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MODEL EXPERIMENTAL TESTS OF TYRES AND THEIR ANALYSIS

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The contents of the paper points out the necessity of combining the theoretical and experimental approaches in the investigation of tyres load in vehicles. The majority of transparent elastic materials are photoelasticimetrically active. Their photoelasticimetric behaviour is known and there are formulations to investigate stress in structural parts made of rubber elastic materials. This constitutes an assumption of carrying out tests on models of passenger tyres and truck tyres. The models are planar and they model the cross-section of the tyre, enabling the consideration of the bottom load and the internal pressure in the tyre, as well as the influence of the lateral force. The paper presents the findings, the formulations necessary for solving the task and the resulting stress values obtained in the experimental model tests and serving as a basis for comparison with the results obtained from purely theoretical approaches, e.g. by the method of finite elements, with identical load conditions.

Keywords: Tyres, rubber materials, photoelasticmethod, deformations, shear stress.

Introduction

Many transparent elastic rubber materials are photoelasticimetrically active. Their photoelasticimetric behaviour has been described by several authors [1], [2], [3], [4]. Formulations concerning investigation of stresses in structural parts made of elastic rubber materials have also been recorded [5], [6], [7], [8]. They gave an impulse to carrying out tests on planar car tyre models that represent a cross section of a tyre in which the stressing of the tyre bottom and the internal pressure in the tyre are considered.

Theory

When dealing with extensive deformations, it is more suitable to describe the deformation condition not as the main deformation (ε_i) but as elongations (λ_i) or by real main specific elongations.

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According to [10], the single-parameter formulation with the modulus of elasticity in shear constant is valid up to $\lambda_i = 1{,}5$, the two-parameter formulation with the elastic constants C_1, C_2 is valid up to $\lambda_i = 2$.

The main stresses σ_1 , σ_2 , σ_3 , refer to the deformed shape of the investigated part. Incompressibility of the material is assumed and hydrostatic stress σ_o is considered.

In the case of extensive deformations, planar stressing may be considered only for complete layers, and thus it is of almost no interest for technical application. Hence, the case of planar deformation remains the field of the main interest for the tasks to be solved by planar photoeasticimetry.

The basic law of deformation optics for extensive deformations is expressed by the relationship

$$m = d\,D\,(\varepsilon_1^* - \varepsilon_2^*) = d\,D\ \ln(\lambda_1 / \lambda_2) \qquad (1)$$

where m - is the isochromatic order,

d - is the thickness of the model,

D - is the deformation-optical numeric characteristics of the model material,

$\lambda_1 = l_1 / l_0 = 1 + \varepsilon_1$ and $\lambda_2 = l_2 / l_0 = 1 + \varepsilon_2$

In the case of extensive deformations, no proportionality between the load and the deformation and therefore a strict similarity is required in the test of the model [11]. In the single-parameter formulation, the following must be valid for the model (M) and the final roduct (V)

$$(\sigma_1 - \sigma_2)_V = (\sigma_1 - \sigma_2)_M \,.\, G_V / G_M \qquad (2)$$

At extensive deformation, no proportionality exists between σ_1-σ_2 and m, therefore instead of the photoelasticimetric constant only the photoelasticimetric characteristic function can be expressed, which is defined by the relation

$$S(m) = d\ \partial/\partial m\ (\sigma_1 - \sigma_2) \qquad (3)$$

In the case of planar deformation, equation (3) in the single-parameter formulation will have the following form

$$S(m) = 2G / D\ \ sh(m/dD) \qquad (4)$$

and in the two-parameter formulation it will have the form

$$S(m) = 2(C_1 + C_2) / D\ \ sh(m/dD) \qquad (5)$$

In order to enable a comparison with the common hard materials of the models, the limit value of $S(m)$ may be considered as the photoelastometric constant for small values of the isochromates

$$S = [\ S(m)\ ]_{m \to 0} = 2G / D \qquad (6)$$

or

$$S = 2(C_1 - C_2) / D \qquad (7)$$

In the case of planar deformation, the deformation optics law for $\lambda_3 = l_3/l_0 = 1 + \varepsilon_3 = 1$ and $\lambda_1 \lambda_2 \lambda_3 = 1$ will have the form of

$$m = d\,D\ \ln(\lambda_1^2) \qquad (8)$$

from which the limit values of the single-parameter and two-parameter formulation validity range can be determined as the functions of the isochromatic order**.**

Experimental and results

The experimental tests have been carried out on tyyre models fitted between glass or plexi-glass plates. The deformation of the tyre by the pressure exerted upon the bottom and by the lateral force in the real tyre must also be reflected in the model. The internal pressure in the model will be calculated from the pressure in the real tyre in operation on the basis of the similarity condition in Equation (1).

Owing to their low deformation-optical constant, models made of a gelatine mixture proved to be suitable for the modelling of stresses under load.

The isoclines in the tyre with a radial reinforcement and asymmetrically deformed by a radial force is shown in *Fig. 1*.

The corresponding chart showing the isochromatic lines is shown in *Fig. 2*. The integer isochromatic lines are shown in full line, the isochromatic lines of the m^{th} order are shown in a broken line.

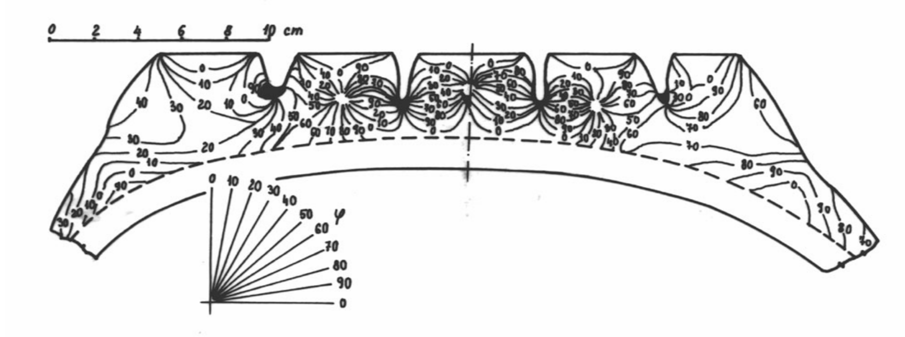

Fig. 1. A chart of the isoclines in the tyre with a radial reinforcement and asymmetricallydeformed by a radial force

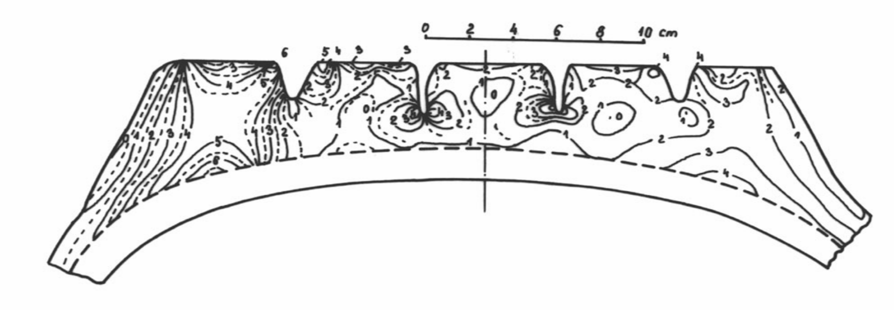

Fig. 2. A tyre with a radial reinforcement and a lateral force

Based on the charts of the isochromatic lines, the graphical shapes of the circumferential stresses along the notches in the tyre tread for each particular loaded tyre type, *Fig. 3*.

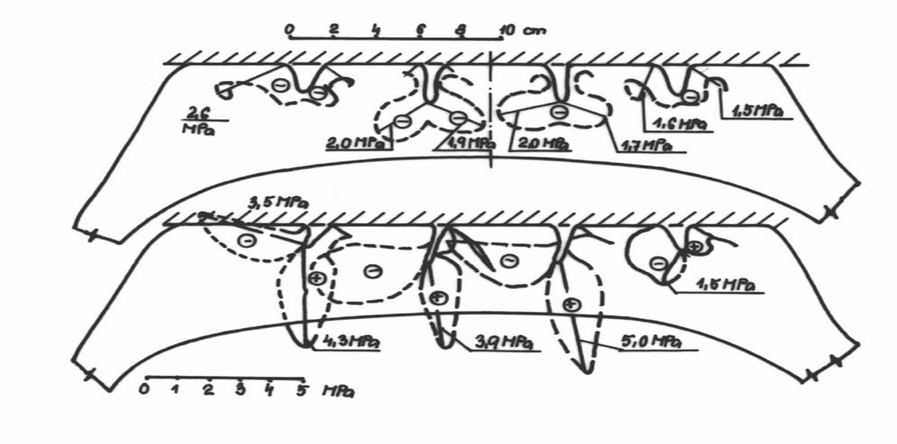

Fig. 3. A tyre with a radial reinforcement and a lateral force in the lower part

The charts show that the stress peaks increase in the presence of lateral force by reversing the stress peak sign because thus the occurrence of cracks in the tyre tread will be observable more easily. Based on the charts of isochromatic lines and isoclines, the graphical shape of shear stresses along the boundary between the tyre tread and the reinforcing plies has been determined by the relationship

$$\tau = (\sigma_1 - \sigma_2)/2 \,.\, \sin(2\varphi) \qquad (9)$$

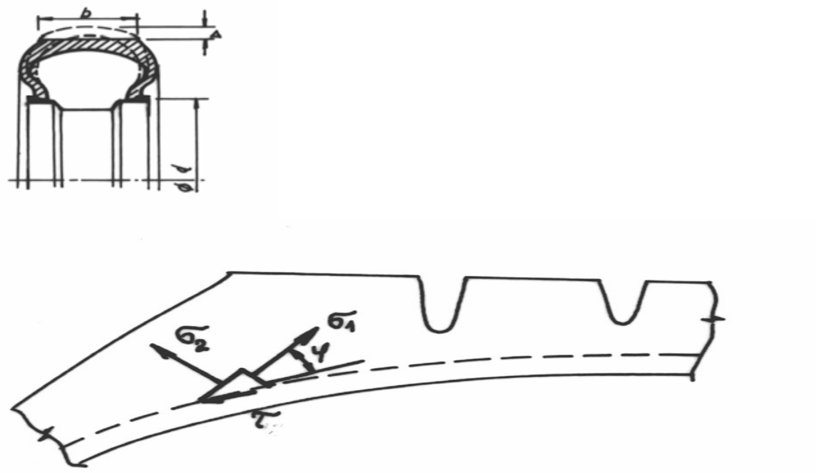

Fig.4. Shear stress along the reinforcing ply

The φ angle between the tangent to the surface of the reinforcing ply and the direction of the main stress σ_1 follows from the chart of isoclines, *Fig. 4*.

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Distribution of the shear stress τ over the reinforcing ply area are shown in *Figs. 5* and *6*.

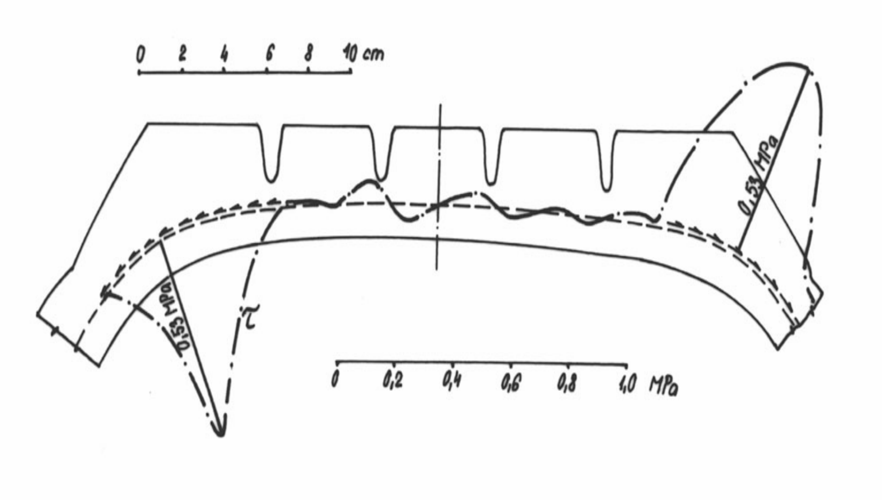

Fig. 5. A radial tyre with no lateral force

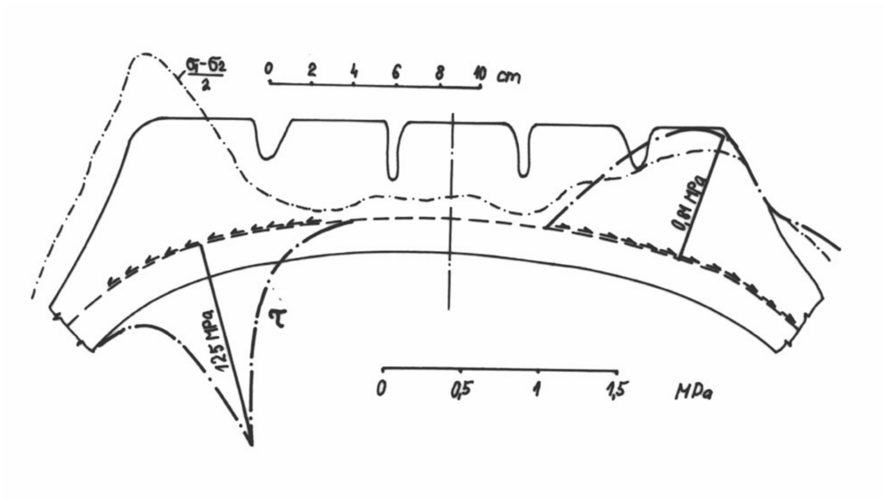

Fig. 6. A radial tyre with lateral force

This shear stress is the cause of the separation of the tread from the reinforcing ply, and hence of a failure of the tyre. This brings out the advantage of radial tyres at lower values of shear stress. It also becomes evident that a higher air pressure and a lesser decrease in the profile under load causes less shear stress than a greater decrease at a lower air pressure.

Conclusion

The results of these investigations may be utilised in the development of new tyre tread patterns. A comparison of these results with results obtained by different methods may also be of interest.

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