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Small Punch Tests with a Recently Developed Device in IPEN: First Results and Future Program at Low Temperatures

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1. Introduction

The testing of small specimens is not only very promising as well as desirable to reduce, for instance, the amount of irradiated material used in a surveillance program of a nuclear reactor. Taking, for instance the Small Punch Test (SPT), its test specimen (usually a disc with diameter d=8mm and thickness t=0.5mm), has a volume which is about 200x small than a regular *Charpy* specimen (10x10x55 mm^3), and, in some cases, it can be taken from an in service component without affecting its performance. So, this technique can also be considered as a non-destructive method.

A description of the test itself is given in [1] and in short: a force *F* is applied against a small sphere (diameter d=2.5mm) that presses the specimen until it rupture. The force (*F*) and the displacement of the sphere (*d*) are recorded. Together with the analysis of the fractured surface and the macroscopic fracture itself, the *F x d* curve has inherent characteristics that allows to infer several mechanical properties of the tested material as the yield stress, tensile strength and fracture properties.

One first SPT device was recently designed at IPEN and already manufactured. Is was immediately tested for acceptance and these test results were very good ones, as shown in [1]. More details about this SPT can be seen in [2]. The present paper shows some tests performed after the acceptance ones, at room temperatures, and will, also, describe the near future and medium term activities. All aiming to allow the use of this kind of testing device in the future Brazilian Multipurpose Reactor (RMB) hot cells laboratory, LAMI - Irradiated Material Laboratory, to characterize the degradation, under the neutron irradiation, of the material (steel) used in its main components.

2. Developed Device and First Results

The Nuclear and Energy Research Institute (IPEN), located at São Paulo, Brazil, recently implemented an interdisciplinary project, aiming the development of small punch test (SPT) devices to be used at room temperatures and at sub-zero ones. This will allow to obtain, among other properties, the toughness x temperature curve, for a given carbon steel, and its Ductile to Brittle Transition Temperature (DBTT).

To reach the goal of the approved project, a first SPT device was designed to perform tests at or near room temperatures, which separated parts are shown in Figure 1. The sphere is not shown. The punch has a concave lower part to accommodate and position the sphere. A procedure to mount the device, with the specimen inside, was also prepared. Figure 2a shows the device already assembled and figure 2b shown it on the test machine.

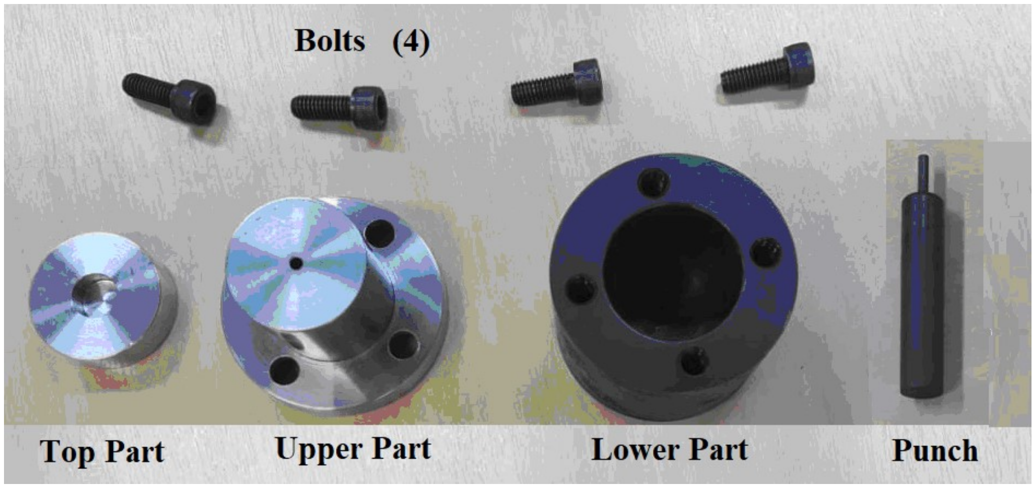
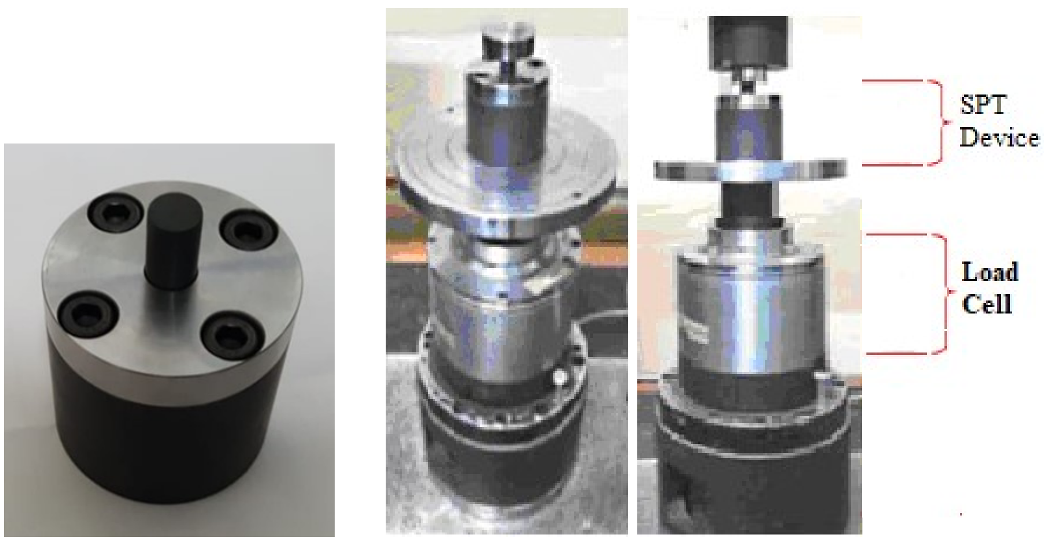


Figure 1 – Separated Parts of the Developed SPT Device



(a) Just Mounted (no top part) (b) In the Test Machine (Complete)

Figure 2: Mounted SPT Device Developed at IPEN

As evident from the figures above, this a small device. The first tests results are shown in Figure 3. Three carbon steel specimens (Carb0x) and one stainless steel ones (Inox01) were tested. The very first test, Carb01 did not run to the specimen rupture due to machine settings. The other tests run until the expected end. The specimens Carb01 and Carb02 were taken from the same batch material. Carb03 was taken from another batch. Figure 3 shows all four test results together in the same chart. It is worth to point the level of the maximum force, around 2500 N. This force is, roughly, the weight of a mass of 250Kg.

All results show good agreement with the expected ones, as seen in the literature. Therefore, the device is working Ok as well as the test procedure/ practice applying the recommendations in [3].

3. Program for the Near Future

The following activities are planned for the near future:

a. Machining and testing some SPT specimens of an nuclear grade ferritic steel (SA508) to determine their mechanical properties. Initially at room temperature and, also initially, the tests will investigate the influence of the specimen thickness and surface roughness. Ref. [4] shows the influence of mechanical properties in the reliability of the used correlation. The specimen are taken from some *Charpy* halves made from this steel (SA508), already used (tested) in other research project.

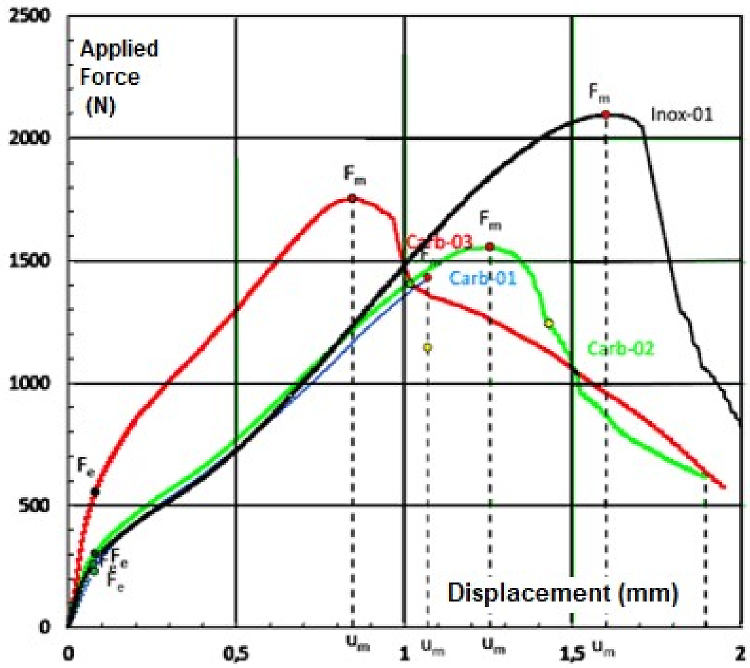


Figure 3: First SPT Experimental Curves: Applied Load x Displacement

b. Design and manufacture a second device to perform tests mainly at sub-zero temperatures and, thus, allow the obtainment, for the tested material, its toughness x temperature curve in order to determine its DBTT (Ductile to Brittle Transition Temperature). A preliminary project has already been done (as depicted in figure 4). The specimens mentioned above will also be used in this step.

c. Proceed with the numerical simulation of the SPT test using the Finite Element Method. A damage model will be used in the simulations to detail the specimen failure process. The conventional material properties to be used in the models will be those got from the specific material SA508 to be tested.

By now, to get experience, a simplified axisymmetric 2D model was prepared for the simulation where the specimen was modeled with quadrilateral elements (QUAD8), with reduced integration and a mesh size of 0.02 x 0.02 mm. The spherical punch and the upper and lower dies were introduced as rigid bodies and, so, not requiring a mesh. The contact behavior of all parts was defined as frictional ($\mu = 0.1$). Large displacements and large deformations are defined in the model, shown in Figure 5.

Two damage models are been planed to be tested/used: XFEM (Extended Finite Elements) e GTN (*Gurson-Tveergard-Needleman*).

4. Conclusions

The described project aims, among other, to perform a systematic study using, mainly, a nuclear ferritic steel (SA508 steel), at room temperature as well as at sub-zero temperatures, considering the influence of some parameters as specimen thickness, surface roughness, etc. Within the scope is, also, to obtain the toughness x temperature curve for this material and its Ductile to Brittle Transition Temperature (DBTT), an important parameter in the surveillance program of a Nuclear Power Plant. And using very

small specimens to reduce the amount of irradiated material to be manipulated. Besides all the experimental work also some numerical simulations are planned and already under development.
A first device was manufactured and the already obtained results are good ones. This shows, also, that all is ready for the next phase. By now, the necessary SA508 steel specimens are all already manufactured. The sub-zero temperatures device is under development and almost ready to be manufactured. The numerical simulations will start as soon as the experiments. This will allow the better understanding of the influence of various factors on the results.

Figure 4: Preliminary Project of a SPT Device for Tests at Sub-zero Temperatures

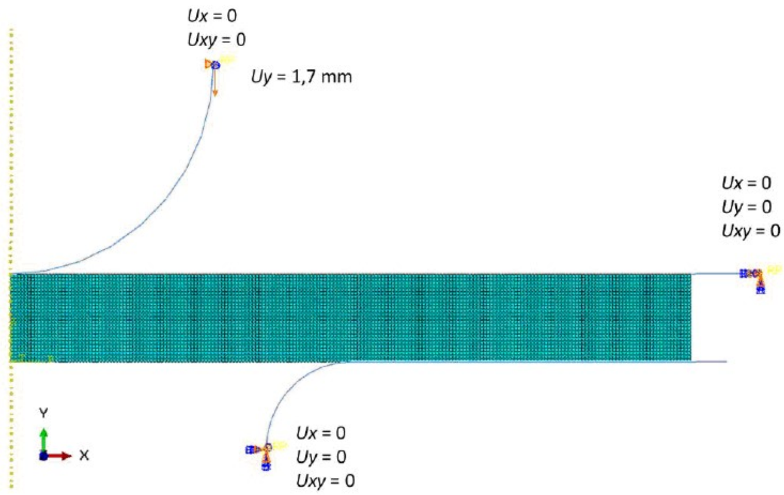


Figure 5: Simplified Axisymmetric FE Model

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