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Reduction of the sheet thickness variation and its negative effects on the accuracy of mini drawn parts using different geometries of tool components

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ABSTRACT

Like in the case of macro deep drawing, the sheet thickness of mini drawn parts, with dimensions smaller than 20 mm and made from very thin sheets, is unevenly distributed and varies from minimum values resulted in the zone of part edge radius to maximum values in the upper zone of part vertical walls. Such variation of sheet thickness can cause for the resulted drawn parts some geometric deviations from their theoretic geometry or it can determine the parts failure. Hence, the main objective of the mini scale deep drawing processes is to obtain an increased accuracy by reducing the sheet thickness variation, or in other words to minimize the values of sheet thinning and thickening. The present paper analyses the results of investigations made by experiment and simulation concerning the use of different geometries of the tool components that permit to control and minimize the sheet thickness variation in the mini cylindrical drawn part zones where this phenomenon can generate negative effects and determine the part inaccuracy. The new geometries of tools were obtained by modifying the state of stress in the deformed sheet using adequate geometries of active surfaces of the die cavity and blank holder plate.

1. Introduction

In the case of macro deep drawing processes, the sheet thickness is unevenly distributed in the part after deep drawing, its variation taking place as follows: uniform distributed at the bottom zone of the part, minimum at the part edge radius and wall zone, and maximum at the flange zone and upper wall zone. The thickness variation is caused by a complex mechanism of deformation of the sheet material during deep drawing process [1,2]. It is well known that the sheet thickness variation and its effects on the drawn part are influenced by the values and variation of stresses along part profile or on the outer and inner part faces, variation that is characterized by an alternation between tensile and compressive stresses. Thus, in the cold formed material and in different part zones the following connection exists between the stress state and thickness variations (Fig. 1): in part flange, the material is thickened as result of large compressive stresses developed in this zone; in the upper zone of part wall, where a combination of compressive and tensile stresses acts, the amount of thickening diminishes; near the part edge radius zone the thinning occurs as the maximum tensile stress is generated in this zone; in the part bottom, where low tensile stresses act, little or no deformation occurs and hence the material retains its original thickness. Different parameters, such as: punch/die edge radii, blank holder force, friction between sheet and die/punch/blank holder plate, affect the process of thickness variation, the finding of their optimum values being made by trial and error methods or by finite element and numerical methods that are used to shorten the time and cost of optimization process [3–5].

The thickness variation during the sheet forming process can cause or influence some negative effects in the drawn parts, like: stresses variation and concentration in zones with variations of sheet thickness; part cracking and failure that occur in zones of the formed part with maximum sheet thinning and are influenced by different factors (improper limit drawing ratio, die and punch geometry, improper tool clearances) [6–10], part diameter variation [1], etc. The industrial practice recommends to limit the maximum thinning to 18–20% compared with initial blank thickness but, sometimes, severe stamping conditions can lead to higher thinning [11].

Compared to macro scale, the mini scale deep drawing processes introduce new factors that increase the processes complexity (e.g., small dimensions of parts, small sheet thickness, etc.) or are characterized by common or specific phenomena that can affect the accuracy of the drawn parts. The variation of the sheet thickness takes also place from its maximum thinning in the zone of part edge radius to its maximum thickening at the part end but it is influenced

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Table 1
Mini cylindrical drawn parts dimensions.

Part diameter [mm]	Part height [mm]	Sheet thickness [mm]	Part edge radius [mm]
2.0	1.5, 2.0, 2.5	0.2	0.5
20.0	20.0, 30.0, 40.0		2.0

by the annealing conditions, scaling factors and by the orientation of single grains [12,13]. Many aspects concerning the sheets thickness variation during mini scale drawing processes (e.g., its variation depending on different factors of influence, its effects, its prediction, compensation or control) were not or few studied.

Like in the case of macro scale deep drawing processes, an important objective in the mini scale deep drawing process is to reduce or eliminate every phenomenon that can affect the drawn part quality. This objective can be realized for example by minimizing the unintended variations of sheet thickness in the drawn part or in other words by minimizing the values of sheet thinning and thickening. This result can be obtained by designing an optimum tool geometry and process that will permit to maintain a minimum difference between the thickness of the blank flat sheet and the sheet of the final drawn part and thus to eliminate or minimize the effects of thickness variation. Hence, the objective to reduce the thickness variation and its effects in the mini deep drawn parts, i.e. to minimize the values of thinning and thickening, can be accomplished for example by varying the state of stress generated in material by different forming phases of the deep drawing process.

The present paper analyses the results of investigations made by experiment and simulation concerning the application of some geometries of tool components that will permit to control and minimize the thickness variation in cylindrical mini drawn parts (with diameters having 2.00 and 20.00 mm) made from copper alloy sheets and hence to increase the parts accuracy.

2. General conditions of simulation and experiment

The investigations were performed on mini cylindrical parts whose geometry and dimensions are indicated in Fig. 2 and Table 1, respectively. The material used in investigation was a CuZn37 alloy whose mechanical properties are presented in Table 2, the used sheet having a thickness equal to 0.2 mm. The anisotropy coefficients were determined for three orientations in relation to the rolling directions at 0°, 45° and 90°. The friction coefficients calculated using the friction function according to [14,15] are presented together with blank holder forces in Table 3.

The parameters analyzed in simulation and experimental investigations were as follows: part diameter (D), part edge radius (r_{ep}), drawing depth (d), blank holder force (BHF), friction coefficient (μ), blank diameter (D_b), initial sheet thickness (t_0), tool clearance (c), punch edge radius (r_p), punch diameter (D_p) and die diameter (D_d).

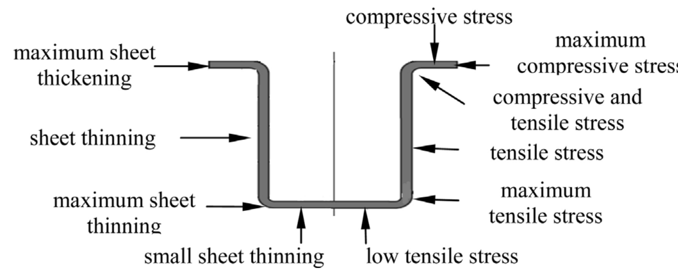

Fig. 1. Stress and thickness variations in a cylindrical drawn part.

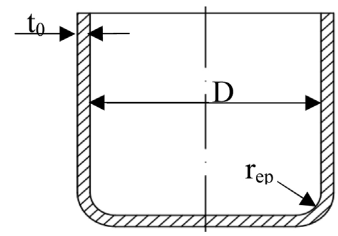

Fig. 2. Drawn part geometry.

Table 3
Working conditions.

Part diameter [mm]	Friction coefficient	Blank holder force [N]	Drawing force [N]
2.00	0.15	20.00	37
20.00	0.11	100.00	550

Table 2
Mechanical properties of metal sheets.

Initial thickness [mm]	Young modulus [MPa]	Yield strength [MPa]	Poisson ratio	Anisotropy coefficients			Total elongation [%]
				0°	45°	90°	
0.200	115,000	24.550	0.300	0.725	0.848	0.888	36

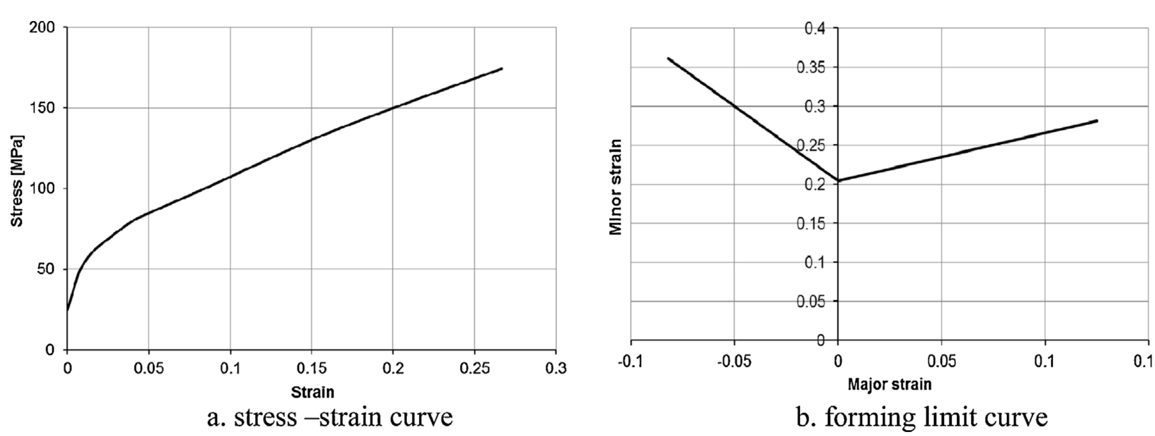

Fig. 3. Mechanical and deformability properties of the CuZn37 alloy.