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Influence of a defined pre-load on the stress state in the precision cutting process

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ABSTRACT

Precision cutting is a single stroke shear cutting process to achieve a flush-cut amount between 60 and 90% of the sheet thickness by using a single-acting standard press. This paper presents a method to quantify the amount of required compression stresses based on theoretical and experimental precision cutting tests in which the stress state is overlaid by an additional radial pre-load on the strip. It was found that even a minimal pre-load of 30% of the yield stress can move the stress level to a state with lower tensile stress.

1. Definition and state of the art

Precision cutting (Fig. 1) is defined as "a single stroke shear cutting process on sheet metal with a flat blank holder and counter holder, using rounded cutting edges and a small cutting gap" [1].

Procedure characteristics are therefore the counter holder, which prevents the part from deflection when the punch penetrates the sheet, and precisely rounded cutting edges on the active tool parts (punch or die). In combination with a very small cutting gap of 1.3% of the sheet thickness s_0 it leads to flush-cut amounts of up to 90% of the sheet thickness s_0. No V-ring is required for precision cutting and this is the main difference to fine blanking, beside the larger cutting gap as well as the use of a single-acting standard press.

In precision cutting the strain hardening in the area of the cutting surface is slightly lower than in fine blanking. However, hardness value and hardening depth are higher compared to conventional shear cutting [2] or high speed impact cutting (HSIC) [3,4].

Precision cutting can be classified in terms of the achievable dimensional tolerance on the components as well as with regard to the tool costs between the shear cutting and fine blanking processes. Tolerances between IT 7 and IT 11 can be achieved on conventional, single-acting forming machines, using relatively simple tools. The required counter holder force is generated using suitable tool-side spring elements. The application of this procedure has also benefits in terms of the space available for tools and, therefore, the range of parts, which can be manufactured. In general, in a conventional single-acting mechanical or hydraulic press both are not as limited as in triple-acting fine blanking presses. High flush-cut amounts on components in progressive tools can also be achieved by means of precision cutting.

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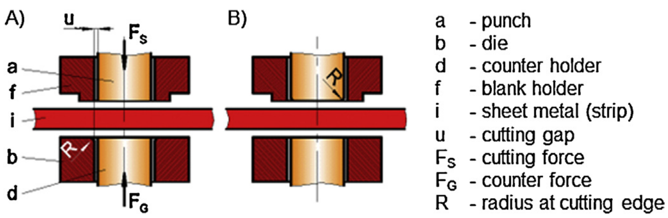

Fig. 1. Principle of precision cutting [1] – (A) recommended for cutting of outer forms and (B) recommended for punching of inner forms.

In order to geometrically represent stresses Mohr's circle is used [5]. From Ref. [6] it follows that, during shear cutting, the shear fracture limit of a material ascertained in experiments is reached early on due to the tensile stress, which is the cause of the fracture rather than the prevalence of a compression stress state on all sides, as it is the case with fine blanking, for example [7]. In literature it can be found, that due to increasing compression stresses reaching the shear yield stress before the shear fracture limit is supported and that crack formation can be delayed [5,6]. However, no explicit information is given on the level of these compression stresses.

The increased compression stresses, which are aimed at precision cutting (Fig. 2), are mostly caused by the very small cutting gap, the radii at cutting edges, the blank holder force and the additional impact of the counter holder force during the cutting process.

The calculation of these forces is carried out depending on the cutting force, so that an indirect reference to the tensile strength R_m of the sheet material via the shear strength τ_S is given. A detailed description of the relationship between the compression stress superposition and the yield point of the sheet material for the shear cutting process cannot be found in literature, apart from statements by Bates [8] on the Gripflow® process; although without quantitative information.

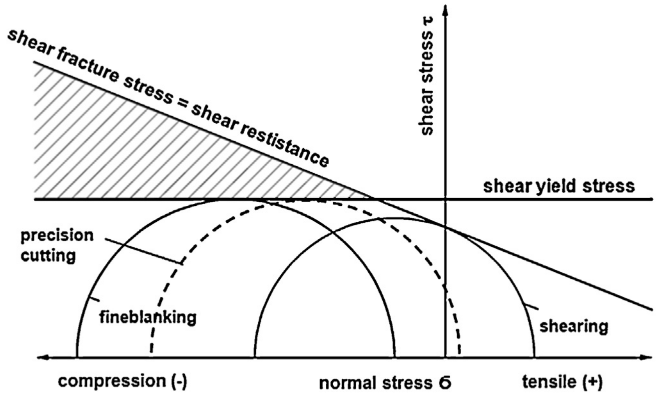

Fig. 2. Stress state within the sheet metal in the vicinity of cutting edge [6,10].

The results of experiments on precision cutting [9] confirm the findings of Hoffmann [10] regarding the influence of the design of the cutting edge on the state of compression stress during fine blanking and, consequently, on the flush-cut amount of the cutting surface. By using various geometries on the cutting edge of the punch such as radius (reference contour), cone, extrusion shoulder and tractrix, qualitative differences can be observed by means of numerical simulation, both in terms of loads on the cutting edge and with regard to the stress state within the component.

The precision cutting process was analyzed by means of the finite element method using the DEFORM-2D^{TM} system. With a punch penetration of 5 mm, the nodes of the FE mesh directly below the punch were evaluated with regard to the related mean value of stress σ_m/σ_V and the equivalent plastic strain φ_V. Fig. 3 shows that, with the tractrix contour, the state of stress can be almost entirely shifted into the range of increased compression stresses. As a result, the separation of the material is induced around the plastic flow and the highest flush-cut amount is achieved in comparison with the investigated cutting edge geometries of the punch.

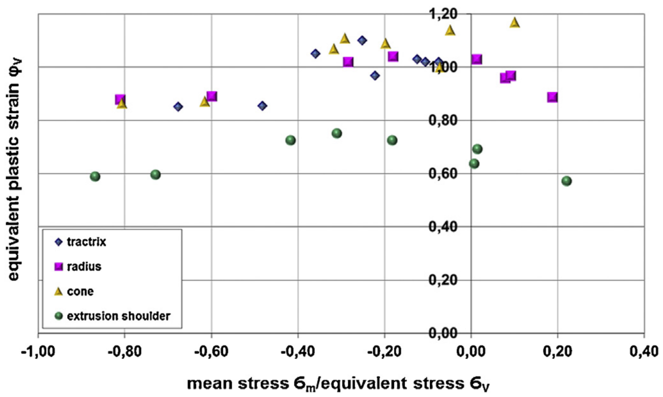

Fig. 3. Comparison of the ratio σ_m/σ_V with different geometries of punch cutting edge in precision cutting [9].

In contrast to Aoki [11] it can be summarized that the generation of additional compression stresses in the cutting zone by the interaction of a flat blank holder, a counter holder and modified geometries at the active tool parts has positive effects on the cutting result, especially on the flush-cut amount [2,9]. However, it does require special methods with regard to the tool and systems engineering. Since the active parts of the tool can only endure a certain pressure load during fine blanking or precision cutting without experiencing an unacceptable level of buckling, the tool load has to be minimized while also generating the amount of compression stresses on the component required for the greatest possible amount of flush-cut. With regard to this level of load, patents and national or international technical publications provide limited information, merely indicating that the amount of compression stress to be applied should not exceed the yield point. Therefore, investigations into precision cutting with additional superposition by means of radial pre-load were carried out in order to quantify the amount of compression stresses required for achieving a considerable increase in the flush-cut amount of a cutting surface.

2. Influence of additional radial pre-load on the stress state

2.1. Design of tool system

An existing tool set-up for punching a hole with a diameter of 30 mm was modified in order to be able to generate the additional stresses and to measure the forces in the axial directions [12]. The investigation included sheet materials with different strength and elongation values:

- AlMg4.5Mn0.7 (3.3547) – aluminum wrought alloy;
- X5CrNi18-10 (1.4301) – acid-proof stainless steel;
- S500MC (1.0984) – micro-alloyed fine-grained steel;
- S235JR (1.0037) – general-purpose structural steel.

With regard to the definition of the level of pre-load for the design of the tool system and the experiments it was decided to analyze the flush-cut amount in dependence of the superposed stresses, beginning with minimal stress superposition up to an additional stress level close to the yield stress of the material. Accordingly, the pre-load was graded, depending on the yield strength of the sheet material: 1. $\sigma = 0.3 \times R_e$; 2. $\sigma = 0.5 \times R_e$ and 3. $\sigma = 0.8 \times R_e$.

Furthermore, the tool set-up was designed to investigate the different cutting gaps u of 0.2, 0.5 and 1 mm.

With the given tool design, hydraulic cylinders were used as a solution for generating the direct radial pre-load on the sheet metal section (Fig. 4). The workpiece to be cut (d) is positioned on a cutting die, while two of its contact surfaces touch the workpiece support (a). Double-acting hydraulic block cylinders (b) are attached to the experimental tool system by a fixture. Buckle-resistant moveable elements (e) assume the force exerted in the workpiece. They are controlled lateral by adjustable blocks and protected against lifting. The precise control of these tool components is essential in order to prevent contact with the workpiece support and, consequently, tool damage during the transmission of force.

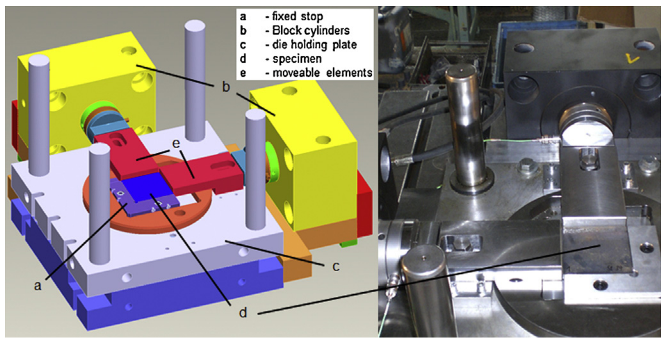

Fig. 4. Test setup of the lower tool [12].

2.2. Test set-up and test procedure

Prior to the experiments, the process forces required were determined (cutting force, blank holder force and counter holder force) based on the foundations ascertained in previous tests [1,9]. In the first test series the dimensions of the blanks were 100 mm × 100 mm × 10 mm and the cutting surface in the strip (inner form) was analyzed. In the second test series blanks with 60 mm × 60 mm × 10 mm were selected and it has been focused on the cutting surface of the part, which has been cut out from the