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A Small Punch Test Device Developed for Low Temperature Tests with Initial Acceptance Results

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1. Introduction

The correct knowledge of the mechanical properties of irradiated structural materials is an inherent need in the design and maintenance of nuclear facilities due to the high responsibility inherent to the components and involved risks. Handling samples of such materials is risky as they are radioactive and their masses are great. That is true even for the Charpy specimen (10mm x 10mm x 55mm). So, it is of strong interest the use of small specimens like the ones for the Small Punch Test (SPT) as presented in the ASTM standard E3205/2020 [1]. The test consists basically of pressing a small sphere or semi-sphere against a (circular) plate of the investigated material until it ruptures. The applied force (*F*) and the displacement of the sphere (*d*) are recorded while the plate deforms.

From the analysis of the *F x d* curve, which has certain characteristics, and from the analysis of the fracture surface of the ruptured sheet, and the shape of the macroscopic fracture itself, it is possible to obtain several mechanical properties of the tested material, such as, for example, the yield stress, tensile strength besides fracture properties of the material such as its toughness (for this specific see, for instance, [2]). This technique is a very new one and can be considered still under development but is very promising. In the Brazilian Multipurpose Reactor (RMB) project there is the prevision of a hot cell laboratory to characterize the degradation of irradiated structural components used in a nuclear reactor compared with the virgin material.

Recently at IPEN, a Research Institute at São Paulo City, Brazil, started an interdisciplinary project aiming the development of a small punch test (SPT) device for tests at room temperature and another one to be used at Low temperatures. The project has the main following goals: (i) design and manufacture of two mechanical devices to perform SPT tests at ambient as well as subzero temperatures; (ii) Carrying out SPT tests on standardized nuclear materials (ferritic and stainless steel), not irradiated, for later correlation with conventional mechanical tests; (iii) Develop numerical simulations using the finite element method to correlate them with experimental results and determine the parameters used to obtain the respective mechanical properties.

2. SPT Device, Test Specimen and Typical Results

In the SPT test the specimen of the material to be tested typically is a disk with diameter d=8mm and thickness t=0.5mm, which has fixed edges, pressed by a sphere that has a diameter d=2.5mm. Thus, the test device is also very small as the specimen. From a broken half of a post-impact Charpy test

specimen it is possible to remove several specimens for the SPT test.
A typical result is shown in Fig. 1. This typical applied load F vs. *d* displacement (measured at the disc center) curve for ductile steels can be divided into several regions/zones: (i) elastic bending; (ii) transition from elastic bending to plastic bending (iii) plastic hardening; (iv) softening due to striction and damage initiation; and (v) crack growth and failure.

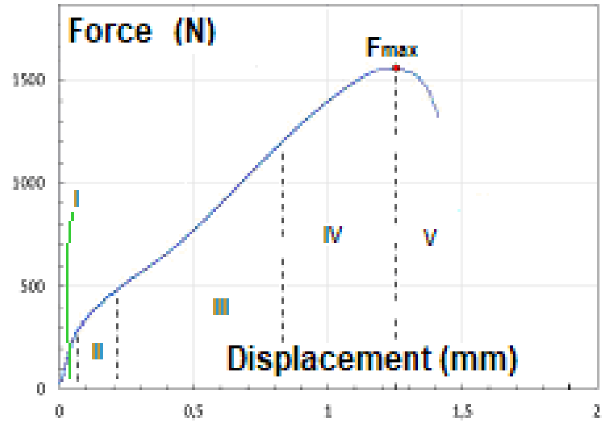
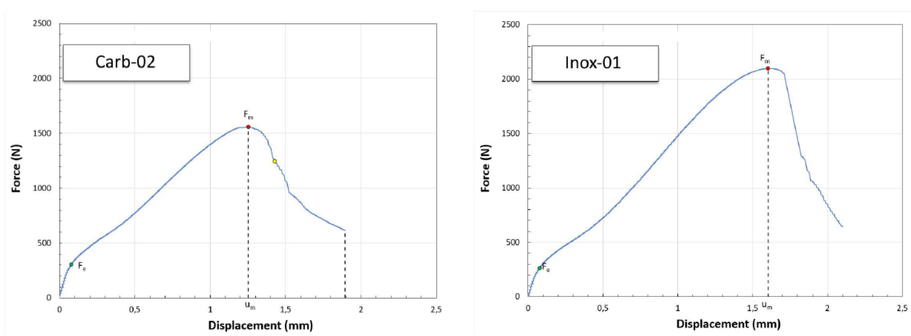


Figure 1: Typical experimental applied F *x* d curve. [2]

A first SPT device was, so, projected and manufactured. In the following, it was tested using Carbon and Stainless steels specimens at room temperature. These specimens were manufactured with non-nuclear materials just to test this first device for acceptance scope. The device description with figures and acceptance results using two Carbon steel and two Stainless steel specimens were already presented elsewhere [3]. Typical results can be seen in Fig. 2, curves force *x* displacement for two materials: (a) Carbon steel and (b) stainless steel



(a) (b)

Figure 2: First SPT device - Curves force *x* displacement: (a) Carbon steel, (b) Stainless steel.

In the following, according the already mentioned IPEN interdisciplinary project, a novel SPT device was conceived allowing to perform SPT tests at low temperatures as well as at high temperatures. The first projected device was designed to perform sub-zero testing only. It was not properly produced by the contracted supplier and it was rejected during the receiving dimensional control because the identified manufacturing problems were so serious that they did not allow for repair.
In the meantime to find a new supplier some project modifications were implemented to allow also the testing at high temperatures. Its basic idea behind its conception is to create a very small oven to cool down or to heat up the specimen to be tested. It should be, firstly, cooled or heated to a near test temperature. After that it is mounted in the device that is closed and filled with a liquid mixture in the test temperature.

Numerical simulations are planned to establish the waiting time necessary to equalize & stabilize the specimen temperature in the desired value. If necessary the liquid mixture inside the device can be drained and a new quantity can be introduced/ poured in it. Beside this, electrical resistances can be introduced to heat up the device near the specimen place as well as thermocouples can be introduced, also in a position near to the specimen, to control its temperature. As the device is small, with around 20cm of diameter and about 12cm high (external dimensions, approx.), it can be easily handled and all the necessary manipulation mentioned above can be done with it positioned in the test machine. Once the desired temperature is achieved the test can start.
Very recently the new conception was manufactured and the device delivered by the supplier passed the acceptance dimensional verification. In the following, some tests were performed, only at room temperature, using also SPT specimens manufactured from two nuclear materials: (a) Steel A508 and (b) Aluminum T6061. Fig. 3 shows the new device already mounted in the test machine, in Fig. 4 with the respective deformed specimens and in Fig. 5 the aacceptance tests performance presented in curves force *x* displacement Steel A508 and Aluminum T6061.

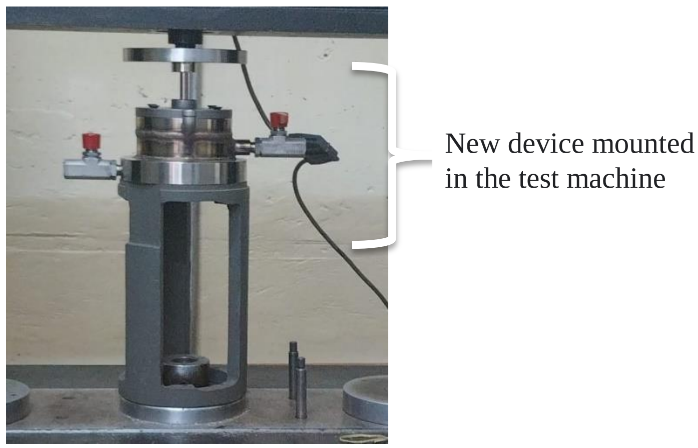
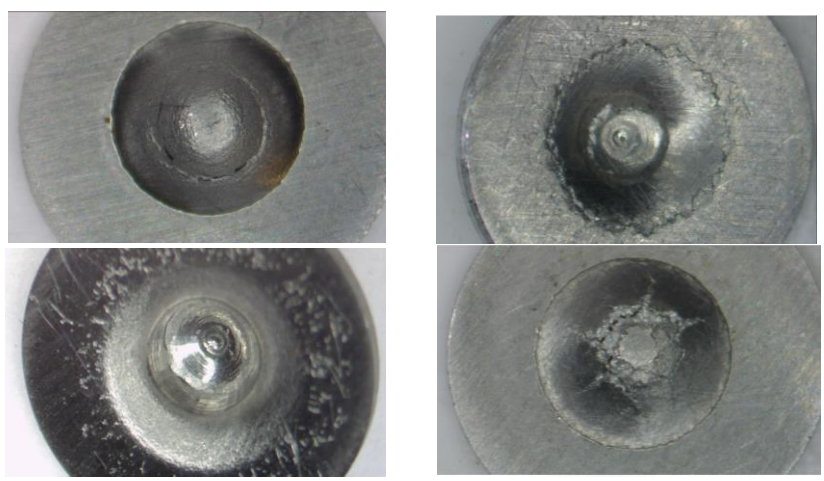
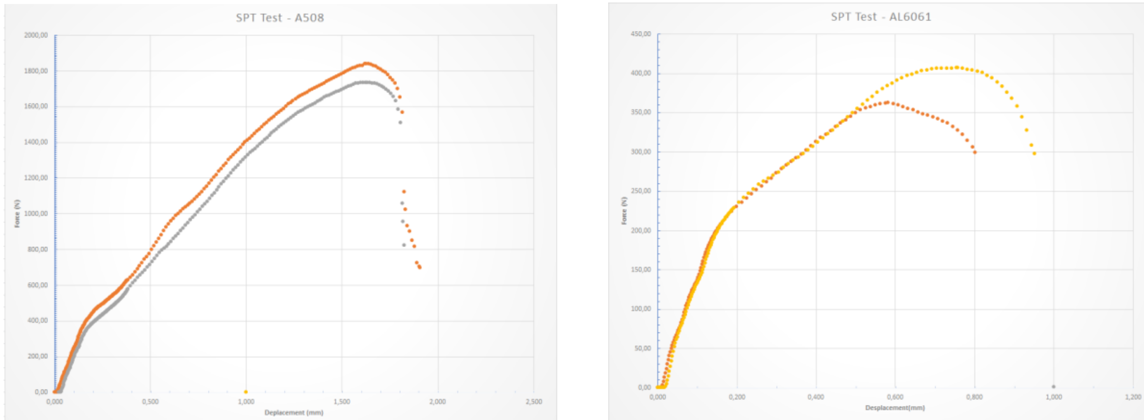


Figure 3: The new SPT device for High and Low-Temperature tests.



(a) (b)

Figure 4: The new SPT device for High and Low Temperature – Deformed Specimens: (a) Steel A508, (b) Aluminum T6061.



(a) (b)

Figure 5: Acceptance tests - Curves force *x* displacement: (a) A508, (b) Aluminum Al6061

4. Conclusions

The results obtained with the new SPT device, conceived for High and Low-Temperature tests, which result is basically curves force *x* displacement, where very coherent with the expected ones. So, the device was accepted and, now (in the near future), it is planned a series of tests with several materials: Carbon steel (nuclear and non-nuclear ones), Maraging steel, Stainless steel and Aluminum, from which we already have the prepared SPT specimens, in some temperatures (ranging from room temperature, ~25 ^{o}C, to sub-zero temperatures (as -20 ^{o}C, -50 ^{o}C, -100 ^{o}C and below) and until 50 ^{o}C, 100 ^{o}C and 200 ^{o}C, for instance. Also, it is planned to test the influence of the thickness, mainly for the Carbon steel, using specimens with thickness of 0,4mm, 0,5mm (the standard) and 0,6mm, all already available.

In the medium term it is also planned to test some carbon steel specimens in an irradiated condition. For this last condition/ test the working group should incorporate at least one more participant capable to establish the time of irradiation in the available reactor, to perform some decay calculation as well as suggest and implement nuclear security measures to perform the test before the RMB hot cells are available.

Acknowledgements

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