Hole expansion test of third generation steels

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Abstract. The trend towards the implementation of new materials in the chassis of the automobiles is considerably making more complex the manufacturing of the components that built it up. In this scenario materials with higher strengths and lower formabilities are daily faced by tool makers and component producers what reduces the process windows and makes the forming processes to be in the limits of the materials. One of the concerns that tool makers must face during the definition of the tools is the expansion ratios that the holes in the sheet may reach before producing a breakage due to the stretching of the material (also known as edge cracks). For the characterization of such limits, a standard test, the hole expansion test, can be applied so that the limits of the material are known. At the present study, hole expansion tests of a third generation steel, Fortiform1050 with a thickness of 1.2 millimeters have been carried out and compared them to a mild steel, DX54D with a thickness of 0.6 millimeters. A comparison for each material in terms of technology used to punch the hole, mechanical punching vs laser cutting has also been conducted. In addition, the measurement technique (online measurement vs offline measurement) followed in the Hole Expansion Ratio (HER) identification has also been analyzed. Finally, differences between both materials and techniques are presented.

INTRODUCTION

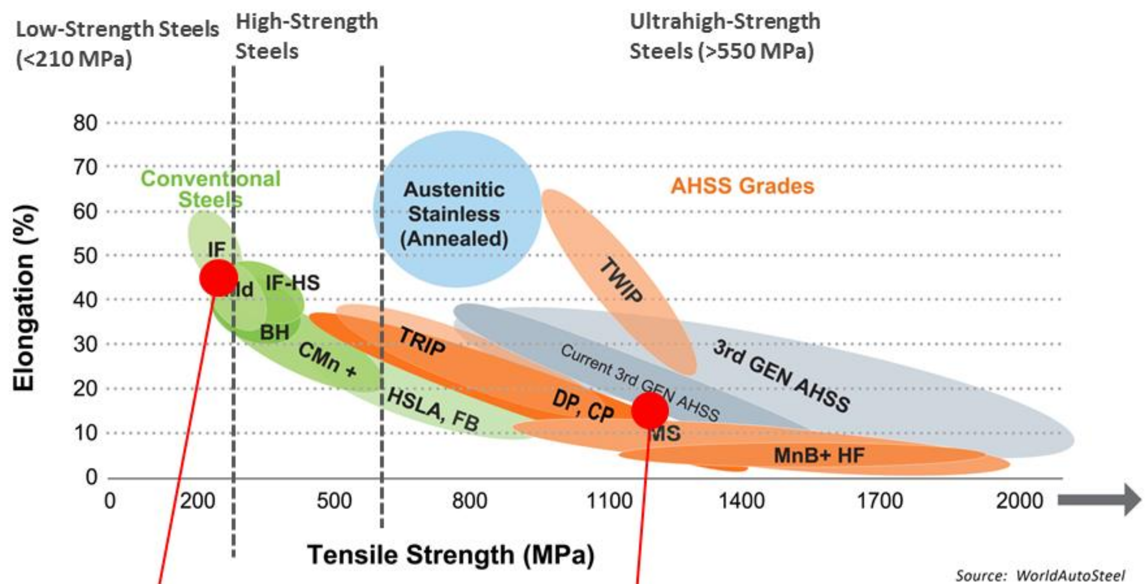
In the last years an increasing interest in the automotive sector has been paid on the forming of ultra high strength steels. Within these materials, third generation of high strength steels is gaining much attention (1). In this scenario, the forming of these materials is now gathering many efforts and different researchers are working in their characterization (2, 3). This type of materials is mainly applied to the internal structures and body components of the cars and within these components the punching of holes and its posterior expansion are typical operations.

When expanding the holes the process designers need to know the maximum achievable results. For this purpose, the Hole Expansion Ratio (HRE) test is used to measure the expandability of the holes. This test must be conducted following the ISO standard 16630-2009 (4) and calculates the ratio between the initial diameter of the hole and the diameter of the hole at which the first fracture appears. Some previous researches deals with a wide range of materials (5) but not much information is available about the hole expandability of the third generation of high strength steels.

In this work hole expansion tests following the ISO standard 16630-2009 are conducted for a mild steel and for a third generation high strength steel, Fortiform1050 from Arcelor. Online and offline measurements have been carried out in order to evaluate the differences between both measuring techniques. Results for both materials and for measuring techniques are given.

MATERIALS

The materials used to make the aforementioned comparison have been a drawing steel DX54D with a thickness of 0.6 mm and a third generation high strength steel Fortiform1050 with a thickness of 1.2 mm. Figure 1 shows the comparison of the materials in terms of tensile strength and elongation as well as the main mechanical properties of these materials.



DX54D

e	0.6 mm
Rp0,2	153.3 Mpa
Rm	309.54 Mpa
ε_e	27.57 %
ε_p	48.71 %
Poisson	0.441

FORTIFORM1050

e	1.2 mm
Rp0,2	756.15 Mpa
Rm	1231.18 Mpa
ε_e	9.9 %
ε_p	10.11 %
Poisson	0.267

FIGURE 1. Mechanical properties of the materials used at the present study

EXPERIMENTAL TESTER

A hole expansion tester following the ISO standard 16630 has been developed at Mondragon Unibertsitatea as shown in Figure 2. The tester is composed of a static die; a blankholder, which avoids the draw in of the material during its expansion and a cone-shaped punch. The tester has been installed in a 100kN tensile/compression universal testing facility (Instron4206). In order to capture the hole expansion ratio online, a video recorder camera has been introduced below the punch so that online pictures at 0.3 frames per second are taken. The resolution of the images is 1920 pixels by 1080 pixels. The online images also allowed the operator to stop the experiment when the initiation of the crack was observed in the screen of the video recording system. After each test has been carried out, the specimen has been released from the tester and the final diameter of the hole has been measured offline. For these measurements an interior micrometer with a measurement resolution of 0.01 mm has been used.

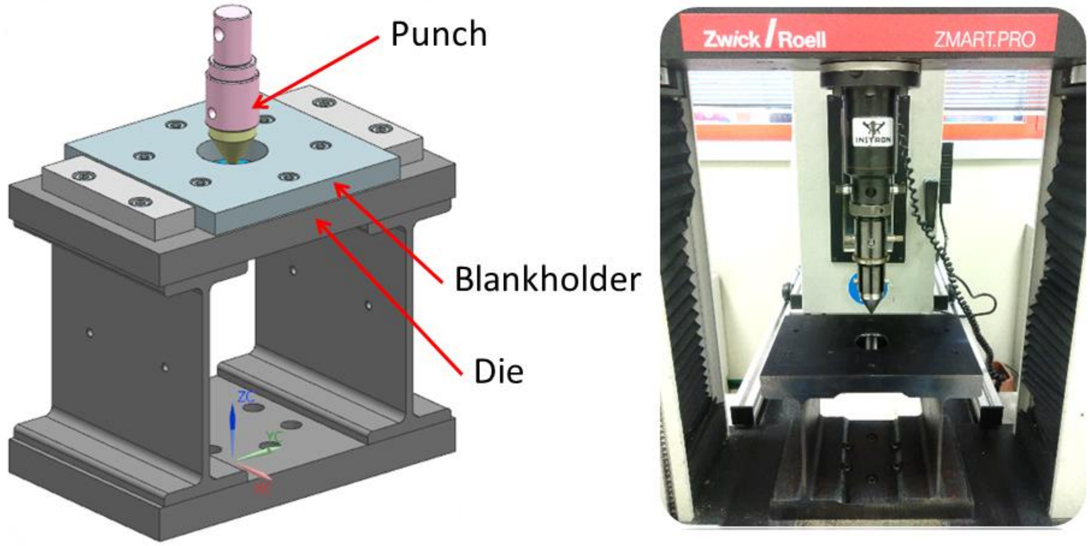


FIGURE 2. Hole expansion tester design (left) and mounted in the compression facility (right)

The discs used for the analysis have 95 millimeters in their external diameter and the internal hole used for the hole expansion ratio evaluation has a diameter of 10 mm. A sketch of the disc can be seen in Figure 3. The dimensions have been defined following the ISO standard 16630.

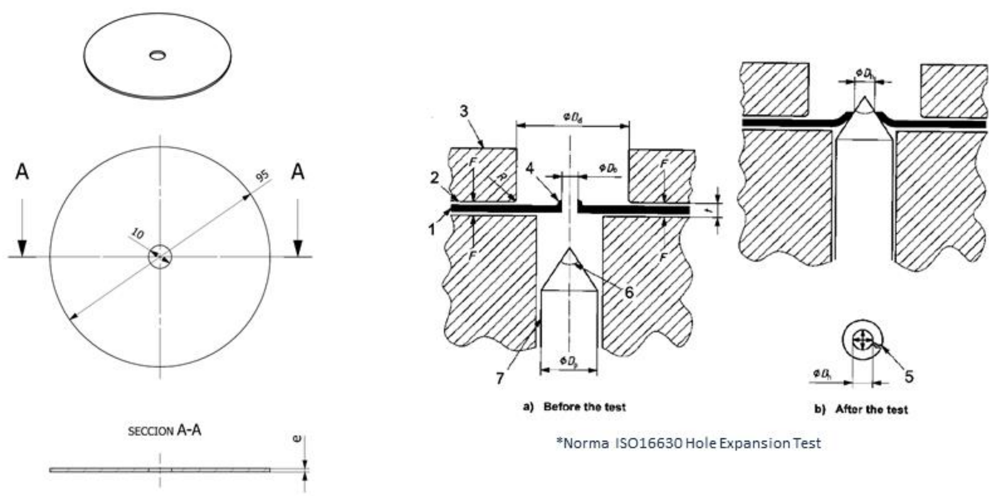


FIGURE 3. Hole expansion disc (left) and its position in the tester facility (right)

The internal holes of the discs for the evaluation of the hole expansion ratio have been obtained following two different manufacturing technologies. On the one hand, a first set of samples have been cut using a laser cutting machine (following a tangential entrance in order not to generate any localized defect in the perimeter of the hole). On the other hand, a second set of samples have been cut using a mechanical cutting process in a punching tool. For this second procedure a 10 mm punch and a 10.20 mm die have been used. Therefore, the cutting clearance has been 0.1 mm giving a clearance of 16.6% for the DX54D material and a clearance of 8.3% for the Fortiform1050 material. The cutting tool also has a blankholder plate for improving the cutting quality and avoiding any deformation of the discs during the cutting of the internal hole.

In order to avoid any draw in of the material during the test, a mechanical blankholder fixed with bolts has been used to blockage the movement of the discs. The punch velocity has been set as 0.1 millimeters per second in all cases.

RESULTS AND DISCUSSION

At least six repetitions have been carried out for each combination of material, DX54D and Fortiform1050, and each cutting technology, mechanical punching and laser cutting. Each test has been video recorded in order to be able to determine the online fracture point. Afterwards, once finished the tests, the diameter of the internal hole has been measured using an internal micrometer.

Figure 4 and Figure 5 show the results achieved for both materials and for both cutting technologies. The left side of the figures shows the results achieved for the laser cut holes meanwhile the right side of the figures shows the results achieved for the mechanically punched holes. For each of the technologies the first bar shows the hole expansion ratio measured with the micrometer after the release of the disc from the facility. The second bar shows the hole expansion ratio measured online with video camera recorder. Finally, the third bar named as springback shows the change in the hole expansion ratio from the online measurement to the offline measurement. This is an interesting measurement since the real hole expansion ratio should be measured online during the test in order to capture its real value avoiding the influence of the material springback. For each of the measurements the dispersion bars achieved for the six measurements are also plotted.

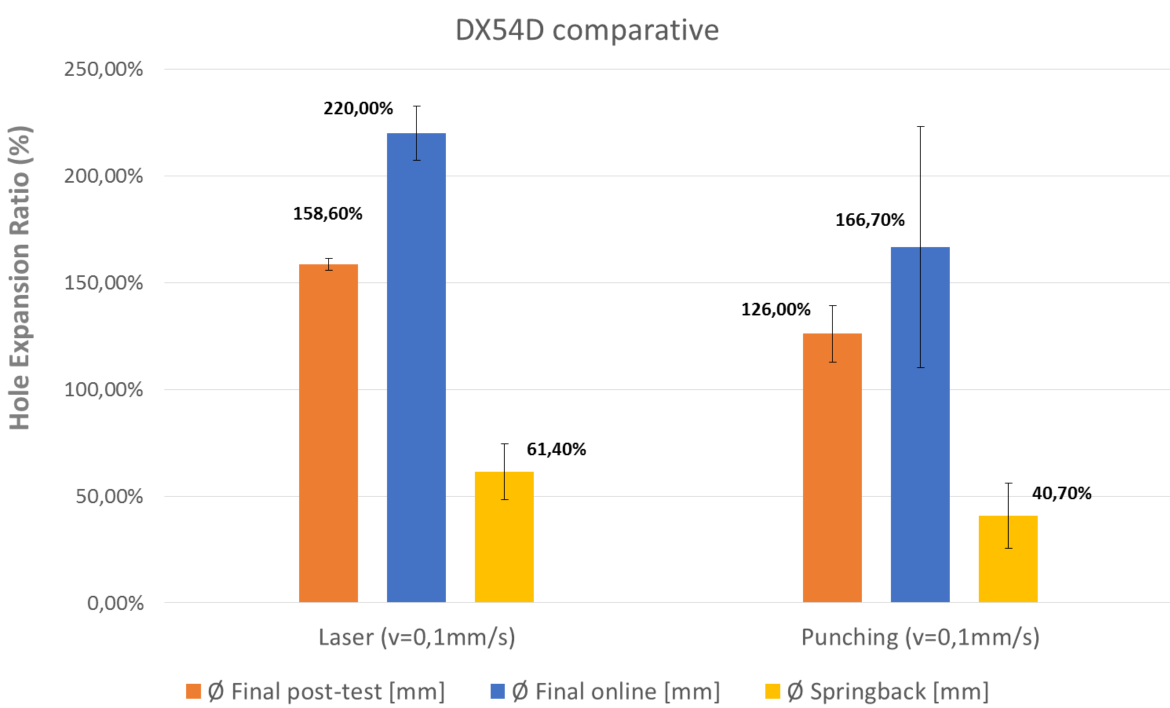


FIGURE 4. Results achieved for the DX54D material. Laser cutting (left) and mechanical punching (right)

Figure 4 shows the results achieved for the DX54D drawing steel. It can be seen that the hole expansion ratio achieved when using the mechanical punching technology is lower than the hole expansion ratio achieved when using the laser cutting technology. Therefore, and under the conditions followed at the present study, it can be stated that this material offers greater hole expansion ratios when laser cut. However, it must be noticed that the clearance used for this material has been about 16.6% of the material thickness and this could have influenced the results in terms of the hole expansion ratio of the punch holes. It can also be noticed in Figure 4 that the dispersion in the results is higher for the punched holes than for the laser cut holes what could be an indication for the lower edge quality of the mechanically punched holes. When comparing the online vs offline measurements, as expected, the online measurements are offering greater hole expansion ratios. Furthermore, in the case of the DX54D material, the differences are not negligible ranging from the 40.7% for the punched holes up to the 61.4% for the laser cut holes. General values of the hole expansion ratio range from 126% to 158.6% in the case of the offline measurement and from 166.7% to 220% in the case of the online measurement.

Figure 5 shows the results achieved for the Fortiform1050 third generation steel. In this case, as expected, the hole expansion ratio is much lower than in the case of the DX54D drawing steel. When comparing both technologies, the results achieved with the mechanical punching are slightly better than the results achieved with the laser cutting technology. This could also be due to the better edge quality of the mechanical punch holes since a lower cutting clearance was used, 8.3%. The much higher mechanical properties of the material may also have improved the edge quality of the punched holes. Anyway, if the dispersion bars are considered it may be estimated that the results achieved for both cutting technologies are very similar in this case. Finally, it must also be noticed that as the previous case the online measurements are also greater than the offline measurements achieved after the release of the discs from the facility. Not negligible values of the springback have been observed due to the fact that the global hole expansion ratio for this material is really reduced, ranging from a 13.5% to a 15.5% in the case of the offline measurement and from a 21.2% to a 23% in the case of the online measurement.

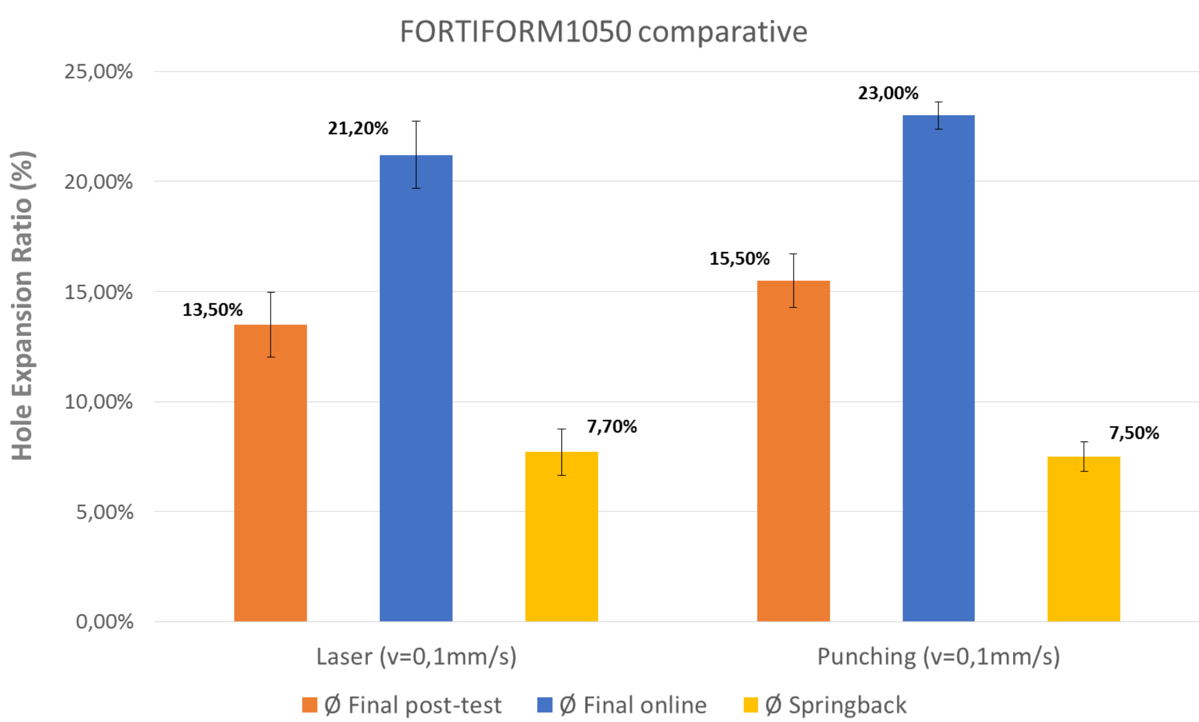


FIGURE 5. Results achieved for the Fortiform1050 material. Laser cutting (left) and mechanical punching (right)

CONCLUSIONS

As a conclusion of this work the following statements can be summarized:

- The hole expansion ratio of third generation steels is very reduced with values ranging in the order of 20%. As a reference, the values obtained for the drawing steel analyzed at the present study have been in the order of 150%.
- The differences between the online and the offline measurement techniques are not negligible and online measurement techniques should be used to accurately predict the hole expansion ratio of materials.

- Third generation steels, in contrast to drawing steels, offer greater hole expansion ratios when mechanical punching techniques are used to manufacture the holes. This conclusion may also be influenced by the punching clearance which has been different for both materials so further investigations should be needed.

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