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Mechanical Characterization of Impact Resistance by Pendulum Tensile Test on PETG and PA6 Thermoplastics

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Abstract

This article presents the results of the mechanical characterization of the impact resistance of PETG and PA6 thermoplastic polymers. This type of polymer is being widely used in industrial applications and the characterization of its mechanical properties is a subject of great academic and industrial interest. The impact pendulum technique has been used as the most widely known. The tests have been carried out under different conditions and varying the greatest number of parameters in order to obtain data that allow a rigorous characterization of these materials.

Keywords: Impact resistance, pendulum test, PETG, PA6

1 Introduction

The impact test is the most critical environment in which toughness can be determined, many polymers in service suffer impact situations (shocks, drops, accidental blows) and it is of great academic and industrial interest to predict the impact response for correct selection and design [1]. This type of quality control testing is generally preferred by industry to characterize the toughness of thermoplastic polymers [2]. Measures the ability of a sample or end piece to withstand sudden loads, is a quick test but the impact resistance is dependent on the method used [3]. Among the main factors affecting the measurement are the shape and geometry of the impactor. Sharp objects tend to concentrate stresses and increase the severity of the impact. The thickness of the molded plastic product. Thin-walled structures are more fragile than heavy cross-sections; they have less volume to absorb and dissipate impact energy. The geometry of the plastic product and the area affected by the impact can interact with other factors that reduce the overall impact resistance. Exposure to the environment, creep, temperature, UV exposure, chemicals, and other factors can weaken impact resistance [4]. The variables of the molding process affect the impact resistance of plastic products by inducing orientation, both in molecular chains and in the type of reinforcement, molten polymer flow, residual stresses, degradation, crystallization, morphology, internal voids, and welding lines [5].

The problems associated with design under impact conditions are complex, with the significant involvement of effects due to speed, load rate on polymer deformation, temperature and stress state as a consequence of the visco-elastic-bissile character of the polymers [6]. The main testing techniques are the Pendulum impact test, Izod impact test, Charpy impact test, Tensile impact test. The main parameters to be monitored include temperature, impact velocity, impactor geometry and test configuration [7]. Measuring impact resistance is an essential part of any material evaluation program. Most test methods are basically simple, but the interpretation of the emerging results is far from simple, especially since impact resistance is not an inherent physical property, but rather a combination of several [8]. Laboratory results often correlate poorly with service performance. In general, the results of the different tests do not correlate with each other; tests with similar stress states show a better correlation [9]. The evaluation of the materials and the selection of the impact performance should be done with a test as similar as possible to the application, both from the tension state and the characteristics that are measured. Traditional tests do not lead to intrinsic measurements [10].

2 Methodology

The shock-traction test consists of applying to a test piece designed for this purpose generally in the form of a halter (under ISO 527-1,527-2) [11], an impulsive tensile stress, i.e. a rather high tensile force over a short period of time. The impact-tension tests are carried out using the RESIL pendulum impact tester from Ceast, Italy. This is normally the same equipment used for the Charpy and Izod assays, differing from these in the type of impactor and the support base of the test piece, designed in such a way that the impactor arms and the base holding the test piece can be interchanged. See Figure 1. This testing technique has been developed to try to eliminate some of the limitations that occur with Izod or Charpy. In particular, some variables such as specimen thickness and notch sensitivity can be eliminated by means of tensile impact. In addition, the shape and thickness of the specimen allows testing with materials, such as films, that could not be tested with Izod and/or Charpy techniques. The specimens for this test were obtained from the square PETG and polyamide plates of 100mm side, machined and shaped into halter-type specimens, then cleaned and the measurements of their dimensions taken to make the test. The equipment records the information and then the curves obtained are processed. Some authors even agree that the results obtained are much more related to breakage conditions in service than in the techniques mentioned above [12]. In our research, it is important to deal with tests of this type in which samples are subjected to a high rate of stress. Since it helps us both to obtain information on the response of the material in this range, as well as to work on the instrumentation of the tests in order to obtain more information. In addition, it allows us to deepen our knowledge of the technique, since the related literature is comparatively inferior to that which is available at low solicitation speeds. Finally, it is important to establish that the application of the impact-traction technique is consistent with the previous low velocity study performed, because it allows the characterization of the materials to continue covering the spectrum at high velocity of solicitation.

Figure 1. Ceast Resil Pendulum Impact Tensile Test Equipment.

3. Results and discussion

From the shock-traction tests, the force-time curves of the materials were obtained. All materials were tested with a pendulum drop angle of 150 degrees, corresponding to an impact velocity of 3.70 m/s. Figure 4.13 shows, as an example, the stress-strain graphs for PETG.

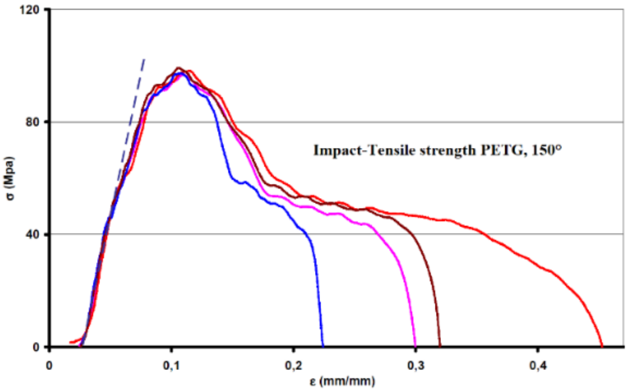

Figure 2. Stress-strain diagram of PETG impact-traction.

The series of tests carried out on all the samples at 150º angle of fall of the pendulum, it was observed that the curves recorded many oscillations, especially the tests carried out on polyamide. These oscillations are mainly due to the dynamic effects that occur at this level of test speed, since the amount of movement (impulse) at the start of the impact, causes the mobile clamp to move out faster than the pendulum. Generating a discontinuous contact between the two elements. These oscillations can at any given time lead to errors in the calculation of the elastic modulus of the material. In order to reduce the occurrence of dynamic effects, two options are proposed.

1. Reduce the impact velocity (decrease the drop of the pendulum) velocities between 0.5 and 1.6 m/s.
2. Cushion the impact by using plasticine strips on the impactor that collides with the moving clamp.

The effect obtained in the curves by applying the reduction in the impact velocity (1.6 m/s) and the damping (plasticine tape) of the contact between the head and the moving clamp, can be seen in the improvement in the appearance of the curve, Figure 3. It is important to establish that the presence of the damper located in the pendulum head does not affect the force values recorded, since the load cell that registers the force is located in the fixed clamp of the instrumented impact device.

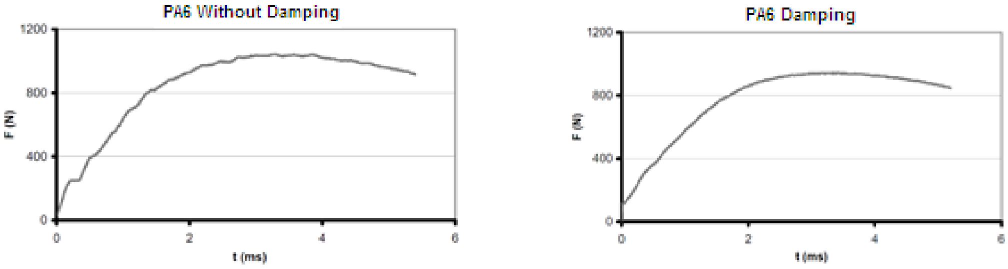

Figure 3. Visualization of the damping effect in a PA6 shock-traction test.

In the experimental development phase of an investigation, the tests are performed through instrumented equipment that has sensors or detectors located in the element that subjects the sample, and it records the response information of the sample. However, in the development of our research it was considered important to analyze, not only the information obtained by the team, but also to provide the test tube with mechanisms that allow us to obtain information about what is happening directly in it. In this regard, a strain gauge system was designed to record information in parallel with the test equipment. That is, it allows information to be recorded directly from the sample (see Figure 4.). However, there are some limitations to the conditioning of the experimental design: A) It was not possible to instrument the test piece in all the tests since only one unit had two channels for signal reception, B) the geometry of the test piece and C) the polymer matrix of the sample, since the formulation of the adhesive of the gauges conditions it. Therefore, two types of test were implemented based on the above limitations. Charpy and Impact-traction.

Figure 4. PA6 specimen reinforced with strain gauge for impact traction.

Once the series of tests with the system described above had been carried out, it was obtained:

- The load applied to the specimen.
- The deformation of the specimen recorded by the equipment.
- The output voltage of the Wheatstone bridge that is directly related to the strain of the specimen recorded by the gauge.

In figure 5 some force-time deformation curves (millivolts) can be seen, obtained from tests applied to the simple and reinforced polyamide 6 longitudinal type at different angles of pendulum drop.

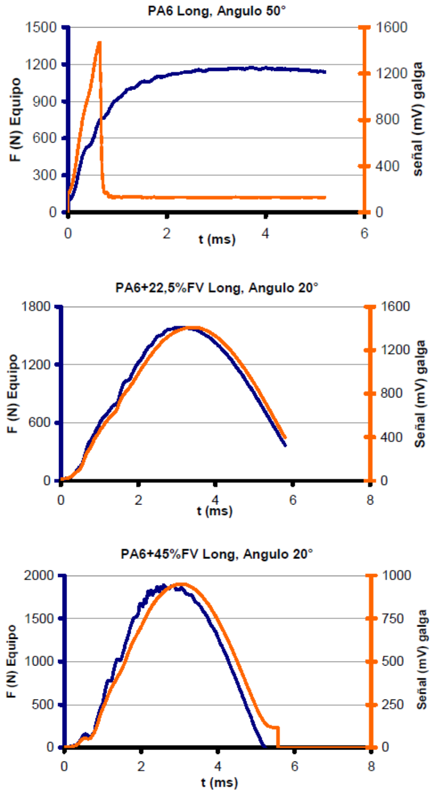

Figure 5 Curves obtained with force-time instrumentation (Blue Curve) and strain-time strain gauge system (Orange Curve) on PA6 longitudinal type specimens

In the previous figure, in the case of the PA6 Long 50º, it can be seen that the signal recorded by the gauge system travels until it reaches a maximum point, at which point it falls catastrophically. This is related to the characteristics of single polyamide 6, which has a higher deformation capacity because it has no load, the strain gauge quickly reaches the manufacturer's design elongation limit of 3% elongation. The stress-strain curves obtained by the impact machine and strain gauge system are shown in Figure 6.

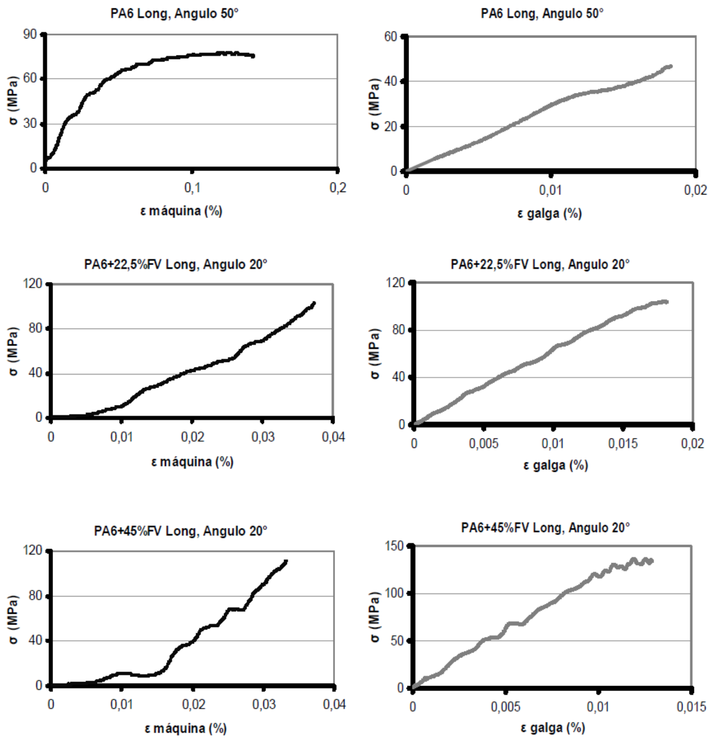

Figure 6. Stress-strain curves given by the machine (left) and strain-strain curves given by the strain gauge system (right)

Once the experimental tests have been carried out and the information processed, we can establish two comparative analyses:

- Relate the modules obtained to low speed traction and those obtained to impact-traction.
- Analyze the information obtained in parallel by the strain gauge system.

It is interesting to establish a comparative analysis between the results obtained by traction at low speed (5mm/min) and those obtained by impact-traction since in the latter its configuration is very similar to that of traction but at higher speeds. In addition, we have information from tests carried out at 100 mm/min on longitudinally reinforced polyamide, which will allow us to observe the evolution of the composite material at a higher speed of loading. Table 1 presents a summary of the modules obtained in the different trials.

Table 1. PETG and PA6 modules with traction at speeds of 5 and 100 mm/min and impact traction.

Material	**Elastic Modulus E (MPa) to 5 mm/min**	**Elastic Modulus E (MPa) to 100 mm/min**	**Elastic Modulus E (MPa) Impact-Tensile**
PETG	2100	2150	2445
PA6 Long	938	1020	1290
PA6+22.5%FG Long	2797	2976	3100
PA6+45%FG Long	4733	5267	5400

Two important considerations arise from the table, in the case of simple materials such as PETG and PA6 Long single unloaded, the module values at 5 and 100 mm/min increase slightly but not as significantly, as when they are requested to impact-tension in which there is a significant jump of the module depending on the rate of stress applied to the sample, which is consistent with the theory of the increasing rate of deformation in a polymer. In the case of composite materials such as polyamide 6 loaded with 22.5 and 45% glass fibre, the tensile modulus values at 100 mm/min and the impact-traction values do not show a significant quantitative jump. This is because there is a high percentage of longitudinally oriented fiber, which restricts the movement of the matrix and therefore reduces the effects of the viscous component of the material. This is why the module does not increase in greater proportion even though the test speed is much higher.

4. Conclusions

If the values of the deformation velocities obtained by the instrumented equipment are compared, at the same pendulum drop height (PA6) between tests with and without damping, a decrease in the deformation velocity is observed in the tests with damping, this is due to the fact that before the specimen begins to deform, the tape placed on the impactor deforms, which produces a small decrease in velocity, however, this decrease is in the order of 3 to 5%. A comparison between the values of the strain rates obtained by the instrumented equipment (column .e machine (-1)) and those obtained by the strain gauge system (column. ε gauge (-1)) shows that the latter is lower in both cases, which affects the slope inclination of the curve values and therefore explains the higher module values. One of the causes that may explain this divergence and that in the future will have to be investigated in order to solve the problem are the following: A) dynamic effects that, even if reduced, can cause the gauges to measure poorly; B) a software problem when using 2 measurement channels (the factor by which it multiplies to convert the electrical signal into deformation); C) poor calibration of the shock-traction equipment. Therefore, despite having been able to detect and process the signal emitted by the probes and obtain information on the evolution of the impact on them, these modules will not be taken into account for subsequent analysis.

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