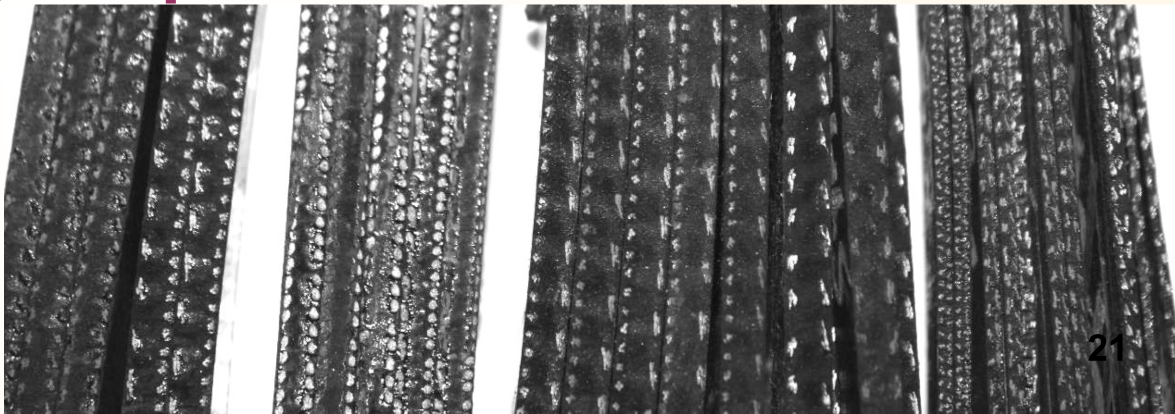


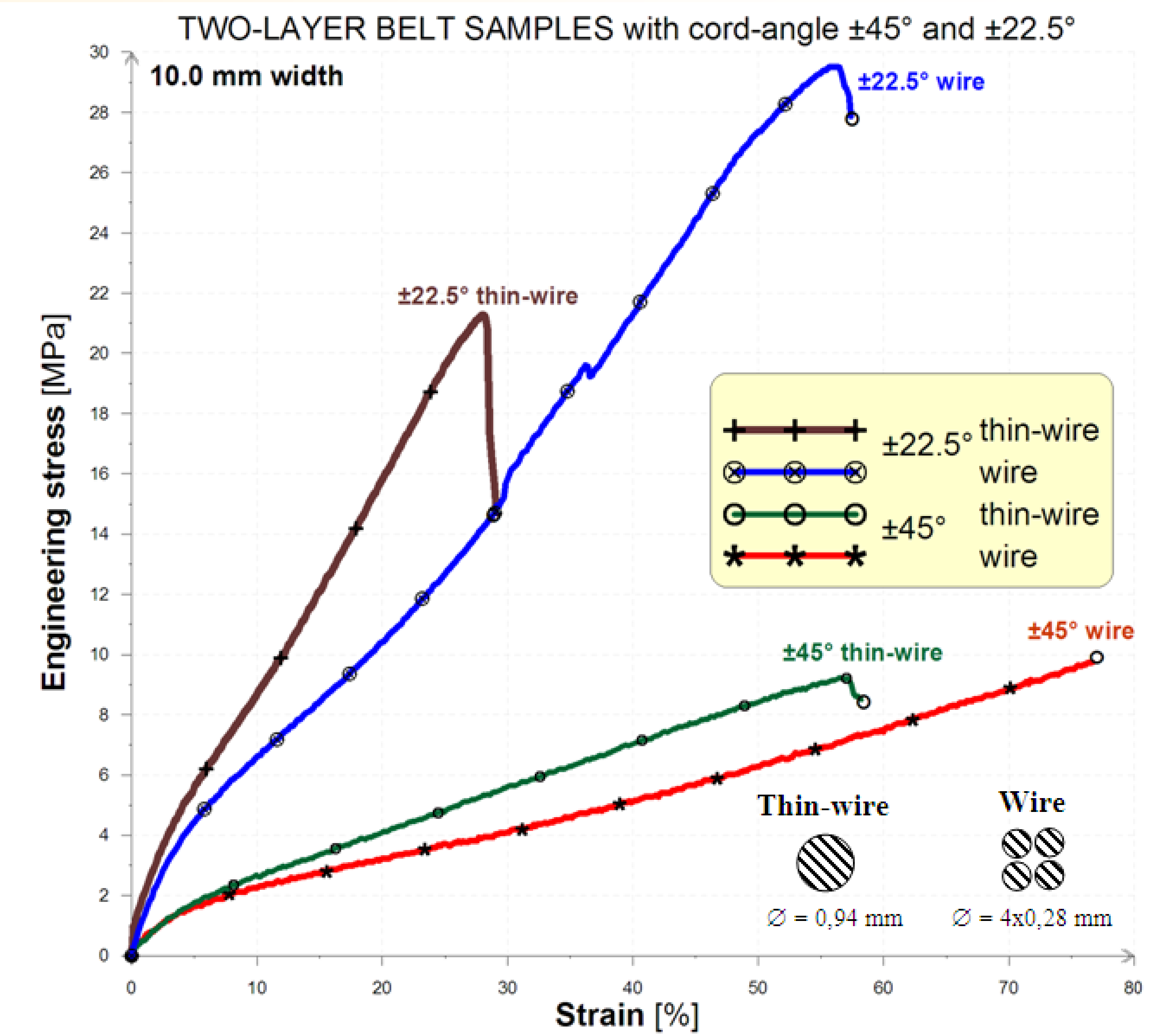




The samples must have different:

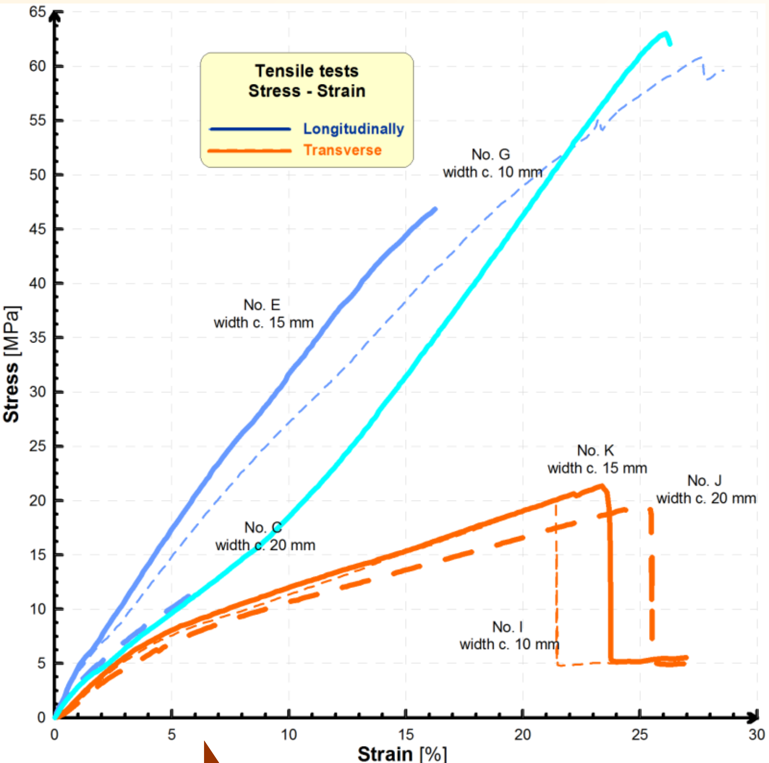
- **Angle** of cord (with respect of the direction of loading – not only longitudinal and transverse orientated samples);
- **Material** of cord (surface treatment);
- **Form** of cord (wire, thin wire);
- **Number of layers** (single-layer, two-layer, multi-layer);
- Specimen **width, shape** etc.

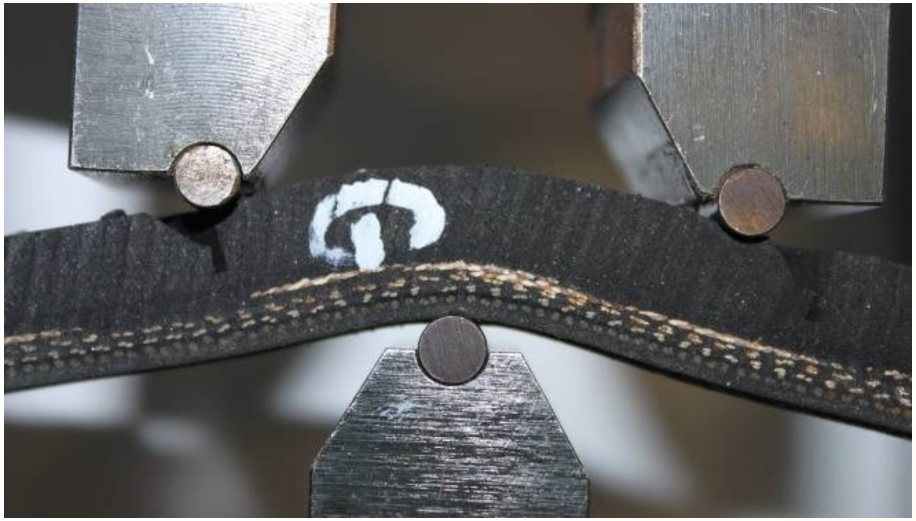


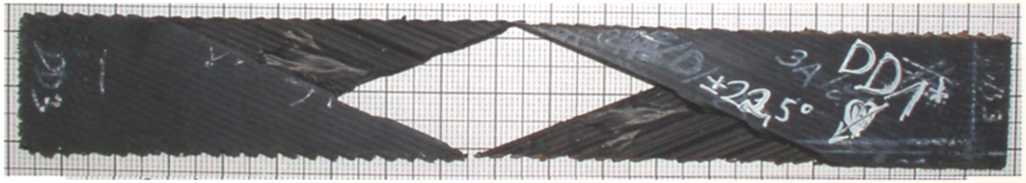


Outputs from tensile test of steel-cord belt samples – stress-strain dependences

TENSILE TESTS: The specific initial conditions of uniaxial static tensile tests are the speed of loading 10 mm/min and the initial length of specimen 80 mm between the clamps of the test machine.
BEND TESTS: The distance between outside points = 50 mm. The loading speed = 5 mm/min.







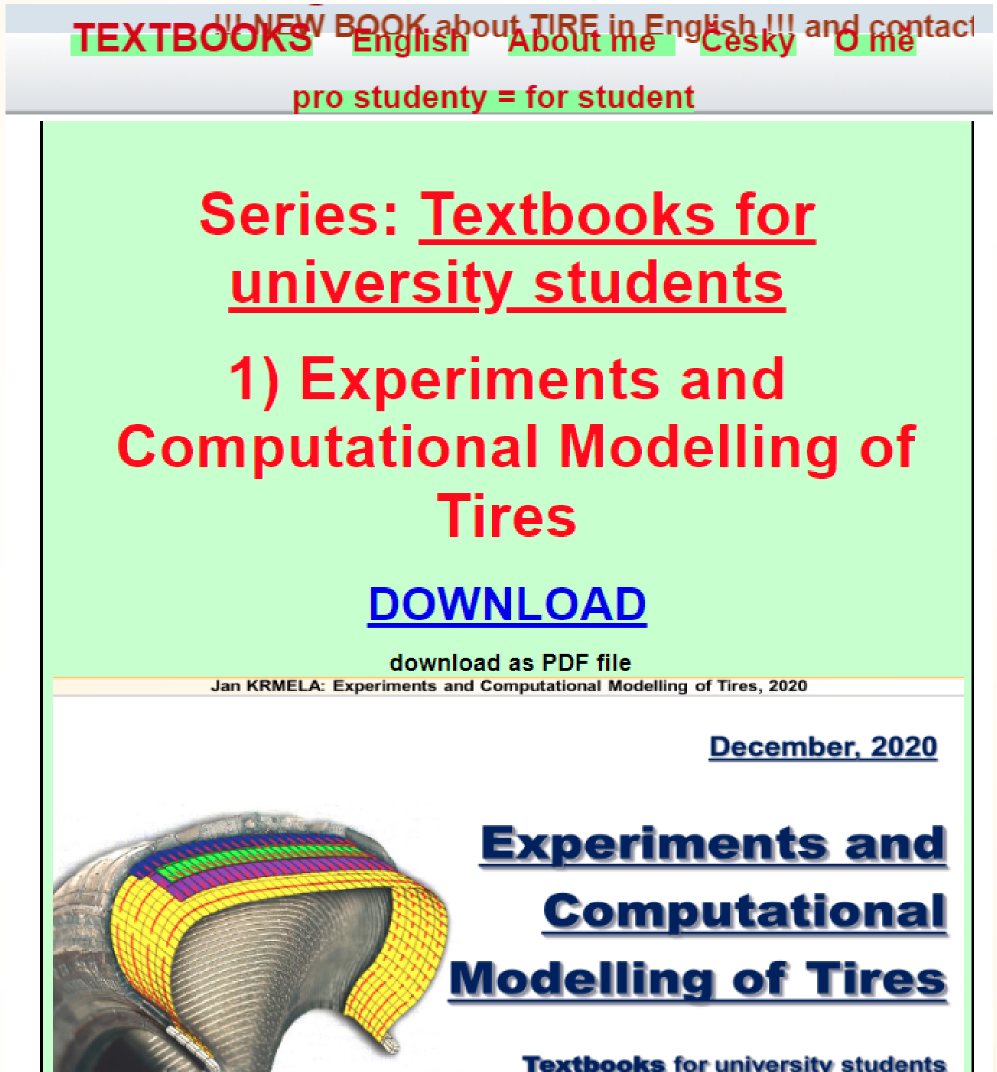
MODULES OF ELASTICITY

245/40 R18

Modulus of elasticity [MPa]		Specimen width 10 mm	Specimen width 15 mm	Specimen width 20 mm
Loading in direction	Longitudinally [1]	380	400	285
	Transverse [1]	200	205	185
	Radial [2]	90-110 for longitudinally specimens		

krmela.wz.cz

http://krmela.wz.cz/krmela_textbook_tire.pdf



MATERIAL PARAMETERS MATRIX

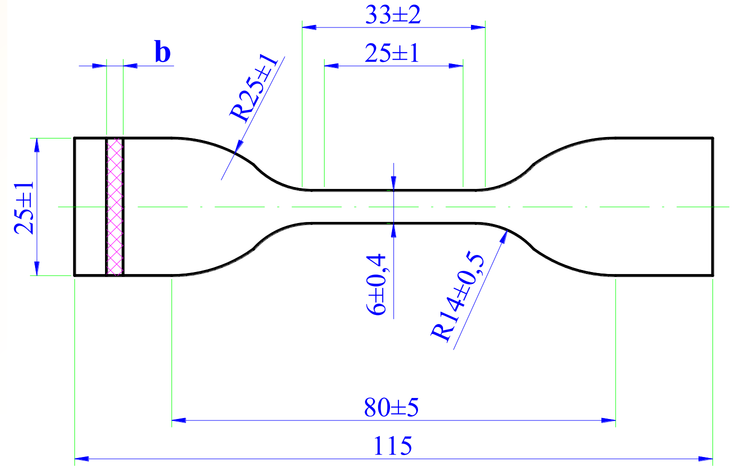


Table: Mooney-Rivlin parameters for elastomer parts

Mooney-Rivlin parameters	C_{10} [MPa]	C_{01} [MPa]	d [MPa^{-1}]
Tread	0.417	0.519	0.103
Inner liner	0.109	0.259	0.206
Bead elastomer	0.692	0.371	0.267
Sidewall with a tread side edge	0.532	0.065	0.138
Bead bundle	-0.111	1.945	0.088
Elastomer drift for a steel-cord belt	0.638	0.284	0.151
Elastomer drift for a textile carcass	0.328	0.119	0.101
Elastomer drift for a textile cap	0.548	0.112	0.056

or Mooney-Rivlin from hardness - excel tables and word

SPECIFIC CYCLE LOADING TESTS

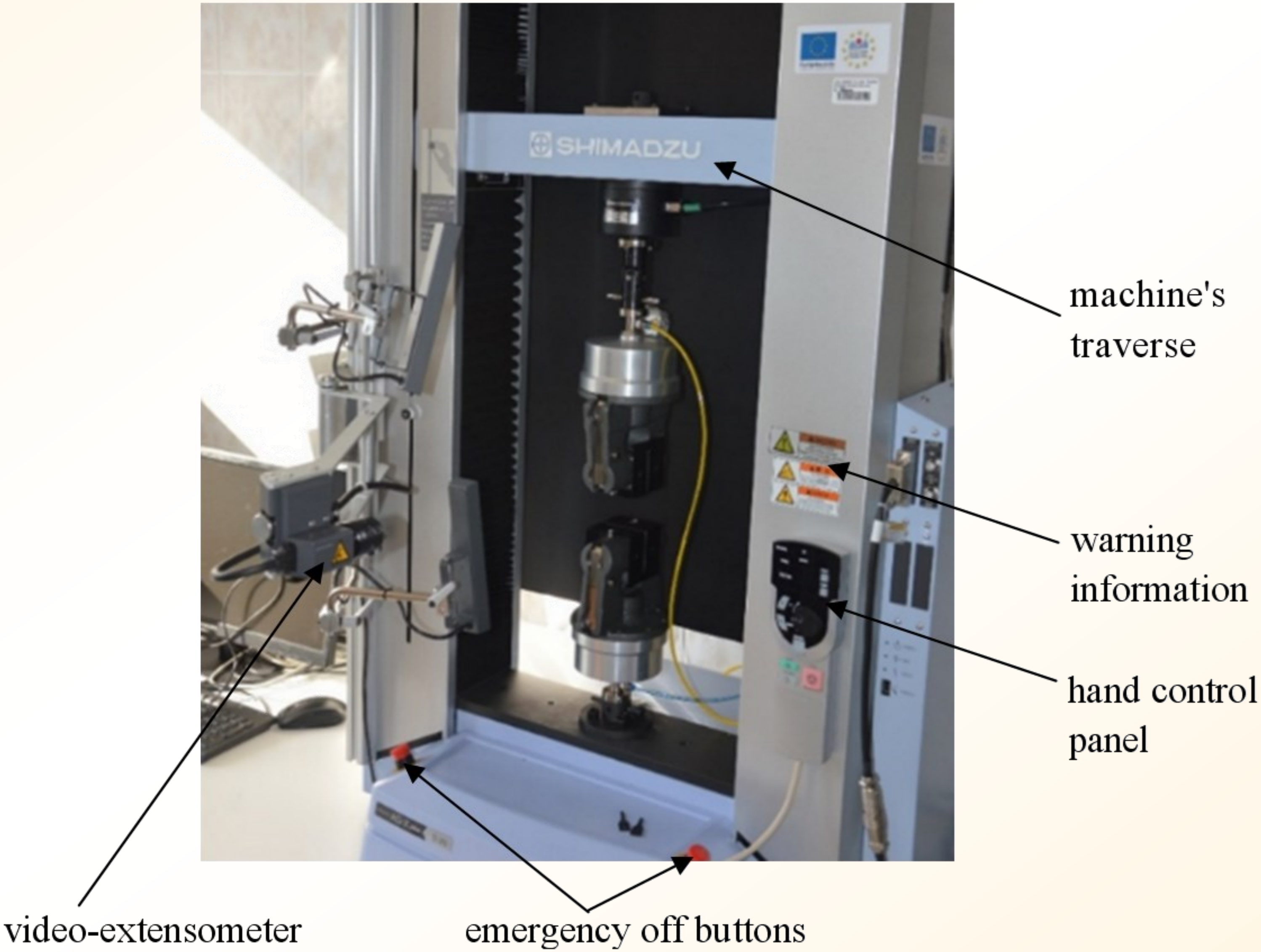
It is necessary to deal with cyclic tensile tests of long-fiber composites with textile and steel reinforcement together as tire casings.

The tests of cyclic loading of polymer composites are requested for the verification analyses between tests and computational modeling of tires.

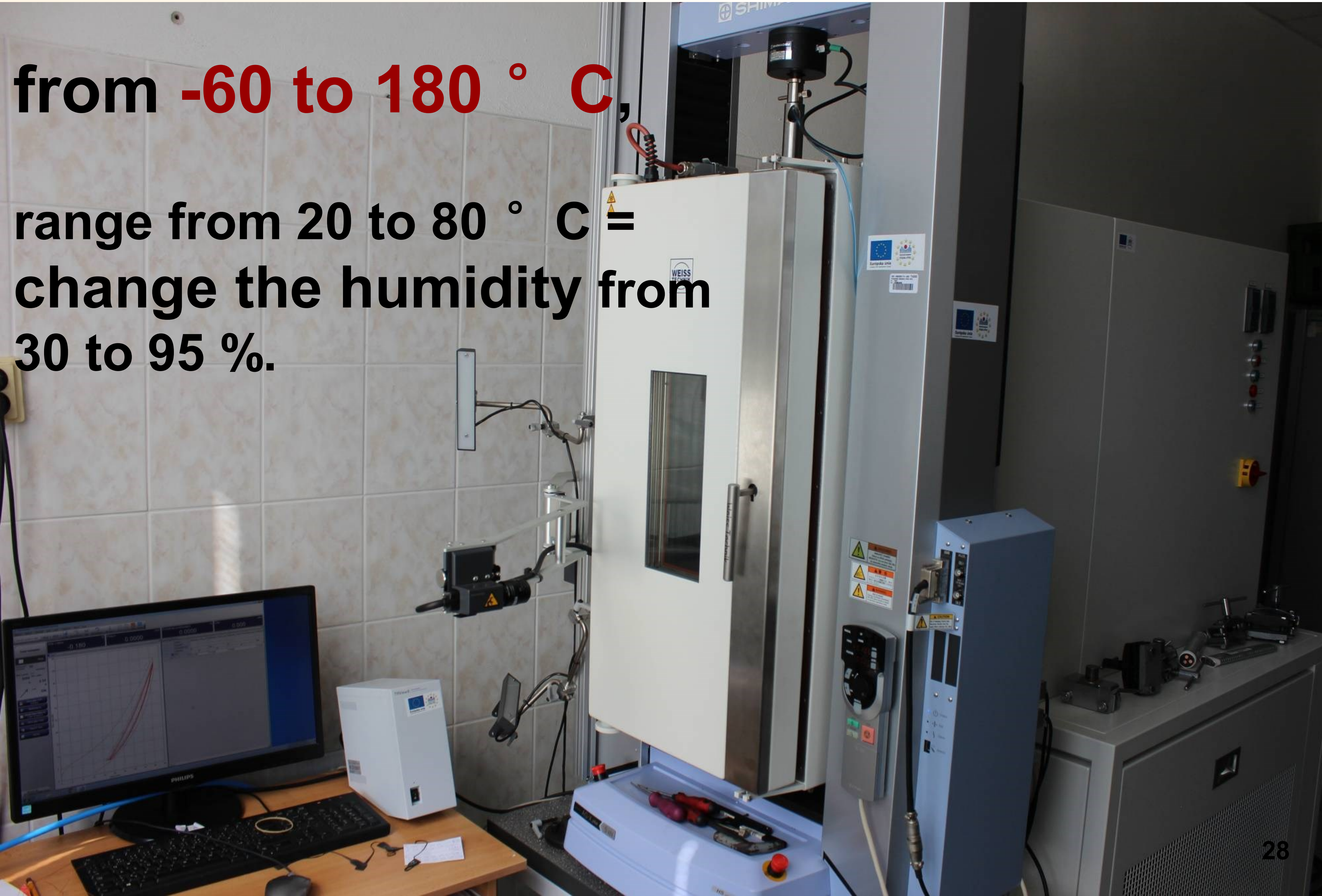
The geometric parameters of specimens are a length of 195 mm, a width of 35 mm, initial length between clamps of a test machine 100 mm and a thickness of the specimen of 1.05 mm.

Testing machine: Autograph AG-X plus 5 kN – Shimadzu <u>with a video-extensometer</u>

Control mode of TrapeziumX software.

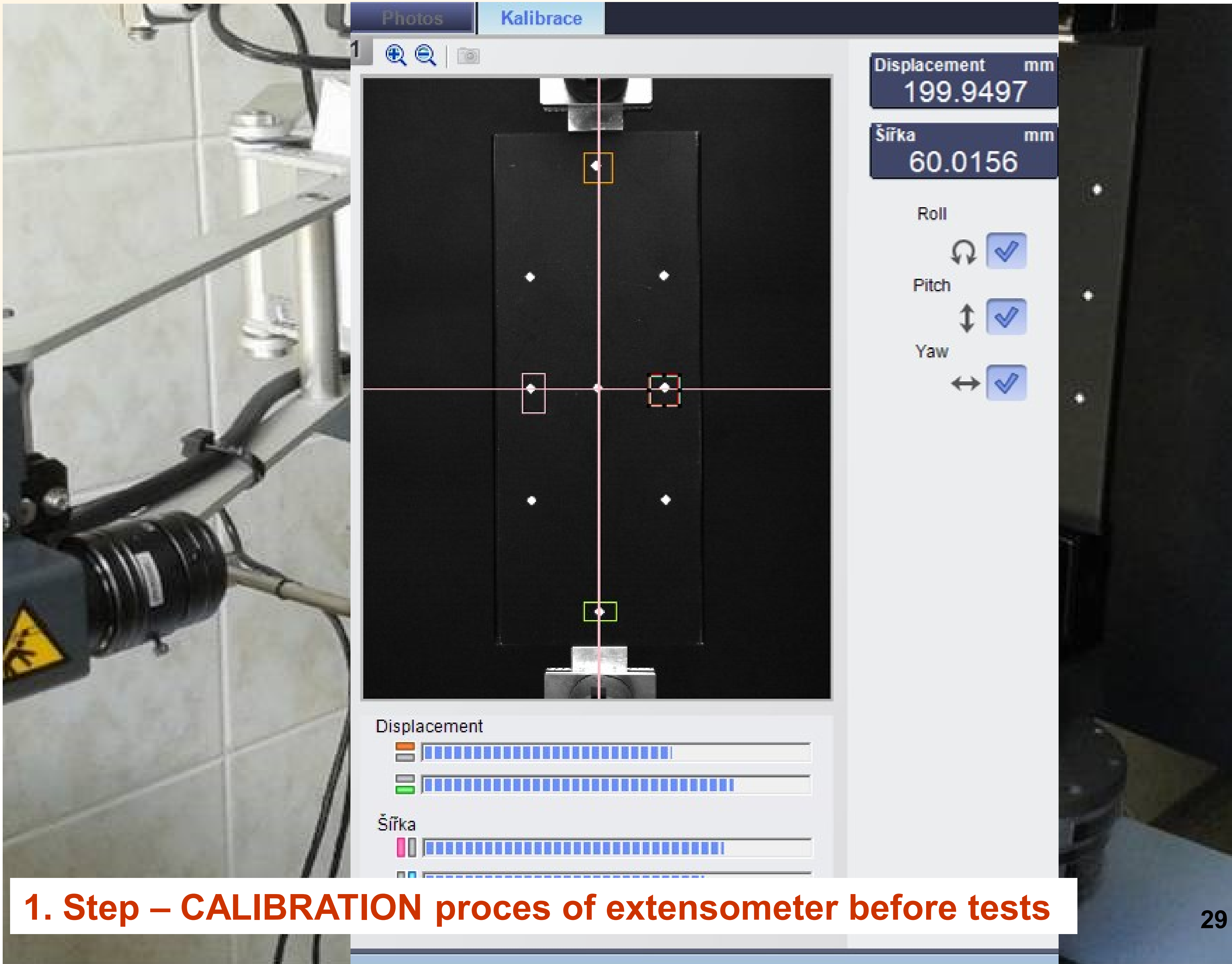


with a hybrid temperature-humidity chamber !

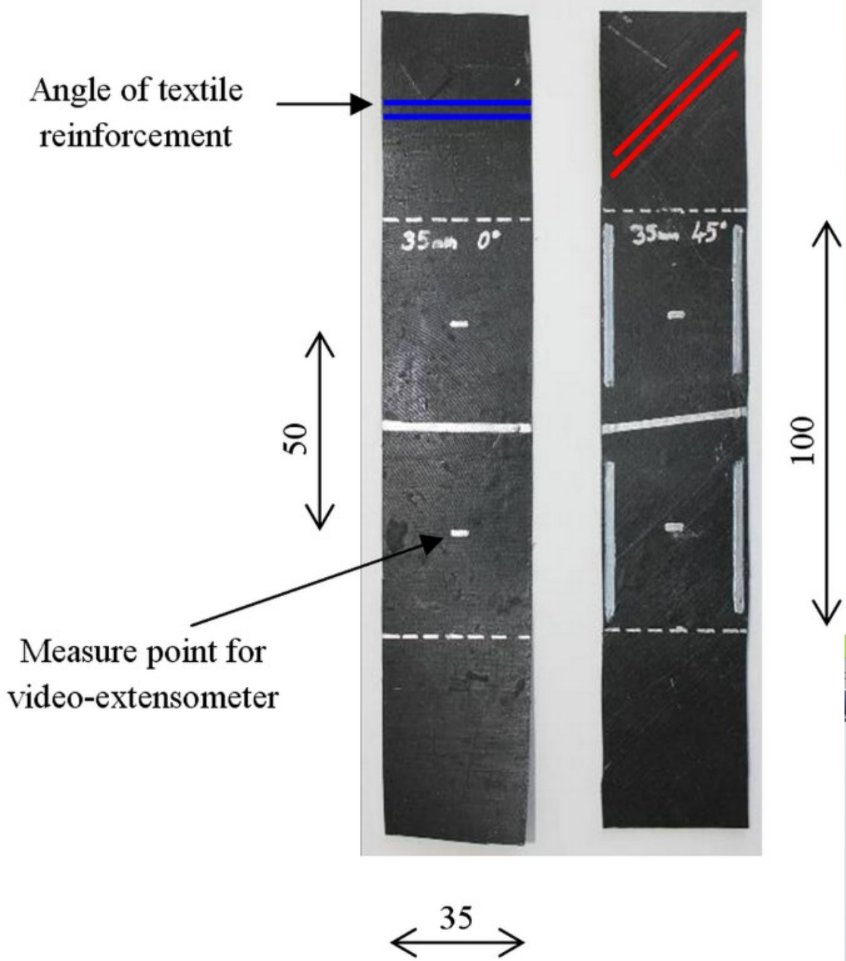


from -60 to 180 ° C,

range from 20 to 80 ° C = change the humidity from 30 to 95 %.

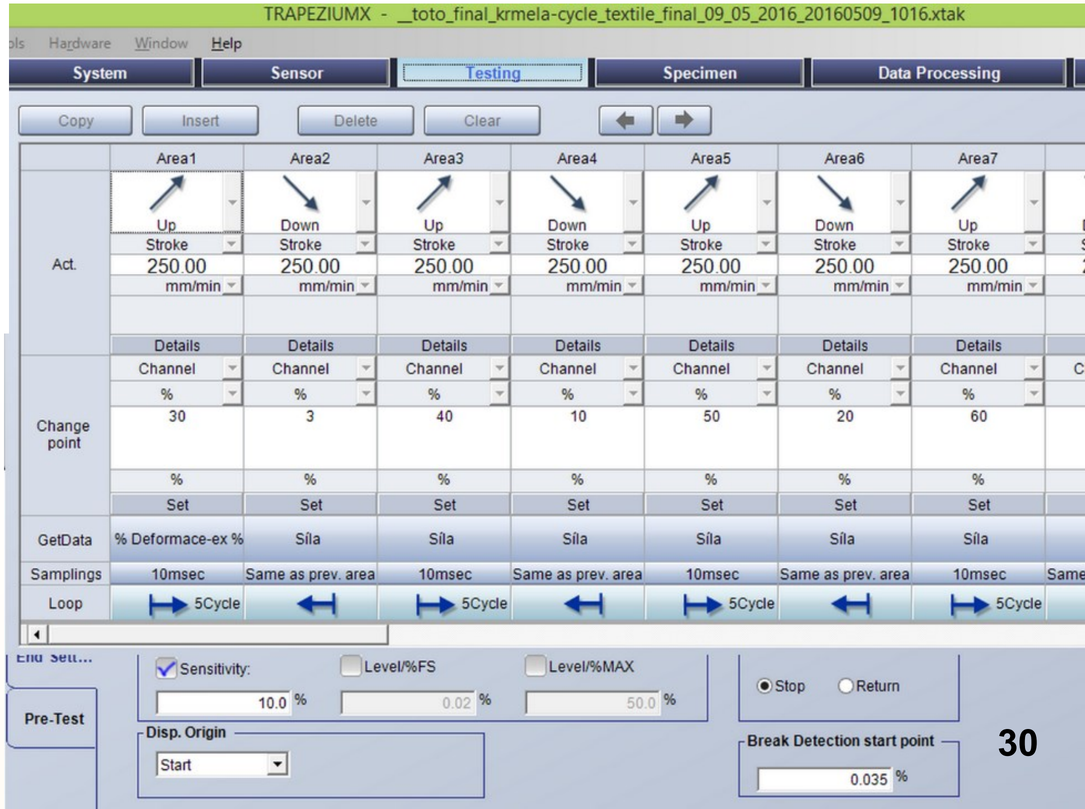


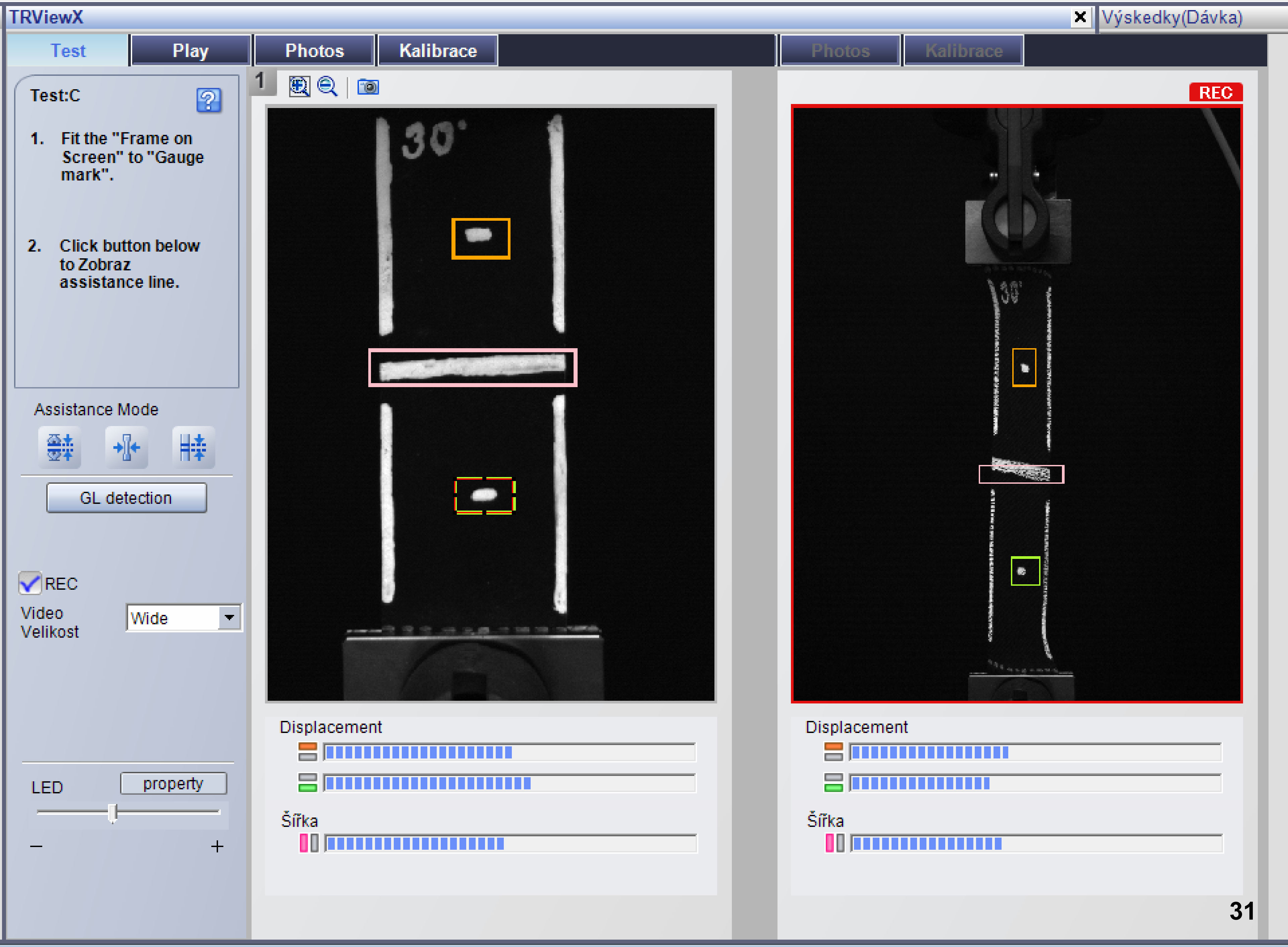
1. Step – CALIBRATION proces of extensometer before tests



2. Step - Design of SPECIMENS of composite

3. Step - Design of METHOD for cyclic loading test




TRViewX
Výskedky(Dávka)
Test
Play
Photos
Kalibrace
Photos
Kalibrace
Test:C
1. Fit the "Frame on Screen" to "Gauge mark".
2. Click button below to Zobraz assistance line.
Assistance Mode
GL detection
REC
Video Velikost
Wide
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property
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+
1
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REC
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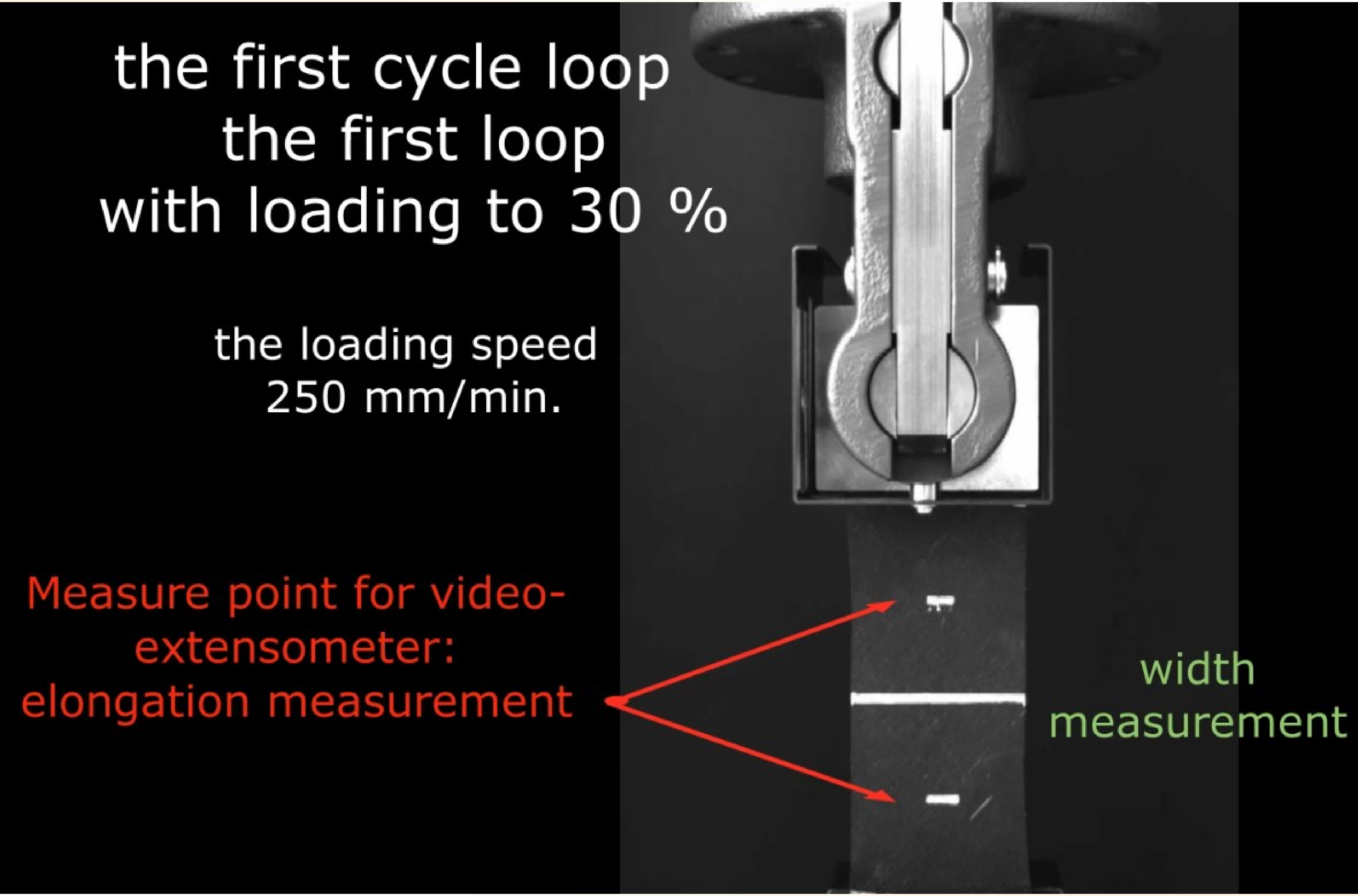
Displacement
Šířka

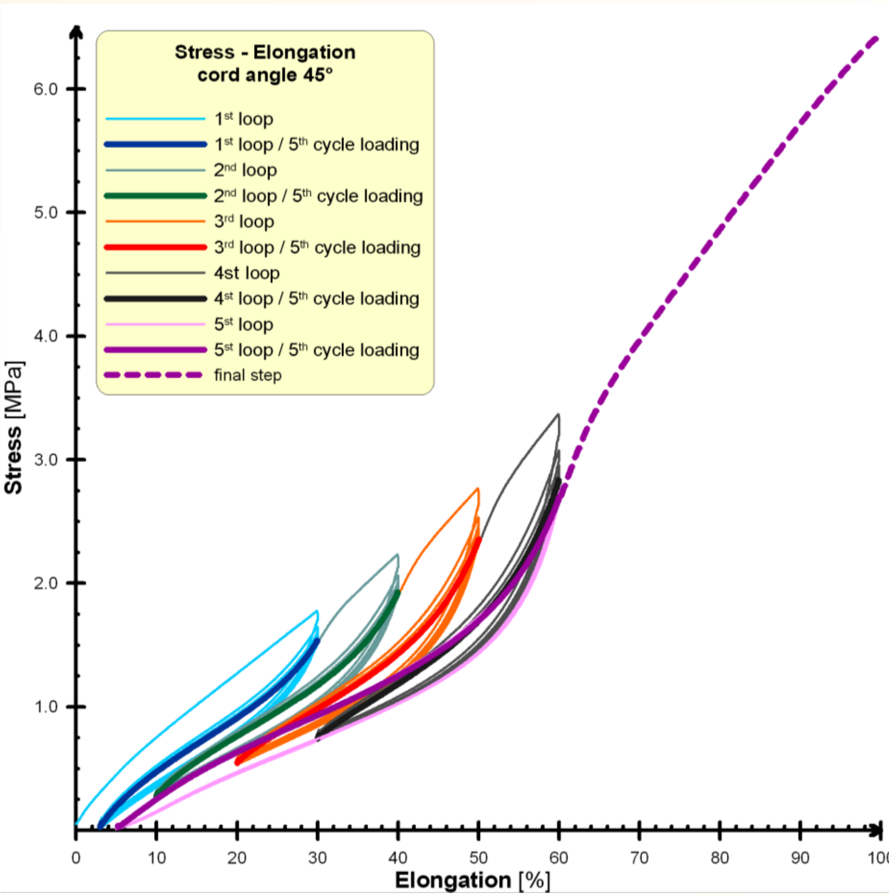

the first cycle loop
the first loop
with loading to 30 %
the loading speed
250 mm/min.
Measure point for video-
extensometer:
elongation measurement
width
measurement

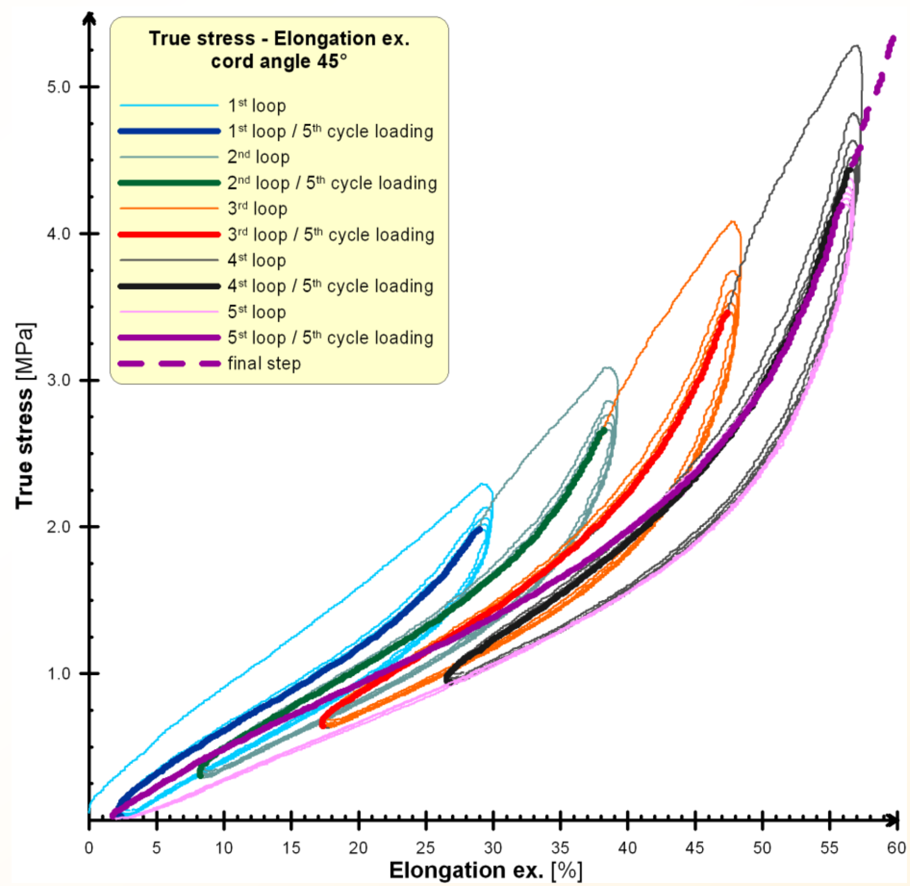
composite test

THE TESTS OF LOW CYCLIC LOADING

a cord angle of 45°

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.





true stress on elongation between points for a video-extensometer

DYNAMIC TESTS OF TIRES „DYNAMIC ADHESOR"

Radial loading max **0.5 t**

Max. **velocity 180 km/h**

The tire test data results from the static and dynamic test machines such as contact footprints and radial stiffness are evaluated.

COMPUTATIONAL MODELING

It is necessary to **quickly create computational models** with the required cord geometry parameters, the computational models **for strain-stress analyses were created using APDL (ANSYS** Graphical User Interface) procedures **for the automatic creation of models from geometric parameters** such as a cord diameter, cord distance and one-layer thickness, width and length of the layer and **material parameters**.

The APDL procedure includes parameterization with the following parameters:

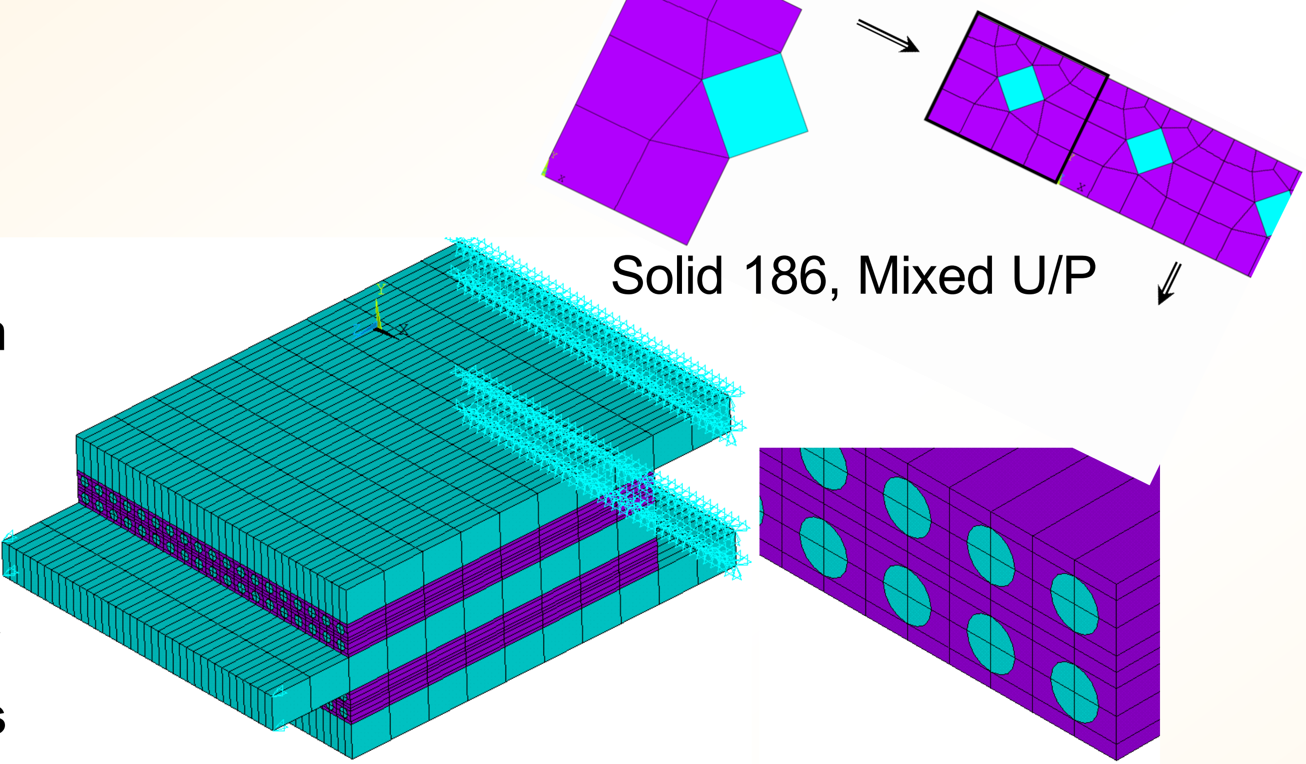
***cset,1,3,Distance,'Distance between cord [mm] ',1.04 !for steel-cord**
***cset,4,6,Diameter,'Cord diameter [mm]',0.60 !for steel-cord**
***cset,7,9,Thickness,'Thickness of layer [mm]',0.95 !for steel-cord**
***cset,10,12,Width,'Width of layer [mm]',20**
***cset,13,15,Lengh,'Lengh of layer [mm]',20**
***cset,16,18,Angle,'Cord angle [degree]',0**
***cset,19,21,E,'Modul of elasticity of cord [GPa] ',190 !for steel-cord**
***cset,22,24,PR,'Poisson ratio [-]',0.30 !for steel-cord**

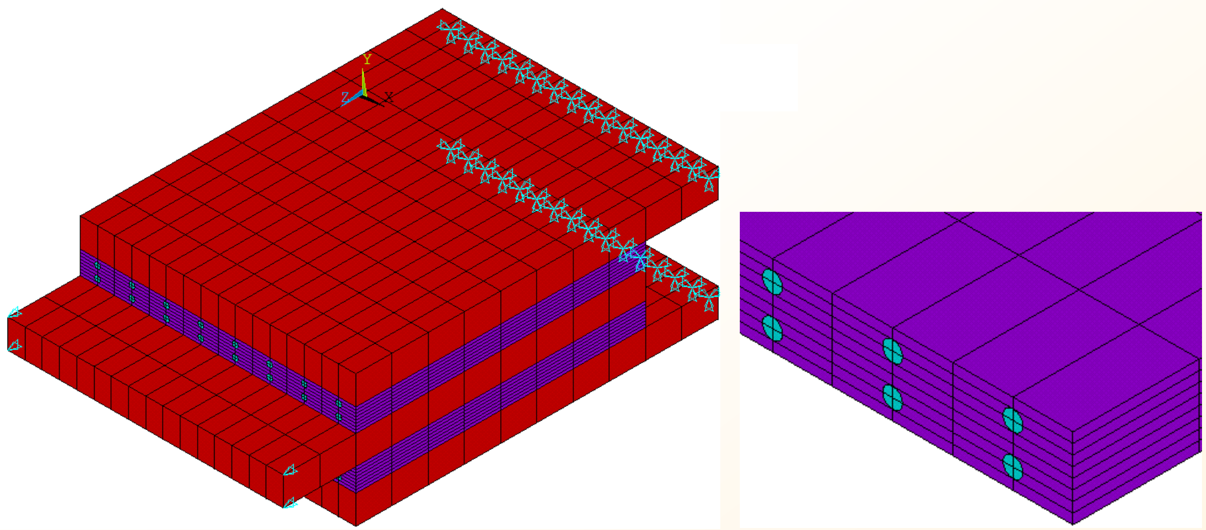
The APDL procedure includes the computation of rubber moduli based on M-R parameters which can be entered directly or are determined on the basis of data from a tensile test:

```
D = (2*(1-2*PR_E))/(CONST1(1)*(5*PR_E-2)+CONST1(2)*(11*PR_E-5)) !parameter of incompressibility
TB,HYPE,2,1,2,MOON
TBDATA,,CONST1(1),CONST1(2),D,,,    !parameters are in MPa;
E_E = 6*(CONST1(1)+CONST1(2)) !modul of elasticity
G_E = 2*(CONST1(1)+CONST1(2)) !shear modul
K_E = 2/D !volume modulus
```

…… over 1000 code lines

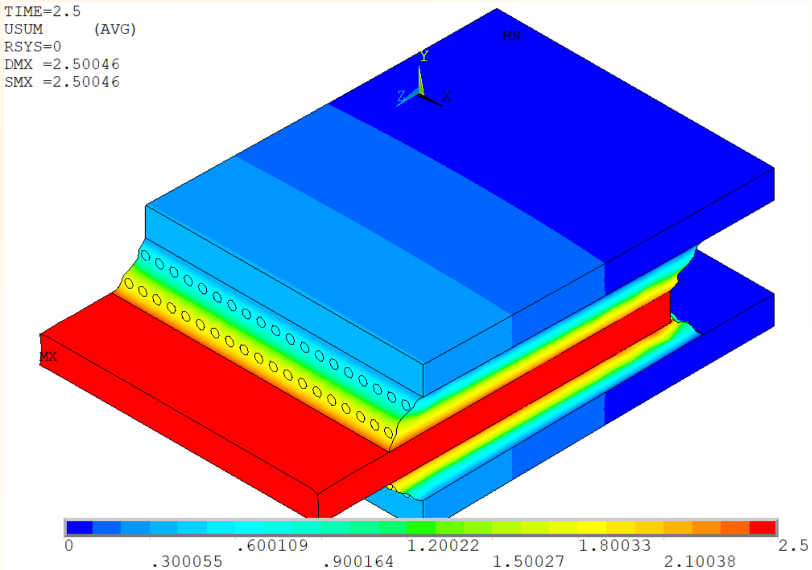
The models are reverse loaded, the displacement in *z*-axis is defined and the sum reaction forces at the area of steel edges (using these edges, the specimen will be clamped in the jaws of the testing machine) is searched.



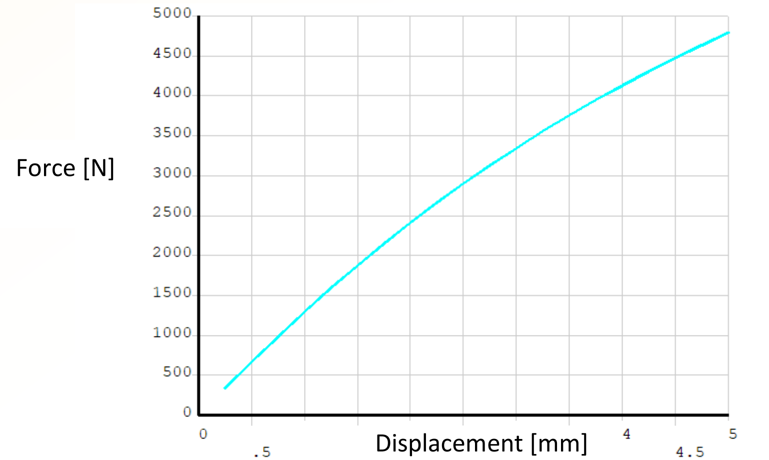


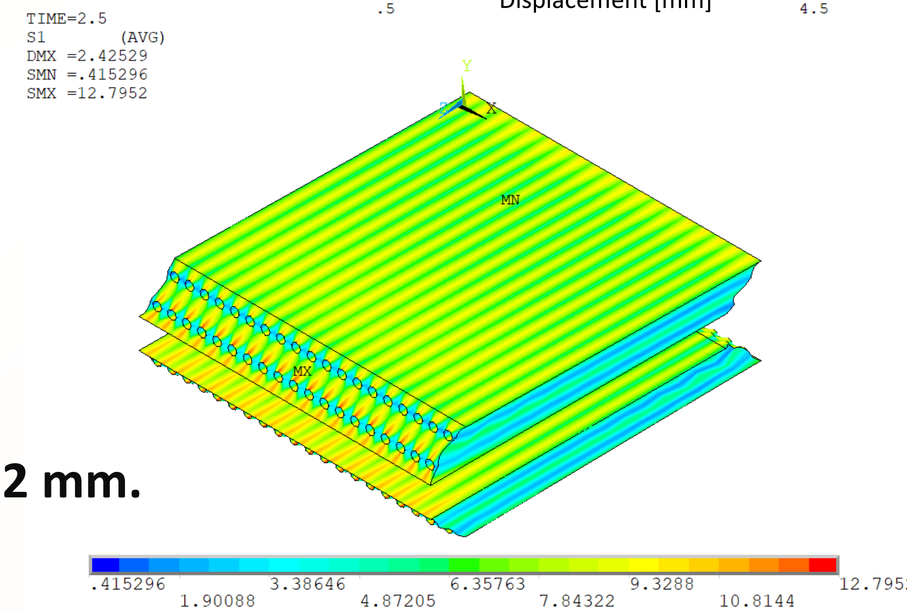
The computational model with a steel-cord diameter of 0.60 mm and a textile-cord diameter of 0.40 mm (down) with details of meshing.

steel-cord with diameter 0.6 mm



Sum displacement – computational model with steel-cord “2+2”.



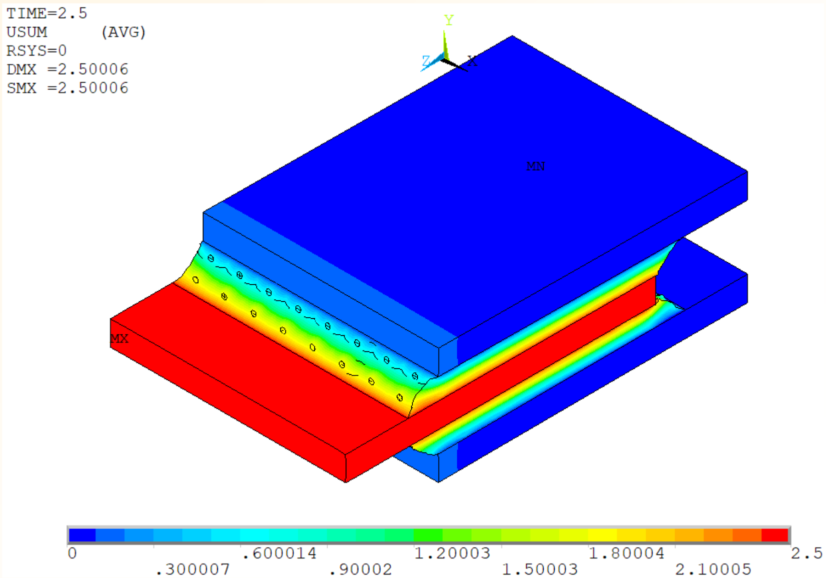


Sigma1 – computational model with steel-cord “2+2”.

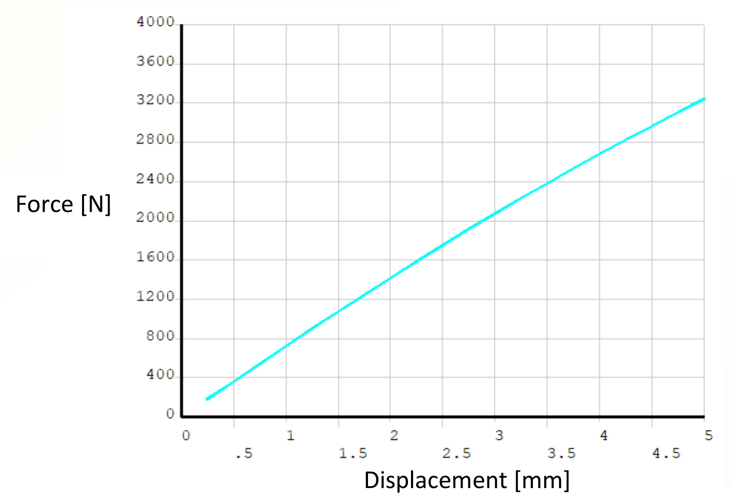
F = 2866 N for deformation of 2.5 mm.

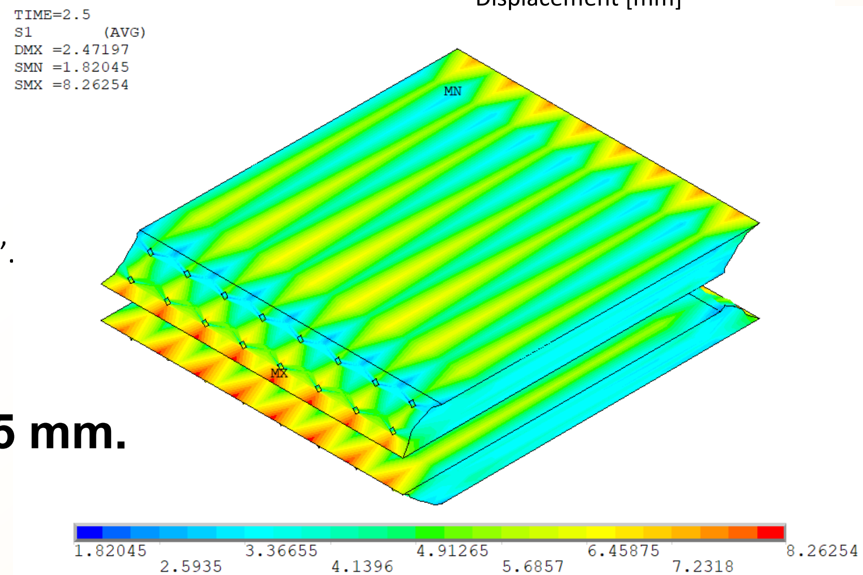
Sigma1 = 12.8 MPa for deformation of 4.2 mm.

PA66 cord with a diameter 0.4 mm



Sum displacement – computational model with PA66 cord “2+2”.

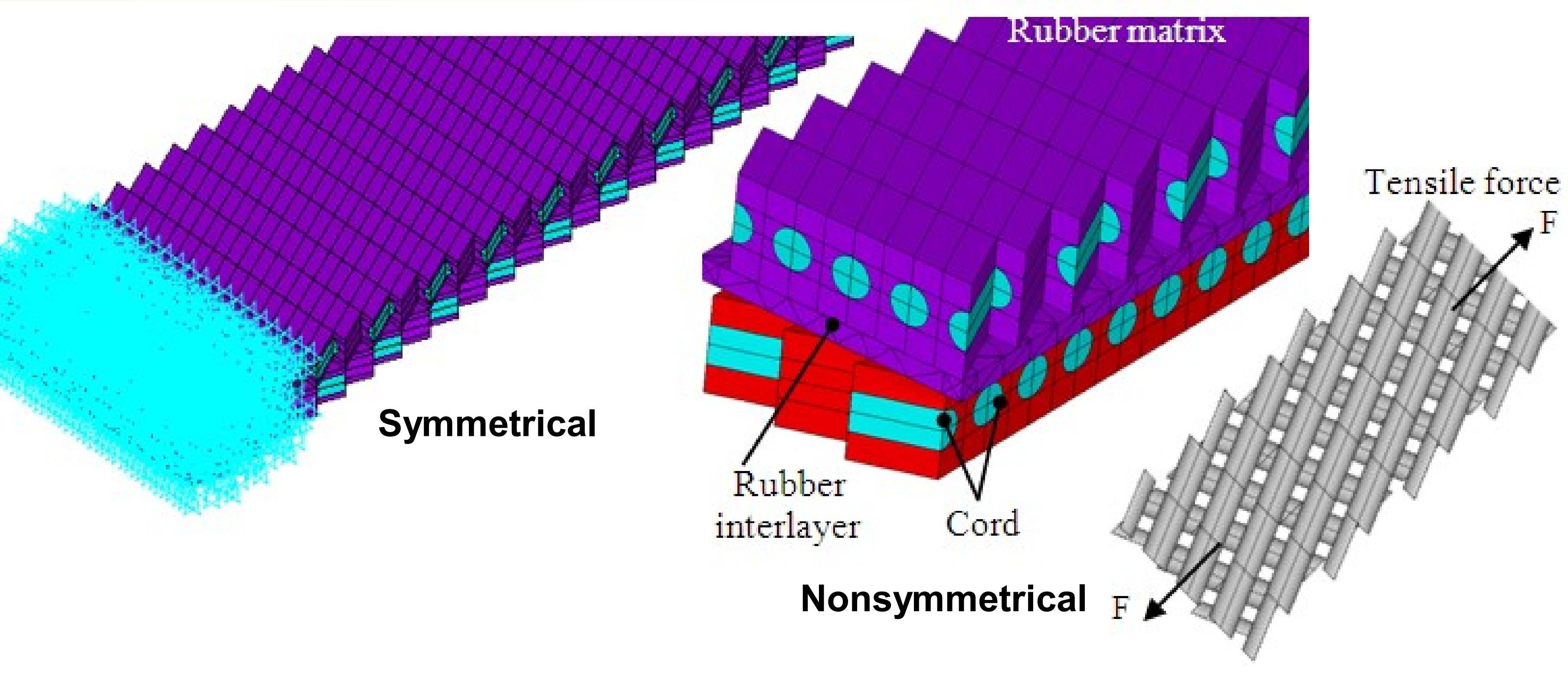




Sigma1 – computational model with PA66 cord “2+2”.

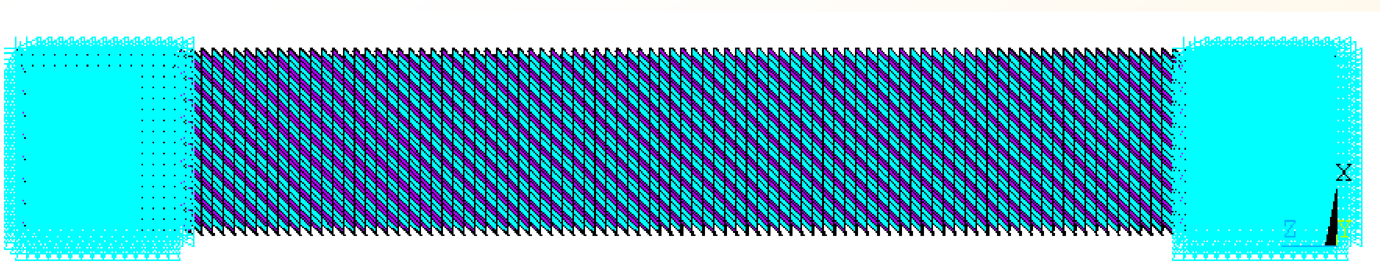
F = 1753 N for deformation of 2.5 mm.
Sigma1 = 8.3 MPa for deformation of 2.5 mm.

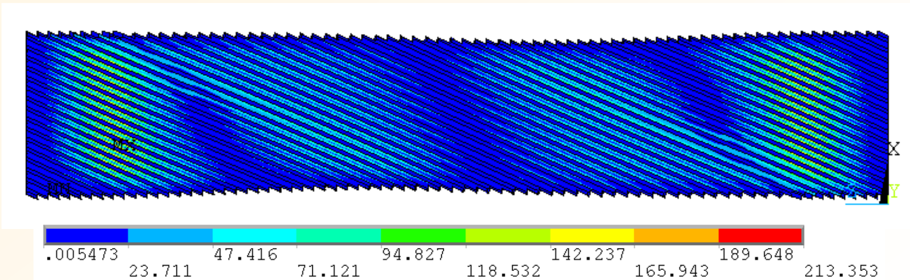
The difference in forces between the steel cord and textile PA66 cord is about 61 %.



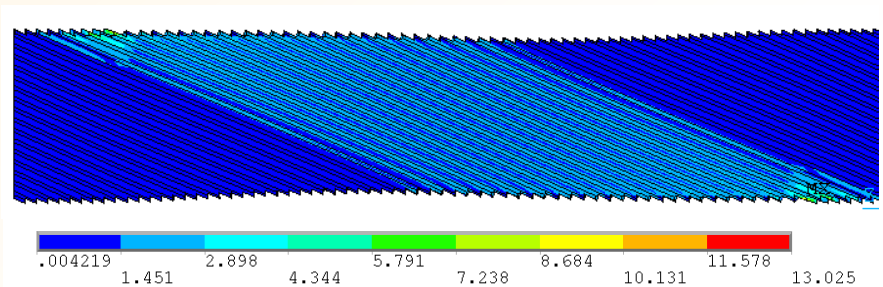
Tensile
Bend

One-layer / Two-layer

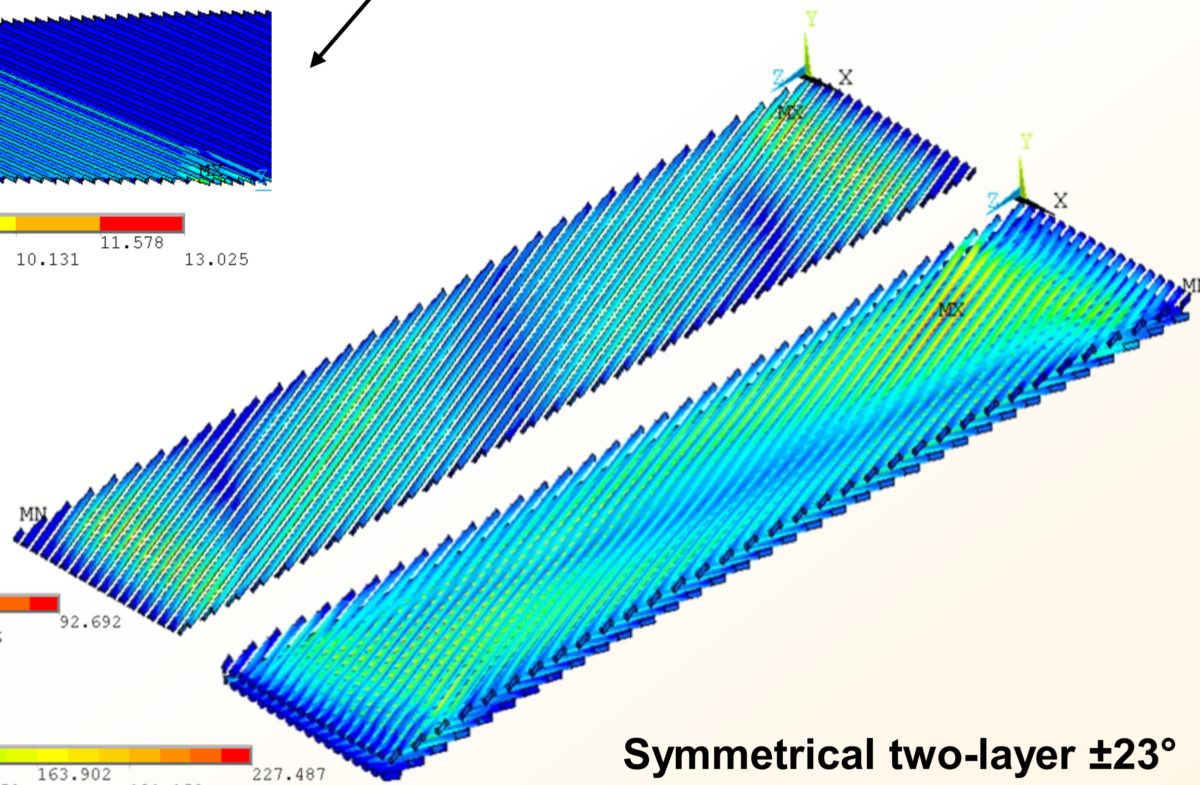


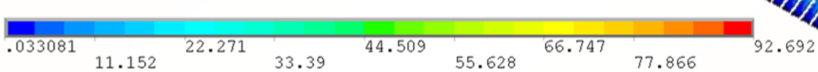


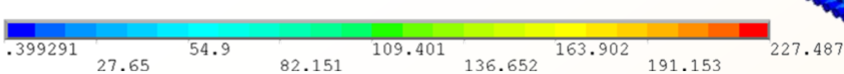
One-layer 23°
stress [MPa]
- **cord stress**
- **matrix stress**



TENSILE

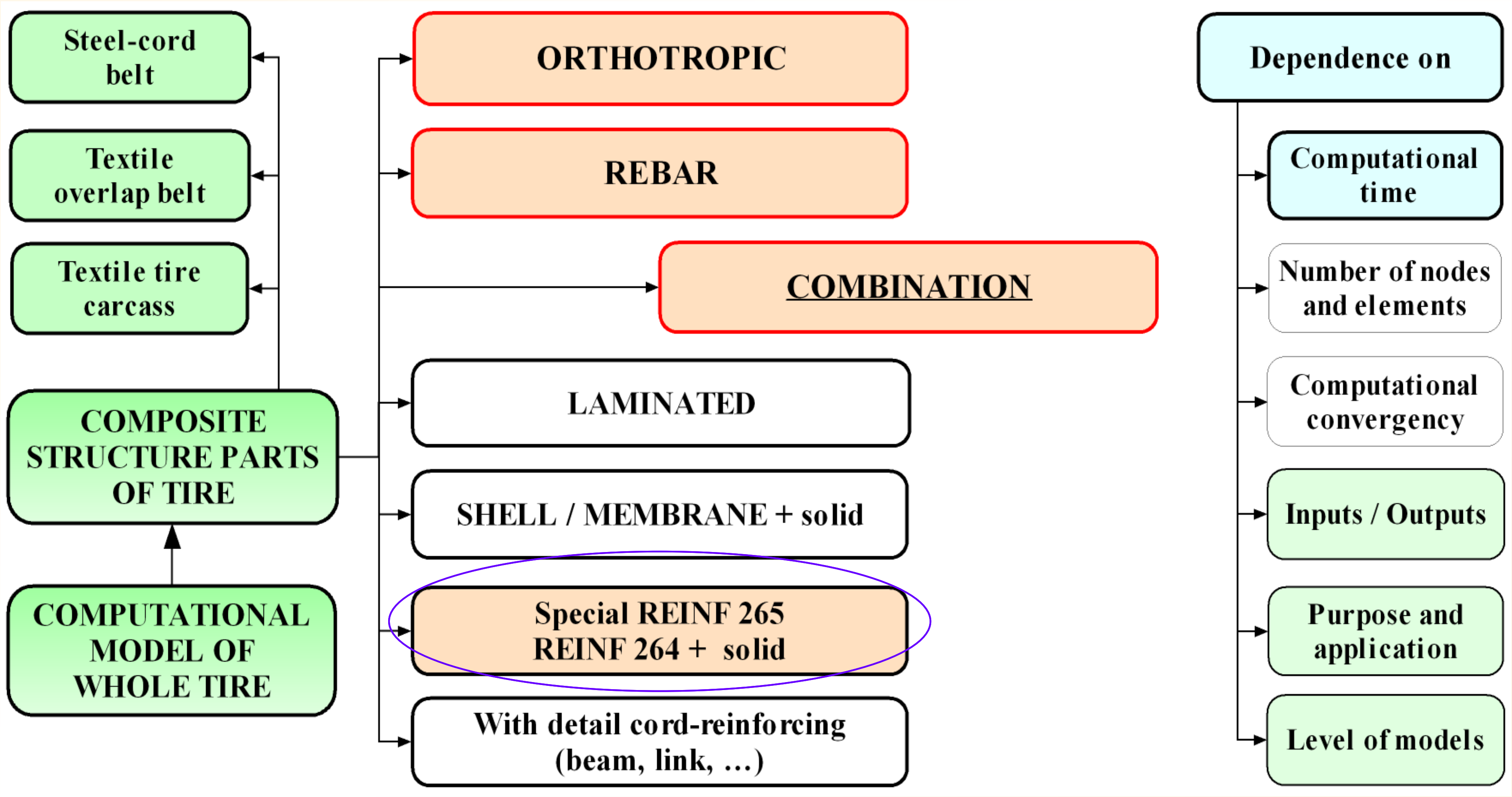


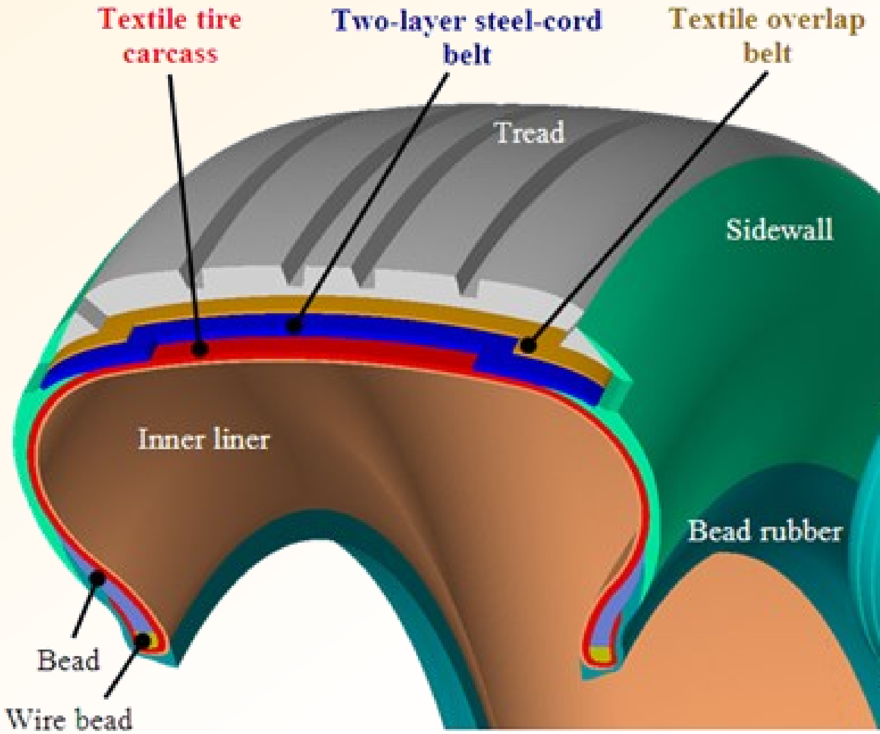


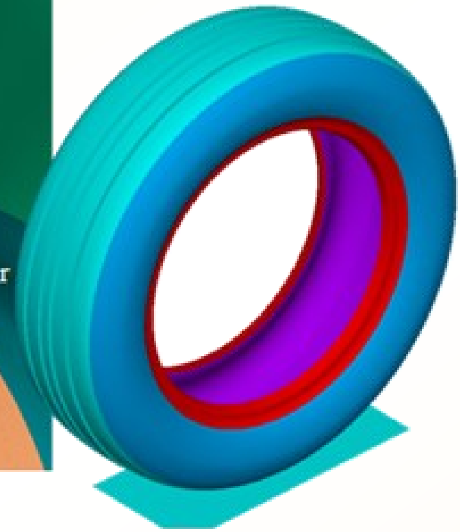


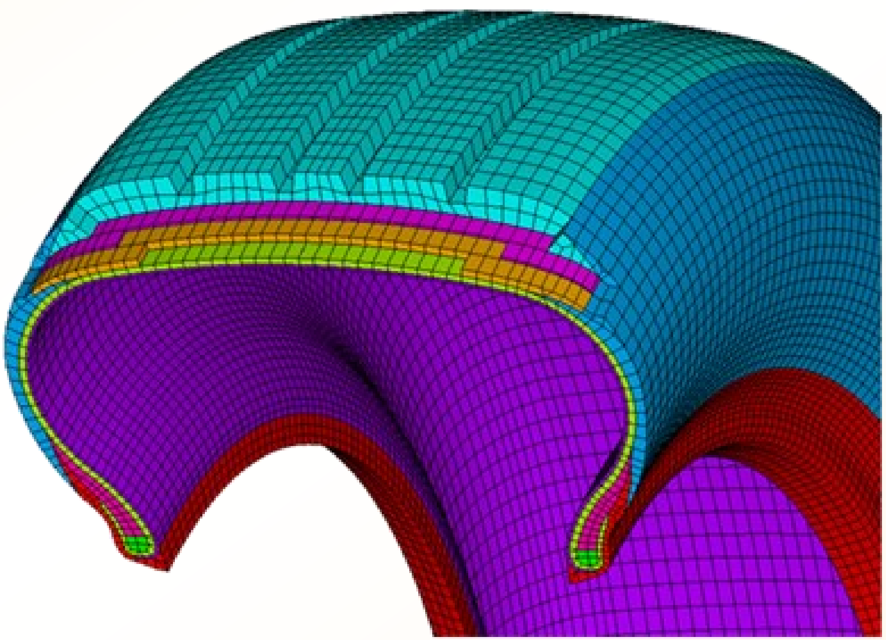
Symmetrical two-layer ±23°
cord stress [MPa]

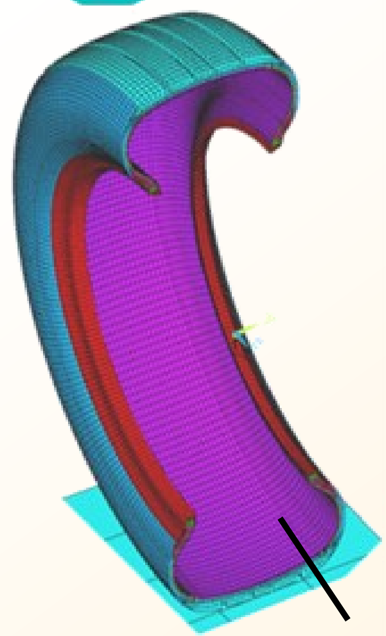
Different descriptions of composite structure parts into tire computational models





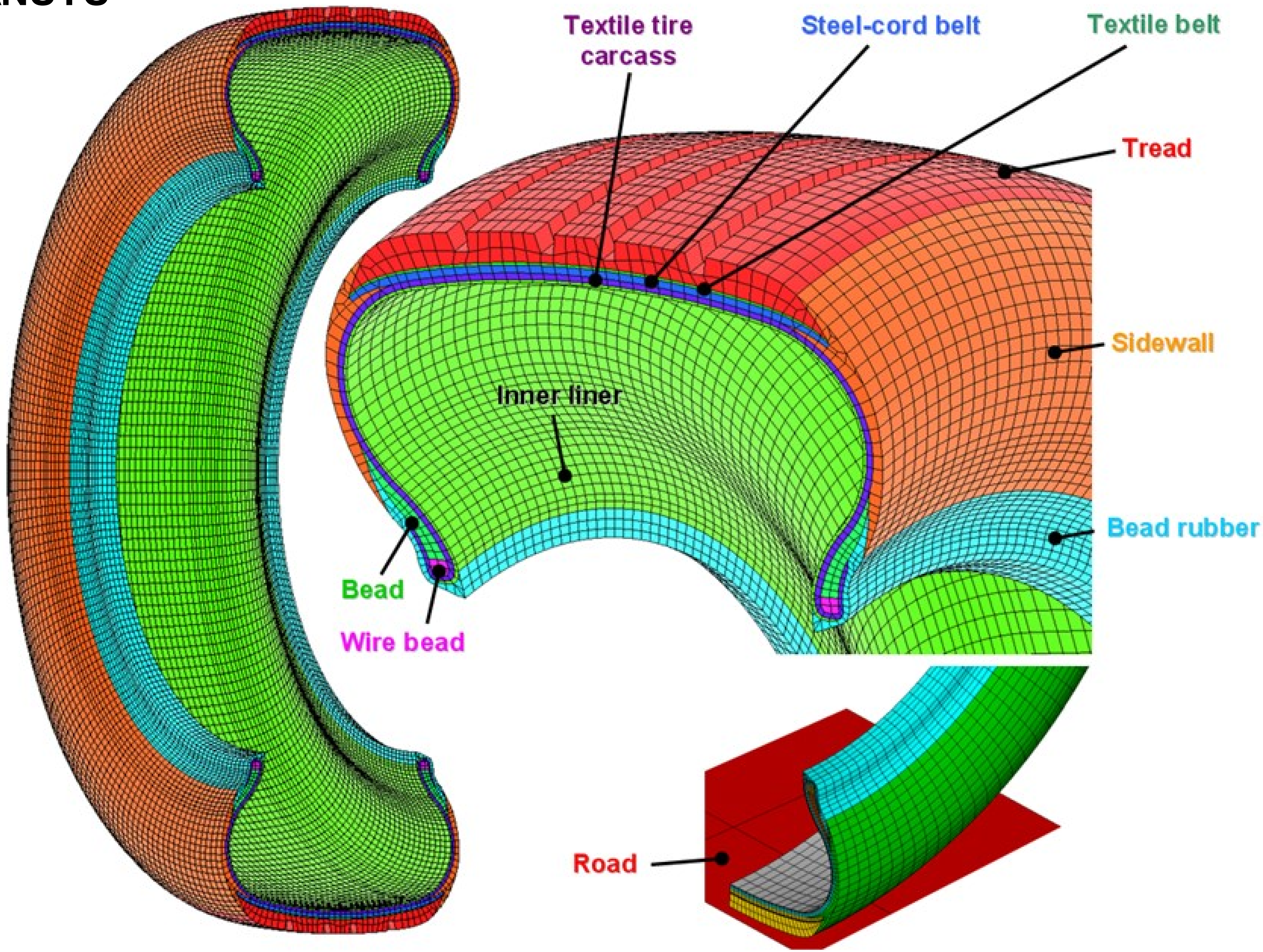




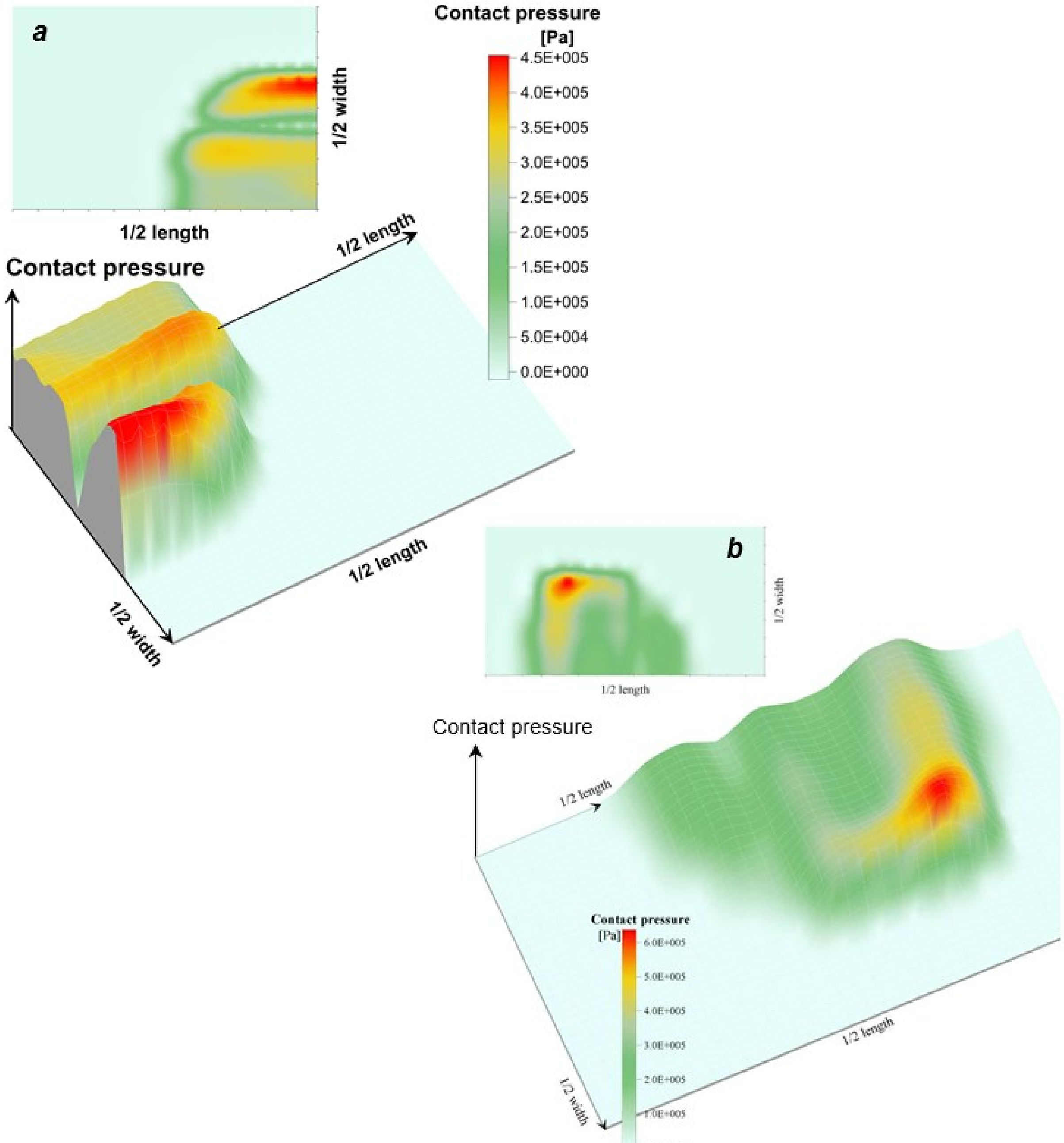


Fourth part of model:
36 000 elements
155 000 nodes

ANSYS



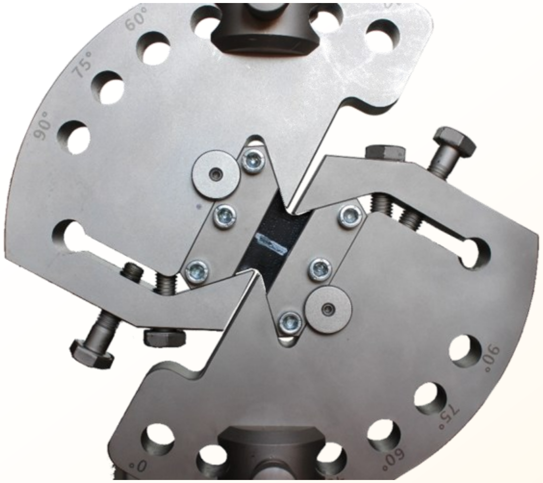
Textile tire carcass
Steel-cord belt
Textile belt
Tread
Sidewall
Inner liner
Bead rubber
Bead
Wire bead
Road



Distribution of contact pressure in a three-dimensional image: *a* – a plane road for radial deformation 15 mm; *b* – a concave obstacle for radial deformation c. 20 mm (inflation pressure 180 kPa)

CONCLUSIONS

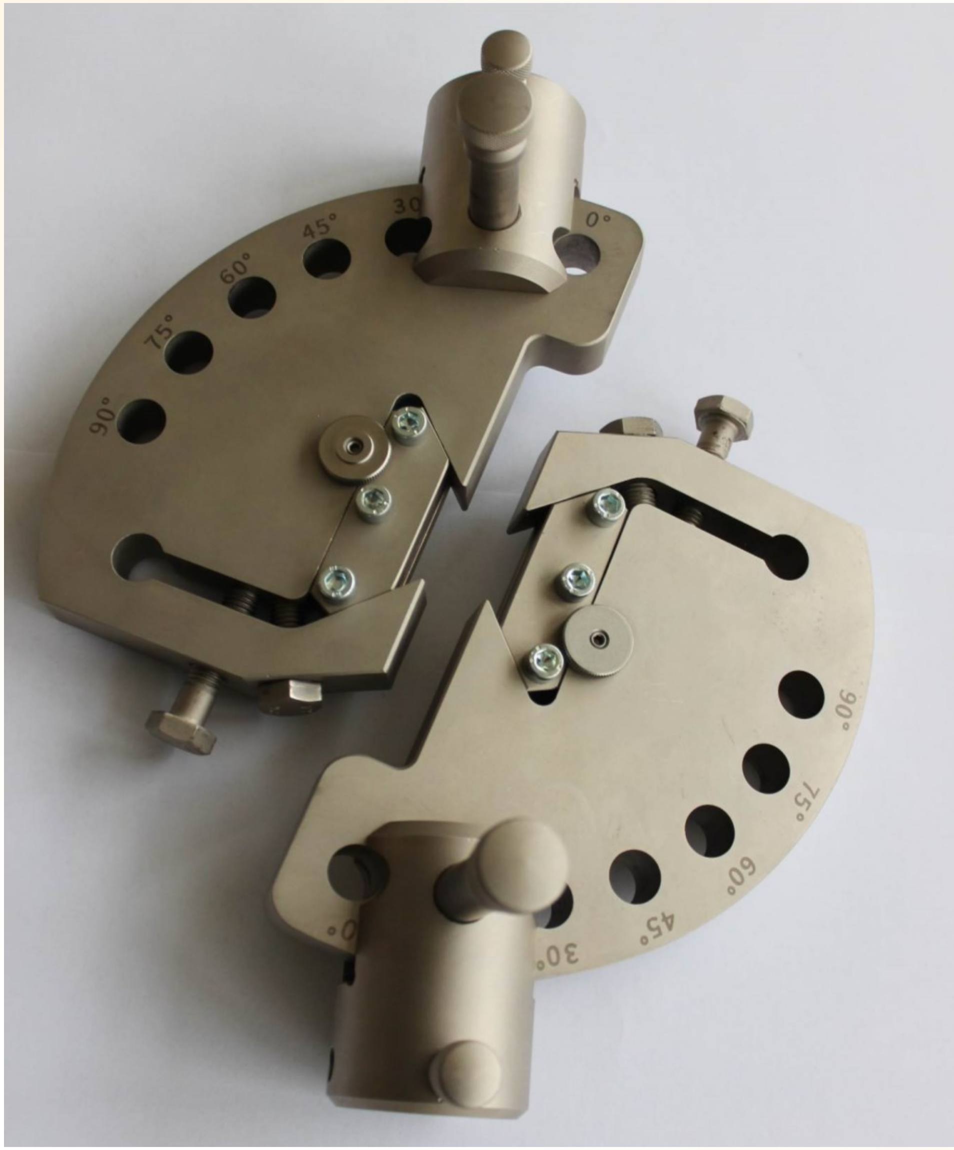
<u>The results from tests and computational modeling of POLYMER COMPOSITES</u> provide better understanding of the mechanical properties under static and specific loading.



Next computational models will be created for <u>combination</u> load states and for simulation of <u>multi-axis load</u>.

<u>Acknowledgments:</u>

This research work had been supported by the Cultural and Educational Grant Agency of the Slovak Republic (KEGA), grant No. KEGA 003TnUAD-4/2022 „Simulations of basic and specific experiments of polymers and composites based on experimental data in order to create a virtual computational-experimental laboratory for mechanical testing“ and Aktion Austria - Slovakia, project No. 2019-05-15-001 “Determination of material parameters for computational modeling of next-generation tires”.



NEXT RESEARCH:

Composites
Arcan + cycles +
temperature
EXPERIMENT

↓

COMPUTATIONAL
SIMULATIONS

↓

...

The Influence of Temperature and Other Parameters on the Tensile Properties of Polymer Composites and Polymers under Cyclic Loading

Jan Krmela

The present scientific monograph is focused on specific testing of polymer composites and textiles cords, which are used as reinforcement for the composites. The basic mechanical tensile test at standard temperature does not provide all the information for obtaining the material parameters. It is also necessary to perform the tests at elevated or reduced temperatures, depending on where the polymer composites and polymer reinforcement will be used. It is necessary to consider stress relaxation in specific tests for practical use. This work experimentally investigates the effect of temperatures of 20 °C and 120 °C and relaxation times 60 and 120 seconds on the mechanical properties of selected textile yarns from PA66 under uniaxial tensile tests. Furthermore, the angle of the cords to the resulting material parameters of the composites is also evaluated based on low cycle load. A testing machine with a video-extensometer is used for testing, so that outputs are true stress values. The monograph also deals with computational modeling in the program ANSYS (by APDL procedures) – shear test simulations with determination of material parameters for calculations.

Videos of specific low cyclic loading tests of composites and polymers, and video-presentation are included on the enclosed DVD.

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Częstochowa, POLAND

ISBN 978-83-63978-91-4

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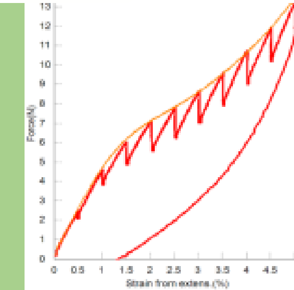
Jan Krmela: The influence of temperature and other parameters on the tensile properties of polymer composites and polymers under cyclic loading

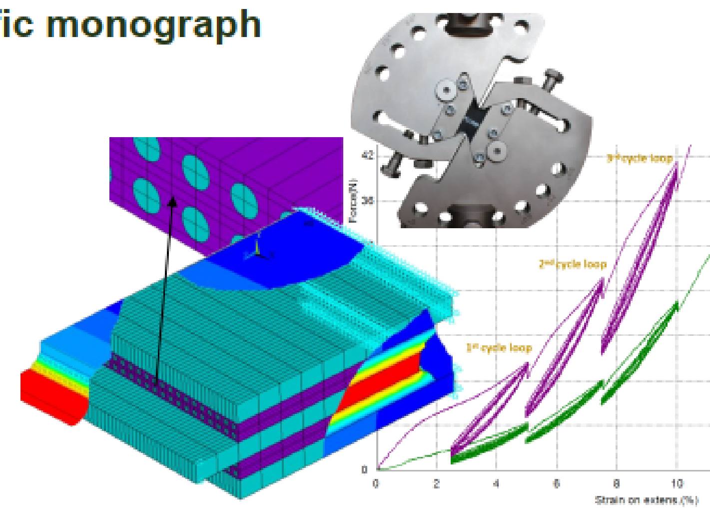


Jan KRMELA

The Influence of Temperature and Other Parameters on the Tensile Properties of Polymer Composites and Polymers under Cyclic Loading

Scientific monograph

2021



Tire Casings and Their Material Characteristics for Computational Modeling

Jan Krmela

The scientific monograph is focused on computational modeling of car tires in combination with experiments with an emphasis on input material parameters into computational models. Monograph divided into three parts.

The first part is focused on the determination of geometric and material parameters of tire casings, planning of experiments and tire experiments with pressure footprint analyses as well as the prediction of radial stiffness with the introduction of special test charts from the dynamic tests of tires.

The second part is devoted to experiments of parts of tire casings, tests of low cycle loading with use of modern instrumentation, tests of samples after corrosion and methods for determination of modules of elasticity.

The third part focuses on creating of computational models with the inclusion of hyper elastic and orthotropic material models for replacing of composite elements of a tire casing with parameters obtained from experiments. An emphasis is placed on the comparison of results from calculations with experimental data from both stress-strain analyses of tire and specific parts of tire casings and modal analyses of tires.

Videos from dynamic tests of tires and low cyclic loading tests of composites are included on the enclosed DVD.

ISBN: 978-83-63978-62-4

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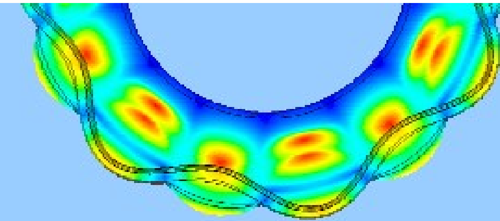
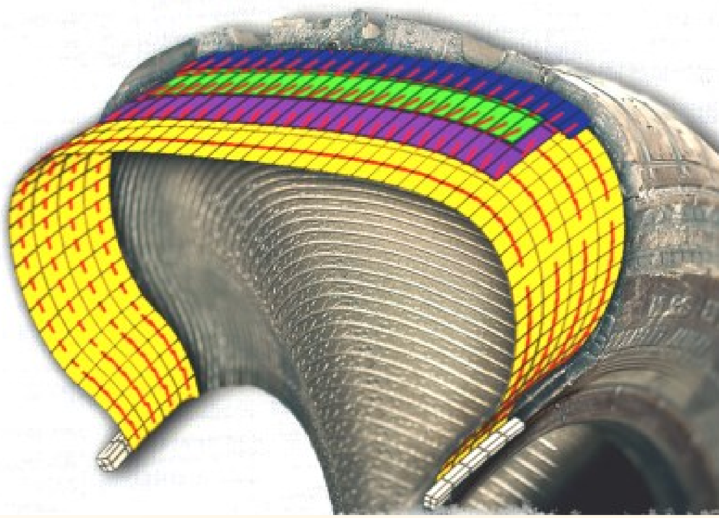


Jan Krmela

Tire Casings and Their Material Characteristics for Computational Modeling

Scientific monograph



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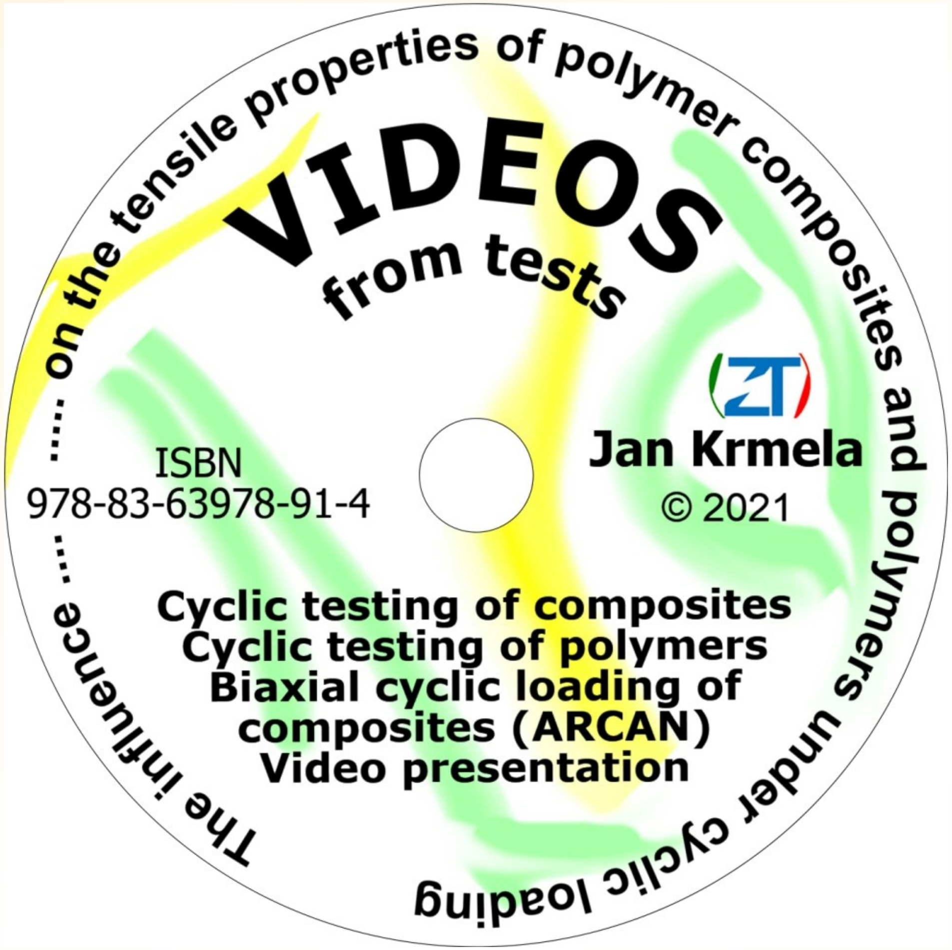

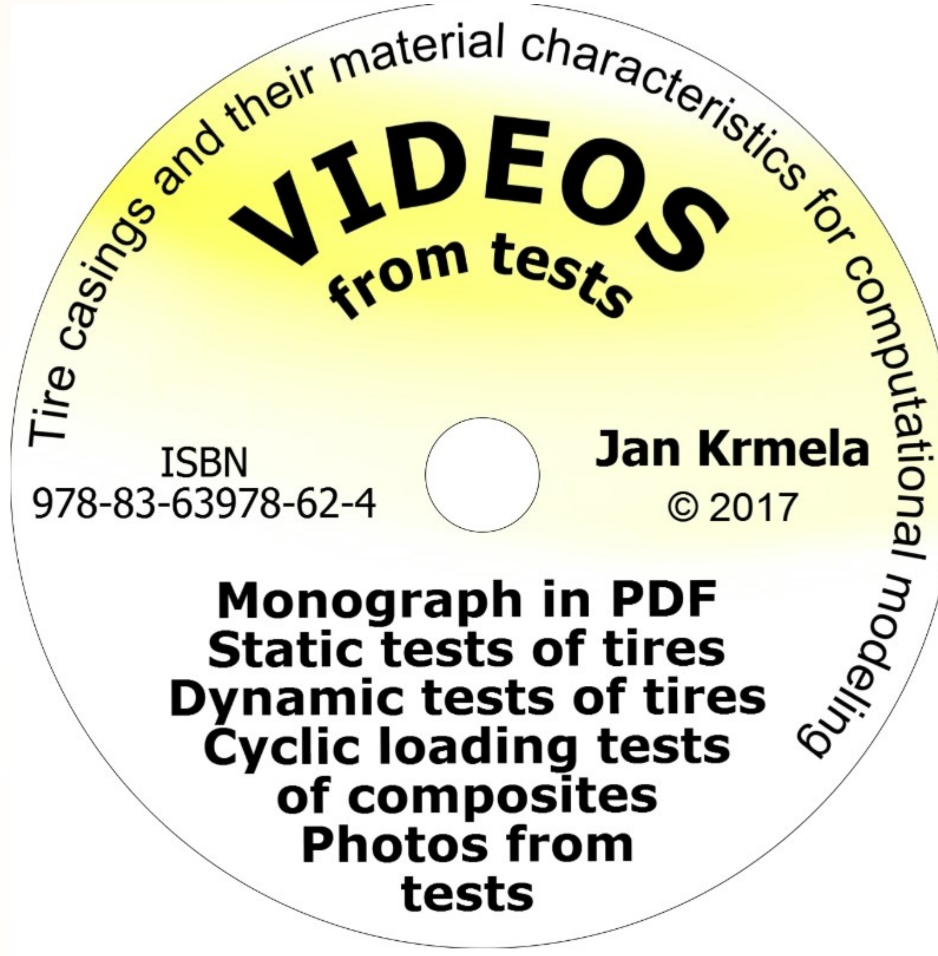

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