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Analiza raznosa tlaka pri uporabi prilagodljivega pridrževala z možnostjo nadzora pridrževalne sile med globokim vlekom

An Analysis of the Spreading of a Holding Pressure by Means of a Pliable Blank Holder with the Controllable Holding Force during a Deep-Drawing Process

Boris Jerman - Roman Hodnik - Janez Kramar

Eden od pomembnejših parametrov globokega vleka je sila pridrževanja preoblikovanca. Zaradi izboljšanja kvalite zahtevnejših izdelkov je v zadnjem času izražena potreba po možnosti časovnega in krajevnega nadzora sile pridrževanja. Za učinkovit krajevni nadzor je potrebno toga pridrževala nadomestiti s prilagodljivimi ali segmentnimi. V prispevku so prikazane razmere pridrževanja s prilagodljivim pridrževalom debeline 30 mm, ki pritiska na preoblikovanec s 16 hidravličnimi valji med postopkom izdelave testnega izdelka. Rezultati raziskave prikazujejo krajevno porazdelitev tlaka prilagodljivega pridrževala na preoblikovanec za več zaporednih stanj med postopkom ob upoštevanju spremembe oblike in debeline preoblikovanca.

(Ključne besede: globoki vlek, pridržala, sile pridrževanja, analize uporabnosti)

One of the most important parameters in the deep-drawing process is the force holding the blank. In a desire to improve the quality with products of complex geometries, forming technology has focused developments on better time-and-place control of the holding force. For a more efficient location control of the holding force it is necessary to replace highly rigid blank holders with pliable or segmented blank holders. This paper discusses the holding conditions when a pliable blank holder of thickness 30 mm presses against the blank with 16 hydraulic cylinders during the process of forming a test product. The results of the research show the local distributions of pressure acting on the blank for a sequence of states during the process, taking into account the changes in the shape and the thickness of the blank.

(Keywords: deep drawing, holders, holding force, applicability analysis)

0 UVOD

Globoki vlek pločevine je postopek preoblikovanja, ki se v velikoserijski proizvodnji s pridom uporablja že dlje časa. Navkljub široki uporabi v industriji, pa postopek še zdaleč ni optimalen. Poleg razvoja preoblikovalnega postopka samega, se v zadnjem času velik poudarek daje tudi obliki izdelka, ki naj poleg funkcionalnosti zagotavlja tudi optimalen izdelovalni postopek, torej optimalno obliko orodja in minimalno število preoblikovalnih operacij ([1] in [2]).

Kljub omenjenim uspehom, ostaja ena od najpomembnejših nalog načrtovalcev zagotovitev optimalnih parametrov globokega vleka. Med temi parametri je pomembna tudi primerno porazdeljena sila pridrževanja preoblikovanca [4]. Zaradi zakonitosti

0 INTRODUCTION

The deep drawing of sheet metal is a forming procedure that has found widespread use in high-volume production. In spite of this, the deep-drawing process is far from being optimized. Besides development of a metal-forming process, in recent years, great emphasis has been put on the product's shape, which should, in addition to functionality, enable the optimized running of the forming process, i.e. the optimum shape of the forming tool and the minimum number of forming operations ([1] and [2]).

Despite considerable success, choosing the best parameters for the deep-drawing process still remains an important task for process planners. One of the parameters that is especially difficult to optimize is the adequately distributed blank-holding force [4].

toka materiala med preoblikovalnim postopkom se debelina in površina preoblikovanca pod pridrževalom s časom spreminjata, zaradi česar v splošnem ni mogoče shajati niti s časovno, niti s krajevno konstantno silo pridrževanja. Problem je velik predvsem pri zapletenejših izdelkih. Lokalno povečanje sile pridrževanja pri stiskalnici s togim pridrževalom je možno, vendar imajo uporabljene metode kar nekaj pomanjkljivosti.

V zadnjih letih je opazen razvoj sistemov, ki omogočajo krajevni in časovni nadzor sile pridržavanja med postopkom globokega vleka, kar omogoča izboljšanje kakovosti izdelka in večjo stopnjo preoblikovanja med eno operacijo. Naštete prednosti so pomembna vzpodbuda za raziskave in nadaljni razvoj takih pridrževalnih sistemov, katerih osnova je bodisi: pridrževanje s prilagodljivim (podajnim) ali pa s segmentnim pridrževalom. V pričujočem prispevku je analizirana možnost zagotovitve optimalne krajevne porazdelitve pridrževalnega tlaka s prilagodljivim pridrževalom. Tako pridrževalo se pod vplivom pridrževalne sile deformira ter se (delno) prilagodi trenutni obliki površine preoblikovanca. S tem se poveča njuna medsebojna dotikalna površina in doseže ustreznejša lokalna porazdelitev pridrževalnih tlakov. Za uspešno uporabo predstavljenega koncepta je potrebno zagotoviti predvsem ustrezno preoblikovalnost pridrževalne plošče in ustrezno število (hidravličnih) aktuatorjev.

Zadana naloga zahteva izračun tlakov pridrževala na preoblikovanec. V ta namen je bilo treba izdelati analizo prostorskega dotika (kontakta) med preoblikovancem in pridrževalom. Taki kontaktni problemi so malo raziskani že na elementarni ravni [5], raziskave v smeri kontaktnih napetosti v tehnoloških pogojih globokega vleka pa se pojavljajo šele v zadnjih letih ([3], [4] in [6]). Za razliko od raziskav ([3] in [4]), ki se nanašajo na učinkovanje enega hidravličnega valja preko toge plošče in primerno dolgih vmesnih stebričkov na tanko prilagodljivo ploščo, ima pričujoča raziskava namen proučiti interferenco (medsebojno učinkovanje) več hidravličnih valjev neposredno na tanko prilagodljivo ploščo (prilagodljivo pridrževalo). Za analize je izbrana metoda končnih elementov (MKE). Uporabljen je programski paket ANSYS®. Opazovane so razmere pri nekaterih elementarnih primerih dotika in kasneje tudi razmere med realnim globokim vlekom.

1 PORAZDELITEV TLAKOV POD PRIDRŽEVALNO PLOŠČO V ODVISNOSTI OD NJENE DEBELINE

Za uspešno načrtovanje krajevnega nadzora pridrževalne sile je potrebno poznati porazdelitev tlaka pod pridrževalno ploščo. Raziskan je vpliv enega hidravličnega valja na tlak pod pridrževalno ploščo v odvisnosti od njene

Due to the laws of material flow during the forming process, the thickness and area of the blank covered by the holder will vary with time. This is why, in general, it is not possible to do the job with a locally constant or time-constant force, and the problems get bigger for products with complex geometries. On a press with a rigid blank holder it is normally possible to increase the local holding force, but the methods applied to achieve this have a few disadvantages.

In recent years, development trends have been directed towards systems with place and time control of the holding force during the deep-drawing process. This type of control would improve product quality and forming efficiency in a single operation. These advantages have encouraged further research and development to improve blank-holding systems. There are two main principles for this kind of holding systems: a system with an elastic (pliable) blank holder and a system with a segmented holder. In this paper we have looked at ensuring optimal local distribution of the holding pressure with a pliable holder. Under the influence of the holding force applied, a pliable blank holder deforms and (partially) adjusts itself towards momentary blanks shape. So the size of the interacting contact surface increases and a better local distribution of the holding pressure is achieved. In addition to a suitable number of hydraulic actuators, such a system requires the appropriate deformability of the holding plate to give us the desired local pressing effects.

In order to achieve our objective we had to calculate the pressures acting on the blank. This meant we had to analyse the space contact between the blank and the holder. This kind of contact problem has been given little attention, even on an elementary level [5], and research reports that focused on the technology of deep drawing can be traced only in recent years ([3], [4] and [6]). In contrast to reports ([3] and [4]), where an action of one hydraulic cylinder is transferred to a thin pliable plate by means of rigid plate and intermediate bars, this paper shows the combined effects of multiple cylinders, acting directly on the thin plate (pliable blank holder). In the performed analysis the finite-element method (FEM) and ANSYS® software package were used. Initial observations were of the conditions present in some elementary cases of contact, after which conditions during a real deep-drawing process were also studied.

1 THE PRESSURE DISTRIBUTION UNDER THE HOLDING PLATE AS A FUNCTION OF ITS THICKNESS

For the successful planning of the local control of the holding force it is necessary to know the pressure distribution under the holding plate. An analysis was made of the influence of one hydraulic cylinder and a series of cylinders on the pressure under the holding debeline ter vpliv več zaporedno nameščenih valjev. Proučevana so pridrževala debelin 60, 80 in 100 mm. Modelirana so s prostorskimi končnimi elementi. Analiza temelji na predpostavki, da je površina, na katero pritiska pridrževalo, ravna in toga ter je zato nadomeščena s podporami v ustrezni smeri. Med pridrževalom in podlago so nameščeni kontaktni elementi. Trenje med pridrževalom in podlago ni upoštevano. Sila posameznega valja znaša 684 kN. Predstavljena je kot tlak v krogu s premerom 60 mm.

plate as a function of its thickness: holders with a thickness of 60, 80 and 100 mm were studied. The holders were modeled by volume finite elements, with the analysis based on the assumption that the surface pressed down by the holder is flat and rigid and can be replaced by supports acting in the required direction. The contact elements were placed between the blank holder and the support. The friction between the plate and the support was not considered. Each of the applied cylinders acted with a force of 684 kN. This force is represented as a pressure acting on a circle with a diameter of 60 mm.

1.1 Model z enim hidravličnim valjem

Pridrževalo je predstavljeno kot kvadratna plošča s stranicama 500 mm. Celotna spodnja površina se opira na togo oporo. Na gornjo stran pridrževala (v središču) deluje en hidravlični valj. Porazdelitve napetosti, glede na debelino pridrževala so v tem primeru skoraj simetrične okoli simetrijske osi hidravličnega valja (diagram 1).

1.1The model with one hydraulic cylinder

The blank holder is represented as a square plate with sides of 500 mm. Its complete lower surface is supported by a rigid support. One hydraulic cylinder acts on the upper side of the blank holder (in the centre). The distributions of stresses as a function of the blank-holder thickness are, in this case, nearly symmetrical, spreading around the symmetry axis of the hydraulic cylinder (Graph 1).

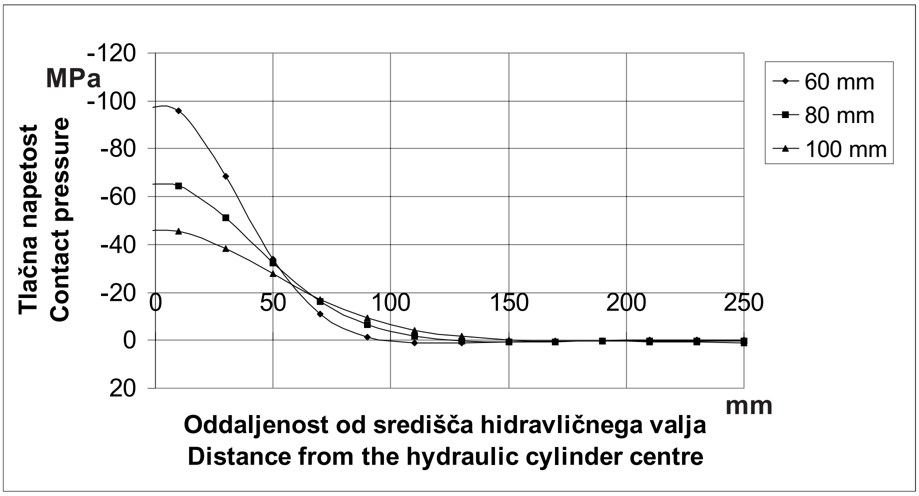


Diagram 1. *Porazdelitev tlakov pod pridrževalom v odvisnosti od oddaljenosti od središča hidravličnega valja za debeline pridrževala 60, 80 in 100 mm*

Graph 1. *The pressure distribution under the blank holder versus the distance from the hydraulic cylinder centre for the blank holder thicknesses 60, 80 and 100 mm*

Iz diagrama 1 je razvidno, da debelejše pridrževalo (kot je bilo pričakovati) delujočo silo hidravličnega cilindra »razmaže« po večji površini, torej se pojavi pritisk pridrževala na platino na večjem območju in z manjšim povprečnim in manjšim največjim tlakom.

From graph 1 we can see that the thicker blank holder — as expected — spreads the applied force of the hydraulic cylinder over a larger area. The pressure of the blank holder occurs over a wider area of the blank having a lower average and lower a maximum pressure.

1.2 Model s šestimi hidravličnimi valji

Pri dejanski izvedbi pridrževanja s prilagodljivim pridrževalom je običajno uporabljenih več hidravličnih valjev, nameščenih tako, da največkrat pritiskajo na površino pridrževala v bližini kakšnega od robov. Tak rob predstavlja npr. rob platine, ki med procesom globokega vleka potuje in

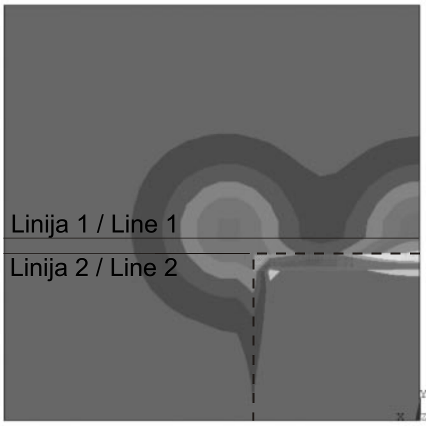
1.2 The model with six hydraulic cylinders

In the actual process of holding a blank with a pliable blank holder, usually more than one hydraulic cylinder is used. In most cases the cylinders are positioned in such a way that the pressure produced is acting near an edge. Such an edge can be a blank's edge (changing position and shape during the protudi rob matrice, na katerem se platina začne preoblikovati. Od teh robov dalje preoblikovanec pridrževala ne podpira več.

V modelu je pridrževalo predstavljeno kot kvadratna plošča s stranico 1000 mm. Vpliv robov matrice je popisan s pomočjo izreza na platini v velikosti 400 x 400 mm. Na zgornjo stran pridrževala, ob robovih matrice, je nameščenih 6 hidravličnih valjev. Njihova lega je razvidna is slike 1. Iz diagrama 2 je razviden skupen vpliv sosednjih valjev.

cess of deep drawing) or a draw ring's edge. From these edges onwards the blank holder is no longer supported by the sheet metal.

The blank holder is represented as a square plate with sides of 1000 mm. The draw ring's edges are represented as a square-shaped cutting with sides of 400 mm. To the upper side of the blank holder beside the draw ring's edges six hydraulic cylinders are acting. Their positions are shown in figure 1. Graph 2 shows the combined effects of the adjacent cylinders along two lines.



Sl. 1. *Prikaz četrtinke modela s šestimi hidravličnimi valji in izrezom*
Fig. 1. *One quarter of a model with six hydraulic cylinders and square-shaped cutting*

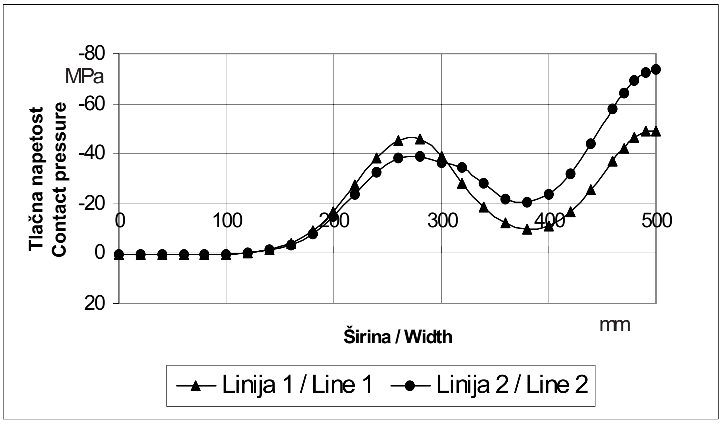


Diagram 2. *Porazdelitev tlakov pod pridrževalom na linijah 1 in 2*
Graph 2. *The pressure distribution under the blank holder along lines 1 and 2*

2 RAZISKAVA VPLIVA RAZLIK V DEBELINI LAMELE NA POGOJE PRIDRŽEVANJA

Analize v prejšnjem poglavju temeljijo na predpostavki, da je pločevina, na katero pritiska pridrževalo, ravna in toga. To zadosti dobro velja za začetek in začetno fazo globokega vleka. Kasneje se, zaradi zakonitosti tečenja materiala med globokim vlekom, pojavijo opazne razlike v debelini pločevine ([4], [1] in [2]). Zaradi tega je potrebna analiza, ki upošteva dejansko debelino in obliko preoblikovanca, na katerega nalega pridrževalo.

2.1 Vhodni podatki za analizo

2.1.1 Oblika in izmere testnega izdelka

Ker je izbrani tip analize (MKE) numeričnega značaja, je za opazovanje potrebno izbrati izdelek določenih dimenzij. Izbran je pomivalnemu koritu podoben izdelek z izmerami 400 x 400 mm s polmeri zaokrožitve 80 mm na vogalih med stranicami in 45 mm na dnu korita. Na sliki 2 je vidno nastajajoče korito ter deformirani robovi platine (pred deformacijo pravilni osemkotnik). Odtenki sivine predstavljajo razliko v debelini

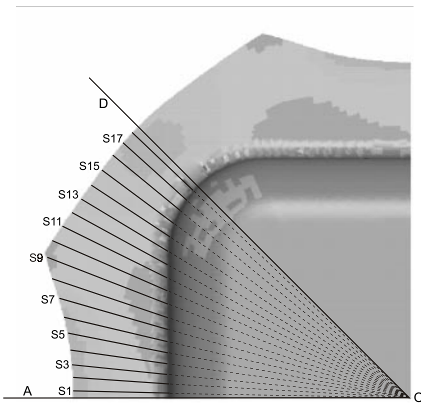
2 THE STUDY OF THE EFFECTS OF VARYING THE THICKNESS OF THE SHEET-METAL PLATE ON THE HOLDING CONDITIONS

The analysis in previous section is based on the assumption that the sheet metal subjected to the blank-holder pressure is perfectly flat and rigid. This is true for the initial conditions and the first phase of deep drawing. In subsequent phases, however, due to the laws of material creep in the deep-drawing process, large differences occur in the thickness of the sheet metal ([4], [1] and [2]). This fact requires to make a further analysis that considers the real thickness and shape of the blank which is in contact with the blank holder.

2.1 Entry data for analysis

2.1.1 Shape and dimensions of the test product

Because the selected form of analysis (FEM) is of the numerical kind, the studied object has to have concrete dimensions. Our object was a semi-finished product resembling a kitchen sink with dimensions of 400 x 400 mm and a radius of rounding of 80 mm in the corners between the sides, and 45 mm at the bottom of the sink. The formation of the sink and the deformed blank's edges are shown in figure 2. Beams S1 till S18 are also shown (the meaning of these beams is ex-



Sl. 2. *Prikaz četrtinke preoblikovanca med globokim vlekom (pogled od zgoraj)*
Fig. 2. *A fourth of the blank during the deep-drawing process (viewed from top)*

preoblikovane pločevine [2]. Prikazani so tudi žarki S1 do S18, katerih pomen je pojasnjen v poglavju 2.1.2. Črki A in D označujeta robova 1/8 modela preoblikovanca in pojasnjujeta položaj teh robov na slikah 3 in 8.

2.1.1 Oblika in izmere preoblikovanca med globokim vlekom in optimalna sila pridrževanja

Za izdelavo testnega izdelka je bila izbrana platina debeline 0,7 mm v obliki pravilnega osemkotnika (slika 4-b), katerega velikost je določena z oddaljenostjo 700 mm med njegovimi vzporednimi robovi.

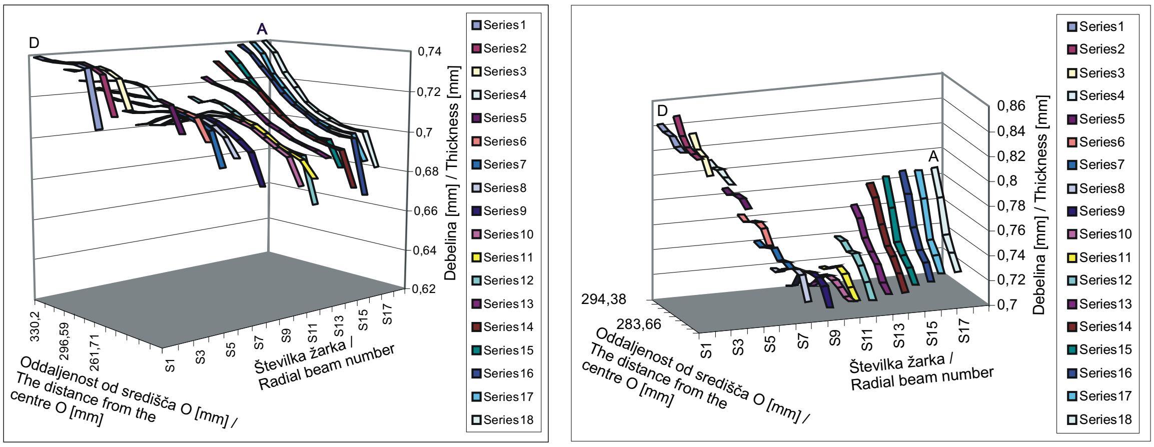
Platina se med postopkom globokega vleka plastično deformira, zaradi česar se pojavi pomikanje ter deformiranje njenih robov ter lokalno spreminjanje

plained in section 2.1.2). The intensity of the grey colour shows changes in the thickness of a blank [2]. Using letters A and D the edges of 1/8 of the model of the product are signed. This designation explains the position of this edges in figures 3 and 8.

2.1.2 The shape and dimensions of the blank during the deep-drawing process and the optimum holding force

To manufacture the test product we chose a blank with a thickness of 0.7 mm in the form of a regular octagon (Fig. 4b), with the distance 700 mm between the parallel edges.

During the deep-forming process the blank deforms plastically, while its edges move and deform resulting in a varying local thickness. The thickness



a) Stanje 5: Razlika med najmanjšo in največjo debelino plošče je ~ 0,07 mm
a) Phase 5: The difference between the minimum and maximum thickness of the sheet bar is ~ 0.07 mm

b) Stanje 8: Razlika med najmanjšo in največjo debelino plošče je ~ 0,15 mm
b) Phase 8: The difference between the minimum and maximum thickness of the sheet bar is ~ 0.15 mm

Sl. 3. *Prikaz debeline preoblikovanca med globokim vlekom za stanji 5 in 8. Serije S1 do S18 predstavljajo radialne žarke S1 do S18 iz središča modela (točka O na sl. 2) proti njegovim robovom. Žarki so enakomerno porazdeljeni na 1/8 modela (45^O). Za lažjo orientacijo sta označeni tudi mesti A in D (glej tudi sl. 2 in 8)*
Fig. 3. *Thickness of the blank during deep drawing in phase 5 and 8. The series from S1 to S18 represent the radial beams S1 to S18 from the centre of the model O /Fig. 2) towards its edges. The beams are evenly distributed over 1/8 of the model (45^O). For better orientation, spots A and D are marked, too (see also Fig. 2 and 8)*

njene debeline. Debelina se poveča na mestih, kjer se pojavijo večji presežki materiala [2]. Postopek globokega vleka testnega izdelka je bil simuliran z uporabo programskega paketa PAM-STAMP®, od koder izhajajo podatki o obliki in izmerah preoblikovanca za 10 zaporednih stanj in tehnološka optimalna sila pridrževanja F_o = 848 kN [2]. Končna globino vleka je bila 180 mm.

Analiza obnašanja prilagodljivega pridrževala je bila izvršena za začetno fazo (0), kjer je platina še popolnoma nedeformirana (sl. 4b), ter za stanji 5 in 8, kjer se pokaže najprej zmerna in nato velika sprememba debeline preoblikovanca (sl. 3a in 3b).

2.2 Model preoblikovanca s pritisnjenim pridrževalom

Osnova za izgradnjo modela z MKE so podatki o debelini pločevine preoblikovanca na posameznem mestu, v skladu s poglavjem 3.1. Rezultati iz PAM-STAMP®-a so bili za posamezno opazovano stanje preneseni v ANSYS® s pomočjo vmesnika, napisanega v programskem jeziku Fortran. V prostorskem modelu sta z elementi modelirana pridrževalo in preoblikovanec v ustreznem stanju. Dotik med njima je ustvarjen z ustreznimi kontaktnimi elementi. S spodnje strani je preoblikovanec podprt v smeri svoje debeline, s čimer je za začetek vpeljana predpostavka ravne in nedeformljive podlage (matrice). Vpliv hidravličnih valjev je vnesen kot tlak na površino naleganja pestiča valja na pridrževalo. Površina naleganja je krog s premerom 50 mm (sl. 5). Zaradi večkratne simetričnosti je modelirana le 1/8 modela, kar omogoča znatne prihranke pri računskem času. Na slikah je včasih zaradi lažje predstave prikazana bodisi četrtina ali pa polovica modela.

2.2.1 Preoblikovanec v modelu

Matrica orodja za prvo stopnjo globokega vleka ima robove, obdelane v obliki krivulje, ki omogoča čim boljši pretok materiala. Ta krivulja zasede v tlorisu pas 12 mm okoli osnovne oblike korita, tako da znese površina, kjer platina (sl. 4-b) ne nalega na matrico (in torej tudi pritisk pridrževala na platino ni smiselen) 424 x 424 mm s polmerom zaokrožitve 92 mm (400+2x12=424, 80+12=92). Na tej površini platina ni modelirana. Debelina in oblika zunanjega roba platine oz. preoblikovanca je modelirana v skladu s poglavjem 2.1.2 za vsako izmed opazovanih stanj.

2.2.2 Pridrževalo v modelu

Pridrževalo je modelirano kot kvadratna plošča s stranico 720 mm (sl. 4a). V sredini ima luknjo za pestič orodja za globoki vlek. Analizirana so bila

increases at spots with bigger surpluses of material [2]. The deep-drawing process that we used for the test product was simulated with the PAM-STAMP® software package. The simulation gave us data on the shape and dimensions of the blank during the process for ten sequential states and the optimum technological holding force F_o = 848 kN [2]. The drawing depth was 180 mm.

The analysis of the behaviour of the pliable blank holder was made for the initial phase (0), where the blank is still completely undeformed (Figure 4-b) and the phases 5 and 8 where first a moderate and then a large change in the thickness of the blank can be observed (Fig. 3a and b).

2.2 Model of the blanks with a pressed-down holder

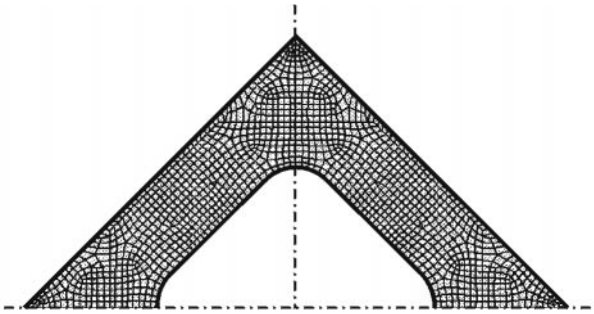
The FEM model was built on the basis of the thickness data at individual points on the blank, defined in 2.1. For each phase of the study the results obtained with PAM-STAMP® were transferred into ANSYS® using an interface written in FORTRAN. In the space model, the volume elements are used to model the holder and the blank in the appropriate phase. The contact between them is created by adjustable contact elements. From the bottom up the blank is supported in the direction of its thickness, and an initial assumption of a flat and undeformable support (die) is introduced. The influence of the hydraulic cylinders is entered as the pressure acting on the bearing area of the cylinder punch on the holder. The bearing area is a circle with a diameter of 50 mm (fig. 5). Because of the multiple symmetry only 1/8 of the model is modeled, which enables considerable savings in computation time. To give a clearer picture the figures are sometimes shown as either a quarter or a half of the model.

2.2.1 The blank in the model

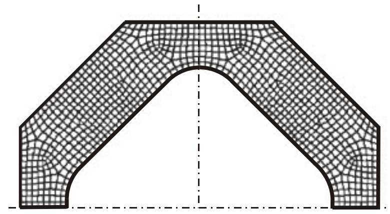
The die of the tool for the first degree of deep drawing has its edges machined in the form of a curve to ease the flow of material. In the ground plan this curve takes a 12-mm wide band around the basic shape of the trough so that the area where the blank (Fig. 4-b) is not carried by the die (so the pressure of the holder on the blank is ineffective) is 424 x424 mm with a radius of curvature of 92 mm (400+2x12 = 424, 80+12=92). The blank is not modelled on this area. The thickness and shape of the outer edge of the blank or blank are modelled as described in section 2.1.2 for each of the observation phases.

2.2.2 Blank holder in the model

The blank holder is modelled as a square plate with sides of 720 mm (Fig. 4a). In the middle it has a hole for the punch of the deep-drawing tool.



a) Pridrževalo z luknjo za pestič
a) Blank holder with a hole for the punch



b) Plošča brez dela, ki nima opore na matrici (stanje 0 tik pred začetkom vleka)
b) Sheet bar without the area not carried by the die (Phase 0 right before the start)

Sl. 4. *Pridrževalo in plošča v modelu po MKE (prikazana ena polovica)*
Fig. 4. *FEM models of blank holder and sheet bar (only half of each model is shown)*

pridrževala različnih debelin, prikazani pa so rezultati za $t = 30$ mm.

2.2.3 Obremenitve modela

Proučevanih je bilo več primerov namestitve hidravličnih valjev. Prikazani so rezultati za primer pridrževanja s 16 valji (2 valja na 1/8 pridrževala - sl. 5). Sila na en valj je bila (v skladi s poglavjem 2.1) $F_{o1} = 848/16 = 53$ kN.

Sili F_{o1} valjev 1 in 2 (sl. 5) bi bili lahko različni, za kar pa v konkretnem primeru ni bilo potrebe, saj sta bili, zaradi pojava neenakomernih debelin preoblikovanca, že enaki sili dovolj za dokaj dobro ujemanje dobljenega stanja z željenim, dokler je pridrževalo s svojo prilagodljivostjo lahko sledilo obliki neravnin (sl. 8 in 9).

Analiza je bila opravljena za več vrednosti pritisne sile hidravličnih valjev F_{v1}. Vpeljan je faktor k, kot večkratnik optimalne obremenitve: $F_{v1} = k \cdot F_{o1}$. Rezultati so prikazani za $k = 1$ in 1,5.

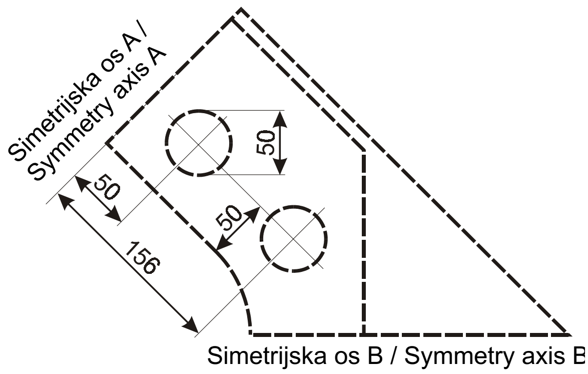
Several thicknesses of blank holder were analyzed. The results are shown for $t = 30$ mm.

2.2.3 Loads in the model

Several arrangements of hydraulic cylinders were studied. The results are shown for the case of holding with 16 cylinders (2 cylinders per 1/8 of the holder, see fig. 5). The force per one cylinder was (according to 2.1) $F_{o1} = 848/16 = 53$ kN.

The forces F_{o1} of cylinders 1 and 2 (Fig. 5) could be different, but there was no requirement in the studied example because the occurrence of a non-uniform thickness of the blank meant that equal forces were enough to make the resulting state match relatively well to the required state as long as the blank holder could, thanks to its pliability, follow the uneven shapes (Figs. 8 and 9).

The analysis was carried out for several values of the compression force of the hydraulic cylinders F_{v1}. Factor k is introduced as a multiple of the optimum load: $F_{v1} = k \cdot F_{o1}$. The results are shown for $k = 1$ and 1.5.



Sl. 5. *Lega pestičev (premera 50 mm) hidravličnih valjev na 1/8 pridrževala*
Fig. 5. *The position of punches (diameter 50 mm) of the hydraulic cylinders on 1/8 of the holder*

2.3 Rezultati

Rezultati so prikazani kot tlaki na površini preoblikovanca na strani, ki je v dotiku s pridrževalom. Opazovana je napetost v smeri z, torej v smeri debeline preoblikovanca.

2.3.1 Rezultati stanja 0

Po pričakovanju so razmere zelo podobne razmeram pri dotiku na togo in ravno podlago. Ujemanje je logično, ker je platina na začetku konstantne debeline.

Iz slik 6 in 7 je razvidno, da navkljub povečevanju pridrževalne sile preko njene optimalne vrednosti (k = 1,5), ne dobimo tlaka pridrževanja na celotno območje platine. To se ne zgodi niti pri dvojni (k = 2) optimalni sili (analiza je izvršena, vendar rezultati zaradi pomanjkanja prostora niso prikazani). Iz tega bi lahko sklepali, da je pridrževalo pretanko, ker ne omogoča dovolj širokega raznosa tlačnih napetosti, da bi se sosednja napetostna stožca prekrila in bi bila razporeditev pridrževalnega tlaka enakomernejša. Kot bo razvidno iz nadaljnih rezultatov pa to ne drži povsem, saj povečanje debeline pridrževala zmanjšuje preoblikovalnost in s tem prilagodljivost.

2.3.2 Rezultati stanja 5

Razmere nasproti stanju 0, ko je bila platina še konstantne debeline, so se pri stanju 5 močno spremenile. Iz slik 8 in 9 je razvidno, da se je slika pridrževalnih tlakov močno spremenila. Slika 8 prikazuje razmere pri optimalni sili (k=1). Največji tlaki se ne pojavljajo več pod pestičema hidravličnih valjev, temveč na mestih A in D, kjer je pločevina trenutno najdebelejša (glej tudi sliko 3).

Ker je pridrževalo dovolj tanko in s tem podajno, se toliko upogne, da dobimo dotik med pridrževalom in platino tudi na mestih pod valjema (mesti B in C) in s tem bistveno enakomernejšo porazdelitev pridrževalnih tlakov. Pri analizi enakega modela z debelejšim pridržalom (t=60 mm), tega dotika ni bilo (analiza je izvršena, vendar rezultati zaradi pomanjkanja prostora niso prikazani), zaradi česar sta bili izrazitejši konici na mestih A in D, podobno kot se to dogaja pri neprilagodljivih pridrževalih.

Pri povečani pridrževalni sili (k=1,5) se poveča tudi površina pridrževala, ki se dotika preoblikovanca, kar zmanjšuje intenzivnost konic napetosti v točkah A in D.

2.3.3 Rezultati stanja 8

Iz slik 10 in 11 je razvidno, da kljub povečevanju pridrževalne sile preko njene tehnološke

2.3 Results

The results are shown as pressures on the blank surface on the side that is in contact with the blank holder. The stress in the direction of z-axis is observed, i.e. in the direction of the thickness of the blank.

2.3.1 Results of phase 0

As expected the conditions are very similar to those present in the contact with the rigid and flat support. This resemblance is logical since at the beginning the blank has a constant thickness.

From Fig. 6 and 7 we can see that in spite of an increase in the holding force beyond its optimum value (k = 1.5), the holding pressure is not obtained over the entire area of the blank. This does not happen even when the optimum force is doubled (k =2 – results are available but not shown because of the space limitation). From this it is possible to conclude that the blank holder is too thin, as it does not provide a wide enough distribution of compressive stresses for covering the influence of adjacent cylinders and providing a more uniform distribution of stresses. As will be seen from the results below, this is not true since an increase in the thickness of the blank holder reduces the deformability and consequently the pliability.

2.3.2 Results for Phase 5

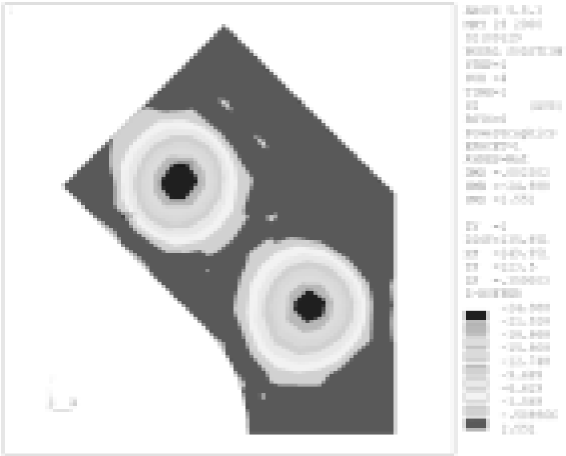
Compared to phase 0, when the blank still had a constant thickness, the conditions in phase 5 are very different. From Fig. 8 and 9 we can see a considerable change in the pressing effect. Fig. 8 denotes the conditions at the optimum force (k = 1). The highest pressing effect no longer occurs under the punches of the hydraulic cylinders but on the points A and D where the sheet metal is momentary the thickest (see also Fig. 3).

Since the blank holder is thin enough, and therefore pliable, it bends sufficiently to also create a contact between the blank holder and the blank on the places under the cylinders (spots B and C), providing a substantially more uniform distribution of pressure. In the analysis of the same model but with a thicker blank holder (t = 60 mm) this contact was not created (results are available but not shown because of the space limitation) and peaks on spots A and D were more explicit, similar to the case of the non-pliable holder.

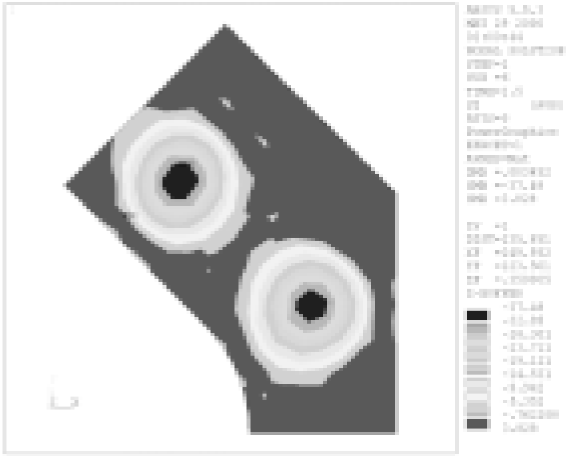
For the increased holding force (k = 1.5) the area on the holder touching the blank increases, too, resulting in a lowering of peak pressures on spots A and D.

2.3.3 Results for Phase 8

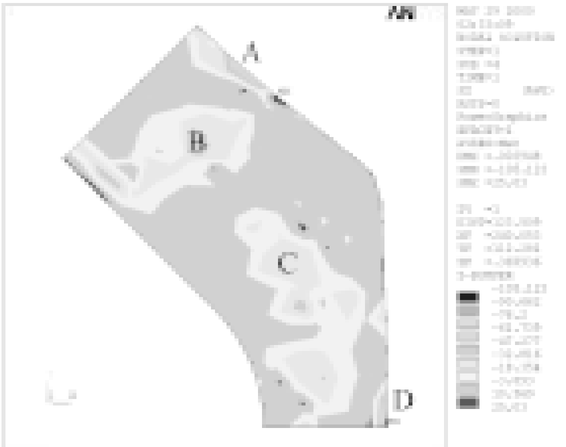
From figs. 10 and 11 we can see that in spite of an increase in the holding force beyond its



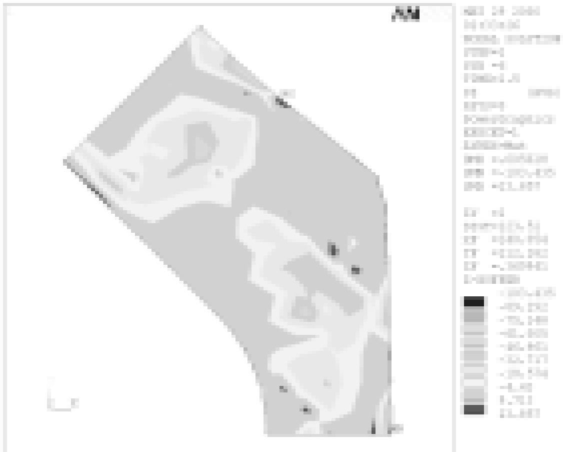
Sl. 6. *Stanje 0: tlak pridrževala v MPa na preoblikovanec pri k= 1*
Fig. 6. *Phase 0: Pressure [MPa] on the blank at k = 1*



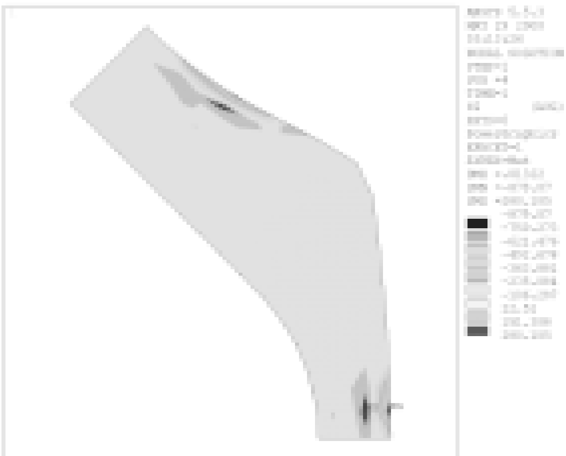
Sl. 7. *Stanje 0: tlak pridrževala v MPa na preoblikovanec pri k= 1,5*
Fig. 7. *Pressure [MPa] on the blank at k = 1.5*



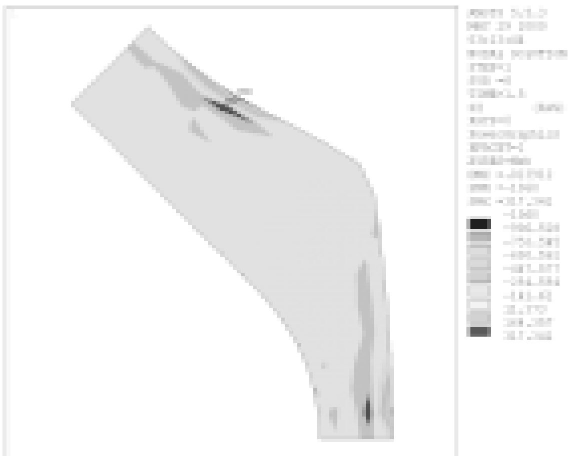
Sl. 8. *Stanje 5: tlak pridrževala v MPa na preoblikovanec pri k= 1*
Fig. 8. *Phase 5: Pressure [MPa] on the blank at k = 1*



Sl. 9. *Stanje 5: tlak pridrževala v MPa na preoblikovanec pri k= 1,5*
Fig. 9: *Phase 5: Pressure [MPa] on the blank at k = 1.5*



Sl. 10. *Stanje 8: tlak pridrževala v MPa na preoblikovanec pri k= 1*
Fig. 10: *Phase 8: Pressure [MPa] on the blank at k = 1*



Sl. 11. *Stanje 8: tlak pridrževala v MPa na preoblikovanec pri k= 1,5*
Fig. 11: *Pressure [MPa] on the blank at k = 1.5*

optimalne vrednosti (k = 1,5), neposredno pod valjema ne dobimo več dotika med pridrževalom in preoblikovancem, kar kaže na premajhno prilagodljivost pridrževala glede na velikost neravnin (sl. 3b). Seveda pa je treba opozoriti na dejstvo, da napetosti v pločevini v konicah bistveno presegajo mejo plastičnosti (primerjalna napetost je še večja). Zaradi tega se vrhovi neravnin v naravi plastificirajo in zmanjšajo, s čimer se spremeni porazdelitev tlakov. V sedanjem modelu plastifikacija pločevine še ni upoštevana.

3 ZAKLJUČEK

Analiza prilagodljivega pridrževala in kontaktnih razmer med njim in platino je pokazala, da se da z ustrezno postavitvijo pritisnih hidravličnih valjev, velikostjo pritisne sile v posameznem valju in debelino pridrževala, ustvariti približno željen pritisk pridrževala na platino, vendar le med prvo fazo vleka, ko ima platina še konstantno debelino. Zaradi sprememb debeline preoblikovane pločevine med vlečenjem (deformacija platine), se razmere v dotiku spreminjajo in slika dotika med pridrževalom ter preoblikovancem se spremeni – dotik se ohrani le na območjih, kjer je pločevina preoblikovanca odebeljena. Če želimo dotik in s tem pridrževalni tlak na tem mestu ohranjati, je potrebno uporabiti še tanjše pridrževalo in mesta pritiska hidravličnih valjev izbrati ustrezno, glede na pričakovano deformacijo preoblikovane pločevine. Zaradi pojava deformacije pločevine, se ne da ustvariti povsem poljubnega stanja pritiskanja pridrževala, mogoč pa je vpliv v tolikšni meri, da se na določenem področju zagotovi v povprečju potreben pridrževalni učinek.

Navedene ugotovitve kažejo na naslednje potrebne korake ob nadaljevanju raziskav: analiza ter proučitev možnosti uporabe prilagodljivega pridrževala posebne oblike (izvedba z ustreznimi zarezami za dosego neenakih togosti vzdolž površine pridrževala in s tem povečanja njegove deformljivosti ob možnosti hkratnega povečevanja njegove imenske debeline) ter proučitev možnosti uporabe segmentnega pridrževala (sestavljeno pridrževalo).

Poleg tega bi bilo potrebno uvesti tudi nekaj izboljšav modela. Ker se lokalno pojavljajo napetosti preko meje plastičnosti, bi bilo treba upoštevati plastičnost platine (izvedba nelinearne, elasto-plastične analize). Upoštevati bi bilo treba tudi vpliv dodatnih normalnih napetosti (ki nastajajo zaradi postopka globokega vleka) na postopek plastifikacije. Izboljšanje modela bi dosegli tudi z upoštevanjem elastičnosti (podajnosti) matrice.

technologically optimum value (k = 1.5) directly under the cylinders no greater contact is obtained between the holder and the blank. This points to a lack of pliability of the blank holder with respect to the size of the uneven planes (fig. 3b). Here it should be mentioned that the stresses in the sheet metal in the peaks significantly exceed the yield point (the equivalent stress being even higher). Therefore the peaks of the uneven planes undergo plastification and are flattened out and this changes the pressure distribution. In the existing model the plastification of the sheet metal was not considered.

3 CONCLUSION

The analysis of a pliable blank holder and the contact conditions between the holder and the blank has shown that through a suitable arrangement of the hydraulic cylinders, magnitude of the pressing force and thickness of the blank holder it is possible to achieve a more-or-less desirable pressing effect of the holder on the blank, but only during the first phase of deep drawing when the blank still maintains a constant thickness. Due to the changes in the thickness of the formed sheet metal during the drawing process (deformation of the blank) the conditions in the contact change and the contact intensity between the holder and the blank changes, too. The contact remains only on the points where the sheet metal is thickened. If we want to maintain the contact and the pressing effect on this point it is necessary to use an even thinner blank holder, and select the locations of the contact pressure of the hydraulic cylinders considering the expected deformation of the formed sheet metal. Because of the deformation of the sheet metal it is impossible to achieve the exact pressing effect required, however, it is possible to influence the conditions to such an extent to obtain the pressing effect that is usually required.

These findings point to the following necessary steps in future research: analysis and study of the possibility of using a pliable blank holder with a special shape (a design with cut outs to achieve non-uniform rigidity along the surface of the blank holder which would increase its deformability while at the same time providing the possibility of increasing its nominal thickness), and the study of the possibility of using a segmented holder (segment-built holder).

In addition, it would be necessary to introduce a few improvements to the model. Since locally stresses exceed the yield point, it would be necessary to consider the plasticity of the blank (a non-linear, elasto-plastic analysis). It would also be necessary to consider the effects of additional normal stresses (occurring due to the deep-drawing process) affecting the plastification process. The model could also be improved by considering the elasticity (pliability) of the die.

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4 LITERATURA
4 REFERENCES

[1] Kampuš, Z., K. Kuzman, D. Noe, J. Kramar, T. Perme, A. Bergant, T. Pepelnjak, B. Jerman, P. Vogrič (2000) Globoki vlek pločevine z logistično usklajeno avtomatizacijo: letno in zaključno poročilo aplikativnega raziskovalnega projekta v letu 1999. *Fakulteta za strojništvo Ljubljana*.

[2] Pepelnjak, T., Z. Kampuš (2001) Analize kakovosti pridrževanja pločevine pri globokem vleku, *Strojniški vestnik*, Vol. 47, 2, str. 94-105.

[3] Doege, E., L.E. Elend (2001) Design and application of pliable blank holder systems for the optimization of the process conditions in sheet metal forming, *J. of Materials Processing Technology*, Vol. 111, str. 182-187.

[4] Doege, E., L.E. Elend, C. Ropers (1999) Pliable blank holder systems for the optimisation of process conditions in deep drawing, *Advanced Technology of Plasticity*, Vol. I, Proceedings of the 6th ICTP, 19-24.

[5] Hills, D.A., D. Nowell, A. Sackfield, (1993) Mechanics of elastic contacts, *Butterworth-Heinemann Ltd*, Oxford.

[6] Siegert, K., E. Doege (1993) CNC Hydraulic multipoint blankholder system for sheet metal forming presses, *Annals of the CIRP*, Vol. 42/1, str. 319-322.

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