Design and conceptualization of a cutting tool to investigate the influence of the shear cutting process on edge crack sensitivity

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Abstract. High-strength and ultra-high-strength sheet materials are becoming increasingly integrated in the automotive and commercial vehicle industries. Consequently, their edge crack sensitivity requires particular attention, starting with the component design. In addition to the only standardized testing method, the hole expansion test according to ISO 16630, various testing procedures characterize the occurrence of edge cracks. However, neither the ISO standard nor any other published experimental setup focuses on the design of the cutting tool used to generate the cutting surfaces, which is fundamental in order to produce conclusive results with low variance. This paper presents the constructive design and choice of materials with regard to a cutting tool for the Edge-Fracture-Tensile-Test as well as a punching tool for the hole expansion test. The modular concept allows an evaluation of the influence of the following parameters on the edge crack sensitivity: single-stage or multi-stage shear cutting process, open or closed cutting line, die clearance, cutting edge geometry.

1. Introduction

Weight reduction, cost minimization, improved crash behavior, and electro-mobility are the driving forces behind the choice of materials for automotive applications. Those factors not only serve as incentives to increasingly develop new and innovative sheet metal materials, but also to implant those materials in various applications. Compared to material concepts used up to now, the characteristic properties of these new materials and their alloys generally lead to improved formability, high component strength, and energy absorption capacity in the case of a crash. High-strength steels offer a combination of those beneficial properties and, therefore, have developed into one of the fastest growing lightweight construction materials in recent years.

Nevertheless, the increased use of these materials in body construction entails new challenges with regard to process stability, which manufacturers in the automotive industry have to face, particularly those who manufacture structural components. The major problems here include so-called “edge cracks” on shear cut edges of high-strength materials. They result from a reduced forming capacity of the cutting surface for subsequent forming processes, which is caused by work hardening at the component edge induced by previous cutting processes.

For adequate process safety and productivity, it is important to take not only process-appropriate, but also load-appropriate material characterization into account in order to determine the deformation limits of the material and to utilize possible forming potentials. Therefore, it is essential to know and apply suitable test methods to determine the maximum deformations of such materials. The hole expansion test is the only standardized test procedure to detect the edge crack sensitivity of a sheet material.
standardized method of the test includes the hole production procedure, but not explicitly the shear cutting tool or the shear cutting process. Thus, the punching process can be carried out with or without blank holder and with sharpened or rounded cutting edge, which, in each case, results in different cutting surfaces on the specimens. [1]

![Cutting surfaces](image)

**Figure 1.** Cutting surfaces manufactured a) with sharp cutting edges, b) with rounded cutting edges.

Due to the considerable influence that the cutting tool has on the properties of cutting surfaces (see figure 1), test results from different test devices are not comparable, since the cutting surfaces have a different residual formability. It is imperative to define guidelines and recommendations for the production of shear cutting tools in order to ensure comparability of test results.

2. **State of the Art**

2.1. **Shear Cutting Tool**

2.1.1. **Components of a Shear Cutting Tool** Shear cutting tools typically comprise a plurality of components. Besides the tool frame made of plates, these include the tool guide elements and various additional components, such as active elements (punch and die), spring, band guides, positioners, strip lifters or component ejectors, and sliders. Different tool materials are used depending on the tool size, component contour, piece number, stroke rate, sheet material, etc. These range from inexpensive cast iron materials for large-scale tools up to cold work steel and powder-metallurgical steel, and even ceramics for active elements.

The blank holder force is applied by springs, which can be either coil springs or gas pressure springs, depending on the application. Coil springs are available in different strength grades, but they also have a substantial disadvantage in the almost linearly increasing spring force with increasing spring travel. It should be noted that coil springs must be installed pre-loaded in the tool. This can be done via pre-loaded spring packs or via the blank holder plate. Gas pressure springs can be either purchased pre-filled from a manufacturer or filled using an appropriate filling device. An interconnection of the gas pressure springs in the tool allows an equalization of the spring pressures and thus permits a constant blank holder force in the entire tool. Depending on the design of the gas pressure springs, an almost position-independent blank holder force can be realized, which counteracts tilting of the blank holder plate. It must be considered that gas pressure springs must not be subjected to lateral forces. Otherwise, the leak tightness is lost. Furthermore, gas pressure springs may only be used up to 200 strokes/min [2], which means that coil springs must be used in high-speed applications.

The strip guide can be implemented by various means, for example, with guide rails, or in case of a plate guidance tool, with the tunnel forming guide plates. The components and metal bands are positioned with locators. For simple components, this can also be done via mechanical stops, which require recess areas in the band. If it is not a tool used exclusively for cutting, it may be necessary to lift
the band with a strip lifter. This can be constructively implemented by elastic pressure pieces for example.

2.1.2. Tool Technology for Shear Cutting

In principle, three different tool designs are distinguished between: unguided free-cutting tools, plate guidance tools, and column-guided tools. Figure 2 shows a schematic illustration of the three different types and their functional components. Depending on the number of components to be produced, the required accuracy of the components, and the available machinery, the most economical tool solution is selected.

The unguided cutting tool with a shank (figure 2 a)), which can be used for free cuts, is the cheapest design. This constructively very simple design only requires a lower active element on a base plate and a blade located on top. Since there are no guiding elements on the tool side, the plunger guide of the forming machine is used as guidance. Therefore, the accuracy of the forming machine determines the maximum possible precision for the cutting process. In particular, the positioning of the punch relative to the die is challenging. An inaccurate alignment of those two active elements relative to each other can lead to a varying die clearance along the cutting line, which in turn causes uneven wear on the active elements. Even a collision between the punch and the die is possible. The tool is usually operated without a blank holder, only a stripper is used to strip off the punching scrap after the cutting process. These shortcomings make this tool only suitable for small quantities of components with low cutting surface requirements and simple geometries.

The plate guidance tool (figure 2 b)) is a further development of the unguided shank tool. It has an additional guide plate, which is positioned relatively to the cutting plate and forms a tunnel in combination with the strip guide. The guide plate supports the punch guide and improves the positioning of the cutting punch. This allows for a uniform adjustment of the die clearance, avoids collisions between the active elements, and prevents buckling of thin cutting punches. The quality of the cutting surface is thus improved, even for complex component geometries. Furthermore, the guiding plate acts as a stripper of the cutting lattice when the tunnel is adequately adapted to the sheet metal bands. If the tunnel is too narrow, the risk of jamming the band increases, which leads to process errors. This tool design is
a comparatively cost-effective solution and is used for large quantities of components with medium to high accuracy requirements.

The column-guided tool (figure 2 c)) is generally used in multi-stage tools, such as stage or step tools. This design consists of at least two plates, and three when a blank holder is needed. A special feature of this column-guide configuration is that the guiding is distributed over several guide elements, which reduces the stress on the forming machine guide as well as the punch guide. The guide can be realized by means of plain bearings (column slide-bush combination) or roller bearings (column roller-element bush combination). These types of guides are used for large quantities of components with high accuracy requirements. The implementation of roller elements enables the production of high-precision components with complex geometries. For applications in high-speed presses, this column-guide design allows stroke rates of up to 2,000 strokes/min. A disadvantage is the susceptibility to lateral forces. The reduced contact length results in lower transverse stiffness, which in turn increases wear.

2.2. Strategies for Edge Crack Detection

2.2.1. Hole Expansion Test (HET) The HET according to ISO 16630 [1] is the only standardized testing method to determine edge crack sensitivity of shear cut edges. The testing procedure is divided into two stages; first, punching a hole in the sheet metal blank and, next, expanding it gradually. The initial hole is identical for all materials, 10 mm in diameter and punched with a relative die clearance of 12 %. The subsequent hole expansion setup includes the previously punched sheet metal specimen, a conical punch of arbitrary diameter centered on the hole, and a blank holder to prevent plastic flow. As soon as a crack appears over the entire thickness of the metal sheet, the test is terminated. The obtained parameters are the expansion ratio λ, the initial diameter D₀, and the expanded diameter Dₜ.

The comparability of the test results depends on various parameters, such as orientation of the specimen and precise detection of the crack formation [4]. If the burr of the initial shear cut hole is facing towards the expansion punch, unfavorable high or even damaging deviations and hole expansion ratios are the consequence. Hence, having the burr on the opposite site of the punch causes earlier failure and protects the equipment [4]. In the standardized setup, the press operator monitors the crack initiation, which makes the detection susceptible to human errors. This represents a major restriction in this testing method and leads to a lack of reproducibility due to the operator’s perception and reaction speed. In order to improve the reproducibility of the HET and to eliminate the influence of the operator, [5] and [6] expand their experimental setup. [5] uses an optical forming analysis system, while [6] suggests using the stamping force as an indicator for crack initiation.

2.2.2. Edge-Fracture-Tensile-Test (EFTT) The EFTT [7] was developed at the Chair of Metal Forming and Casting of the Technical University of Munich. It combines a defined shear cutting process with a special shear cutting tool and a subsequent tensile testing procedure with an optical deformation analysis. The test allows an analysis of edge fracture tendencies and metal forming limits of shear cut metal sheets. The EFTT fulfills the following criteria [8, 9]:

- Frictionless testing method without any strain gradient before local necking occurs
- Uniaxial tensile load on the cross section, which is a common edge load arising from forming processes
- Possibility to differentiate between the failure modes of ductile fracture and mechanical failure due to edge cracks
- Scatter-resistant evaluation method with a high repeat accuracy
- Cost-efficient and simple production of specimens combined with a reliable preparation of the specimen’s edges
- Different abort criteria, for example the start of local necking [10, 11] or fracture, can be applied, in which the strain distribution to be determined has to be recorded
- Possibility to use the results, especially the residual formability, as limit values for finite element simulations
Edge cracks are influenced by various factors, such as separation process, cutting surface characteristics, shear affected zone, tool wear and material microstructure. [4, 10, 12] Using the tool described below allows to evaluate the edge crack sensitivity and its influencing factors. In addition to the lack of friction, distinguishability between ductile fracture and mechanical failure is also a great advantage of this method. Figure 3 shows the steps needed for manufacturing an edge fracture tensile specimen. The forming potential of the basic material is determined by performing the comparative test with milled reference specimens.

![Diagram of EFTT specimen](image)

**Figure 3.** Production process of a shear cut EFTT specimen for a closed (a)) and open (b)) cutting line [13].

The specimens are tested with a constant strain rate of 0.004 1/s according to DIN EN ISO 6892-1 [14] with a universal tensile testing machine Allroundline 150 kN (Zwick GmbH & Co. KG, Ulm, Germany). The optical deformation measuring system ARAMIS (GOM GmbH, Braunschweig, Germany) is used to observe the deformation, major and minor principal strain, sheet metal thinning, and residual forming potential at the specimen’s edge. The collected data provides information on the underlying failure mode.

2.2.3. Other Non-standardized Edge Crack Testing Methods There are several testing methods which allow the evaluation of the edge fracture sensitivity dependent on material and cutting parameters, for example the collar-forming test [15], the HET with a Nakajima punch [16], the open hole tensile test [17], the Diabolo test [18], the BMW edge crack test [19], the strip tensile test [20], the half-a-dog-bone tensile test [21], and the tensile test with a notched specimen [22].
3. Shear Cutting Tool for Manufacturing Edge Crack Specimens

Regardless of the specific specimen geometry, the computational and structural tool design can be carried out analogously to the approach described below. To illustrate the procedure, the cutting tool [7] (see figure 4) for the preparation of EFTT specimens is explained in detail.

![Figure 4. 3D cross-section of the EFTT shear cutting tool.](image)

3.1. Computational Design

For the computational design of the tool, an estimation of the forces occurring at the upper active element is required. The cutting force is obtained from the empirical formula (1) [23], based on the assumed shear factor \( k_s = 0.8 \), tensile strength of the material \( R_m = 1,200 \) N/mm\(^2\), sheet thickness \( s = 6.0 \) mm, and the length of the cutting line \( l = 194.25 \) mm, the cutting force is calculated to \( F_S = 1,119 \) kN.

\[
F_S = k_S \cdot R_m \cdot s \cdot l
\]

According to the literature, the blank holder force is supposed to be 15 % to 30 % of the maximum cutting force. Since four gas pressure springs are installed in the tool to maintain symmetry and to prevent tilting of the blank holder, the maximum blank holder force of \( F_{BH} = 336 \) kN is distributed to a required maximum spring force of \( F_{Spring} = 84 \) kN for each spring. Using gas pressure springs filled with nitrogen in a variable manner between the minimum pressure of 25 bar and maximum pressure of 150 bar [2], the necessary blank holder force can be realized.

In order to implement a self-opening tool, the opening force of the coil springs needs to be assessed. From the CAD data, the weight of the upper tool can be determined as 147 kg, which results in an opening force of \( F_{open} = 0.36 \) kN for each of the four installed springs. Therefore, the springs are pre-loaded until the necessary opening force is exceeded. With a nominal stroke of 19.0 mm, the required spring deflection must be set significantly larger.

To keep the head clearance of the upper active element constant with respect to the punch mounting plate, a hardened pressure plate is added between the active element and the uncured head plate. From the previously determined cutting force \( F_S \) and the punch cross-section \( A_S = 2,207 \) mm\(^2\), a surface pressure under the punch head of \( \sigma_D = 507 \) N/mm\(^2\) is calculated. The permitted surface pressure for S355 J2G3 steel (material number 1.0050) was assumed to be \( \sigma_{D,S355J2G3} = 250 \) N/mm\(^2\) [24], which leads to the required area for the hardened pressure plate of \( A_{eff} = 4,476 \) mm\(^2\).

A dimensioning of the fastening screw is necessary due to the retraction force which frequently occurs during the shear cutting process, which acts on the upper cutting active element. In addition, the
base plate (thickness 80 mm) should be designed for deflection because cutting tools are generally operated on a press bed with a passage opening. The base plate was designed using a quick static FE simulation. For this purpose, a line load was applied along the passage opening of the tool base plate in the size of the maximum punching force. This reflects a worst-case scenario, since the stiffening effect of the die plate (thickness 30 mm) is not taken into account. The plate was supported according to the real application on a BSTA 1600-181 from Bruderer AG, Frasnacht, Switzerland, with a 130 mm passage opening of the press bed. Figure 5 a) visualizes the deflection of the base plate scaled by a factor of 100.

![Base plate deflection](image)

**Figure 5.** Simulated translational displacement of the base (a)) and guiding plate (b)) of the shear cutting tool.

The guide plate should be designed for deflection (figure 5 b)) with regard to prestressed gas pressure springs with a preload distance of 1.0 mm and a load of 42 kN per gas pressure spring. To prevent jamming of the upper active element in the blank holder due to excessive deflection, a thickness of 40 mm was selected for the guide plate. In the simulative design, the blank holder plate (thickness 30 mm) was not taken into account since this leads to a reduction of the deflection of the guide plate. The blank holder force was applied as a surface load at the corresponding positions of the installed gas pressure springs. The change in the spring force due to the penetration of the plunger rod during the cutting process is not to be taken into account, since the spring force is introduced into the base plate via guide, blank holder and die plate. The permissible surface pressure between the plunger rod and the guide plate must also be checked. The maximum permissible spring force is 9.4 kN for a plunger rod surface of 47 mm² and a material strength of \( \sigma_{D, S355 J2G3} = 250 \) N/mm², so a hardened plate must be inserted between the plunger rod and the guide plate if a higher spring force is required.

3.2. **Constructive Design and Tool Assembly**

3.2.1. **Constructive Design** The modular design of the shear cutting tool allows high flexibility, e.g. in the production of edge crack specimens with different outside contours. This means that the active elements can be changed with little effort and without adjusting the tool peripherals. Multiple standard parts (FIBRO GmbH, Weinsberg, Germany, [2]) are installed:

- Locator with tapered tip, DIN ISO 8020
- Demountable guide pillar with center fixing
- Ball cage with assembly aid
- Flanged guide bush for ball bearing, DIN 9831/ISO 9448
- Gas spring
- High performance compression spring, DIN ISO 10423
- Spring plunger, with spring loaded pin, with hexagon socket, increased spring force
- Spring and spacer unit
Filling unit with armature

The tool accuracy and thus the homogeneity of the cutting surface along the cutting line depends on several aspects. The punch movement is significantly affected by type and positioning of the guide columns in the tool frame (base plate, guide plate, top plate (thickness 80 mm)) as well as the manufacturing accuracy of the punch guide, which is integrated into the blank holder. To reduce the risk of tilting and deflection, columns (diameter 40 mm) fixed to the guide plate (maximum column length 100 mm) are used. The holes for the guide bushes (maximum guide bush length 76 mm) in the base and head plate are drilled in one clamping, which increases the positioning accuracy and reduces positioning errors in relation to the guide plate. Since the guiding accuracy of the upper active element depends on the blank holder clearance, the tolerance was set to ± 1.5 µm. A head clearance (approximately 20 µm) between the punch and the punch pressure plate is mandatory to prevent jamming or seizing of the punch in the blank holder. In addition, it is necessary to precisely position the blank holder in relation to the lower cutting plate, which allows for a homogenous die clearance along the cutting line. For this purpose, the positioning holes (diameter tolerance ± 2.0 µm) and the contour of the upper active element are eroded in one clamping. Subsequently, the cutting edge of the lower active element is manufactured to the nominal dimension.

The blank holder force is applied by the four built-in gas pressure springs, which are linked by tubes and connected to a filling unit with armature to detect leaks in the gas system and to adjust the blank holder force on a process-specific and material-specific basis. The connection by tubes ensures that the pressure is the same in all the springs, and thus prevents tilting of the guide plate and the blank holder plate. In addition, leakages in the gas system can be detected as well. The distance between the upper surface of the guide plate and the lower surface of the head plate are precisely adjusted by the means of four distance units and the associated counter bores, whereby the integrated gas pressure springs are pre-tensioned. The distance units are also used to retract the guide plate. When manufacturing the counter bores, it must be ensured that these are produced to the same depth (depth tolerance ± 20 µm) to prevent the guide and blank holder plate from tilting.

Four integrated, pre-tensioned coil springs are used to open the tool when the upper part of the tool is detached from the forming machine. Thus, the sheet metal blanks can be inserted into the tool.

Spring-loaded thrust pieces in the lower active elements serve as stops for the positioning of the blanks. During the tool closing process, these pressure pieces are displaced by additional spring-loaded thrust pieces installed in the blank holder. This allows for the integrated locators to precisely align the blanks with the active elements before clamping them down onto the lower active element by the blank holder.

3.2.2. Tool Assembly

In order to generate cutting surfaces with constant properties along the cutting line and to examine the influence of the shear cutting parameters on the edge crack sensitivity, it is necessary to assemble the tool in a defined order, which is described below. Figure 6 illustrates the described tool assembly.

**Step 1:** Prior to integrating the active elements and the tool periphery involved in the cutting process, the ball guide bush and demountable guide pillar must be loosely screwed into the tool. The head, guide, and base plate are then assembled via the ball guide and the associated screws of the guide columns as well as bushings are tightened with appropriate torque. This procedure largely compensates possible position inaccuracies caused by manufacturing the fits for the columns and bushes.

**Step 2:** Subsequently, individual components are attached to the head plate, such as gas pressure springs, including filling unit with armature, pressure plate, punch holding plate, and punch adapter.

**Step 3:** The lower active element is only positioned on the base plate with screws, which are not tightened yet.

**Steps 4-5:** The blank holder is positioned via dowel pins and screwed on the guide plate. The guide plate is placed via ball guides onto the base plate equipped with preassembled elements. To position the lower active elements, the dowel pins already located in the blank holder are further driven in. The screws already located in the lower active element are tightened with appropriate torque through recesses.
in the blank holder and guide plate. The dowel pins, which are no longer of use, are then removed from the tool.

**Steps 6-7:** After that, the punch, which is prepared with a defined cutting edge radius, is inserted into the blank holder, the preassembled head plate is placed on the guide plate, and both plates are connected by four distance units. The upper active element is screwed to the punch support.

**Step 8:** Finally, the upper tool part is pulled off, the spring-loaded thrust pieces in the blank holder and lower active element are screwed in, and the four pre-tensioned coil springs in the tool are set accordingly. The assembled tool has a weight of 310 kg and external dimensions of 370 x 520 x 400 mm.

![Shear cutting tool assembly](image)

**Figure 6.** Shear cutting tool assembly.

### 3.3. Tool Materials

In accordance with the specific requirements for individual tool parts, some components are hardened, such as punch pressure plate, guide plate, active elements, punch adapter, and locators. These components, except for the locators, are made of ledeburitic cold work tool steel K110 (X153CrMoV12) (see table 1) with a hardness of 58 + 2 HRC.

| Tool material | C   | Si  | Mn  | Cr   | Mo  | V   | W   |
|---------------|-----|-----|-----|------|-----|-----|-----|
| K110          | 1.55| 0.30| 0.30| 11.30| 0.75| 0.75| -   |
| S600          | 0.9 | -   | -   | 4.10 | 5.00| 1.80| 6.20|

The K110 material was chosen for the tool because it is operated in single stroke mode and the active elements are replaced after a few strokes to ensure comparability between different materials and process parameters. In addition, this material has sufficient toughness under medium pressure load and high wear resistance against abrasion [26], thus avoiding unwanted pitting at the active elements. Pitting can lead to anomalies on the cutting surfaces and, therefore, influences the residual formability of the cutting edge.
The locators are made of high-speed steel S600 (table 1) with a shaft hardness of 64 ± 2 HRC [2]. The demountable guide pillars are made of steel with a core tensile strength of greater than 900 N/mm² and a surface hardness of 60 ± 3 HRC [2]. The ball cage (length 96 mm) with assembly aid is made of brass [2]. The corresponding flanged guide bushes for ball bearings are made of tool steel with a hardness of 62 ± 2 HRC [2].

Head plate, blank holder, base plate, and punch holding plate are made of S355J2G3.

4. Results of the Edge Crack Investigation

EFTT specimens [13] were used to determine edge crack sensitivity. The following figure exemplary visualizes the differences between ductile fracture (figure 7 a)) of a milled reference specimen and an edge crack failure (figure 7 b)) of a shear cut EFTT specimen based on images from ARAMIS (GOM GmbH, Braunschweig, Germany). The shear cutting process induces work hardening in the shear affected zone, which causes a localized deformation on the specimen’s edge and leads to edge cracks.

With respect to the relevant strain distribution at mechanical failure [16], the material’s susceptibility to edge crack formation can be determined. As stated in [17], further material parameters can be obtained, such as the start of local necking indicating the failure limit. The obtained data can then be used in FE simulations to predict edge cracks.

![Figure 7](image-url)

**Figure 7.** Strain distribution of a milled reference (a)) specimen and an EFTT sample (b)) before the formation of cracks (according to [27]).

Various process settings, such as die clearance [4], cutting line geometry (open / closed) [13], cutting strategy (one stage / two stage) [28], and edge geometry of the active elements have an impact on the cutting edge in a shear cutting process. This includes the geometry of the cutting surface, the microstructure, and the amount as well as depth of work hardening, which in turn lowers the residual formability $\varepsilon_1$. The major strain detected during failure of the EFTT specimen during the tensile test is referred to as residual formability.

Five samples were tested for each series of experiments. The determined residual formability at the start of local necking [10] was averaged and displayed as bars in the following diagrams. The error indicator represents the spreading width of the detected strains. The detected standard deviation $S$ was also entered into the diagrams.

Figure 8 illustrates the influence of the type of cutting line (open / closed) on the edge crack sensitivity of a specimen made of HCT780X with a thickness of 1.5 mm. The EFTT specimens were produced using a pressing, full-edged shear cutting process with sharpened cutting edges and a relative die clearance of 15 %. In the piercing process, the scrap width was 5.0 mm and 4.0 mm with an open cutting line. The graph shows that the residual formability of the cutting edges of the EFTT specimens
is reduced due to the stress distribution in the shear zone when using a closed cutting line. The strain loss due to the shear cutting process compared to the milled reference specimen is 22 % in the hole punching process and 13 % with the open cutting line.

Figure 8. Influence of the cutting line geometry on the residual formability.

Figure 9 shows the results for different die clearances and otherwise unchanged process parameters. It can be observed that the choice of the die clearance has a significant influence on the residual formability and thus on the edge crack sensitivity. The results shown in figure 8 and figure 9 reflect the first cut blank in the press plant.

Figure 9. Influence of the die clearance on the residual formability.

In mass production, the active elements wear out due to abrasion. This type of wear can be simulated by rounding the edge of the active elements. [29] The rounding of the upper active element of \( r = 50 \ \mu m \), as illustrated in figure 10, corresponds to the wear after 10,000 strokes with a lateral tool stiffness of 1,300 kN/mm when cutting the material SZBS800 with an open cutting line. The Docoll200M material shows this wear condition after approximately 55,000 strokes. [30] An edge radius of \( r = 200 \ \mu m \) on the
punch represents a worn edge. It can be seen in figure 10 that the residual formability of the edges of shear cut EFTT specimens decreases with an increased cutting edge roundness, due to the change in the microstructure and geometry of the shear cut surface during the shear cutting process.

Figure 10. Influence of the cutting edge condition on the residual formability.

5. Conclusion
The investigation of the influence of shear cutting process parameters on edge crack sensitivity requires a stiff tool with a high guide accuracy of the active elements. The tool is supposed to produce reproducible cutting surfaces with set shear cutting parameters, such as the die clearance. This ensures qualitatively comparable test results of different research facilities, in order to be able to classify a material with regard to its edge crack tendency and to choose suitable cutting parameters to avoid edge cracks during the production process. The experiments demonstrated that different cutting strategies have an influence on the residual formability and thus on the edge crack sensitivity of the shear cut specimens as compared to the milled reference specimens.

Acknowledgements
The EFTT was investigated in various projects at the Chair of Metal Forming and Casting (Technical University of Munich, Germany). This work was kindly supported by the Stiftung Stahlanwendungsforschung im Stifterverband für die Deutsche Wissenschaft e.V. under the grant number P 1072/07/2014.

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