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EROSION OF ASPHALT AS A RESULT OF AUTOMOBILE TIRE STUDS IMPACTS

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Abstract> The main objective of the presented research is to develop a model in order to predict fracture of asphalt road surface impacted by an automobile tire stud. As a result of the analysis it is demonstrated that the critical automobile speed leading to creation of fracture in asphalt does depend on combination of asphalt mean elastic modulus and special dynamic strength characteristics responsible for the incubation process of microcracking caused by impacts. It is shown that in certain conditions smaller elastic moduli combined with bigger ductility of compound and increased dynamic strength can result in greater threshold car velocities giving brittle damage to asphalt. At the same time larger elastic moduli can provide better performance of asphalt layer undergoing quasistatic loading (slow heavy traffic). One of the practical solutions to maximize durability of highways is to use different asphalt mixtures in right (slower) and left (faster) traffic lanes. This can be, for example, achieved by addition of plasticizers into asphalt mixture used to cover high-speed traffic lanes. FEM simulation is giving a quantitative prediction of critical vehicle velocities leading to initiation of fracture in asphalt.

1. Introduction

It is often believed that the main contribution to fracture and deformation of asphalt covered road surfaces is made by heavy weight traffic. Indeed, for low speed traffic, heavy vehicles (lorries, buses etc.) create loads on the road surface, which significantly exceed loads created by much lighter motorcars. In this case the road surface is loaded *quasistatically*. The process of road surface deformation and fracture in this case is well studied. The situation can be significantly different if one allows for high-speed traffic. Moving on Russian high speed motorways it can be observed that the main damage to the road surface is concentrated at left (high-speed) traffic lanes. It is also seen that this damage is caused by erosion-type fracture of the asphalt surface (fracture connected with material removal). At the same time heavy trucks are rarely or never moving in these lanes. Obviously, fast-moving motorcars induce this damage. For a car moving at the speed of 110 km/h time of interaction between the tire and the road is around 5 milliseconds. An impact of a tire stud on the road surface is 2-3 microseconds long and the energy of this impact is increasing as the square of the vehicle velocity. It is believed that the main reason for the erosion-type damage in the left traffic lanes on high-speed roads is the result of impacts of tire studs of vehicles moving at high speeds.

2. Fracture criterion

Adequate choice of fracture criterion is one of the central problems in order to create a model predicting erosion-type fracture of asphalt impacted by automobile tire studs. Nowadays it is known and generally recognized that classical fracture criteria (critical stress criterion, critical

there is a significant dependency of material properties on temperature.

The current research is focused on brittle fracture of asphalt impacted by tire studs. It is known that lower temperatures are normally leading to “more brittle” behaviour of material (probability of brittle fracture is increased).

As a reference temperature of asphalt layer we accept temperature equal to -5 Celsius, which is a normal winter temperature for the European part of Russia. Higher temperatures will result in lower probability of brittle fracture (higher critical motorcar speeds leading to asphalt fracture). Lower temperatures will have opposite influence.

Based on the available experimental data [13-15] the following material properties typical for asphalt used for construction of top layer of Russian motorways at -5 Celsius were used:

- Young's modulus (E) $1.1 \cdot 10^9$ Pa;
- Poisson's ratio (ν) — 0.3;
- Density (ρ) 2100 kg/m^3;
- Ultimate stress (σ_c) $45 \cdot 10^5$ Pa;
- Critical stress intensity factor (K_{IC}) $114 \cdot 10^3$ Pa m$^{1/2}$;
- Brittle fracture incubation time — 12 microseconds;
- Structural size d for this material can be calculated using (2) and is equal to 0.4 mm.

This reference material will be compared to “modified” asphalt mixtures. It is assumed that there is a possibility to change material elastic modulus (Young’s modulus) of asphalt (for example, by introduction of plasticizer). Effect of elastic modulus change on other material parameters can be evaluated on the basis of the previous research [2, 11, 12].

Following [16] it is supposed that ultimate stress and critical stress intensity factor are not significantly affected by the change of the elastic modulus. Thus, structural size d is neither affected significantly. In [17] it is demonstrated that the incubation time for many materials is proportional to the structural size d and back proportional to the speed of waves in the fractured material.

Thin rod elastic wave speed is given by $c_s = \sqrt{E/\rho}$. Assuming that the material density is not significantly changed, it can be received that in the studied case the fracture incubation time should be back proportional to the square root of the elastic modulus.

4. Spall fracture

The first approximation used in order to assess influence of change of asphalt elastic modulus on its dynamic strength is the problem of spall fracture in a plate made of asphalt. Suppose the impact has a rectangular time shape (this time shape is close to time shape of pressure created by a stud impacting the surface). Duration of the load is given by the stud linear size. Its amplitude is given by the impact initial velocity.

The problem can be solved analytically using the incubation time criterion (1) in order to predict fracture. As a result, critical load parameters, leading to spall fracture in asphalt plate can be calculated.

Taking into consideration that the usual length of an automobile tire stud is 16 mm and longitudinal wave speed in steel is around 5000 m/s, it can be found that duration of the stud impact is about 3.1 microseconds. Impact amplitude will depend on the stud initial velocity.

The solution is received as a sum of an incident and the reflected waves. The incident wave is given by:

$$\sigma_+ = -P\left[H(t+\frac{x_2}{c_1}) - H(t+\frac{x_2}{c_1}+T) \right],$$

where P is the load amplitude; T is its duration; H is the Heaviside step function; t is the time;

$$h(t) = 0; \quad v(t) = v_0 . \tag{5}$$

Solving (3)-(5) for *h*, one can receive:

$$h(t) = h_0 \sin\left(\frac{\pi t}{t_0}\right), \qquad h_0 = \frac{v_0 t_0}{\pi}, \qquad t_0 = \sqrt{\frac{m}{k}}\pi . \tag{6}$$

where h_0 is the maximum particle penetration and t_0 is the duration of the contact between the particle and the half-space.

Maximum of the tensile stresses can be approximated by [18]:

$$\sigma(v_0, R, t) = \frac{1-2\nu}{2}\frac{F(t)}{\pi R^2} = \frac{(1-2\upsilon)E}{\pi(1-\upsilon^2)}\frac{h_0}{R}\sin\left(\frac{\pi t}{t_0}\right).$$

Fracture condition (1) for this case can be rewritten as:

$$\int_{t-\tau}^{t} \sigma(v_0, R, s)ds \le \sigma_c \tau .$$

The following condition corresponds to critical situation leading to raptures in the half-space:

$$\max_t \int_{t-\tau}^{t} \sigma(v_0, R, s)ds = \sigma_c \tau . \tag{7}$$

Utilising (7), one can find threshold velocity v_0 of the particle leading to initiation of fracture in the area of asphalt impacted by a cylinder.

Cylinder mass is taken to be equal to 2.1 g, being the mass of a standard tire stud. Standard stud length is 16 mm, giving *R*=12 mm.

Solving (7) for v_0 (initial particle velocity), critical stud velocity can be found as a function of asphalt elastic modulus. Figure 2 presents the received dependency.

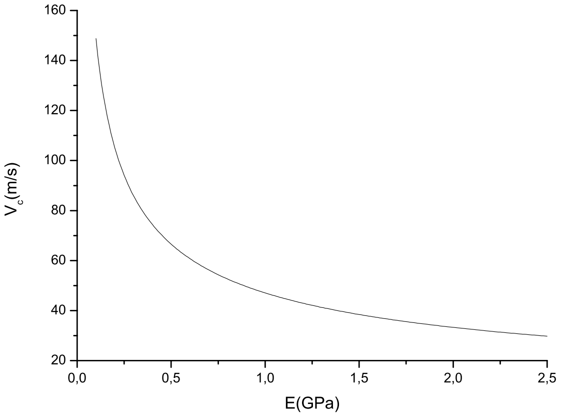

Fig. 2. Critical stud velocity can be found as a function of asphalt elastic modulus.

As it follows from Fig. 2, lower elastic moduli of asphalt result in higher critical motorcar velocities, i.e. lower elastic modulus provides an increase in the material dynamic strength properties. The received dependency should qualitatively coincide with dependency of critical velocity of an automobile tire stud fracturing asphalt layer (erosion-type fracture).

6. Numerical simulations

Predictions of asphalt fracture closest to real process can be received on the basis of FEM

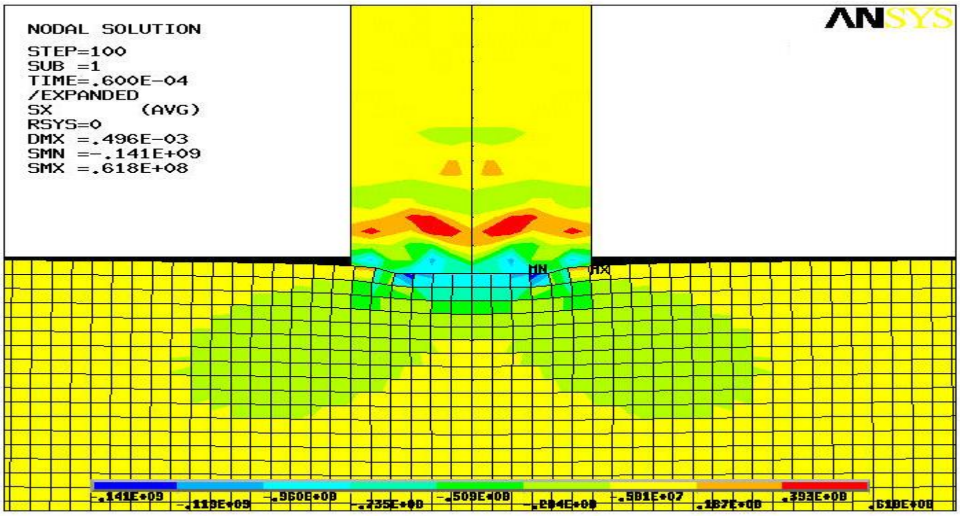

Fig. 3. Typical field of the horizontal stresses in the process interaction of a stud with asphalt media.

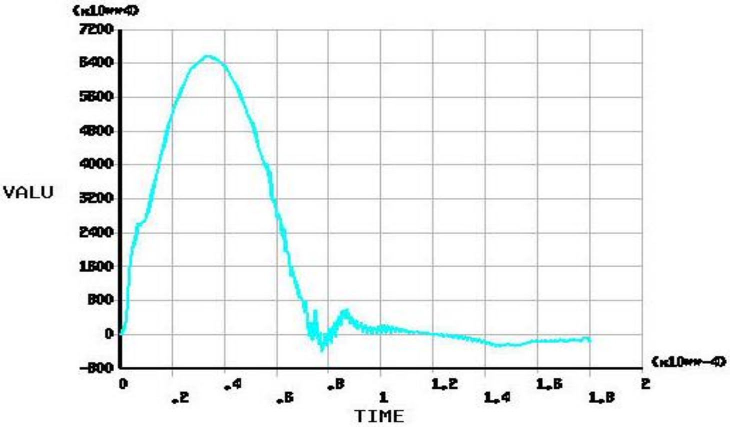

Fig. 4. Typical history of stresses on the asphalt surface at a point adjacent to the stud impact area.

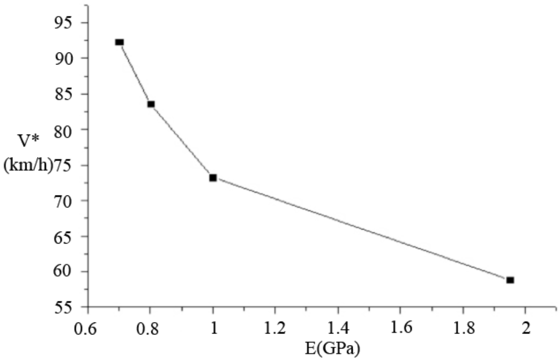

Fig. 5. Critical (minimal) vehicle velocity leading to initiation of fracture in asphalt as a function of asphalt elastic modulus.

7. Summary

Two analytical models serving as qualitative approximation to the process of automobile tire stud impacting asphalt layer are analysed. Using these models an important effect is demonstrated: decrease in the elastic modulus of asphalt can lead to a significant increase of the critical stud (or motorcar) velocity leading to initiation of asphalt rapture.

FEM being a much better approximation of a real process is used to predict critical vehicle velocities leading to creation of ruptures in asphalt layer. The received dependency of critical automobile velocity as a function of asphalt layer elastic modulus is providing a possibility to quantitatively assess the effect of the asphalt elastic modulus change on the asphalt strength. Critical velocity of automobile for “standard” asphalt (74 km/h) is very close with the value evaluated experimentally [19] and the speed limit of 80 km/h imposed on cars with studded tyres in some of the European countries (Switzerland, Lichtenstein, Austria).

One of the practical solutions to maximize durability of highways is to use different asphalt mixtures in right (slower) and left (faster) traffic lanes. This can be, for example, achieved by addition of plasticizers into asphalt mixture used to cover high-speed traffic lanes. Presented simulations are giving a quantitative prediction of critical vehicle velocities leading to initiation of fracture in asphalt.

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