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Experimental characterization of small thickness elastomeric layers submitted to impact loading

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ABSTRACT

An experimental device has been developed to submit small thickness ($<6\text{ mm}$) elastomeric layer specimens to reproducible impact conditions at high initial impact velocities ($1.9\text{--}3.8\text{ m s}^{-1}$). An impulse force test hammer is used as an impactor to measure directly the dynamic force applied on the specimen. As an alternative to classical methods in which position is measured by time integration(s) of accelerometers or velocity sensors, the measurement of the hammer position during impact is achieved by recording its motion with a high-speed camera (at a rate of 30,000 frames per second) and by detecting its position by further analysis on the individual images. Additionally, the initial impact velocity is determined from measurements of the hammer position on the images before contact. The impact model proposed only requires five parameters: two parameters for the impactor (its mass and initial impact velocity) and three parameters for the Hunt–Crossley contact force law describing the specimen. Using a relation issued from the force versus penetration depth diagrams, the estimation of these three contact force parameters can be reduced to the estimation of two independent parameters which roles are well defined and distinct; therefore this estimation can be accomplished with a straightforward trial and error procedure. The method is used to characterize eight impacted elastomeric specimens and is validated with comparisons between experimental and simulation results. These comparisons show that the model is appropriate to simulate with reasonable precision the main experimental characteristics of force and penetration depth signals.

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1. Introduction

One way to reduce the sound generated during an impact between two colliding bodies is to reduce the impact force magnitude by adding a soft material layer in the contact zone between the two bodies. Elastomeric materials such as rubber are often used for this interfacing layer. Because of design constraints such as minimal mass and space, the use of a small thickness elastomeric layer is often required in mechanical systems that generate impacts, such as snowmobile tracks, conveyor belts and plastic granulators. Finding the optimal specimen, in terms of material and thickness, has been the motivation to undertake this research on the characterization of impact force for elastomeric layer specimens of small thicknesses.

Among experimental methods for testing rubbers, static indentation is the simplest method to characterize the ability of a material to resist the penetration of an indenter under a specified loading and is notably used to measure the hardness

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of elastomeric layer specimens (see ISO 48 [1] and ISO 7619 [2]). However, specimens of thickness superior to 6 mm are required and the load applied is low, resulting in small penetration depths into the specimen compared to its thickness. Furthermore, static methods do not take into account the lossy behavior of elastomeric materials, hence dynamic methods have to be used. Vriend and Kren [3] notably proposed a “dynamic indentation method” in order to investigate the viscoelastic properties of elastomeric materials under impact. The experimental method they use consists in an impact device with an indenter attached to a rotating lever. The only variable measured during the impact is the velocity of the indenter, by mean of a stationary inductive coil placed on the specimen and of a permanent magnet mounted on top of the indenter. The contact force and the indenter displacement are determined, respectively, by numerical differentiation and numerical integration of the velocity signal. In this approach, only one material thickness of 6 mm is considered and only one impact velocity ($< 1.2 \text{ m s}^{-1}$) is tested, leading to small penetration depths compared to the specimen thickness. Another limitation is the use of the linear model of Kelvin–Voigt to describe the behavior of the material because it leads to an unrealistic jump of the force signal values at the beginning of contact, whereas the experimental force time signals are characterized by a continuous increase from zero.

In order to propose a more realistic impact model able to simulate the observed characteristics of our impacted rubber specimens, studies of impact forces achieved in other fields of interest were examined. Based on small elastic strains of two colliding bodies considered as elastic half spaces, Hertz’s nonlinear law of contact $F(t) = Ku(t)^{3/2}$ (see [4] for instance), where $u(t)$ represents the relative approach of the impactor and the impacted structure, is certainly the most widely used because K can be easily computed for simple geometries (in particular for sphere–sphere interaction or sphere–plate interaction) in function of the curvature radius and elastic constants (Young modulus and Poisson’s coefficient) of both bodies. In several studies, Hertz’s contact force is approximated by trigonometric functions in order to simplify the calculations. However, Akay and Latcha showed in [5] that the half-period sinus wave approximation induces unrealistic discontinuities in the acceleration response of the plate during contact whereas the squared half-period sinus wave, by inducing smooth beginning and end of the acceleration response, gives a better approximation of experimental results. A model without this contact force approximation and with the inclusion of a plastic strain phase is presented in [6] to simulate the inelastic impact of a steel sphere on an aluminum plate, but energy losses are still neglected. Many studies of impact force have been found in musical acoustics to simulate percussive instrument sounds because the characteristics of the force (in particular its duration) determine the spectrum of the tone. For simulation of piano sounds, the interaction force between a piano hammer (made of wood and covered with felt) and a piano string has been widely treated in the literature. In order to find the dependencies between the force and the felt compression, several experimental studies used a setup where the piano hammer impacts a force sensor fixed to a rigid surface (see for instance [7,8]). If authors like Chaigne and Askenfelt in [9] started with nonlinear elastic models for their simplicity of use, these models had to be improved to take into account the more complicated experimental characteristics of the felt such as hysteresis and viscoelasticity. One of the latest models (used notably by Bensa, Gipouloux and Kronland-Martinet in [10]) which successfully describes the energy losses and reproduces well the experimental characteristics of the felt is the nonlinear viscoelastic contact force law originally formulated by Hunt and Crossley [11]. Consequently this model used for felt is chosen to test if it can simulate the observed behavior of the elastomeric layer specimens as their dependencies between force and displacements have similar characteristics, the only difference being that the magnitudes of force and penetration depth signals are much larger for the elastomeric specimens than the magnitudes of force and compression signals for the piano hammer felt.

The method used in this paper to characterize the behavior of elastomeric layer specimens under impact includes two steps. The first step, presented in Section 2, is the experimental measurements of the force and the penetration depth into the elastomeric layer specimens under reproducible impact conditions. Details are given on the method developed to measure the penetration depth of the impactor into the specimen from image files of the impactor motion recorded by a high-speed camera; typical experimental curves are also shown to point out their main characteristics. The second step, presented in Section 3, is the use of an appropriate impact model and the extraction of its parameters from the experimental data. Finally, in Section 4, the unique set of contact force parameters for the eight specimens are presented and comparisons between experimental and simulated signals for specimen #1 are shown.

2. Experimental method

2.1. Experimental setup

In order to compare the behavior of different elastomeric layer specimens under various impact conditions, the experimental setup should provide a mean to submit the specimens to reproducible impact conditions (mass m and initial velocity V_0 of the impactor) and a mean to measure during the impact both the impact force and the penetration depth of the impactor into the specimen.

2.1.1. Impact device, force measurement and specimens

The experimental device, presented in Fig. 1, consists in an impact hammer mounted in a rotating lightweight plastic arm to guide its fall towards an elastomeric layer specimen fixed on the vertical face of a massive steel block. A crosshair is

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