Analysis of the causes of damage to the wires of the steel belt of car tires

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Abstract: *The main when buying car tires we would like them to serve us as long as possible while the experts recommend their replacement after six years at the latest – is it really necessary? In this work the analysis of the impact of car tires operation on microstructure of the steel belt wires has been presented. The results of the presented research have proven that as a result of the complex stresses in the belt wire material the transverse cracks of individual cementite lamellae appear. The observed structural changes are a major cause of fatigue cracks development and finally result in breaking continuity of steel belt wires, breakthrough of the rubber layer and eventually damage to the tires, preventing their further work*.

Key words: *tire, belt, pearlitic steel, cementite*

1. Introduction

Each car, to be admitted to the road movement, needs motor, car body, a driver, and first of all tires. They are responsible for road adhesion on dry and wet surface, controllability and noise reduction [1]. Car tires produced nowadays are characterised with complex build. They are composed of even more than a dozen of elements, which are assembled into one during the vulcanisation process. Each of the elements is responsible for individual properties of a product. In the typical car tire we can distinguish: tread, belt, warp and footer [2, 3].

The tread is responsible for traction and driving of a car. The footer consists of a bead and a filler and it enables assembling the tire on the wheel rim and provides for air tightness of the connection. Whereas the warp is a basic carrier component in the whole microstructure providing for dimensional stability and blowout strengths of tire. Another, extremely important component is a belting, the basic function of which is stiffening of the tire front and providing resistance to the devastating effects of centrifugal force at high speeds [1, 2]. The belting consists of one or several layers of steel cord, a layer of tough wires of 0.2-0.5 mm diameter, made of unalloyed pearlitic steel containing some 0.8% of carbon (PN-EN 10323:2005 (U)) [2, 4].

One of the problems widely discussed in the subject literature is cracking of pearlitic steel subjected to plastic working and being in the operation. According to the literature data [5-7] one of the reasons for cracking of wires made of pearlitic steels is presence of too high quantity of non-metallic inclusions. The non-metallic inclusions, especially those of minimum plasticity, such as oxides or brittle silicates, cause reduction in ductility of wire and hindering of technological processes [5]. Moreover, according to studies of Golis [6,7] around the impurities the material discontinuities are formed capable of exceeding the critical size of the defect and causing cracks in the component during operation.

The research conducted by Zelin [8,9], Sauvage and Ivanisenko [10-13], Gridnev and Gavriluk [14-17], as well as Langeford [18,19], have shown that cracking of singular lamellae of cementite takes place as a result of plastic deformations of material resulting from wires operation. The changes were observed both, during tension and torsion of the wires. During growth of the applied force the coalescence of the created micro-delaminations and cracking propagation follows resulting in decohesion of the whole component.

Despite the mechanism of the belting wire material cracking, the experts of the independent organisation Dekra [20,21], based at case studies have found that after six years the risk of tire failure drastically increases and therefore they recommend exchange of tires after six years of operating or driving about 100 000km at the latest.

Unfortunately, despite knowledge of the subject, one of the problems frequently encountered by car users are defects of tires. According to Continental company most of the defects is caused by the following factors [21,22]:
- improper driving style (sudden acceleration, sharp breaking with locked wheels),
- improper air pressure in tires,
- driving off-road, on uneven surfaces,
- running into inequalities at high speed,

- inappropriate drive speed to the load,
- improper assembling, including mismatched tire to the rim and the car,
- rubber aging defects.

2. Materials and methods

The object of the tests were two defective car tires (Fig. 1 and 2). As a result of failure the break in continuity of steel belting, being a component of reinforcing the tire microstructure, the breaking of rubber layer with steel wires and finally a failure of the tire disabling its further operation took place. The puropse of the presented tests was determining causes of steel belting wires breaking in the ivestigated tires.

Fig. 1. Defective tire No. 1. Visible fragments of wires from the damaged belting, which pierced the tread of the tire.

Fig. 2. Defective tire No. 2. Visible fragments of wires from the damaged belting, which pierced the side wall of the tire.

Metallographic sections of specimens were prepared by means of mechanical grinding and polishing, as well as chemical etching with 3% Mi1Fe. For evaluation of microstructure of the ivestigated steel a NIKON ECLIPSE MA200 light microscope and a Phenom G2 scanning electron microscope was applied. Observations were performed at magnifications from the range of 100x ÷ 6000x.

Each sample was mechanically ground on SiC abrasive papers (1000 and 1200) to thicknesses of 70 μm and after that polished. Samples were rectangular in shape and size of the samples ranged within 1,5 x 2 mm. Samples were electropolished using a solution consisting of 25 vol.% HNO3 and 75% methanol at 10 V voltage in a TenuPol. Overview of the microstructure studies by SEM was the basis for detailed TEM analyses, using Hitachi H-800 transmission electron microscope. Observations were performed at magnifications from the range of 5000x ÷ 40 000x.

For fractographic tests JEOL JSM 6610A G2 scanning electron microscope was applied. Observations were performed at magnifications from the range of 1000x ÷ 10 000x.

3. Results

The initial macroscopic tests have shown that most probably damaging of the tires happened as a result of multiple hitting of the face of the ivestigated tires against an obstacle or as a result of driving on bumps at high speed. However, in order to understand the mechanism of fracture of the ivestigated tires belting material, for further tests the ends of defective wires that pierced through the layer of rubber were cut off and subjected to detailed macroscopic analysis.

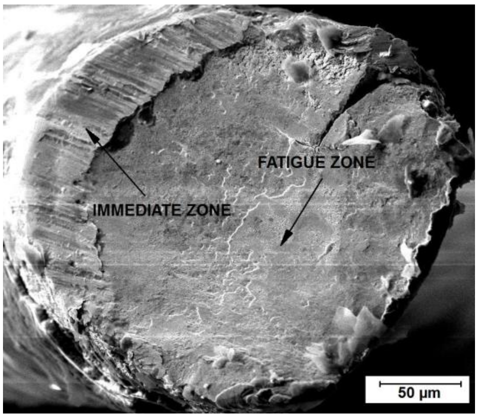

Fig. 3. Microscopic image of fatigue fracture of the cracked wire coming from tire No. 1, shown in Fig. 1. Visible smooth fatigue zone and the immediate zone.

The fractographic tests of the wires performed with the use of scanning electron microscope have shown presence of surfaces indicating for fatigue character of the damage (Fig. 3). The fatigue part of the fracture was smooth with characteristic fatigue stripes arranged almost parallel to the direction of the fraction development (Fig. 5). The fracture focus was localised at external edge of the wire, that is in the area of the highest concentration of the complex operational stresses. At external circumference of the wire fractures the immediate zone of plastic character and extensive surface topography was visible (Fig. 4).

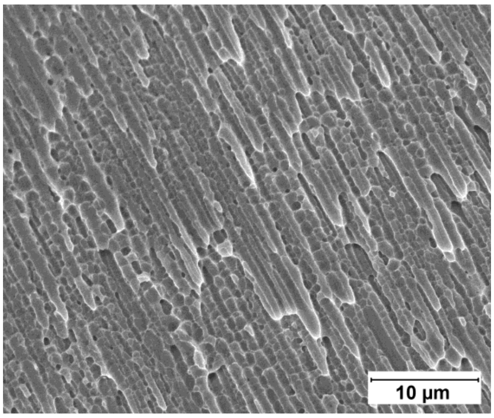

Fig. 4. Microscopic image of immediate zone of the fatigue fracture of the cracked wire coming from tire No. 1, shown in Fig. 3. Visible fracture of the plastic character and extensive surface topography. SEM.

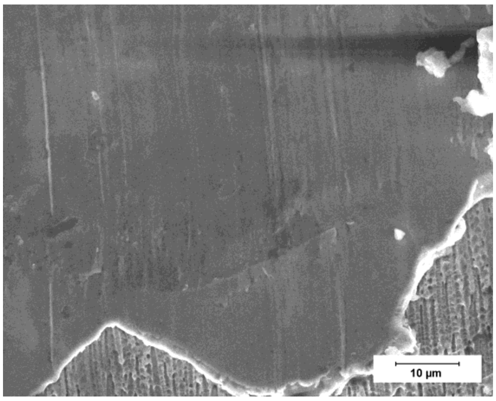

Fig. 5. Microscopic image of fatigue zone of the fatigue fracture of the cracked wire coming from tire No. 1, shown in Fig. 3. SEM.

The microscopic observations of the ivestigated wire material in the non-etched state have shown presence of small quantity of non-metallic inclusions, mainly in the form of oxides. The impurities were distributed punctually and appeared in quantity equal to the standard 1, according to PN-64/H-04510 standard (Fig. 6), which according to the literature data [6,7] is within the permissible content of non-metallic inclusions and by that it eliminates that factor as responsible for damage to the material microstructure.

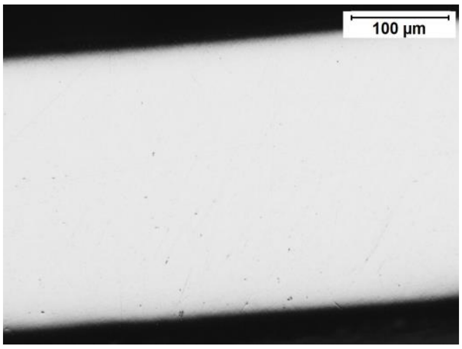

Fig. 6. Material of the steel wire specimen coming from the defective tire No. 1. Visible non-metallic inclusions in the form of punctually distributed oxides in quantity equal to standard No. 1, according to the PN-64/H-04510 standard. Non-etched state. LM

According to the literature [6,7] the maximum permissible content of non-metallic inclusions in steels should not exceed the size of the standard No. 2, according to the EN 10247:2007 and GOST 1778-70 standards. The non-metallic inclusions, and particularly those of the minimum plasticity such as oxides and brittle silicates, will decrease ductility of wire and hinder the technological processes. Presence of inclusions is the main reason of decreasing the material deformation degree. Moreover, around the impurities the material discontinuities appear capable of exceeding the critical defect size and cause cracking of wire.

The microscopic tests performed at transverse sections of the ivestigated wires have shown, that all the parts ivestigated in compliance with recommendations of the PN-EN 10323:2005 standard (U), were made of unalloyed pearlitic steel. The microscopic analysis of the specimens at longitudinal sections have revealed the presence of material crushing texture of the 80-90% order, being the result of applied cold plastic working (Fig. 7).

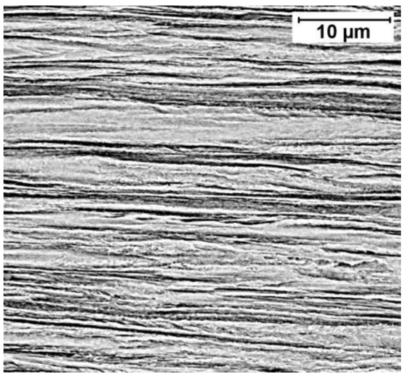

Fig. 7. Microstructure of the wire specimen com-

ing from defective tire No. 1. Visible texture of material crushing, being the result of the applied cold plastic work. SEM

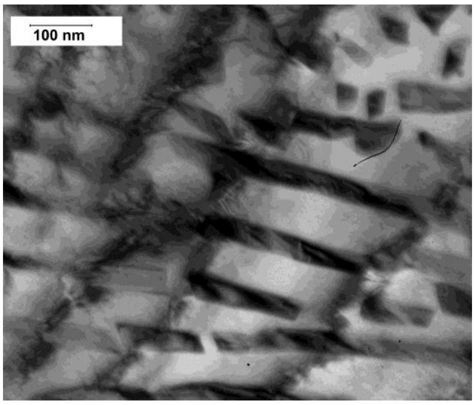

Fig. 8. Microstructure of the wire specimen from the defective tire No. 1. Visible transverse cracks of cementite lamellae created as a result of the tire operation. TEM

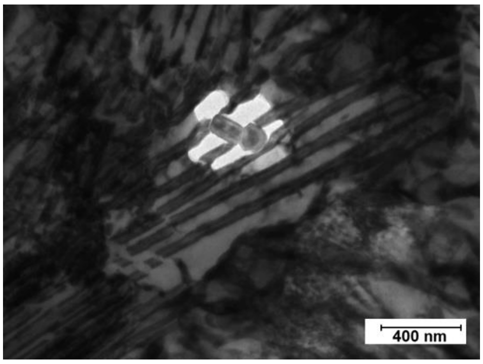

Fig. 9. Microstructure of the wire specimen from the defective tire No. 2. Visible transverse cracks of cementite lamellae created as a result of the tire operation. TEM

The initial microscopic tests have not shown significant differences in microstructure of the ivestigated specimens, but further observations with the use of transmission electron microscopy, have highlighted the clear impact of operation on microstructure of the ivestigated material. The microscopic analysis of the ivestigated wires material have shown presence of transverse cracks of singular cementite lamellae (Fig. 8 and 9). The observed cracks most probably were created as a result of the impact of complex stress state during the tire operation, and in combination with improper use of the tires they led to damage of the belting wires.

5. Conclusions

Operation of car tires in such extreme conditions as continuous contact with ground, frequent breaking and multiple hitting bumps in the road leads to micro damages of the steel belting material and changes in its mechanical properties. The results of the presented research have proven that as a result of the complex stress state in the belting wires material the transverse cracks of singular cementite lamellae are created. The observed structural changes constitute the main cause of the fatigue cracks development observed in the ivestigated parts.

While purchasing tires we would like them to serve us as long as possible. At the base of case studies the experts of the independent organisation Dekra have found that after six years the risk of tire failure increases drastically and therefore they recommend exchange of tires after six years at the latest [20, 21]. The test results presented in the work confirm that each kilometre of the trip has an impact on quality of steel belting, and by that at properties of the car tire and, most importantly, on the driving safety.

References

[1] Lefever I., Lombaerts J., Automobile Symposium Proceedings, 1991, 6, 42

[2] Slavens R.A., Modern Tire Dealer 1991, 11, 30

[3] Saiwari S., at all, Upscaling of a Batch De-Vulcanization Process for Ground Car Tire Rubber to a Continuous Process in a Twin Screw Extruder, Materials 9(9), 2016

[4] Ashby M.F., Jones D.R.H., Engineering Materials: An Introduction to Microstructures, Application and Design, Elsevier, Oxford 2005

[5] Golis B., Błażejowski Z., Pilarczyk J.W., Steel wires for tire reinforcement. Faculty of Production Engineering and Materials Technology Publishing House, Czestochowa 1998.

[6] Higgins R.A., Materials for Engineers and Technician, Newnes, 2006

[7] Henkel D., Pense A.W., Structure and Properties of Engineering Materials, The McGraw-Hill Higher Education, Singapore 2002

[8] Zelin M., Microstructure evolution in pearlitic steels during wire drawing, Acta Materialia 50 (2002) 4431-4447

[9] Courtesy Mr Taniyama T. Sumitomo, Tetals Ind, 1999

[10] Sauvage X., Thily L., Blavette D., Microstructure evolution during drawing of a pearlitic steel containing 0.7 st.% copper, Scripta Materialia 46 (2002) 459-464

[11] Sauvage X., Copreaux J., Danoix F., Blavette D., Phil Mag A, 2000, 80, 781

[12] Danoix F., Julien D., Sauvage X., Copreaux J., Materials Science and Engineering A 250, (1998), 8

[13] Ivanisenko Y., Sauvage X., The roe of carbon segregation on nanocrystallization of pearlitic steels processed by severe plastic deformation, J Mater Sci (2007) 42, 1615-1621

[14] Gavriljuk V.G., Decomposition of cementite in pearlitic steel due to plastic deformation, Materials Science and Engineering A 345 (2003), 81-89

[15] Gridnev V.N., Gavriljuk V.G., Meshkov Y.Y., Strength and plasticity of cold-worked steel, Naukova Dumka, 1974

[16] Gridnev V.N., at. all, Phys. Stat. Sol. (a) 31, 1975, 201-213

[17] Gridnev V.N., Gavriljuk V.G., Kushnereva N.P., Phys. Met. Metall. 42 (1976), 578

[18] Langeford G., Deformation of pearlite, Metal. Trans. A, 8A (6), 1977, 861-875

[19] Langeford G., Metal. Trans. A, 1A, 1970, 465

[20] Dobras Daniel, Karkocha Jakub, Grygier Dominika, Rutkowska-Gorczyca Małgorzata J., Jasiński Robert, Influence of the exploitation of car tires on the mechanical properties and structure of the steel belt, XLII School of Materials Engineering, Krakow-Rytro, 23-26 IX 2014 : [monografia / pod red. Jerzego Pacyny]. Kraków : Scientific Publishing House Akapit, 2014. s. 263-265.

[21] Kinga Jaskórzyńska, Bartosz Pietruszkiewicz, Dominika Grygier, Macroscopic analysis of the most common car tire damages 2015: Interdisciplinary of scientific research 2015 red. Jaroslaw Szrek. Wroclaw University of Science and Technology Publishing House, 2015. p.116-121

[22] Kinga Jaskórzyńska, Bartosz Pietruszkiewicz, Dominika Grygier, The internal construction of the Continental car tire at the turn of the last 27 years, Interdisciplinary of scientific research red. Jaroslaw Szrek. Wroclaw University of Science and Technology Publishing House, 2015. p.110-115