AN EXPERIMENTAL-NUMERICAL ANALYSIS OF THE DROP WEIGHT TEAR TEST

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Abstract. *The DWTT test consists in the rupture of a standard beam specimen by the vertical free fall of a mass. The test is a good indicative of the material toughness and it is the subject of an API standard. Such a standard is followed here so that a set of experimental data were produced at different impact energies. These tests were then simulated using the finite element method and a simple failure criterion, yielding good results.*

Keywords*: Drop Weight Tear Test, Impact, Finite Element Method*

1. INTRODUCTION

Among various applications, pipelines are used for the transportation of fluid (oil or gas) to a processing unit. Due to the increasing consumption of gas and oil, to long distances and to the preservation of natural regions, it has been observed an increase demand for pipelines. On the 60’s, pipeline networks were made of the steel grade X52 and in the present time even grade X80 is being used (Hashemi, 2009). Nowadays in Brazil, with reference to the pipeline projects for the period from 2009 to 2012, approximately 42% are related to the X65 and 34% to the X70.

The principal parameters involved in the project of the pipelines are the transportation distance, the volume and type of fluid. They are necessary for the calculation of the fluid pressure which defines then the pipe thickness and the steel grade to be used. An increase in productivity leads to an increase in the fluid pressure and for this reason, it is required to use pipes with higher strength or higher thicknesses, with the former being preferred.

The Drop Weight Tear Test (DWTT) is one of the major test methods used to evaluate the performance of both the raw material and pipes, over a wide temperature range, in terms of thoughness and fracture mode, i.e. brittle (cleavage or flat) and ductile (shear or oblique). The DWTT consists in to raise a weight up to a specific height and then release it, in free fall, over a simple supported specimen resting on a rigid base (called as anvil). It is a dynamic version of a three-point bending test.

With the DWTT it is possible to study the influence of metallurgical variables on the base material, so indicating its suitability for a given application (AS, 2004). Clear, the DWTT evaluates the material toughness, i.e. its capacity to absorb impact energy. This evaluation is important because gas/oil pipelines can be exposed to severe environmental conditions such as when they are located in deep sea, deserts, glaciers or regions with earthquake, hurricane and so on. For these reasons, it is important that the behavior of the material, when submitted to these conditions, should be known since its failure can cause serious accidents.

The evaluation of toughness has been obtained traditionally through the Charpy test. However, the Charpy test is limited when the tested material is too thick (more than 10mm). This is not the case with the DWTT provided enough impact energy is available. Other advantage of the DWTT over the Charpy one is that the former allows in a simple way the use of higher impact energies. Nevertheless, there are experimental correlations to predict the Charpy energy test from the mechanical properties of the tested material as the Battelle two curve models, which relates pipe geometry, material and loading conditions to its Charpy fracture energy (Hashemi, 2008). On the other hand, there is a paucity of data concerning the DWTT.

The study reported here analyzes the DWTT in a joint experimental and numerical approach. The first part of this paper presents the mechanical properties of the studied material (X65 steel), the configuration of the experimental tests and the characteristics of the numerical model developed in this work. The second part involves the analysis and discussion of the results obtained from the experimental evaluation, using a slow motion video analysis and numerical finite element results.

2. EXPERIMENTAL TEST

2.1. Material properties

The material properties of the X65 steel were obtained from standard tensile tests, Table 1. The specimens were cut from the main lamination direction of the plate used to manufacture the tube.

Table 1. Mechanical properties of the API X65 steel.

Young Modulus (GPa)	229.3
Yield Strength (MPa)	519
Tensile Strength (MPa)	592
Elongation (%)	31

2.2. Experimental DWTT test

A drop weight impact test machine was used for the experiments. The test machine has an impact capacity up to 20 kJ and Figure 1 shows the drop weight mass and the support of the specimen mounted in the anvil. Each specimen was centered on the anvil with the impact point being directly above a previous pressed V-notch. The anvil was designed in accordance to the test standard (API, 1966).

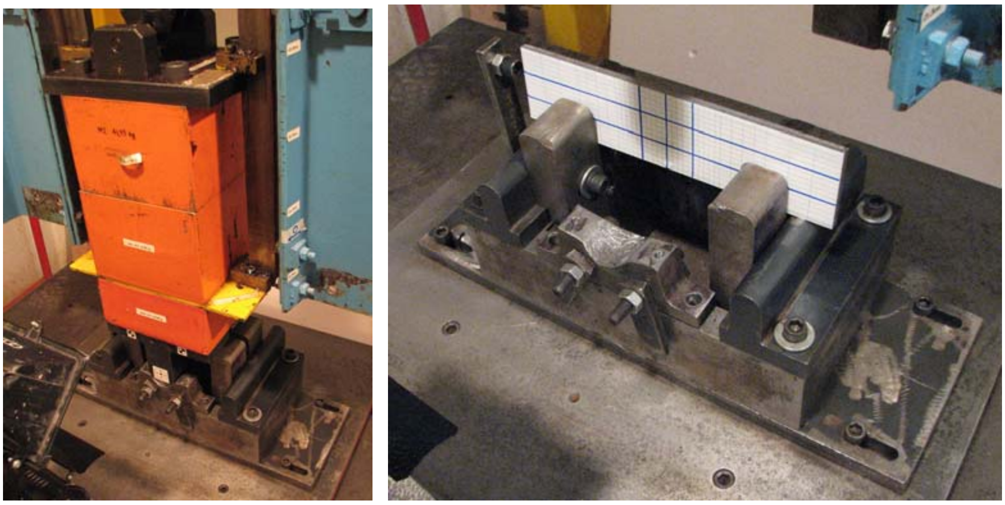


Figure 1. Hammer and anvil support of the specimen.

Here, two DWTT are reported. The first one has such impact mass and velocity parameters that only partial fracture of the specimen occurred. In test 2, the specimen fails completely. For both tests, a drop mass of 150 kg was used. Heights of 2.08m and 2.85m were used for tests 1 and 2, respectively. All tests took place at room temperature. Due to the material high strength, V pressed notches were introduced so to facilitate the fracture, according to the API standard (Hara, 2008). The geometry of the specimen is shown in Fig. 2.

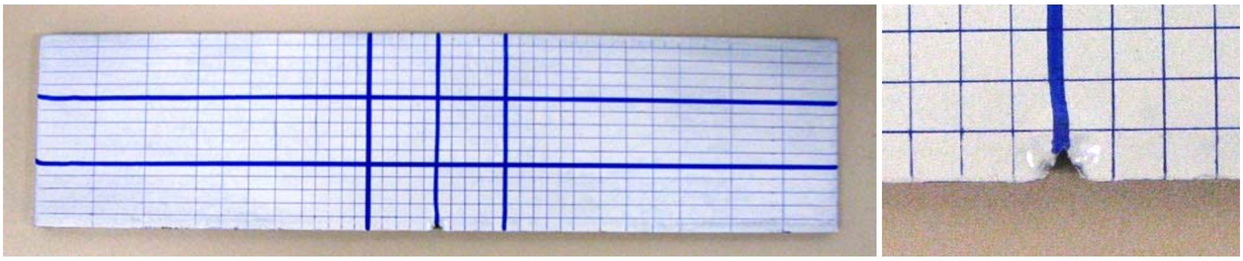


Figure 2. DWTT test specimen and detail of the pressed V-notch.

The specimens were painted and outlined with a pattern of rows and columns for easy identification of the global deformation pattern. The patterns are also helpful for the video analysis, which was recorded for each test with a Photron, Fastcam APX RS, at 2500 frames per second, Figure 3.

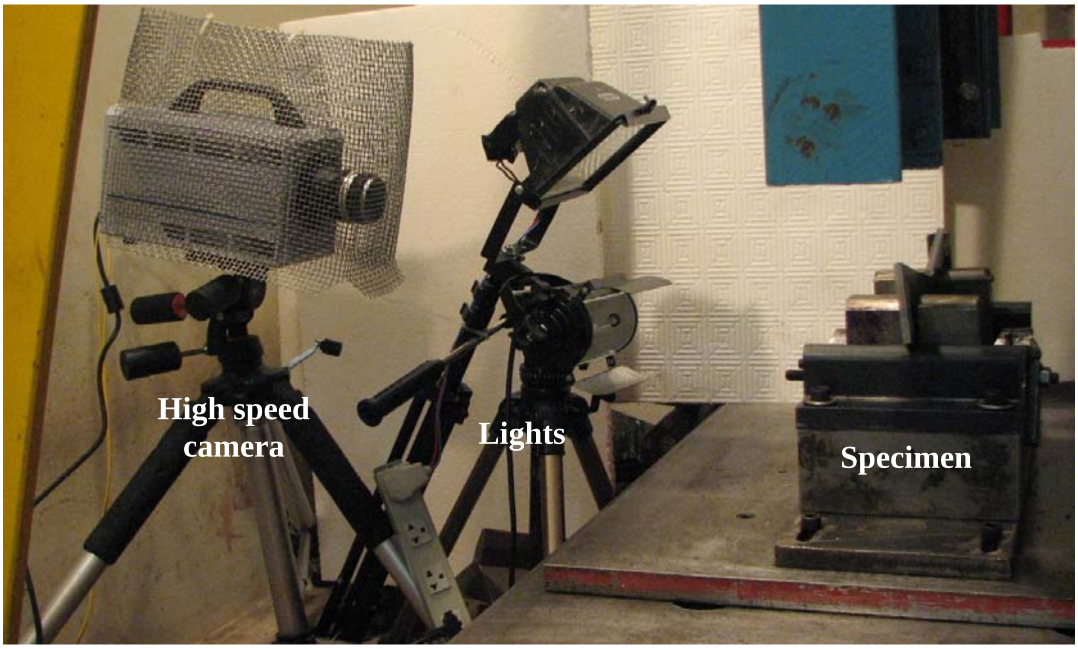


Figure 3. Recording arrangement of the DWTT test.

3. FINITE ELEMENT MODELLING

3.1. Characteristics of the model

The finite element model was developed using Ansys v10.0. 2366 quadrilateral finite elements were generated based on the physical configuration of the experimental test. The geometry comprises the specimen, the constrained lateral supports of the anvil and the drop mass, Figure 4.

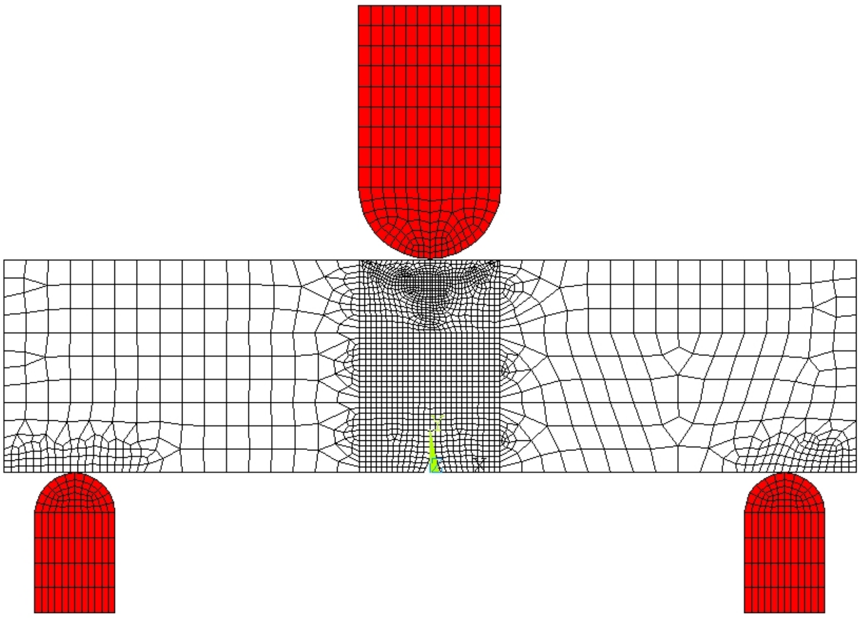


Figure 4. Meshing of the DWTT test model.

The material model is multilinear elastic-plastic, isotropic, whose strain rate sensitive is taken into account using the Cowper-Symonds equation with the parameters *C* and *p* taken as 1300 s^{-1} and 5, respectively (Stranart, 2000). The drop mass and supports were considered elastic since no plastic deformation was observed in the tests in these components. The impact velocities were estimated from the drop height, amounting to 7.48 m/s and 6.39 m/s for test 2 and 1, respectively.

4. DISCUSSION OF THE RESULTS

4.1. Analysis of the experimental results

The image analysis based on the Image-J software allowed one to obtain the drop mass displacement and velocity for the two tests, which are depicted in Figures 5 and 6. It can be seen that the displacement in test 1 presents a gentle rebounding . Test 2 presents a large displacement since the specimen failed. For both specimens, the hammer shows similar movement during the first 5 ms of the impact event.

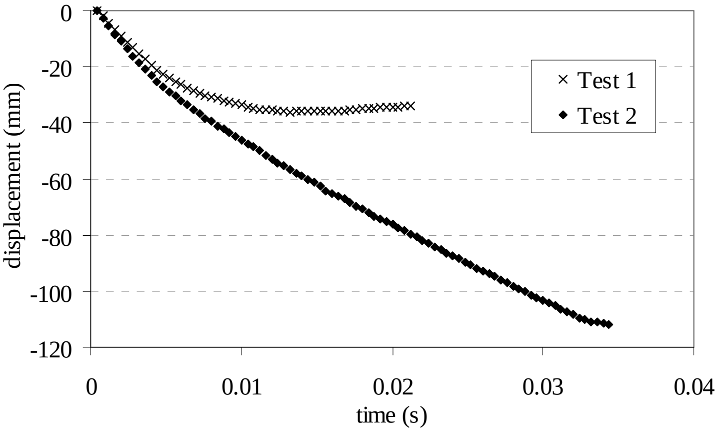


Figure 5. Displacement of the hammer along impact time.

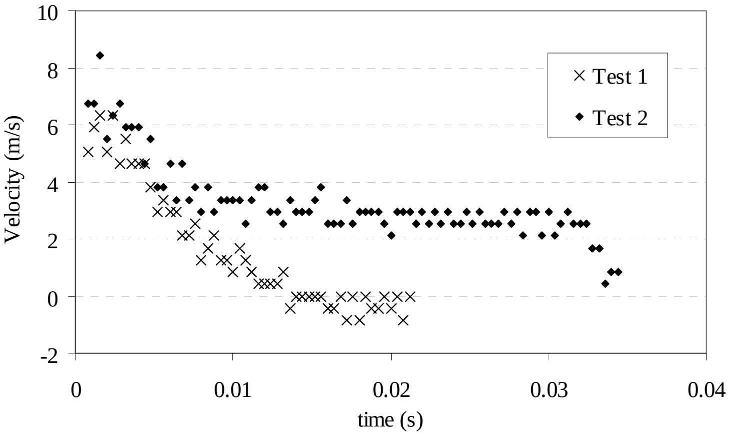


Figure 6. Velocity of the hammer along impact time.

The first part of the velocity curves of tests 1 and 2 in Figure 6 present a linear decreasing. For test 1, the velocity reaches zero at 13.2 ms when all the potential energy of the hammer is used to bend and fracture the specimen. Conversely, the second test does not show a zero velocity but a constant velocity of about 3 m/s, between 9.6 and 33.2 ms. During this period of constant velocity, the acceleration is zero as no force is applied to the specimen. After that time, the velocity falls when the hammer stops abruptly because of the support limit.

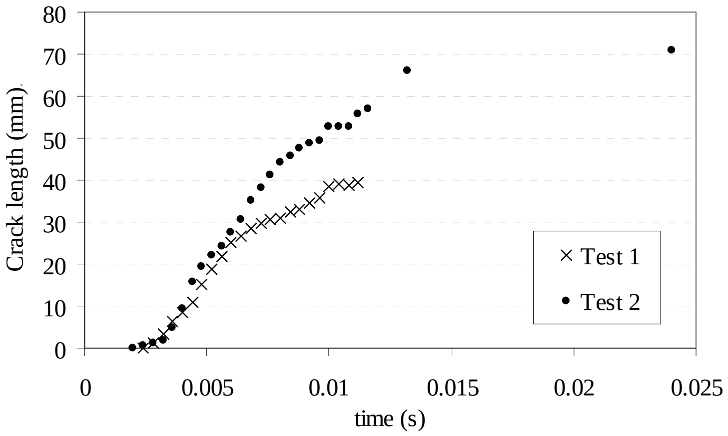
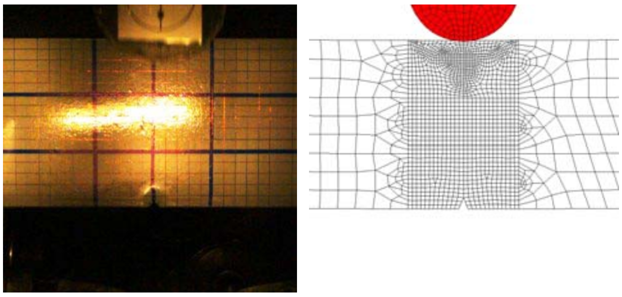


Figure 7. Specimen crack length along impact time.

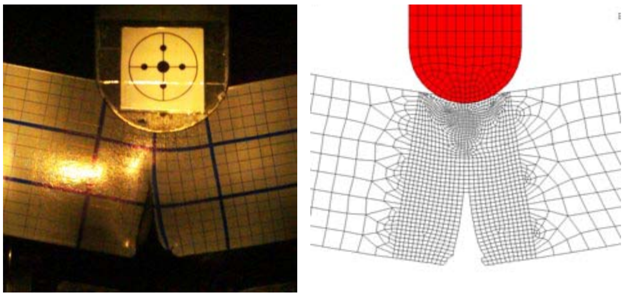
In Figure 7, the specimen crack length indicate a similar growing behavior up to the crack length of 30 mm, which is equivalent to 40% of total fracture. After that, in test 1, the growing rate of the crack decrease and the crack is arrested when it reaches 40 mm length, 56.3% of total fracture.

4.2. Comparative analysis of the specimen geometry

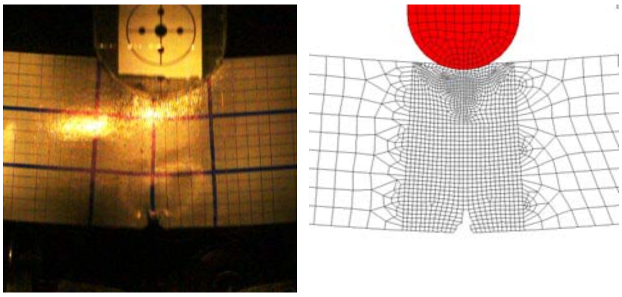
A comparative analysis between the experimental tests and the numerical simulation can now be done and it is seem in Figures 8 and 9. The sequence of images was recorded at every 2 ms.



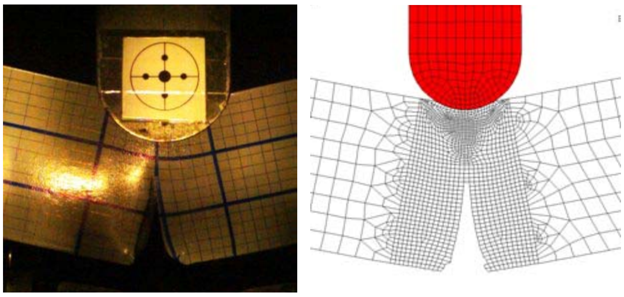
time = 0 ms



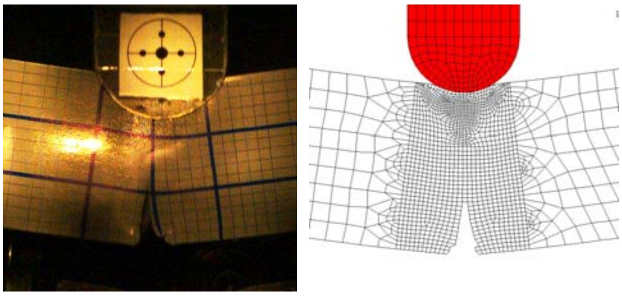
time = 6 ms



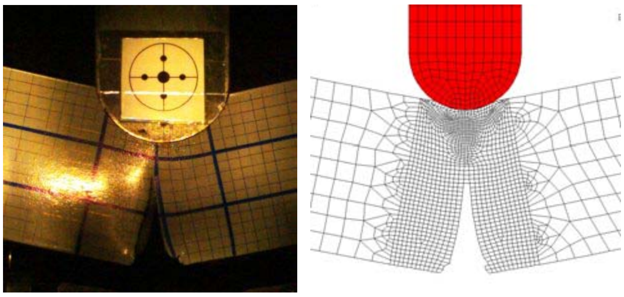
time = 2 ms



time = 8 ms



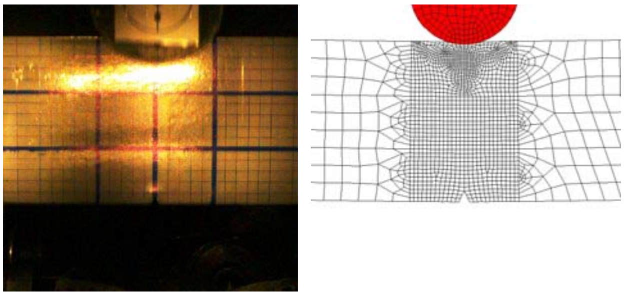
time = 4 ms



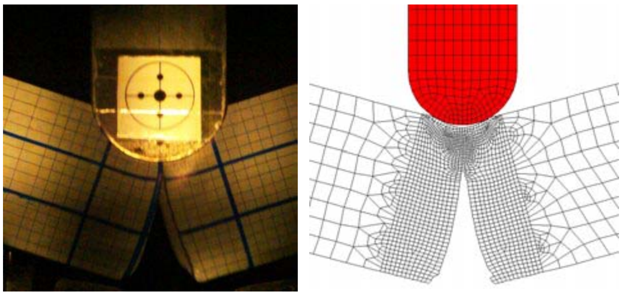
time = 10 ms

Figure 8. Comparison between experimental and numerical DWTT test 1.

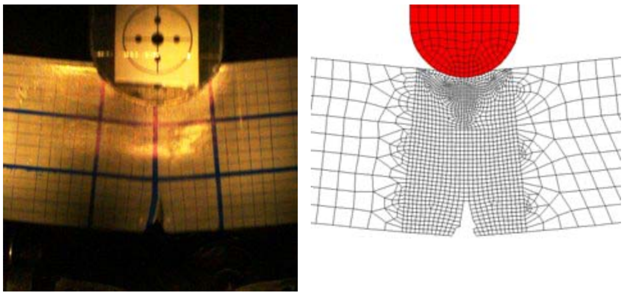
It can be seen in the first test, Fig. 8, how the elements are deactivated when its deformation reaches a given failure strain. Failure begins in the pressed notch and grows untill all the kinetic energy of the impact mass is transformed in plastic work, mainly.



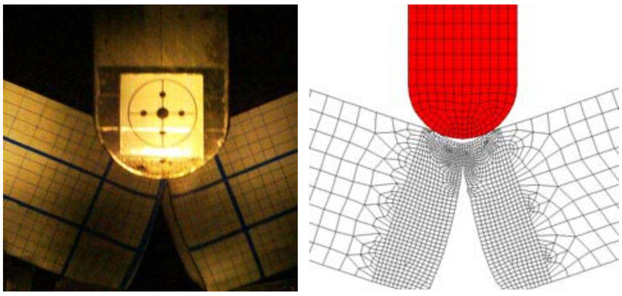
time = 0 ms



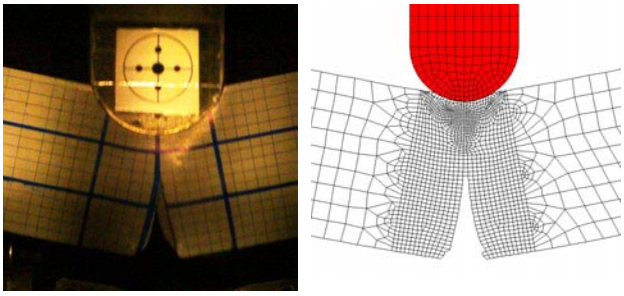
time = 6 ms



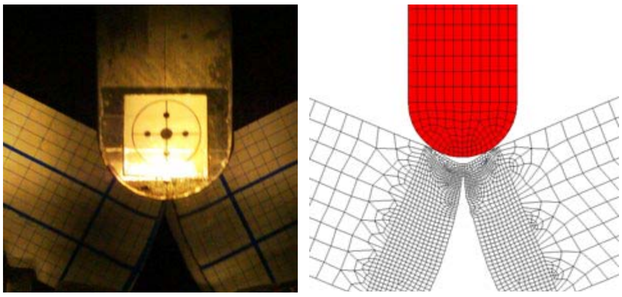
time = 2 ms



time = 8 ms



time = 4 ms



time = 10 ms

Figure 9. Comparison between experimental and numerical DWTT test 2.

Figure 9 presents test 2 and similar comments as test 1 are also valid here. At 10 ms the specimen continues to be deformed by the hammer and only a little layer of material keeps the two parts of the DWTT specimen together. This aspect can be corroborated by observing the fracture section of the specimen obtained in the experimental test shown in Fig. 11. Moreover, Figures 10 and 11 compare the geometry of the broken specimens for both tests with the numerical simulation. It is clear that a good correlation exists. Also, it can be noted the supports permanent deformation, both in the model and in the actual specimen.

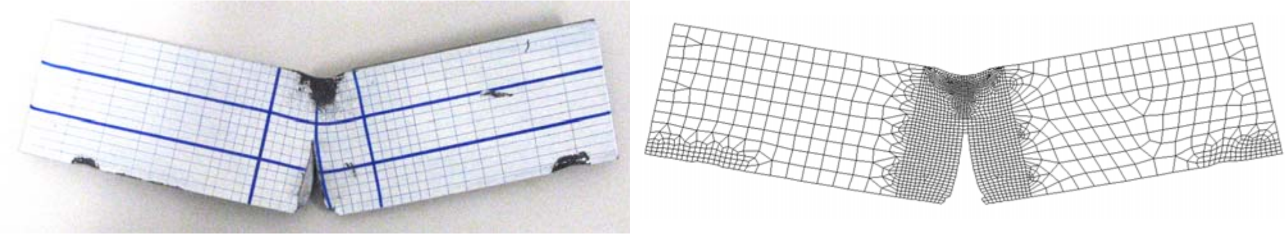


Figure 10. Final shape of the specimens from DWTT test 1.

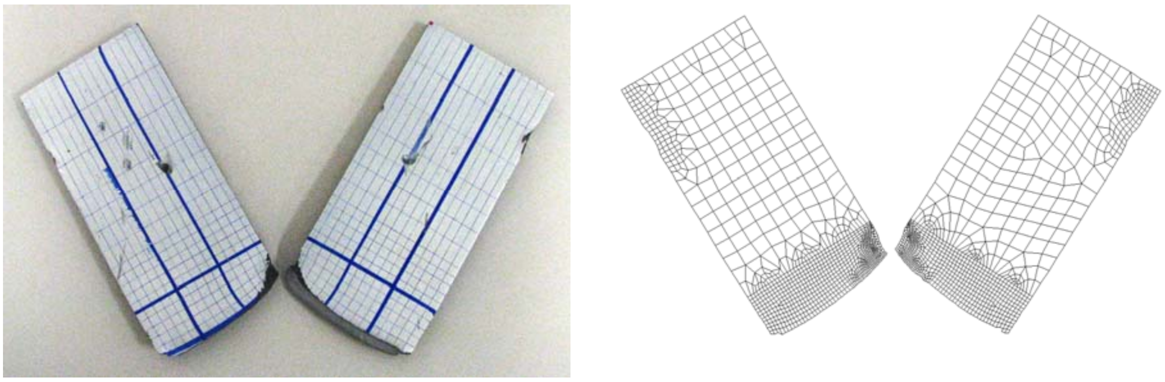


Figure 11. Final shape of the specimens from DWTT test 2.

4.3. Analysis of the stresses in the numerical model

The contour plots of the Von Mises stresses for both tests are shown in Figure 12 at 6 ms, 9 ms, 20 ms and 30 ms.

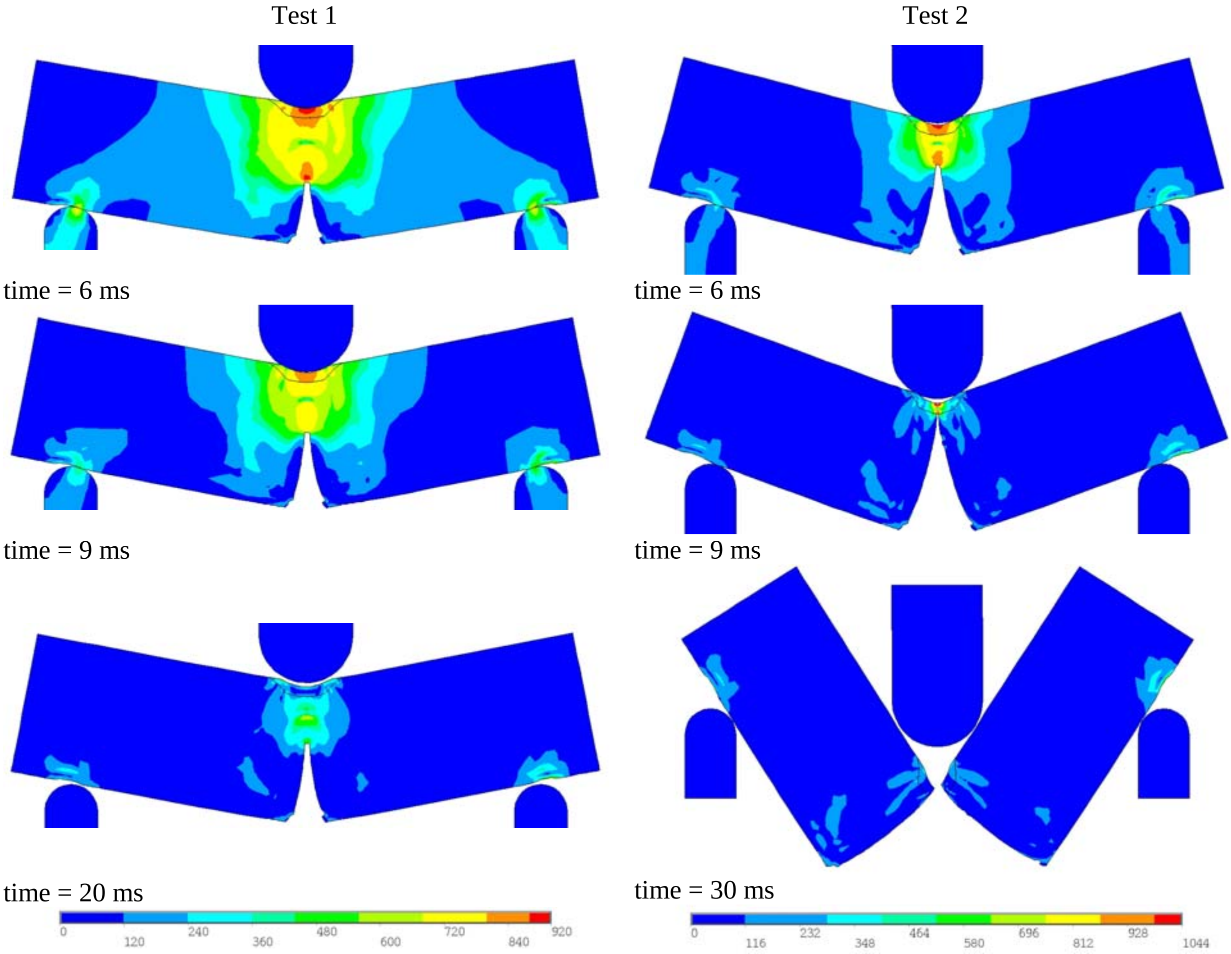


Figure 12. Contour plot of the Von Mises stresses of the DWTT tests 1 and 2 (MPa).

At 6 ms and 9 ms the maximum stresses are located in the crack, due to the tensile stress imposed by the bending dynamic load of the hammer. Also, there is a high stress localization in the contact surface between the specimen and the hammer, due to the compressive stress imposed likewise by the bending dynamic load and, also, by the contact pressure of the hammer. In test 1, after the hammer reaches its lower point and begins rebounding, occurs a reconfiguration of the stresses field, in the minor section of the specimen, due to the elastic part of the total deformation imposed to the specimen. This reconfiguration relocates the maximum tensile stress in the middle of the minor section of the specimen. On the contrary, in test 2, all the stresses almost disappear when the specimen is separated in two parts.

5. CONCLUSIONS

A simple and efficient test technique for modeling numerically the DWTT test using the finite element method was described. Using this technique, it was possible to predict the final shape of the DWTT specimen and crack length. The use of a high speed camera was helpful in determining the drop mass velocity as the tests progressed.

It has been observed from the two tests reported here that the crack speeds are somewhat similar. In the range of 6.4 m/s to 7.5 m/s it seems that the impact velocity does not influence much the crack growth.

This numerical analysis can be used as a preliminary evaluation to estimate how much energy is necessary to cause complete failure of the specimen. With this energy value it is possible to develop the experimental tests using the minimum requirements of the test machine and avoid additional wasted energy to be absorbed by the anvil and the supports which wear and decrease the service life of the components.

6. REFERENCES

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7. ACKNOWLEDGMENTS

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8. RESPONSIBILITY NOTICE

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