Chapter 13

The Chosen Aspects of Materials and Construction Influence on the Tire Safety

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Additional information is available at the end of the chapter

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1. Introduction

Security of the road transport depends on the quality of basic and applied research concerning materials and internal construction of tires. The design shapes and material properties characterized by low hysteretic losses as well as a construction have an influence on the driving comfort, adhesion, wear resistance and fatigue resistance. Thick fibre reinforced composites are used extensively in rubber products such as tires and conveyer belts. Generally, the reinforced parts of rubber products on a sub macroscopic level are highly heterogeneous and anisotropic because they are composed of rubber compounds, and textile and steel cords. Rubber compounds consist of natural or synthetic rubber, carbon black, curing agents, cure accelerators, plasticizers, protective agents and other ingredients.

First, the properties of the different parts of the studied tire will be outlined. A bead is a part of the tire, which fixes to the rim. The bead consists of a steel bead wire, a core, a bead filling and a carcass. They help to transmit loading and breaking.

Particularly we will focus our attention on the influence of breaker angle on tire deformation and potential risks resulting from improper breaker construction.

Experimental results of tread and side wall deformation (influenced by rubber blend as well as a breaker construction) measured independently by both line laser and Aramis system are compared with those obtained by computer simulation in Abaqus environment. The tire tread contributes to a good road grip and water expulsion, the multi-ply steel belt optimizes the directional stability and rolling resistance, the steel casing substantially determines the driving comfort, the inner-liner makes the tire airtight, the sidewall protects from lateral scuffing and the effects of the weather, the bead core ensures the tire sits firmly on the rim, and bead reinforcement promotes directional stability and a precise steering response.

The high security and long life of a tire can be assured only by its correct assignment to the particular type of vehicle and automobile as show Figure 1 (tires only for road operation, for off-road, combined operation as well as for summer or winter conditions). Tires are divided by type of tire-casing on radial, diagonal, bias-belted and special tire.

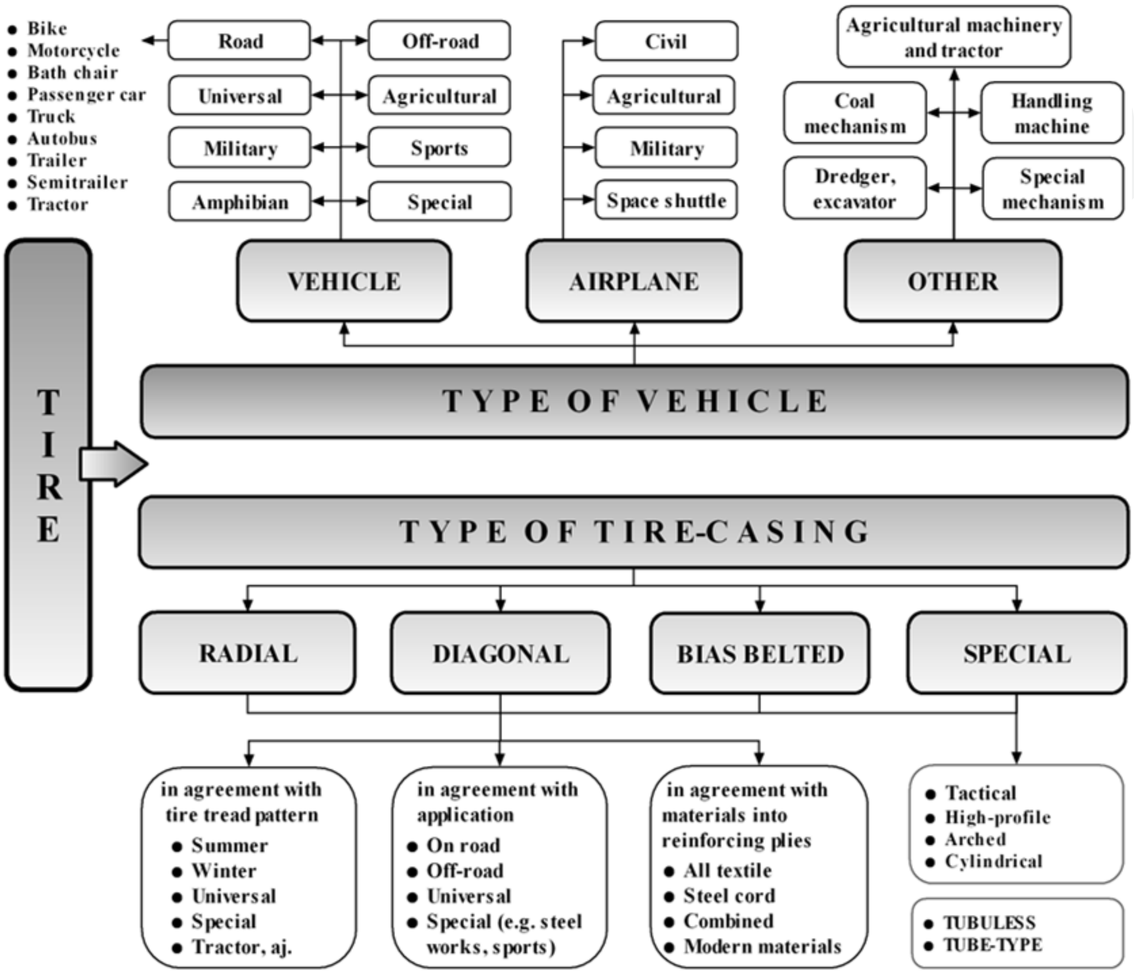


Figure 1. Type of tire by vehicle and construction

Radial tires can be considered as pressure vessels with a maximum pressure given by the particular type of tire. A tire can be generally considered as a statically and dynamically loaded automobile element. The structured view of a tire is apparent from the Figure 2.

The function of wheels with tires is not only to align a car reliably. As can be seen in more detail from the Figure 3 there are more requirements on tires. The main operating requirements on car tires are that car wheels should be as light as possible and at the same time tough, statically and dynamically balanced.

The main requirements on tires are, apart from other things, high wear resistance, optimal deformation characteristics, low rolling resistance, high operational life and safeness, etc. Wheels with tires must meet particular functional requirements given by parameters of tires which affect the running properties of the car, i.e. affect their dynamic behavior (car maneuverability, stability, acceleration, deceleration, driving comfort, etc.).

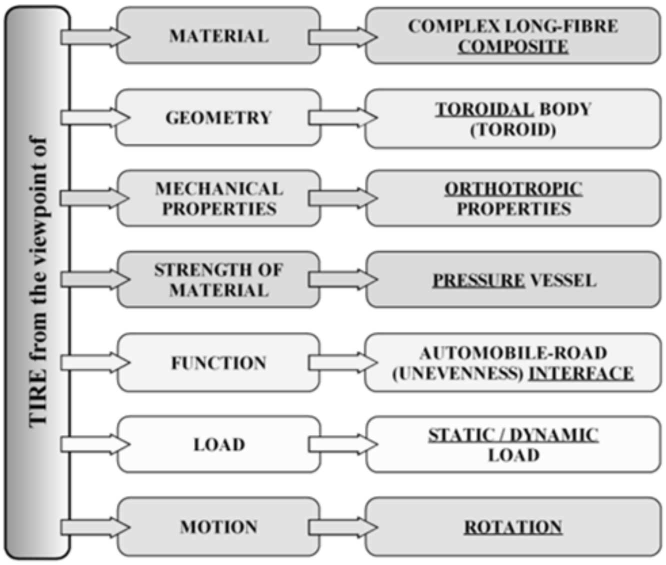


Figure 2. Definition of tire from various viewpoints

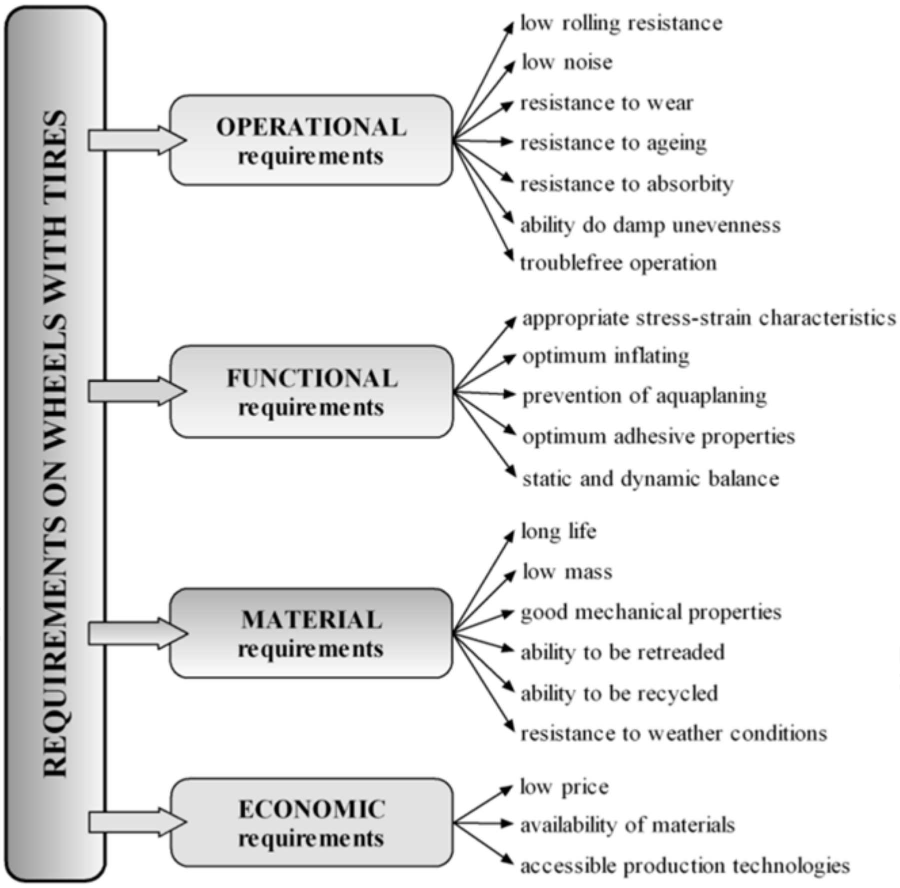


Figure 3. Basic requirements of wheels with tires

Tire safety is passive and active - see Figure 4. Passive safety depends on the quality of the production of a tire casing, the applied technology and used materials and in the case of computational modeling also on the accuracy of the performed calculations and appropriate choice of the computing algorithm.

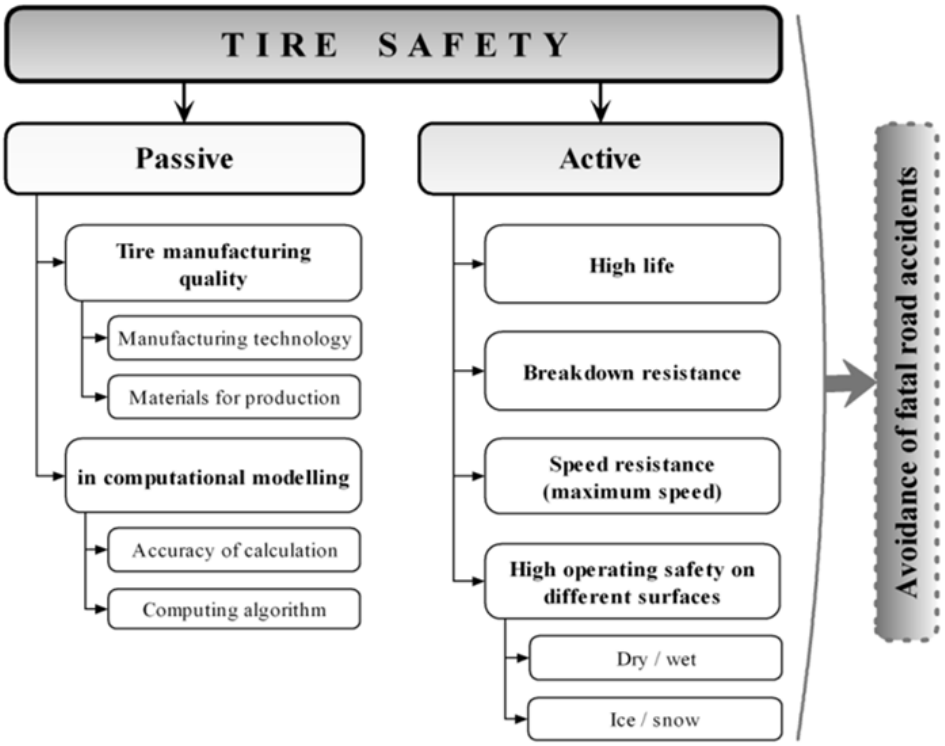


Figure 4. Viewpoints of tire safety

Requirements on active safeness are particularly high running safety on various types of road surfaces, breakdown resistance, speed resistance and high life of materials used for the production of tires, namely reinforcing materials.

Tire life is affected by many factors (e.g. manufacturing way of a tire, its operation and handling, storage conditions of base materials for tire production etc.) while it's assumed an ideal adhesive bond among the rubber elements in matrix (e.g. an interface between tire tread and textile overlap belt) and the cord reinforcing and rubber drift inside tire carcass, and belts is assumed in this cases. For long life tires must resist during operating to surrounding effects, to negative effects of operation and to other effects, which could lead to wear and degradation processes as are e.g. delaminations. The aim is to avoid fatal road accidents which might be caused by tire casing defects either by neglecting operating conditions of tires (depth of tire tread pattern, tire inflation pressure, use of inappropriate tires with a different structure, etc.) or by bad vulcanization during the manufacturing process creating delaminations.

The tire is during the operation exposed to combined loading as from a mechanical (statical, dynamic) as a temperature point of view (local heating in subzones, overall heating in the tire-tread area permeating into the tire during breaking). Also this has to be considered in defining tire safety at high speeds. For this reason tires and wheels as a unit are modified from the structural point of view, particularly for special army vehicles where even a sudden drop of pressure does not put an end to the operating capability of the vehicle (system with a central collar providing circular indexing of the casing with respect to the wheel rim).

New features are introduced for high speeds, e.g. electronic systems which warn the drivers in the case a gradual drop of the tire pressure or adjusting systems for inflation based on the temperature load of the tire casing. Each manufacturer protects the results of his developments and patents considering them as private „know-how". Consequently all new information is only very scarcely available.

In the material point of view a rubber blend could be considered as a composite material which consists of a matrix, a filler and a mesophase.

The dynamic – mechanical properties of such composites can also be described by an elastic, viscous modulus and a loss factor, (Simek 1987, Sepe 1998, Wang 1998, Schaefer 1994, Murayama 1978, Ferry 1980, Jančíková 2006, Jančíková & Švec 2007 and Jakubíková et al 2007). Such properties depend, in turn, on the operating temperature and frequency of the external excitation. Biodegradability of polymers has been studied in (Jakubíková et al 2007).

In a molecular scale, the mechanical properties of rubber blends are influenced mainly by the structure of the blend. The interaction between a matrix and filler plays the most important role and this role is closely connected with dependency of E and G modulus to an applied load or a frequency (both functions have falling tendency and this phenomenon is called Payne effect) (Payne 1965). The polymer in the network loses its identity, and behaves like a filler. The loss factor E'' depends on the dissolution and regeneration speed of the network. It is reflected on the decreasing trend of complex Young's modulus dependence versus increasing sample loading. The values of elastic modulus (E') for vulcanizates without fillers are not changed with the increasing of dynamic deformation (Payne 1965, Medalia 1978 and Maier & Gand Göritz 1996).

The blend properties are characterized by the following parameters: T_g is a glass transition temperature, it is influenced by the silica filler, and for not filled rubber it is approximately *-40°C*. The phase shift between stress and strain is the loss angle. It is postulated that the loss factor, represented by $\tan \delta$, in the temperature span *-10°C to 5°C* (frequency 10000 Hz) characterizes the adhesion of the tire on a wet road. In the span *60°C* to *80°C* (at the frequency 100 Hz) the course of $\tan \delta$, characterizes the rolling resistance (http://ao4.ee.tut.fi/pdlri).

The breaker angle (see below) also influences the security of a tire as well as the driving comfort and stiffness of a tire. The driving properties of the tire as a whole could be substantially improved by optimizing such angle of steel wires of the breaker.

2. The tire description

The work of the authors over a long period of time is devoted to radial tires. The automobile radial tire consists (e.g. cross-sections of selected tire 165 R13 Matador are on the Figures 5 and 6, in detail on the Figures 6 below and 7) of rubber parts and composite structure parts (Figure 8) with textile cords (especially PA 6.6 and PES textile fibers are used) and steel-cords into tire tread as reinforcements.

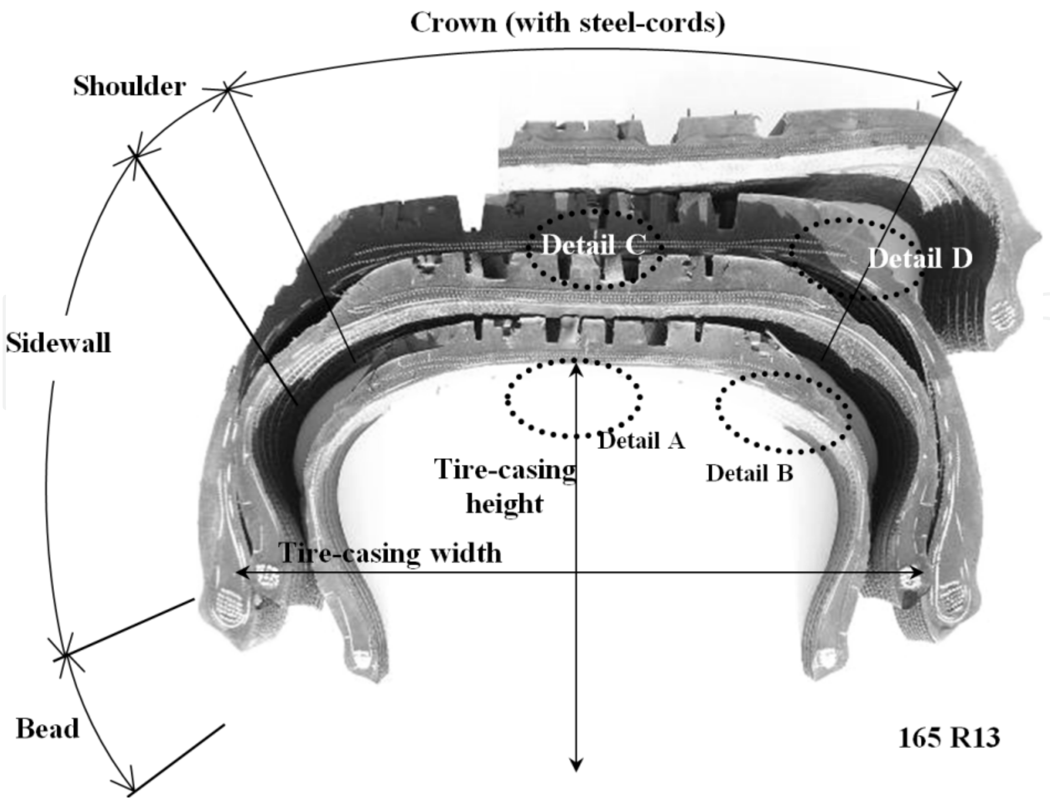


Figure 5. Cross sections of tire-casing

The composite structure parts applied into radial tires (Figure 8) are:

- Textile tire carcass;
- Textile overlap belt;
- Steel-cord belt.

These structures of tire have got:

- Different cord-angle (e.g. for steel belt applied angle 21-27° into radial tire for passenger car);
- Material of cords (steel, textile, Kevlar, combine);
- Shape and construction of cord (wire, wire strand);
- Numbers of layer (single-layer or multi-layer).

So a tire has got characteristic specific deformation properties.

One construction of tire is used for passenger cars, other constructions for trucks, off-highway cars and sports cars. The tires for air transportation, agricultural vehicle, mining machine and other vehicles have got complicated structured in comparison radial tires for passenger cars. The tire structures are differentiated by numbers of reinforcing plies into belt tire, construction of belts, materials and cord-angles, geometry parameters of tire, width of belts etc. These aspects are influenced on final behavior of tires, namely deformation characteristics of tires. It is possible increase of resistance of tire to some degradation processes by suitable tire construction.

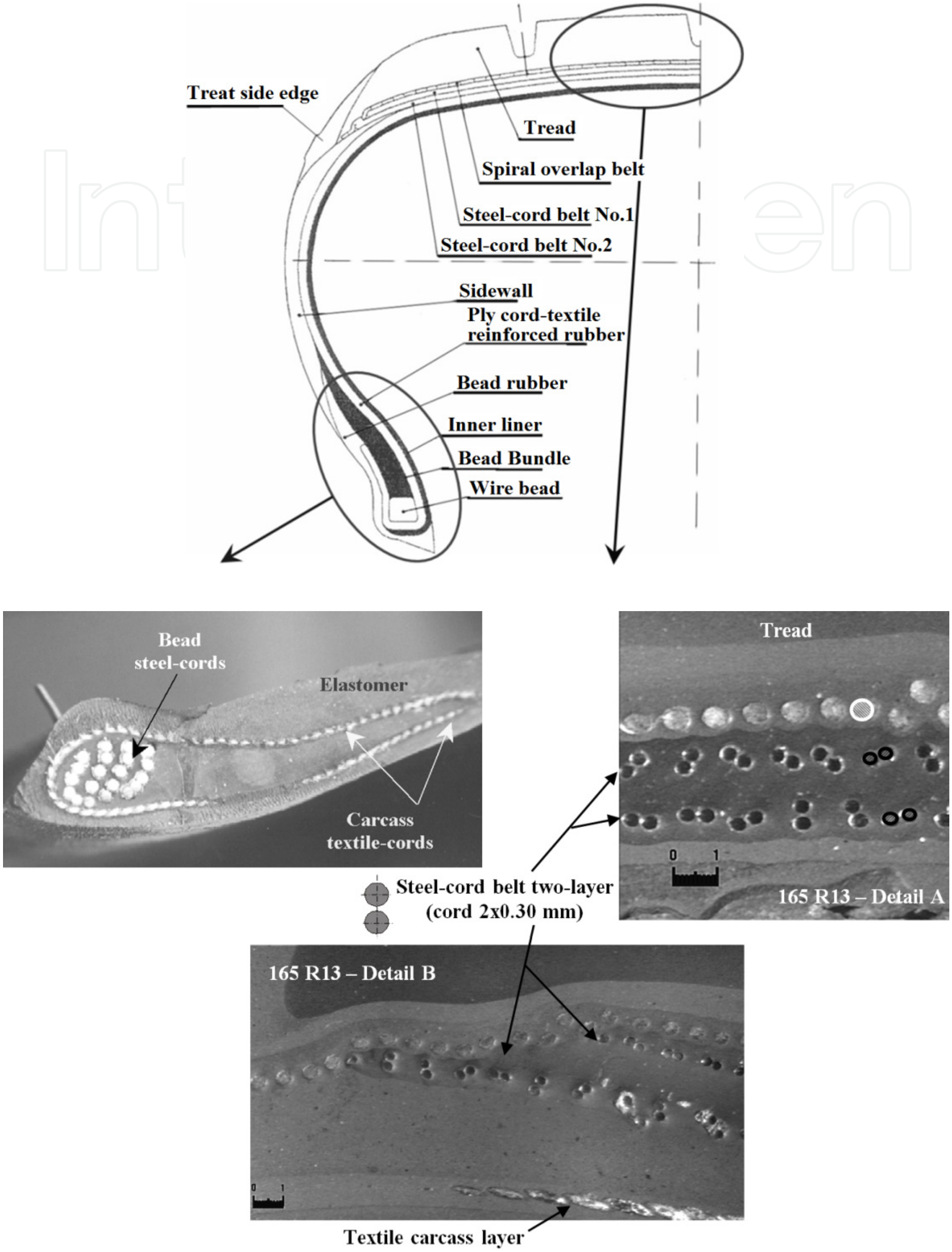


Figure 6. Structure of the tire 165 R 13 [based on Matador] with microstructure of reinforcing plies detail A in the area of tire crown and detail B at the end of steel-cord belt (below)

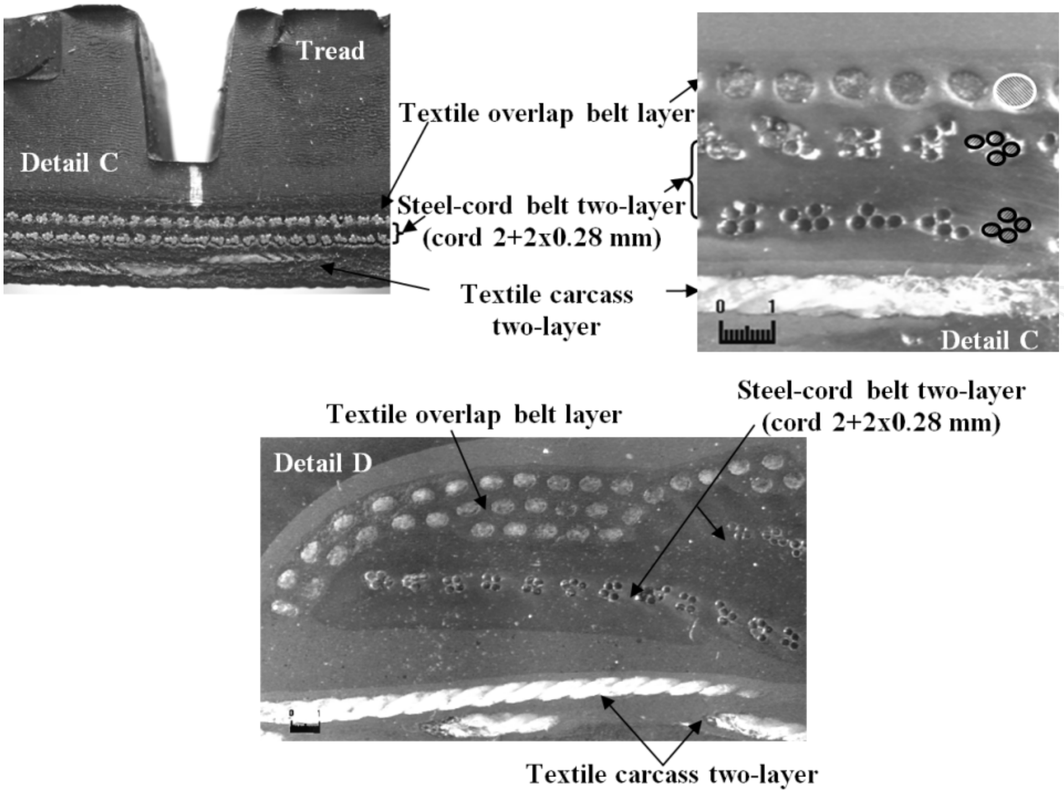


Figure 7. Detail C in the middle of tire crown and detail D at the end of the belt layers (below) of different radial tire

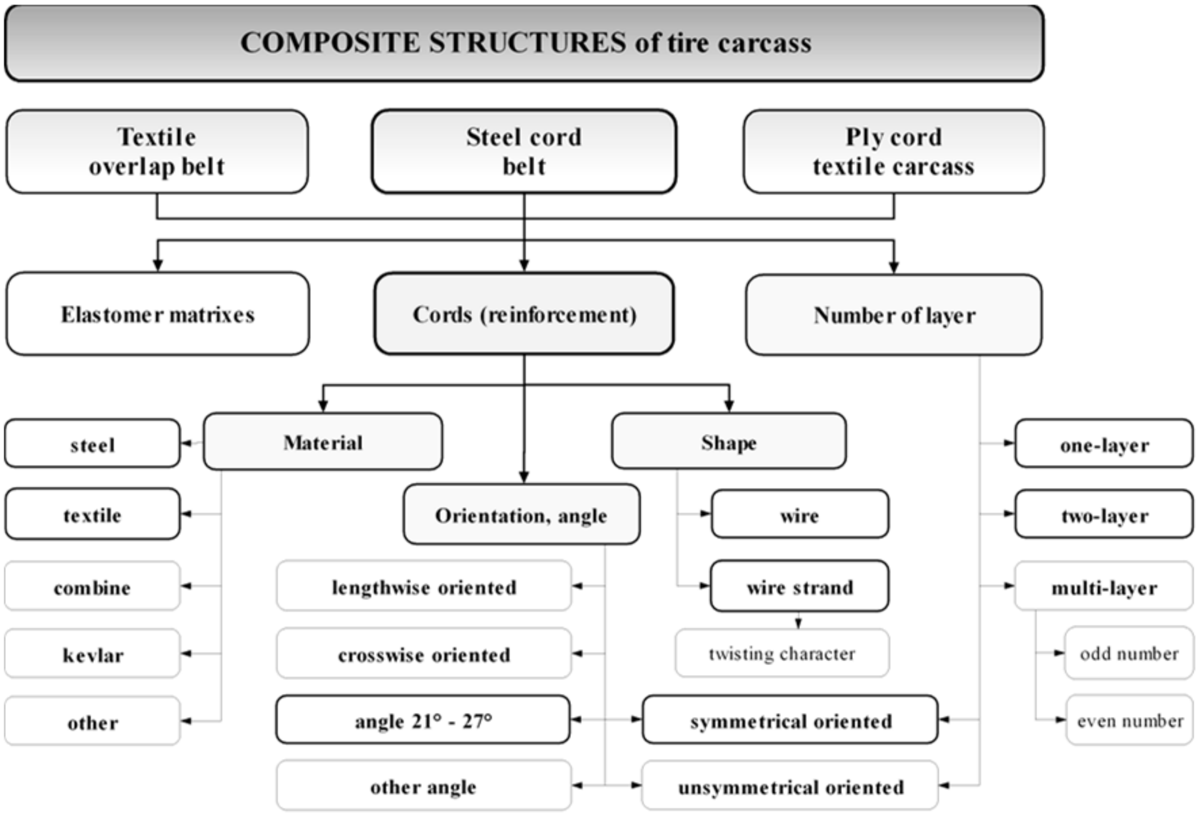


Figure 8. Composite structures used in tire

Two-layer steel-cord belt is used in radial tire *165 R13 Matador* with construction of cord *2x0.30 mm* with texture *961* (number of cord over meter width of belt). The cord angle is *23°*, the layers are symmetrical.

Structure – cord orientations of radial tire *22.5″* for truck vehicles presented in the Figure 9 as an example.

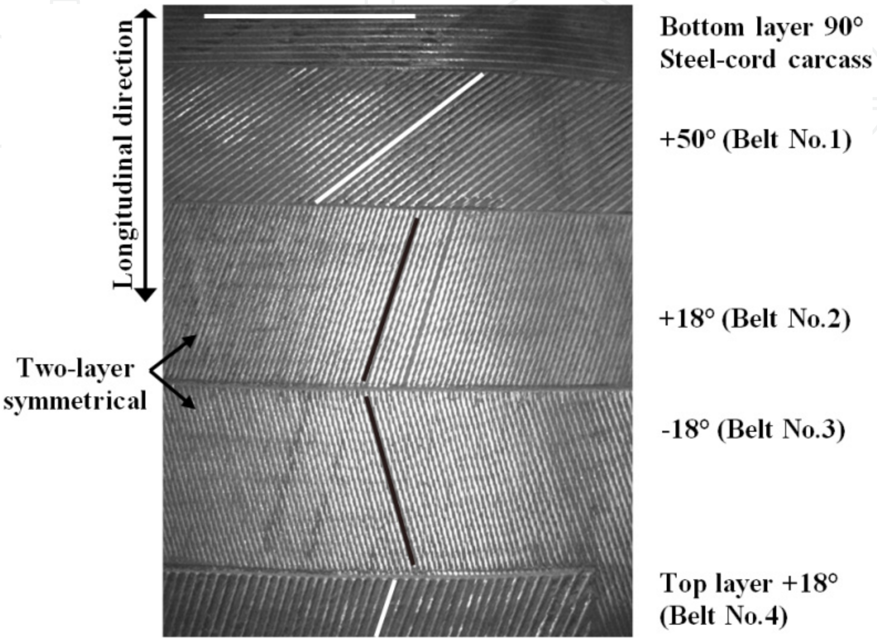


Figure 9. Structure of truck tire in the middle of tire crown

Steel-cords can be in form of thin wire or wire strand with different constructions. High-strength steels are used exclusively for steel-cord production and good adhesive bond between rubber and cords required. Steel-cord surfaces are modified by chemical-thermal treatment (braze or copperier, Figure 10) to achieve the best adhesive bond of a steel cord and rubber and get it corrosion resistant. The substantial factor, which expressive influence on coherence of whole tire, is good adhesive bonds between reinforcement materials and rubber parts of tire.

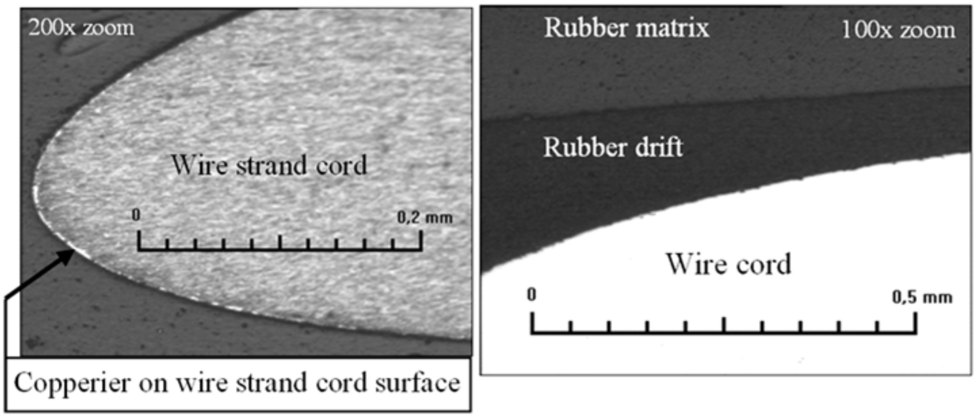


Figure 10. Steel-cord surface and interface between cord-rubber drift-rubber matrix

The tire steel-cords are exposed to various chemical and thermal influences (Figure 11) during cyclic loading states by tensile-compression in tire loading processes. Account on this the adhesive bond is more exposed to be damaged than the basic materials (steel, textile and rubber). The aggressive environment (e.g. action of salts in winter) activates the corroding process on steel-cord surfaces that can lead to decreasing of the adhesion between reinforcement-and-matrix, which demonstrates itself by negative changes in material properties of steel-cord belts and such of whole tire too.

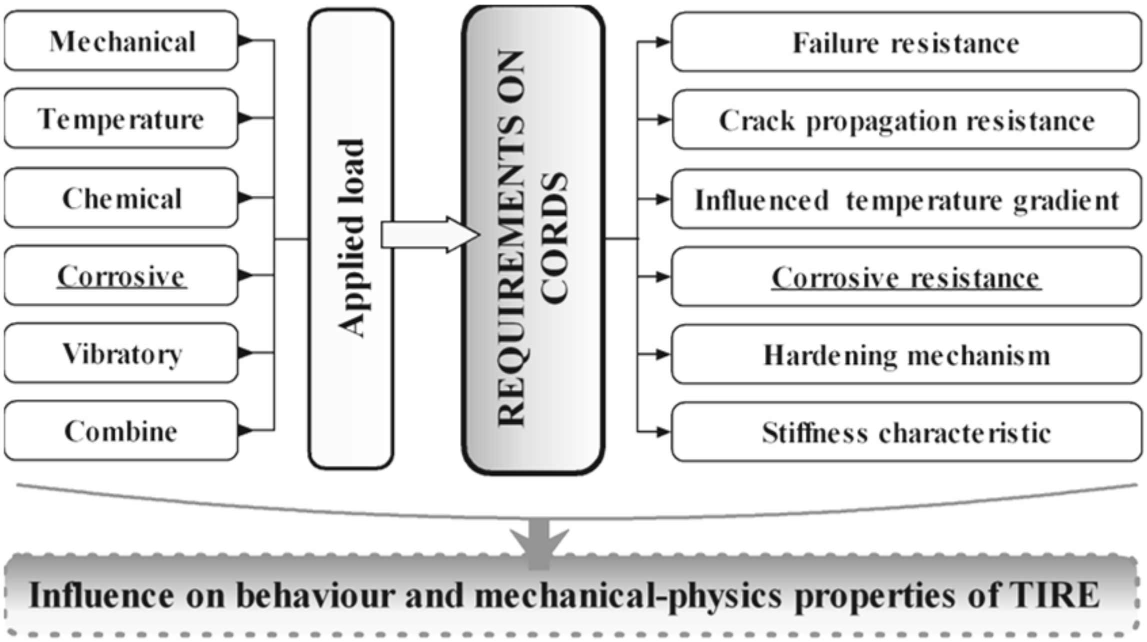


Figure 11. Requirements on reinforcing tire cords

In addition if the tire is in use is defected in tire crown (e.g. defect caused by sharp object as a nail and after the repair is placed back into operation) the initiation of corrosion with faster process is being assumed. Consequently this can lead to gradual or sudden failure of the steel-cords and bonds of steel-cord and rubber with a serious car accident as a final consequence.

Any damage in the area of tire crown, namely into steel-cord belt, is perilous.

3. Degradation processes of tires

Tires are subject to internal and external effects which can more or less cause limit states leading to degradation processes Figure 12. Ones of them marked as very dangerous and unacceptable tire casing damage are so-called separations and delaminations (Figure 13 left). Breakdown or damage is not necessary only at the border of single layer e.g. between the layers of steel-cord belt plies in the tread of tire casing, but also between rubber matrix and reinforcing cords. Delamination between rubber drift-rubber matrix on Figure 13 right.

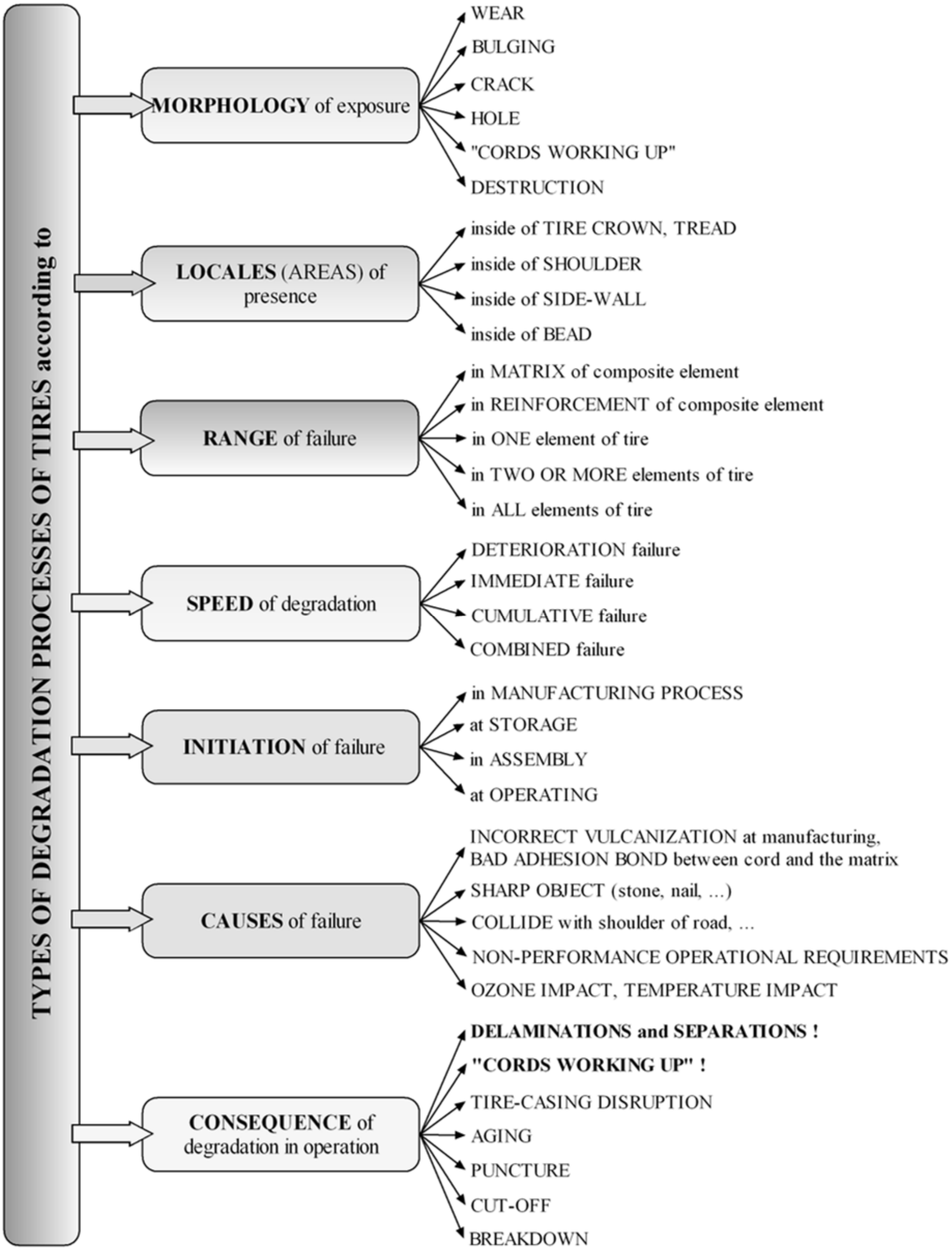


Figure 12. Degradation processes of tire

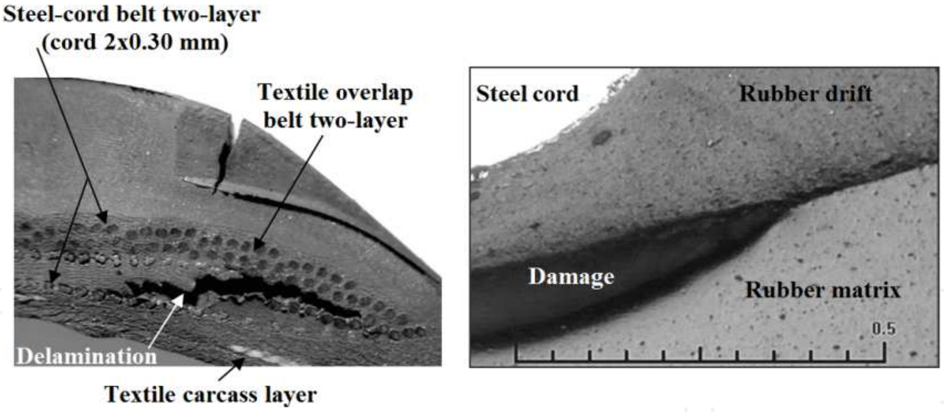


Figure 13. Factitious delamination between belt plies and damage between rubber drift-rubber matrix (right)

Root cause of mentioned degradation processes can be caused by using of low quality materials for the tire in manufacturing process, their incorrect storage leading to early aging especially at rubber compositions, not keeping optimal manufacturing conditions – vulcanization, as well as by the influence of incorrectly pressurized tire and damaged adhesive bond between cords-matrix and belt plies etc. Damaged adhesive bond is greatly decreasing of tire safety during the operation of a vehicle at high speeds. This has a significant influence to the quality of the tire casing expressing by lowering the level of usage (decreasing speed index) or leading to the catastrophic situations. In every case it is mandatory to avoid these premature limiting states.

In tires can be caused:

- Cords release leading to the cords working-up;
- Separations – delaminations;
- Combined wear;
- Total breakdown.

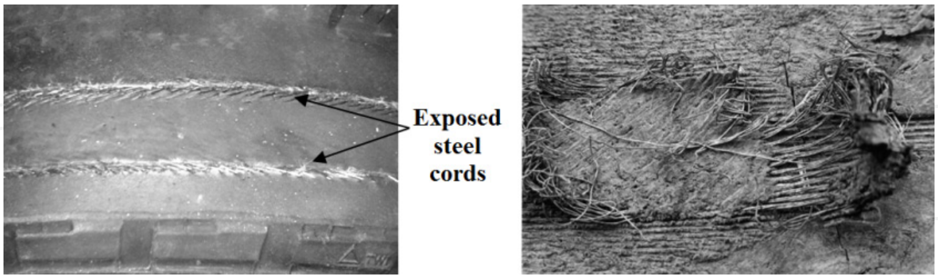
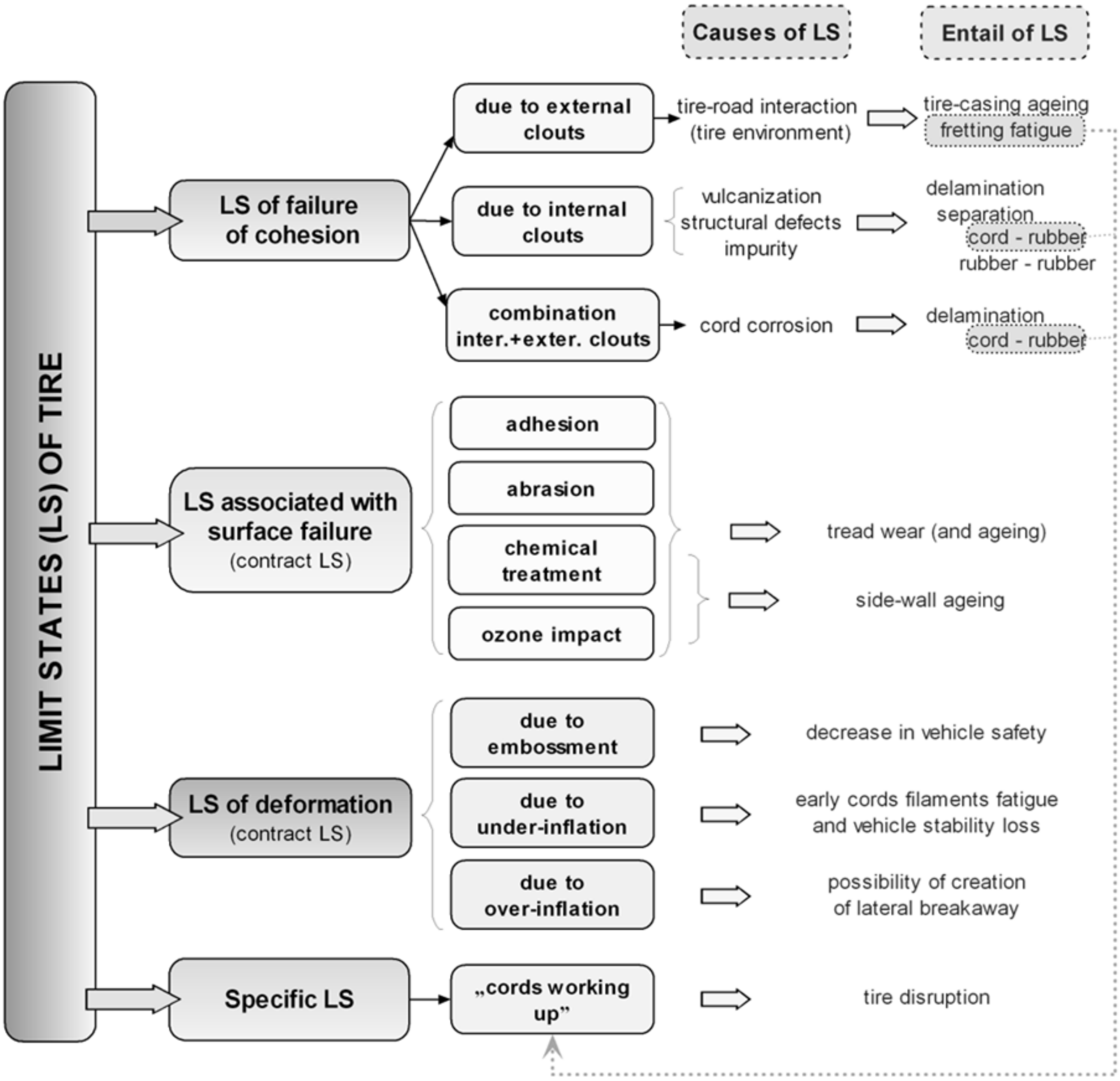


Figure 14. Extreme wear of tire on tread surface; and "cords working-up" (right-photo by Prof. Janíček, VÚT Brno, Czech Republic)

Results of wear due to adverse change (Figure 14) of tire casing surfaces are gave in impairment of mechanical-physics properties of whole tire. This will be influenced the incoming behavior of tire in operation and related interfaces between of tire and surroundings. Particularly dangerous is creation of failure in such places where initiation is not assumed to be caused by impairment of the surface. Structural changes in a part of tire as composites are not only responsible for the impairment of its properties but also of its geometry which can initiate vibrations leading to loss of the part's functional ability of whole vehicles (automobiles).

Wear can be of various character (development, place, form, appearance) and leads to the failure of the tire (Figure 15a and 15b). The task of prediction is to find ways how to reduce wear and to postpone initiation of dangerous degradation processes such as delamination and separation and to focus on the removal of initiators of these degradation processes.

Wear due to adverse changes of surfaces results in impairment of properties and behavior of parts. Particularly dangerous is failure in such places where initiation is not assumed to be caused by impairment of the surface. Structural changes in a part are not only responsible for the impairment of its mechanical properties but also of its geometry which can initiate vibrations leading to loss of the part's functional ability. All this resulted in environmental and economical losses.



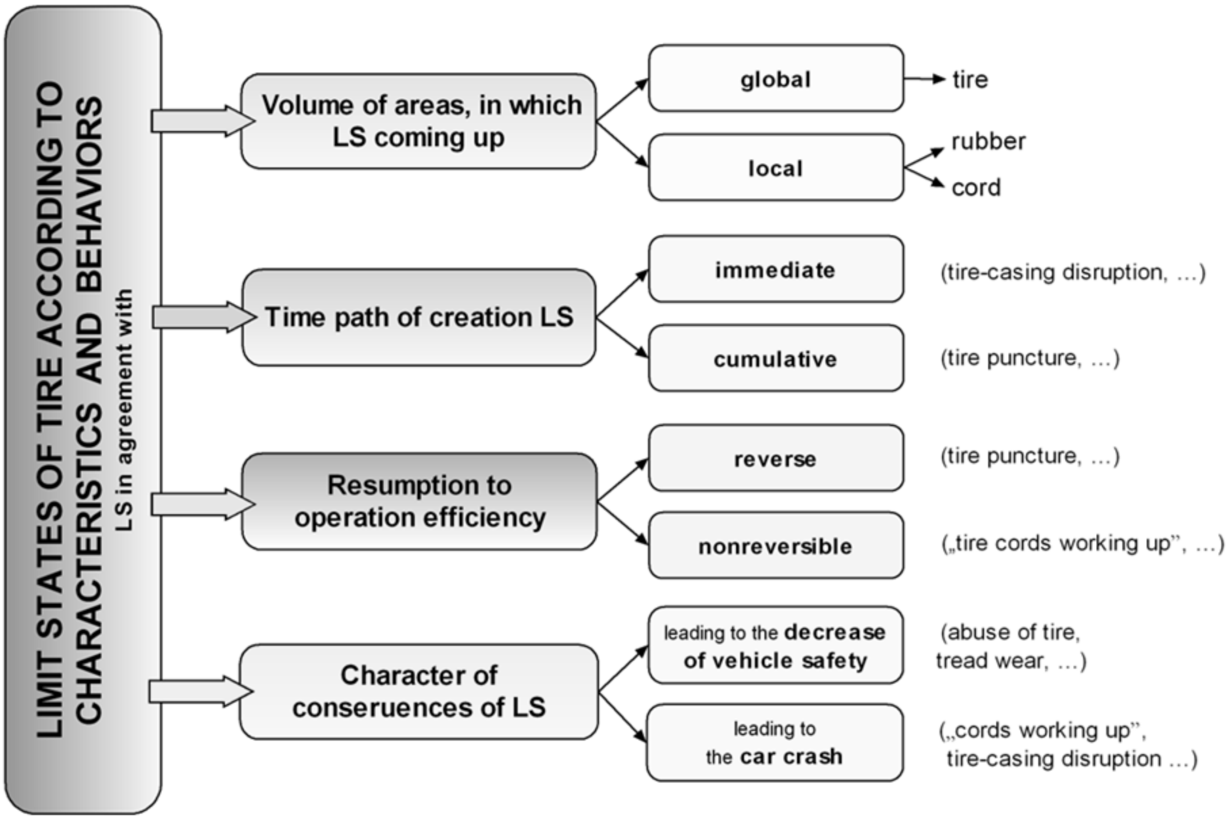


Figure 15. a. Limit states of tire; b. Limit states of tire

Tires must resist during operating to surrounding effects, to negative effects of operation and to other effects, which could lead to wear and degradation processes as are e.g. delamination. Resistance to the following effects is considered (Figure 16):

- Puncture – capability of tires to resist puncture by sharp objects;
- Cut-through – capability of tires (especially of the tread and sidewall) to resist contact with sharp objects;
- Breakdown – capability of tires to resist damage during short-term loading by concentrated forces;
- Fatigue – capability of tires to resist material fatigue and defects in consequence of repeated loading cycles;
- Separation and delamination – capability of structural tire components to maintain integrity of the system during operation;
- Humidity – tire elements must be able to resist degradation by contact with water;
- Ozone influence – capability of tires and of theirs components to resist degradation caused by ozone present in atmosphere;
- Temperature – tire components must be able to resist high and low ambient temperatures and also consequences of contact with the road;
- Chemicals – capability of tires and theirs components to resist degradation caused by chemicals (in winter – influence of salt solutions);
- Corrosion processes – capability of tire reinforcing cords to resist corrosion, etc.

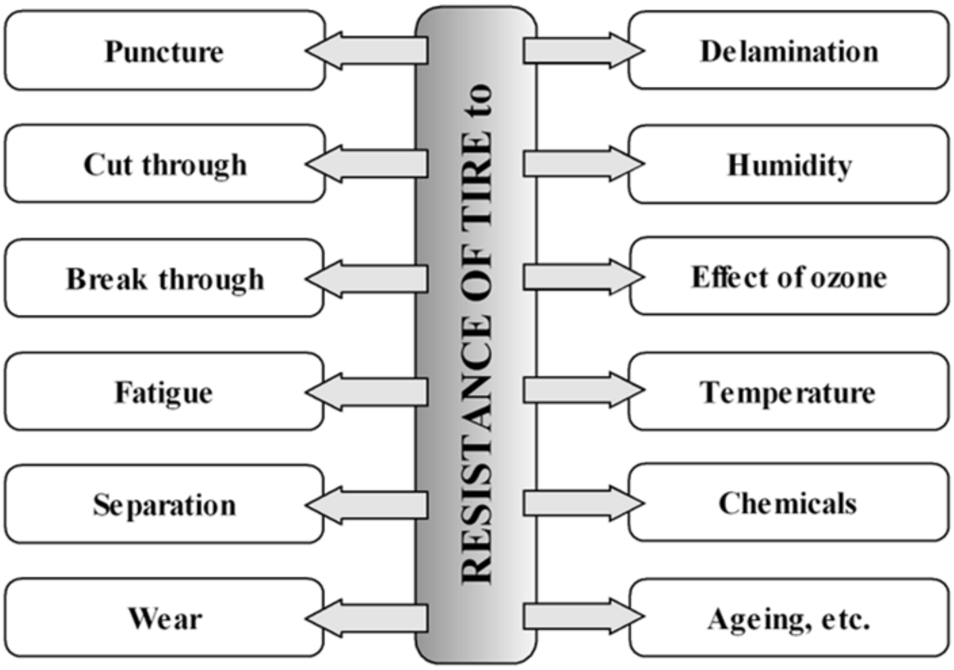


Figure 16. Basic requirements on the tire resistance

An appropriate design will help to increase resistance of the tire to certain degradation processes such as e.g. corrosive attacks initiated by local damage of the tire in cases where damaged are the steel cord reinforcements. Design optimization aimed at resistance to degradation and at achievement of longer life can be well performed by computer modelling. The computer modelling has reached such a level that it can work with a great amount of input data which represent the initiation of degradation effects on such a complicated technical object as a tire.

It is important to design such structure that the tire would be as much resistant to any degradation type as possible. These are required complex approach to experiments and computation of tire from macrostructure and microstructure too. It is necessary to have a good knowledge about:

- Structure of tire-casing;
- Material parameters of matrixes and reinforcements (steel-belt);
- Adhesive bonds cord-rubber, which obtained by metallography observation of reinforcements-matrix transit;
- Influence of degradation processes – corrosion effect on composite materials from micro and macrostructure point of view.

4. Testing of tires

It is necessary to run tests of tires as a whole, as shown in the Figure 17, and tests of individual tire casing components, purposely separated parts etc. This is how an overview which structural modifications can lead to an increase of the level of safety criteria, increase of resistance, life etc. can be obtained.

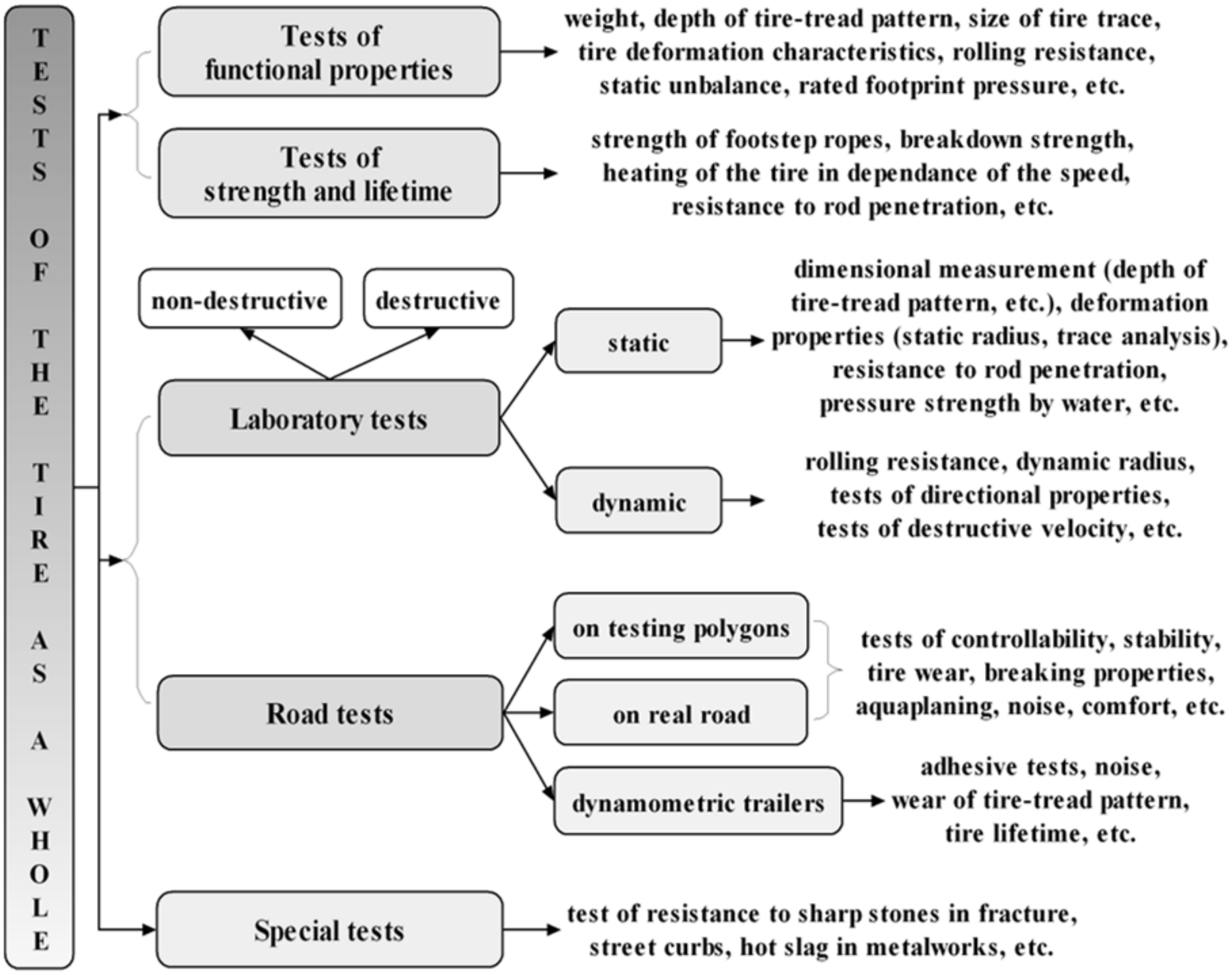


Figure 17. Tests of the tire as a whole

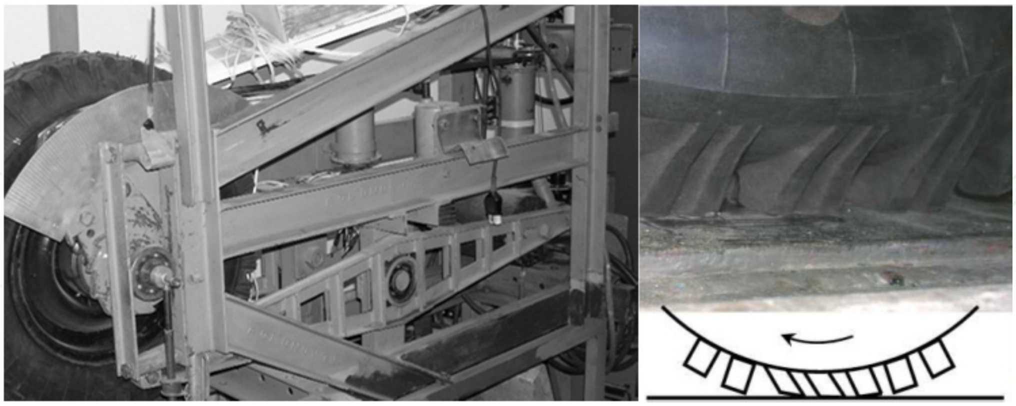


Figure 18. Static adhesor with detail of contact patch

Also basic statical deformation characteristics of tires can be obtained from a device called statical adhesor (Figure 18), which is available to author. The statical adhesor also enables measurement of data from the contact surface under defined conditions – shape of obstacles, vertical loading and inflation pressure. It is possible to obtain outputs from experiments on statical adhezor:

- Radial deformation characteristic (by vertical tire force loading);
- Torsion deformation characteristic (slip curve by twist moment);
- Size and shape of contact area and distribution of contact pressure;
- at following conditions:
- Loading (vertical);
- Tire pressure (under-inflation, overinflated tire, specified pressure);
- Size of radial deformation;
- Shape of obstacle etc.

5. Test of tire structure

Material parameters of long-fiber composite structural parts as the tire steel-belt are necessary input data for tire computational models (e.g. steel-cord belt) and for subsequent comparison of computational models with experiments. Knowledge is necessary of the behaviour of composites as belts 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 as tire belts 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 fibers-cords. Composites of tire 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 rubber matrix-cord interface. Tests of specific long-fiber composite materials with hyperelastic matrixes (namely steel.-cord belt test sample) are not standardized and neither are the shapes and dimensions of test samples, namely for tensile tests, which are for the observation of mechanical behaviour absolutely essential. For determination of material parameters of rubber matrixes and cord-reinforcements are necessary make experiments in agreement with standard specifications.

In composite samples or in samples with a certain content of composite layers of concern are the configurations of cords with respect to the direction of loading which results in a change of the stiffness characteristics. Therefore is necessary to design the geometrically parameters and shapes of one or multi-layer tested samples before experiments. The samples must have different:

- Angle of cord (with respect of the direction of loading – not only longitudinal and transverse orientated samples) – see figure 19;
- Material of cord (surface treatment);
- Form of cord (wire, thin wire);
- Number of layers (single-layer, two-layer – Figure 19, multi-layer);
- Specimen width, shape etc.

The author Krmela was designed multi-layer test samples with different wide *10, 15* and *25 mm* and of *length 120 mm*. The cord-angle orientations in single-layer specimens are *0°, 22.5°,* *45°, 67.5°* and *90°*. Two-layer specimens (Figure 19) 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°* (it is *+22.5°/-112.5°*, specimen D) with thickness *4 mm*. Real single and two-layer specimens are presented Figure 20 as an example.

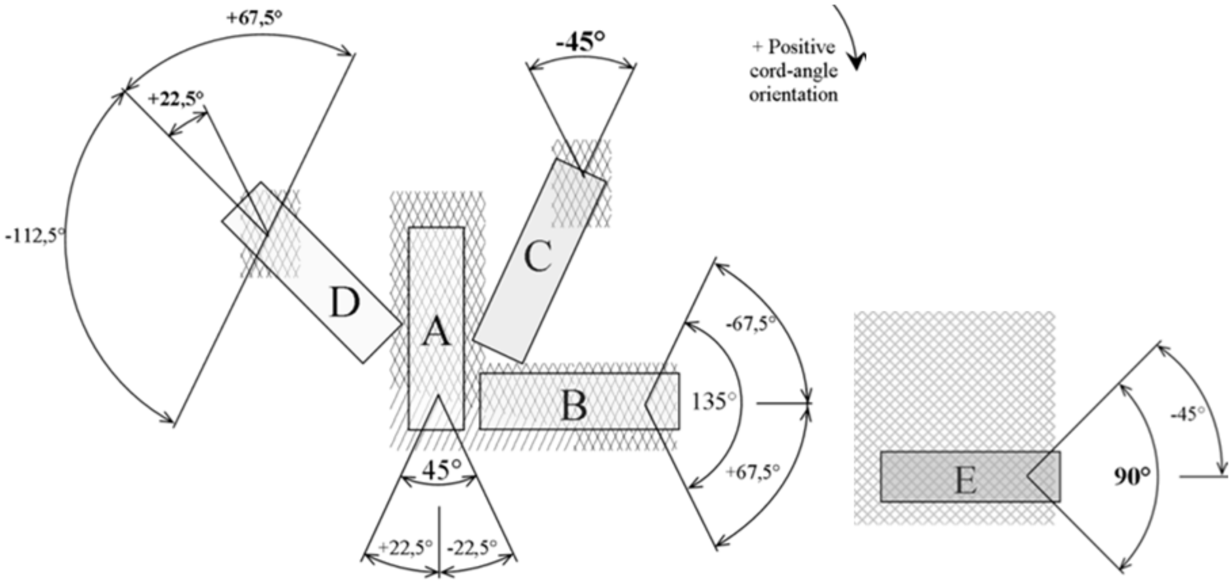


Figure 19. Two-layer specimens from plates with cord orientations 45° (left): A – lengthwise symmetrical specimen with 22.5°; B – transverse symmetrical specimen with 67.5°; C – asymmetrical specimen with +0°/-45°; D – asymmetrical specimen with +67.5°/+22.5°; Specimens from plates with cord orientations 90° (right): E – symmetrical specimen with 45°

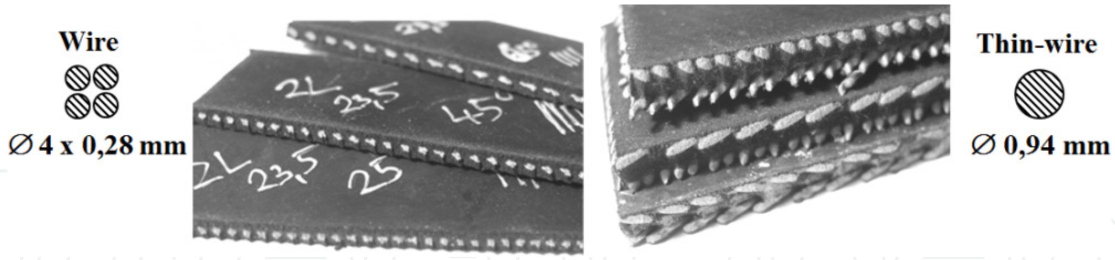


Figure 20. Single-layer specimens of steel-cord belt with wire cord and two-layer specimens with thin-wire cord (right)

Also must be determined conditions for individual type of tests, namely:

- Statically tensile tests (uniaxial and biaxial);
- Statically bend tests;
- Statically tests of composites under combined loading states (combinations tensile with bend) - that are to be approximated tire real state during tire operational loading (predicate about real deformation behaviors of steel-cord belt plies);
- Corrosion tests in a corrosion chamber (exposition time);
- Dynamically test etc.

Statical tensile tests of steel-belt samples are important for obtaining knowledge about stiffness characteristics and material parameters. The conditions of the tensile tests are:

- Initial length between the jaws of the testing machine is *92 mm*.
- Elongation measured on the same length and also measured on *50* (or 25 mm) in centre of specimens.
- Rate of test is *10* or *25 mm/min*.

As output example from tensile test of two-layer belt for different cord-angle and cord-type Figures 21 and 22 give tensile force-elongation and stress-strain dependences (elongation measured on the length between the jaws).

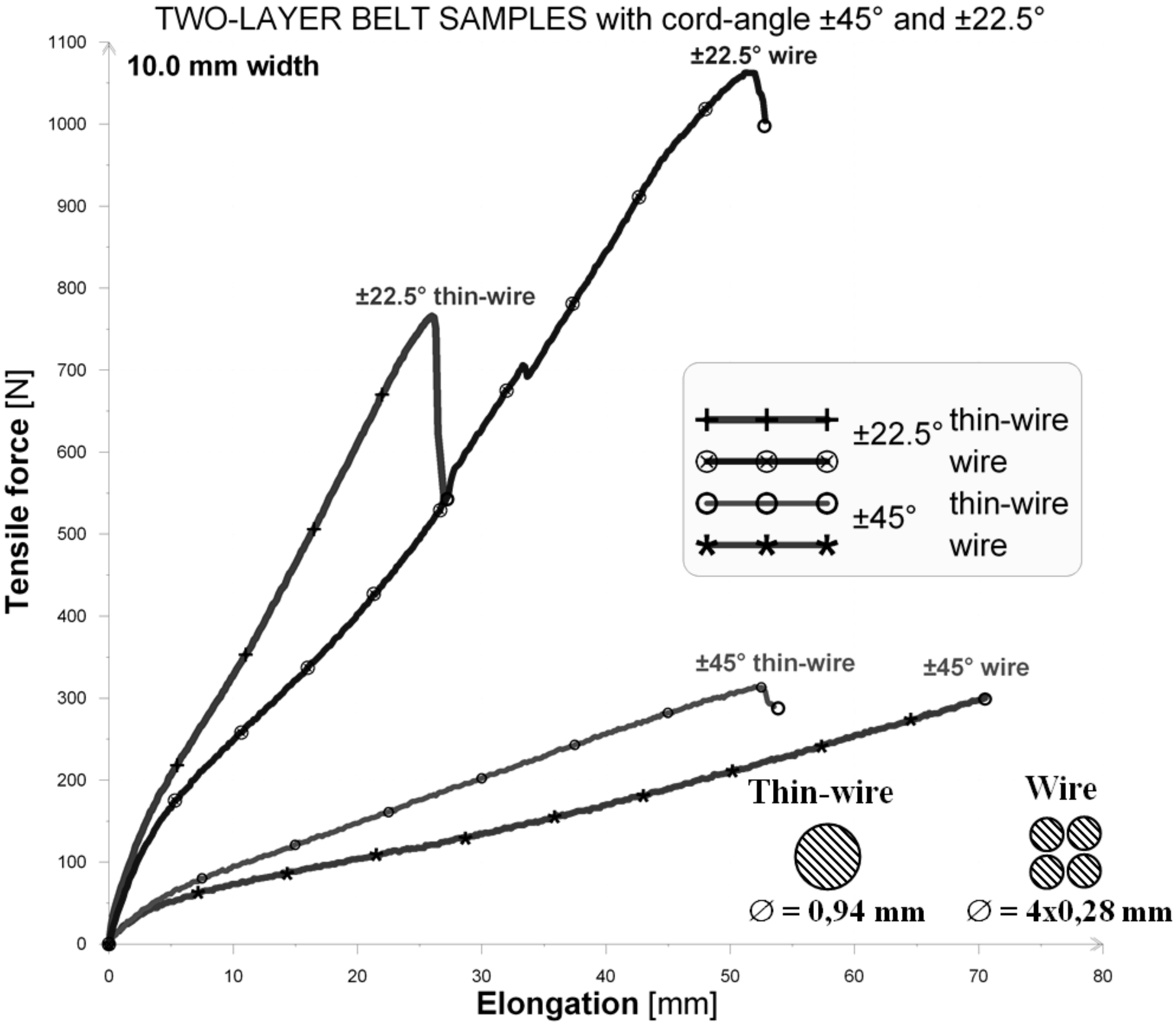


Figure 21. Outputs from tensile test of steel-cord belt samples – force-elongation dependences

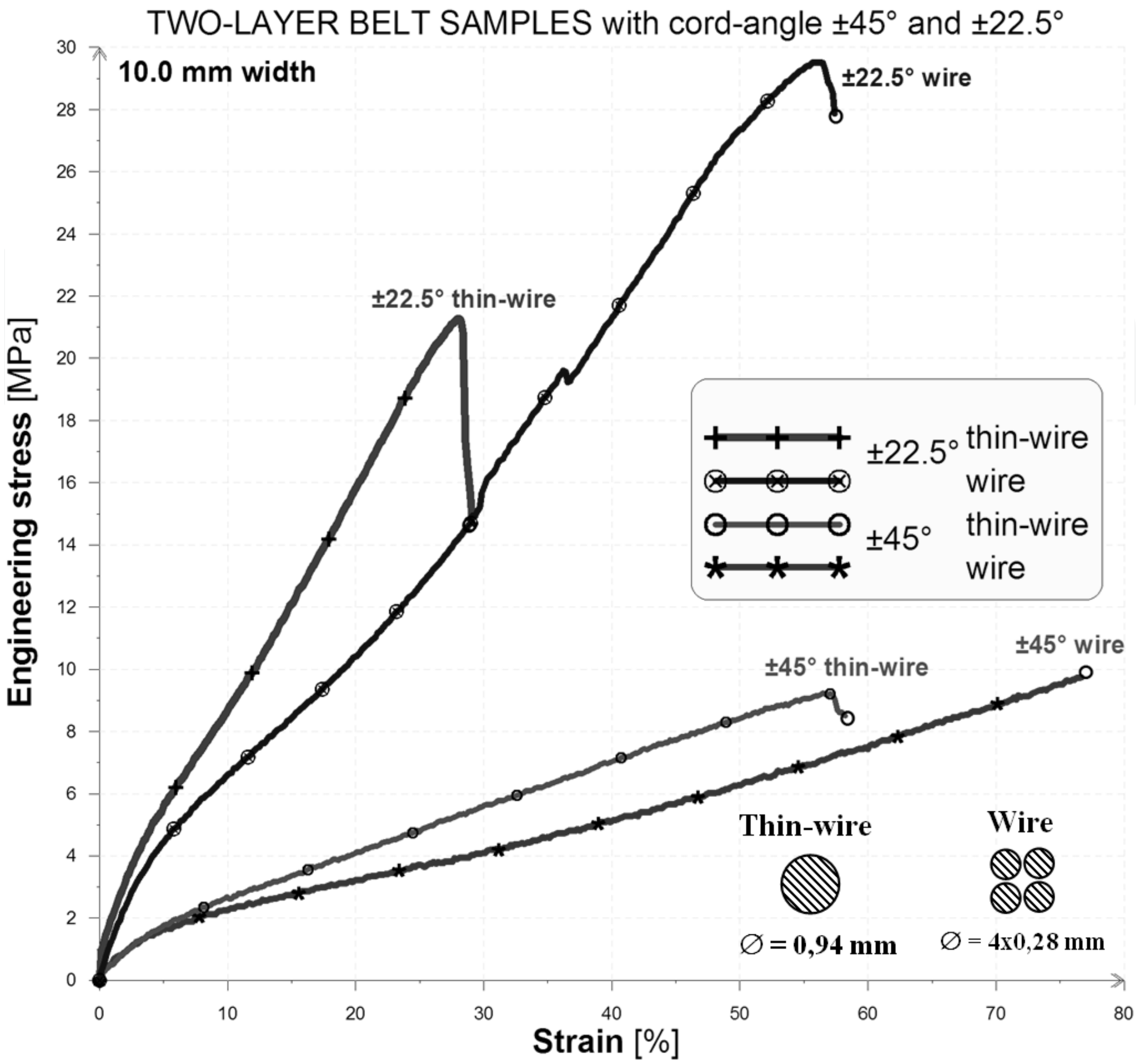


Figure 22. Outputs from tensile test of steel-cord belt samples – stress-strain dependences

Figure 23 presents some examples of specimens' failure after tensile test.

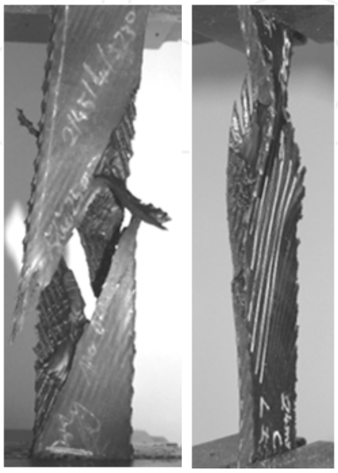


Figure 23. Failure of two-layer symmetrical ±22.5° and asymmetrical specimens +67.5°/+22.5° (right) after tensile test

The selected specimens were subject to statical tensile, also compression, shear and bending tests. Also testing conditions have been designed. Tests is necessary perform not only at ambient temperature 20°C but also at lowered and elevated temperature (from -30° into 180°Celsius).

6. Corrosion test of steel-cord belt

It will be possible uniform statically test conditions for samples affected by corrosion and samples without corrosion.

Selected single and two-layer composite test specimens are exposed to corrosion tests in a corrosion chamber *Gebr. Liebisch S 400 M TR* (for 500 or 265 hours in saline application by temperature at 70°Celsius – authors note: such extreme conditions should not ever appear in tire operations if proper conditions are kept) and to static tensile tests till the failure. The aim of these tests is to find the influence of the degrading process on the stiffness characteristics of the composite structures. Also will be investigated an influence of degree of degradation on the adhesive bond matrix-reinforcement.

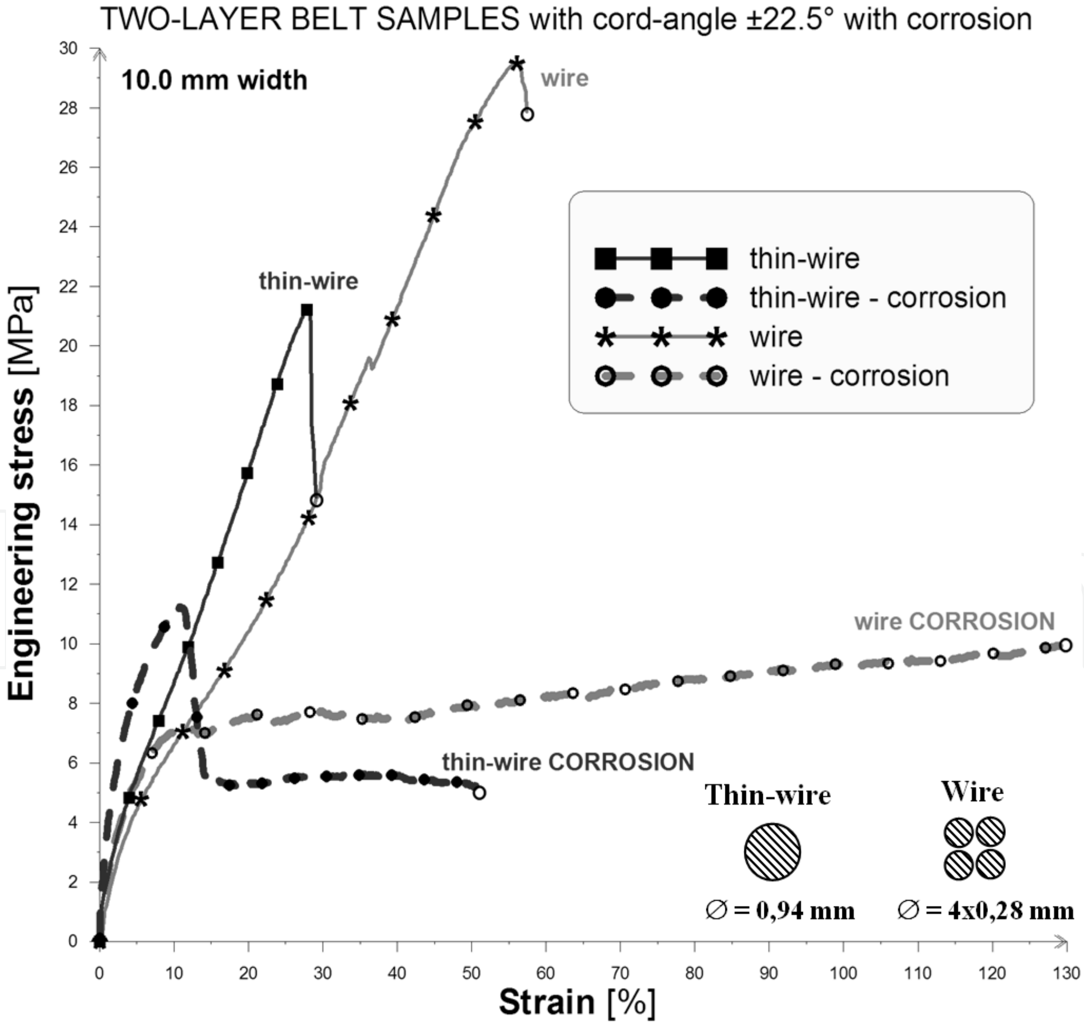


Figure 24. Outputs from tensile test of steel-cord belt samples – stress-strain dependences

The results obtained from tensile test will be compared with results obtained from tensile test on samples without corrosion. The experimental results of tensile tests of undamaged (non-corrosion) steel-cord belt ply (two-layer with cord-angle ±22.5°) for comparison analyses with belt ply after corrosion tests are shown in Figure 24 as dependences stress on strain.

The influence of corrosion on the stiffness and tensile force-elongation or engineering-stress dependences is sizable. The oxide film is strongly affected on failure of adhesive bond.

The fracture characters of test specimen after tensile and corrosion test in a corrosion chamber were accounted. The fracture of test specimen with *22.5°* angle and thin wire cord is on Figure 25 as an example. The corrosion processes on cord surfaces is very dangerous. Therefore, it will be important to study also adhesive bond.

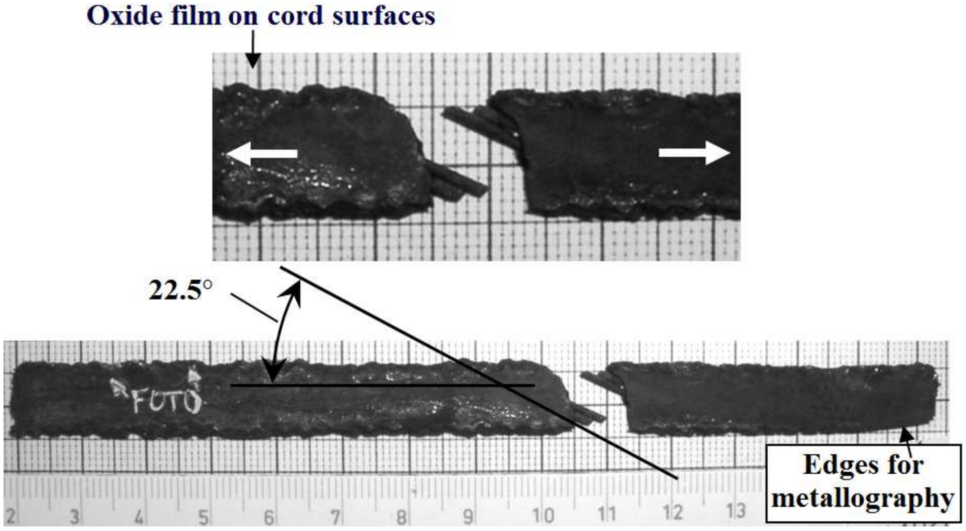


Figure 25. Fracture character of specimen with corrosion after tensile test

7. Metallography of Interface between Cord-Rubber

The light microscope is used for metallography observations of the adhesive bond between steel-cord and rubber after failure after corrosion test in corrosion chamber and statically tensile test and without corrosion too. The edges of steel-cord belt specimens were observed in detail – (see Figures 25 and 26).

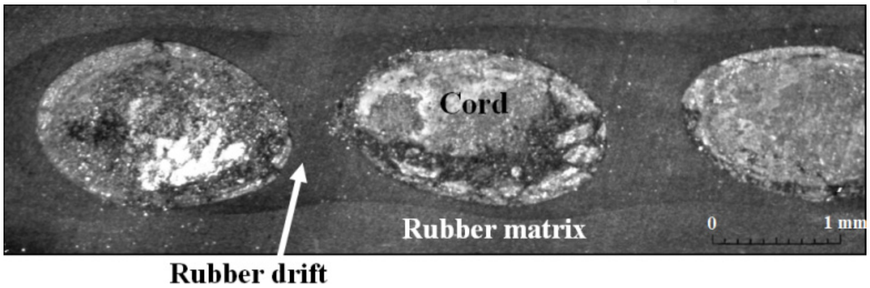


Figure 26. Interface between thin wire steel-cord/rubber drift/rubber matrix after corrosion and tensile tests

Microscopy with *100x-200x* zoom will be used for the evaluation of adhesive bonds from level of failure point of view. It appears that sufficient zoom from setting of failure level point of view (detection of delaminations, separations).It is necessary to prepare of samples for microscopy observation of structures so that the samples included different:

- Form of cord;
- Geometrical configurations and number of layers;
- Level of corrosion impact of steel-cords – adhesive bonds (without corrosion, easy corrosion, after corrosion test behind extremely conditions).

For selected cords were accounted:

- Uniformity of layer of rubber drift on cord surfaces;
- Surface treatment of cords;
- Interface between cord-rubber matrix after tire production;
- Structural change into microlocality of cord-rubber after corrosion.

The corrosion processes on cords are shown Figure 27. The results from microscopy observation are presented in Figures 28-33.

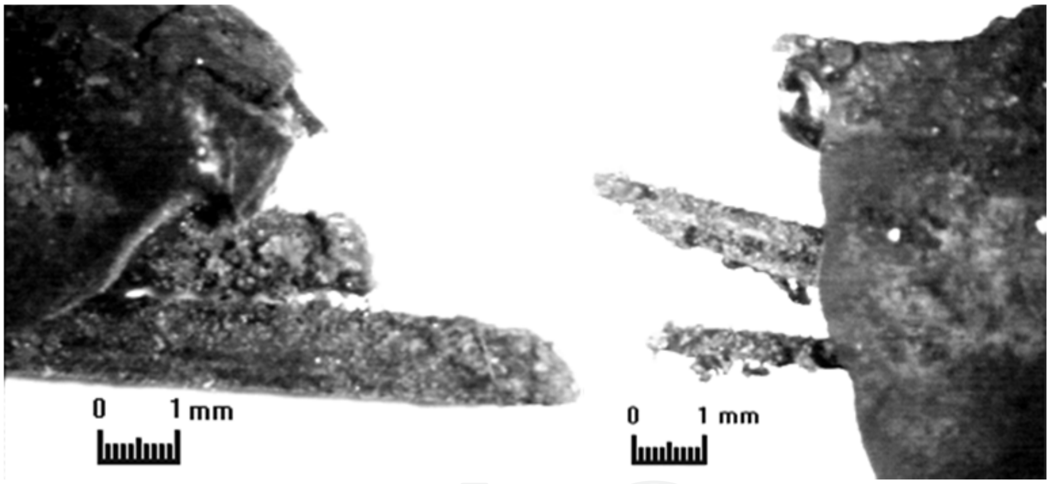


Figure 27. Corrosion processes on steel-cord surfaces – thin wire versus wire (right)

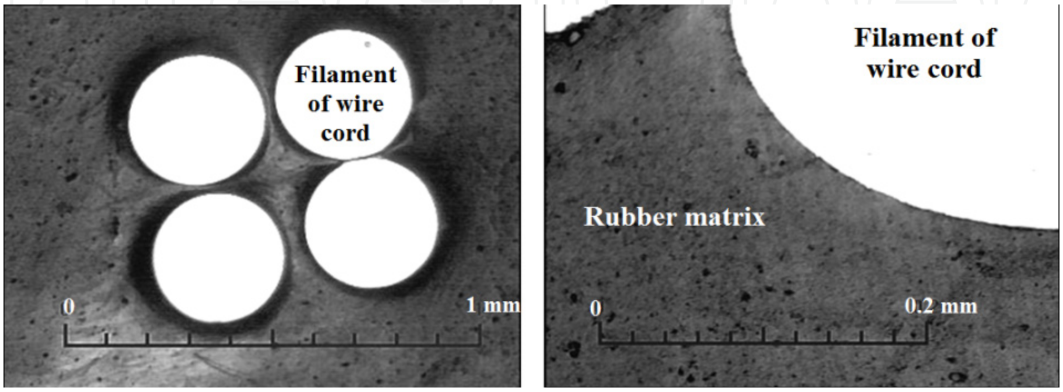


Figure 28. Good adhesive bond between wire steel cord 2+2×0.28 mm (cord consists of 4 filaments) and rubber after tire production (without corrosion)

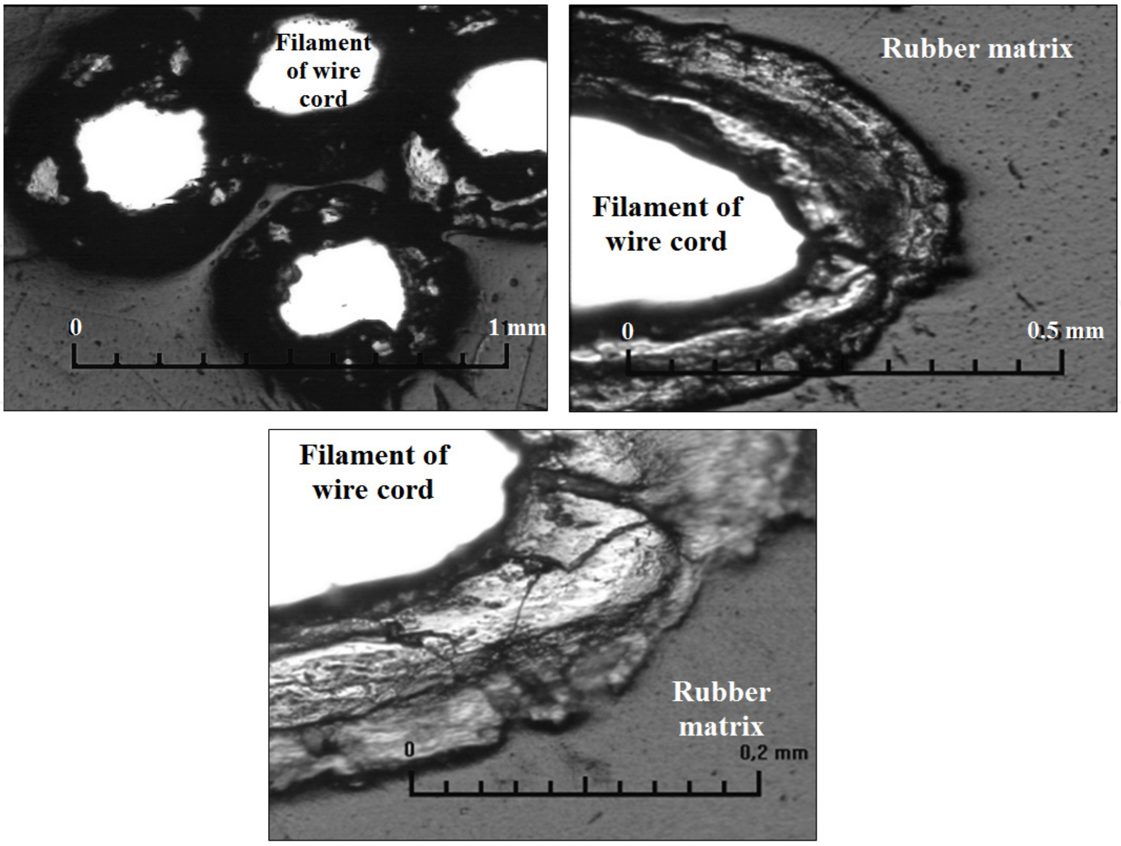


Figure 29. Damaged adhesive bond between wire steel cord 2+2×0.28 mm and rubber after corrosive attack (with extreme corrosion and tensile loading) with detail of oxide on filament surfaces

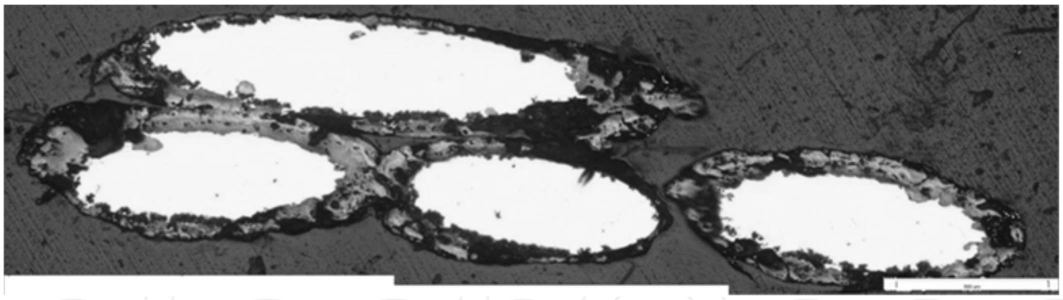


Figure 30. Damaged whole wire steel cord 2+2×0.28 mm

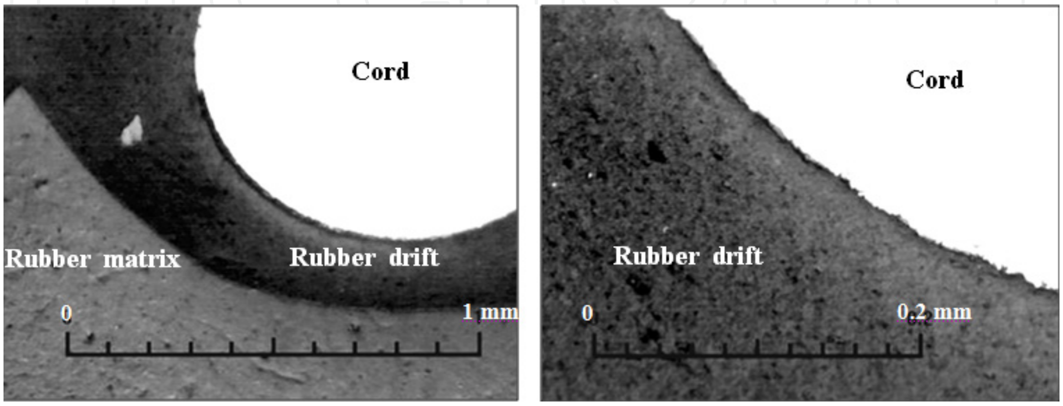


Figure 31. Good adhesive bond between thin-wire steel cord 0.94 mm and rubber drift after tire

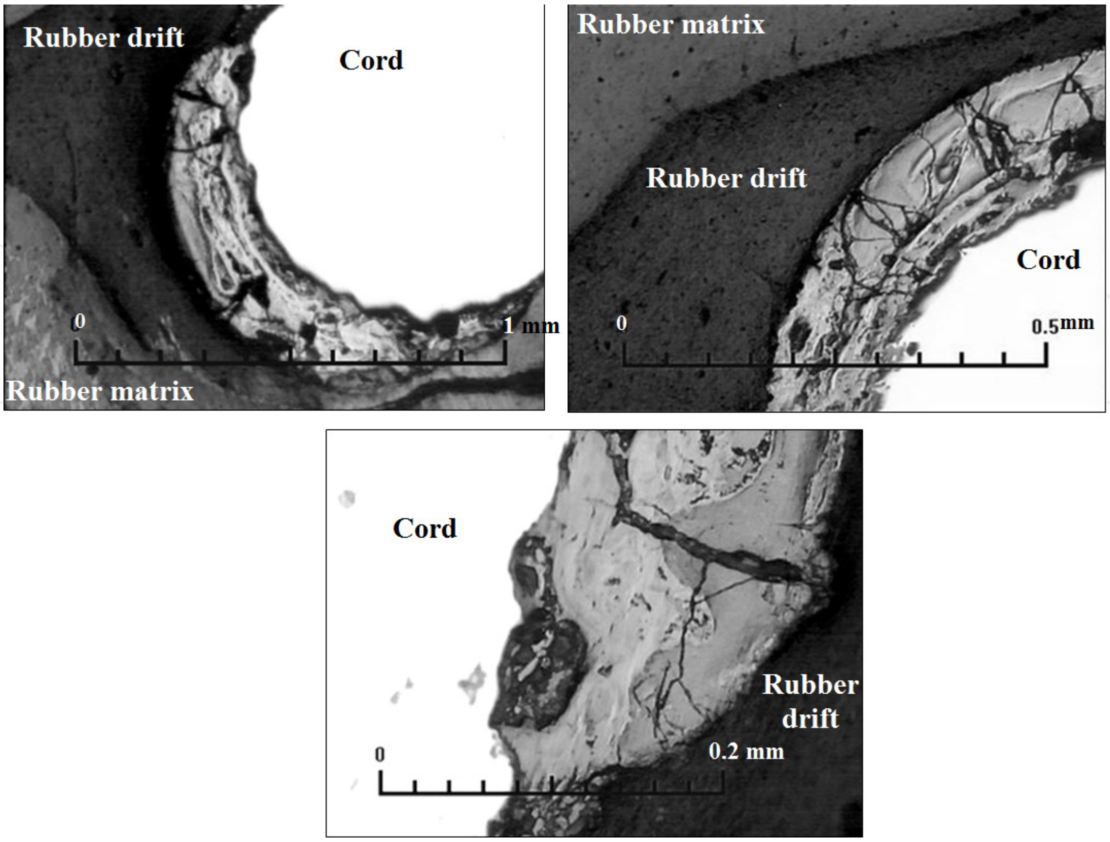


Figure 32. Damaged adhesive bond between thin-wire steel cord 0.94 mm and rubber drift after corrosive attack (with extreme corrosion and tensile loading) with detail of oxide on cord surfaces

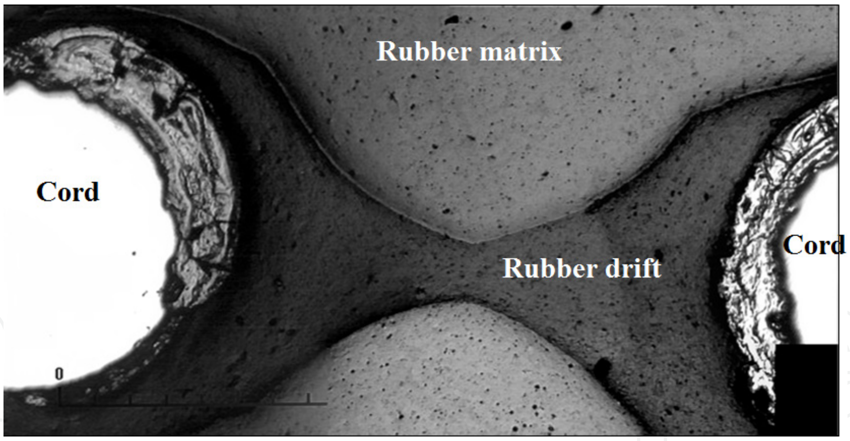


Figure 33. Damaged whole thin-wire steel cord 0.94 mm

On the base of corrosion tests is possible note:

- Arise of uniform surface corrosion;
- Fragility and hardness of corrosive layer;
- Quicker grow of oxides near cord surfaces;
- Fracture of oxide layer;
- Quality of cord-surfaces and surface treatment of cords with respect to corrosion attack;
- Decreased of material characteristics of steel-cord belt on the basic of tensile tests.

The adhesive bonds are influenced internal impacts (inserted during production, mounting) and external impacts (operating conditions, surrounding conditions etc.) or their interaction. It can be caused degradation on reinforcement-matrix adhesive bond, when its effect is failure into whole macro volume of tire which isn't permissible from safety aspect of vehicle.

- Any damage in the area of tire crown, namely into steel-cord belt plies, is perilous.
- If extreme corrosion on cords then cord surface treatment lost function of corrosive protection.
- If cords are with corrosion then adhesive bonds between cord-rubber matrix are damaged and safety of steel-cord belt plies and also tire is decreased.
- For predication of damaged belt ply is possible used combination of computational with experimental modeling.
- Corrosive attacks on reinforcing cords in whatever form can reduce the quality and operating safety of the whole tires.

8. Dynamic testing

In this part we continue with a description of dynamic materials behavior as well as a dynamic tire testing.

The tread displacement changes caused by the breaker angle changes were measured by an apparatus presented in Figure 34. The apparatus consists of a line laser, CCD camera and a computer with an appropriate measuring software. The CCD camera records the changes of the line laser spot, which copies the tire dimension changes. This system measures the main dimension of the rotating tire (the illuminated part of tread) at constant velocity. For more details see the work (Koštial et al 2006).

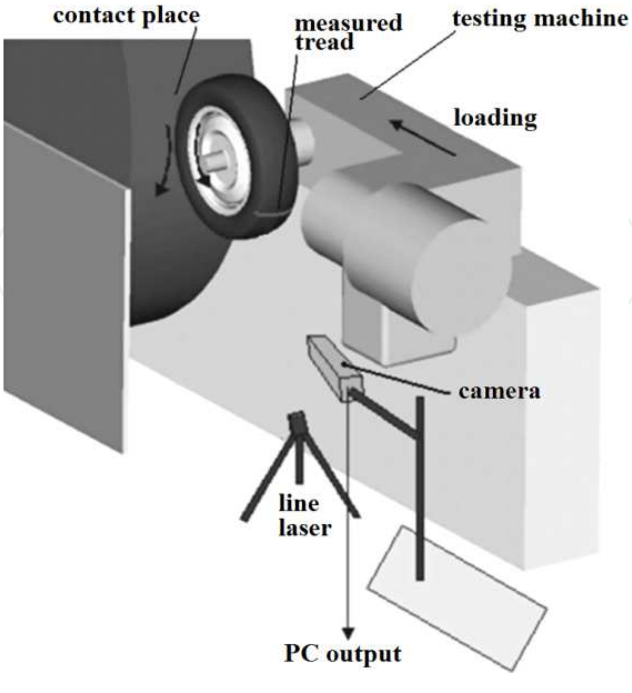


Figure 34. The measuring system for a tread deformation

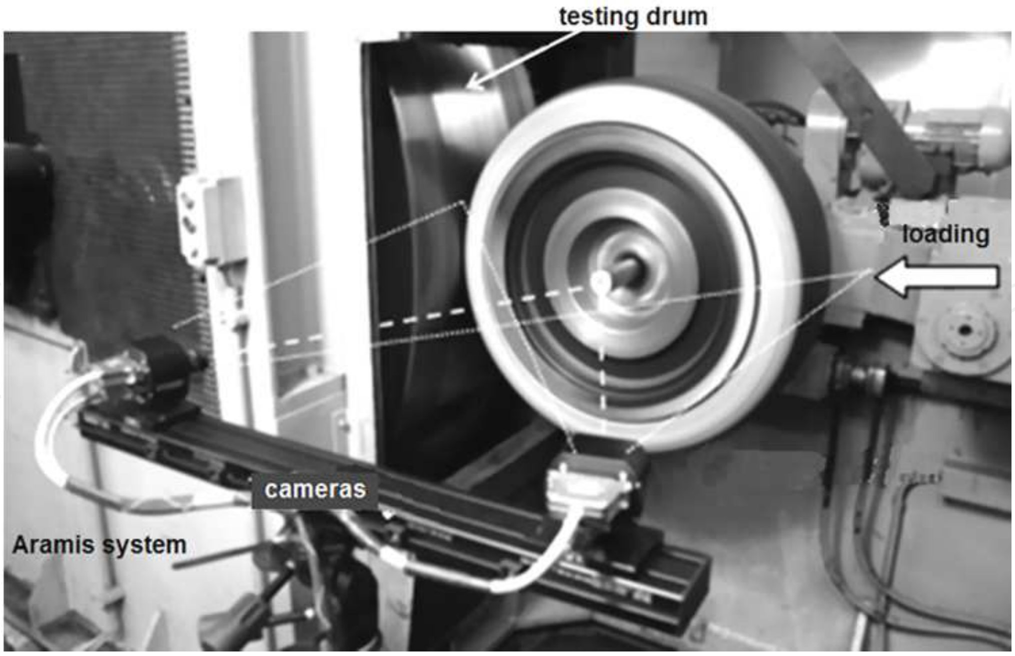


Figure 35. The measuring system for a sidewall displacement measurement

I. mixture	
Hardness of vulcanizate [ShA]	73
Modulus 300% [MPa]	15
Strength [MPa]	16.2
Elongation [%]	340
II. mixture	
Hardness of vulcanizate [ShA]	85
Modulus 300% [MPa]	12
Strength [MPa]	16.5
Elongation [%]	285
III. mixture	
Hardness of vulcanizate [ShA]	60
Modulus 300% [MPa]	7.2
Strength [MPa]	17.9
Elongation [%]	570

Properties	S	T	D
Strength , LOP, [MPa]	19.23	17.08	23.27
Elongation [%]	565	495	440
Modulus 300% [MPa]	7.8	9.2	17.4
Hardness [ShA]	58	66	72
Elasticity [%]	35	18	48
Tear resistance [kNm^{-1}]			
at 20°C	57.1	37.5	74.8
at 90°C	43.4	29.9	74.3

Table 1. The physical parameters of bead core blends (left) and other part of the tire (right part).

The sidewall displacement changes caused by both, bead core and the breaker angle, were measured by a contactless system Aramis. This system is able to measure changes of the displacements (radial and axial) during the rotation of the tire. More experimental details about the apparatus are in the work (Koštial et al 2005) (see Figure 35.) The statistically evaluated precision of both described equipments at the actual arrangement of the apparatus was 0.05mm (the result of ten independent measurements on the same tire). The radial loading was *7360 N* (that is 80% of the maximum available load) with a tire inflation of *290 kPa*. After the tire conditioning (30 min at the velocity 80 km/h) the tire inflation increased (due to heat generation at the tire movement) to a pressure of *310-320 kPa.* The considered testing velocities were *10, 50, 80, 120, 150 and 180 km/h*. The reference velocity was *10 km/h* (zeroth stage). The image of a sidewall obtained at *10 km/h* is compared with other images obtained at different velocities. The difference between those images determines a displacement.

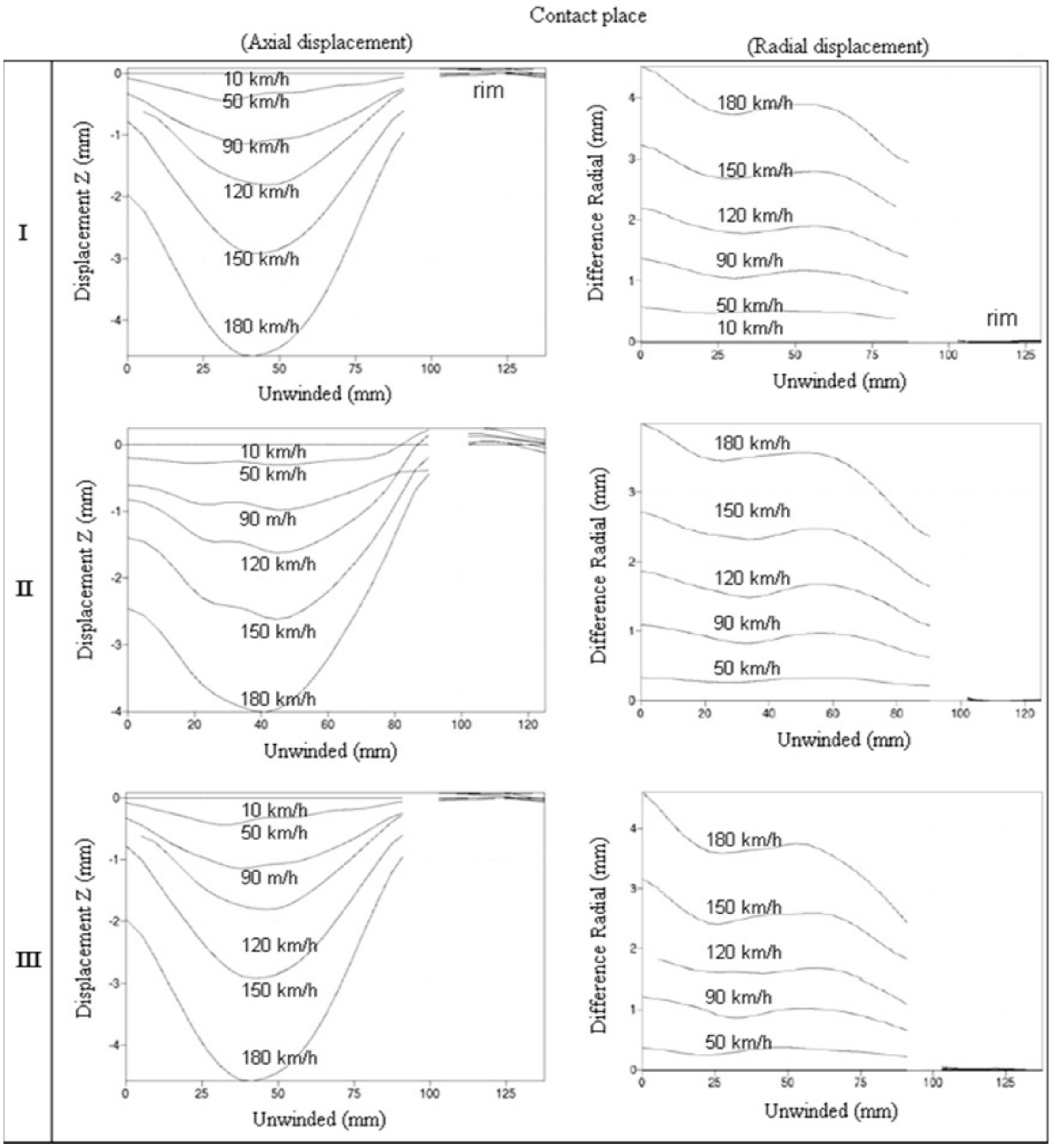


Figure 36. The axial displacement changes at the contact (left side) and radial displacement (right side) for three different bead core blends. Unwinded means a length of a given sidewall part.

The physical parameters of the bead core blends are described in the left part of Table 1. The characteristic physical parameters blends used for the construction of the other part of a tire are collected in Table 1 – right part. The abbreviations used in Table 1 mean: *S* – sidewall rubber mixture, *T* – tread rubber mixture and *D* – depositional rubber mixture on the steel cord.

The measurements of the sidewall displacement at the contact of the driving drum and tire presented in Figure 36 also show the smallest radial and axial value for the sidewall containing the blend *II.* The upper line is for the reference velocity *10 km/h.* The minimum showing at the bottom of every picture (for axial displacement) corresponds to the velocity of *180 km/h.* According to the presented results it is possible to conclude that in the current case the blend *II* has the best properties (the smallest displacement of a sidewall means higher mechanical stiffness and smaller rolling resistance, for instance) for the sidewall construction. Further we will analyze the changes of the tread and sidewall displacement caused by changes of breaker angle with unchanged bead core blend. The tread and sidewall materials were also the same according to the description presented above (Table 1).

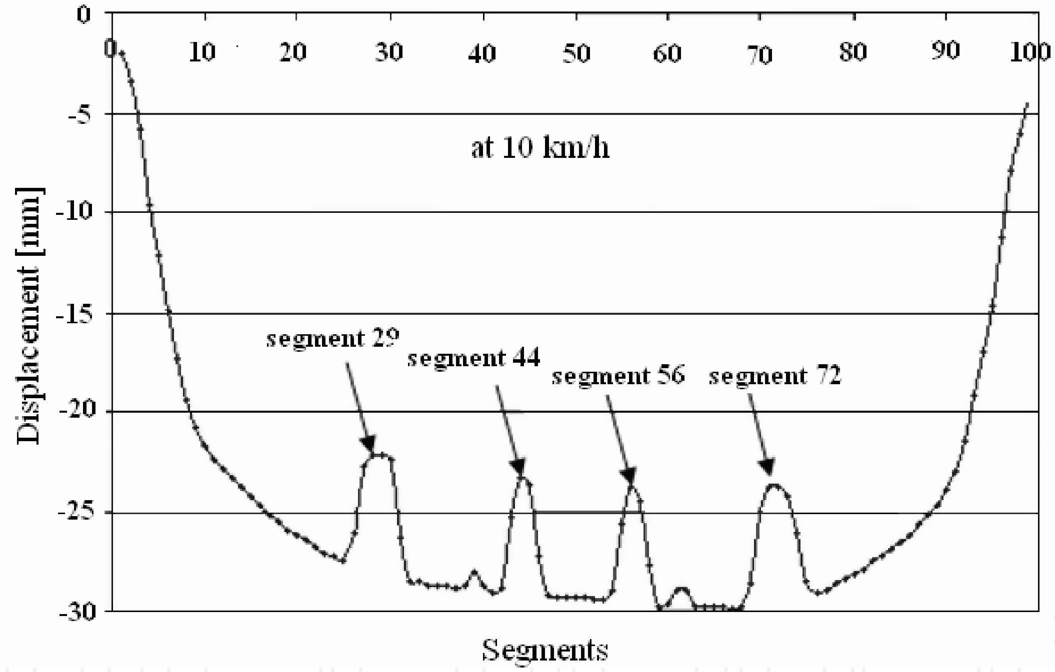


Figure 37. The electronic picture of a tread with characteristic points marked as "segments"

Figure 37 shows the electronic picture of the tread with characteristic points marked as "segments" obtained by an optical system with a line laser. The tread displacement changes in radial direction (at above defined velocities) caused by a breaker angle change are visible in Figure 38.

Rising of the breaker angle changes the shape of the tread deformation from convex to concave. The best solution was obtained for the breaker angle equals *27°*, where practically the full profile of the tread is in contact with the road. In order to study the influence of breaker angle changes on "sidewall displacement dynamic" at different velocities we also tested the sidewall displacement changes (measured by ARAMIS, breaking angle equal to

20° and 27°). The experimental results of both the axial and radial displacement in this case were compared with those obtained by the *FEM* simulation in *ABAQUS* environment. It is possible to see a good agreement between both simulated and measured curves. Differences occur at higher velocities for radial displacement. Both, the experimental and simulated axial displacements for different velocities and chosen breaker angles (*20*° and 27°) are displayed in Figures 39 and 40. The corresponding simulation and experimental results obtained for radial displacement also show the best results (the highest axial displacement) for breaker angle *27*°.

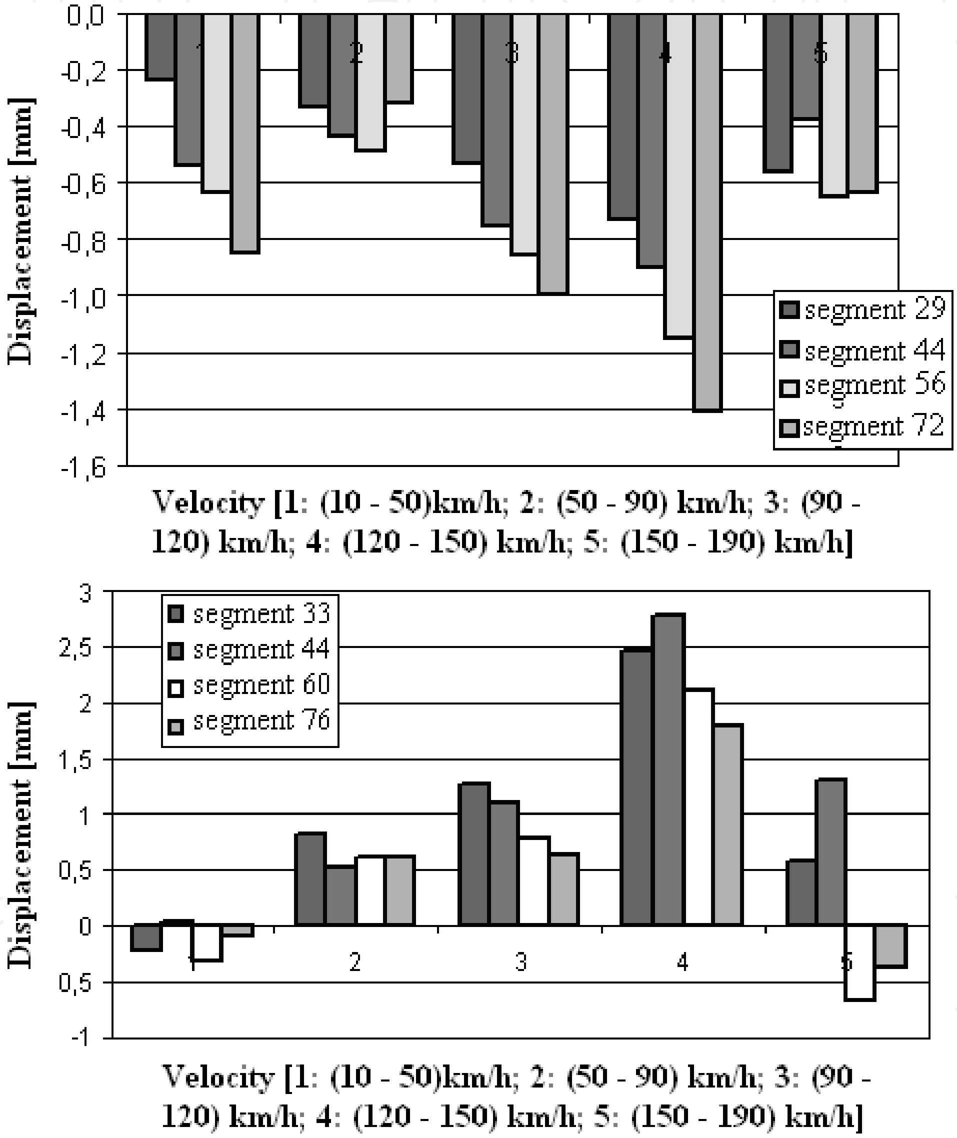


Figure 38. The displacement differences for the breaker angle 20° (variant 1 - left) and the displacement differences for the breaker angle 27° (variant 4 - right)

On the basis of these results it is possible to state that the higher the breaker angle the higher the displacement is in both axial and radial directions. In other words, the tire "grows" with rising of the breaker angle.). These results support the highest values of elongation and a relatively high value of strength and elasticity which provide also the so called driving comfort. On the other hand, the highest tear resistivity, 300 % modulus and hardness of the depositional rubber mixture on a steel cord provide all together good tire safety (see parameters in Table 1).

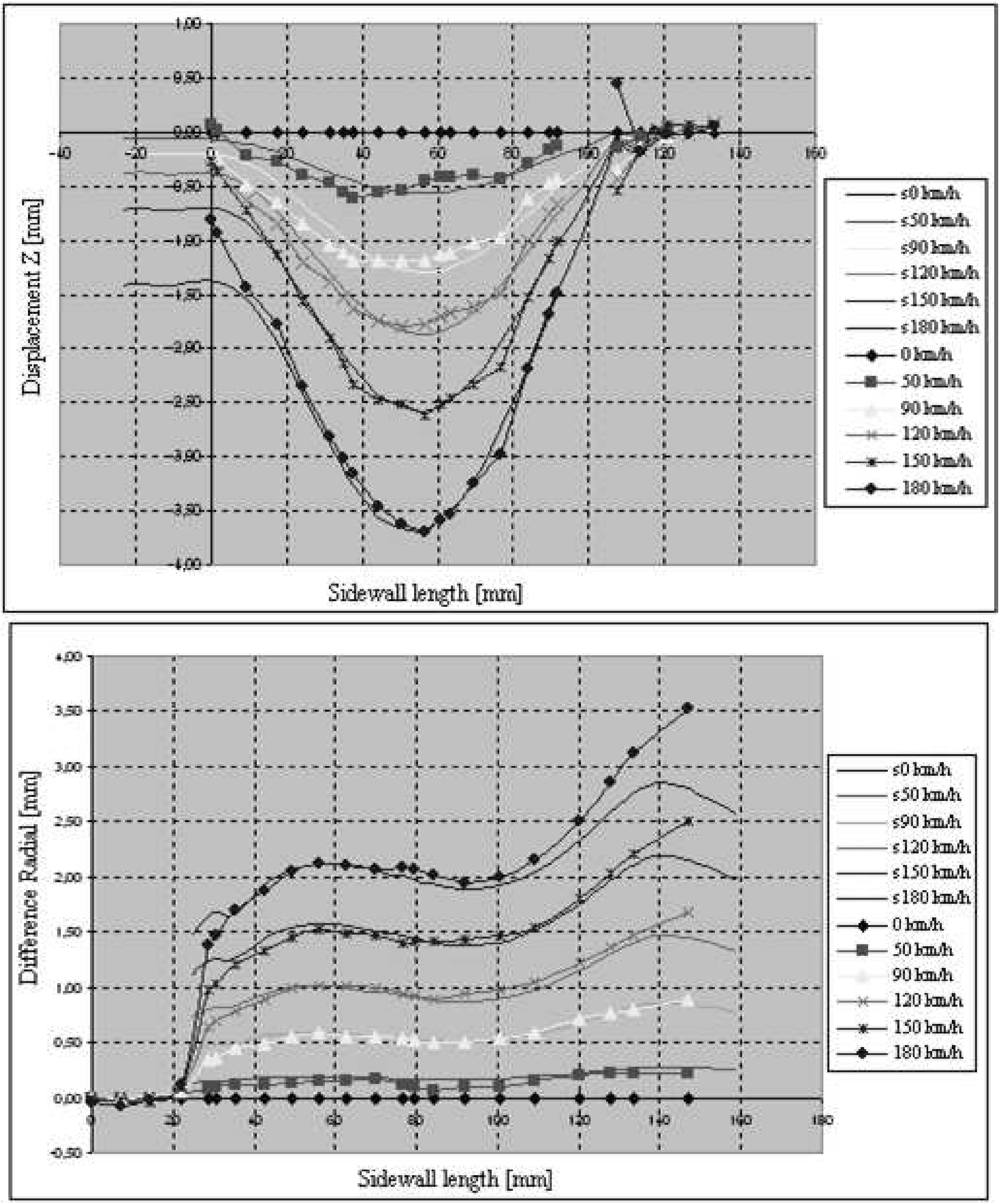


Figure 39. The axial (left) and radial (right) displacement of the sidewall for 20° breaker angle (s-simulation)

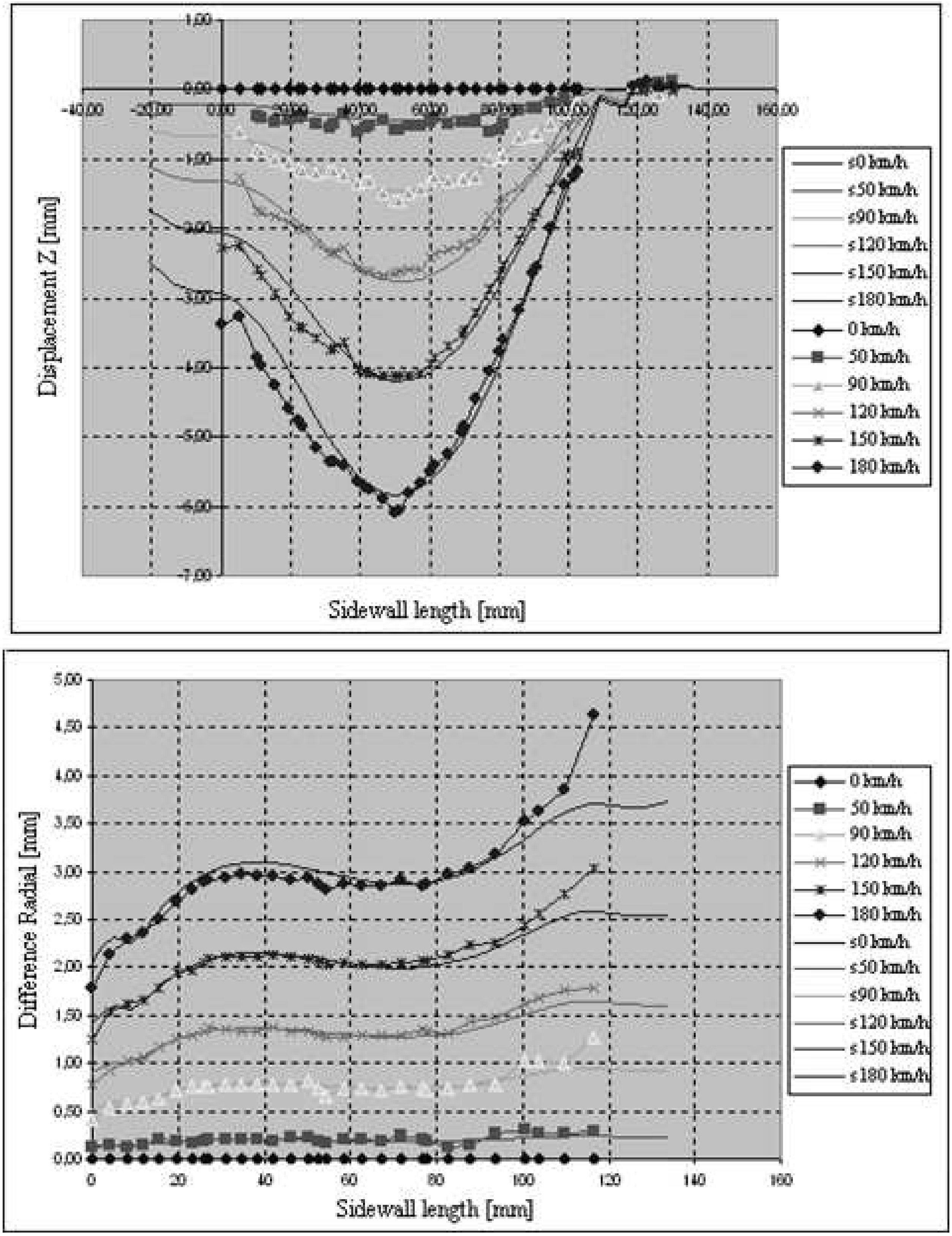


Figure 40. The axial displacement of the sidewall for 27° breaker angle (s-simulation)

9. Conclusion

The chapter presents the large scale view on the problem of tire safety concluding materials aspects, damage and experimental testing of tires and tire components materials. For more information about the solution of tyres, see reference (Krmela 2008).

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