SIGNIFICANCE AND LIMITATIONS OF VARIABLE BLANK HOLDING FORCE APPLICATION IN DEEP DRAWING PROCESS

S. Aleksandrovitsh, M. Stefanovitsh

Faculty of Mechanical Engineering, Kragujevac, Serbia & Montenegro

ABSTRACT

Control of the blank holding force (BHF) enables control of friction on the flange during deep drawing process and significantly influences the course and process results in that way. In the paper we are presenting analysis of the influence degree of flange friction on plastic forming process and significance of variable blank holding force (VBF) like normal force as a part of that. Also, we are giving the results of experimental researches of VBF influence on deep drawing process. Cylindrical part is realized by deep drawing in conditions of: a) constant BHF application (literature recommendation), b) constant BHF application (optimized) and c) VBF application. Material is coated low carbon steel sheet and 3 regimes of friction are used (dry, oil and oil + PET foil). Drawing depths, sheet surface strains, thinning strains, drawing forces and BHF forces are monitored.

We can conclude, at the end, that there is possibility of important process improving by application of VBF beside evident limitations.

KEYWORDS*: Thin sheets, Deep drawing, Variable blank holding force*

1. INTRODUCTION

Deep drawing is among the most dominant technologies in modern industry. Such statement is best confirmed by the produced quantities, consumption and intensity of development of these materials during the last few decades. According to the data of International Iron and Steel Institute (IISI, Brussels, Belgium) (web sites, /1/), the estimated world production of crude steel in 2003 was 968 256 000 tons. In the following year, 2004, it set a record of 1 005 000 000 tons. The estimated production of all kinds of steel sheet metals (cold rolled, hot rolled, and coated) in 2003 was 204 500 000 tones (web sites, /2/). Registered export of these sheet metals in 2002 was 107 100 000 tons (web sites, /1/). All previously specified data for steel refers to the world production.

Total production of primary aluminium worldwide for 2004 is estimated to 54 872 000 tons (web sites, /3/). Only In west Europe, in the same year, the production of aluminium sheet metals was 4 157 000 tons (web sites, /4/). It is also interesting that the production of Al sheet metals in Brazil only for 2003 was about 274 000 tons (web sites, /5/).

The specified data illustrate the importance of steel and aluminium sheet metals, and consequently the importance of technologies intended for their processing. Among those technologies, deep drawing has the major importance. The current status of this technology development is characterized by efforts to accomplish the complete control of the process /1, 2, 3, 4/. Numerous computer control systems were realized, often of very complex structure. In each of them, the control actions are performed in only two ways: by means of friction on flange and by means of control of sheet metal sliding on flange. In the first case the key parameter is blank holding force, and in the second case it is the height of impressing draw beads. Those are the only two parameters that can be controlled (modified by desirable laws) in the course of forming process. Quantifying of the degree of their influence on the entire process is a complex task. This paper represents a contribution to that matter regarding blank holding force.

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On the other hand, experiments are being conducted with various types of holders. One-piece rigid holder (applied in this paper) is a classic one, and in addition to that, elastic holder /2/ and segment holder /3/ are also applied and are particularly important for complex geometry pieces.
The framework within which the deep drawing process runs is determined by two possible defects: appearance of wrinkles on flange and appearance of fracture in critical piece zone (for cylindrical piece, it is usually the bottom radius zone). Blank holding force has a primary function of preventing the appearance of wrinkles on flange. However, each increase of intensity above minimally needed one influences the sheet metal thinning in critical zone and danger from fracture. Optimal dependence of minimal blank holding force on punch travel in order to avoid the wrinkles has not been identified, even in theory. That makes space for experimental researches and detection of parts of mosaic consisting of interacting influences within plastic forming process in deep drawing.

2. INFLUENCE OF BLANK HOLDING FORCE ON PROCESS

It is very convenient to observe how the change of blank holding force influences the change of drawing depth, which is the main technological indicator (figures 1, 2, 3 and 4) and the change of forming drawing force, which is the second significant process parameter (figures 5 and 6).

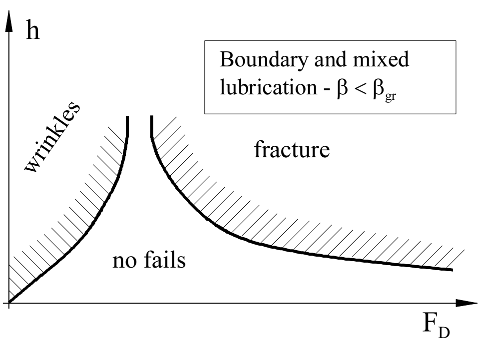

Figure 1: Dependence of drawing depth on blank holding force (a)

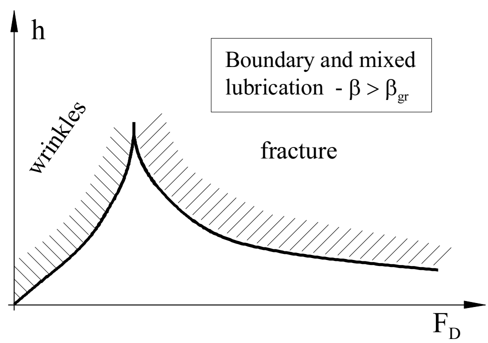

Figure 2: Dependence of drawing depth on blank holding force (b)

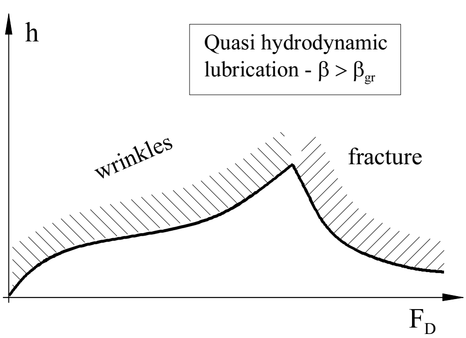

Figure 3: Dependence of drawing depth on blank holding force (c)

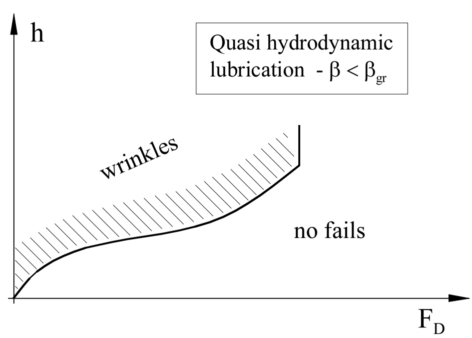

Figure 4: Dependence of drawing depth on blank holding force (d)

Based on figures 1 to 4, it is obvious that it makes sense to discuss the influence of blank holding force only if the entire tribological process is taken into consideration (friction, i.e. lubrication conditions). Moreover, blank holding force itself represents a tribological parameter

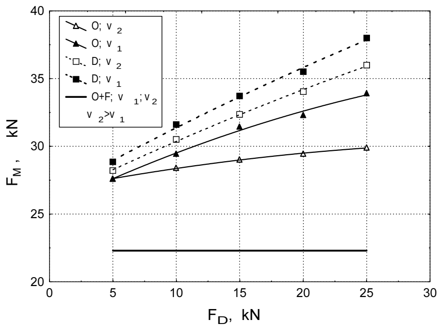

Figure 5: Dependence of maximal drawing depth on blank holding force (a)

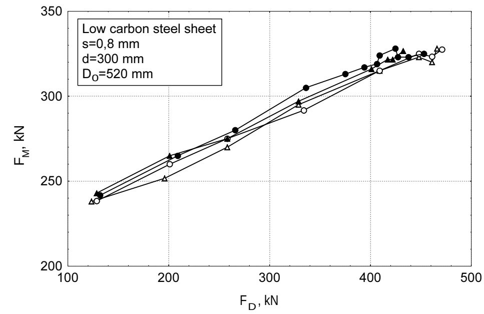

Figure 6: Dependence of maximal drawing depth on blank holding force (b)

(normal force for friction on flange). In addition to that, the knowledge of limit drawing ratio for actual case of forming is of vital importance. It is obvious that the optimal range of blank holding force according to maximal drawing depth criterion exists in any case. Obtainment of such diagrams by experiments is a long-lasting and expensive process. It is necessary to investigate work piece series (one curve point is obtained for one piece). High-quality computer simulations can be useful for that purpose.

Simple, but illustrative quantifying of the influence of blank holding force can be performed by calculating components of drawing stress /5, 6/. Work piece geometry is cylindrical ("pure deep drawing"), so the following formulas are applicable:

$$F_{iz} = A \cdot \sigma_{uiz} \tag{1}$$

$$\sigma_{uiz} = \sigma_r + \sigma_{trd} + \sigma_{trM} + \sigma_{savis} \tag{2}$$

In drawing force formula (1), A represents the surface of cross (carrying) section, and components of total drawing stress (2) are: σ_r– radial tension stress on flange, σ_{trd}– stress due to friction on holder, σ_{trm}– stress due to friction on die rounding and σ_{savis}– stress due to bending and unbending at sheet metal sliding over die rounding. σ_r can be determined by means of the following formula:

$$\sigma_r = 1{,}15\overline{K}\, ln\frac{D_0}{d} \tag{3}$$

D_0 is blank diameter, d is nominal piece diameter and $\overline{K}$ is medium value of equivalent stress, i.e. true stress. It is defined form strengthening curve, on the basis of medium value of natural strain:

$$\overline{\varphi} = \frac{1}{2}\left(\varphi_{iM} + \varphi_{iO}\right) \tag{4}$$

$$\varphi_{iM} = ln\frac{\sqrt{R_0^2 + r^2 - R^2}}{r} \tag{5}$$

$$\varphi_{iO} = ln\frac{R_0}{R} \tag{6}$$

$$\overline{K} = K(\overline{\varphi}) \tag{7}$$

φ_{iM} (5) is strain on inside edge of flange towards die rounding, and φ_{iO} (6) is strain on outer edge of flange. R_0 is blank radius, r is nominal piece diameter, and R is instantaneous value of flange radius.

By empirical method, it has been determined that when outer flange radius R reaches the value $0{,}77R_0$, i.e. $\varphi_{iO}=0{,}2614$; drawing force has the maximal value, or it is in maximum zone.. Radial stress σ_r should be identified at that exact moment.

$$\sigma_{trd} = \frac{2\mu F_D}{d\pi s} \tag{8}$$

μ is friction coefficient , F_D blank holding force, and s sheet metal thickness.

$$\sigma_{trM} = (\sigma_r + \sigma_{trd})\left(e^{\mu\frac{\pi}{2}} - 1\right) \tag{9}$$

e is basis of natural logarithm.

$$\sigma_{savis} = \frac{R_M}{2\frac{r_M}{s} + 1} \tag{10}$$

R_M is tensile strength, and r_M die rounding radius.

According to specified formulas, the actual values were calculated. The piece material is single-side galvanized low-carbon steel sheet metal of 0.8 mm thickness intended for manufacture of car body parts.

In this paper, mark TyZnl will be used. Its tensile strength is R_M=311,8 MPa; yield stress R_P=199,8 MPa and strengthening curve in the form of exponential approximation $K=537{,}6\varphi^{0{,}221}$ MPa. Friction coefficient for the case of lubrication with oil for deep drawing (mixed friction) μ=0,1. Geometrical data are: nominal piece diameter d=50 mm; height h=52,5 mm; sheet metal thickness s=0,8 mm; bottom radius r=6,5 mm; die rounding radius r_M=3,5 mm; blank diameter D_0=110 mm. We should mention that the piece geometry was selected in such a way that drawing ration is slightly larger than the limit ratio for dry and mixed friction, and slightly smaller than the limit ratio for quasi-hydrodynamic friction. In that way it was possible to monitor the effects of blank holding force influence.

Table 1 gives the values of total maximal drawing stress and its components. In addition to that, the percentage share of components in total stress is given. Stress due to friction on holder is the smallest regarding intensity (4,23%), but is significance is greater, first of all due to its possibility to be changed in the course of process. The remaining three components can only be influenced before the beginning of process (selection of proper formability material, defining of geometry, material and tool surface condition; selection of lubricant; defining of speed). Blank holding force, i.e. stress due to friction on holder represents a sort of trigger which can take the process to the unfavourable direction (appearance of wrinkles or danger from fracture). For value σ_{trd} in table 1 blank holding force has the intensity 13928,5 N determined according to recommendations and method given in /6/. Small percentage share of σ_{trd} in total stress matches the reality, but it can be increased by changing blank holding force and friction conditions. This is illustrated in figure 5 and 6.

Drawing stresses (MPa)		
$\boldsymbol{\sigma_{uiz}}$	524.6	%
$\boldsymbol{\sigma_{r}}$	398.8	76.0
$\boldsymbol{\sigma_{trd}}$	22.17	4.23
$\boldsymbol{\sigma_{trm}}$	71.6	13.65
$\boldsymbol{\sigma_{savis}}$	32.0	6.12

Table 1: Components of drawing stress

Both diagrams refer to pieces made of low carbon steel sheet metal, without coating, intended for deep drawing. Data in figure 5 are applicable to work piece of 50 mm diameter and it is obvious that stronger friction (D-dry contact surfaces), smaller forming speed (v_1) and higher intensity of blank holding force result in increase of influence on maximal drawing force. In the case of larger piece dimensions (fig. 6), the influence is similar. Dependence is determined in conditions of mixed friction (oil lubrication), /7/.

3. EXPERIMENTAL RESULTS

According to previously specified data, it is obvious that blank holding force has a significant influence on forming process, although the friction on flange does not influence the total drawing stress to a great extent. A theoretical and practical problem is how to define the dependence of blank holding force on punch travel (or time) in order to improve the process results. The performed experiment illustrates one possible approach to that task. The concept is such that the first part involves the realization of the process with constant blank holding force defined on the basis of empiric recommendations (CBF), the second part is realized with CBF, but optimized with special experiment and, finally, the third part is realized with variable blank holding force (VBF) which has the increasing character during the process. The experiment was carried out on hydraulic laboratory press of triple action with computer measuring-control system /6, 8/. Its main property is that it enables accomplishment of desired dependence of VBF on travel (or time) of any form, in the course of forming process. The intensity of main CBF (marked R) is specified in chapter 2, as well as data on piece material and geometry. Optimization was performed with a special experiment. For three contact conditions (dry –D, oil application –O and PET foil –O+F) dependence of depth (h) on blank holding force (F_D), i.e. wrinkles and fracture curve (figures 7 and 8), was defined.

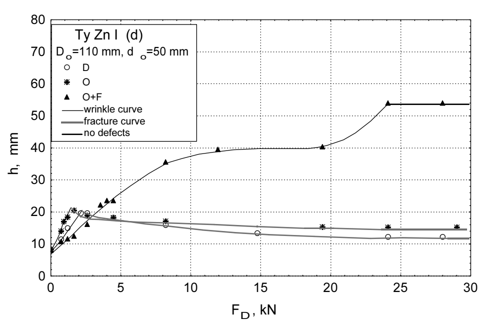

Figure 7: Dependence of drawing depth on blank holding force (a)

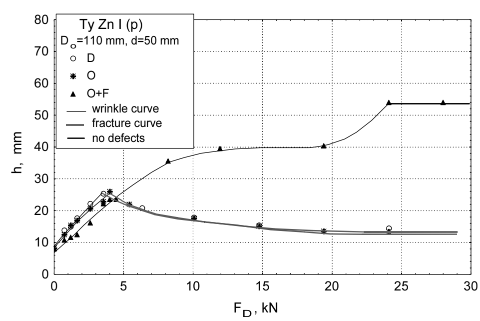

Figure 8: Dependence of drawing depth on blank holding force (b)

For results in figure 7, the side with coating faces the die, and in figure 8 it faces the punch. In the conditions of dry (boundary) and mixed friction, the difference in depths is very prominent. This is explained by deterioration of friction conditions in case when zinc coating faces the die. At sliding, coating is partially removed and deposit is very quickly developed on die. All following results refer to the case of coating which faces punch.

According to the criterion of maximal drawing depth, optimized value of CBF (mark E) is easily defined.

Dependency characters in figures 9 and 10 are similar, but larger piece depth is observed if CBF is used in optimized variant (E). Actual values are given in table 2.

In figures 11 and 12 the effect of blank holding force influence is clearly perceived. The smaller friction coefficient is, the smaller is the possibility for blank holding force influence. However, at mixed, and especially dry (boundary) friction, the change of blank holding force can

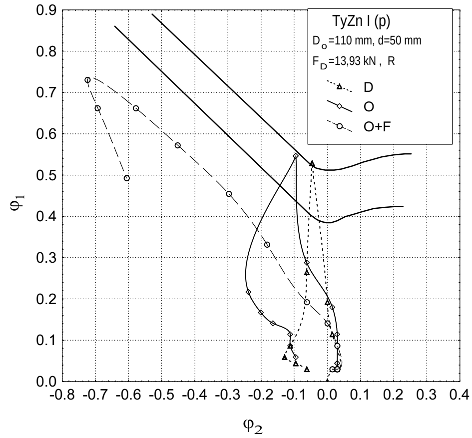

Figure 9: Drawing forces at CBF (version R)

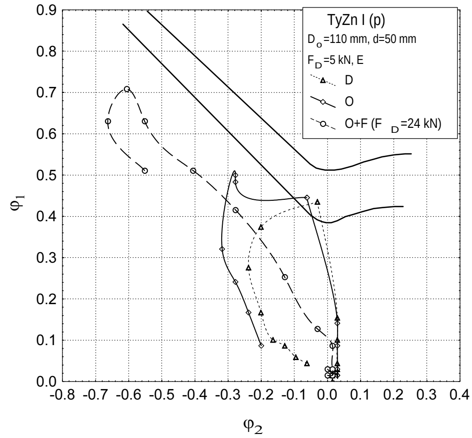

Figure 10: Drawing forces at CBF (version E)

Drawing depths (mm)					
F_D=13,93 kN		F_D=5 kN (O+F 24 kN)	increase %	VBF	increase %
D	13.1	17.6	34.3%	21.0	60,3%
O	17.2	25.6	48.8%	26.8	55.8%
O+F	52.5	52.5	successful	52.9	successful

Table 2: Drawing depths

result in significant improvements. In figure 11, appropriate distribution curves have sharp peaks which go deep into the critical area of limit formability curves. In figure 12, although the process finished with fracture, we see a significant deflection of curves towards left safer side of limit formability diagram. Consequently, the process can be improved significantly only by changing the intensity of blank holding force.

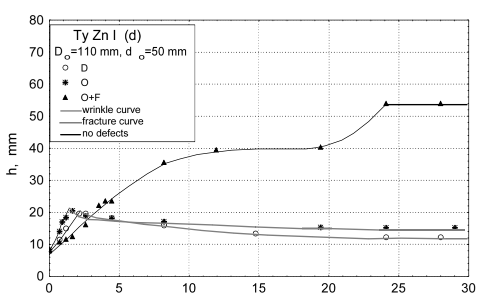

Figure 11: Strain distributions in sheet metal plane (CBF-R)

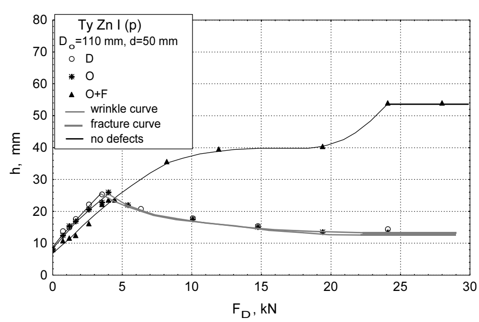

Figure 12: Strain distributions in sheet metal plane (CBF-E)

In the following step, an attempt was made to improve the results additionally. First of all, this involved the increase of drawing depth. Increasing dependence of blank holding force on travel, i.e. time, was selected. Based on previous experimental researches of various authors /6/, which aimed at determining minimal blank holding force for prevention of wrinkles, the approximate function in the following form was obtained:

$$F_D = b \cdot F_{DR} \cdot sin\left(\frac{\pi}{2}\frac{h}{h_{max}}\right) \tag{11}$$

In the argument of sine function, time can be applied instead of travel h:

$$F_D = b \cdot F_{DR} \cdot sin\left(\frac{\pi}{2}\frac{t}{T_{max}}\right) \tag{12}$$

b is empiric coefficient (it acquires values from 1,1 to 1,25); F_{DR} is blank holding force defined on the basis of recommendations (here marked as CBF-R); h_{max} and T_{max} are maximal piece depth and suitable process duration.

For conditions of actual investigation, the following functional dependence was adopted:

F_D= 16116,2 sin(0,5456 t), N.

In figure 13, previous dependence is shown as dotted line. Over it, there is experimentally realized graded line. Specific contact pressure on holder in the first part of the process, at such dependence, is smaller in relation to CBF application. It should be taken into account that the contact surface between sheet metal and holder decreases all the way until the end of drawing process. Figure 14 shows even greater success of increasing VBF. Drawing depths are increased in relation to application of CBF-R and CBF-E (numerical values are given in table 2). Loops of main strain distributions in sheet metal plane at application of increasing VBF have larger width and more favourable position towards limit formability curves in relation to both types of constant blank holding force. That is confirmed by relieved process running with postponement of critical thinning which, finally, results in larger drawing depth.
Previous conclusion can also be applied to figure 15. Distribution of thickness strain is, perhaps, the best example of process running and conclusion. The change in case of VBF application is clearly perceived.

Drawing depth is doubtlessly the most significant technological indicator. It represents the final goal of forming by deep drawing. Table 2 summarizes the realized depths at application of all three types of blank holding force and all three types of friction. Increase percentages evidently show the significance of both optimized CBF and increasing VBF. The difficulties related to increasing the drawing depth only by change of blank holding force can be best seen in various researches (e.g. /4/).

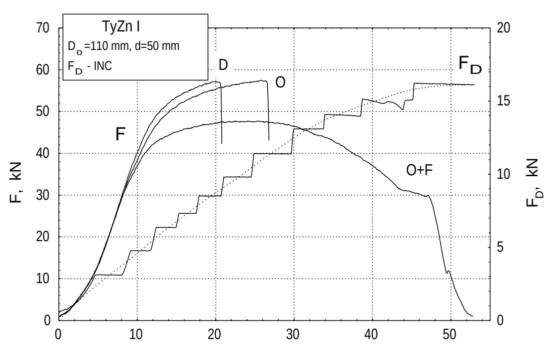

Figure 13 Dependence of drawing force and increasing blank holding force on travel

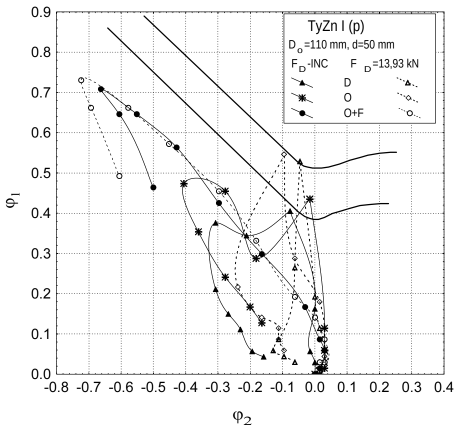

Figure 14: Strain distribution in plane at increasing VBF

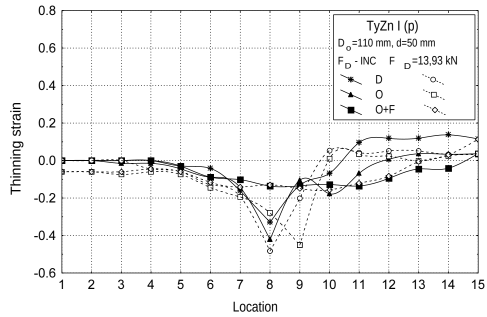

Figure 15: Thinning distribution at increasing VBF

4. CONCLUSION

Stress due to friction on sheet metal holder usually participates in total drawing stress with less than 10%; however, blank holding force, as normal force for that friction, has significantly larger influence on the process – on one hand by preventing the appearance of wrinkles on flange, and on the other hand by influencing the sheet metal thinning in critical zone. A very significant property of blank holding force is its possibility to be changed in the course of process. On the basis of previously exposed results it can be observed that by applying one type of VBF it is possible to accomplish a quality improvement of process results. In this case, VBF of increasing character provides significantly larger drawing depths in relation to CBF determined according to recommendations. However, there are still some unanswered questions: which VBF dependences give the best results in different forming processes and is it possible to find the solution of final process control only by complex computer control systems.

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