

Effect of Punch-Die Clearance on Fracture Angle in Blanking

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ABSTRACT

Shearing (blanking) is an important manufacturing operation for producing electrical-steel laminations used in electric machines and transformers. Sheared-edge quality governs the functional performance of the parts because it is linked to the geometry of the rollover zone, the length of the burnished (clean-cut) zone, the extent of the fracture zone, and burr height. These features influence residual stresses, local strain hardening, magnetic losses, and thus the efficiency and acoustic performance of the final assemblies. Punch–die clearance, sheet properties (grade and thickness), punch speed, tool wear, and tool geometry (including cutting-edge radii) are among the parameters that decisively shape the resulting sheared-edge integrity. The aim of this work is to investigate the effect of punch–die clearance on the fracture-surface angle (β) in the shearing process. Experimentally measured angle β values were compared with a blanking simulation performed in Simufact Forming under the same input conditions as those used in the experiment. In evaluating angle β , the smallest angles were observed primarily at punch–die clearances of 10%. Both the experimental and simulation results indicate that at punch–die clearances of 10%, the sheared-edge quality is the lowest.

KEYWORDS; Blanking, shearing, fracture angle, simulation

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I. INTRODUCTION

Shearing (blanking) is the preferred process for manufacturing electrical-steel sheets and laminations for electrical machines and transformers. Ideally, the operation should produce precisely cut parts whose properties are equivalent to those of the parent material. In practice, however, process-induced defects can occur during shearing. The presence of defects at and near the sheared edge remains the most serious issue because it affects the performance of the final product [1, 2].

During shearing, the material undergoes plastic deformation and residual stresses are generated, especially at and near the sheared edge. The induced deformation can affect the mechanical and magnetic properties of electrical-steel sheet due to changes in the material state and the edge profile within the shear affected zone.

The sheared surface is defined by its geometry and quality, which are influenced by several factors, including punch and die clearance, punch speed, the properties of the workpiece material, and the cutting-edge geometry and condition of the punch and die. Figure 1 shows the characteristic zones of a sheared edge: the rollover, the burnished (clean-cut) zone, the fracture zone, and the burr.

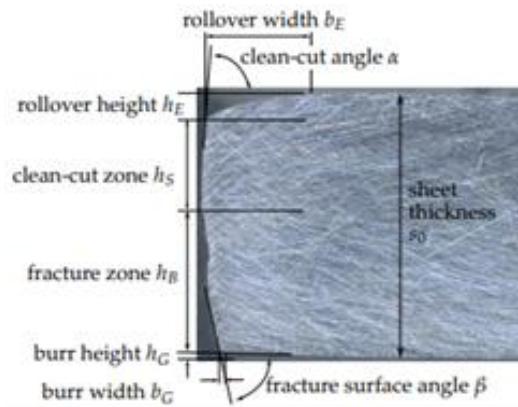


Figure 1 Characteristic zones of a sheared edge

In general, a high-quality sheared edge is characterized by smaller rollover height and width, a reduced fracture zone, lower burr height and width, and a larger burnished (clean-cut) zone with an edge angle close to 90° . Numerous studies have examined the impact of punch–die clearance—the gap between the cutting elements (blades or the punch and die). Increasing the clearance typically degrades shearing quality by increasing rollover, the fracture-zone length, the fracture-surface angle β , and burr height, while decreasing the burnished zone. These trends have been reported as approximately linear up to moderate relative clearances (on the order of 20–30% of sheet thickness), although the exact range is material- and thickness-dependent. Further investigation using the Cockcroft–Latham failure criterion has shown that increasing clearance widens the shear band, promoting premature crack initiation and earlier separation [3].

According to Altan and Tekkaya [2], for shearing 0.58-mm sheet metal, as the punch–die clearance increases, the rollover zone, the fracture zone, the fracture-surface angle β , and burr height increase, while the burnished zone decreases. Excessive clearance causes large plastic deformation and shortens tool life. Conversely, with insufficient clearance, secondary shearing can occur cracks initiated at the punch and die edges do not coalesce, additional loading is required, and energy consumption rises. The influence of punch–die clearance and tool-edge radii on the characteristic zones of the sheared surface is shown in Figure 2.

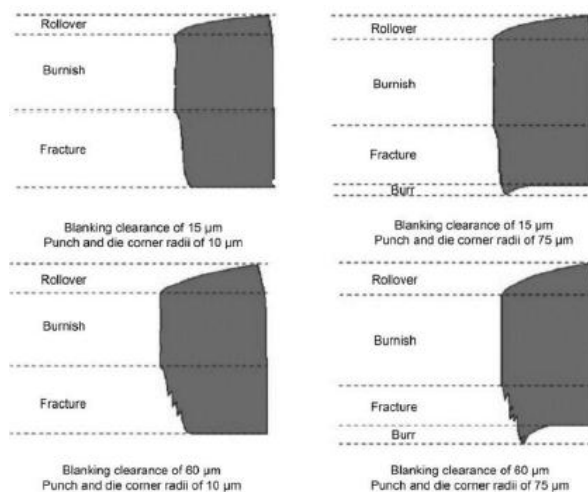


Figure 2 Influence of punch–die clearance and tool-edge radii on the zones of the sheared edge [4]

Slota et al. investigated the shearing of electrical-steel sheets under various process conditions using finite-element (FEM) simulations. They found that punch–die clearance and the wear condition of the punch and die have a significant effect on the residual stresses induced during shearing. Sharp cutting edges consistently yielded better results than worn edges. The depth of the residual-stress-affected layer near the sheared edge was significantly lower when shearing was performed with smaller punch–die clearance. Conversely, the FEM results also indicated that smaller clearances can increase the peak residual stresses along the sheared edge. The simulations further showed a clear influence of worn cutting edges on burr height [5].

II. MATERIAL AND METHODOLOGY OF EXPERIMENT

The Mechanical Properties Testing Laboratory, part of the Institute of Technology and Materials Engineering, conducted experimental tests. For this study, non-oriented (isotropic) electrical steel with a thickness of 0.50 mm was used.

Table 1 shows the material properties of the electrical steel used in the experiment. Mechanical properties tests were performed in accordance with the following standards: STN EN ISO 6892-1:2019 for room-temperature tensile testing, STN EN ISO 10113:2020 for determination of the plastic strain ratio (r-value) in sheet and strip, and STN EN ISO 10275:2020 for determination of the strain-hardening exponent in tension. Testing was carried out on a TIRA test 2300 universal testing machine equipped with a force transducer, a longitudinal extensometer, and a width-measurement sensor for r-value assessment. Specimen preparation for tensile testing followed STN EN ISO 6892-1:2019.

Table 1 Average mechanical properties of electrical steel, $t = 0.50$ mm

Direction [°]	$R_{p0.2}$ [MPa]	R_m [MPa]	A_{80} [%]	r	r_m	Δr	n	n_m	Δn
0	366	492	24.1	0.741	1.067	-0.386	0.186	0.179	0.002

The shearing experiments were performed on a ZD-40 hydraulic press equipped with a load cell for force measurement. Force signals recorded by the press controller were exported to a PC and processed in Microsoft Excel. Figure 3 shows the shearing tool (punch and die set) used in the experiments.



Figure 3 Shearing tool used in the experiment

The measurements were performed on ring-shaped blanks with an inner diameter of 15 mm, and an outer diameter of 25 mm. Figure 4 shows the blanks. For the experiment, the punch–die clearance was set to 1%, 5% and 10% of the sheet thickness (t).



Figure 4 Experimental ring-shaped blanks

The objective of the simulation in Simufact Forming 2022 was to quantify the fracture-surface angle (β) as a descriptor of the sheared-edge profile and to assess its influence on the quality of the sheared edge during blanking of the experimental specimens (blanks). Within the application, the Cold Forming module was used, and the process type was set to Cutting (Figure 5).

Measured fracture-surface angle β values for material show a dependence on punch–die clearance. As the clearance increases, angle β decreases. Smallest deviation occurred at 5% ($\Delta\beta = 0.12^\circ$). The lowest predicted fracture-surface angle for material A was obtained at 10% clearance ($\beta_{\text{sim}} = 80.01^\circ$). However, the experimental measurement yielded $\beta_{\text{exp}} = 77.22^\circ$, corresponding to a deviation of $\Delta\beta = 2.79^\circ$. For comparison, the individual fracture-surface angle values from the simulations and the experiments are plotted in Figures 6–8.

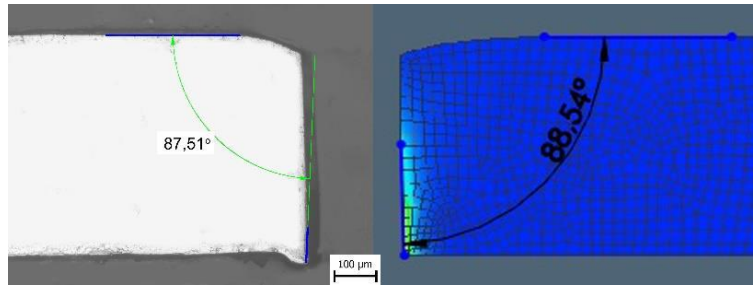


Figure 6 Fracture-surface angle β for material A at 1% punch–die clearance

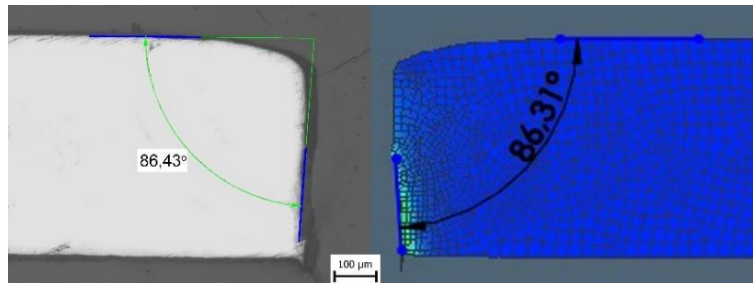


Figure 7 Fracture-surface angle β for material A at 5% punch–die clearance

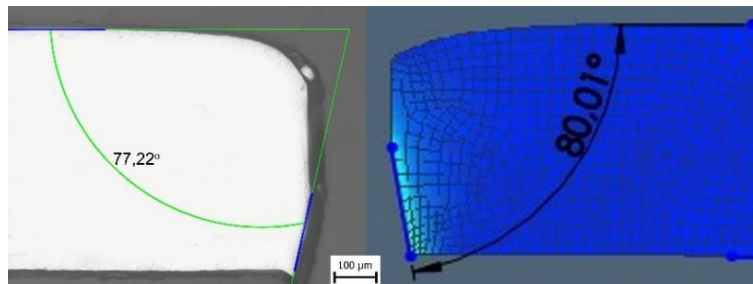


Figure 8 Fracture-surface angle β for material A at 10% punch–die clearance

IV. CONCLUSION

The experimentally measured fracture-surface angle (β) values were compared with the results of a shearing simulation performed in Simufact Forming under the same input conditions as those used in the experiment. For tested steel, the largest discrepancy between experiment and simulation was 2.79° . A plausible reason for the lower accuracy of the fracture-angle prediction in used material is its coarse-grained microstructure, which was not explicitly incorporated into the simulation model. Both the experimental and simulation results indicate that, at punch–die clearances of 10%, sheared-edge quality is the poorest among the tested conditions.

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