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Case Study on the Influence of Forming Parameters on Complex Shape Part Deformation

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ABSTRACT

Drawing operations are commonly used to shape metallic thin-walled products for variety of industries – automotive, aerospace, household appliances etc. The basic indicator characterizing cold drawing process is possibility to decrease weight of a product, while at the same time increasing its stiffness in comparison to other conventional manufacturing technologies such as casting, forging or machining. In this research authors presented results of a numerical study on the influence of parameters such as blankholder pressure, forming force, tooling shape and part shape design on the success in manufacturing a part of complicated shape designed as an element of a phase change material heat accumulator. The subject of wrinkling (first and second degree of buckling) was discussed, and the research presented the manufacturing process design which allowed manufacturing discussed drawpiece without defects and within dimensional tolerances. The paper analyzes the phenomenon of drawpiece folding during the forming process for various groups of materials. Experimental research was carried out on a prototype tool for stainless steel (X5CrNi18-10), aluminum alloy (AW-5754) and copper alloy (CW024A).

Keywords: forming; drawing; wrinkling; stamping; flanging.

INTRODUCTION

In stamping of thin metal sheets, drawing operations hold a large quantitative share. Within this group of operations, we can include simple drawing, redrawing and stretching. Drawing is a general plastic forming operation, during which a flat pre-product (usually a thin sheet of metal - that is a blank) is transformed into a drawpiece – a three dimensional product with non-developable surface. The deformation occurs in the same direction as direction of the force applied by the press, through the tool shaped the same as the final product. Redrawing is an operation (or group of operations), during which a previously shaped drawpiece is extended and reshaped in a manner that height of the part is increased in exchange for its cross-section diameter, maintaining similar wall thickness of a product in all stages of processing. Drawing with stretching is a process during which a height of a pre-drawn halfproduct is increased by stretching its walls, maintaining the drawpiece initial cross-section internal diameter, but lowering its wall thickness [1, 2].

In the forming process, essentially two different methods of deformation can be described. The first method, called flanging, is used in the area of the drawpiece bottom and consists of shaping the sheet at the expense of reducing its thickness as a result of the action of a plane stress state. In the area of the flange, the sheet is shaped by increasing its thickness under the influence of compressive stress and stretching it in the radial direction (Fig. 1). The involvement of pure drawing and dressing in the shaping process is primarily determined by the shape of the punch and die and the ratio of the size of the blank to size of the finished drawpiece. In case of using flat-ended punches, pure drawing process is mainly carried out, meanwhile if the stamp is shaped spherically – dressing additionally occurs. During different steps of the forming process, local values of stress and strain at selected observed zones of the formed part tend to change. The largest stress values are usually observed on the edge of the formed shape, close to the punch corner radius, due to thinning of the material and caused by it large tensile stress value [3–5]. Various methods of forming and plastic deformation of sheet metal affect the appearance of defects, including including the crease of the drawpieces. In order to eliminate the disadvantageous phenomenon of folding, it is possible to control the forming process by appropriately shaping the die and punch, as well as by appropriately adjusting the size of the initial blank. Moreover, the material grade, which is more or less plastic, has a great influence on the reduction of the phenomenon of folding for the given geometry of the part and the forming process. Therefore, during the design process, the appropriate material is selected so that a given part not only meets the strength requirements, but is also feasible.

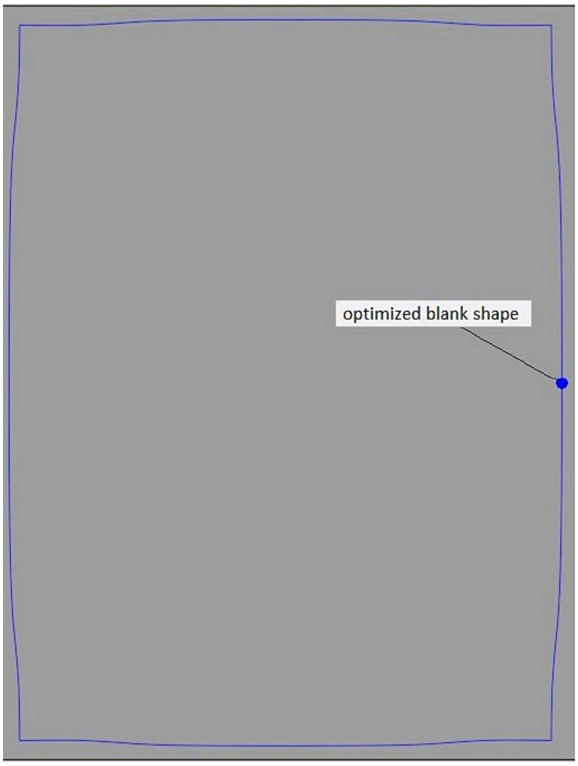

Fig. 1. The minimal size of the blank, determined numerically (visible differences in the amount of material collected along the side length as a result of anisotropy)

STATE OF DEFORMATION IN THE DRAWPIECE

The distribution of deformation in the direction of the wall thickness is often different along the circumference of the drawpiece (Fig. 2). These variations result from the anisotropic properties of the material [6]. The intensity of the material's plastic flow in a given direction depends on the orientation of the sheet in relation to the rolling direction during sheet metal manufacturing process. The differences in the plastic flow of the material are clearly revealed by uneven flow of the material within the periphery of the formed part. The locations of the protrusions and their size depend on the value of the flat anisotropy coefficient, as seen in Fig. 3.

PRIMARY AND SECONDARY DEFORMATIONS DURING THE FORMING PROCESS

With sufficiently high values of the r_s/g ratio (where r_s is stamp edge radius and g is thickness of a preproduct), the corner zone lies further from the product bottom and undergoes considerable plastic deformation. The accompanying strengthening of the material also lowers the malleability of the material (Fig. 2). Primary and secondary deformations during the forming process reach the highest possible value of σ_{gr} (plastification stress); in industrial practice most commonly selected ratio comes from the range: $r_s/g \geq 4$–6 [7, 8]. Lowering r_m/g (where r_m is the radius of the die edge) ratio increases σ_{gr} value, decreasing maximal forming force F_{max} at the same time. To diminish this effect, in industrial practice r_m/g is most commonly selected from a range between 5 and 10.

The force applied on the sheet by the blankholder introduces friction to the process – between the blank and die, and between the blank and the blankholder. Friction forces also occur in radius area of the die. To overcome beforementioned friction forces, σ_{gr} has to achieve sufficient value, which increases as the friction coefficient μ_m between the die and the blank increases in value as well. The friction between deformed metal and stamp surface affects the process positively because it increases the value of maximal allowed forming force. Under tensile stress, the

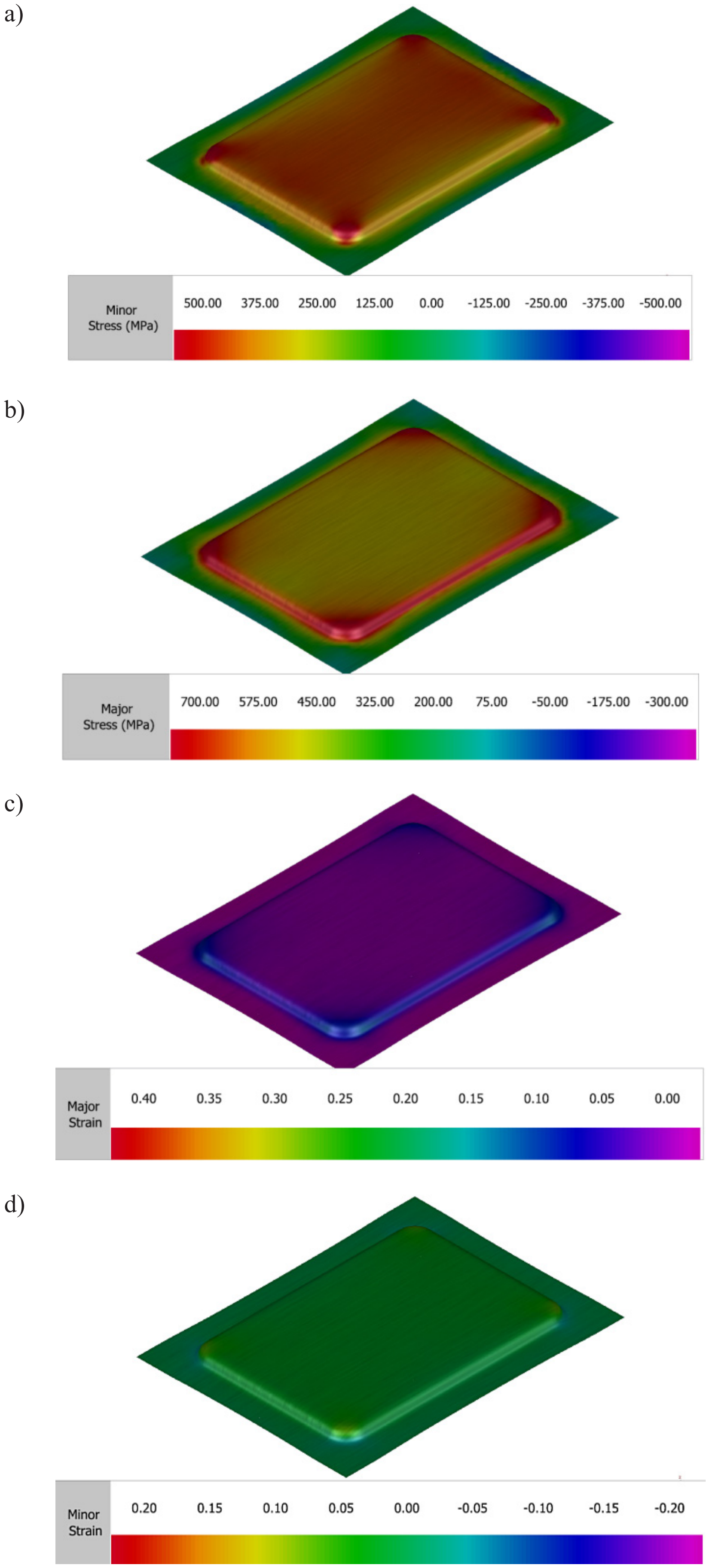

Fig. 2. Primary and secondary deformations during the forming process

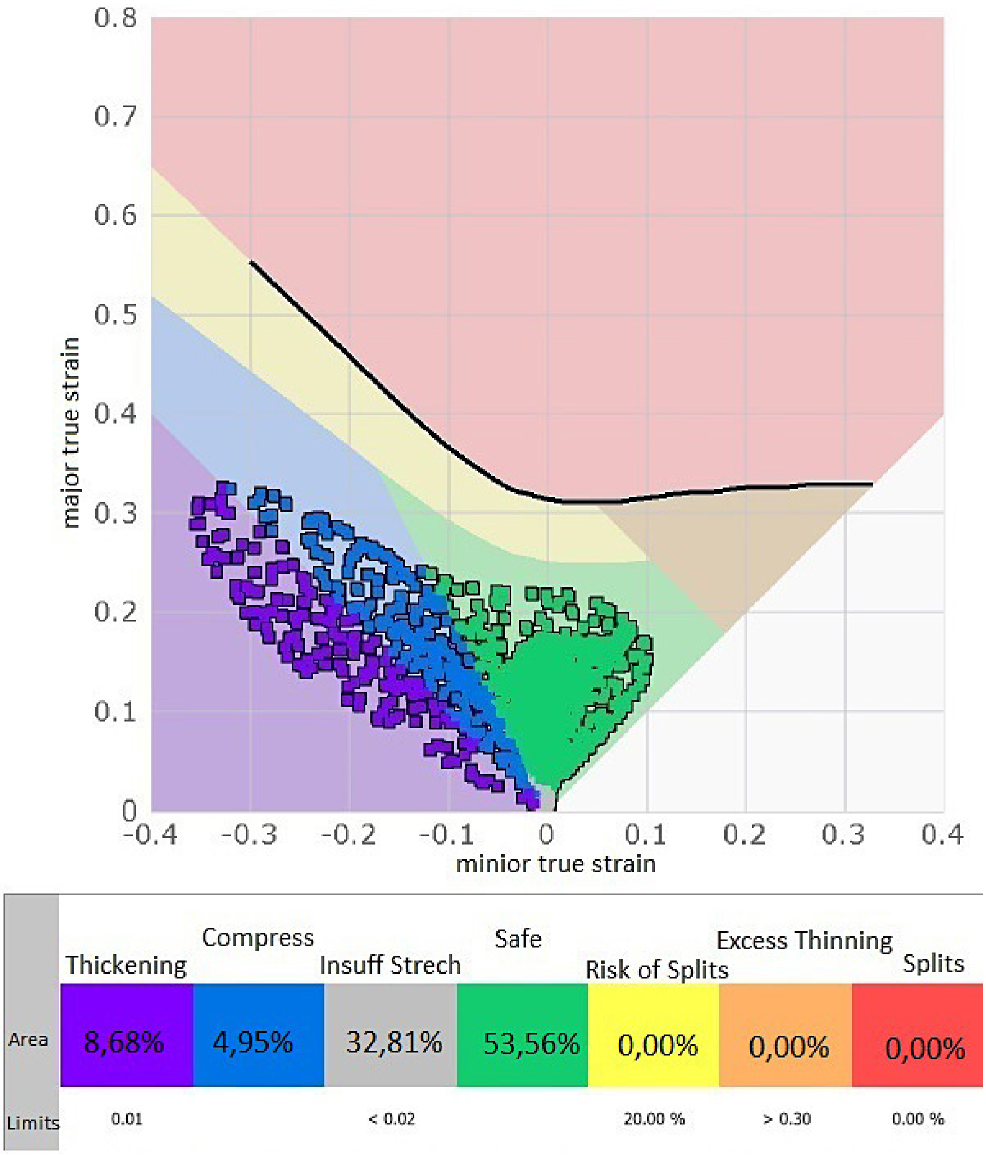

Fig. 3. Forming curve for material X5CrNi18-10, with marked values during the forming simulation

drawpiece is crimped on the stamp's side surface. Thanks to that, the critical stress between the side surface of the drawpiece and the bottom radius is lowered. Selecting proper lubrication method for the process can counteract the unwanted effects of friction during forming [9]. Change of the friction coefficient μ_s between the stamp and the wall of the drawpiece does not affect the forming force during drawing, buy it affects the maximal allowed forming force F_{br}. In the analyzed case, the value of the critical stress σ_{gr} is not constant. Parameters influencing the value of σ_{gr} can be divided into two groups:

- those that define the geometry of the designed drawpiece and the tool,
- those related to the conditions of the process implementation.

LOSS OF MATERIAL STABILITY

With a high degree of deformation caused by a deep drawing and a low material thickness, slenderness of the part is increased and a wrinkling of the flange occurs, which makes it difficult or impossible to carry out the manufacturing process and leads to poor product quality. Wrinkles can also form on the side surface of the stamped part. The wrinkling phenomenon occurs only when one of the two principal stresses is a compressive stress large enough to cause buckling of the sheet in certain areas. Even a relatively small compressive stress acting upon a sufficiently thin sheet may cause its folding (Fig. 3, 4). Most often, the area of the sheet most vulnerable to this type of deformation is the area adjacent to the periphery of the part (Fig. 5), and therefore the area which during drawing takes the form of a flat flange. During the discussed process, the wrinkled area widens in the direction of the forming force vector, in some cases encompassing nearly the entire flange of the drawpiece. Both the folding within the periphery of the extrudate and the material overlap are defined as first order folds. Most often, moldings are formed on the flange as a result of the tangential force acting due to compressive stress. Compressive stress applied to the flange of the stamped part can prevent wrinkling of the part. In terms of plasticity theory, such stresses are on average, by authors experience, between 1 and 5 N/mm². The required blankholder pressure during forming can be estimated empirically or by numerical simulation[10]. The pressure is determined by the surface area of the blank relative to the sheet thickness (s_0/d_0) and tensile strength of the processed material – the higher the strength of material the higher the unit pressure is required (Fig. 6, 7).

In the applied model, the stiffness of the forming tool and the blank in elastic range of deformation was expressed by the tangential modulus. Materials with a lower modulus of elasticity, such as aluminum, tend to stick to a tool, while steel tends to slip and deform, and therefore requires more surface pressure on the blanks to be shaped.

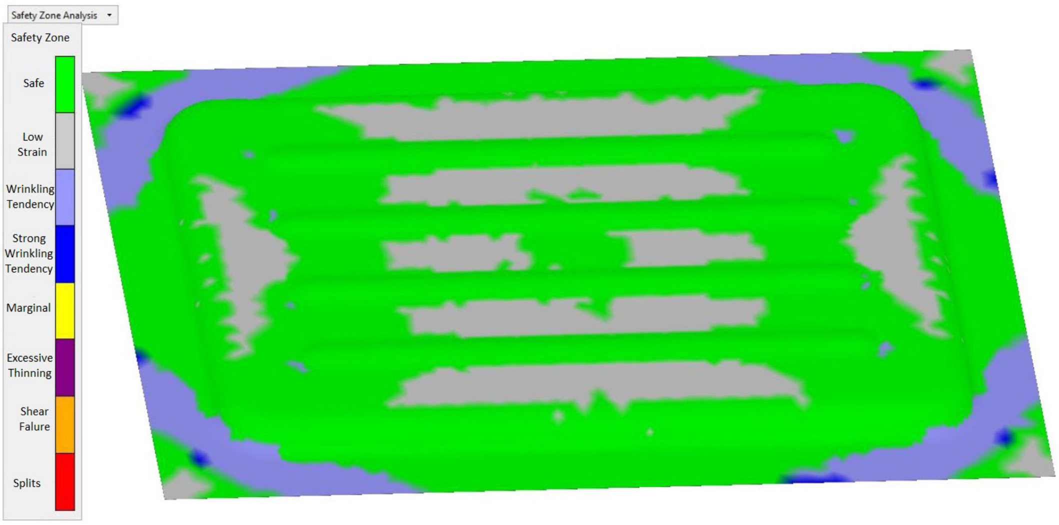

Fig. 4. Risk areas resulting from the forming curve

a) b)

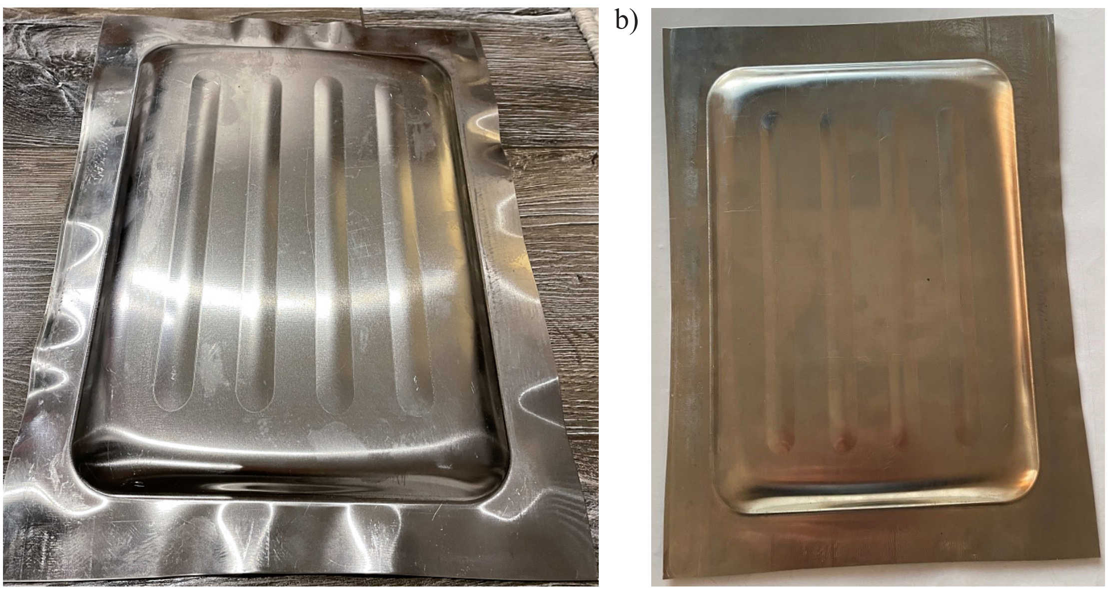

Fig. 5. The drawpiece made of material X5CrNi18-10 incorrectly formed with folds on the edge (a), and correctly - without folds (b)

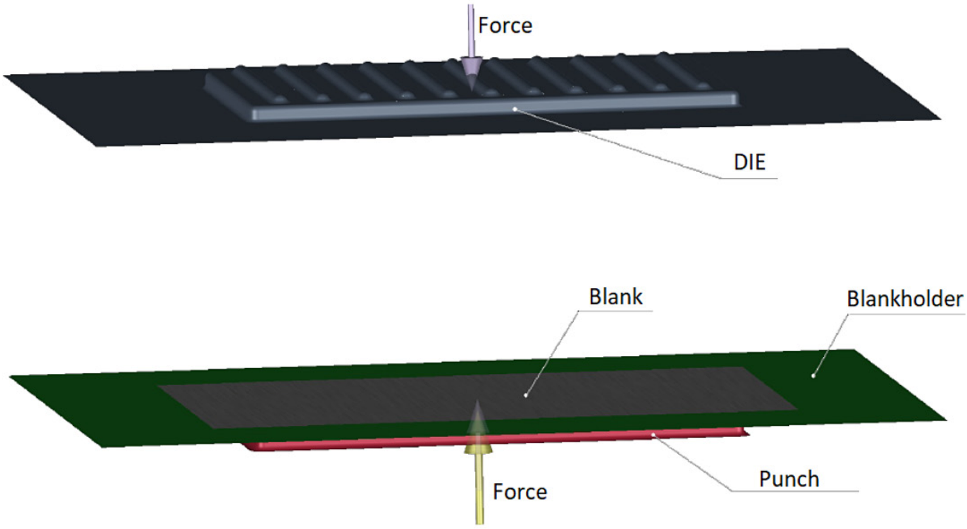

Fig. 6. Blankholder pressure during forming process. Simulation of the forming process where the die, punch and blankholder shape the blank sheet

Operation View Legend		
Tools	Legend Color	Max Force
DIE_10		80,6 kN
HOLDER_10		8,9 kN
PUNCH_10		71,7 kN
Weight		5,8 kN

Fig. 7. Forces diagram with blankholder forces and unit pressure

Thinner sheets require greater blankholder pressure than thicker sheets. A suitable sheet holder prevents the sheet metal from buckling during deep drawing of thin sheets as a result of tangential compressive stresses. The larger the sheet area not held by a blankholder, the greater is the excess of material in the tangential direction, that can be affected by the wrinkling effect. It is challenging to completely prevent second-order wrinkling, since due to the constantly changing geometric conditions along the entire embossing path, the tool cannot be in contact with the formed part throughout the entirety of forming process. In a general case, there is certain range of forces applied by the blankholder with the limit of upper holding force value Q_p, which if exceeded would lead to breakage of the part due to material's inability to flow during forming.

Uneven height of the drawpiece along the perimeter, the so-called earing is related to the anisotropy of the mechanical properties of the sheet [11]. Shaping materials with a high tendency for galling may lead to scratches on the outer surface of the formed piece [12]. Usually, the pressure applied by the blankholder takes value of a few N/mm². Factors that influence how the folding phenomenon occurs are among others:

- sheet thickness – thinner sheets are more prone to buckling and therefore require larger sheet allowance,
- blankholder pressure – due to the lower buckling resistance, with all other conditions being the same, aluminum sheets require higher blankholder pressures than steel sheets,
- the use of complex tools, the working surface of which reflects the shape of the element formed in order to obtain increased accuracy of the shape of the part with reduced pressing force compared to shaping with traditional tools.

The folds in the contact area between a blankholder and a material are called 2nd order folds. They are created as a result of the occurrence of specific conditions and parameters, namely:

- insufficient size and holding force,
- material with a hardness too high for the workpiece's desired degree of deformation,
- small sheet thickness, usually in a range between 0.4 and 1.5 mm,
- the stress state (under the force of the plate grip).

Introduction of the grooves at the bottom of the drawpiece (visible on Fig. 8) minimized the effect of sheet wrinkling, as expected [13, 14]. Introduction of the grooves to the analyzed part geometry was also dictated by the required change in the stiffness of the part which would serve as a phase change material (PCM) container. The smooth drawpiece is not very stiff in the bottom part. Studies have shown that for designated application, greater stiffness may be required because of plans to reduce the thickness of the preproduct or changing the material of the part from stainless steel to copper CU-DHP material or aluminum alloy AW-5754 type or other. Such plan is dictated by the desire to use the device in aviation (AW-5754 material), where mass is important, and to increase the intensivity of heat transfer (CU-DHP material). Taking the above into account, four longitudinal stiffeners several millimeters deep were designed on the lower surface of the heat container.

SPRINGBACK EFFECT

After the forming process is finished and the load is removed, material's elastic properties cause an unintentional change in the shape of the formed element. The phenomenon of changing shape after unloading is called springback. The springback of the material (with its magnitude presented on Fig. 9) depends on many factors: the mechanical properties of the bent material, the type of material and its strengthening characteristics, the degree of deformation determined by the ratio of the punch bending radius to the material thickness ratio, bending angle, product shape, bending method, final bending force and blankholder force.[15] The prediction of the springback effect is a significant engineering problem, in particular in obtaining the desired product shape and dimensions within required tolerances in a production of thin sheet metal parts (0.6–1 mm). The elimination of this phenomenon by additional finishing or calibrating operations also allow to reduce local folding of drawn parts [2, 16]. In the present research, the relationship between the reduction of the springback effect and the simultaneous reduction of the corrugation of the finished product for a thickness of 1 mm for steel grade X5CrNi18-10 was proved experimentally.

THE INFLUENCE OF FRICTION ON THE PHENOMENON OF FOLDING

Frictional forces have a significant influence on the course of the drawing process[3]. During the process of shaping the drawpiece, there are areas on the drawpiece that differ in terms of their state of stress, state of deformation, speed of deformation and frictional conditions[17]. The wrinkling of different deformation patterns is caused by the interaction of tools and technological factors that alter the friction conditions. In most sheet metal forming processes, the wrinkling caused by frictional resistance is an undesirable phenomenon and leads to:

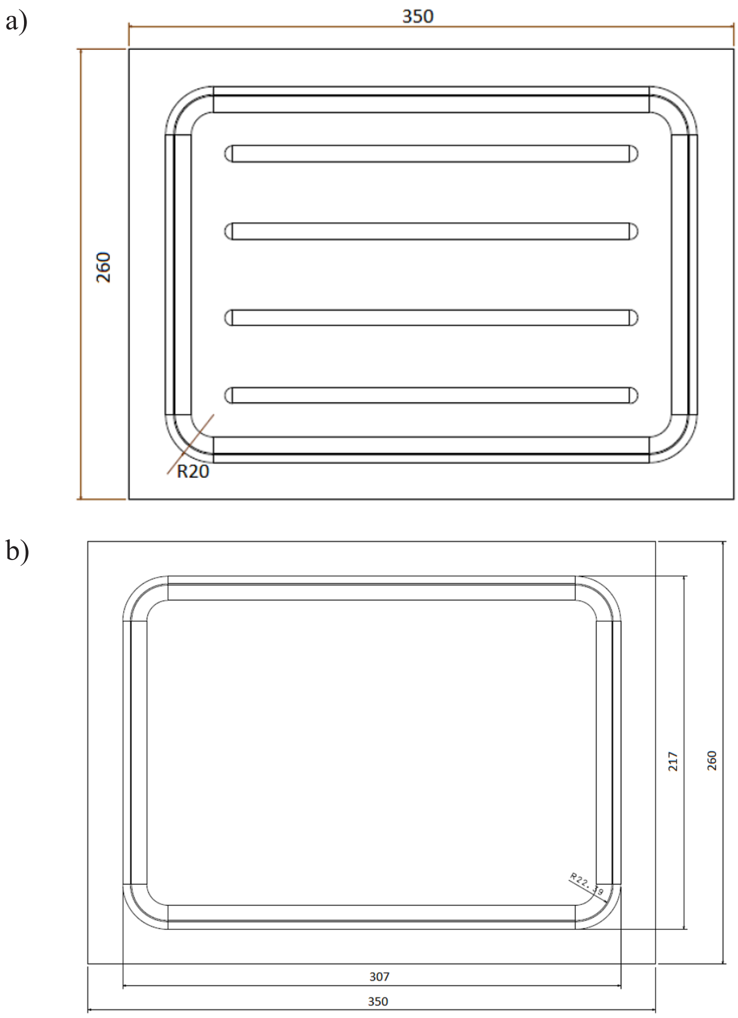

Fig. 8 Comparison of the geometry of the part with and without stiffeners

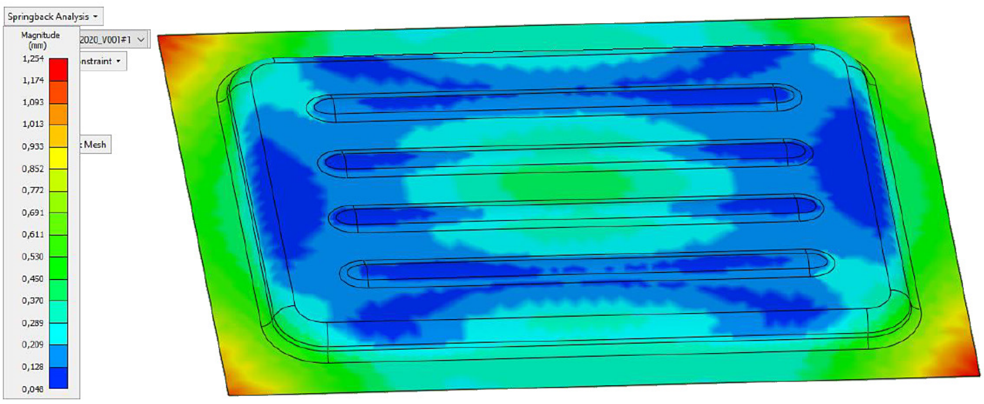

Fig. 9 The springback effect of the values in mm in the z axis (along the sheet thickness)

- the wrinkling caused by irregular material deformation, causing significant changes in the thickness of the sheet during the forming process,
- an increase of radial stress that increases the risk of cracks in the drawpiece and an increases the required maximal forming force,
- a temperature increase in the contact area, which adversely changes the contact conditions,
- reduction of tool life and product quality.

Frictional forces i.e., the tangential components of the forces interacting between the working surfaces of the tool on the surface of the plastically shaped material have a significant impact on the field and state of stress in the deformed material, and especially in its cover layers adjacent to the working surfaces of the tools [3]. The stress field, in turn, affects the course of metal deformation, and thus the movement of its surface in relation to the tool surface, i.e., the frictional forces. However, this local increase in friction allows the phenomenon of folding to be eliminated by appropriately stretching the material during the part forming process. Due to both the complexity and specificity of friction conditions and wrinkling in plastic metal processing, it is not possible to use a simplified friction model [5, 18].

CONCLUSIONS

The conclusion of the work carried out are as follows. Optimal control of the value of the holding force and a method of applying it is required to improve the quality of stampings and allows to increase the degree of sheet deformation during stamping. Modern developments in the design of presses used for sheet metal pressing is associated with the improvement of traditional methods of sheet forming by using flexible clamps with a computer-based pressure control system but also using segment holders [19, 20]. The use of the so-called pulsating blankholder (the pressure takes place sequentially with the appropriate amplitude) allows one to increase the drawing coefficient, which, in turn, allows for the stamping of products made from materials with reduced plasticity [21]. Increasing the amplitude of the holder pulsation leads to a reduction in frictional resistance and has a decisive and positive influence on the quality of the stampings. The use of complex drawing tools, the working surface of which imitates the shape of the extruded element leads to products with increased accuracy of shape allowing to simultaneously reduce the pressing force in comparison to parts shaped with traditional tools. The use of dies with a variable side surface angle and pressure plate allows one to increase the degree of deformation and minimize the holding force. Such improvements minimize the effect of sheet corrugation. The change in the geometry of the analyzed part, by its reinforcement with transverse stiffeners, increased the stiffness of the bottom head. For a sheet thickness of 1 mm, the stiffness was satisfactory, allowing to reduce thickness of a preproduct by 25–30% in the future.

Acknowledgements

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