EXPERIMENTAL ANALYSIS OF CRACK FORMATION AT SHEET METAL EDGES

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Abstract

During the pressing of sheet metal parts, cracks may form around the holes that weren't predicted by numerical simulations. These cracks are caused by the partial depletion of the forming capacity at the edges of the hole due to the preparation technology used, most often shearing. The aim of this article is to refine the simulation models by introducing boundary conditions to describe this condition. The Hole Expansion Test (HET), described in ISO 16630 and currently the only worldwide standardised method for determining the sensitivity of a material to edge crack formation, is used to determine the limiting deformation at the edge of the material. Materials commonly used in the automotive industry were chosen for the experiment. Holes were made in samples of each material according to ISO 16630 by shearing, laser cutting, and electro-discharge machining. The testing was carried out according to ISO 16630 at room temperature and the specimens were evaluated manually just before failure. The results obtained were evaluated and compared with theoretical premises. By refining simulation models and introducing boundary conditions that account for the depletion of forming capacity at the edges of holes, manufacturers can better predict and prevent the formation of cracks during the pressing of sheet metal parts. This can improve the quality and durability of automotive parts and lead to safer and more reliable vehicles.

Keywords: Sheet metal forming; hole expansion test; sheared edge formability; fracture criterion; edge plasticity evaluation

1. INTRODUCTION

The shape complexity of many sheet metal products, especially in the automotive industry, imposes great demands on the technological preparation of production. It is now a widespread practice to use finite element simulation software (such as AutoForm or PamStamp) for tool design. The formability criteria used in software is mainly the formability limit curve (FLC). Observations in practice have revealed that in the surroundings of the hole edge, the real behaviour of the material is not identical to its behaviour in the simulation software. The analysis showed that material failure occurs in this area at strain values lesser than the FLC limit value used by the simulation software. [1-4]

All commonly used methods for creating holes in sheet metal always affect the surrounding area in some way. The affected areas then have different properties that are not accounted for in the simulation model. The aim of this paper is to describe this phenomenon by means of a standardized Hole Expansion Test (HET) and to compare between the manufacturing methods of shearing, laser cutting and electro erosive machining (EDM). Another aim is to provide a methodology for the evaluation of the HEC parameter after the hole expansion test. The testing will be performed on five types of steel commonly used in the automotive industry and stainless steel X5CrNi18-10.

2. HOLE EXPANSION TEST PRINCIPLE

The Hole Expansion Test (HET), described in ISO 16630 and currently the only worldwide standardised method for determining the sensitivity of a material to edge crack formation, is used to determine the limiting deformation at the edge of the material. Other tests are being developed to address this issue, such as the Diabolo test, however some aspects of testing conditions are not yet precisely defined. [5-8]

The standard ISO 16630 requires specimen with a hole with 10 mm diameter in centre. It also prescribes that no hole shall be closer than 45 mm to the edge of specimen. During the test, the central hole is enlarged with a conical punch with apex angle of 60°. The diameter of the cylindrical part of the tool must be large enough to enlarge the hole to such an extent that cracks appear on its edge. The resulting formability value is the ratio of the hole diameters i.e., the ratio of the deformed hole to the original hole (**Figure 1**). [8]

The test is terminated when a full-thickness crack begins to form at the edge of the enlarged hole. The termination is done manually by the operator of the test machine, so the results are dependent on human perception. For this reason, the measurement should be repeated several times to obtain the most accurate results. [8]

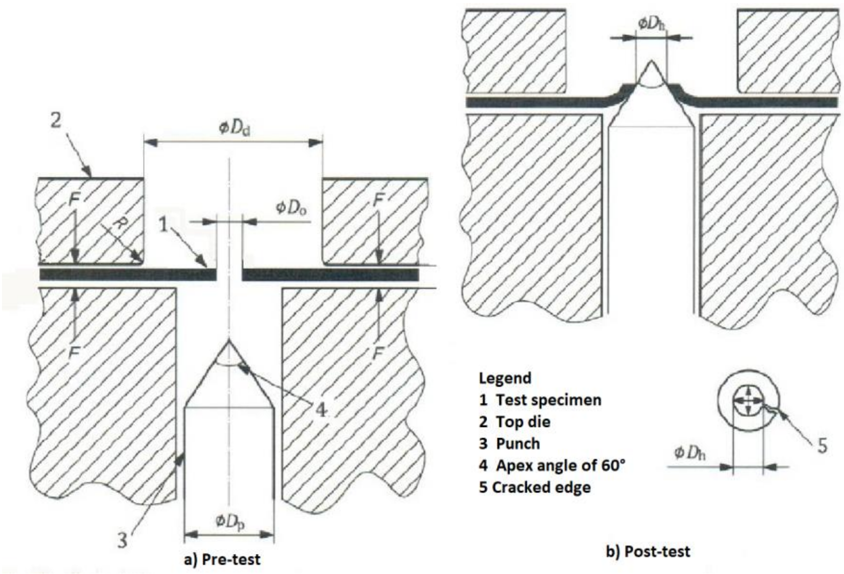

Figure 1 Depiction of HET [8]

3. PREPARATION OF TEST SPECIMENS

The test specimens were made of steels commonly found in the automotive industry and stainless steel X5CrNi18-10. The steel grades and mechanical properties are given in **Table 1**.

Nine blanks were prepared for each grade of steel in form of 100 mm x 100 mm squares with thickness of 0.7 mm. As required by the standard, holes of 10 mm diameter were made in the centre of these specimens as shown in **Figure 2**. Thus, all requirements for the shape of the test specimens were met, including the minimum distance of the hole from the edge [8].

Table 1 Tested steel grades and their mechanical properties according to standards [9-11]

Grade	Proof Strength (MPa)	Tensile Strength (MPa)	Elongation after fracture (wt%)	Strain hardening exponent (-)	Plastic strain ratio (-)
	$R_{p0.2}$	R_m	A_{80mm}	n	r
DX57D+Z	120-170	260-350	41	0.22	2.1
HCT500X	300-380	500	23	0.15	1.0
DC06	170	270-330	41	0.22	2.1
DX56D+Z	120-180	260-350	39	0.21	1.9
HX180BD	180-240	290-360	35	0.16	1.5
X5CrNi18-10	230	540-750	45	0.5	0.95

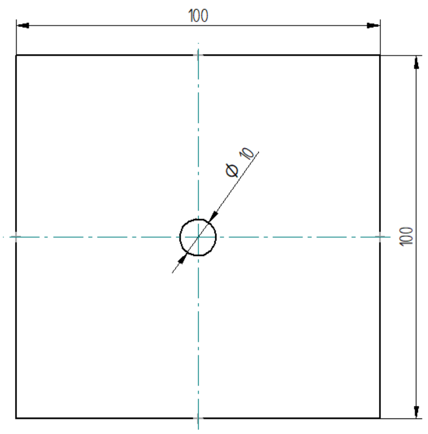

Figure 2 Test specimen dimensions

The centre holes were produced using three different technologies, namely shearing, laser cutting and electric discharge machining (EDM). These methods were chosen primarily because of the different effects on the area in the vicinity of the formed edge. This influence then affects the sensitivity of the material to crack formation and subsequent crack growth. The influence introduced into the material is determined by the principle of the material cutting method.

During shear, the edge material is formed, which reduces its plasticity reserve and makes the material harder. During laser cutting, heat is introduced into the cutting area, which can cause a change in the internal structure. Influences like these can lead to different mechanical properties than expected from the material during the design of the forming process in the simulation software. The EDM method was chosen as a comparative method because there is almost no influence on the material during the process. For each hole manufacturing technology and each material, three test specimens were made, as recommended in the standard.

4. TEST DESCRIPTION

The testing equipment was a universal machine for sheet metal formability testing BUP 600 from Zwick Roell, which was equipped with a cone tool according to ISO 16630. The test was carried out at a speed of 1 mm/s at 20°C and standard atmospheric pressure. After the sample was placed in the machine, centering was performed on the hole using the cone tip. Subsequently, the specimen was clamped with a holding force of 100 kN. Throughout the test, the edge of the material was inspected by the machine operator, who stopped the test when a crack developed through the entire thickness.

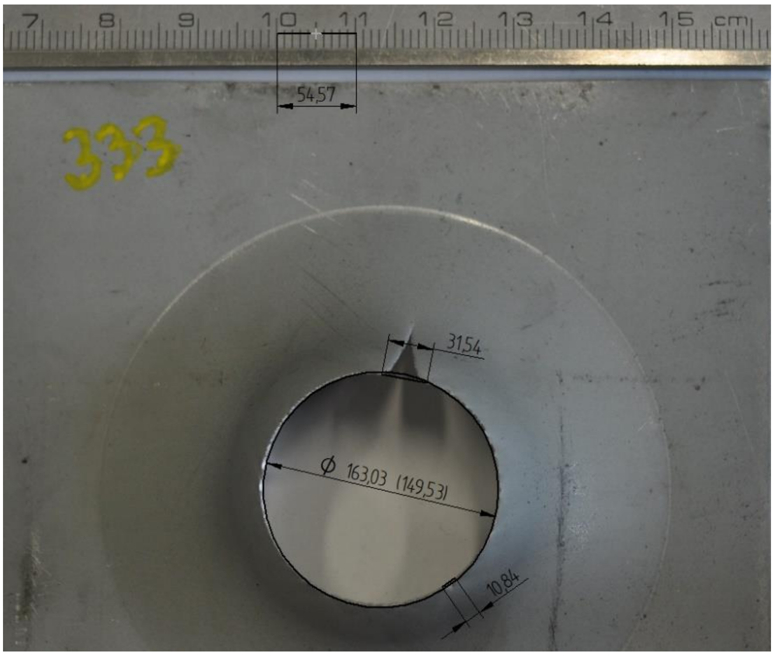

Figure 3 Measured specimen in CAD

After the specimen was removed from the machine, a detailed photograph of the specimen was taken along with an attached ruler. This photograph was then manually analysed using CAD software. A circle was drawn through the resulting cracked hole and the width of the crack at the edge of the hole was also measured. To determine the formability value, the diameter just before the crack formation needed to be determined. Therefore, the crack width was subtracted from the circumference of the lined circle to obtain the circumference of the hole before the crack as shown in **Figure 3**. The diameter was then calculated from this circumference and used for the final calculation.

From the diameters obtained, the HEC coefficient (Hole Expansion Capacity) was then calculated using the formula below,

$$HEC = \frac{D_n - D_0}{D_0} \cdot 100\ [\%] \qquad (1)$$

where: D_n - post-test diameter (mm); D_o - pre-test diameter (mm) [5].

5. SUMMARY OF RESULTS

From the measurements obtained, average values were calculated for the respective steel grades and the respective hole manufacturing technology. Their comparison is shown in **Figure 4**. For DX57D+Z and HCT500X materials, results for laser cut specimens are not available for manufacturing and logistical reasons. In general, the highest HEC coefficient is achieved by EDM produced specimens. Specimens produced by this method had HEC values ranging from around 150% for materials less suitable for forming (HCT500X) to 270% for materials intended for deep drawing (DC06). On the other hand, the worst results were achieved by specimens prepared by the shearing method, which only achieved HEC = 50% for the non-ductile material HCT500X and HEC = 165% for the ductile material DC06. From the available data, the samples prepared by laser cutting show lower HEC values than the EDM specimens, but higher than the specimens prepared by shearing. The differences between laser cutting and other technologies are not the same for all technologies, even shearing seems to be better for some materials.

The measured results confirmed the assumptions obtained from the theoretical analysis of the problem. In shearing there is a hardening of the material, and this occurs across the whole spectrum of materials. On the other hand, for EDM, it was confirmed that the material is not negatively affected and therefore achieves the highest HEC values. For laser cutting, thermal effects around the hole edge were assumed and proved to be present. However, this influence cannot be simply described as negative, as for some materials it can have a positive effect.

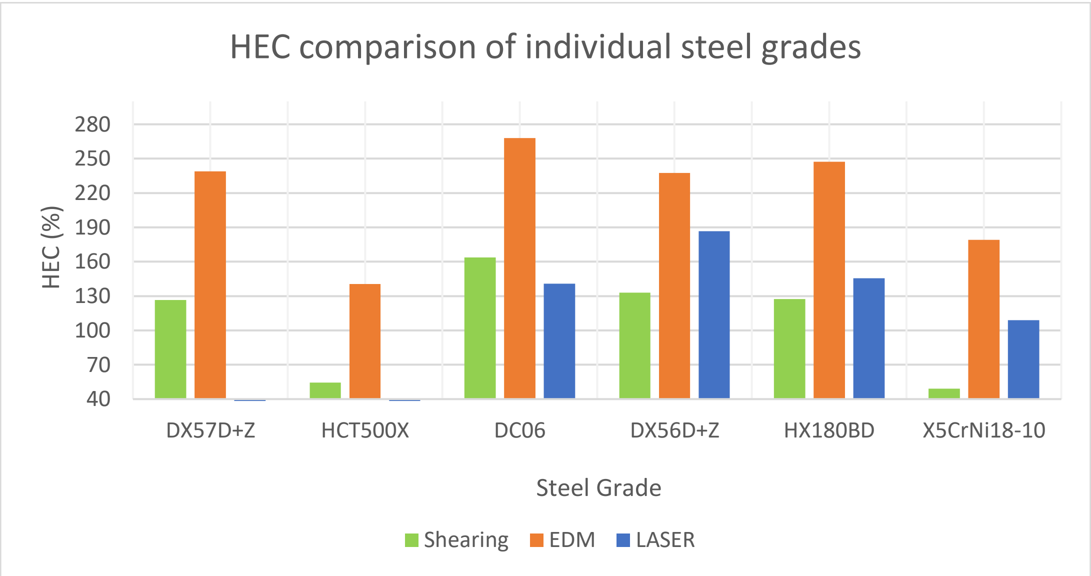

Figure 4 HEC comparison of individual steel grades

6. CONCLUSION

The cracks that form around the edges of the holes during the forming process are a direct result of the technology used to prepare the holes. A Hole Expansion Test (HET) has been carried out for various automotive materials to determine the HEC coefficient (Hole Expansion Capacity). In correlation with the theoretical analysis, it was found that the hole edge is most affected by the shearing method, where a HEC in the range of 50 %-165 % was obtained. On the other hand, the EDM method does not affect the hole edge at all and the HEC is in the range of 150 % - 270 %. In the shearing operations, the higher strength materials (HCT500X and X5CrNi18-10) were shown to be more susceptible to edge failure than the other deep drawing materials. For practical applications, simulation software needs to be updated to define the hole making technology and to accurately describe the relevant boundary conditions, rather than replacing fast and cheap shearing with slow and expensive EDM.

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Research of mechanical properties of new materials after technological processing.

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