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Issue Article

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ASSESSMENT OF THICKNESS CHANGES (THINNING AND THICKENING) OF THIN-WALLED SQUARE PARTS AFTER DRAWING

Abstract: *Using finite element modeling, characteristic areas of thinning and thickening of a sheet model formed into a box-shaped part were obtained. It was noted that the minimum thinning of the sheet thickness occurs when drawing of DC05 high-quality cold-rolled low-carbon steel, and the maximum thinning occurs when drawing of 5754 deformable aluminum alloy.*

Key words: *drawing, thinning, thickening, material, modeling.*

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1. Introduction

The process of forming sheet metal parts, such as square drawing, inherently involves significant plastic deformation. A critical aspect of the analysis of this forming operation is the investigation of local changes in material thickness, in particular thinning and thickening phenomena. These dimensional changes are not simply secondary effects but determine the final structural integrity and functional characteristics of the drawn part.

From a mechanistic perspective, thinning occurs primarily in regions where the material is subjected to biaxial tension and limited flow, often near the deepest draw radii or at the perimeter of the forming cavity. This thickness reduction is directly related to the deformation experienced by the sheet metal, indicating a complex interaction between the applied stress and the constitutive behavior of the material. Conversely, thickening may appear in areas where material buildup or localized overload occurs, although this is generally less common in simple drawing operations unless there is significant material bridging or die-side restriction. The magnitude and spatial distribution of these thickness changes depend on the original sheet geometry, the drawing ratio, the yield strength of the material, and the design of the tooling.

The field of sheet metal processing requires the application of advanced computational and experimental methods to accurately predict material behavior, especially in complex deformation modes such as deep drawing and stamping. A significant portion of modern research is devoted to the development of predictive models for managing material inherent limitations and optimizing process parameters.

In the field of computational modeling, significant efforts have been directed towards creating reliable simulation models. For example, analyses studying the axisymmetric deformation of cylindrical components have used numerical models to simulate sheet metal machining processes [1]. Furthermore, predictive capabilities extend to analytical approaches designed to evaluate thickness distribution and quantify plastic strain experienced by axisymmetric deep-drawn parts, providing engineers with quantitative metrics for design verification [4]. In addition to these efforts, research into multidimensional forming has led to the development of sophisticated three-dimensional prediction methods that are crucial for understanding how sheet thickness changes gradually during the drawing process [6].

A critical area of research is understanding the failure mechanisms and material response during deep drawing. Studies have documented in detail the various types of failures encountered during deep drawing operations [2]. The influence of specific geometric and material characteristics has been assessed empirically and numerically; for example, the interaction between sheet thickness and grain size in deep drawing of square geometries has been critically analyzed [3]. Similarly, the formability of specialized materials such as pure titanium in deep drawing of square cups has been demonstrated, highlighting the material-specific nature of forming limitations [9].

Beyond simple prediction, a significant amount of work has been devoted to controlling and minimizing material thinning, which is a major problem in forming operations. The influence of die design parameters on sheet metal thinning characteristics during deep drawing is a well-documented topic [5]. To reduce unwanted thickness variations in multi-stage stamping processes, research has focused on optimization methods [7]. Furthermore, comprehensive thickness analysis of the product, especially in cup drawing applications, has provided the foundation for determining material consumption and structural integrity [8].

Taken together, these studies demonstrate a methodological progression from basic modeling to highly specific, optimized modeling. While some works have used analytical approaches to represent thickness variations [4], others have presented detailed case studies of geometric variations such as deep drawing of square parts [3]. Continuous advancements in these tools – including 2D, 3D, and axisymmetric modeling – enable a deeper and more detailed understanding of the constitutive relationships that govern sheet metal behavior in various manufacturing scenarios. By applying finite element modeling to various materials, the objectives of this study are achieved by accurately modeling and analyzing the stress distribution and resulting geometric changes across the entire processed surface. This approach provides important insights into material limitations and optimal formability parameters.

2. Materials and methods

The drawing process of a thin-walled box-shaped part was simulated using the LS-DYNA program in a three-dimensional setting. The shell models of the blanks had a constant thickness of 0.8 mm. A drawing depth of 20 mm allows for the creation of a sufficient stress-strain state of the formed part to analyze the degree of thinning or thickening of characteristic zones. To predict the maximum tensile/compressive stress of a part after drawing, the following materials with transverse anisotropy properties were selected: DC01 structural high-quality carbon steel, DC05 high-quality cold-rolled low-

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	ISI (Dubai, UAE) = 1.582	РИНЦ (Russia) = 0.191	PIF (India) = 1.940
	GIF (Australia) = 0.564	ESJI (KZ) = 8.100	IBI (India) = 4.260
	JIF = 1.500	SJIF (Morocco) = 6.004	OAJI (USA) = 0.350

carbon steel, AISI 304 austenitic stainless steel, S355MC high strength low-alloy steel, 5754 deformable aluminum alloy, and Ti Grade 4 commercially pure titanium. The dimensions of the models, properties of the materials and conditions for simulating the drawing process are presented in [10].

3. Results and discussion

The ranges of change in the initial thickness of sheets of various metal materials after drawing to a depth of 20 mm are shown on models of box-shaped parts in the form of color maps (Figure 1). Parameter values are given as percentages. The physical meaning of the signs in the scales to the right of the models is distributed as follows: positive values characterize the thinning of the material (the thickness decreases), and negative values determine the thickening of the material (the thickness increases).

For all materials studied, the central region exhibits the greatest thinning, with the maximum thickness reduction ranging from approximately 12.4% in 5754 deformable aluminum alloy to approximately 3.5% in Ti Grade 4 commercially pure titanium. The thinning is surrounded by zones of slight thickening at the edges, reflecting the flow and redistribution of material during drawing.

The ratio of positive to negative values varies depending on the material. For example, 5754 deformable aluminum alloy exhibits the highest thinning to thickening ratio, indicating a more pronounced thinning compared to local thickening. In contrast, steels such as DC01 and DC05 exhibit more balanced ratios, suggesting more uniform material deformation with moderate thinning and thickening.

Physically, positive values correspond to areas where the material is stretched and reduced in thickness due to tensile stresses, while negative values occur where the material is subjected to compression or swelling, causing localized thickening.

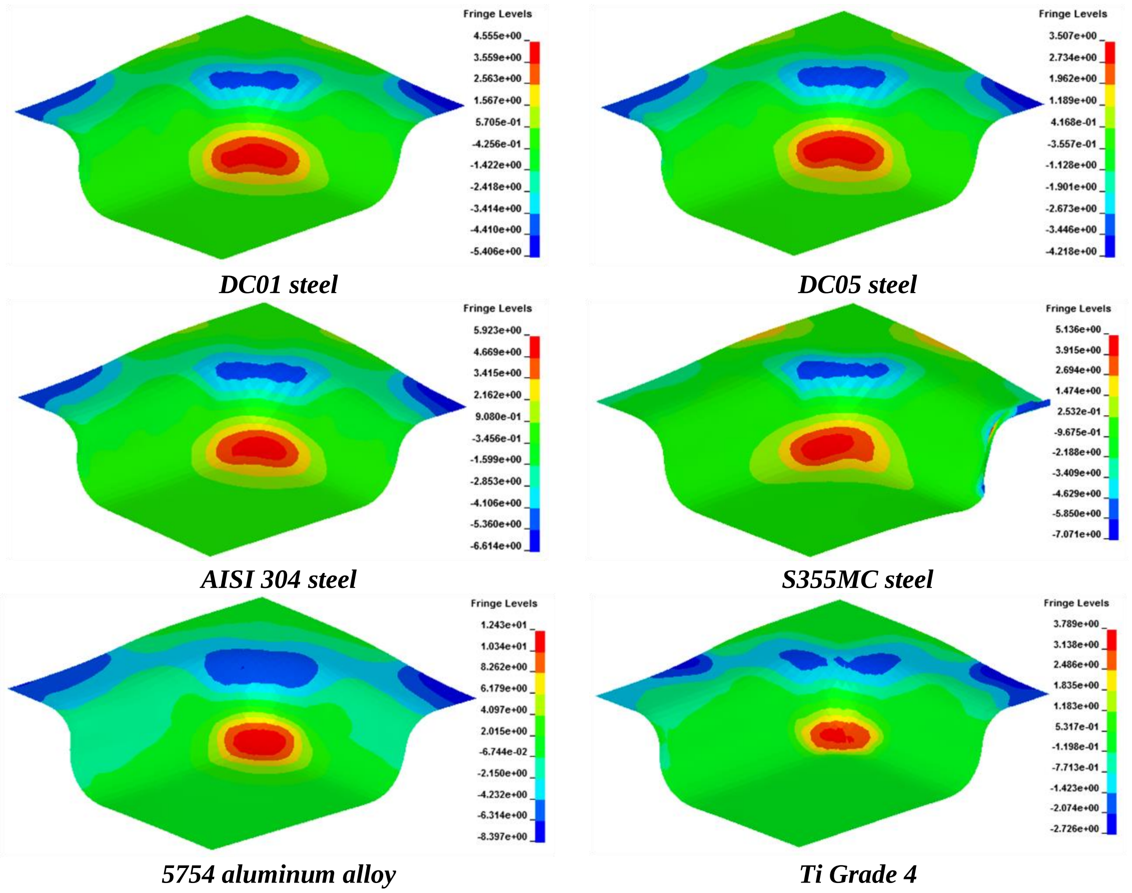

Figure 1. Changes in the thickness of metal sheets after the drawing process of the box-shaped part (in percent).

Below are technological recommendations for optimizing the drawing process for the materials under study:

5754 deformable aluminum alloy exhibits significant thinning. Careful control of drawing speed and lubrication is necessary to prevent failure due to excessive thinning.

AISI 304 austenitic stainless steel is characterized by moderate thinning with some thickening. The drawing process parameters must optimize the strain distribution to avoid defects such as wrinkling.

DC01 structural high-quality carbon steel and DC05 high-quality cold-rolled low-carbon steel achieve balanced thinning and thickening, indicating good formability. To ensure uniform thickness distribution, it is necessary to maintain constant holder force.

S355MC high strength low-alloy steel exhibits moderate thinning and noticeable edge thickening. Minimization of edge burrs and improvement of thickness uniformity is achieved through a rational die design.

The lowest thinning is determined for Ti Grade 4 commercially pure titanium. This material is suitable for deep drawing with a lower risk of thinning-related failure, but attention must be paid to the elastic recovery of the material.

Overall, process optimization for a specific material, including die geometry, lubrication, holder force, and draw speed, is critical to managing thickness variations and producing high-quality drawn components.

4. Conclusion

The study showed that when drawing to a depth of 20 mm, the initial thickness of sheets of various metal materials changes within characteristic ranges. The central region of the parts for all materials exhibits the maximum thickness thinning, ranging from 12.4% to approximately 3.5%. Thickening is observed at the edges, which reflects the redistribution of material during the drawing process.

The thinning/thickening ratio depends on the material: 5754 deformable aluminum alloy has a pronounced thinning, while DC01 and DC05 steels show a balanced strain distribution.

Optimization of drawing parameters (die geometry, lubrication, holder force, and speed) is critical for high-quality thickness control and defect prevention.

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