Characterizing Complex Materials with Impact Testing

Introduction

During the European Congress on Composite Materials (ECCM16) seminar in Seville, Spain, Andrea Calzolari – Instron Italy – presented research that was carried out in cooperation with the University of Turin and the LIMA Corporate Group.

The aim of the research was to prove that from the impact properties point of view, an instrument – as simple as an instrumented Charpy pendulum – is capable of characterizing complex materials. Four different composite materials, based on a PEEK matrix and reinforced with carbon fibers, were studied. The results obtained show how it is possible to discern amongst various composites, that appear to be very similar or the same, the material with the best impact resistance.

To demonstrate this, we used a CEAST AN50 Automatic Notchvis, a CEAST 9050 Motorized Pendulum with an instrumented Charpy impact hammer, and a DAS 64k with VisualIMPACT Software.

Which Specimens were Tested?

The matrix was made of PEEK for all samples; however half were reinforced with Polyacrylonitrile (PAN), and the other half used PITCH carbon fibers. The tested specimens were manufactured by means of injection molding and two different set of specimens, for each of the two reinforcements, were prepared for the analysis:

- one set of specimens were cooled for 40 seconds
- one set of specimens were cooled for 55 seconds

Theoretically, the different cooling times should lead to different impact behaviors. This is due to the fact that the manufacturing process is done at a high temperature and a high pressure and the thermal history can affect final properties of the material. One of these properties is certainly the degree of crystallinity, which has a direct influence on the impact performance of a material.

Each set of specimen (PEEK-PAN 40 seconds, PEEK-PAN 55 seconds, PEEK-PITCH 40 seconds and PEEK-PITCH 55 seconds) were in the shape of a bar with dimensions of 80 x 10 x 3.3 mm.

To complete the specimen preparation process, a notch has been machined onto each of the four samples. This notching procedure was performed with the fully automatic CEAST AN50 system, which allows for better refinement

and control of the notching conditions. Two tungsten carbide knives, with different radii, were used to obtain specimens – one with a 0.25 mm radius and one with a 1.00 mm radius.

Figure 1 shows an example for two specimens obtained with different notches.

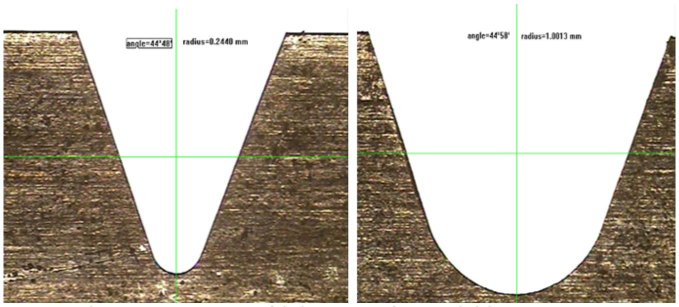

Figure 1. Typical example of 0.25 mm (left) and 1.00 mm (right) radius notch obtained in the CFR-PEEK specimens are shown.

What Set Up was Used?

The notch radius plays an important role on the results acquired; the data shows that the smaller radius causes the material to become more fragile as it fails. This is shown in figure 2.

Figure 2. A comparison of the Force versus Displacement curves obtained for two CFR-PEEK specimens having different notch radius. The Green curve was acquired testing a beam with 0.25 mm radius, while the Red is showing the behavior for the same material notched with a 1 mm radius.

From the previous analysis, we identified that the notch equal to 1 mm was the most useful for the characterization of these materials because it gives a more ductile and reproducible result. For this reason, after the pre-screening of the material properties, we notched all specimens with the 1 mm radius.

The motorized CEAST 9050 was useful in this particular study because it allowed for modification of the starting angle for the test, leading to different impact velocities. In fact, it was immediately clear (Figure 2) that high-speed impacts were dominated by dynamic effects making it impossible to distinguish amongst the different materials. The most common impact velocity range (about 3.8 m/s) is not able to provide the necessary detail to the resolution of the problem. Using a moderately-high range (about 1 m/s), the dynamic effects have been reduced making more evident the mechanical properties of the material. Figure 3 shows an example for the PAN CFR-PEEK composite. The areas behind the two curves, which shows the energy absorbed during impact, are quite similar but the curves obtained at 1 m/s are less affected by the test velocity and boundary conditions.

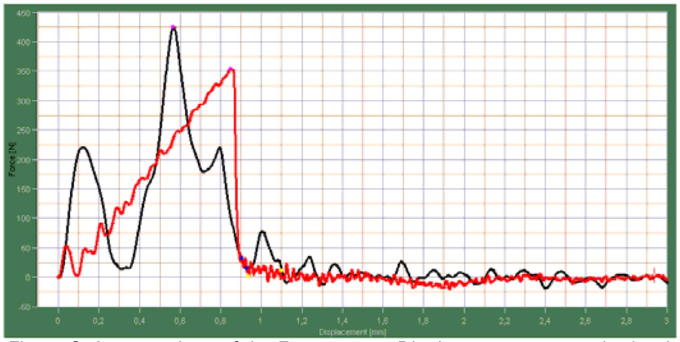

Figure 3. A comparison of the Force versus Displacement curves obtained for two CFR-PEEK specimens having same notch radius (1 mm) but impacted with different velocities. The Black curve was acquired testing at 3.8 m/s, while the Red is showing the behavior for the same material impacted at 1 m/s.

What were the Achieved Results?

Once the proper test conditions were identified, the materials were tested to acquire the impact properties for each of the four groups of specimens. To increase the statistics, we tested each set of specimens twice and screened ten specimens per set.

Figure 4 shows the experimental setup: the CFR-PEEK specimen to be impacted is supported in a three-point bending configuration and the Charpy instrumented hammer is ready to be released.

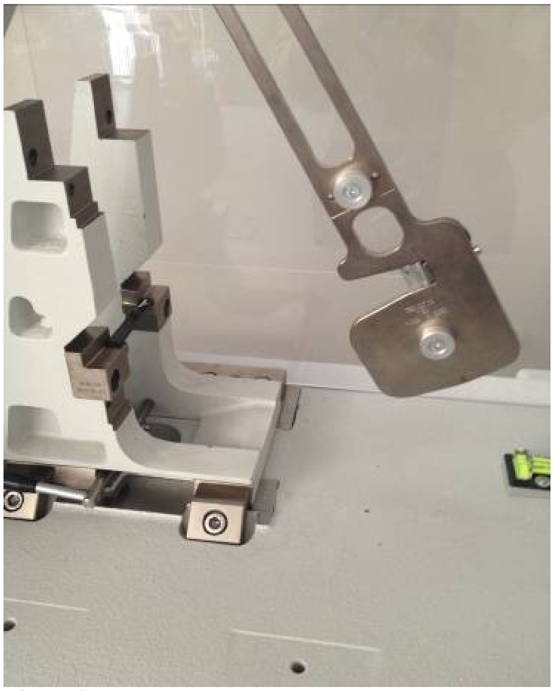

Figure 4. The Charpy impact setup. The instrumented impact hammer at the starting angle, the vice with shoulders and the specimen ready to be impacted are clearly identifiable in this photo of the experimental setup.

The force, as a function of time curves measured for all materials, was very repeatable and essentially linear upon maximum load. Figure 5 shows an example of a Force versus Time curve for each of the four samples.

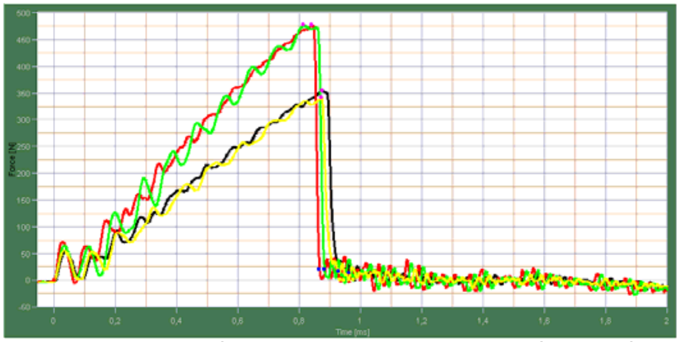

Figure 5. An example of Force versus Time curve acquired for each of the four composite materials:
--- PITCH CFR-PEEK cooled 55 seconds;
--- PAN CFR-PEEK cooled 55 seconds;
--- PITCH CFR-PEEK cooled 40 seconds;
--- PAN CFR-PEEK cooled 40 seconds.

Specimen failure propagates so fast that the total test time is lower than 1 millisecond for all the composites tested. The CEAST Data Acquisition System (DAS) 64k was very helpful since it allowed a sampling rate up to 4 MHz, ensuring enough points for the analysis on each curve.

At the same time, the VisualIMPACT Software allowed us to manage the tests and provided us with the necessary results and calculations to characterize the composite materials. We were able to calculate the displacement, the energy absorbed and the impact strength value from the raw data acquired. In addition, the software also calculated the slope of the curves. The slope of the impact curve, evaluated up to the peak force, represents the stiffness of the composite material. This value can provide an estimation of the elastic modulus of the material, due to the fact that it is directly dependent on the stiffness.

Comparing all the results obtained testing the CFR-PEEK composites we found a slight, but not negligible, increment of all impact properties where the material was cooled for 55 seconds. Furthermore, it was also clearly evident that the PAN-reinforced PEEK composite has better impact properties in comparison to the PITCH-reinforced one.

As a conclusion, the applicability of the Charpy instrumented technique to composites has been proved. The graphs obtained by means of an instrumented test can be considered as the “fingerprint” of these materials, giving the clear understanding of their behavior during an impact event and its possible employment for any specific application. For this reason, it has been identified as the simplest and reliable experimental method to characterize the CFR-PEEK under analysis.