



NEW TECHNOLOGICAL PROCESS OF DRAWING

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Abstract

Production of cylindrical axisymmetrical billets is often used at many branches of industry. At many plants such shells are produced from thin sheets by process of drawing, but length of such billets is limited by their stability. New technological process was created and gave possibility of producing shells of large length and good quality. This process was used for producing for many high quality products.

Keywords: Axisymmetric plastic deformation, Tangential stress, Loss of stability.

1. Introduction

Axisymmetric deformation of sheet metal blanks are widely used in the manufacture of cylindrical pieces made of flat metal sheets.

Such products as various vessel bodies, nozzles, connecting pipes are made of low carbon steels as well as of copper, brass, magnesium alloys and other metals.

This paper examines the deformation of the products with axial symmetry, which are increasingly used in industry.

Regularities of plastic deformation are studied

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in research papers [1-4]. They demonstrate that under the pressure of a cylindrical die on the center of the workpiece which was initially shaped like a disk, the plane stress is developed, with only two of the six tensor components being nonzero. Due to tensile radial stress and compressive tangential stress [1, 2] the buckling of deformable workpiece accompanied with folds is possible. Therefore it is necessary to limit the length of a product, to use drawing with subsequent additional deformation (secondary drawing operation, rolling).

To prevent the occurrence of folds the blank holders are used, but this significantly increases the deformation strain to an extent of the occasional overdrawing occurrence in a deformable work piece. Sometimes drawing with the billet or its edge parts heating (near the maximum diameter) is used. For some metals

billet heating can increase the allowed length of a product by 1,5-2,0 times.

Magnesium alloy sheets are thought to be used for deep drawing only with the billet heating. But as the thickness of a sheet metal to be deformed is small (up to 1-3mm) and is exposed to chilling it has to be heated directly on a die. That complicates the design of the equipment, enhances significantly power consumption and makes it difficult to ensure safety conditions. In this paper new drawing process is proposed.

2. Kinematically Admissible Velocity Fields by Drawing Deformation

The graphic pattern of drawing deformation is illustrated in **Figure 1**, where one can see matrix 1, deformed billet 2 with outer radius R_0 and inner one R_1 , thickness h and punch 3 which moves along axis Z with constant velocity $V_z = -V_0$.

Kinematically admissible velocity field determines the upper limit of deformation capacity N and the associated moving die force P . Such a velocity field is to satisfy: a) the incompressibility condition, b) velocity boundary conditions, c) the condition under which the deformation capacity is positive [1]. The volume of a deformable billet can be divided into two parts. One of them having a cylindrical shape with inner radius R_1 moves with velocity $V_z = -V_0$ together with moving die 3 [2, 3]. In this zone V_r is equal to 0 (the coordinate axes location is shown in **Figure 1**). As this part of a billet moves like a rigid body, its capacity of plastic deformation is equal to zero [3]. The second zone includes the part of a billet which has a shape of a ring with thickness h limited by radius $r = R_1 + h$ and $r = R_0$. Some features of this deformation are considered in paper [4]. In this area the kinematically admissible velocity was used:

$$V_r = -V_0 \frac{R_2}{r}; V_z = 0 \tag{1}$$

with the strain-rate tensor components

$$\epsilon_r = V_0 \frac{R_2}{r^2}; \quad \epsilon_\theta = -V_0 \frac{R_2}{r^2}; \quad \epsilon_z = 0$$

(the other tensor components are equal to zero). Value V_0 is velocity under $r = R_1$ and the second invariant of strain-rate tensor is equal to

$$H = 2 \frac{V_0 R_2}{r^2}.$$

This velocity field can be assumed as kinematically admissible only if exists such surface $z(r)$ separating the two selected deformation zones, that normal components of velocities for two zones are equal. Such a surface exists and is a paraboloid [5]. As a result, it is possible to determine the deformation capacity

$$N_1 = \int_{R_1}^{R_0} k 2\pi r h H dr = 4\pi k V_0 R_1 h \ln \frac{R_0}{R_1},$$

where k - yield point in shear. Shear capacity over the surface of paraboloid is

$$N_2 = \int_{R_1}^{R_1+h} k 2\pi r k \Delta V \sqrt{1 + \left(\frac{dz}{dr}\right)^2} dr,$$

with paraboloid equation:

$$z(r) = \frac{(R_1+h)^2 - r^2}{2R_1+h} \tag{2},$$

$$\frac{dz}{dr} = \frac{-2r}{2R_1+h};$$

tangential components break at the boundary of two zones is equal:

$$\Delta V = V_0 \sqrt{1 + \left(\frac{dz}{dr}\right)^2} \left(\frac{dz}{dr}\right)^{-1}$$

with shear capacity

$$N_2 = 2\pi k V_0 R_1 h \left(1 + \frac{h}{2R_1}\right),$$

Full capacity with provision for friction load at the surface of lower die is

$$N = P V_0 = N_1 + N_2 + \mu V_0 P,$$

where μ - coefficient of sliding friction.

Moving die force is

$$P = \frac{N_1 + N_2}{V_0(1-\mu)} \tag{3}$$

If the deformation is carried out with the use of blankholder, with force T , the friction load increases and force P is equal to

$$P = \frac{N_1 + N_2}{V_0(1-\mu)} + \frac{2T\mu}{1-\mu} \tag{4}$$

Usually $\frac{h}{2R_1} \ll 1$ and the force is

$$P = \frac{2\pi k R_1 h}{1-\mu} \left(1 + 2\ln \frac{R_0}{R_1} + \frac{2T\mu}{1-\mu}\right) \tag{5},$$

$$k = \frac{\sigma_T}{\sqrt{3}}$$

If the steel sheet deformation is carried out without the use of blankholder, as shown in **Figure 1** (with $T=0$, $R_1=80\text{mm}$, $R_0 = 96\text{mm}$, $\frac{R_1}{R_0}$

$= 1, 2$; $h = 1\text{mm}$, $\mu = 0.10$, $\sigma_T = 300 \frac{\text{MH}}{\text{m}^2}$, $k=173 \frac{\text{MH}}{\text{m}^2}$), the value of force according to (5) is $P = 0,13\text{MN}$.

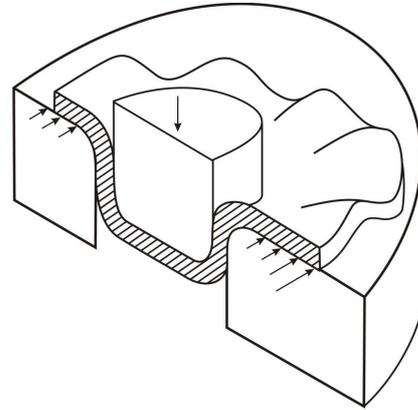
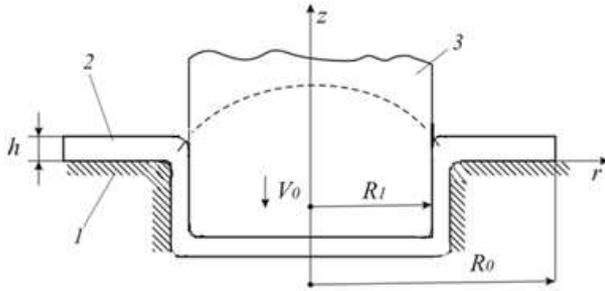


Figure 1. Scheme of deformation

Figure 2. Development of Folds

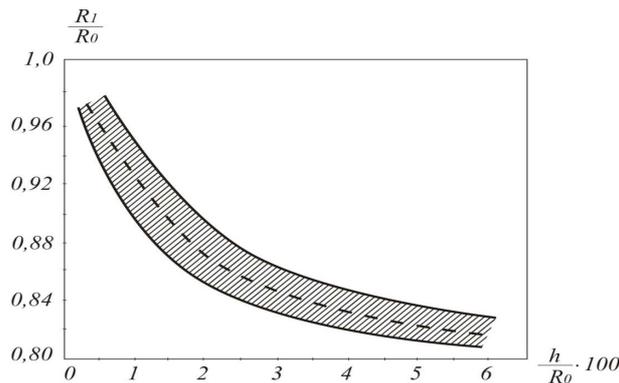


Figure 3. Graph of Function $\frac{R_1}{R_0} \left(\frac{h}{R_0} \right)$

As usual, the kinematically admissible velocity field determines the upper limit of forces (i.e., overstated values of P). According to experimental data, in case of drawing this overstatement amounts to 20-25%. This is acceptable for the choice of equipment in most cases.

3. Workpiece Buckling in the Drawing Deformation

In the process of deep drawing a sheet shaped initially like a disk undergoes tangential compressive stress that can lead to loss of stability. Thereby folds occur on the part of a

surface, as shown in **Figure 2**. Paper [1] indicates that the location and number of folds depends on the metal anisotropy, for example for some alloys the number of waves is four, with the location being at an angle of 45° to the rolling direction of a sheet. But the number may come up to six [1].

Usually, the fold occurrence, i.e. wavy surface with amplitude of up to 10-20mm, leads to inability to output products and to rejected material. From Saint-Venant condition end equation of equilibrium

$$\frac{d\sigma_r}{dr} + \frac{1}{r}(\sigma_r - \sigma_\theta) = 0 \quad (6)$$

and condition of plasticity

$$\sigma_y - \sigma_g = 2k$$

it is clear that stress is $\sigma_y = 2kln \frac{R_0}{r}$

$$\sigma_g = 2kln \frac{R_0}{r} - 2k \quad (7)$$

where the integration constant is determined by the condition of $\sigma_r = 0$ with $r = R_0$.

Tangential stress with $r = R_0$ is equal to $\sigma_g = -2k$.

The minimum allowable value $\frac{R_2}{R_1}$, (under which folds occur) is determined by parameters: $R_0, R_1, h, \sigma_T, E_T$ with the dimensions: m (for the first three) и MH/m² for yield limit σ_T and plastic deformation hardening modulus $E_T = \frac{d\sigma}{d\varepsilon}$. Here E_T is a value characterizing metal hardening in plastic deformation.

Out of these five variables it is possible to form three dimensionless parameters:

$$A_1 = \frac{R_1}{R_0}, A_2 = \frac{h}{R_0} \quad \text{and} \quad A_3 = \frac{E_T}{\sigma_T},$$

as well as to determine approximately strain-hardening characteristic $E_T = \sigma_B - \sigma_T$, where σ_B is ultimate strength.

According to π theorem the relationship between the above-mentioned parameters must take the following form $f(A_1, A_2, A_3) = 0$. Having solved it for A_1 , we get

$$\frac{R_1}{R_0} = f(A_2, A_3) \quad (8)$$

Based on the data of many deformation experiments with carbon steel sheets of 0,5mm, 1,00mm, 1,5mm and 2,0mm thicknesses the

graphs $\frac{R_1}{R_0} = f(A_2, A_3)$ $\frac{R_2}{R_0} = f(A_2, A_3)$

were plotted as given on **Figure 3**.

The relationship (8) can be determined with the empirical formula for a maximum permissible (minimum) value

$$\left(\frac{R_2}{R_0}\right)_{min} = 1 - 0,5 \frac{E_T}{\sigma_T} \sqrt{\frac{h}{R_0}} \quad (9)$$

To provide the sheet stability the following condition should be fulfilled:

$$\frac{R_2}{R_0} > \left(\frac{R_2}{R_0}\right)_{min} \quad (10)$$

$$\frac{R_1}{R_0} > \left(\frac{R_1}{R_0}\right)_{min}$$

Since the maximum possible upset length is equal to $l = R_0 - R_1 = R_0 \left(1 - \frac{R_1}{R_0}\right)$

$$R_1 = R_0 \left(1 - \frac{R_1}{R_0}\right), \quad l = R_0 - R_1 = R_0 \left(1 - \frac{R_1}{R_0}\right),$$

it follows from (9) that the maximum possible length of work is

$$l_{max} = 0,9 R_0 \frac{E_T}{\sigma_T} \sqrt{\frac{h}{R_0}} \quad (11)$$

For example, for a steel sheet of $h=1$ mm

$$\text{thickness with } \sigma_T = 250 \frac{MH}{m^2}$$

$$\sigma_B = 490 \frac{MN}{m^2}, \quad \frac{E_T}{\sigma_T} = \frac{490 - 250}{250} = 0,96 \frac{E_T}{\sigma_T};$$

$$R_0 = 100 \text{ mm}, \quad \frac{h}{R_0} = 0,01 \quad \frac{h}{R_0} \text{ according to}$$

$$\text{formula (9) we get } \left(\frac{R_2}{R_0}\right)_{min} = 0,914,$$

$$R_1 = 91,4 \text{ mm}; \quad l = 8,6 \text{ mm}.$$

$$\text{Formula (9) can be applied if } \frac{E_T}{\sigma_T} \sqrt{\frac{h}{R_0}} \geq 0,4$$

and the experimental data spread is considerable which is seen from **Figure 3**. The dotted line here divides the data span into two parts. Below the dotted line there is a zone for specially selected samples with thickness differences of no more than 0,02mm. The higher the gage interference, the more often the buckling failure and buckle development happen. Therefore it is important to increase the dimensional accuracy of sheets used for deep drawing. Empirical formula (9) gives that if $\frac{E_T}{\sigma_T} \rightarrow 0, \left(\frac{R_2}{R_0}\right)_{min} \rightarrow 1$. It

conforms to the test which shows what should be applied for metal (alloys) drawing with high hardening: the higher $\frac{\sigma_B}{\sigma_T}$ is, the easier the deformation can be made, and the larger work length can be produced when drawing. Metals with minor hardening with graph of function $\sigma(\epsilon)$ being close to a perfectly plastic body graph (i.e. when $\sigma = const. = \sigma_T$) are unfit for deep drawing.

Steel sheets with up to 0.05-0.15% temper and not more than 20-30 μm grain size with extension strain of no less than 40% are often used for drawing.

According to the above-mentioned the holder allows to increase l value and decrease parameter $\left(\frac{R_2}{R_0}\right)\left(\frac{R_1}{R_0}\right)$. However, the ring crack

wastage increases as shown on **Figure 4**. There can be seen ring cracks being the reasons of up to 10% and more increase of waster number which aggravates the manufactures' economic indexes significantly.

4. New Method of Drawing

Based on the research conducted a new technological drawing process has been suggested (see Patent Application of Russian Federation №2011123174/02, MPK 7B1D 22/02 from 08 June 2011) [6].

The method consists in forming a series of waves (ridges) along a ring on a disk-form billet, see **Figure 5**. The amplitude of the waves is small (usually not more than $(1 \div 2)h$) but their quantity is large up to 16-28 waves located along the ring as can be seen on **Figure 5**. All the deepening's (waves) are reasonable to be made simultaneously with one die then the billet should be upturned and deformed by



Figure 4. Blanks with Cracks

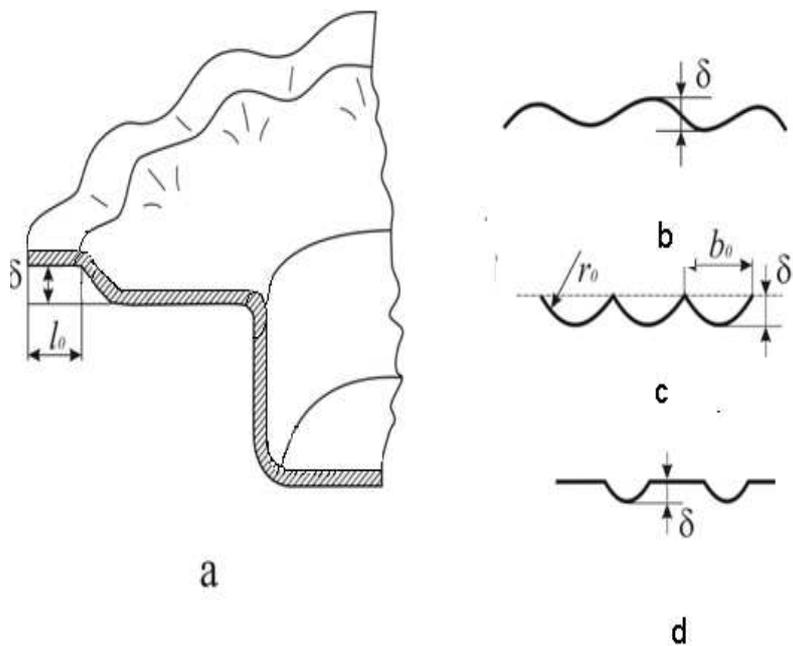


Figure 5. New Method of Drawing



Figure 6. Filter Casing Blanks Produced with New Method

drawing, the clearance between the sheet being deformed and the punch should exceed the “waves” amplitude 1,5-2,0 times in order to avoid sheet jamming. With drawing deformation the buckled sheet compressive deformation relieves (its hardness is reduced).

The waves may be located not along the billet edge as shown on **Figure 5a** but in its middle as on **Figure 5b**. Even making 0,5-1mm amplitude waves on a billet parallel portion gives a positive result after partial drawing deformation.

Various wave variants are also shown on **Figure 5 c,d, e**. The depth for 0,5mm sheets of carbon steel was 0,5mm, the number of waves being 18-26. “The loss of stability” with large wave formation, e.g. shown on **Figure 2**, does not occur and there is a possibility of manufacturing products with a length 2-3 times higher the admissible length of a conventional drawing.

The deformation is sure to result in increasing the wave amplitude, sometimes 1,5 times (there occurs their compression with “wave” shortening sometimes in 2-3 times), but the new waves of large amplitude do not emerge (e.g. as those shown on **Figure 2**).

The main idea of the method consists in making a large number (18-26) of waves of small amplitude on a sheet (disk) in advance in order to avoid the potential of emerging 4-8 “waves” (buckles) of large amplitude (up to 10-20mm). It decreases the rigidity of a deformed billet, with the amplitude being able to reach 1.5mm after drawing, which does not lead to sharp

changes of the whole product pattern (it usually happens with the stability loss) and allows to manufacture the required product of high quality.

Figure 6 shows the samples manufactured at OAO TsBPR (the town of Tver, Russia) with the new method used.

The artificial waves (ridges) are certain to remain on the product. The method is sure not to be used in cases when even small waves on the product cannot be allowed. But in many cases such waves with amplitude of less than 1mm do not at all make the product quality worse and therefore are possible. So the above-mentioned Tver plant manufactured more than 10 thousand filter casings (**Figure 6**) of high quality.

Conclusions

The following conclusions can be deduced from the above-said study:

1. The axially symmetric sheet blank deformation under drawing has been examined. The kinematically admissible velocity field for force upper limits has been built.
2. A new method of drawing which included making ridges-waves of small amplitude on a blank before drawing has been proposed and studied. The number of such waves should be considerable and it gives the possibility to avoid the formation of more significant form distortions of a billet.
3. The method was used for producing oil filter casings and getting a high-quality product.

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