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Issue Article

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MODELING AND ANALYSIS OF THE SHEET METAL DRAWING PROCESS TAKING INTO ACCOUNT NORMAL AND SHEAR STRESSES

***Abstract**: During the drawing process, the metal sheet is subjected to various types of deformation. To evaluate the stress and strain state of the material after drawing under the same conditions, several grades of steel, a deformable aluminum alloy, and commercially pure titanium were considered. The description of shear deformations and tensile and compressive deformations of the materials under consideration was carried out using the calculated maximum values of shear stress along three coordinate planes and normal stress along three coordinate axes.*

***Key words**: metal sheet, drawing, normal stress, shear stress.*

***Language**: English*

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1. Introduction

The sheet metal drawing process is a key step in the production of complex metal parts and requires careful consideration of both normal and shear stresses occurring in the material. Despite significant progress, challenges remain in managing residual stress distribution and preventing defects such as thinning and excessive deformation.

In recent years, research in the field of deep drawing has focused on modeling and experimental analysis methods, as evidenced by the work of El-Garf et al. [1], who conducted a comprehensive study using simulations and experiments to understand the formation process of cylindrical cups. Hartmann and Volk [2] and Serebrennikova et al. [8] study the forming of hybrid parts, emphasizing the influence of process parameters on product quality. An important aspect is the analysis of residual stresses and their influence on the properties of materials, which is investigated in the works of Zein et al. [3], Danckert [4], and in the latest publications of Zaława and Medei et al. [5-7]. Modern methods, including the use of artificial neural networks for stress prediction, show promise for improving modeling accuracy [9-10].

The aim of this study is to apply computer modeling for a comprehensive analysis of the drawing process of thin-walled housing parts, taking into account normal and shear stresses in the deformed material, which will optimize the technological process and improve the quality of final products made of steel, deformable aluminum alloy and commercially pure titanium.

2. Materials and methods

To calculate the stress state of a three-dimensional model of sheet metal with a thickness of 0.8 mm, the LS-DYNA special program was used. The process of modeling the drawing of a square metal sheet was carried out to a depth of 20 mm. Since the object of study was a sheet metal model, the remaining models of the drawing die (punch, die and blankholder) were created as absolutely rigid bodies. In this case, the accuracy of the modeling results was achieved by assigning to the sheet models the Lankford coefficients, strain hardening exponents, physical and mechanical properties of DC01 structural high-quality carbon steel, DC05 high-quality cold-rolled low-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 calculated values of the stress state of each model after drawing were taken from the parameters of *x*-stress, *y*-stress and *z*-stress, which characterize the normal stresses arising in the material along the corresponding coordinate axes and from the parameters of *xy*-stress, *yz*-stress and *zx*-stress, which characterize the shear stresses arising in the material along the corresponding coordinate planes.

3. Results and discussion

Figure 1 shows the deformed geometry of a square metal sheet model after a drawing process to a depth of 20 mm. The model reflects characteristic changes in shape, which is important for assessing the manufacturability and reliability of processing.

Table 1 shows the calculated values of normal stresses (σ) and shear stresses (τ) for various grades of steel, deformable aluminum alloy and commercially pure titanium along three coordinate axes and planes, respectively. Negative normal stress values indicate compression regions, while positive values indicate tension regions. Shear stresses with a positive sign are oriented along the positive direction of the coordinate axis on the face with a positive normal, and negative ones are oriented in the opposite direction.

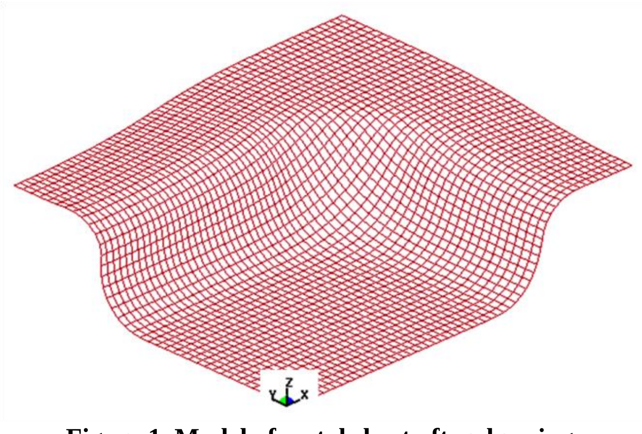

Figure 1. Model of metal sheet after drawing.

Table 1. Calculated values of normal and shear stresses in the material of the part along the coordinate axes of *X*, *Y*, *Z* and coordinate planes of *XY*, *YZ*, *ZX*.

DC01 structural high-quality carbon steel		
σ_x, MPa	-409.981	446.834
σ_y, MPa	-461.286	445.416
σ_z, MPa	-32.517	350.354

τ_{xy}, MPa	-108.263	316.76
τ_{yz}, MPa	-47.1775	231.404
τ_{zx}, MPa	-61.5755	219.193
DC05 high-quality cold-rolled low-carbon steel		
σ_x, MPa	-365.508	455.794
σ_y, MPa	-419.436	456.5
σ_z, MPa	-51.216	349.127
τ_{xy}, MPa	-87.4779	302.985
τ_{yz}, MPa	-50.7705	234.896
τ_{zx}, MPa	-53.0267	224.666
S355MC high-strength low-alloy steel		
σ_x, MPa	-523.616	1172.81
σ_y, MPa	-522.54	1331.52
σ_z, MPa	-231.783	826.302
τ_{xy}, MPa	-203.332	386.024
τ_{yz}, MPa	-238.873	731.7
τ_{zx}, MPa	-197.838	539.682
AISI 304 austenitic stainless steel		
σ_x, MPa	-425.68	420.822
σ_y, MPa	-478.401	425.885
σ_z, MPa	-26.136	327.19
τ_{xy}, MPa	-118.053	321.791
τ_{yz}, MPa	-34.8687	216.723
τ_{zx}, MPa	-53.851	203.703
5754 deformable aluminum alloy		
σ_x, MPa	-164.6	210.079
σ_y, MPa	-187.918	213.868
σ_z, MPa	-18.7518	223.423
τ_{xy}, MPa	-57.2409	145.954
τ_{yz}, MPa	-37.7327	122.015
τ_{zx}, MPa	-33.0665	117.408
Ti Grade 4 commercially pure titanium		
σ_x, MPa	-658.116	1289.89
σ_y, MPa	-694.225	1165.49
σ_z, MPa	-47.2773	1320.11
τ_{xy}, MPa	-199.486	597.837
τ_{yz}, MPa	-218.952	593.169
τ_{zx}, MPa	-217.1	588.064

Data analysis shows that all materials exhibit significant stress states, with maximum normal and shear stress values occurring on the *X* and *Y* axes. Particularly high stresses are characteristic of S355MC high-strength low-alloy steel and Ti Grade 4 commercially pure titanium, indicating their high strength and simultaneous difficulty in deformation. At the same time, the 5754 deformable aluminum alloy exhibits the lowest stress values, which is associated with its higher ductility and lower strength.

This stress distribution indicates non-uniform deformation in the drawing zone: the central sections experience tension, while the peripheral sections experience compression. High shear stresses indicate the presence of significant shear deformations, which is important to consider when designing a process to prevent cracks and surface defects in the housing part.

4. Conclusion

During the study, a detailed calculation of the stress and strain state was carried out for various grades of steel, deformable aluminum alloy, and commercially pure titanium, which made it possible to obtain quantitative values of normal and shear stresses. The highest values of normal stresses along the *X* and *Y* axes were recorded for Ti Grade 4 commercially pure titanium – up to 1289.89 MPa and 1165.49 MPa, respectively, as well as for S355MC high-strength low-alloy steel with maximum values of up to 1172.81 MPa and 1331.52 MPa. The shear stresses of τ_{xy}, τ_{yz} and τ_{zx} also reached maximum values for these materials, which indicates their high strength and ability to withstand complex loads.

DC01 and DC05 steels, as well as AISI 304 austenitic stainless steel, showed moderate stress values, making them optimal for structures requiring strength and ductility. In contrast, the 5754 deformable aluminum alloy is characterized by significantly lower stress values, which corresponds to its use in lightweight structures and products with low weight requirements.

The practical value of the results lies in the possibility of using the obtained calculation data to optimize the design and selection of materials depending on operating conditions and strength requirements. These stress values can serve as a basis for further analysis of the fatigue strength and durability of products, as well as for the development of effective technological processes for processing and strengthening materials.

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