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Determination of edge strain in DP steel sheet for predicting edge cracking

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Abstract. This contribution is concerned with determining the edge strain in edges with different finish qualities associated with crack formation in the free edge of a deep drawing blank. The sheared edge quality is of major importance, particularly in high-strength steels which are used for safety components. The purpose of this study was to determine for various parting processes for sheet metal the limit strain which leads to cracking in the free edge. The parameter which was varied in this investigation was the parting process that produced the edge: shearing and machining. A special fixture was employed for measuring the strain value. The values were verified using FE modelling with AutoForm software. The surface finish qualities of the edges were compared using a special test procedure, the Diabolo test, which had been previously described in publications by Held [1] and Liewald and Gall [2]. In this test, the sheared edge is subjected to loading under plane strain conditions. Another test of susceptibility to edge cracking is the hole expansion test [3], in which crack is induced in a circular hole in the centre of a part. The limit edge strain can be identified using a DIC optical measuring system which monitors strain increments in the course of the test. Thanks to these results, the factors which affect the susceptibility of the sheared edge to edge cracking material have been identified and validated in the DP1000 material.

Keywords: edge cracks, shear cutting, Diabolo test, finite element simulation.

1 Introduction

In recent years, several approaches have been developed to predict the formation of a free-edge curve by numerical simulation [1]. They share the use of FLC as the basis for calculating reduced forming ability. These models require experimental data obtained from tests most commonly used for this purpose and the hole expansion test according to ISO 16630. In this test, a hole is extended by a conical piston until it breaks in its circumference. The evaluation criterion is defined as the ratio of the extension of the opening between the original diameter and the fracture size. However, this test does not provide the maximum strain value, which is achieved before crack formation. Therefore, several alternative tests [5] have been developed to measure this value. In the present article, the so-called Diabolo test described by Held [1] was used and DP1000 steel was analyzed. The susceptibility of the sheared edge was tested on two test specimens. Each was produced by a different cutting method: shearing and chip cutting. Each specimen had a size of 40×200 mm. The Diabolo test set-up involved optical measurement. Thanks to a special punch geometry, the strain was localized into a small region adjacent to the sheared edge. This strain can be measured by the GOM Aramis strain measurement system. In this study, the maximum major strain φ1 before cracking was evaluated to characterize the edge cracking sensitivity. The moment of necking was detected by a time-dependent approach similar to the approach suggested by Volk and Hora for the Nakazima test [6]. The configuration of the punch and sample before the forming process is shown in Fig. 1a. The maximum edge strain values were then fed into a numerical model of the Diabolo test implemented in AutoForm software.
2 Experimental material and method

Diabolo test was performed using our Nakazima test machine [7], in which the classical spherical punch was replaced by a diabolo punch. The measurement and evaluation methodology was based on ISO12004, which describes the determination of the FLC curve from measurements. The ARAMIS DIC system and the time dependent method described by Prof. Hora were used for online measurement and evaluation. The measurement procedure consisted of assembling and calibrating of the setup, measurement, evaluation and processing of the measurement data, and finally their application in an FEM software. Edges created with two types of processes have been tested. One specimen had been sheared and the other machined. The outcome of the measurement was the dependence of force on the piston displacement.

The shear cutting procedure can be defined as two edges working towards each other to separate material into smaller pieces. The material between the edges is deformed so that fractures appear and eventually the material will separate. Material properties such as strength, Young's modulus and ductility have great impact on the cutting procedure. When the two edges engage in the material, see Fig 3, a fracture will appear on each side and will continue to grow as the edges continue to move through the material. A basic condition that must be met to perform a shear cutting operation is that the material of the cutting tool needs to have larger hardness and strength than the material to be separated.

After a shear cut operation, an edge with several different zones appear, see Fig. 2, and depending on the adjustment of the cutting tool the lengths of these zones can vary. With optimal adjustments of the cut tool, the shear zone represents 25–35% of the edge surface. An edge with a large burr zone is a sign that the adjustment of the shearing tool was suboptimal.

With the shearing knives appropriately adjusted, the cracks running from both sides meet, resulting in material separation, as in Fig. 3. With increasing clearance between or wear in the knife edges, the cracks are less likely
to meet. This leads to higher forces needed for separation and poorer quality of the sheared surface. The resultant sheared surface quality can be altered by making changes related to the gap (clearance) between the knife edges, the wear in the knives, the shearing edge geometry and the amount of lubricant.

![Diagram of shearing process](image)

**Fig. 3** With optimal adjustments, the fractures will meet and give a fine cut. When the edge advances approx. 40% (0.4t) of the thickness of the material, a fracture will appear.

### 2.1 Sheared edges of specimens

Both specimens were examined under an optical microscope to evaluate the effect of the surface condition on the risk of edge cracking. The edge qualities were analyzed under a microscope and micrographs were taken. Fig. 4 below shows the quality of the sheared surface in the sheared specimen.

![Micrographs of sheared surface](image)

**Fig. 4** Quality of the sheared surface in the sheared specimen of DP1000 steel sheet of 0.8 mm thickness

The figures below document the quality of the edge surface in the machined specimen.
2.2 Measurement results
The measurement revealed considerable differences resulting from the processes that had been used for creating the edge surfaces. The maximum force prior to cracking depended strongly on how the specimen edge had been created. For the specimen with a machined edge, the force was almost 2.5 times higher than for the sheared specimen. The first response recorded early in the graph was the specimen bending. Then, once the entire shaping punch surface had come into contact with the specimen, the force increased steeply, after which a crack initiated and began spreading from the free edge (Fig. 4).

ARAMIS is a Digital Image Correlation (DIC) system developed to measure displacements, surface strain, velocity and accelerations of a test object. The system creates a 3D measurement and uses digital images to measure changes of the material specimen of just a few millimeters to several meters in size. The measured data is used to determine material properties of the test specimen such as Young’s modulus (elastic modulus) and Forming Limit Curves (FLC).
An example of what major strain distribution prior to cracking may look like in the ARAMIS system is shown in Fig. 7.
Numerical modelling of the Diabolo test was performed using the AutoForm software. The longitudinal axis of the specimen was parallel to the rolling direction. The “roll angle” in the software was therefore set at 90°. Only a single-action draw was simulated, where the positions of the punch, the die and the blank holder are precisely defined. In this case, the specimen is held firmly by two high-strength bolts, which is why the blank holder was affixed securely. The friction value in AutoForm was set to different values in order to test which value gives results similar to the actual tests. This was done by exporting force and punch depth data and comparing it with results from the real tests in a diagram.

The material model embodied in the work-hardening curve has a major impact on the force magnitude computed in numerical simulation. The simulated and actually measured forces were in relatively good agreement. The damage parameters in the AutoForm software were only considered for visual evaluation of the threshold. They had no effect on the force calculation. The main goal was to adjust the damage parameters in the AutoForm software to ensure that the simulated crack forms at the same time and piston position as in the real-world test. Input values were based on the measurement and had to be defined for two manufacturing processes. The threshold strain was determined directly from the DIC ARAMIS data and then calibrated with the AutoForm software. When the threshold value is correct, red regions in the simulation identify the same critical locations for cracking at the same piston positions as in the real-world measurement. The critical region is usually associated with values near unity. This threshold value also depends on the left side of the FLC diagram which depicts the uniaxial stress state generated in the free edge and in its vicinity.

![Fig. 8 An overview of the die, blank holder, punch and specimen used for the simulation](image)

![Fig. 9 Evaluation of the risk of cracking by simulation](image)
4 Conclusion

This paper evaluates the effects of various cutting processes on crack formation in a blank edge using the Diabolo test. The test specimens of 0.8 mm thickness were made of DP1000 steel and had two types of edges. Those were produced by shearing and chip cutting. The microstructures in their material were examined, which revealed new aspects related to this issue. The measured strain values were fed into numerical simulation of the Diabolo test carried out using AutoForm software which offers the capability to use such values for modelling deep drawing processes. Measured values can be used for any computational software that allows calculation of material damage.

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References

[1] Held, C., Schleich, R., Sindel, M., Liewald, M.: Investigation on advanced forming limit prediction techniques for high strength steels, in: Proceedings of the IDDRG 2009 Conference, 461–470.
[2] Liewald, M., Gall, M.: Experimental investigation of the influence of shear cutting parameters on the edge crack sensitivity of dual phase steels, in: Proceedings of the IDDRG 2013 Conference, Zurich, Switzerland 219–224.
[3] ISO 16630, Metallic materials - Sheet and strip - Hole expanding test, Berlin, Beuth, 2009.
[4] Falk, J.: Fracture prediction of stretched shear cut edges in sheets made of Dual-Phase steel, Master’s degree thesis, Blekinge Institute of Technology, Karlskrona, Sweden 2017.
[5] Bouaziz, O., Douchamps, S., Durrenberger, L., Bui-Van, A.: The double bending test: a promising new way for an optimal characterization of cut-edges ductility, in: Proceedings of the IDDRG 2010 Conference. Graz, 575–582.
[6] Volk, W., Hora, P.: New algorithm for a robust user independent evaluation of beginning instability for the experimental FLC determination. International Journal of Material Forming, 4, 339–346, 2011.
[7] Fedorko, M., Urbánek, M., Rund, M., Prediction of thinning of the sheet metal in the program AutoForm and its experimental verification, in: IOP Conference Series: Materials Science and Engineering, ISSN: 17578981, 2017