GV-CONF 2013

Proceedings in
Global Virtual Conference

The 1st International Global Virtual Conference

8. – 12. April 2013

INFLUENCE OF THE POSITION OF AN APERTURE DERIVED IN THE INITIAL MATERIAL ON THE DRAWING WORKABILITY OF THE COLD ROLLED METAL SHEETS

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Abstract—**In this paper, a research about the influence of the position of a previously derived hole in the initial material intended for drawing onto the drawing workability of the cold rolled metal sheets is made. This influence is researched by hydraulic drawing of round steel sheets with previously derived holes on them. The research was made by drilling equal holes in the center of the metal sheet plate and displaced from the center, but placed in the main directions of the normal planar anisotropy of the metal sheet. The goal is to proof that by changing the position of the previous derived holes the processing of the cold rolled sheets can be improved and that will help to solve technological problems in the production when the method of drawing pieces with previously derived holes in the initial material is used.**

Keywords: drawing, initial material, plastic deformability, effective stress, limit of deformation, continual initial material, initial material with derived holes.

I. INTRODUCTION

Very often on the parts (pieces) manufactured by drawing from sheet steel in their walls there are apertures that don't meet strict requirements for their form, position and dimensions and are intended for different purposes such as air vents, apertures for draining water and dirt, various exemptions for access to the assembly tools, forming flat surfaces near a vertical wall, etc.

Performing these apertures after the process of drawing, especially in areas with a complex form is quite difficult, sometimes impossible, requires preparation of complex and expensive tools, increases the time of manufacture, and therefore the cost of the product. It is much better and more economical if these apertures are made before the drawing of the initial material.

In such cases the process of drawing is different from the process of drawing parts with continuous surfaces. The working experience with technological processes of drawing with previously derived apertures in the initial material showed that very often these apertures are a critical point in the process. Therefore it is necessary to study the influential factors in the drawing process from initial material with a previously derived aperture, so that the process itself is improved as well as the utilization of the available plastic properties of the material.

II. MODELING OF THE PROCESS

The technological process of drawing cold rolled steel sheet of an initial material with a previously derived apertures which remain in the side walls of the part (piece) after the drawing is quite specific. It is assumed that the limit deformability or the limit degree of drawing will be achieved when at some point in the intersection of the hazardous material a certain critical stress σ_{zmax} will be reached.

Speaking of drawing cylindrical parts of metal sheet with continuous surfaces, i.e. continuous starting material, the critical stress in the vertical wall depends only on how big the resistance of drawing is and equals:

$$\sigma_z = \frac{F}{\pi d s}$$

where:

F - strength of drawing;

d - medium diameter of the cylindrical part and

s - thickness of the wall.

When drawing cylindrical parts with noncontiguous surfaces, i.e. drawing starting material with previously derived apertures the resistance of deformation depends on additional factors such as: reducing the cross-section in the vertical wall, the size of the aperture, the type of processing that defines the quality of the treated surface of the aperture, the shape and the location of the previously derived aperture in the initial material etc. The influence of the additional factors can be taken into consideration by correction coefficients such as:

ξ_1 - degree of reduction of the cross-section;

ξ_2 - size of the previously derived aperture in the starting material;

ξ_3 - surface quality of the previously derived aperture;

ξ_4 - form of the previously derived aperture;

ξ_5 - location of the previously derived aperture;
and other corrective coefficients.

In the case of drawing parts of noncontiguous areas of a initial material with previously derived apertures, the critical stress can be defined as:

$$\sigma_{zmax} = \sigma_z \cdot \xi_1 \cdot \xi_2 \cdot \xi_3 \cdot \xi_4 \cdot \xi_5 \cdots = \sigma_z \cdot \xi$$

The successful flow of the technological process of drawing with noncontiguous areas, as well as drawing with continuous surfaces the condition must be satisfied:

$$\sigma_{zmax} \leq (1,1 \div 1,2)\sigma_M$$

where σ_M is the tensile strength of the material.

The correction coefficient for the degree of reduction in the cross-section is:

$$\xi_1 = \frac{\pi d s}{\pi d s - n l s} = \frac{1}{1 - \frac{n l}{\pi d}}$$

where:

n - number of apertures in the critical section and

l - arc width of an aperture in tangential direction.

Additional experimental research is required to determine the corrective coefficients of other influential factors.

For the analysis on the impact of the location of previously derived circular aperture in the initial material onto the workability of the cold-rolled metal sheets, experimental research using initial material made out of cold rolled steel sheet Č 0147 (RSt 13 according to DIN 17006) with 1 mm thickness is made. Strips are cut out from the metal sheet, and from them, using punching round plates with diameter Φ179 mm are made. The research was carried out using six initial materials in the shape of a flat round metal sheet plates. A measurement grid of concentric circles and radial routes is drawn mechanically onto the metal sheet plates. A circular grid with dimension of the circle $d_{0M} = 5$ mm is drawn onto the radial directions. On two out of the six experimental pieces there are no apertures. In the center (the axis of symmetry) on the fourth piece a round aperture with Φ 12 mm is drilled. At each of the last three metal sheet plates, at a distance R = 25 mm from the center in the radial direction, which coincides with the characteristic axis of planar anisotropy, an aperture with Φ 12 mm is derived as follows: in the direction of rolling of the metal sheet 0^0, normal to the direction of rolling 90^0 and at angle of 45º in respect to the direction of rolling. This specific layout of the apertures is chosen in order to study the impact of the anisotropy of the metal sheet on the maximum stress-deformation state. All four apertures are made with the same drill and the same regimens of processing. This way the quality at the surface of each derived aperture is held approximately constant.

In Table 1 are given the markings of the metal sheet plates with the position of the derived apertures in the starting material (the round flat metal sheet plates) respectively.

TABLE I.

Markings of the metal sheet plates in the starting materials	Location of the derived apertures in the starting materials
2.3 and 2.4	no apertures
3.3	In the center
7.2	at angle of 90^0
7.3	at angle of 0^0
7.4	at angle of 45º

Figure 1 represents a schematic view of the location of the derived apertures in the starting materials in relation to the direction of rolling of the metal sheet.
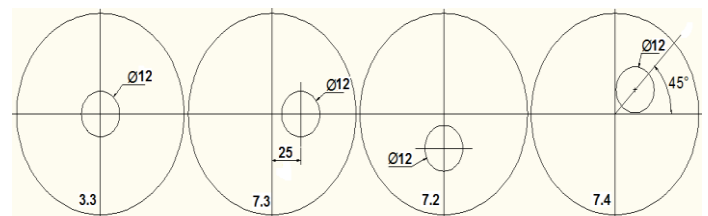

Figure 1. The location of the derived apertures in the starting materials

The experimental researches are performed by hydraulic drawing of the metal sheets. In the process of drawing as a criterion for the limit deformability is considered the moment of appearance of an eye visible crack at the aperture from the

drawn part of the metal sheet plate with previously derived round hole.

The visual analysis of the cracks shows that:

- Maximum stress-deformation state of the pieces drawn from a starting material that has no previously derived circular aperture occurs at the place of a maximum depth of drawing, i.e. nearby the axis of symmetry.

- Maximum stress-deformation state of the pieces drawn from a starting material with previously derived circular aperture occurs at the circular surface of the derived aperture.

Figure 2 shows an image of a piece drawn from the starting material marked as 3.3 at

which is made a hole in the center of the starting material.

Visual analysis of the piece marked as 3.3 shows that from the aperture start two cracks. One in a radial direction at an angle of $\approx 15^o$, and the second one in the radial direction of $\approx 90^o$ in respect to the direction of rolling.
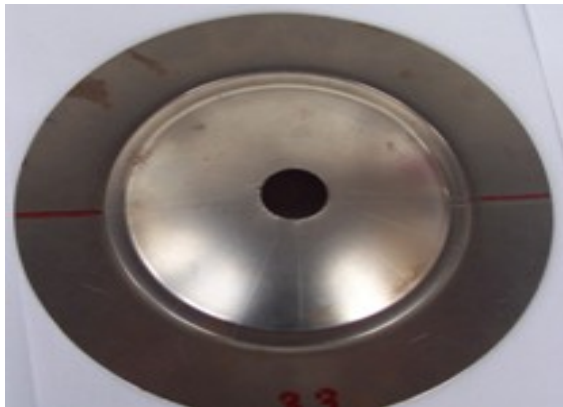

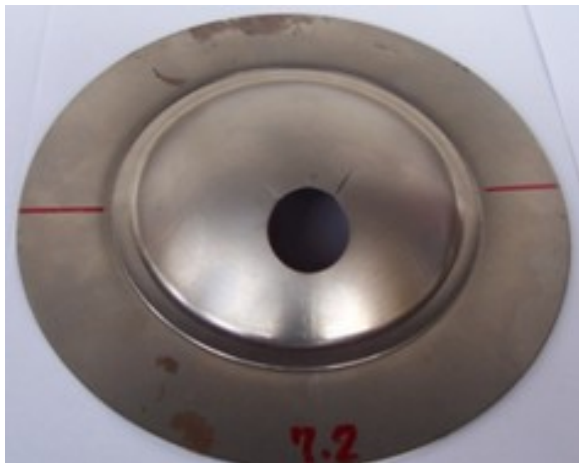Figure 2.   Piece drawn from a starting material marked as 3.3 with a central derived aperature

Figure 3.   Piece drawn from a starting material marked as 3.3 with

as 7.2 with an aperture at 90^0 aperture in relation to the direction of rolling

Figure 3 shows an image of a piece drawn from a starting material marked as 7.2 with a derived aperture at 90^0 in relation to the direction of rolling of the metal sheet.

The visual analysis of the piece marked as 7.2 shows that, from the surface of the aperture right from the radial direction which covers an angle from 90 ^{o} with the direction of rolling, and tendon distance of 8.5 mm from the intersection of the specified direction with the surface of the derived aperture, starts a crack that with the radial direction covers an angle of $\approx$ 40° and a localized deformation on the left from the specified direction, completely symmetric to the previous crack.

The visual analysis of the piece marked as 7.3 shows that, from the surface of the aperture left from the radial direction which coincides with the direction of rolling, and at tendon length of 9 mm from the intersection of the rolling direction with the surface of the derived aperture, starts a crack that covers an angle of $\approx$ 40^0 with direction of rolling. The visual analysis of the piece marked as 7.4 shows that, from the surface of the aperture starts a crack which direction coincides with the radial direction, which covers an angle from $\approx$ 45° with the direction of rolling.

The location of the cracks shows that changing the location of the aperture in relation to the axis of the planar anisotropy, the location and the direction of the maximum stress can be directed.

III.   MEASUREMENT AND PROCESSING OF THE RESULTS

After the drawing the circles of measuring grid with diameter d_{0M} are deformed into ellipses with axes d_{1M} and d_{2M}.

The d_{1M} indicates the greater axis of the ellipse and lies in tangential direction and d_{2M} is the smaller ellipse axis and lies in a radial direction. A measurement of the ellipses' axes in the radial direction which coincides with the direction of rolling of metal sheet with an accuracy of 0.1 mm is made. That way the impact of the planar anisotropy is removed, and it is made possible to compare the obtained maximum stress-deformation state of a drawn piece marked as 2.4 made of starting material without derived aperture and the piece marked as 3.3, which was made of the starting material with a derived aperture at the center.

Using the measured dimensions of the axes of the ellipses obtained from the measuring grid's deformed circles are determined:

- Logarithmic deformations, φ_{1M}, φ_{2M}, and φ_{3M} by the equations:

$$\varphi_{1M} = \ln \frac{d_{1M}}{d_{oM}} \ , \quad \varphi_{2M} = \ln \frac{d_{2M}}{d_{oM}} \ \text{and}$$

$$\varphi_{3M} = -(\varphi_{1M} + \varphi_{2M})$$

where:

φ_{1M} - tangential logarithmic deformation;

φ_{2M} - radial logarithmic deformation and

φ_{3M} - logarithmic deformation on the wall thickness.

- Effective deformations (deformations intensity) φ_{eM}

and

- Effective stresses (stress intensity) σ_{eM}

After the process of drawing, the previously derived apertures in the starting material get deformed. Measuring the axes of the deformed apertures the deformations are defined φ_{1O}, φ_{2O} and φ_{3O} according the equations :

$$\varphi_{1O} = \ln \frac{d_{1O}}{d_{oO}} , \quad \varphi_{2O} = \ln \frac{d_{2O}}{d_{oO}} \quad \text{and}$$
$$\varphi_{3O} = -(\varphi_{1O} + \varphi_{2O})$$

IV. RESULTS

Fig. 4 shows the diagram of the experimentally determined effective stress σ_{eM} changing in relation to the concentric circles' radius r of the measuring grid engraved onto the starting flat metal sheet plate, while the radial direction coincides with the rolling direction of the metal sheet. 2.4 marks the change of the effective stress curve σ_{eM} of a piece drawn from the starting material without previously derived aperture, and 3.3 marks the effective stress curves' σ_{eM} changes of the piece drawn from a starting material with an already derived circular aperture in the center of it.

From the diagram it can be seen that the effective stress curve for piece marked as 2.4 drawn from a starting material without previously derived aperture lies above the curve of the effective stress for the piece 3.3 that had an aperture in the center of the starting material. This means that the previously derived aperture in the starting material leads to deterioration of the drawing workability of the cold-rolled sheets.
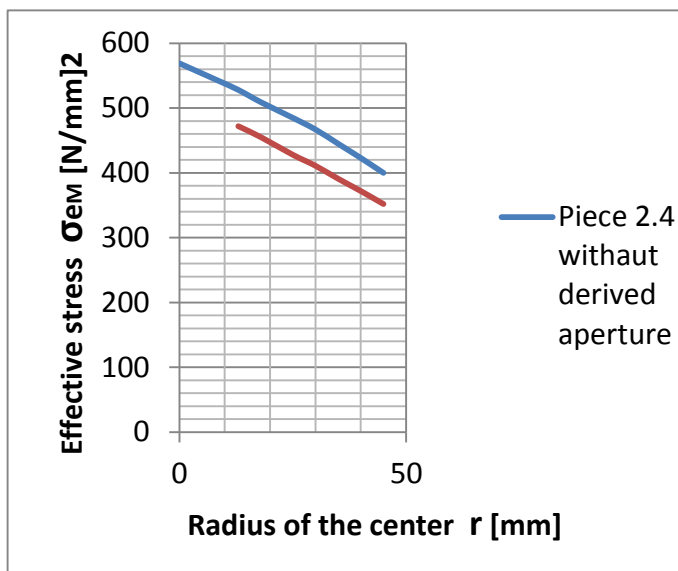

Figure 4. Effective stress curves of the two drawn pieces 2.4 without an aperture and 3.3 with a derived aperture in the center of the starting material

The influence of the size of previously derived circular apertures in the starting material on the drawing workability of cold rolled metal sheets expressed by the correction coefficient can be defined as:

$$\xi_2 = \frac{\sigma_{egp}}{\sigma_{ego}}$$

where:

σ_{egp} - Effective limit stress for a complete material and

σ_{ego} - Effective limit stress for a material with a derived aperture

The correction coefficient of the size of a previously derived aperture in the starting material for the analyzed material, the location and type of processing of the circular aperture with Ø 12 mm is:

$$\xi_2 = 1.128$$

The pieces marked as 7.2, 7.3 and 7.4 drawn from starting materials with previously derived circular apertures at distance of 25 mm, are not symmetrical in relation to the axis passing through the center of the starting material. At the radial cross-section passing through the center of the derived aperture and the center of the starting material, the curve is steeper at the side of the aperture, compared with the opposite side. For these reasons, maximum stress-deformation state of these pieces in a certain radial direction, can not be compared to the pieces 2.4 and 3.3 which are symmetrical in respect to the axis passing through the center of the starting material.

However, since the derived apertures in the outgoing materials of the drawn pieces marked as 3.3, 7.2, 7.3 and 7.4 are equal, the deformations can compared.

Figure 5 shows the logarithmic deformations of the apertures of the drawn pieces 3.3, 7.2, 7.3 and 7.4 with previously derived apertures in the starting material. From the diagram it can be seen that the aperture of the piece numbered 3.3 drawn from a starting material with a derived aperture in the center, deforms in a proper circle so that the radial and the tangential deformation are equal. The apertures made in the pieces marked as 7.2, 7.3 and 7.4 deform into ellipses. In this case the radial deformations are bigger than the tangential ones.

The diagram at Fig. 5 shows that deformations of the drawn pieces 7.2, 7.3 and 7.4 coincide. This means that in this particular case the planar anisotropy does not affect the maximum stress-deformation state. The apertures of the pieces 7.2, 7.3 and 7.4 submit bigger plastic deformations compared to the aperture of the piece 3.3 drawn from a starting material with a derived aperture in the center of the starting material.
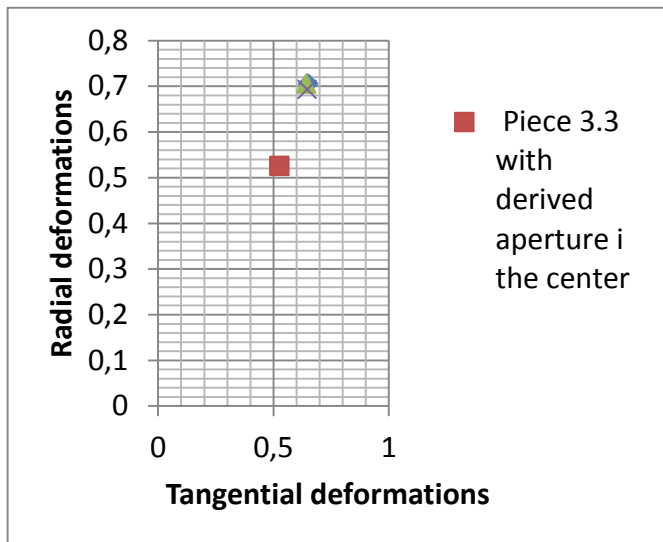
Figure 5. Deformations of the derived apertures in the starting materials after the drawing of the pieces

V. CONCLUSION

➤ The derived apertures in the starting (initial) material worsen the drawing workability of the cold rolled metal sheets.

➤ The location of the previously derived aperture in the starting material impacts the use of plastic properties of the cold rolled metal sheets when processing by drawing.

➤ By placing the aperture at a certain distance from the centre of the starting material grows the utilization of the material's plastic properties.

➤ The proper placement of the aperture in relation to the axes of planar anisotropy can affect the location and direction of the maximum stress.

➤ For fuller understanding, of the previously derived aperture's location impact, further research is needed, with deriving apertures that vary in size and that are placed at different distances from the starting material's center in the radial direction, which coincides with the planar anisotropy axes of the sheet. This is the only way to define more precisely the location's coefficient of the previously derived aperture.

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