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Influence of Sample Thickness and Indenter Mass on Dynamic Indentation Tests of PEGT and PA6 Thermoplastics

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Abstract

In this article the results of the impact characterization of PETG and PA6 thermoplastics are presented, they have been characterized statically and dynamically by the indentation test, and mathematical models developed in previous works have also been used to adjust the obtained models. The thickness of the specimen used and the mass of the impactor used were studied. The results have shown that the specimen thickness influences the value of some of the measured properties as the thickness increases, as well as that the impactor mass influences the velocity that is printed during the test run.

Keywords: Impact resistance, Indentation test, PETG, PA6

1 Introduction

The beginning of the study of the impact resistance properties of plastic materials has been based on the experience gained on metals [1]. Over time, the techniques have become more and more different. In addition, with the increasing importance of plastic materials, more advanced techniques have been developed. If you think about how many ways a crash can occur, it is not easy to reproduce them [2]. For example, a helmet can fall to the ground, hit a wall or receive a projectile at high speed, so to conclude that the state of stress varies between different types of impact, the only common thing is that in most cases the force is applied instantly. This makes it more difficult for technicians trying to design products with good impact breaking strength [3]. Indentation testing generally provides a non-destructive method for evaluating or calculating different material properties [4-6]. These tests can be subdivided into static and dynamic indentation, depending on the deformation rate applied during contact [7]. Static indentation is a powerful tool for determining material properties such as hardness under very low strain rate conditions.

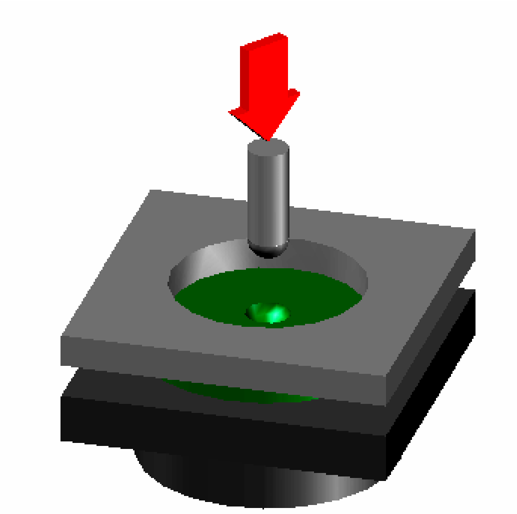


Figure 1. Indentation test.

Dynamic indentation, on the other hand, allows properties such as elastic modulus to be calculated and different degrees of stress to be applied depending on the impact velocity [8]. The study in this section on dynamic indentation comes from the classic problem of understanding and quantifying energy loss during a collision [9]. Specifically, the objective is to develop dynamic indentation tests and model the behavior of polymer materials using mathematical tools. Also, establish the factors that influence the response of the material. In this sense, a series of tests have been carried out in which the initial impact velocity (V0) has been varied through the drop height of the impactor dart (h). Although the dynamic indentation tests were carried out on all materials. The following must be specified.

- The Serial Indentation model, described in [10], has been selected for application to these materials because, according to literature and experience, it better interprets the behavior of the material in this kind of solicitation. The fit of the curves is very approximate unlike conservative models or other configurations.

- ➢ An exhaustive indentation characterization has been carried out on the PETG, varying the test conditions, so that the parameters that influence or do not influence the test and its results are known.
- ➢ Finally, the results of all the materials obtained from the dynamic indentation tests are presented.

In the following figure 2, the force-time curves obtained from dynamic indentation tests applied to PETG and PA6 and the respective adjustment of the force-time curves carried out with the indentation model in series at different heights of dart drop [10] are shown for illustration. The tests were conducted at room temperature.

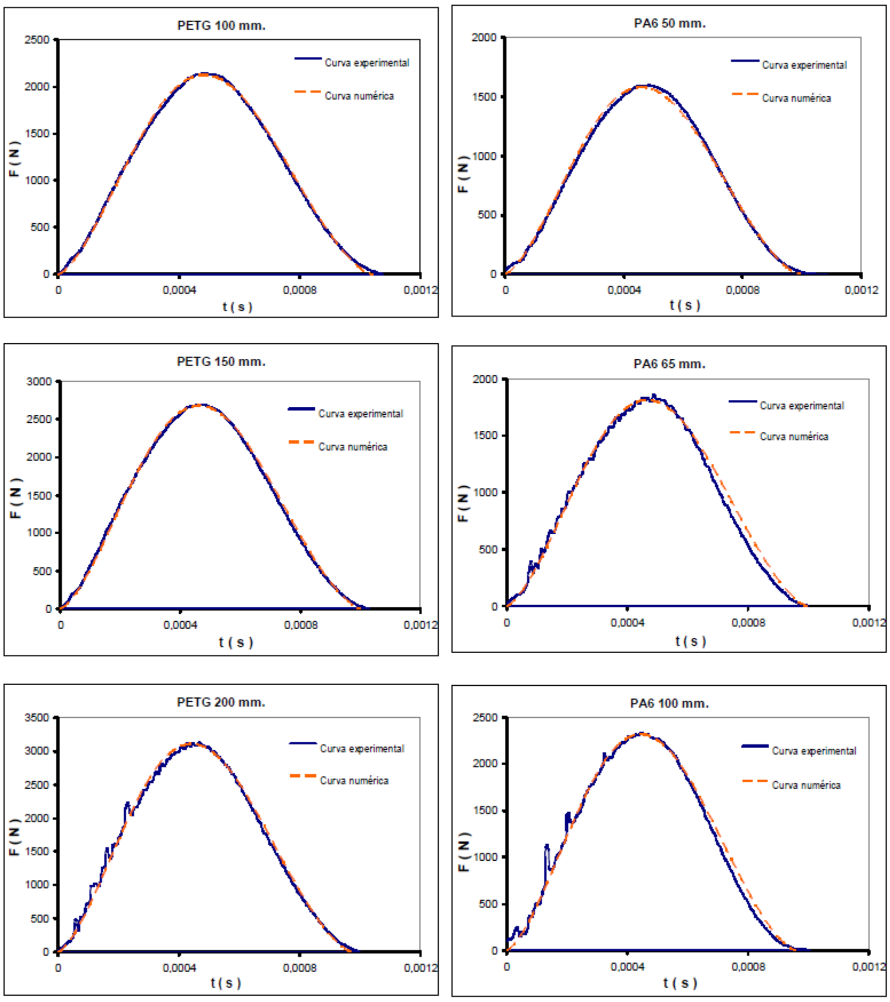


Figure 2. Adjustment of force-time curves of indentation tests applied to PETG and PA6 specimens at different dart drop heights with the series model.

As can be seen in the previous figure, the adjustment made by the series model is very close to the experimental curve, this is achieved by adjusting the contact time and the maximum force value through the parameters of the aforementioned model. From now on, the factors influencing the results of the trial will be studied.

2 Methodology

The first factor to take into account is the thickness of the sample to be tested, since the serial model is based on Hertz's theory of contact [11], which assumes that the material tested occupies a semi-infinite space. Therefore, thickness is a critical variable, and in the event that the minimum thickness condition is not met, the stress distribution generated inside the material may interfere with the steel plate supporting the sample. For this purpose, five series of tests have been carried out with specimens of 5 different PETG thicknesses, under the test conditions shown in Table 1.

Table 1 Indentation test conditions at PETG, varying specimen thickness.

test	Indenter mass (Kg)	Indenter diameter (mm)	Thickness test piece (mm)	Interval V_0 (m/s)
1	0.743	12.7	10	[0.606-1.632]
2	0.743	12.7	8	[0.606-1.632]
3	0.743	12.7	5	[0.606-1.632]
4	0.743	12.7	3	[0.606-1.632]
5	0.743	12.7	1.5	[0.606-1.632]

In order to evaluate the influence of the indenter mass on the development of the assay, a series of tests were conducted to distinguish whether the indenter mass was a system parameter that could alter the results. The test conditions are shown in Table 2.

Table 2. Indentation test conditions at PETG varying indenter mass.

test	Indenter mass (Kg)	Indenter diameter (mm)	Thickness test piece (mm)	Interval V_0 (m/s)
1	0.503	12.7	10	[0.606-1.632]
2	0.743	12.7	10	[0.606-1.632]
3	1.043	12.7	10	[0.606-1.29]
4	1.343	12.7	10	[0.525-1.17]

3. Results and discussion

Once the series of tests had been carried out, the information on the force-time and deformation-time curves of the impact equipment was recorded. The experimental curves were then adjusted with the serial model to determine: the value of the modulus of elasticity, the value of Ci (constant of the shock absorber) and the coefficient of restitution in each test. Figure 3 shows the graph of the elastic modulus as a function of the initial impact velocity for each thickness according to the conditions indicated in Table 1. The figure shows that the modules for thicknesses of 8 and 10 mm are constant with the evolution of the velocity, while, in thicknesses of 5, 3 and 1.5 mm, the distribution of stresses generated during the impact interferes with the steel plate located under the specimen, significantly altering the results.

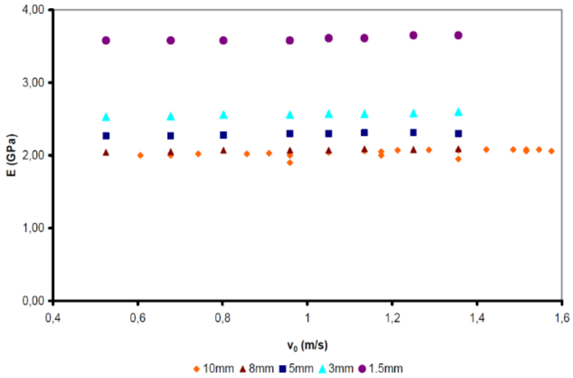


Figure 3. Influence of specimen thickness on the elastic modulus.

Another element of analysis is the evolution of the indentation constant Ci which, as explained above, is associated with the shock absorber and is a clear indicator of the degree of energy loss in the impact. If the value of Ci is higher, the shock absorber is therefore more rigid and therefore less energy loss, i.e. the higher the value of Ci, the higher the spring of the series model tends to act alone, on the contrary, the lower its value the shock absorbs or dissipates more energy and therefore more energy loss in the impact. This in turn is directly linked to the value of the coefficient of restitution ε, since a decrease of ε or Ci means an increase in energy dissipated during the impact. This increase in energy dissipated during indentation is justified because in thicknesses less than 8 mm, the specimen is not a semi-infinite and limited space. When considering this, it can be established that the energy is not lost by excessive deformation of the indented specimen, nor by friction of the indenter with the specimen, but is lost when the indenter interferes with the steel plate. Figures 4 and 5 show the evolution of the two coefficients ε and Ci as a function of the initial impact velocity.

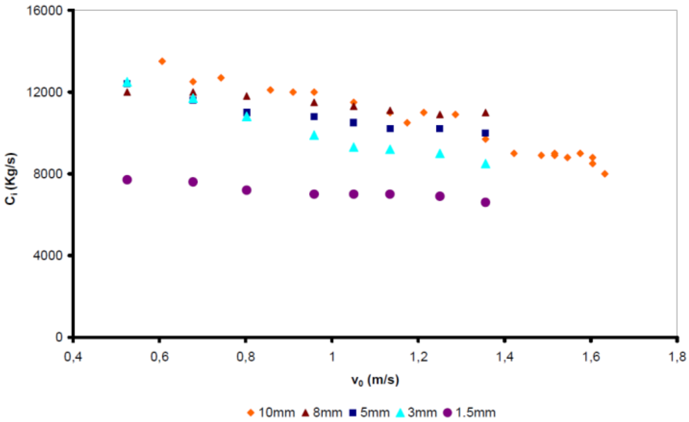


Figure 4. Influence of specimen thickness on the indentation constant Ci

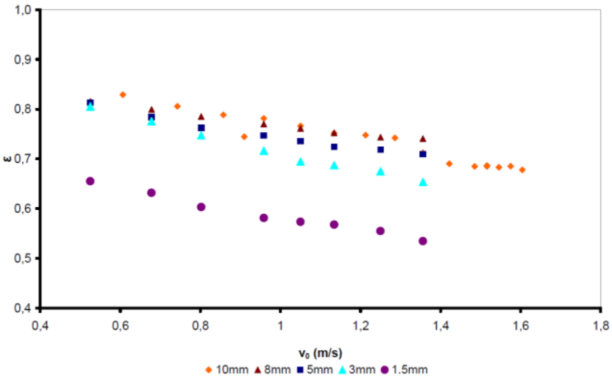


Figure 5. Influence of specimen thickness on the restitution coefficient ε.

The indentation stress distribution proposed by Hardy [13], Figure 5, showing the stress distribution areas during impact and their associated plastic deformation field. The stress and deformation approach proposed by Hardy is very illustrative and clearly explains the fact that samples with thinner thicknesses such as 5, 3 and 1.5 mm specimens have a higher modulus. In our particular case, the thin plates do not allow the material to distribute the deformations correctly due to the volume of the specimen, therefore, the material is no longer continuous (interference from the steel support) and the mechanical properties of the material recorded in the test are modified.

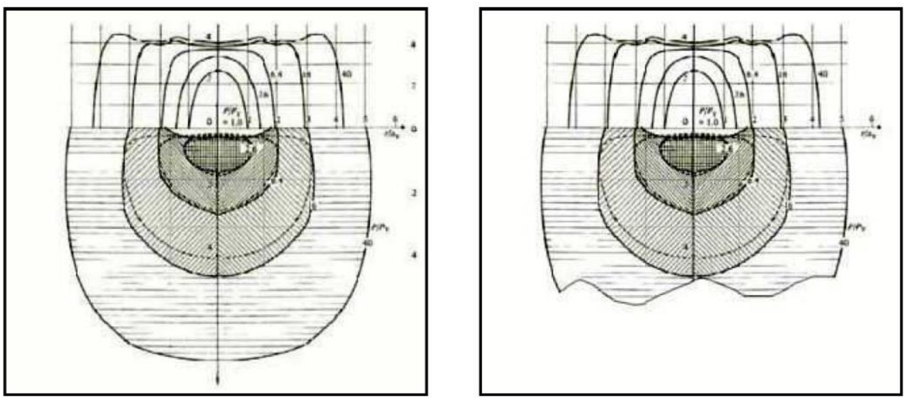


Figure 6. Stress distribution in indentation (Hardy) a) Indentation of an elasto-plastic material, plastic zones. b) Indentation of an elasto-plastic material with insufficient thickness.

Figure 6a represents the distribution of stresses in the thicknesses of 8 and 10 mm, while Figure 6b shows a cutting area, which represents an area of uncertainty. This area in our case belongs to another material with different mechanical properties, which causes the alteration of the results obtained. The above allows us to select the minimum thicknesses for the dynamic indentation tests and to avoid the influence of the steel plate on the distribution of stresses in the sample, as well as the influence on the final results obtained in the test. Figure 7 shows that the value of the elastic module remains constant in all four series. This indicates that the use of different indentation masses does not influence the model's fit. The same is not true for parameter Ci, which registers the influence of the indenter mass.

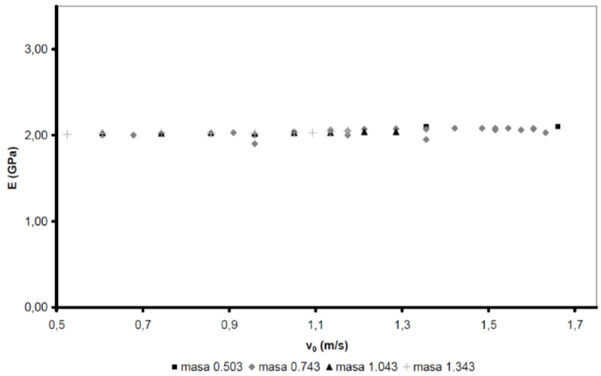
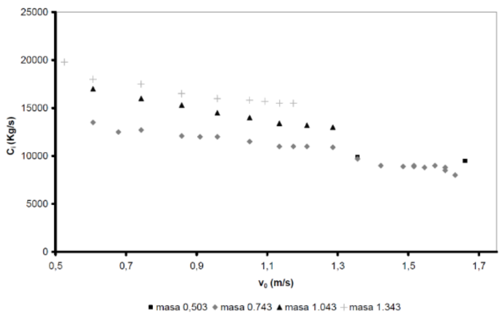


Figure 7. Influence of the indenter mass on the elastic modulus.

As can be seen in Figure 8, the values of Ci vary considerably when changing the indenter mass. Taking into account that Ci represents the energy losses during the impact it must be assumed that the material, when increasing the mass, increases its deformation in the plastic zone. This is consistent with the visco-elastic nature of polymers, which increase energy dissipation as the mechanical stress increases.



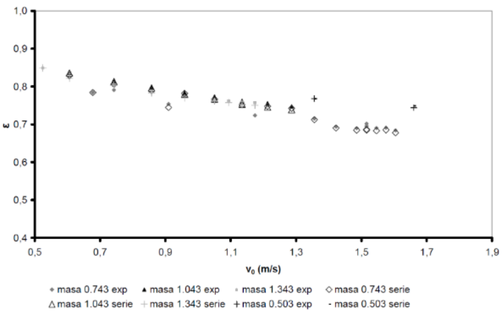


Figure 8. Influence of indenter mass on the indentation constant Ci.

Figure 9. Influence of indenter mass on the coefficient of restitution ε

The coefficient of restitution varies according to the mass of the indenter (see Figure 9). These differences, or variations between the test series, are due to their direct relationship with the energy loss and energy relative to mass described above.

4. Conclusions

The thickness of the sample was not a factor that influenced the modulus of elasticity of the material, in terms of the coefficient of indentation Ci and the coefficient of restitution ε, it was found that its value decreases with the increase in the thickness of the sample. As for the influence of indenter mass, it was found that the values of restitution coefficient and indentation coefficient show variations with changes in mass values. The restitution coefficient is not an intrinsic property of the material, as it was observed that it varies significantly with the initial impact velocity as well as with the load conditions applied. Analysis of low energy impact tests on polymeric materials should be carried out using non-conservative models given the obvious loss of energy in non-elastic deformations.

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