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Assessment of adequacy of behavior models of materials of a LS-DYNA package in relation to tasks of the tire industry

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Abstract

Consider the definition of the input parameters LS-DYNA rubber and metal cord models materials based on laboratory experiments. The resulting material models used in numerical simulations of static loading tires heavy-duty trucks. Comparison with the results of static tests confirmed the adequacy of the tire material models parameters.

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Keywords: rubber; hysteresis losses; viscoelasticity model; searching for model parameters

1. Introduction

The accuracy and reliability of the numerical simulation depends on the correct description of the physical properties tire’s materials.

To determine the materials parameters were laboratory tests sample of various parts of the vulcanized tire heavy-duty trucks. The samples were cut from the tread, the undertreat and rubber-carcass.

Laboratory tests were in the laboratories of Belarusian State Technological University on a computerized test rig Tensometer «Instron 2020" company Alpha Technology. This machine is an electromechanical test machine, which in this case was controlled by the software Bluehill. Samples of rubber were tested for tensile strength and triaxial compression. The metal cord was tested for stretching.

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2. Test samples rubber tensile

Text Static tensile tests were performed, and the specimens were evaluated with respect to stress at given elongation, which are aspects of their basic mechanical properties. Specimens are tested into a "dumbbell" shaped specimen type 4 by GOST 270-75 at a constant speed of 500 mm per minute. Cycles of loads and unloading are carried out in accordance with GOST 252-75 [1, 2]. The specimen fixed in tensile grips.

Then the sample was stretched by 140% – 150 %. After that was changed the direction of the grips: the sample thus reduced to a complete discharge (force is equal to zero). The test was repeated four more times with the recording of the hysteresis loops. By Stress-strain curves were determined the stress at specified elongation. The test specimen in tension rubber is shown in Fig. 1.

Fig. 1. Rubber tensile strength test.

3. Tensile strength test

The tensile test was carried out for five samples of vulcanized rubber each parts of tyre represented BELSHINA JSC. Then, five graphs are averaged relaxation curve. The diagram "force - displacement" of the tyre tread is shown in Fig. 2.

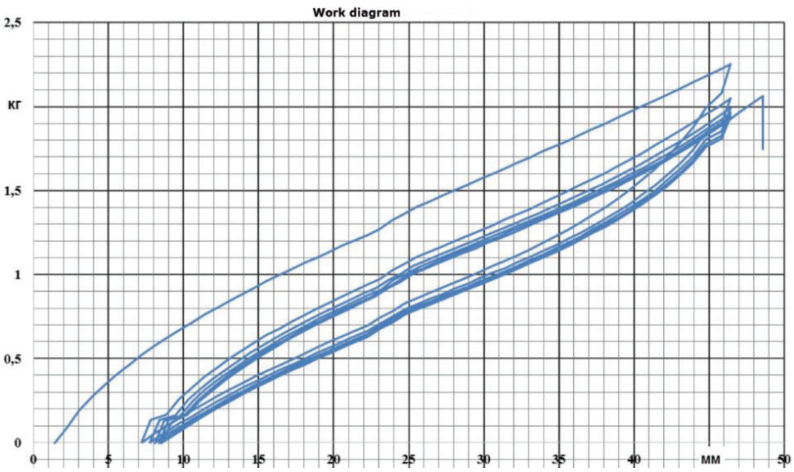


Fig. 2. Load-extension diagram of the tread sample.

4. Compression rubber test

The vulcanized rubber specimens were tested under compression load and were evaluated the bulk modulus. The testing of the vulcanized rubber sample has been conducted according to GOST 9.029-74 (a specimen type I). The loading 9000 H was applied at a rate of approximately 1 $mm.min^{-1}$ and 50 $mm.min^{-1}$. The test setup and the procedure are shown in Fig. 3. The laboratory tests were obtained for the tire tread are presented in Fig. 4 [3]. As show in Fig. 4, the bulk modulus weakly depend on the loading rate. When a compressive strain reaches of approximately 1.5% the graph is linear. An amount of bulk modulus of the tire tread is 346.7 MPa.

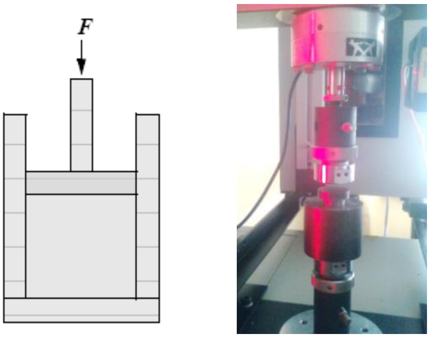
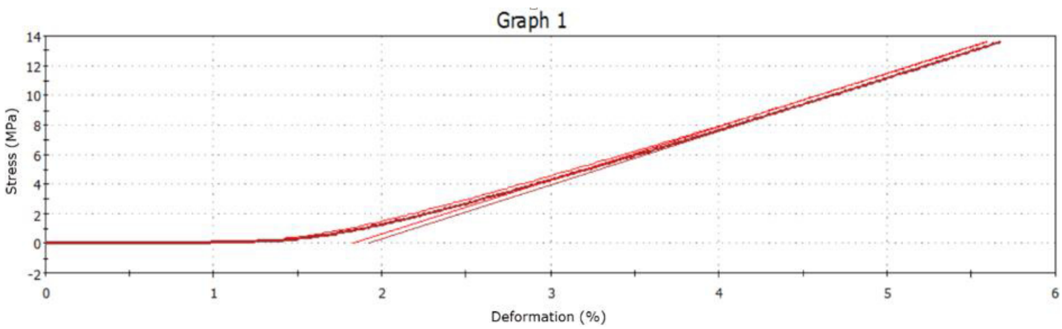


Fig. 3. Compression test.



	Maximum Load (N)	Compressive Strength (MPa)	Modulus (Automatic) (MPa)
1	9000.259	13.626	344.16233
2	9000.283	13.626	344.72311
3	9000.246	13.626	346.69793

Fig. 4. Results of compression test.

5. Searching for model parameters LS-DYNA

To describe the behavior of rubber tyre in the virtual modeling used material model LS- DYNA type 6: *MAT_VISCOELASTIC. This model allows the modeling of viscoelastic behavior for solid elements. The card of material model type 6 is shown in Fig. 5 [4]. Parameters of the material card are shown in Table 1.

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	BULK	G0	GI	BETA		

Fig. 5. Card of viscoelastic material LS-DYNA.

Table 1. Input parameters of material card *mat_viscoelastic.

	Name of variable	Variable
1	Mid	Material identification
2	Ro	Mass density
3	BULK	Elastic bulk modulus
4	G0	Short-time shear modulus
5	Gi	Long-time (infinite) shear modulus
6	Beta	Decay constant

The shear relaxation behavior is described by:

$$G(t) = G1 + (G0 - G1)e^{-\beta t} \tag{1}$$

Decay constant β calculated by the relaxation curve obtained under uniaxial loading standard sample testing machine (Fig. 5).

When a tensile test is performed, the measured quantities are the loading force and the displacement. The displacement is measured with an extensometer as the current length of the initial test length. The load cell of the machine measures the force *F*.

The engineering stress determined by the formula:

$$\sigma_E = \frac{F}{A_0}, \tag{2}$$

where A_0 is the original area.

The true stress σ_T may be defined as:

$$\sigma_T = \sigma_E(\varepsilon_E + 1) \tag{3}$$

where ε_E is the engineering strain:

$$\varepsilon_E = \frac{L - L_0}{L_0}, \tag{4}$$

where *L* is the current length, L_0 is the initial length of the tensile test specimen.

The true strain defined as:

$$\varepsilon_T = \ln\left(\frac{L}{L_0}\right), \tag{5}$$

The elastic modulus determined by the formula:

$$E = \frac{\sigma_T}{\Delta l} \tag{6}$$

where Δl is the extension elongation.

Current shear modulus at specified elongation determined by the formula:

$$G_i = 3 \cdot K \cdot \frac{E_i}{(9K - E_i)}, \tag{7}$$

where K is bulk modulus [5].

Shear modulus was determined based on data obtained from five tensile tests. Average shear modulus-time curve is shown in Fig. 6. Shear modulus was calculated on the basis of the relaxation curve in five cycles (Fig. 7).

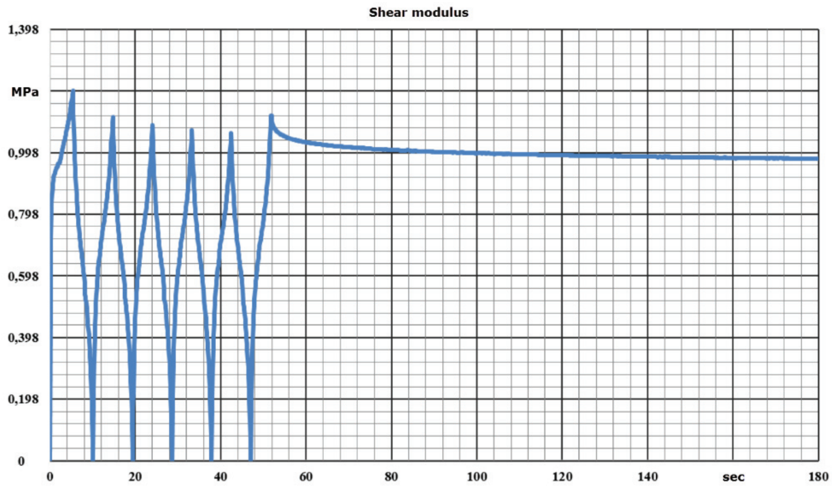


Fig. 6. Shear modulus-time curve.

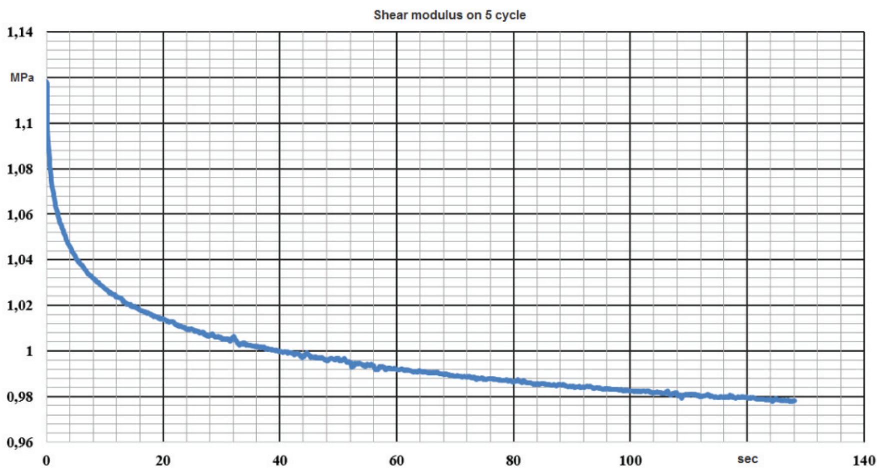


Fig. 7. Shear modulus in the last cycle.

On the assumption of the plot (Fig. 7) is defined long-time shear modulus (*Gi*) and short-time shear modulus (*Go*). In order to obtain the delay values (beta) uses the exponential trend line on the basis of the damping curve. Resulting values of the material card for the different parts of the tire are tabulated in Table 2.

Table 2. Variables of values *MAT_VISCOELASTIC card.

Material model	Bulk modulus *K* (MPa)	Decay constant beta	Short-time shear modulus G0 (MPa)	Long-time shear modulus G1 (MPa)
Tread	345.19	0.0108	0.69	0.450
Undertread	346.81	0.0133	1.24	0.75
Belt	351.37	0.0245	2.275	0.85
Carcass	349.04	0.0257	2.01	0.72

6. Testing the tensile of tire cords

Test objective was to determine the elastic modulus of steel cord tire. Test circuit of tire cords is shown in Fig. 8. Loading force amounted 9000 N. Results of tensile cord tire testing shown in Fig. 9.

Tire cord is tested at a speed of 20 mm per minute. Cycles of loads and unloading are carried out in accordance with GOST 252-75. The specimen fixed in tensile grips.

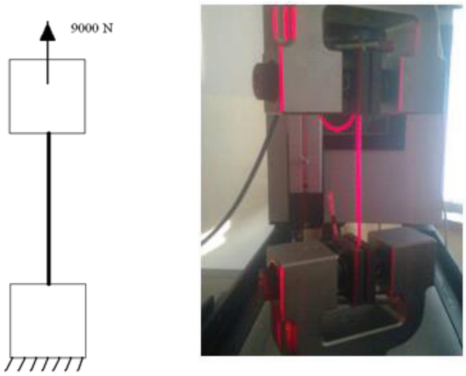
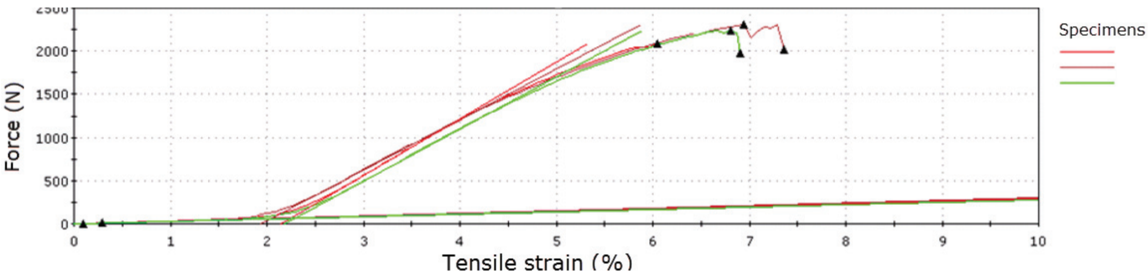


Fig. 8. Test circuit of tire cords.



Results							
	Modulus (Automatic) (MPa)	Young's modulus (Tensile Stress 0.1% - 0.3%) (MPa)	Tensile Stress (Elongation 0.1%) (MPa)	Tensile Stress (Elongation 0.3%) (MPa)	Force (Elongation 0.1%) (N)	Force (Elongation 0.3%) (N)	Deformation (Peak Load) (%)
1	60206.64426	2606.52	2.71	7.96	2.95	8.67	6.05
2	53742.59564	2806.06	3.03	8.65	3.30	9.41	6.94
3	55494.93591	2485.39	2.59	7.60	2.83	8.27	6.81

Fig. 9. Results of tensile cord tire test.

The properties of the tyre cord are represented by an isotropic material model with linear elastic properties *mat_elastic. Variables of values are Young's modulus and Poisson's ratios. These constants were obtained with simple tensile test and are shown in Table 3.

Table 3. Young's modulus of cord.

Type of cord	Young's modulus E (MPa)
50L22/15NT (belt)	45397.34
85L25/20NT (belt)	25371.45
24L25NE (belt)	56489.12
190L18/20NT (carcass)	14760.87

7. Conclusion

The mechanical properties tests of the test rubber specimen and the rubber-cord system are carried out by means of the Tensometr «Instron 2020» manufactured by Alpha Technology. Mechanical testing methods to determine the material constants for large deformation nonlinear finite element analysis in LS-DYNA were obtained. The LS-DYNA keyword for the different parts of the super heavy-duty tire was evaluated. The simulation of super heavy-duty tire is represented by a static structural analysis. The FEA simulation results are quite accurate (within 5% error) as compared with the bench tests.

References

[1] GOST 270-75, Rubber. Method of the determination elastic and tensile stress-strain properties.
[2] GOST 252-75, Rubber. Method of test of the relative hysteresis and useful elasticity by elongation.
[3] GOST 9.029-74, Unified system of corrosion and ageing protection. Vulcanized rubbers. Method of testing of resistance to ageing under static deformation of compression.
[4] LS-DYNA Keyword user's manual, Volume 2, LSTC 2010 – 2500c.
[5] D. Roylance, Engineering viscoelasticity, Department of Materials Science and Engineering, Massachusetts Institute of Technology Cambridge, 2001.