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The Roundness Profile Resulting from a New Adjustable Ironing Punch

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Abstract
The ongoing push for increased flexibility in high-volume metal forming tools often implies increased complexity in design and control, and new phenomena in the forming processes. In common industrial sheet metal forming operations, variations in raw material properties, such as thickness, strength, and anisotropy, makes achieving precise product geometry a challenging task. In this study, a dimensional analysis was performed on EN 1.4404 cups ironed with a novel adjustable ironing punch, as presented by Nielsen et al. [1]. Three cups with different strategies were ironed, revealing a difference in roundness profiles. Tool geometry imperfections were found to have no impact on the cup wall roundness. The R-value of the sheet material was measured in a uniaxial tensile test in three directions and the planar anisotropy gave rise to uneven thickening of the cup wall in deep drawing. This, combined with the reduced plastic deformation during the retraction of the novel ironing punch changes the roundness profile of the cup.

Keywords: sheet metal forming, ironing, flexibility, anisotropy, geometrical metrology

1. Introduction

Digitalization of the forming industry not only requires sensors for gathering data, but also actuators for applying modern control techniques to metal forming processes. Examples of such actuators presented in research in the recent decades include induction heating for springback control in progressive die bending [2], digitized forming dies with adjustable geometry [3] and rolling mills with in-line adjustable roll gap [4].

Nielsen et al. [1] presented a novel sheet metal ironing punch with adjustable diameter (see Fig. 1a), which was shown to reduce punch retraction force by 50% compared to a conventional ironing punch. Additionally, the capability for controlling punch diameter to influence final part wall thickness was demonstrated. The adjustable ironing punch works by extending the mandrel before forming, effectively expanding the punch sleeve and increasing its diameter to a predetermined value, which can be varied between forming strokes. For nominal operation, the mandrel is kept in place during the forming stroke and retracted upon reaching the bottom dead center (BDC), rapidly reducing the radial stiffness of the punch and contact pressure between the punch sleeve and the cup, resulting in reduced punch retraction force.

This study is based on an observation made about the circularity of the formed cups. When the cups were ironed, and the adjustable ironing punch was used as intended, the roundness profile differed from that of a cup ironed with a conventional punch or the adjustable punch but without retracting the mandrel at the bottom dead center (see Fig. 1c). The aim of the study was to determine and explain the underlying mechanism of this change in roundness profiles.

2. Experimental Method

The cups were formed from a 1 mm thick cold rolled EN 1.4404 austenitic stainless steel sheet first by deep drawing an Ø61 mm blank using an Ø32.6 mm punch until the flange diameter was about Ø45 mm. Both the punch nose radius and the die shoulder radius were 2 mm. The cups were then ironed using one of three strategies. Cup 1 was ironed with the adjustable ironing punch, retracting the mandrel from the punch before punch retraction from the cup. Cup 2 was ironed with the same punch, but the mandrel was kept extended during the entire stroke, simulating a conventional ironing punch. Cup 3 was ironed using a conventional ironing punch. Rhenus SU 500A drawing oil was applied to all contact surfaces before both forming steps. The tools and the cups were measured using a ZEISS PRISMO coordinate measuring machine. The R-value of the workpiece material was measured in a uniaxial tensile test. DIN 50125 type H specimens with an initial gauge length of 80 mm were cut from the sheet in 0°, 45° and 90° relative to the rolling direction (RD).

The force was measured using an LC-412-50K load cell. Axial and transverse strains were measured using 3542-080M-050-ST and 3575-500M-ST extensometers, respectively.

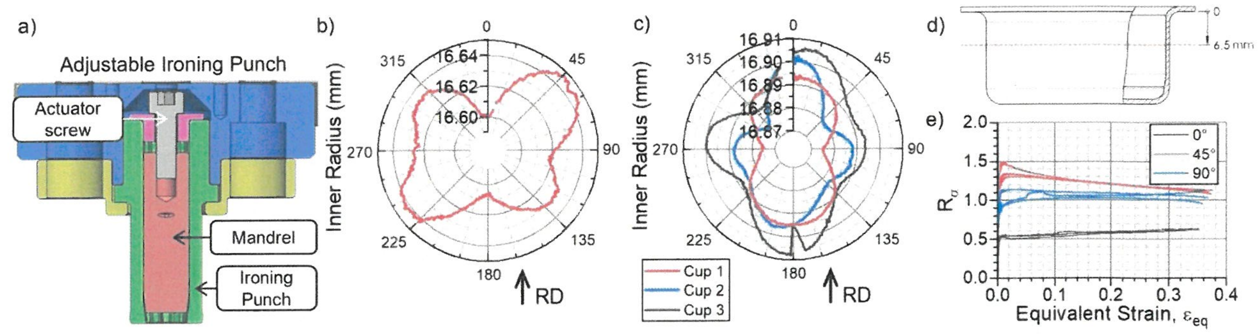

Figure 1. a) Adjustable ironing punch [1], b) roundness profiles of a typical deep drawn cup and c) ironed cups, d) the definition of the measuring plane, and e) R-value ($R_\alpha = \varepsilon_w/\varepsilon_t$) of the EN 1.4404 sheet measured in a tensile test.

3. Results and Discussion

Preliminary analysis concluded that the difference of the roundness profiles is likely caused either by the geometrical imperfections of the forming tools or anisotropy of the workpiece material. The roundness of all relevant tool surfaces was within 8 μm (minimum zone circle method) and no tools had shape errors like seen in Fig. 1b and Fig. 1c. Furthermore, the roundness profile of the cups remained unchanged relative to the rolling direction even when the angle between the rolling direction and the tools was varied. The cup roundness is thus determined by the sheet anisotropy.

Fig. 1e shows that the R-value of the sheet was highest in the diagonal direction (R_{45} = 1.2, at ε_{eq} = 0.2) and lowest in the rolling direction (R_0 = 0.6), while an intermediate value was measured in the transverse direction (R_{90} = 1.05), resulting in a planar anisotropy of ΔR = -0.38. Comparing Fig. 1b to the measured R-values, the deep drawn cup diameter is larger in the diagonal directions, where the R-value is higher, and smallest in the rolling direction, where the lowest R-value was measured. The circularity of the cup is also reflected in the remaining flange material, which is drawn in the least in 45°. The flow rule associated with Hill's quadratic yield criterion under plane stress assumptions in the flange confirms this observation by predicting the largest radial to circumferential strain ratio in directions of larger R-value.

Fig. 1c shows that after ironing, cups 2 and 3 have a roundness profile with maxima in the 0° and 90° directions and minima in the diagonal directions. Cup 1 has the largest diameter also in the rolling direction, but the lowest diameter in the transverse direction. Planar anisotropy is known to give rise to uneven thickening of the cup wall in deep drawing. Directions with lower R-values thicken more. This implies a higher thickness change and larger elastic tool deflections in the rolling direction during ironing, explaining the large diameter in the rolling direction observed on all three ironed cups. As the R-value at the 45° and 90° directions is relatively similar, the roundness profile of the deep drawn cup is maintained at these angles. Ironing with a conventional punch is known to cause plastic deformation also during punch retraction [5]. The lowered radial punch stiffness after forming of cup 1 results in less plastic deformation during punch retraction due to reduced contact pressure. The measured difference in roundness profiles of cups 2 and 3 as opposed to cup 1 is thus attributed to the deformation during punch retraction, which occurs more in the transverse direction with the smallest diameter after ironing. This gradient in the degree of plastic deformation around the cup leads to a local reduction of cup radius in the 45° directions due to elastic springback of the cup wall driven by profile curvature after ironing, which has smaller radius than the cup radius.

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