Wear of Heavy Industry Tires

J. Cerny, D. Manas, Z. Holik, M. Ovsik, M. Bednarik, A. Mizera, M. Stanek and M. Manas

Abstract— The issue of wear represents a very important role in the functionality of most products. The description of the wear process for very heavily strained rubber products, for instance off-road tire treads, conveyor belts for stone transport etc., is very essential. Sharp edges of stones and terrain roughness gradually cut (chip) off rubber parts. This wear considerably damages separate parts of the product and destroy it. In technical terminology, we call this type of wear CHIP – CHUNK effect. High-speed video camera, enabling recording and evaluation of the behaviour of ceramic tool when dropped on the surface of revolving testing rubber sample, was used for detailed analysis of the wear process.

Keywords— Wear of tire, CHIP – CHUNK effect, rubber compound testing

I. INTRODUCTION

IN rubber practice we often meet the problem of wear of the rubber parts. Some types of wear, especially the wear of tire treads, are very similar to machining. The tire tread (Fig. 1.) is a part of tire that which in direct contact of the vehicle with the road and is thus is responsible for the driving force transfer. The wear of the tire tread of passenger and trucks cars travelling on common roads is characterised by its abrasion. The tread of a tire of a car is disposed to the abrasive effect of the road.

However, the mechanism of wear of tires working in very hard terrain conditions is absolutely different. Sharp stone edges and terrain irregularities gradually cut (tear off) parts of the rubber tread surface, which can be understood as a way of working – e.g. milling, although under very specific conditions. The mechanism of tire tread wear working in hard terrain conditions is technically called Chip-Chunk effect and it can be considered as “workability” of rubber surface. [1,2,3]

The tire wear is usually tested under running conditions, these times demanding tests are very expensive. It would be very useful in practice to find a quick test of wear which could be carried out on small samples. Creating a model predicting the behaviour of tire tread compounds would improve the development in wear research.

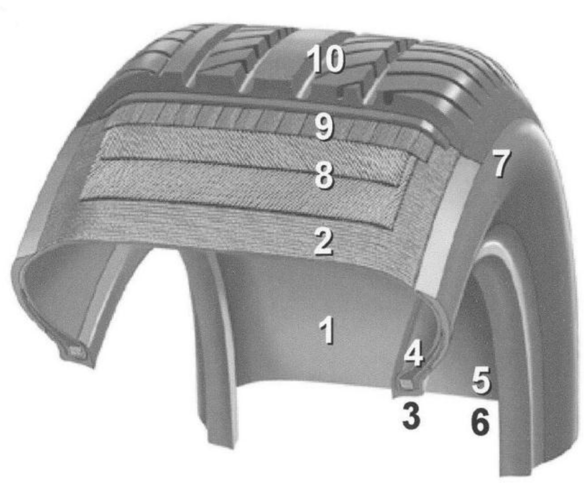

Fig. 1. Cross section of radial tread of a passenger tire [Source Barum Continental]
1 – Inner-Liner, 2 - Carcass material, 3 – Bead wire (Core), 4 – Apex, 5 – Tire strip, 6 – Rim (Bead) strip, 7 – Sidewall, 8 – Breaker strip, 9 – PA Breaker strip,
10 - Tread

II. EXPERIMENTAL PARTS

13 kinds of tire tread compounds used for motorcycle treads subjected to high stress, treads for technical, agricultural and multipurpose vehicles were experimented. All compounds represent real products and are produced and machined:

- Motorcycle tread cross (compounds number I, J, K);
- Motorcycle tread enduro (compound M)
- Technical vehicle treads (compound L)
- Agricultural tire (A, B, C, D)
- Gear tire (E)
- Tire for high-lift (F)
- Farm-tractor tire (G)
- MPT/R (H)

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2.1 Measured properties

Based on the analysis of the properties, which might influence the final behaviour of rubber products, the following series of measurements were carried out:

- Tensile strength (tensile test machine T 2000, Alpha Technologies)
- Elongation (tensile test machine T 2000, Alpha Technologies)
- Resilience Luepke (Testing equipment Luepke)
- Shore Hardness (Hardness tester HPE – D Bereiss)
- Dynamic behaviour (DMA) (DMA DX – 04T, RMI)
- Fast test of wear (Chip – Chunk tester, Manas 2005)

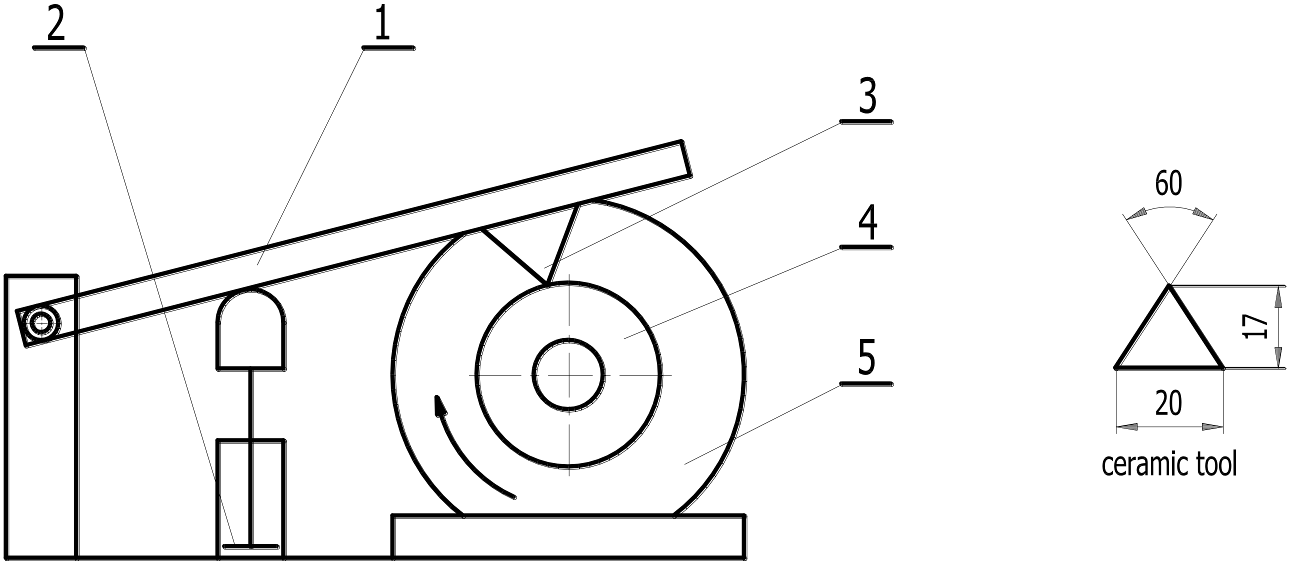

Fig. 2 mapping nonlinear data to a higher dimensional feature space

1 – Arm, 2 – Pneumatic cylinder, 3 – Ceramic tool, 4 – Sample,
5 – Electric motor

The testing samples for all tests were prepared by compression moulding process on laboratory press. The shape and dimensions of the testing samples are according to the norms .[2,3]

2.2 Test of wear

The tests of tire (tread) wear are time and money consuming. They are carried out using real tires in testing rooms or directly in the terrain during driving tests. That is one of the reasons for searching a method that would in a very short time (in minutes) and on small samples test the wear for a comparison of the different kinds of compounds.

Based on these requirements an equipment seen on Fig. 2 was designed. The Chip – Chunk wear testing machine (J. R. Beatty and B. J. Miksch in RCHT, vol. 55, p. 1531.) was used for basal measurements [1]. A new machine enabling changing the tested parameters and true simulations of the process conditions was designed, see Fig. 2.

Arm 1 pivotable around the neck is lifted by lifting part (piston of the pneumatic cylinder) 2. The arm that has a special ceramic edge tool is lifted and dropped 3 on the perimeter of the revolving wheel 4 (testing sample) driven by the electric motor 5. When it drops on the revolving wheel, the ceramic tool gradually chips the material and creates a groove on the wheel. The size of the groove chipped by the ceramic tool in a given time is the scale of wear.

The ceramic edges proved a perfect resistance to wear. If the tool was well manipulated there was no difference between original and “worn” plate.

2.3 Dimensions of the testing sample

For easier preparation of testing samples the form seen on Fig. 3 was designed (The outer dimensions are corresponding to the testing sample of test Luepke).

A groove was made (chipped) by the ceramic tool into the testing sample during the experiment. It was expected from experience with tooling other materials, esp. metals, wood or plastic, that the groove would be regular. Due to the properties of machined rubber – which demonstrated its elasticity – the moment the rotating ceramic tool dropped on the rotating wheel, pieces of material were torn off. For this reason, the initial intension of wear evaluation by measuring the groove diameter was changed to gravimetric evaluation.

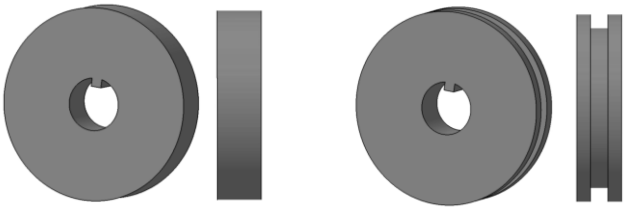

Fig. 3. Testing sample for fast wear test
a) Before the test, b) after the test

2.4 Wear analysis

The influence of drop of the ceramic tool on the surface of the testing sample is crucial. If the sample were rigid, the evaluation of the impact of dropping force would be quite easy. The elastic properties of the testing sample however cause a series of other effects of smaller intensity (jumping on the surface) apart from the main effect (the first drop of the ceramic tool on the testing sample). The main effects of the ceramic tool have only partial influence on the total wear. It turned out that evaluating total work needed for wear (i.e. creating a groove on the testing sample) only by the energy of the drop would be biased. After the first testing of the experiment equipment, it was clear that the results in a given series of measurements would be comparable if the experiments ran under the same conditions. The construction of the main body with a key fitting the groove on the shaft and clamping basement with teeth prevent skidding of the testing sample while running and the control system of the testing machine will secure constant conditions for testing. [5,6]

2.5 Test conditions

The conditions for experimental testing of fast wear were kept:

- Sample revolution 500 rpm, 750 rpm, 910 rpm
- Impact frequency 1 Hz
- Ceramic tool stroke 60 mm
- Temperature 21 °C
- Test period 270s

The testing sample was clamped in the jaws of the machine to prevent is skidding and was rotated. The lifting mechanism for lifting the arm with ceramic tool was started. The time was measured from the first contact of the ceramic tool with the testing sample. The samples from each compound were used for the measurements. The mass loss was investigated by weighing on analytical balances after the experiment. Measured values were statistically evaluated.

The greatest wear was observed with compounds I, K. The best properties according to the wear were reported with testing samples prepared from compounds H, B (Fig. 4.).

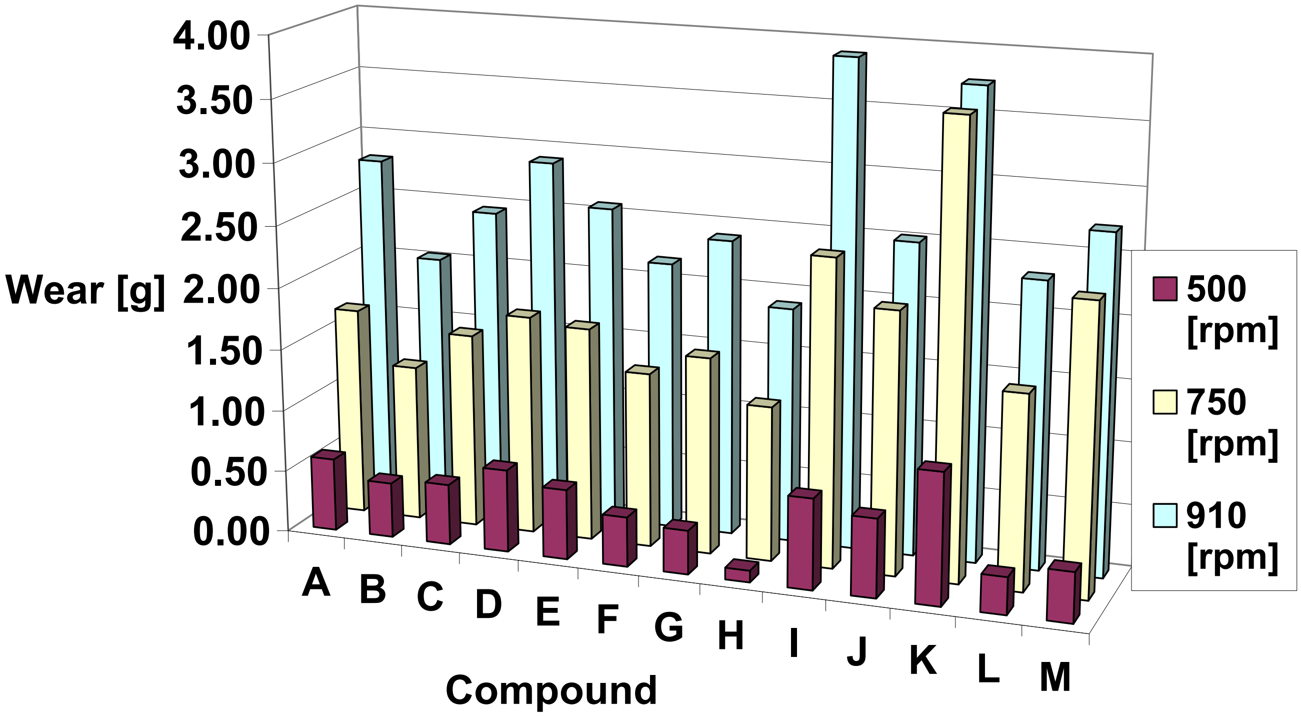

Fig. 4. Comparison of mass loss at different frequencies

2.6 Dependence on running conditions

The vehicles move in a different speed in the terrain in running conditions which can be characterised by the circumferencial speed of the tire tread. For this reason, other experiments were carried out to characterise the wear during different conditions. The wear test was done during the frequencies of testing samples of n_1= 910 revolutions/min, n_2= 500 revolutions/min, n_3= 250 revolutions/min. The other conditions of the experiment remained unchanged. Figure 4 shows the expected increasing tendency of the wear.

2.7 Wear procedure

The aim of the experiment was also to observe the mass difference of the testing sample (wear) during the test.

The mass of the samples was measured in regular intervals (30s) during the wholetime of the experiment (270s). Attention was paid to the interval 0 – 60s due to the different behaviour of the tested compounds and the mass of the tested sample in this interval was measured every 10s.

Most of the samples showed a gradual increase in wear in the first interval of the experiment. A marked increase of the wear starts after the creation of the first rip, which means that before the first rips happen, the surface wear is negligible. The compounds with low resistance to wear (e.g. compound I) increase already from the beginning of the test. The comparison of the chosen compounds is seen on Fig. 5.

Figures 6 and 7 show the mass loss (wear) during the whole experiment (0 – 270)s.

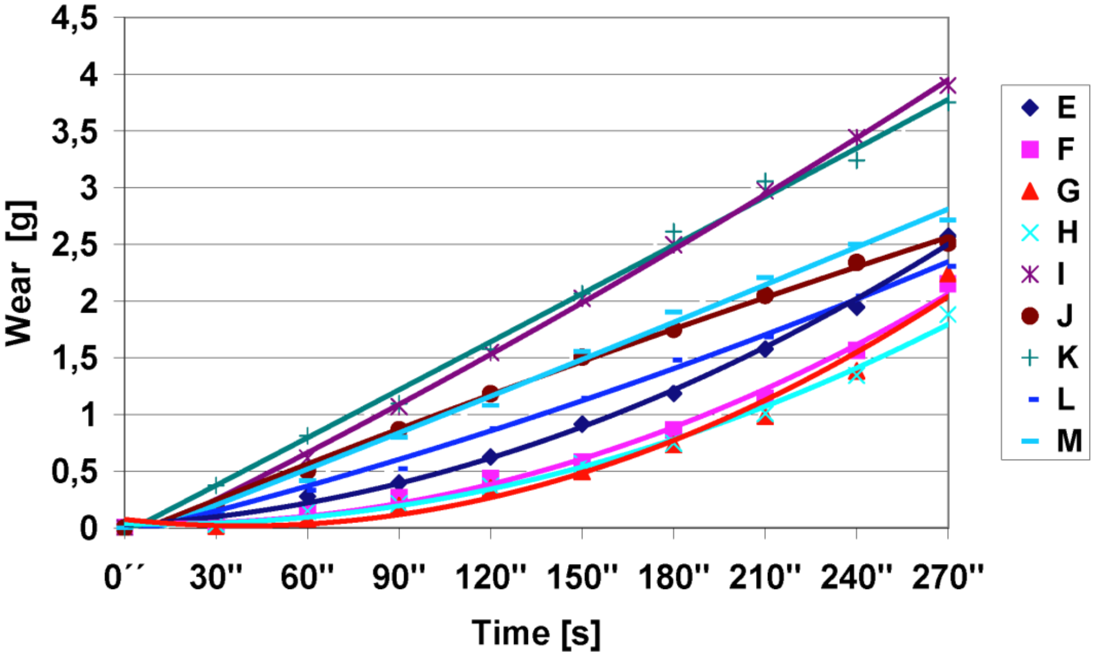

Fig. 6. Gradual mass loss in all compounds in time (0 – 270)s

Gradual tendency to faster wear with proceeding time is observed in most cases. This means that before the creation of first rips on the surface of the tire tread while driving on harsh terrain conditions (sharp stone edges etc.) the wear is quite small. The first damage to the tire tread however starts the “avalanche effect” of other damages and the wear increases faster. Figure 8 shows a remarkable similarity between the real tire tread wear and the wear of the testing sample.

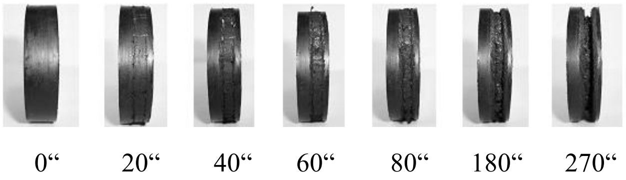

Fig. 7. Wear of tested samples in time (0 – 270)s

III. RESULTS AND DISCUSSIONS

The experimental part includes series of measurements used on set of thirteen different kinds of compounds designed for production of tire treads of agricultural vehicles, off-road cars, technical vehicles and motorcycles.

Eight sets of standard tests (tensile strength tests, tear strength tests, resilience tests, tests of hardness and DMA) were made. In all cases, real compounds used for production of stated types of tires were prepared.

The results of the wear tests were compared with the other physically-mechanical properties. For easier and faster comparison of the measured values, so called dimensionless values ([-]) expressed as the ratio of separate measurements to the maximum value reached during the given measurements were used (Fig.9.).

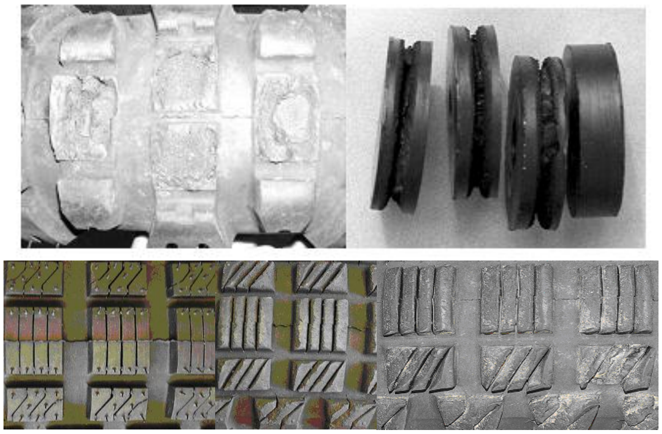

Fig. 8. Comparison of the real wear with the tested sample

The sets of measured values were processed and the results shown in graphs. A wear test under different running conditions, characterised by different rotary frequencies of the testing sample was carried out. The expected increasing tendency of wear with increasing the rotations was proved. (Fig. 4)

The wear behaviour was observed during the test. Special attention was paid to the initial phase of the experiment. The experiments proved that the increase of wear during the test is relatively uniform (Fig. 6.), apart from the initial phase (Fig. 5.). The initial phase of the experiment is characterised by a very gradual increase. A fast increase is triggered by the first rip of the testing sample.

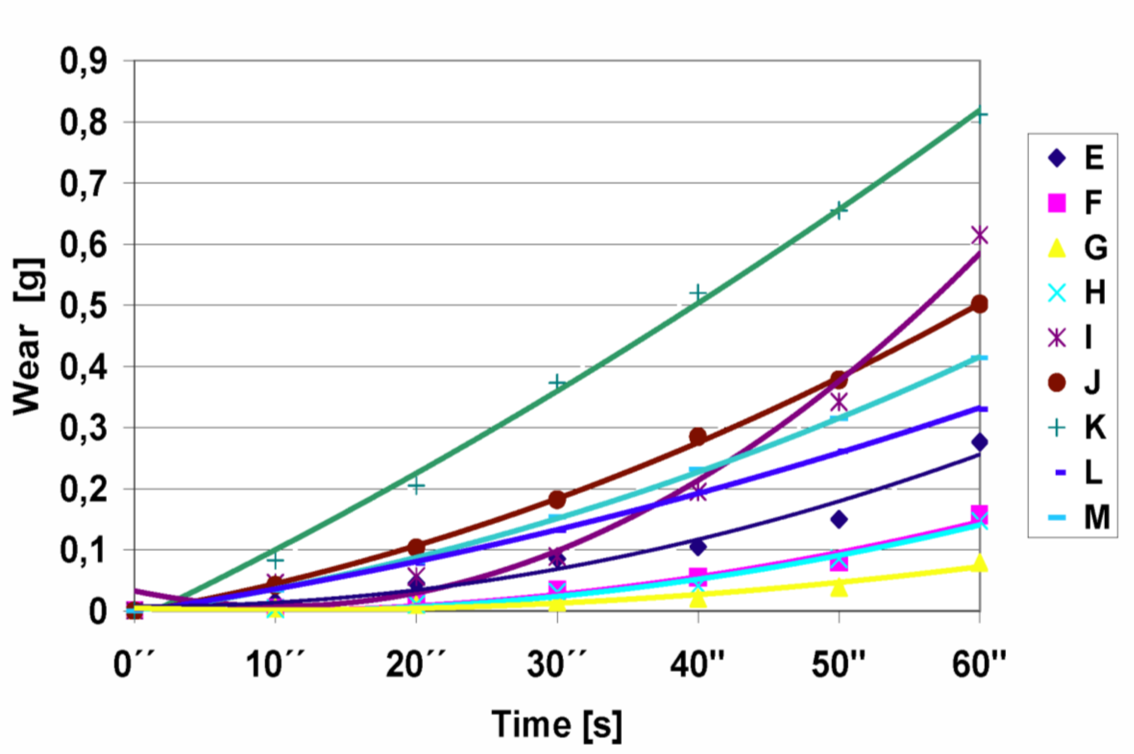

Fig. 5. Gradual mass loss in all compounds in time (0 – 60)s

The results of the wear tests were compared with the other physically-mechanical properties (Fig. 9.).

The wear mechanism itself happens in the area between the “splinter” and testing sample, which is found between already deformed and not yet deformed material. This is usually determined by the proportion between the layer thickness of the chipped rubber material and the thickness of the deformed “splinter”. Considerable part of exerted energy (kinetic energy of the ceramic tool during drop) is - during the wear - concentrated to the place where the rubber material touches the ceramic tool and where parts of rubber material are detached. The amount of the deforming force is closely related to the angle front of the ceramic tool (terrain roughness and sharp stone edges). In practice, this means that the angle front and the speed of motion on terrain roughness and sharp stone edges dramatically influence the conditions of created skid deformation. The area between the splinter and rubber sample represents the crucial moment of the wear process during which material is taken away and splinter created. However, this is also a moment where skid tension and skid force, which have a substantial importance on the process happening on the ceramic tool area, are generated. Friction also plays a very important role, as the rubber material is during the ceramic tool drop exposed to high pressures. The rubber splinter is moving due to the deformation process on the front area of the ceramic tool and affects the temperature slightly by its activity and movement. There is a wide range of rubber mixtures with different properties. For that reason, it is necessary to pay attention to their behaviour and bear in mind that the force ratio distribution during the wear is different with each mixture. [5,6]

This process was confirmed using high-speed video camera (Fig.10).

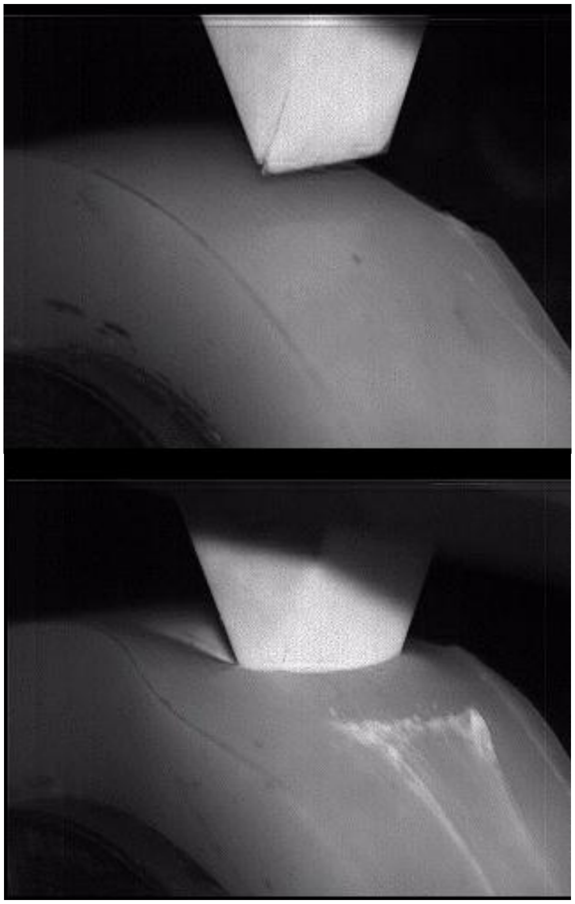

Fig. 10. Ceramic tool during the drop on the testing sample

When investigating properties of the testing samples, high-speed video camera system Olympus i-SPEED 2 was used. The camera system was intended to visualize the behaviour of the tested sample during the ceramic tool drop. The path of the ceramic tool when falling on the tested sample and the course of speed in a certain time was observed (Fig. 12, 13).

The measured data were statically calculated and processed. For evaluation of the measured data the multiple linear regressions was used. We used the linear statistical model of chip – chunk resistance in the form (Meloun – Militky, 2004). [3]

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_1 X_2 + \beta_4 X_3 + \beta_5 X_4 + \beta_6 X_5 + \beta_7 X_6 + \varepsilon$ (1)

with Y … Wear [g]

Xi … measured value of properties of rubber compounds, i.e.

X1 … Tensile Strength [MPa]
X2 … Elongation [%]
X3 … Tear Strength [N/mm]
X4 … Shore Hardness [ShA]
X5 … Resilience [%]
X6 … DMA (Tensile Modulus – E* - complex Modulus) [MPa]

β_i … regression parameters
ε … error

By using the least square method we obtained the estimates of unknown parameters β_i. The answered regression function takes the following form:

$Y = 2{,}619273 + 0{,}034052\ X_1 - 0{,}001868\ X_2 + 0{,}000125\ X_1 X_2 - 0{,}129815\ X_3 + 0{,}116571\ X_4 + 0{,}012328\ X_5 + 0{,}000121\ X_6$ (2)

(Suitability of the model is described by the determinacy index: R2 = 0,850893).

The correlation matrix (Table 1) shows a remarkable dependence between the wear and commonly measured mechanical properties.

Table 1. Correlation matrix

Correlation matrix	X1	X2	X3	X4	X5	X6	Y
X1	1,00	0,35	0,48	-0,573941	0,355879	-0,522965	-0,595387
X2	0,35	1,00	0,27	-0,223167	-0,274672	-0,131786	-0,320170
X3	0,48	0,27	1,00	0,136835	0,121560	0,203524	-0,207062
X4	-0,57	-0,22	0,136835	1,000000	-0,622169	0,967055	0,832489
X5	0,35	-0,27	0,121560	-0,622169	1,000000	-0,600251	-0,486060
X6	-0,52	-0,13	0,203524	0,967055	-0,600251	1,000000	0,782667
Y	-0,59	-0,32	-0,207062	0,832489	-0,486060	0,782667	1,000000

IV. CONCLUSION

This experiment deals with the wear of heavily stressed rubber parts, especially the tire treads. An instrument for fast test of wear was designed and machined. Standard set of measurements was carried out, specifically the tensile tests (tensile strength, tear strength) tests of hardness, resilience and dynamic properties (DMA test).

The experiment included a project and realisation of experimental machine for a fast test of wear. This machine enabled measurements on the testing samples prepared from thirteen different types of tire treads used for the production of tires undergoing high stress such as motorcycle tires and tires for technical and agricultural vehicles. The results of the measurements are compared.

The results of the tests were analysed statistically. Based on the measured values, a model predicting the behaviour of the compounds from the commonly measured properties of the compounds was chosen.

The evaluation of the wear test using a high-speed video camera system Olympus i-SPEED 2 enables very detailed

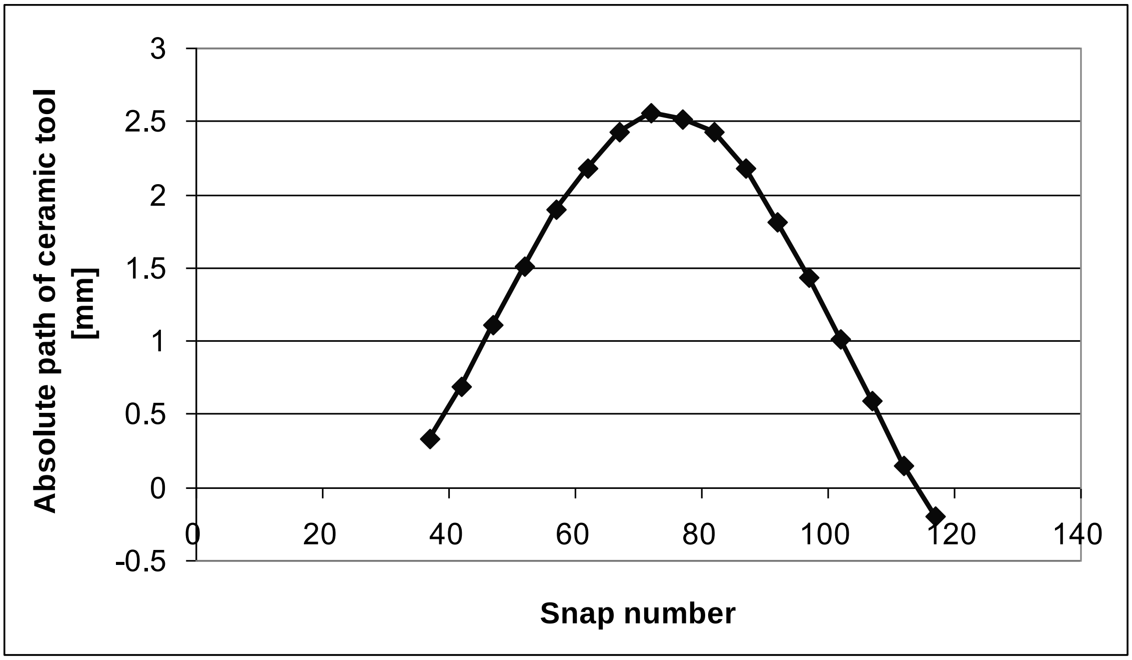

Fig.11. the absolute path of ceramic tool movement after dropping on the testing sample

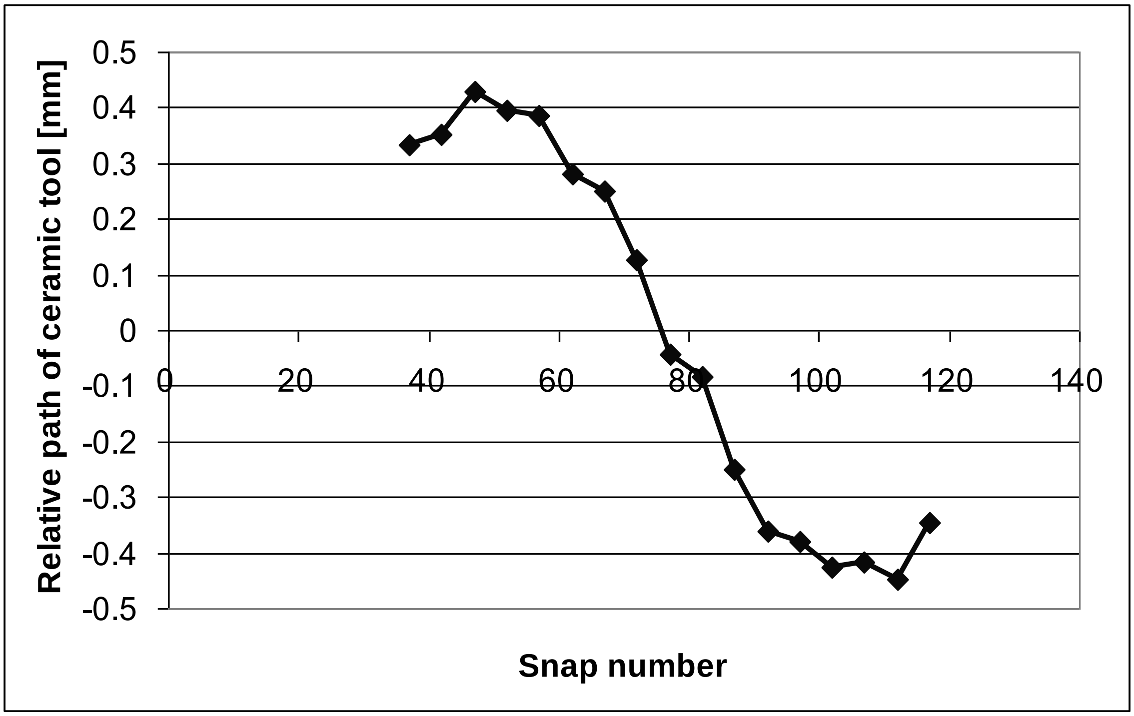

Fig.12. the relative path of ceramic tool movement after dropping on the testing sample

analysis of the wear process of heavily strained rubber parts, tire treads in particular. The visualisation of the ceramic tool drop on the testing samples can determine the path of tool penetration, as well as its speed (Fig. 11). Simultaneously, the deformation of the testing sample can be observed. The path and speed ratio can determine the moment when the surface is damaged and first rips created (Fig. 10.).

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