SOFTWARE APPLICATION FOR CHARACTERIZATION OF VISCOPLASTIC BEHAVIOR OF METALS AT HIGH STRAIN RATES USING SPLIT HOPKINSON PRESSURE BAR DATA

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ABSTRACT
Although SHPB represent the most popular technique for material behavior characterization at moderate and high strain rates, there are few issues concerning data acquisition, as noise or wave dispersion and material model parameters fitting by least squares methods. The paper presents the most relevant steps used in SHPB data processing included in a "user friendly" application dedicated to SHPB test. Also, an application validation algorithm is shown in this paper.
Keywords: SHPB, viscoplastic behavior, material model

1. PRINCIPLE AND BASIC EQUATIONS OF SHPB TEST

The wide know principle of SHPB is induction of a dynamic uniaxial stress state in specimen by two rods impact. The impact creates an elastic wave which travels the input bar, reaches the specimen transmitting a part of energy and reflects the rest.

Figure 1. Schematic of Split Hopkinson Pressure Bar

The strain rate history and also stress history of specimen are obtained by measuring elastic deformation of input and output bars with strain gages mounted on both bars. From signals acquired by this way three fragments (incident, ε_I, reflected, ε_R, and transmitted, ε_T, waves) are isolated, representing the effect of specimen presence on elastic wave propagation, fragments which gives strain rate and stress histories [1] (subscript s indicates specimen properties and b means bars properties):

$$\sigma_s = E_b \frac{A_b}{A_s} \varepsilon_T . \tag{1}$$

$$\dot{\varepsilon}_s = -2 \frac{C_{0_s}}{L_s} \varepsilon_R . \tag{2}$$

$$\varepsilon_s = -2 \frac{C_{0_s}}{L_s} \int_0^t \varepsilon_R dt . \tag{3}$$

2. SHPB TEST DATA PROCESSING

Data acquisition system attached to SHPB records at an established frequency two electrical signals by strain gages mounted on bars. The ASCII file resulted represents the input data of application (Figure 2 upper graphic). First step in data processing is removal of undesired noise. The filtration is based on Savitzky-Golay algorithm, typical result of filtration being presented in lower graphic from Figure. 2. Additionally, this window has slider controls to select the interest area.
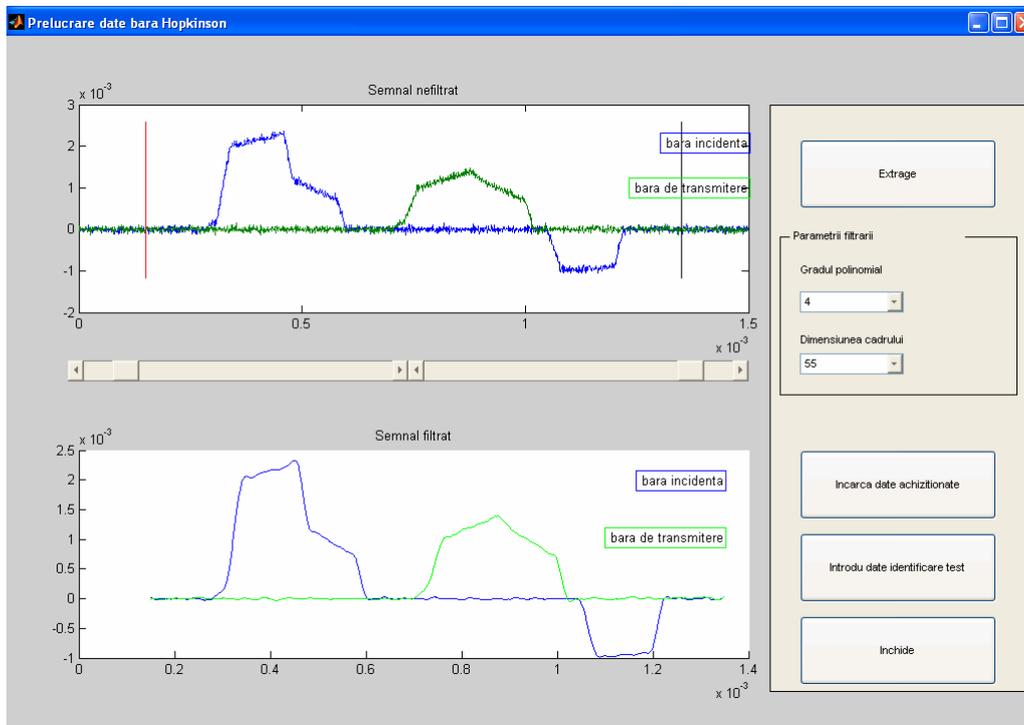
Figure 2. Filtration window

A second window used in SHPB data processing is destinated to introduce general data of test (lenght, diameter, temperature, density, elastic modulus, static flow limit, specific heat and Taylor-Qinney coefficient of specimen; elastic modululus, sound velocity and diameter of input and output bars; constants of strain gages; test date; material and test type) and to compute both engineering and true histories for stress and strain rate.

From filtered signals incident, reflected and transmitted waves are isolated. Each one of them is processed in order to eliminate the effect of dispersion on wave shape, a specific phenomenon to wave propagation in bars. This phenomenon is the effect of lateral inertia. Appling a Fast Fourier Transform algorithm, each of these three waves can be described as bellow:

$$f(t) = \sum_k (a_k \cos(2\pi\ k\omega\ t) + b_k \sin(2\pi\ k\omega\ t)) \qquad (4)$$

where $f(t)$ is the original signal and ω is the fundamental frequency.

Taking account of dispersion can follow two ways, theoretical and experimental. For theoretical way – the method implemented in present application – is necessary to have a relation between longitudinal wave's velocity, C_k, and wavelength. Bancroft [2] obtains a numerical solution, presented in tabular form. He expresses the velocity of longitudinal waves in terms of the velocity of a wave of infinite wavelength, C_0, and two variables: Poisson's ratio and the ratio of the bar diameter to the wavelength.

Having established relation between longitudinal wave's velocity and wavelength, the effects of dispersion can be estimated at distance x, by changing the phase of each component by an amount $\varphi(k)$, giving

$$f'(t) = \sum_k (a_k \cos(2\pi\, k\omega\, t + \varphi(k)) + b_k \sin(2\pi\, k\omega\, t + \varphi(k))) \quad (5)$$

$$\varphi(k) = 2\pi\, k\omega\; x\left(\frac{1}{C_0} - \frac{1}{C_k}\right) \quad (6)$$

Additionally, this window has slider controls to select the area where the dynamic equilibrium condition is fulfilled (equal forces applied on lateral surfaces of specimen).
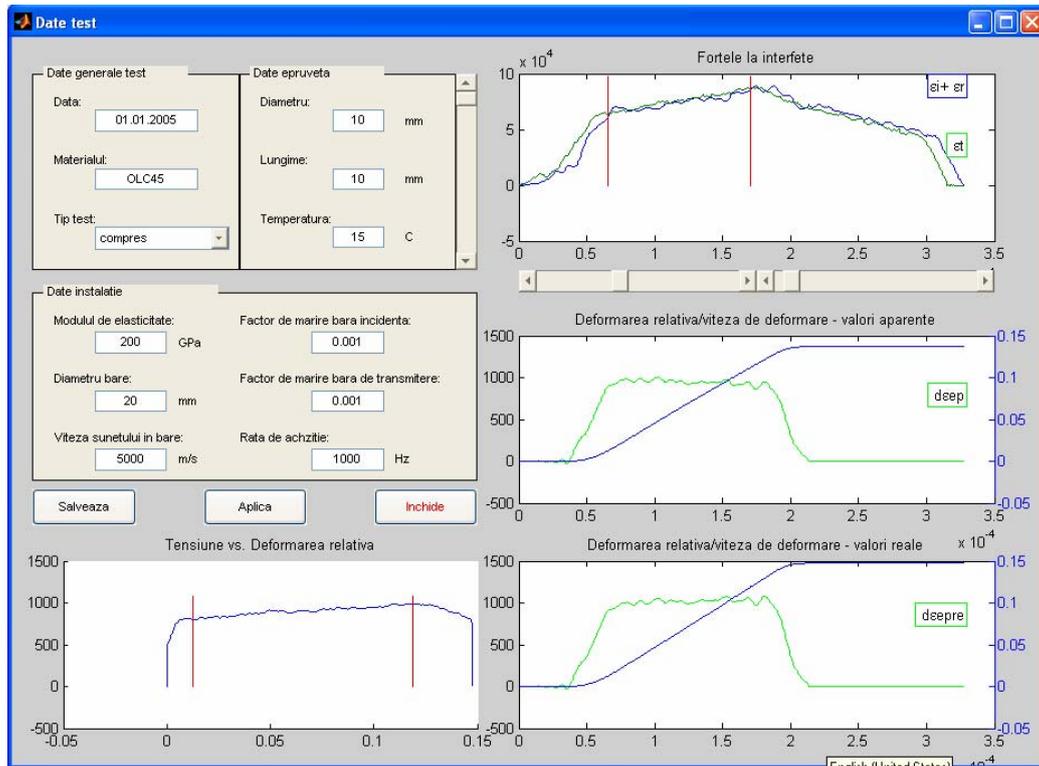
Figure 3. Main window of SHPB test data processing

3. MATERIAL MODEL PARAMETERS IDENTIFICATION

Standard approach to fitting a nonlinear material model (e.g. Simplified Johnson-Cook Model) to SHPB data is the minimum chi-squared method [3]. It is assumed that the model choused is able to predict the values of the measured data. For each measured datum x_i, the model provides a value y_i in terms of the SHPB experiment and a parameter vector *a*, representing the material model. The parameters that best fit the data are typically taken those that minimize χ^2

$$\chi^2 = \sum_i \frac{[x_i - y_i(a)]^2}{\sigma_i^2}, \quad (7)$$

where σ_i is the expected rms deviation of the measurement d_i. The vector which minimizes the value of relation (7) is established following the Levenberg-Marquardt algorithm.

Identification window, Figure. 4, allows to chose material model. Moreover model caracteristics are divided in those which are known and those which will be determined. For unknown parameters, user is allowed to establish his own intervals. At the end of search, the model parameters and their standard errors are displayed together with time histories of measured and calculated stress.
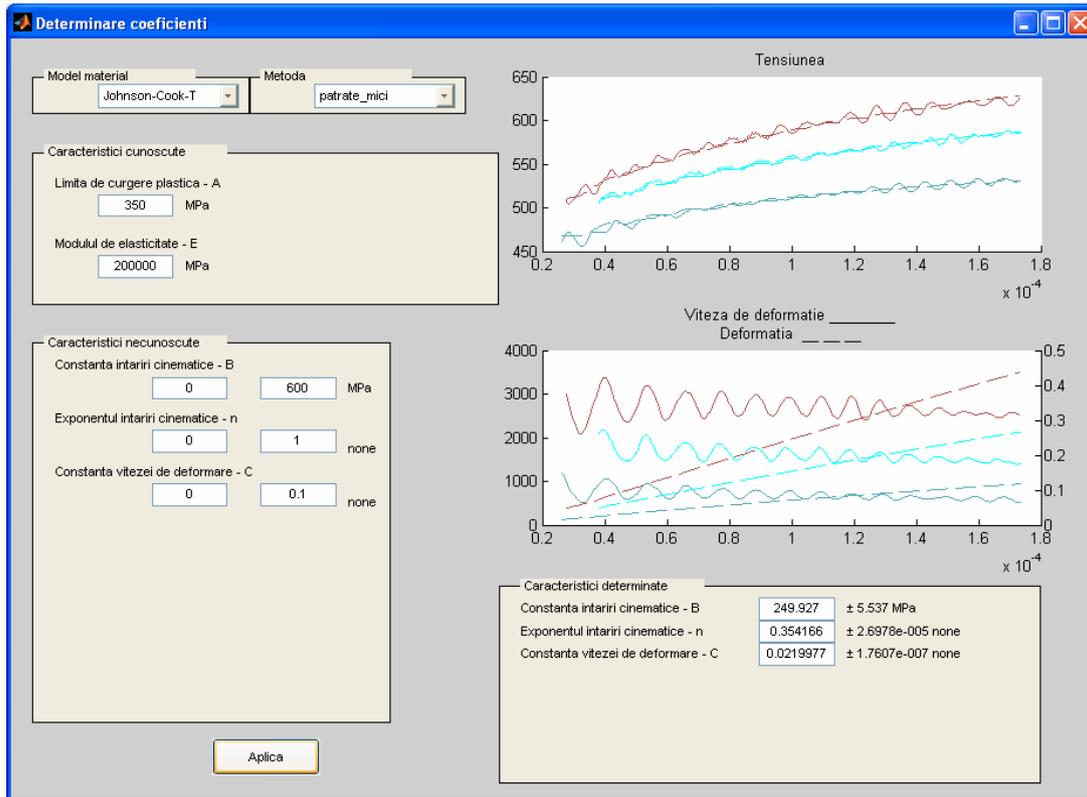
Figure. 4 Material model parameters identification window

4. APPLICATION VALIDATION ALGORITHM

In order to obtain confidence in software application use, a validation algorithm was developed. In a series of three SHPB test simulation, run under LS-DYNA, was input as specimen material a JC-S model representing 1006 steel properties [4]. The simulations results were input in present application as application specific ASCII files. The parameters fitted represent output model. These two models, input and output models, were compared in Table 1. The differences found are very small except B coefficient were the difference is around 9%, tolerance accepted in high strain rates loads area.

Table 1. Input and output 1006 steel Simplified Johnson-Cook models

Model parameters	Known parameters	Fitted parameters		
	A [MPa]	B [MPa]	n [none]	C [none]
Input model	350	275	0.36	0.022
Output model	350	249.9	0.354	0.0219

5. REFERENCES

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