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Determining the influence of shear cutting parameters on the edge cracking susceptibility of high-strength-steels using the edge-fracture-tensile-test

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Abstract

The usage of high-strength-steels allows for the reduction of a component's weight by reducing the sheet thickness. During the production process of such components, shear cutting is commonly used for the initial cutting process. One of the main challenges in the production process is imposed by the shearing operation, which yields high tensile loads on the parts' edges. During the subsequent forming process, edge-cracks occur and therefore limit the forming potential of these materials. Studies at our institute focus on developing a new measuring method to investigate the formation of edge-cracks. This procedure called, an edge-fracture-tensile-test, helps to identify relevant parameters of the shearing process to avoid edge-cracks. The sample geometry resembles the shape of tensile-test-samples. The following test parameters can then be varied: die clearance, cutting edge geometry, and open or closed cutting line. The results show it is possible to influence the formability of cut edges by varying the process parameters.

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Keywords: Edge crack; Cutting; High-strength-steel

1. Introduction

A central challenge in modern car body manufacturing is the application of lightweight components. Mass reduction is necessary for the improvement of product properties as well as for economical and ecological reasons. By applying high performance materials, for example, high-strength steels with yield strengths above 600 MPa and tensile strengths above 800 MPa, an improved crash performance and enhanced driving comfort can be achieved. Higher material-strengths for crash-relevant components allow for the reduction of material-thickness and thus the required weight reduction of the body in white. [1]

Nevertheless, a challenge in the usage of high-strength steels is caused by the edge fracture sensitivity of many steel sheet materials. In addition to the material selection, the cutting process also significantly influences the occurrence of edge fractures. Due to the commonly used shear cutting process in production, high strains are induced in the shear affected zone. [2, 3] This deformation at the edge of the component causes work hardening, which also leads to a significant reduction of the residual formability. During subsequent process steps, which usually generate a nearly uniaxial stress on the component's outline, edge fractures can occur as a result of these loads applied [4].

The evaluation of edge fracture sensitivity can be conducted using a variety of examination methods such as the hole-expansion-test according to ISO 16630 [5], the collar-drawing-test according to VDI 3359 [6], the Diabolo-test [7] or the open-hole-tensile-test. Most of these methods are used to detect edge fractures via direct, friction-based contact at least for parts of the measurement. This may influence the quality of the results obtained. In addition to that, the component edge is usually not exposed to tensile loads, even though this is a common edge load during the forming processes. Only [8, 9] and [10] use samples with an induced tensile load. These experiments are called half-a-dog-bone-tensile-test, the dog-bone-tensile-test, the strip-tensile-test and a tensile test with notched specimen.

Due to the challenges mentioned earlier, an edge crack testing method should fulfill the following criteria:

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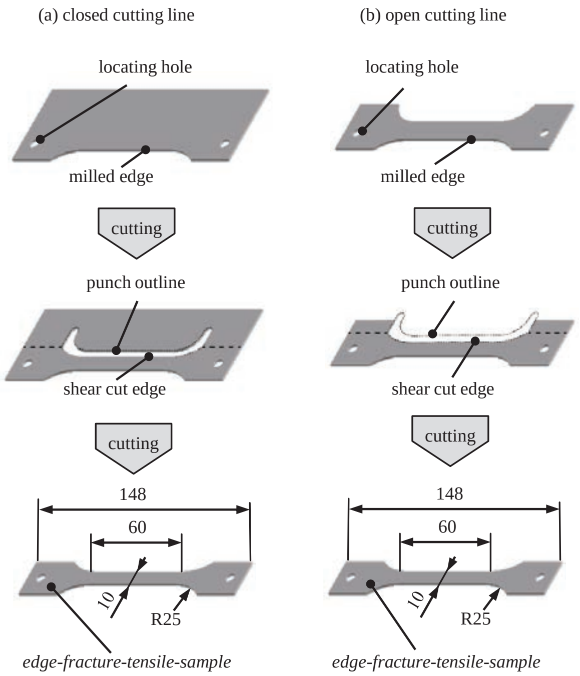

Fig. 1. Schematic draft of sample geometry.

- Cost-efficient and simple production of samples
- Friction free testing method
- No strain gradient
- Uniaxial tensile load on cross section

2. Edge-fracture-tensile-test

2.1. Process idea

The edge-fracture-tensile-test, which was developed at the Institute of Metal Forming and Casting (Technische Universität München), represents a friction-free process. It allows for the characterization of the edge fracture tendency of steel sheet materials and the determination of the forming limit under tensile stress. The main factors of influence on the phenomenon of edge fractures are, among others, the separation method, the cutting surface parameters, the shear affected zone, and the tool wear structure as determined by several studies. [4, 7, 11] The use of edge-fracture-tensile-tests combined with the tool described in chapter 2.2 allows for the separation of the influence factors on the edge fracture and the systematic evaluation of these. [12]

Figure 1 (a) shows the manufacturing steps from the initial sample to the edge-fracture-tensile-sample by using a closed cutting line. The first image shows the initial sample geometry with the locating holes. The lower side of the edge-fracture-tensile-sample is manufactured using a milling process. The sample in the middle shows the geometry of the shear cutting process with a closed cutting line, the outline of the punch and the resulting scrap. The lowest picture shows the final edge-fracture-tensile-sample with its dimensions. Figure 1 (b) shows the manufacturing steps by using an open cutting line. The milled side of the sample must have a higher formability than the shear cut side because of the shear cutting process and the consequent residual formability. This ensures that the crack initiation starts at the shear cut edge. [12]

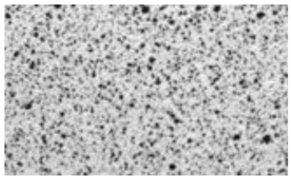

Fig. 2. Stochastically distributed sprinkle pattern on sample area

Depending on the materials analyzed and their edge fracture sensitivity, the initial samples were produced using a milling process in order to get optimal results. In their work, Dykeman et al. [9] test rectangular samples that are shear-cut on both sides and states that the die clearance ‚may not be uniform around the perimeter of the blank' [9]. In order to minimize possible machining tolerances, the edge-fracture-tensile-samples are shear-cut on one side only.

After producing the edge-fracture-tensile-samples according to Figure 1, the sample is painted white (sample area 60 x 10 mm) and a stochastically distributed sprinkle pattern, as shown in Figure 2, is applied.

The sprinkle pattern is used to determine the strain of the sample after the edge fracture test using the optical measuring system Aramis by GOM – Gesellschaft für Optische Messtechnik mbH, Germany. The samples are then placed in a universal testing machine and tested according to DIN EN ISO 6892-1 [13]. During this, tensile stresses are induced in the sides of the samples. In the next step, the Aramis measurement data is evaluated and parameters like strain or sheet metal thinning can be visualized as a function of the image rate used. The material parameters during the necking can then be determined using the procedure described by [14, 15].

2.2. Cutting tool

A modular cutting tool was designed and manufactured to determine the relevant factors of influence. Furthermore, a new-edge-fracture-tensile-sample was developed. The cutting tool for the experimental runs is shown in Figure 3. It allows for the production of edge-fracture-tensile-samples with an open or a closed cutting line, using different cutting parameters (for example edge radii of the active elements or blank holder force). The geometry of the initial sheet only needs to be adapted to realize different cutting line geometries. With different cutting active elements, it is possible to adjust the cutting parameters such as, for example, the die clearance. Moreover, it is possible to realize a single and multi-cutting process. The cutting tool, which is used for the experimental investigation, has a very high stiffness. Due to the high tool

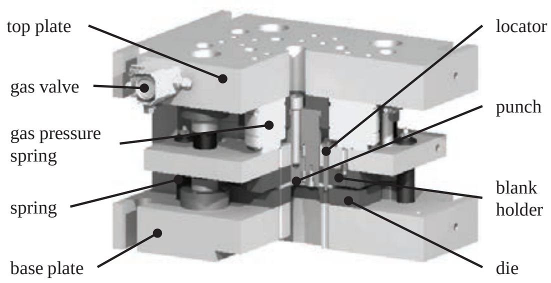

Fig. 3. Used tool for shear cutting of the edge-fracture-tensile-samples [12].

stiffness, there are no displacements of the cutting elements caused by deflection or shifting during the cutting process. The blank holder plate guides the punch; therefore, a minimal guiding tolerance can be achieved. The initial positioning of the blank holder plate and the die is realized with alignment pins. Due to gas pressure springs, different blank holder forces for the different sheet materials and blank thicknesses can be applied. The sample is positioned by locators. A high repetitive accuracy in the orientation of the samples will be achieved by this kind of positioning. [12]

3. Materials

The tool material used for this study was a conventional high chromium, high carbon tool steel (material number 1.2379), which is commonly used for shear cutting processes. This material typically shows type M7C3 carbides with an average diameter of 10 µm.

Table 1. Chemical composition in weight percentage of tool steel 1.2379 [16]

Chemical element	C	Cr	Mo	V
Weight percentage	1.55	12.0	0.7	1.0

It is usually hardened to 60 HRC. When applying higher hardness values, the material tends to be too brittle for the purpose of manufacturing samples. Lower values for the hardness, on the other hand, are usually plastically deformable and therefore inapt for the shear cutting process. [2] Table 1 shows the chemical composition of the material mentioned above.

Table 2. Chemical composition in weight percentage of sheet steel HCT980XD [17]

Chemical element	C	Si	Mn	P	S	Al
Weight percentage	0.11	0.65	2.35	0.04	0.01	0.02-0.06
Chemical element	Cr+Mo	Nb+Ti	V	B	Cu	
Weight percentage	0.95	0.09	0.03	0.01	0.15	

The sheet material to be cut was a zinc coated HCT980XD (DP1000 according DIN EN 10346), with 1.5 mm sheet thickness. In its initial state, the material consists of the main phases, ferrite, martensite, and bainite, as well as residual austenite as secondary phase. It shows minimum yield strength of 700 MPa and a tensile strength between 980 MPa and 1130 MPa. The minimum strain at failure is 8 %. [17] The chemical composition of this sheet steel is shown in Table 2.

4. Experimental design

Using the material HCT980XD with a blank thickness of 1.5 mm, the influence of the following parameters (see Table 3) on the edge fracture sensitivity was determined.

Table 3. Process parameter of the edge-fracture-tensile-tests

Process parameter	
Punch cutting edge radius	Sharp-edged
Die clearance *u*	2 %, 5 %, 10 %, 15 %, 20 %
Cutting line	Open, closed
Blank holder pressure	60 bar

The unusually small cutting offset of only 2 % was chosen to reproduce an inapt displacement of the tool. The blank holder force was not varied because even at the lowest possible setting of the gas springs, the minimum blank holder force of 30 % of the cutting force was already exceeded. For each experimental run, at least five edge-fracture-tensile-samples were tested and all results were averaged. All edge-fracture-tensile-samples were produced using material with an orientation of 90° relative to the direction of rolling.

The cutting surfaces of the components are characterized according to [18]. An analysis of the profile measurement of the cut parts are performed by a device of Mahr GmbH, Germany (MarWin XCR 20, PCV). A thin needle scratches along the sheared edge and thus detects the size of the parameters' rollover, clean-shear, fracture and burr with a scanning accuracy of 1.0 µm (see Figure 4).

In addition to this, the cutting edges of the cut active elements are scanned with this system before the experiments. At the beginning of the experimental runs, the edge radii of the cutting elements are sharp edged which means the cutting edge is whetted after the grinding process.

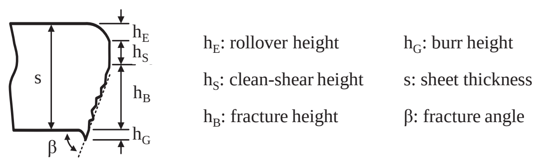

Fig. 4. Significant cutting surface characteristics [18].

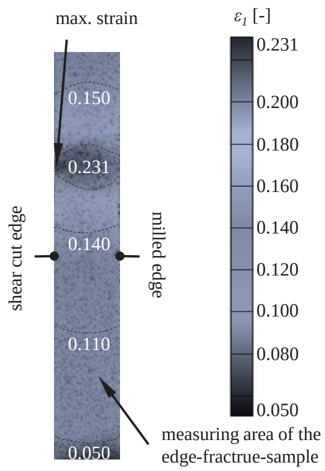

Fig. 5. Visualization of the strain distribution in the edge-fracture-tensile-sample [12].

5. Results

The residual formability of the shear cut edge before fracture initiation is the key parameter for the experimental runs of the edge-fracture-tensile-tests. The beginning of the local necking characterizes the critical limit of failure. Such a local distortion leads to rejected components in the production process. Therefore this failure criterion was chosen. The strain at the beginning of the necking is determined by the method according to [14, 15]. The behavior of the results for the strain at the beginning of the necking or during the fracture is comparable when using the process parameters which are shown in Table 3. The photogrammetric measuring system Aramis by GOM – Gesellschaft für Optische Messtechnik mbH, Germany enables the local detection of the degree of deformation caused by tensile stresses. Figure 5 shows the local concentrated deformation of the shear cut edge of the sample at the beginning of necking.

5.1. Formability of the sample's edges after shear cutting

The following diagram shows the obtainable major principal strains of the sample milled on both sides and the single side shear cut sample at the beginning of necking by using a closed cutting line.

Caused by the shear cutting process, the edge of the sample is significantly deformed. This leads to hardening of the material in an area along the cutting line. The result is a reduced formability in this area. When selecting inapt shear cutting parameters, the forming potential of the shear area is significantly reduced. A displacement of the tool (correspond to die clearance 2 %) can reduce the forming potential by up to 63 % compared to regular samples. This results in a limited use of the material's forming potential since an inadequate edge load can lead to edge fractures even at lower levels for the mechanical load. The maximum formability of a shear cut sample was measured at a cutting clearance of 20 %.

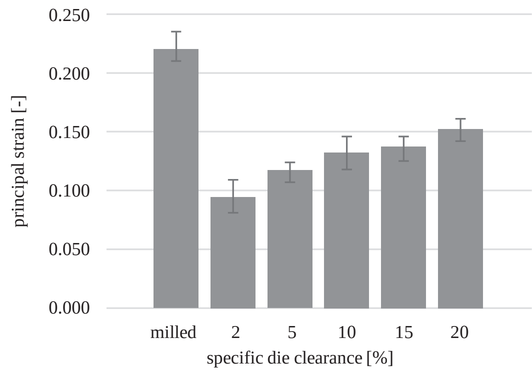

Fig. 6. Comparison of the forming capability of the edges of milled and shear cut samples (closed cutting line).

If the samples are produced using an open cutting line (see Figure 7) with a scrap-width of 4 mm, an increase in the values for the formability at the beginning of necking can be detected when compared to samples with a closed cutting line (as depicted by white bars in Figure 7). This is a result of the modified stress condition in the shear area. When producing samples with an open cutting line, the stiffness of the scrap material is reduced and able to absorb parts of the deformation. The principal strain increases by 50.4 % compared to the closed cutting line when using a specified cutting clearance of 5 %. A principal strain of 0.160 (at beginning of local nacking) at the shear cut edge of the edge-fracture-tensile-sample can be obtained using a cutting clearance of 15 % combined with an open cutting line and a scrap-width of 4 mm.

The graphs in Figure 6 and Figure 7 show the results for the pre-cut blank. The edge-fracture-tensile-samples are taken from sheet material at an orientation of 90° relative to the direction of rolling.

This shows that it is necessary to carefully select the cutting parameters in order to optimally use the forming potential of each material.

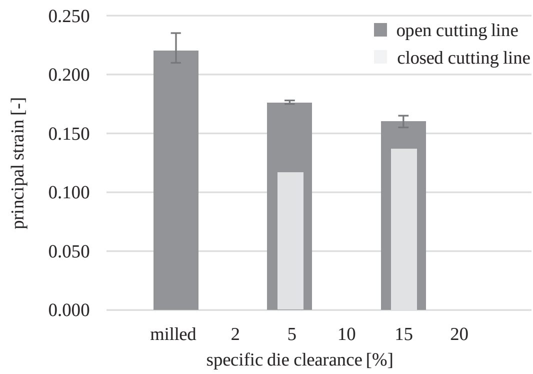

Fig. 7. Comparison of the forming capability of the edges of milled and shear cut samples (open cutting line, scrap-width 4 mm).

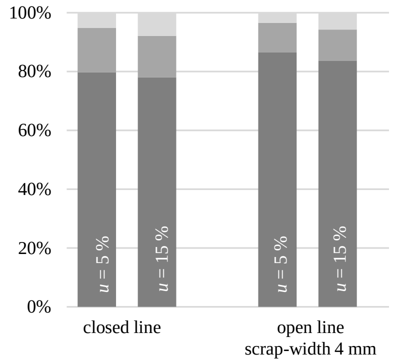

Fig. 8. Comparison of cutting surfaces by using closed and open cutting lines

5.2. Cutting surface characteristics of the component's shear cut edges

Figure 8 shows the characteristic cutting surface parameters according to VDI 2906-2 [18] for closed and open cutting lines (scrap-widths 4 mm) by using a 5 % and 15 % die clearance.

The profile of the sample's edge is significantly influenced by the stiffness of the scrap (as can be seen in Figure 8). This is a result of the change in stress in the shearing zone during the shear cutting process when selecting different cutting strategies (open or closed cutting line).

When using an open cutting line, the rollover height and clean-shear height decrease. The height of the rollover also increases with a higher die clearance regardless of whether an open or a closed cutting line is chosen (see Figure 8).

Therefore, when the cutting clearance is increased from 5 % to 15 %, the clean-shear height decreases when using a closed cutting line and increases when using an open cutting line. When using sharp-edged cutting elements, only a slight burr of 3.5 - 4.5 µm is formed during the cutting process with a cutting clearance of 5 %. The burr slightly increases to 5.5 – 8.5 µm when setting higher values for the cutting clearance. The following Figure 9 visualize the measured cutting surface parameters from Figure 8 at two photomicrographs.

6. Conclusion and future outlook

The edge-fracture-tensile-test allows evaluating the edge-fracture-sensitivity of conventional and high-strength steels with reduced monetary and time efforts In order to utilize the formability of the material in an optimal way, the cutting parameters can be adjusted. A new frictionless investigation method was developed that enables the steel and sheet metal processing industry to characterize new steel grades with little effort and time. The forming potential of high-strength steels is limited by edge fractures caused by the shear cutting process, as shown in the experiments mentioned above. Based on this knowledge, it is necessary to select suitable shear cutting parameters especially for cutting of blanks. Therefore, a higher residual formability can be maintained by using a

- material specific die clearance and an
- open cutting line.

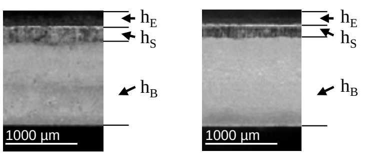

Fig. 9. Cutting surface: closed cutting line (left), open cutting line (right), die clearance 15 %.

Moreover, the focus of continued investigations should be on the influence of die clearance variation, cutting edge geometry and the width of the stamping waste by using an open cutting line.

Acknowledgements

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