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A VISCOPLASTIC MODEL WITH STRAIN RATE CONSTITUTIVE PARAMETERS FOR ASPHALT MIXTURES' RESPONSE SIMULATION

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1. INTRODUCTION

The mechanical behavior of the asphalt pavements is a complex phenomenon conditioned by the heterogeneity of the asphalt composite material. Experimental tests in the laboratory show a clear strain rate dependency in the material's response.
A new viscoplastic model has been developed to simulate de asphalt mixture's response under dynamic loads, assuming the strain rate dependency of the material's response observed in the experimental tests.

It has been noted that the strain rate affects significantly the Young modulus and the viscosity. Taking into account this influence, a new formulation has been developed, implemented in a finite element code. The new viscoplastic model has been validated and calibrated according to laboratory test to obtain mathematical expressions for the constitutive equations.

The new viscoplastic model allows us to simulate the asphalt mixture's response, under dynamic loads and temperature variations, with a significant degree of precision, using few constitutive parameters obtained from simple experimental tests.

2. PAVEMENT'S MECHANICAL BEHAVIOR ANALYSIS

To improve the knowledge about the asphalt mixtures laboratory tests have been. Different curves have been obtained for different rates of loading to remark the dependency of this variable in the material's response, which will be included in the model. According to the experimental result's simulation some material properties can be mentioned:

- The elastic range is not significant. The non linear behavior comes up for low stresses.
- The elastic young modulus is strain rate dependant $E(\dot{\varepsilon})$. This property is much clearer in the non linear range, which is almost the whole domain of the response. Assuming this geometric behavior as hypothesis, a function (1) for the Young modulus is purposed

$$E(\dot{\varepsilon},T) = E_0 \cdot K_E(T)^{Log\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)} \tag{1}$$

where E_0, is the Young modulus for a reference strain rate $\dot{\varepsilon}_0$, and K_E is a constant of the material depending on the temperature, to be calibrated with the experimental tests.

- The viscosity is also strain rate dependant. A geometric behavior is also assumed as hypothesis with a factor K_ξ. Another function for the viscosity (2) is purposed

$$\xi(\dot{\varepsilon},T) = \xi_0 \cdot K_\xi(T)^{Log\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)} \tag{2}$$

where ξ_0, is the viscosity for a reference strain rate $\dot{\varepsilon}_0$, and K_ξ is a constant of the material which depends on the temperature. This constant needs to be calibrated as well.

3. VISCOPLASTIC MODEL WITH STRAIN RATE DEPENDENT YOUNG MODULUS AND VISCOSITY. MATHEMATICAL FORMULATION

3.1 Introduction

The purposed model is generalization of the classical viscoplastic formulation, taking into account the influence of the strain rate in the constitutive parameters. The presented model can be simplified by means of a simple model composed by a strain rate dependent string $E(\dot{\varepsilon})$ in series with a single combination of a friction element and a dashpot { $\tau(\dot{\varepsilon}) \equiv \xi(\dot{\varepsilon})$ } as indicated in **Figure 1**

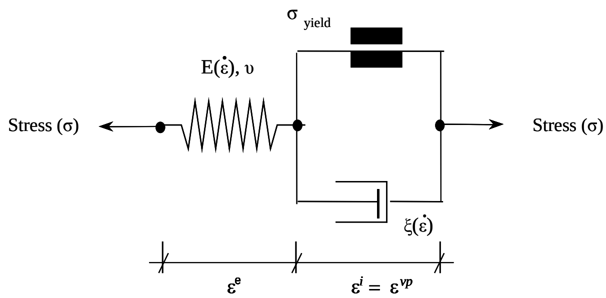

Figure 1. – Rheological scheme for the Viscoplastic model with E, ξ strain rate dependent

The purposed viscoplastic model is presented assuming small strains and constant temperature during all the process.

3.2 Description of the model

The new viscoplastic model is formulated in the frame of the classical thermodynamic theory based in the first and second principles, which are assumed in the Clausius – Duhem expression. The function for the Helmholtz's free energy is a quadratic form used in small deformation problems (3), and is defined as dependent on the total strain ε and the internal variables vector (**q**).

$$\psi(\boldsymbol{\varepsilon},\mathbf{q}) = \frac{1}{2\rho}\boldsymbol{\varepsilon}^{e} : \mathbf{C}(\dot{\varepsilon}) : \boldsymbol{\varepsilon}^{e} + \psi^{vp} \tag{3}$$

where $\mathbf{C}(\dot{\varepsilon})$ is the constitutive tensor, $\dot{\varepsilon}$ is a function of the components of strain rate tensor, and ψ^{VP} is a viscoplastic component of the free energy[3].

The model developed assumes the viscoplastic hypothesis[1] to define the constitutive equation (4) and energy's dissipation expression.

$$\sigma = \rho\frac{\partial\psi}{\partial\boldsymbol{\varepsilon}} = \mathbf{C}(\dot{\varepsilon}) : \boldsymbol{\varepsilon}^{e} = \mathbf{C}(\dot{\varepsilon}) : \left(\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}^{vp}\right) \tag{4}$$

The constitutive tensor $\mathbf{C}$ has been defined depending on the strain rate escalar value $\dot{\varepsilon}$, which has been defined from the elastic energy and the uniaxial equivalent stress (5)

$$\begin{aligned} &\dot{\omega} = \int \boldsymbol{\sigma} : \Delta\dot{\boldsymbol{\varepsilon}}\, dt = \int \bar{\sigma} : \Delta\dot{\bar{\varepsilon}}\, dt \quad \bar{\sigma} \equiv f(\boldsymbol{\sigma}) \\ &\Delta\dot{\omega} = \boldsymbol{\sigma} : \Delta\dot{\boldsymbol{\varepsilon}} = \bar{\sigma} : \Delta\dot{\bar{\varepsilon}} \;\Rightarrow\; \Delta\dot{\bar{\varepsilon}} = \frac{\boldsymbol{\sigma} : \Delta\dot{\boldsymbol{\varepsilon}}}{\bar{\sigma}} \;\Rightarrow\; \dot{\bar{\varepsilon}} = \int \Delta\dot{\bar{\varepsilon}}\, dt \end{aligned} \tag{5}$$

4. APPLICATION OF THE MODEL TO THE SIMULATION OF ASPHALT MIXTURES' BEHAVIOR

The Direct Tensile Test has been chosen to reproduce the stress – strain response of the material under tensile stresses. This test will be employed to study the constitutive variables involved and its influence to calibrate the model. The experimental results have been obtained from a static direct tensile test under prescribed displacement at different loading rates keeping constant the strain rate, according to the dimensions of the specimen. The direct tensile test is performed on two prismatic specimens of asphalt mixture with square base (**Figure 2**) for two different temperatures, to characterize the material properties and constitutive values.

4.1 Calibration of the model

To calibrate de model a numerical modelation of the two experimental specimens has been designed, prescribing the suitable boundary conditions in the symetry axes (**Figure 3**).
The simulation of the laboratory tests allows us to obtain the constitutive parameters, for the three strain rates and two temperatures, chosen as reference. Assuming the geometric relation between the Young modulus and viscosities obtained for each strain rate, the two constants from the strain rate expressions – K_E, K_ξ – can be determined, for every temperature.

The Poisson's ratio is assumed as constant as well as the fracture energy. The Yield stress is also assumed as constant for each temperature, but the range of elastic behavior is not much significant. The prescribed displacements exceeds this elastic limit easily, so the response is practically viscoplastic in the whole range of displacements.

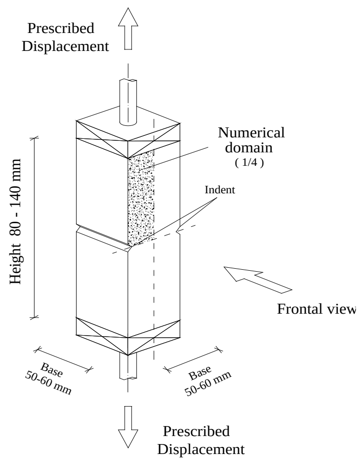

Figure 2.- Direct tensile test scheme

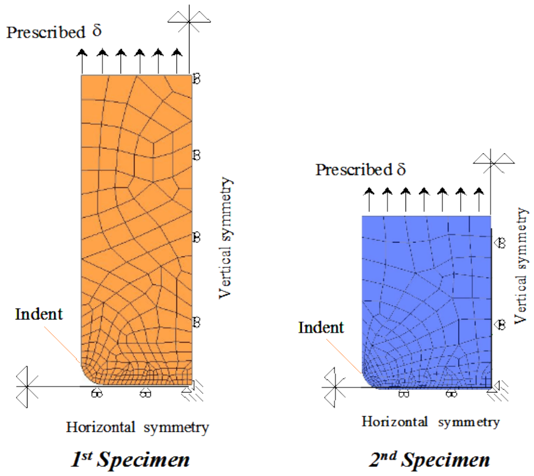

Figure 3.- Specimen 1 (20ºC) & Specimen 2 (8,3ºC)

4.2 Experimental results Vs Numerical results

The described model has been used for the numerical simulation of the asphaltic material response. The results were compared with experimental test for two temperatures and two strain rates named FAST and SLOW. The results are shown in **Figure 4.1** y **4.2**

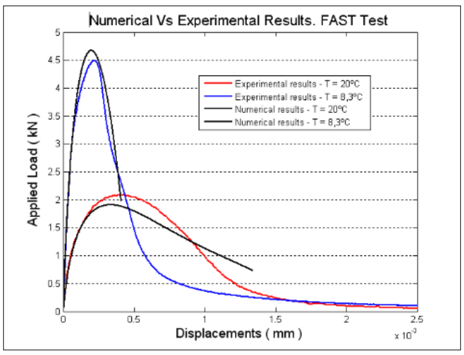

Figure 4.1.- Numerical Vs Experimental test
FAST Test. $\dot{\varepsilon}$ = $1{,}2.10^{-4}$ sec^{-1}

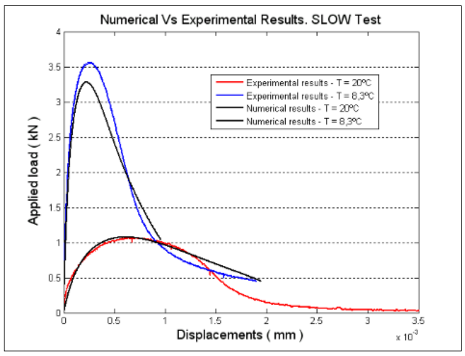

Figure 4.2.- Numerical Vs Experimental test
SLOW Test. $\dot{\varepsilon}$ = $1{,}2.10^{-5}$ sec^{-1}

The numerical approximation to the experimental curves is fairly good for the constitutive values and expressions adopted, taking into account the high level of variation in the material's respose, even for a fixed strain rate and temperature.

5. REFERENCES

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