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Validation of a Non-conservative Mechanical Model Applied to the Low Energy Impact Phenomenon

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Abstract

The impact of materials is undoubtedly the object of research, due to the dynamic condition inherent in the bodies that interact in our universe. This work places special emphasis on the method of plate bending, which, due to its geometric configuration, interprets real impact situations to which some bodies are subjected, in addition to the low energy technique in which the energy available in the impactor is less than that absorbed in the breaking process, makes it possible to obtain information on the material in the elastic, plastic, initiation and crack propagation range. For research, the contribution of technological progress in instrumented test equipment by electronics is important, as it allows us to record much more information on the evolution of the contact between the impactor and the sample step by step. This information must be further processed and this phase of the research requires programming, modelling and simulation of the test dynamics to interpret or even predict the different phenomena that converge in the fraction of time in which the impact occurs. In this sense, our objective has been to study the physical behavior of different thermoplastic materials and their response to impact requests and to develop a series of models that try to simulate the phenomenon, in order to help us establish what happens at each stage of it, this is achieved using powerful mathematical tools, new contributions from the scientific community and continuous experimentation achieved in the laboratory. So that more knowledge can be obtained in this field.

Keywords: Impact, Charpy, Plastics, Non conservative models

1. Introduction

The evolution of the knowledge of physical phenomena has found in modelling a strong tool to interpret their real behavior [1], in this sense, the present work intends to apply this tool to the low energy impact phenomenon, using non-conservative models. The use of non-conservative models is based on the fact that there are considerable energy losses, which explain why conservative models, although they give an idea of the phenomenon, are not the best results [2]. Fracture processes in plastic materials are influenced by their properties. Polymers do not have the structural regularity of other materials such as ceramics and metals, although some polymers have a certain crystalline structure, the presence of macromolecules makes their accommodation and cohesion strength different from that of other materials, thus influencing their mechanical properties [3]. That is to say, an essential characteristic of polymers is that they are formed by long chains of macromolecules that in turn entangle each other, and it can be observed that their structure, apparently a solid, is in fact more similar to that of liquids. This is why it is considered to be a new state of matter between solids and liquids, called the visco-elastic state. Because it is a very elastic solid or a very viscous liquid [4]. Due to the viscoelastic state of the polymers, the deformation mechanisms depend on time, this exclusive property of the polymers is of special relevance for their study and application, since in the search for relating the structure of the materials with their mechanical behaviour, reliable methods must be established to characterize the response of the materials in low, medium and high speed conditions [5]. Within these ranges, materials subjected to impact play an important role and require further research, along with the use of additional techniques and equipment to complement and improve existing impact tests. The impact techniques used to evaluate the impact behaviour of plastic materials have evolved ostensibly from sophisticated equipment and from classical techniques to the development of the theory of fracture mechanics [6]. References of work based on these advances can be found in studies carried out on impact techniques, fracture mechanics, and characterization in quasi-static or high-speed conditions of stressing polymer materials (natural or modified). In the investigations of Sánchez-M [7], Jiménez-O [8] or Gámez-J [9].

2. Methodology

In this model, the collision of the impactor-probe system at low energy is represented by the arrangement of figure 1, the model considers the mass of the specimen (mp).

Where:

m, mass of the impactor.
mp, mass of the test tube.
K, the constant of the springs.
C, damping coefficient.
Subscript *i* is used for indentation and *f* for bending.
The *Ki* spring is non-linear (Hertzian).

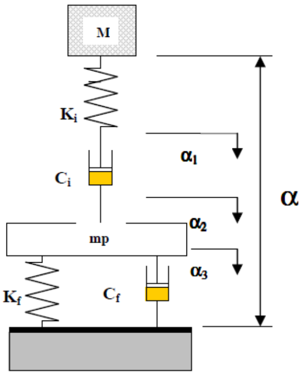

Figure 1. Non-conservative parallel series bending/indentation model with effective specimen mass.

The equations governing the system in Figure 2 are:

$$F_m = m * \ddot{\alpha} + m * g \tag{1}$$

$$F_{Ci} = C_i * \alpha_{Ci} \tag{2}$$

$$F_{Cf} = C_f * \alpha * c_f \tag{3}$$

$$F_{Kf} = K_f * \alpha_{Kf} \tag{4}$$

$$F_{Ki} = K_i * \alpha_{Ki} \tag{5}$$

Expressions (8), (9) and (10) allow you to build the function system required by the Runge-Kutta method. However, the presence of 4 derivatives (3 explicit and a fourth that does not appear) makes it necessary to have a fourth equation, so in addition to the three previous equations, a 4th function was defined to calculate all the variables that appear.

$$\dot{\alpha} = \frac{\partial \alpha}{\partial t} \tag{6}$$

In this way, the set of functions is defined as:

$$f_1 = \frac{K_i}{C_i} * (\alpha - \alpha_2 - \alpha_3)^{3/2} \tag{7}$$

$$f_2 = -\left(\frac{K_i}{m}(\alpha - \alpha_2 - \alpha_3)^{\frac{3}{2}}\right) - g \tag{8}$$

$$f_3 = -\left(\frac{K_I}{mp} * (\alpha - \alpha_2 - \alpha_3)^{\frac{3}{2}}\right) - \frac{K_F}{mp} * \alpha_3 - \frac{C_F}{mp} * \alpha_3 - g \tag{9}$$

$$f_4 = \alpha = \frac{\partial \alpha}{\partial t} \tag{10}$$

With this system of equations an algorithm was developed and programmed.

- Speed of impact $(\alpha_{t=0,} = v_0)$
- Non-elastic strain rate (shock-absorbing element); $\left(\alpha_{2,t=0} = 0\right)$
- The acceleration of the mass element $(\ddot{\alpha} = 0)$
- The acceleration of the mass element $(\ddot{\alpha}_3 = 0)$

The parameters of the model are the mass of the impactor (*m*), the mass of the test piece (*mp*) and the constants *K* (related to the elastic part) and *C* (related to the loss of energy and therefore to the coefficient of restitution). These two parameters can be manually varied to fit the model to the experimental values.

3. Results and discussion

Next, the answers of the developed models are studied, so that by varying different parameters, the response of the model is interpreted and if they match what has been observed experimentally, however, due to the fact that previously it has been observed that both the parallel series model without and with mass give similar answers, only the model with mass is analyzed. Figure 2 shows the graphic of a numerical function that is generated when the program is executed. The curve is a quasi-sinusoidal attenuated curve. There is a certain asymmetry caused by the two damping elements.

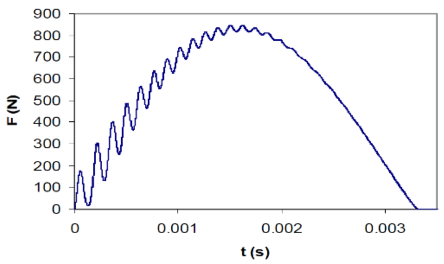

Figure 2. Numerical solution for the model of flexion-indentation series-parallel with mass.

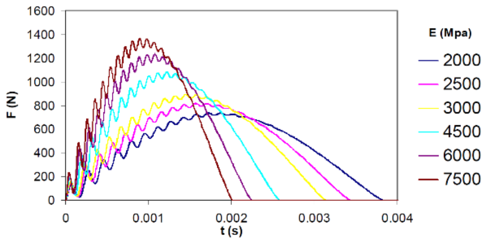

Figure 3. Variation of the behavior of the force with different moduli of elasticity, model of flexion-indentation series-parallel with mass.

As for the change in behaviour when the modulus of elasticity is varied, there is no change in the symmetry of the functions generated, and the relationship between maximum force and contact time is observed, as shown in figure 3. The calculated displacements of the experimental curve and those calculated from the model are also practically the same, as shown in figure 4. In addition, there are three curves obtained by the model that interprets the indentation in its plastic and elastic phase, and the bending experienced by the sample on impact, this information allows us to guess what is happening in the material, and makes it possible to discriminate the dynamic phenomena due to the impact of the energy absorbed and recovered by the material, even making it possible to differentiate the behavior of two materials that can consume the same energy in a phenomenon of this type.

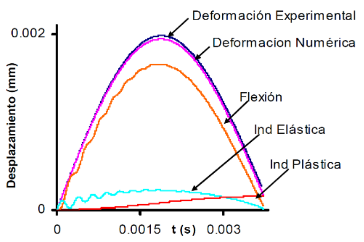

Figure 4. Experimental and numerical displacement series-indentation model series-parallel with mass.

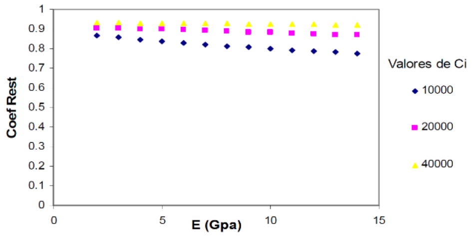

Figure 5. Variation of the coefficient of restitution as a function of the modulus of elasticity and Ci, model flexion-indentation series-parallel with mass.

The behavior of the model reflects very well what has been observed experimentally in various experiences, and which relate the increases in the modulus of elasticity with increases in maximum force and decreases in contact time. On the other hand, the energy loss in the model increases with increasing modulus of elasticity, which is reflected in a decrease in the restitution coefficient values. This decrease is more noticeable the lower the value of Ci, as shown in Figure 5. This shows a strong influence of the indentation component within the behavior of the model, especially in the initial time environment.

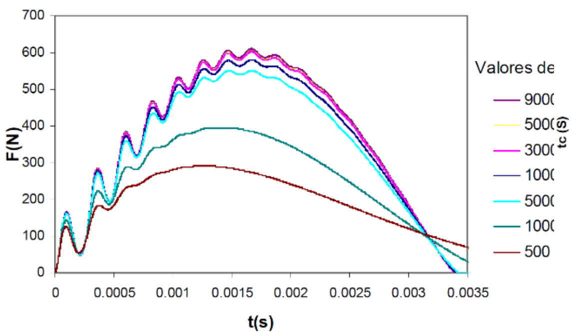

Figure 6. Variation of the behavior of the force with different values of Ci, model of flexion-indentation series-parallel with mass
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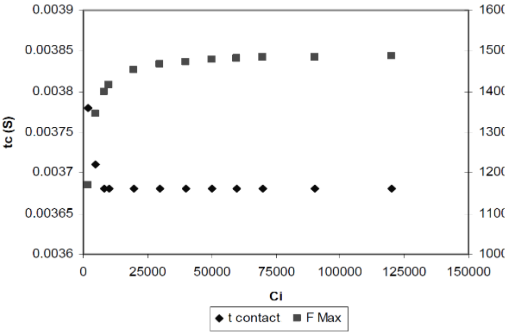

Figure 7. Variation of maximum force and contact time as a function of Ci, model flexion indentation series-parallel with mass.

Analyzing the model from the influence of Ci on its behavior confirms the previous paragraph, since as shown in figure 6, a lower value in Ci will move the curves away from the sinusoidal shape. This would physically represent an increase in the deformation caused by the indentation phenomenon, so that this will be the dominant mechanism in the early stages of the process. However, at high Ci values, the differences between the curves are not as evident, so you would not expect major changes in energy loss. These last affirmations are reflected in figures 6 and 7, where the variations of the behavior of the model according to the values of Ci are shown, in the first figure it can be appreciated that both the maximum force and the contact time will have a smaller variation the greater the values of the referred constant. With regard to the restitution coefficients calculated by the model, as shown in figure 8, they decrease when the Ci value decreases, which is consistent with what physically occurs in materials. In this case three series were calculated, each with a different modulus of elasticity. It is possible to observe that the variations of the restitution coefficient are more marked the smaller the value of Ci and the greater the value of E, although in the extreme of high values, the values of the series converge towards a very similar value, reason why from this analysis it can be said that to high values of Ci it will be had a smaller influence of the phenomenon of indentation, predominating the effects due to the flexion, having in the extreme the case of pure flexion.

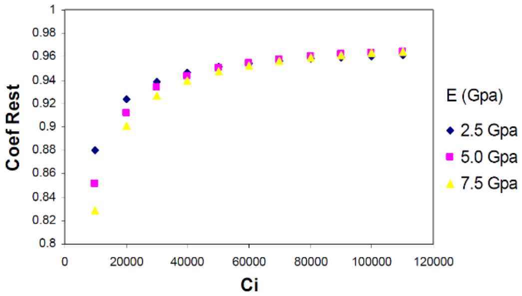

Figure 8. Variation of the coefficient of restitution as a function of Ci for different values of the modulus of elasticity, model flexion-indentation series-parallel with mass.

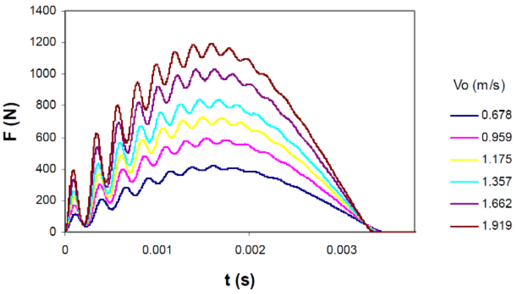

Figure 9. Variation of the behavior of the force with different values of Vo, model of flexion-indentation series-parallel with mass.

Increasing the impact velocity causes a variation in the amplitude of the curve, varying the period of the function, this can be clearly seen in figure 9, where an increase in the maximum force and a decrease in the contact time can be seen, which is recorded in figure 10.

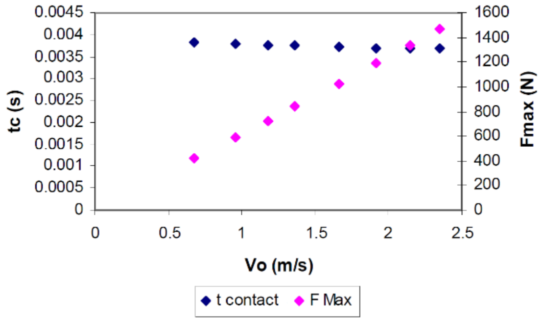

Figure 10. Variation of force and contact time as a function of Vo, series-parallel indentation bending model with mass.

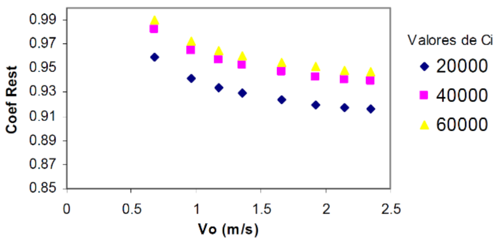

Figure 11. Variation of the coefficient of restitution as a function of the initial velocity for different values of Ci, model of flexion-indentation series-parallel with mass.

The latter figure shows an almost linear trend between impact velocity and maximum force. However, in terms of contact time, the greatest differences occur at low speeds, with a negative slope. On the other hand, the values of the coefficient of restitution vary negatively with increasing impact velocity, as shown in figure 11, this variation will be more noticeable the lower the value of Ci, and therefore the greater the influence of the term indentation, as observed in figure 8. However, if we analyze the effects of the impactor mass value in this model, we can see in figure 12 that the effects will increase due to the indentation of the material according to the model. This explains why in figure 13, it is observed that both the contact time and the maximum force increase, although not in a linear way, with a smaller increase the greater the values of m.

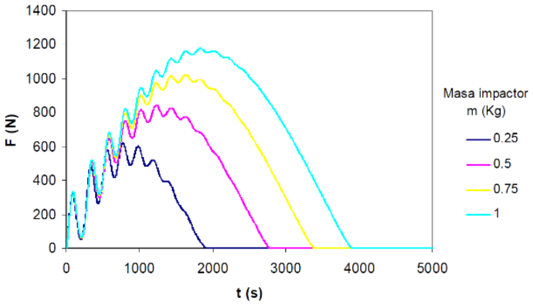

Figure 12. Variation of the behavior of the force with different values of the mass of the impactor, model flexion-indentation series-parallel with mass.

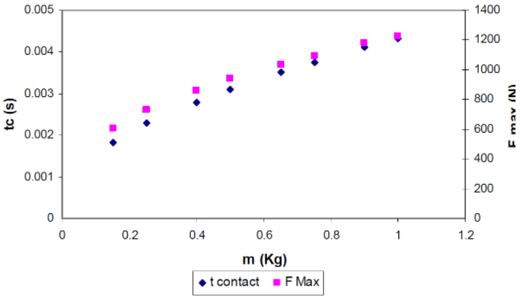

Figure 13. Variation of maximum force and contact time as a function of the mass of the impactor.

An increased presence of the indentation component will influence the values of the coefficient of restitution. Thus, as more energy is used in the latter mechanism, the non-elastic part of it will reduce the values of the coefficients, the greater availability of energy at the same speed will make the deformation speeds of the shock-absorbing elements of both the bending and the indentation part greater, and therefore the amount of energy absorbed will be greater.

4. Conclusions

An increased presence of the indentation component will influence the values of the coefficient of restitution. Thus, as more energy is used in the latter mechanism, the non-elastic part of it will reduce the values of the coefficients, the greater availability of energy at the same speed will make the deformation speeds of the shock-absorbing elements of both the bending and the indentation part greater, and therefore the amount of energy absorbed will be greater.

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