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SIGNIFICANCE OF STRAIN PATH IN CONDITIONS OF VARIABLE BLANK HOLDING FORCE IN DEEP DRAWING

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ABSTRACT

The process of deep drawing is influenced by many factors. The only two factors that could be modified in course of the process, by using special devices, are holding force and position of draw beads.
In this paper the results of investigations of galvanized sheet metal zinc coated at one side (marked TyZnI) will be given. Material is 0.8 mm thick. Work piece is of a cylindrical geometry with diameter 50 mm. Blank diameter is 110 mm. For that geometry, variable holding force (VBF) dependence was obtained by empirically-analytical procedure. Functions were obtained at given condition of constant specific holder pressure (VBF decreasing dependence) and at condition of wrinkling prevention (VBF increasing dependence).
In the first case, VBF was applied, with change of contact conditions (dry, oil, and oil plus polyethylene foil) without strain history change (one phase procedure).
In the second case, two phase procedure was performed. At first phase sheet metal has undergone uniaxial tension towards rolling direction. At the second phase, out of the strained sheet metal blanks were cut out for the operation of deep drawing. The effects of the VBF and variable strain history influence are monitored through principle plain strains distributions, thinning strain distributions, depth and drawing force.
In the conclusion we should emphasise that decreasing VBF shows obvious advantages in case without strain history change. With tension at the first stage, decreasing holding force does not bring to improvement concerning the drawing depth, but more uniform thinning strain distribution is obvious. Improvements brings increasing VBF (enlarging drawing depths, better strain distributions).
By computer simulation, theoretical and experimental investigations it is possible to define the VBF which would improve results in each particular forming case.

Keywords: *deep drawing, complex strain history, variable 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 thin sheets during the last few decades. According to the data of International Iron and Steel Institute (IISl, 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 Brasil 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.
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.
A particular increase of complexity of plastic forming process occurs in conditions of „complex strain paths“, especially in procedures consisting of two and more phases. In this paper, that aspect of process is included as well, in parallel with application of variable blank holding force. Besides general tendency to accomplish complete process control, the undisputed practical significance of such researches is related to forming of sheet metals of lower formability (aluminium alloys, high strength steels, stainless steels etc.).

2. INFLUENCE OF STRAIN PATH

Mathematical description and comprehension of plastic forming process are relatively simpler for monotonous procedures [4, 5]. However, real processes are usually performed in conditions which differ from proportional forming. That is especially prominent in multi-phase (multi-operational) procedures. It is very convenient to show the influence of complex forming paths on forming limit diagram (FLD). The changes on limit curves caused by particular non-monotonous process flow can directly be seen in this diagram. Figure 1 displays three pairs of limit curves (localization – bottom curve, fracture – top curve) for low-carbon steel sheet metal with single-side galvanized zinc coating 0,8 mm thickness, which was also used in the subsequent experiments related to this paper. Curves presented as dotted lines (**a**) are related to monotonous single-phase procedure. For each curve point, strain path is a straight line. Curves marked with **b** are the results of two-phase non-monotonous process, whereat each point is obtained by strain path which has uniaxial tension in the first phase and straight lines in displayed range in the second phase. Curves for two-phase procedure – the one which has pure biaxial tension in the first phase – are marked with **c**. It is important to point out that complex strain paths significantly change the position of limit curves, i.e. it they influence the value of limit strains. For the first procedure (**b**), the curves are displaced to the left and they are somewhat above the curves of main FLD. For the second procedure (c), the curves are displaced to the right with limit strains values similar to main FLD. It can be concluded that previous uniaxial tension has more favourable influence on the position of FLD curves in relation to biaxial tension.

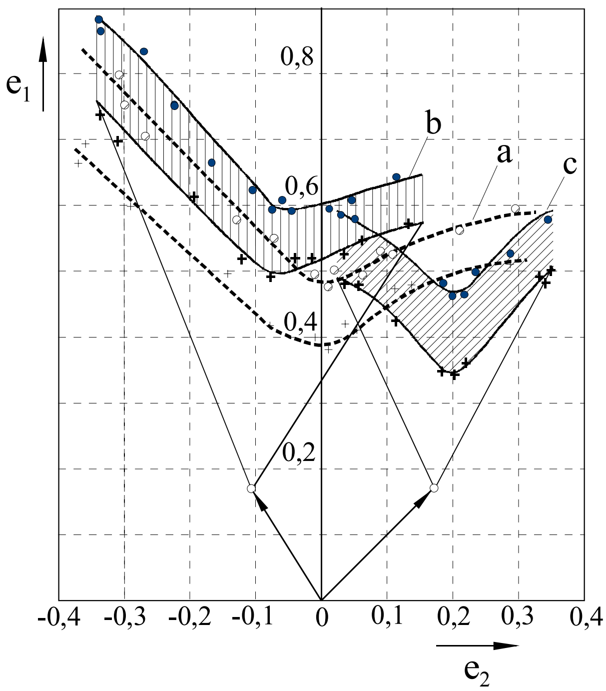

Fig. 1 Forming limit diagram in complex two-phase paths with constant strains at the end of the first phase

For application of FLD obtained in conditions of non-monotonous forming it must be emphasized that it is necessary that procedures for it experimental defining correspond to observed real processes. For example, FLDs in figure 1 are said to have been obtained at congruence of main strains directions in sheet metal plane of one phase in relation to the other phase of non-monotonous forming process. Non-monotonous forming is most often studied by means of two-phase and multi-phase procedures with rectilinear paths in each phase, i.e. with preserved monotonous forming throughout each separate phase. Even if the paths in real processes are not rectilinear, it is always possible to divide the entire forming strain path into stages as convenient, whereat the process is proportionate in each stage. In this paper, complex paths were realized by two-phase procedure in line with figure 1 (curves b).

3. EXPERIMENTAL RESEARCHES

The experiment was so devised that it enables investigation of material properties in the first part, previous uniaxial tension of wide sheet metal bands in the second part, and deep drawing with application of variable blank holding force (VBF) during the forming process in the third part. A more detailed description of experimental equipment is given in [4, 6], and at this point we should emphasize the possibility for obtaining the change of blank holding force in dependence on time (or drawing depth) in any form of analytical or discrete dependence.

Stripes of 130 mm width and 500 mm measuring length were uniaxially strained to strain e_1=9,5% and e_2= –4,75%. Out of such stripess, blanks of 110 mm diameter for deep drawing were cut in the second phase.

Geometry of piece for deep drawing is cylindrical, of 50 mm diameter, with drawing ratio 2,2. Three contact conditions, i.e. three types of friction were applied: dry (mark D), mixed (oil, mark O) and quasi-hydrodynamic (oil and PET foil, mark O+F).

Two types of VBF were used: decreasing and increasing. The application of constant blank holding force (CBF) served as basis for comparisons. Single-phase (monotonous) and two-phase (non-monotonous) drawing processes were realized in parallel.

As previously mentioned, material is single-side galvanized low-carbon steel sheet of 0.8 mm thickness intended for 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.

A very illustrative display of the influence of blank holding force on results of deep drawing process is given in diagrams of drawing depth dependence on blank holding force with wrinkle and fracture limit curves.

Figures 2 and 3 clearly show the effects of contact conditions, limit drawing depth according to criterion of wrinkles and fracture appearance and influence of blank holding force. Drawing depth is a fundamental technological parameter. Larger drawing depth with fulfilled requests regarding potential defects (deviations of shape and dimensions, surface quality) signifies a more successfully performed forming process. For curves in fig. 2, coating faces the die. At intensive friction, it is removed and deposit very quickly develops on die rounding. Contact conditions deteriorate further, which results in smaller piece depth. If coating faces the punch (fig. 3), the appearance of deposit formation is considerably less prominent. Limit diagrams of drawing depth dependence on blank holding force provide the possibility for optimization of constant blank holding force with significant improvement of process results [4]. Series of pieces (one point, one work piece) and suitable laboratory equipment are necessary in order to obtain these diagrams. Quality software for simulation can be very useful.

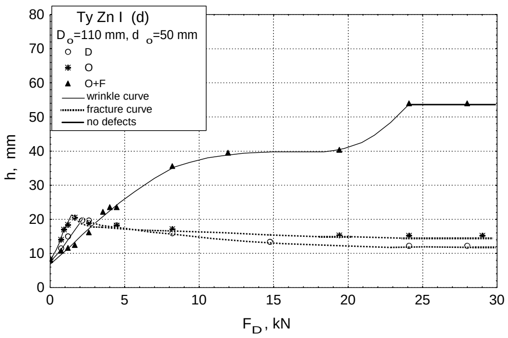

Fig.2 Drawing depth dependence on blank holding force-wrinkle and fracture limiting curve (coating layer on the die)

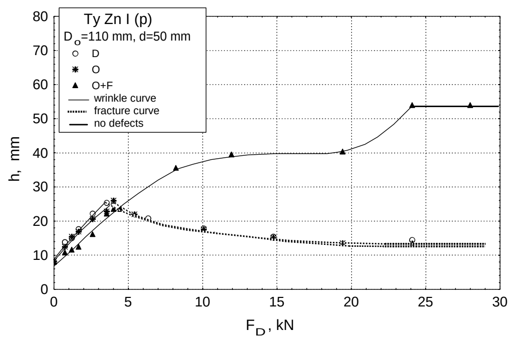

Fig. 3 Drawing depth dependence on blank holding force– wrinkle and fracture limiting curve (coating layer on the punch)

Constant blank holding force (CBF) is defined as medium value 9 of most often used recommendations from literature [4]. In this case, its intensity is 13928,5 N (nominal specific holder pressure q=2,05 MPa).

For variable blank holding force (VBF), the decreasing dependence (DEC) was selected, defined on the basis of principle of preservation of constant value of specific pressure q. Throughout the process, contact surface on holder decreases and, in line with that, it is necessary that blank holding force intensity decreases as well. By means of rather simple geometrical transformations it is possible to obtain the function which gives the flange surface dependence on time [4]. Linear connection of flange diameter and time (t) and punch travel and time is assumed (which corresponds to reality). The final form of decreasing function of blank holding force is:

$$\mathbf{F_D=13928.5 - 120.37 \cdot t + 0.1875 \cdot t^2\ ,\ \ N}$$

Dotted line in fig. 5 represents this function. Graded full line is a real dependence realized by measuring system of the device on which the experiment is carried out. In addition to that, figure 4 and 5 show the dependence of forming forces of deep drawing on travel. Increase of depth in case of VBF application can be observed. At dry contact surfaces, the increase is 23%, and at mixed friction approximately 15%. In case of oil and foil application (quasi-hydrodynamic friction), the process is interrupted at approximately 35 mm depth due to the appearance of wrinkles.

The process results can be observed more thoroughly in strain distribution diagrams (fig. 6 and fig. 7). Distributions in fig. 6 represented by dotted lines refer to the application of CBF, and those represented by full line refer to forming at VBF. At smallest friction (O+F), CBF gives somewhat better results, although some minor wrinkles appear, which can be straightened by passing through die opening. If decreasing VBF is used, wrinkles are large and process must be interrupted. Figure

3 clearly shows that, in both cases, the intensity of blank holding force is not sufficient for prevention of wrinkles. In conditions of more intensive friction, the loops of distributions for application of VBF are displaced downward and to the left (safer forming area with bigger plasticity reserve), which explains why the achieved depths are larger. All this is more evidently shown in figure 7. Thinning strain distributions are obviously more favourable at decreasing VBF.

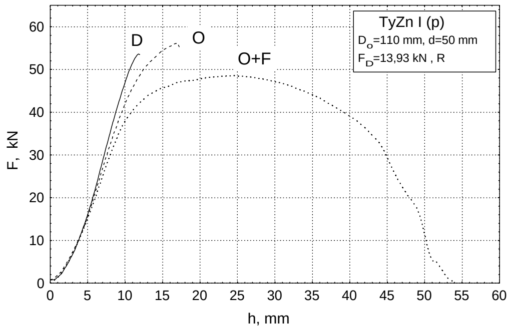

Fig. 4 Drawing forces dependence on travel at CBF

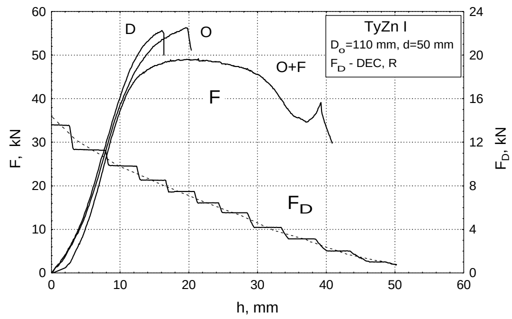

Fig. 5 Drawing forces and decreasing dependence of VBF

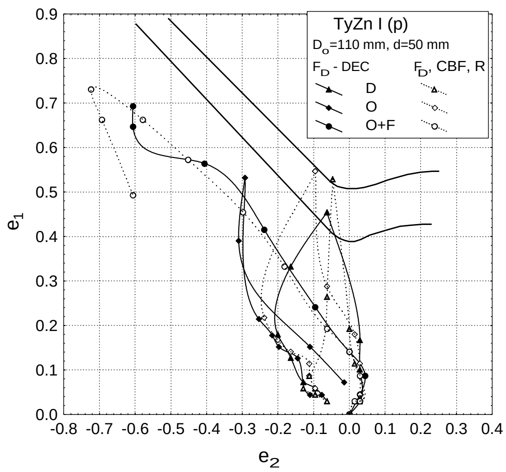

Fig. 6 Comparative display of strain distributions in sheet metal plane

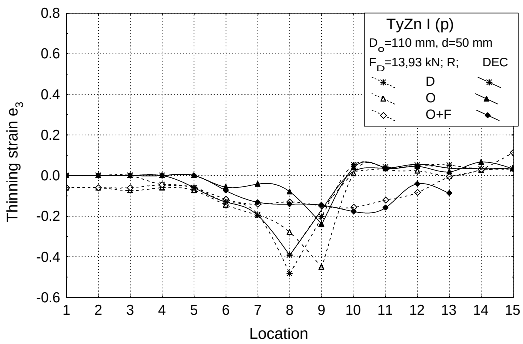

Fig. 7 Comparative display of thinning strains

Fig. 8 displays the drawing depth dependence on blank holding force, i.e. limit wrinkles and fracture curves at complex strain paths (two-phase process). If we compare the diagram with fig. 3, a significant difference is discerned. In case of monotonous procedure, the difference between curves in limit (D) and mixed (O) friction is not prominent, while in fig. 8 the difference is significant. At more intensive friction, the process goes on in difficult conditions, and very small depths are achieved.

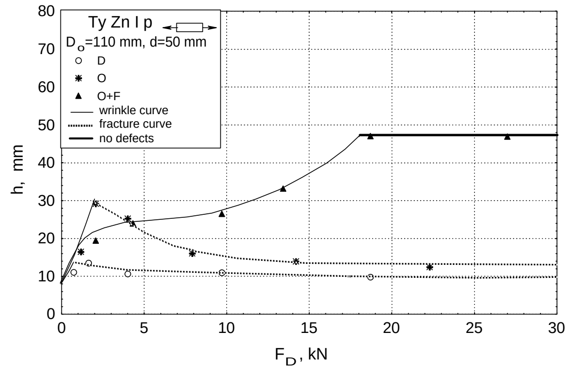

Fig. 8 Limit diagram of wrinkles and fracture in two-phase process

Fig. 9 gives the expected result. At smallest friction (O+F), small wrinkles appear at the end of travel, but the process can be finalized with them. It is confirmed [4, 5, 6], that at quasi-hydrodynamic friction, in order to definitely prevent the wrinkles, the force of sufficiently high intensity should be applied. Exceeding does not cause significant changes. Therefore only the cases with more intensive friction (D and S) will be shown in the following figures. Decreasing VBF (fig. 10) does not result in any significant changes as it does in the case of monotonous forming. Depths are similar as with CBF. Explanation should be sought in the fact that the change of blank holding force did not even reach its maximum, because the function was formed on travel which corresponded to full depth of piece (around 55 mm).

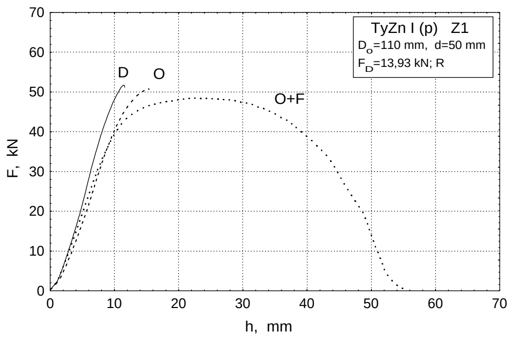

Fig. 9 Drawing forces − non-monotonous procedure and CBF

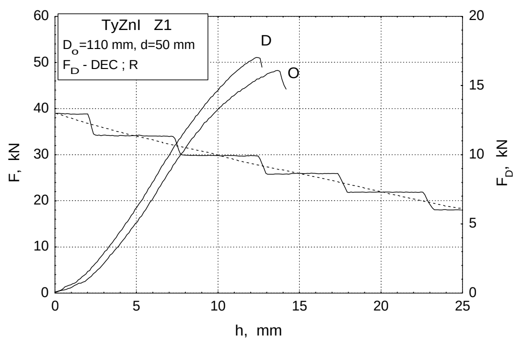

Fig. 10 Drawing forces − non-monotonous procedure and decreasing VBF

Due to bad effect of decreasing VBF, another type of VBF was applied as well – increasing dependence (INC). The function was obtained by approximation of series of wrinkles curves in diagrams of blank holding force dependence on depth, i.e. travel [4]. Those dependences are practically the same as those in fig. 2, fig. 3 and fig. 8, except for the fact that coordinate axes change place. Sine function proved to be convenient, whereat the variable in it is transformed into non-dimensional value smaller or equal to $\pi/2$:

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

b is a correction factor which assumes the value in range 1,1 to 1,25. F_{DM} is CBF defined according to empirical recommendations, and h and h_{max} are proper travels, i.e. drawing depths. If time is applied instead of travels, the following is obtained in the real case:

F_D=16253·sin(0,00952·t), N

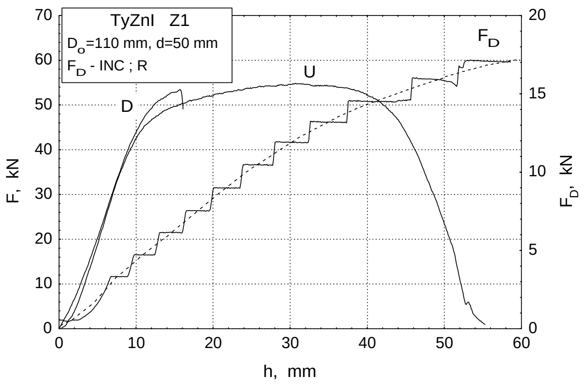

Fig. 11 Drawing forces − non-monotonous procedure and increasing VBF

Graphic presentation of this dependence is shown in fig. 11, as well as experimentally realized graded approximation. Also, considerably larger depths are observed. At dry friction, depth

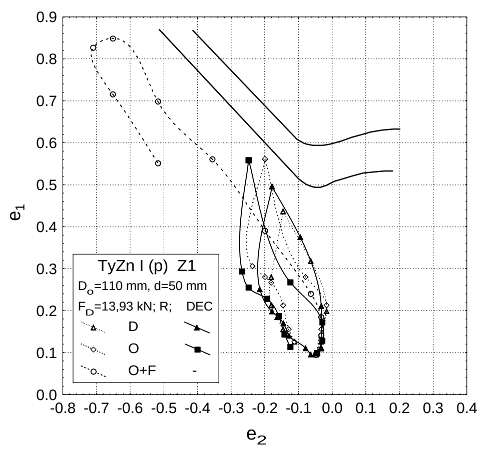

Fig. 12 Strain distribution for decreasing VBF, CBF and non-monotonous process

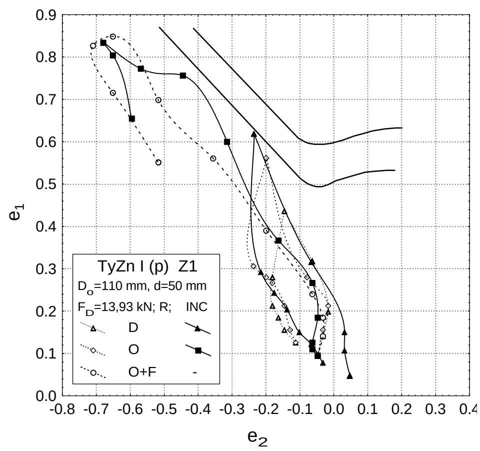

Fig. 13 Strain distribution for increasing VBF, CBF and non-monotonous process

increases for 33% (compared to the application of CBF), and at mixed friction a successful piece can be obtained with small registered wrinkles at the end of travel, which do not influence the process significantly.
Fig. 12 and 13 illustrate the effects of two types of VBF. In case of decreasing VBF, distributions loops are narrow, in unfavourable relation to limit curves of forming limit diagram and are not significantly different from distributions for CBF. By applying increasing VBF, more favourable distribution is obtained even at dry friction; at oil lubrication, the open loop of successful piece is obtained. Such effect of increasing VBF confirms the significance of initial stage of the deep drawing process. By reducing blank holding force in that phase to a minimal intensity sufficient for prevention of wrinkles, a certain unburdening of material is achieved and strain path with minor sheet metal thinning in the first part of process, i.e. more uniform forming, is obtained. Forming strengthening from the first phase, which contributes to resistance to localized forming, is probably influential as well.

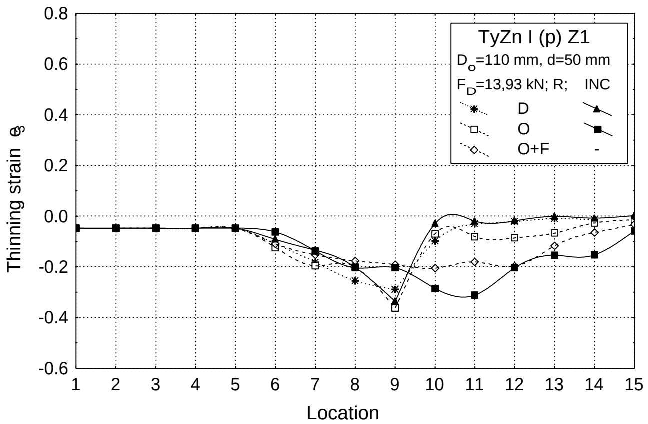

Fig. 14 Thinning distribution for CBF, increasing VBF and non-monotonous process

Previous observations are more easily achieved on the basis of illustrative comparative display of thinning strain distributions (fig. 14) for CBF (dotted lines) and increasing VBF (full lines).

4. CONCLUSION

In this paper, experimental researches were used for investigating complex subjects of plastic forming at complex strain paths, i.e. non-monotonous processes, by means of deep drawing of coated sheet metals. Variable blank holding force was applied in parallel during the process. Two-phase non-monotonous procedure with uniaxial tension was realized in the first phase and variable (in addition to constant) blank holding forces of decreasing and increasing characters were applied. Non-monotonous procedure emphasizes the influence of friction. A minor change of friction regime has more effects on process flow than in monotonous process. The influence of strengthening from the first phase is visible, as well as the influence of thinning. Blank holding force has a strong impact on process and can influence the achievement of larger drawing depths.

Empirically determined constant blank holding forces are inferior in relation to possibility for optimization by means of limit wrinkle and fracture diagrams. Variable blank holding forces request a rather complex computer measuring system, but they offer the possibility for significant improvements. In this paper we showed that proposed increasing dependence can result in quality improvement of results even in aggravating conditions of two-phase non-monotonous process.

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ZNAČAJ ISTORIJE DEFORMISANJA PRI DUBOKOM IZVLAČENJU SA PROMENLJIVOM SILOM DRŽANJA

Srbislav Aleksandrović, Milentije Stefanović

REZIME

Postoji više faktora koji utiču na proces dubokog izvlačenja. Samo dva mogu da se menjaju tokom trajanja procesa i to su: sila držanja i položaj zateznih rebara.
U radu su prikazani eksperimentalni rezultati istraživanja čeličnog lima sa galvanskom prevlakom od cinka. Debljina materijala je 0,8 mm. Radni predmet ima cilindričnu geometriju prečnika 50 mm. Prečnik razvijenog stanja je 110 mm. Za ovakvu geometriju određene su zavisnosti promenljive sile držanja (PSD) empirijsko−analitičkom procedurom. Funkcije su definisane prema principu konstantnog specifičnog pritiska držača (opadajuća zavisnost) i prema uslovu sigurnog izbegavanja nabora (rastuća zavisnost).
U prvom slučaju PSD je primenjena u uslovima sa promenom kontaktnog stanja (suvo, primena ulja, primena ulja i polietilenske folije).
U drugom slučaju primenjen je dvofazni postupak. U prvoj fazi je jednoosno zatezanje u pravcu valjanja, a u drugoj duboko izvlačenje. Efekti složene istorije deformisanja i PSD praćeni su preko: distribucija deformacija u ravni lima, distribucije deformacije stanjenja, sila izvlačenja i dubina izvlačenja.
U zaključku treba istaći da opadajuća zavisnost sile držanja pokazuje povoljan uticaj u slučaju monotonog deformisanja. Pri nemonotonom postupku opadajuća sila držanja ne dovodi do povećanja dubine izvlačenja, ali je nešto ravnomernija distribucija deformacija. Do značajnih poboljšanja dovodi primena sile držanja rastućeg karaktera (povećanje dubine izvlačenja i povoljnije distribucije deformacija).
Kompjuterskim simulacijama, teorijskim i eksperimentalnim istraživanjima moguće je definisati promenljivu silu držanja koja može da unapredi rezultate u svakom slučaju oblikovanja dubokim izvlačenjem.