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ANALYSIS OF HOLE-FLANGING PROCESS IN STAINLESS STEEL SHEET

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ABSTRACT

The paper presents the analytical-experimental method of analyzing the hole-flanging process of the necks upon the elements with the previously-formed hole. The chosen material is high alloy steel Č.4574 that possesses high workability while undergoing a treatmen in the cold state.

The semi-empirical formulae are set up to connect the most important geometric parameters of the hole-flanging (flanging ratio, reduced sheet thickness, height of the extruded neck).

1. INTRODUCTION

Along with blanking and deep drawing, flanging belongs to one of the most frequently applied process in plasticity technology. Depending on the form of a blank two procedures can be distinguished. Namely, the blank can be with an already prepared opening or without it. In the first case, the procedure is a typical process known as the hole-flanging [1], while, in the second case, the term "full-flanging" can be used.

The second procedure can be realized in two variants, that is, like a two-phase process in which, in the first phase, the hole-piercing is done while the second phase is reserved for classical flanging or a simultaneous process of piercing and flanging. In the first variant, as a rule, the flat punches are used while in the second one the conical ones. The difference between these two variants is in the fact that in the second phase there is no scrap. However, they share a low process efficiency, small accuracy and a low quality of the extruded neck surface; these are the reasons why it is most often necessary to introduce additional treatment.

The blank warming is done in the forming of the materials that are difficult to work upon or when it is insisted upon a high flanging ratio. Such a procedure, however, increases the production costs.

The hole-flanging has mostly two purposes:

a) increase of rigidity of various steel sheet elements (structures), and,
b) neck-formation upon steel sheet elements and pipes for the sake of linkage with other parts (directly or by means of subsequently cut threads).

2. FLANGING PROCESS ANALYSIS

Fig. 1 shows the geometry of the blank and the finished part obtained by the typical hole-flanging process that is under study in this paper.

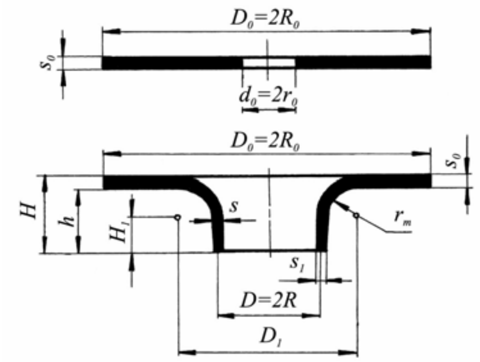


Fig.1- Geometric Parameters of the Blank and the Finished Part

The flanging process and the workpiece geometry are both considerably influenced by the blank diameter (D_0) and the extruded neck diameter (D). For the identification of the workpiece geometry and the way the process is going on it is very useful to turn to V. P. Romanovsky's diagram [2] (Fig. 2).

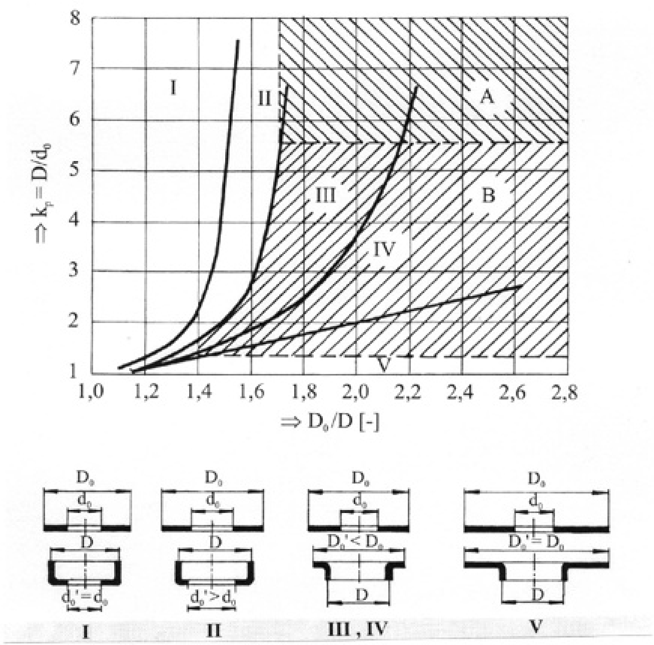


Fig.2- Possible Variants of Forming Ring-shaped Steel Sheet Elements
($s_0/D=0,01$; $r_m/s_0=r_p/s_0=5$)

As can be seen in Fig. 2, depending on the ratio D_0/D, the nominal flanging process can degenerate into some other metal forming processes, that is, in the processes that take place simultaneously. For instance, at small D_0/D ratios, the pure deep drawing is realized (sector I), while at larger D_0/D ratios the purely hole-flanging is obtained (sector V). Of course, at transition forms, the influence of the D/d_0 ratio is also prominent.

Therefore, in order to realize the hole-flanging process in its innovative form, it is necessary to design, for smaller workpieces, the tools with blank holders, while for large steel sheets or pipes this is not necessary.

For engineers in industry it is unfavorable to find that the above-shown diagram is not known for the majority of materials (steel sheets) in use. Namely, the given diagram refers to the sheets of low carbon steel and the given geometric ratios. There is a great need to create such diagrams for some other important groups of steel as well.

2.1. Flanging Ratio

The most important parameter of the flanging process, both for the theoretical analysis and the engineering calculations, is the flanging ratio. This parameter is most often defined as the following ratio [2], [3], [9]:

$$k_p = D / d_0 \tag{1}$$

where: D (mm) - neck diameter, and,
d_0 (mm) - blank hole diameter.

For the rational technological process design it is very important to know the limiting (maximal) value of this parameter. By a simplified analysis of the deformation state at the flanging the following relation is arrived at [9]:

$$k_{p\max} = 1 / (1 - \psi_m) \tag{2}$$

where: ψ_m - uniform deformation of the cross-section.

Unfortunately, formula (2) has not been sufficiently verified in the experimental way. It is interesting that in most of the experiments done there was a considerably larger flanging ratio realized than that calculated according to formula (2).

An interesting attempt at theoretical generalization has been made by A.J.Averkiev [7]. This author has shown that the limiting deformation degrees at steel sheet forming can be brought into a functional correlation with criterion "P" . This criterion represents a specific deformation work at uniform plastic deformation. For the flow curve of form $K= K_0+C\ \varphi^m$ criterion "P" is determined according to the following formula:

$$P = \sqrt{\frac{3(1+r)}{2(2+r)}}\left[K_0 + \frac{(R_m e^n - K_0)^2}{R_m e^n (n+1) - K_0}\right] n \tag{3a}$$

where:

K_0 - initial flow stress ($K_0 \approx R_{0,2}$),
R_m - tensile strength,
n - strain hardening exponent, and,
r - vertical anisotropy coefficient.

On the basis of a series of experiments, the above-mentioned author has set up the following semi-empirical relations for various materials and steel sheet thickness:

$$1/k_{pmax} = \begin{cases} 0{,}3796 + 20{,}2304/P \;;\; s_r = 3\% \\ 0{,}3477 + 19{,}9620/P \;;\; s_r = 4\% \\ 0{,}3090 + 20{,}8150/P \;;\; s_r = 5\% \\ 0{,}2948 + 19{,}5235/P \;:\; s_r = 10 \div 30\% \end{cases} \quad (3b)$$

The calculation of the limiting flanging ratio according to formulae (3) gives the results that are in better alignment with the experiment since the relations themselves are based upon experimental data though in some cases aberrations can be considerable.

The reason for this is that the limiting flanging ratio is under the influence of many factors such as kind of material, steel sheet thickness, tool radii, friction, etc. For the case of hot treatment temperature and the strain rate can also be taken as influential factors.

The experimental-analytical research in this paper refers to high alloy stainless steel Č. 4574 (X10CrNiMoTi18-10 with respect to DIN) that possesses high workability at the cold forming [4]. This steel can be considered as representative of the whole group of chromium-nickel-molybdenum austenitic steels. Otherwise, these steels find a wide application in the manufacture of parts, equipment and devices in many branches of industry (nutrition, chemical, pharmaceutical, textile, etc.).

For the needs of the given research the experimental tool with a set of replaceable punches and dies was designed [5]. The experimental program was realized upon the hydraulic press of the nominal power of 1000 kN. In order to provide for the pure hole-flanging the tool has an adequate blank holder built in. On the other hand, in order to obtain extreme forming conditions no lubrication was done. The holes on the blanks were obtained by piercing as well as by additional subsequent treatment.

As a criterion for determining the limiting flanging ratio the crack length at the edge of the finished part's holes amounting to 5 mm was chosen [6].

The outlook of the blanks used in the experiment and a series of finished parts are shown in Fig.3.

The experimental research of the authors of this paper and of other scientists [1], [2], [3], [7] point to two facts.Firstly,they stress that the most influential factor is reduced steel sheet thickness and, secondly, that (regardless of the kind of material used) the limiting flanging ratio is a monotonously increasing function from the reduced steel sheet thickness with a falling gradient.

In the concrete case, taking into consideration the influence of only the above-mentioned factor, the following regression equation was obtained after processing the experimental data:

$$k_{pmax} = 1{,}8671 + 0{,}0604\, s_r - 0{,}0007\, s_r^2 \quad (4)$$

where: s_r - reduced steel sheet thickness (s_r=100s_0/d_0).

Respecting the influence of the other geometric factors and their interactions, for the same experimental data, the adequate regression equations are obtained:

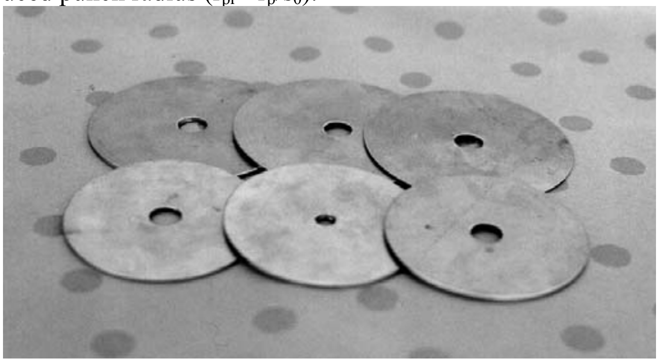
$$k_{pmax}= 1{,}7865+0{,}0448\, s_r+0{,}0178\, r_{mr}+0{,}0262\, r_{pr}+0{,}0078\, s_r\, r_{mr}-0{,}0020\, s_r\, r_{pr} \quad (5a)$$

$$k_{pmax}=1{,}9655+0{,}0397\, s_r-0{,}0519\, r_{mr}-0{,}0627\, r_{pr}+0{,}0078\, s_r\, r_{mr}+0{,}0010\, s_r\, r_{pr}+0{,}0357\, r_{mr}\, r_{pr} \quad (5b)$$

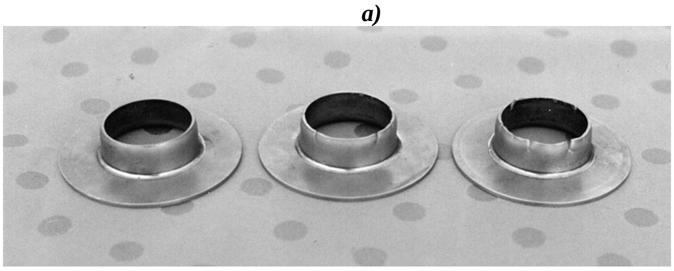
where:

r_{mr} - reduced die radius (r_{mr}= r_m/s_0), and,

r_{pr} - reduced punch radius ($r_{pr}= r_p/s_0$).



a)



(I) (II) (III)
b)

Fig.3- Outlook of the Steel Sheet Elements before (a) and after Flanging (b):
s_0=2 mm; D_p=36 mm; r_m=2 mm; r_p=5 mm
(I) k_p=2,55 ; (II) k_p=2,64 (limiting flanging ratio) ; (III) k_p=2,74

A comparative analysis of the above-mentioned regression equations brings about the conclusion that equations (5) are somewhat more accurate, but inadequate for engineering calculations due to their complexity. As can be seen from Fig. 4, equation (4) provides for sufficient accuracy for practical calculations. The experimental points' departure from the regression curve can be interpreted as being caused by other factors that were not taken into consideration during the data processing.

2.2. Change of Steel Sheet Thickness

It is known that, in the conventional hole-flanging process, the tensile normal stresses are prevailing [2], [3], [9]. Such a scheme of stress state is unfavorable for two reasons, namely, due to reduced material formability and due to steel sheet thinning along the meridian section of the extruded neck.

Starting from E. A. Popov's methodology [9] and in accordance with the denotations in Fig. 5, the blank's steel sheet thickness at an arbitrary flanging moment, at distance z from the hole's edge can be expressed by the following equation:

$$s_{i(z)} = s_o \left(\frac{r_0 + z}{r_i + z} \right)^{\frac{r_i + 2z}{2r_i + z}} \tag{6}$$

On the basis of equation (6) the following relations are easily obtained:

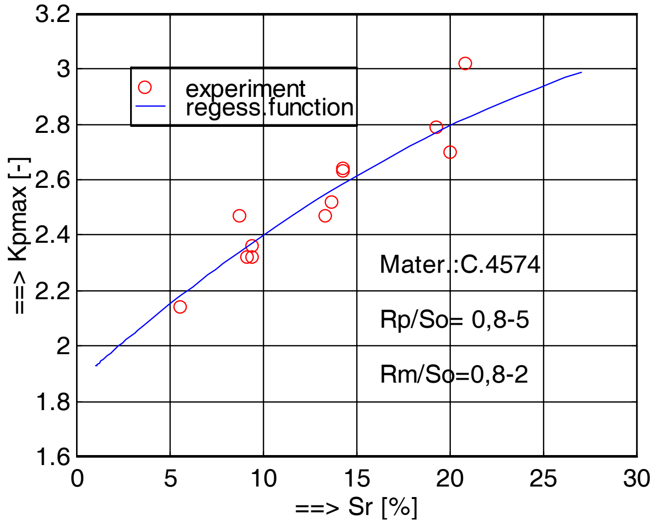


Fig.4- Dependence of the Limiting Flanging Ratio on the Reduced Steel Sheet Thickness

a) for the neck's edge (z= 0),

$$s_{i(0)} = s_0 \sqrt{r_0 / r_i} \tag{7a}$$

b) for the neck's cylindrical part (z= R-r_i),

$$s_{i(R-r_i)} = s_o \left(1 + \frac{r_0 - r_i}{R}\right)^{\frac{2R-r_i}{R+r_i}} \tag{7b}$$

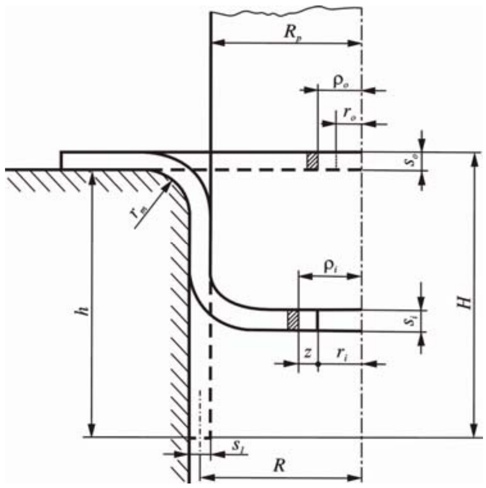


Fig.5- Scheme of Forming at the Hole-flanging

For completing the flanging process (r_i=R) from relations (7a) and (7b) it is directly obtained that:

$$s_1 = s_0\sqrt{r_0 / R} = s_0\sqrt{d_0 / D} = s_0\sqrt{1 / k_p} \quad (7c)$$

Diagrams in Fig. 6 point to a good agreement of equations (7) in the qualitative and quantitative sense with the experimental data.

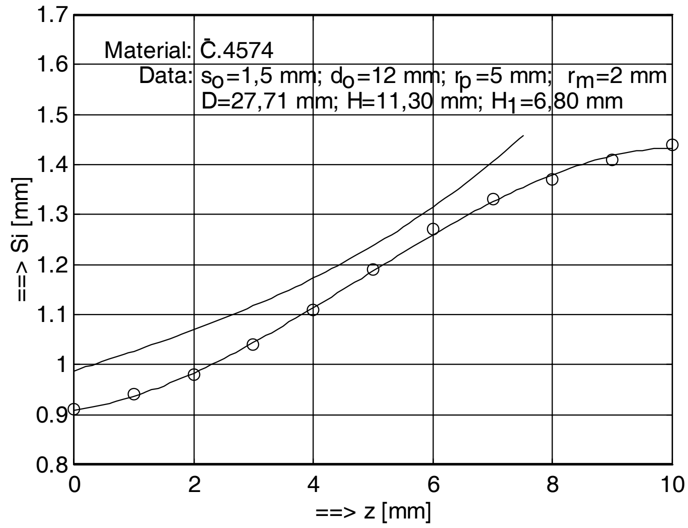


Fig.6- Steel Sheet Thinning in the Hole-flanging Process
o- exp. data ; ___ - regress. function ; _ _ _- theoretical curve

On the basis of relation (7c) a relative change of steel sheet thickness at the extruded neck's edge can be expressed:

$$\delta s = \Delta s / s_0 = 1 - \sqrt{1 / k_p} \quad (8a)$$

On the basis of the experimental results obtained by the authors of this paper the following regression equations can be written:

$$\delta s = 14{,}3310 + 9{,}3729\, k_p \quad (8b)$$

$$\delta s = -78{,}9864 + 93{,}7702 k_p - 22{,}6848\, k_p^2 + 1{,}5819\, k_p^3 \quad (8c)$$

It can be seen in Fig. 7 that, in a wide range of the flanging ratio change, the best approximation of the experimental data is given by relation (8c).

Since the sheet thinning at flanging is unavoidable, it is important to know its amount especially for those steel sheet and other elements that are linked to other components by thread links.

2.3. Height of the Extruded Neck

The extruded neck's height is also an important parameter for designing the given technological process. A simplified analysis of the forming process provides for the following relation [2]:

$$h = 0{,}5\left(D - d_0\right) + 0{,}43\,r_m - 0{,}285\,s_0 = 0{,}5\,D(1 - 1/k_p) + 0{,}43\,r_m - 0{,}285\,s_0 \qquad (9a)$$

Johnson W. and others [1], [10] have suggested, on the basis of the deformation state analysis, a simple formula:

$$h = D/3\left[1 - (d_0/D)^{3/2}\right] = D/3\left[1 - (1/k_p)^{3/2}\right] \qquad (9b)$$

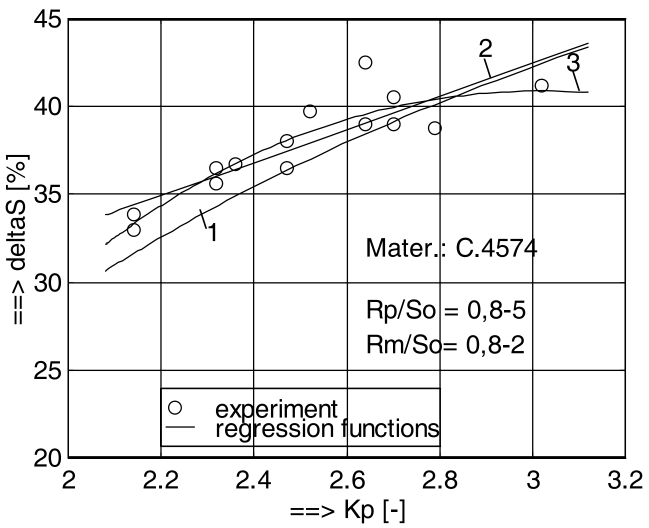


Fig.7- Dependence of Steel Sheet's Relative Thickness on the Flanging Ratio
1- formula (8a) ; 2- formula (8b) ; 3- formula (8c)

Neglecting the steel sheet thinning, from the volume constancy law an approximate formula is obtained [5]:

$$h \cong \frac{D^2 - d_0^2}{4D} + 0{,}43\,r_m - 0{,}285\,s_0 = 0{,}25D\left[1 - (1/k_p)^2\right] + 0{,}43\,r_m - 0{,}285\,s_0 \qquad (9c)$$

For an exact determination of the extruded neck's height it is necessary to take into consideration a complete geometry of the extruded neck including the present steel sheet thinning. By applying formula (7) it is not possible to arrive at the solution in an explicit form. On the basis of the diagram given in Fig. 6 it can be taken, in the first approximation, that the steel sheet thickness decreases in linear way along with the neck's height. Further on, using the volume constancy law a formula is reached that is, due to its complexity, inadequate for engineering calculations; that is why it is not given here.

By processing the experimental data given in this paper, as well as those given by other authors [8], [10], the following facts are confirmed, namely: firstly, formulae (9) give lowered values with respect to the experiment, and, secondly, for very small radii a simple formula (9b) can be used just like (9a) for greater values. In view of all that has been said, for engineering calculations, a corrected formula (9a) can be used with the correction ratio $\xi \approx 1,1 \div 1,2$. Greater values of this ratio refer to smaller die radii and vice versa.

However, when it is not possible to obtain the desired neck height, the forming is done in two operations. In the first one, the deep drawing of the workpiece with an hole is done while in the other the pure hole-flanging is to be performed (enlarging of the hole at the bottom of the drawn cup). In order to rationalize the technological process it is desirable to unite the two operations. For this reason some attempts have been made to determine, by a theoretical method, the limit separating the deep drawing from the hole-flanging [11].

3. CONCLUSION

The theoretical-experimental analysis carried out in this paper points to the following relevant facts:

-high limiting flanging ratios confirm that the chosen material possesses high workability at the cold forming. Such flanging ratios provide for the manufacture of necks of greater heights,

- unfavorable consequence of the flanging process is relative steel sheet thinning. In this way, the reduced neck's rigidity is compensated for by prominent deformation hardening of the material. At the same time, at the expense of thinning, greater heights of the extruded neck at the steel sheet and other elements are obtained, and,

- our analysis of the experimental data has led to the conclusion that there is an important correlation among the most important process parameters. In view of this, adequate regression functions are set up in the presented paper.

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ANALIZA PROCESA PROVLAČENJA NA LIMENIM ELEMENTIMA OD NERĐAJUĆIH ČELIKA

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REZIME

Pod terminom šuplje provlačenje podrazumeva se izrada grla proširivanjem prethodno formiranih otvora na limenim i drugim elementima. Proces provlačenja se primenjuje, po pravilu, radi:

- *povećanja krutosti limenih i drugih elemenata (struktura);*
- *formiranje grla na limenim elementima i cevima radi spajanja sa drugim delovima.*

U prezentovanom radu je analiziran proces šupljeg provlačenja na limenim elementima od čelika Č.4574, koji se može smatrati reprezentantom cele grupe visokolegiranih nerđajućih čelika.

Analitičko-eksperimentalnim metodom postavljeni su adekvatni poluempirijski obrasci, kojima se uspostavljaju kvantitativno-kvalitativni odnosi izme|u najvažnijih parametara procesa provlačenja (graničnog koeficijenta provlačenja, stanjenja lima, visine provučenog grla).