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ASSESSMENT OF THE DEFORMED STATE OF SHEET METAL AFTER DEEP DRAWING BASED ON FLD ANALYSIS

Abstract: *The results of the FLD analysis of plastically deformed aluminum sheets with thicknesses of 0.5 – 5.0 mm after the deep drawing process with a blank holder were presented in this article. The deformation degree of material (Traditional FLD, Engineering FLD and Effective plastic strain FLD) was graphically demonstrated.*

Key words: *deep drawing, cup, strain, stretching, compression, thickness, FLD.*
Language: *English*
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Introduction

The material is subjected to plastic deformation by stretching and compression in the process of deep drawing of sheet metal [1]. Wrinkles form on the flange, which make it difficult for the material to move when the workpiece is pressed into the die hole.

At the same time, the forming force acting on the punch increases. This leads to a significant thinning of the wall of the fragment of the semi-finished product located in the die hole [2]. It is determined that the greatest thinning of the material occurs in the bending zone of the workpiece caused by the radius element on the forming part of the punch. All these factors can lead to partial destruction of the material in the bottom zone of the semi-finished product or in the bending zone of the workpiece when it is pressed into the die hole.

The use of a blank holder reduces the formation of wrinkles on the flange of the metal sheet during deep drawing of the cup. However, even in this case, the risk of partial destruction of the workpiece material remains.

Forming limit diagram (FLD) estimates the degree of strain of workpieces subjected to plastic deformation [3]. The values of the forming force, strain of the material (thinning) and other parameters measured during the experiment are compared with the theoretical values of the ultimate strains and a conclusion is given about the normal formability or risk of the material destruction. Special cases of evaluating the strain of metal semi-finished products by FLD after the deep drawing process were considered by Chemezov [4], Takalkar et al. [5], Keller et al. [6], Feoktistov and Andrianov [7], Li et al. [8], Petroušek et al. [9], Gantar et al. [10].

The purpose of this study was to assess the deformed state of aluminum sheets of various thicknesses during deep drawing with a blank holder to determine the effect of the type and magnitude of strain on the risk of partial destruction of the semi-finished product.

Materials and methods

Simulation of the process of deep drawing of circular metal discs was performed in the LS-DYNA program. A deformable aluminum alloy with appropriate properties was adopted as the material. To compare the deformed state of the obtained semi-finished products (cups), sheet metal thicknesses were taken 0.5, 1.0, 2.0, 3.0 and 5.0 mm. The diameter of the workpiece did not change. To reduce excessive local deformations and the formation of wrinkles on the workpieces, a punch with a spherical working part and a blank holder were used, respectively.

The analysis of the deformed state of the material after deep drawing was carried out on the basis of FLD. The calculation results for Traditional FLD, Engineering FLD and Effective plastic strain FLD were reviewed and analyzed.

Results and discussion

Since the purpose of the work was to compare the stress and strain state of the formed cup material after the deep drawing process, the results of the computer calculation must be evaluated. To do this, diagrams were constructed that determine the nature of sheet metal deformation in dimensionless magnitude and in percentage terms. The values of the minor true and engineering strains are postponed along the abscissa axis. At the same time, negative values of the minor true strains correspond to the compression deformation of the material, and positive values correspond to the stretching deformation of the material.

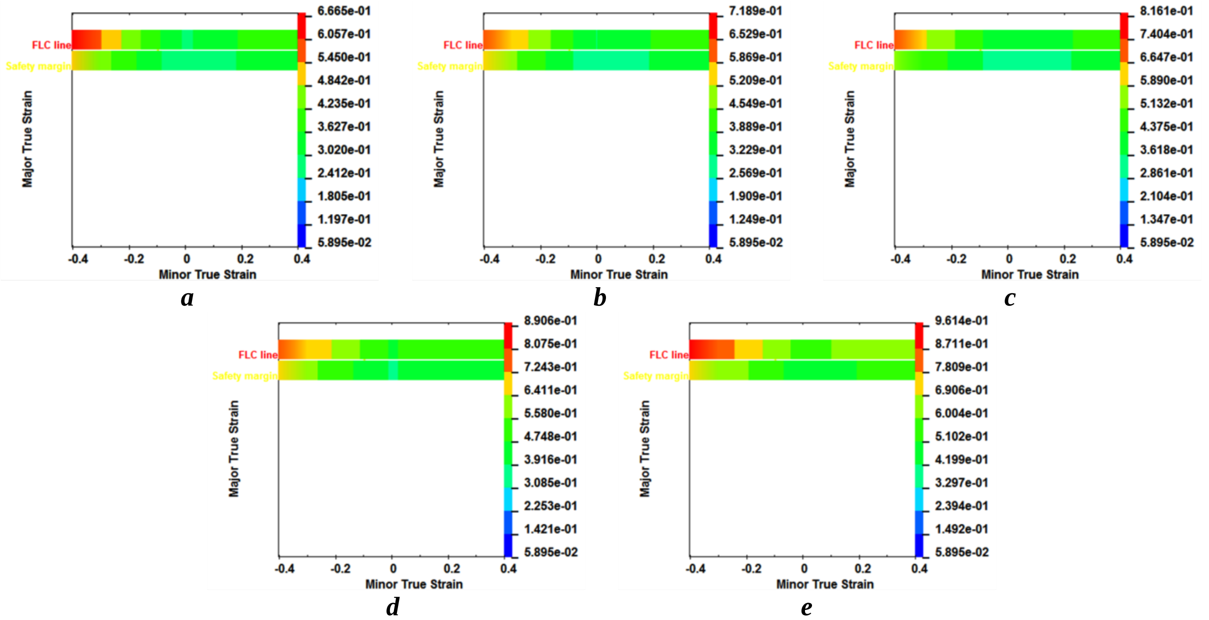

Figure 1. The dependences of the major true strain on the minor true strain: *a*) t = 0.5 mm, *b*) t = 1.0 mm, *c*) t = 2.0 mm, *d*) t = 3.0 mm, *e*) t = 5.0 mm.

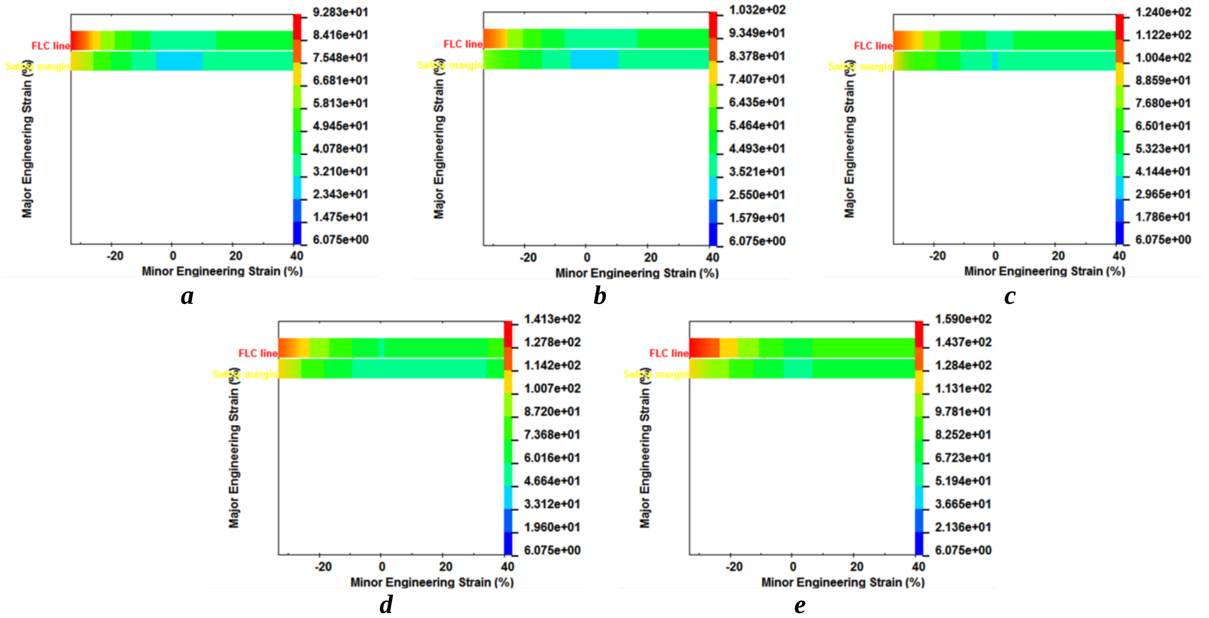

Figure 2. The dependences of the major engineering strain on the minor engineering strain: *a*) t = 0.5 mm, *b*) t = 1.0 mm, *c*) t = 2.0 mm, *d*) t = 3.0 mm, *e*) t = 5.0 mm.

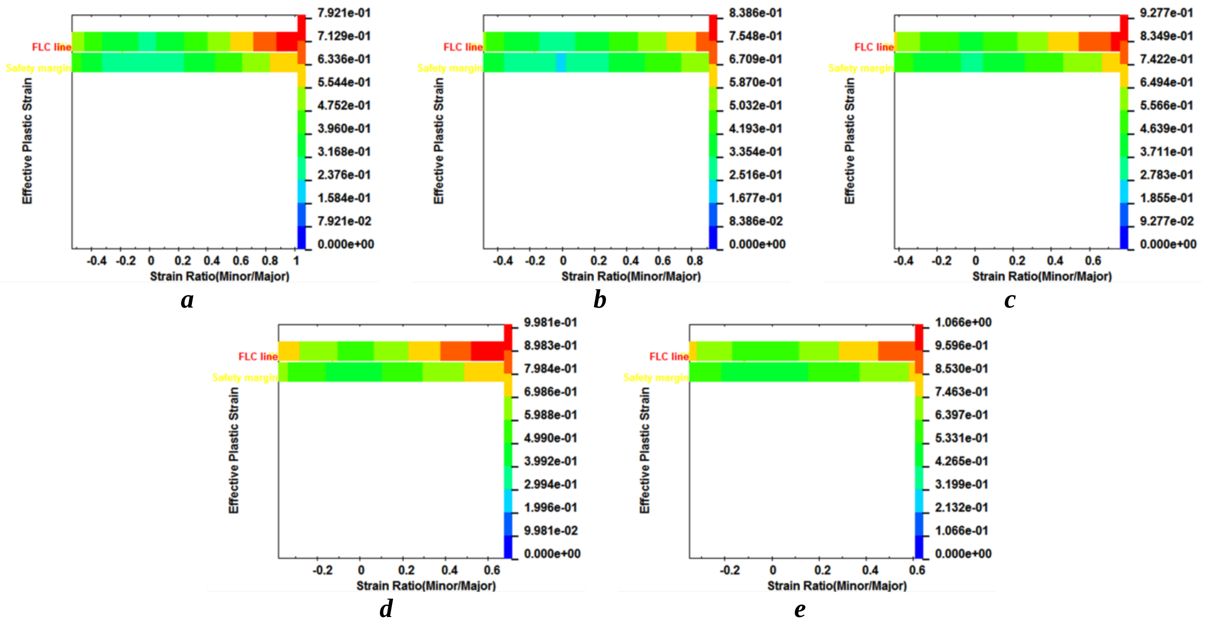

Figure 3. The dependences of the effective plastic strain on the strain ratio: *a*) t = 0.5 mm, *b*) t = 1.0 mm, *c*) t = 2.0 mm, *d*) t = 3.0 mm, *e*) t = 5.0 mm.

The values of the major true and engineering strains on the color scale are postponed along the ordinate axis. Two color bands are placed in the upper part of graphs, which determine the dependence of the values of the major true and engineering strains on the values of the minor true and engineering strains of the material. The upper color band is the line of forming limit curve (FLC). Strain at these values and above them leads to partial destruction of the workpiece material. The lower color band is the line of the material's safety margin during deformation. Strain at these values and below them does not lead to significant damage to the workpiece material. Also, based on the dependences of the effective plastic strain on the strain ratio, the probability of the material destruction was estimated. The results of the computer calculation are shown in the Figs. 1-3.

Workpieces with different thicknesses can be subjected to compression deformation to a greater extent during deep drawing. It is noted that with an increase in the thickness of the sheet metal, the material deformation increases with significant compression. This is due to an increase in the material resistance due to an increase in the volume of the workpiece in three coordinate directions. When drawing thin-walled cups with wall thicknesses of 0.5 and 1.0 mm, deformation of the material destruction can occur at the same maximum values of compression deformation. The process of stretching deformation of the material is characterized by a small range of dangerous strains before destruction (the difference in the values of strain of FLC line and safety margin). Therefore, the most stretched sections of the manufactured semi-finished product are more susceptible to destruction. The undesirable phenomenon can be reduced by optimizing the geometry of the parts of the drawing die and the blank holder force. The elongation or compression of the workpiece during the formation of the cup can reach from 23 to 159% of the initial dimensions. It is noted that with positive values of minor/major strains, the material destruction occurs at higher values of the effective plastic strain.

Conclusion

The following conclusions were made based on the analysis of the results of computer calculation of the deep drawing process of aluminum discs of various thicknesses:

1. The compression deformation of the disk material during deep drawing is 1.5 times greater than the stretching deformation.
2. The zone of critical strain of the material during stretching is less in percentage terms than during compression. With an increase in the degree of stretching of the material, the destruction of the cup can occur almost at the same values of strain, when comparing the values of safety margin and ultimate strain.
3. The same calculated value before the destruction of the cup during stretching is observed when comparing the effective plastic strain of aluminum discs with thicknesses of 0.5 and 1.0 mm. A similar conclusion can be drawn when comparing aluminum sheets with thicknesses of 4.0 and 5.0 mm after deep drawing.

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