ARCHIVES OF METALLURGY AND MATERIALS
Volume 56 2011 Issue 2
DOI: 10.2478/v10172-011-0046-4

J. ADAMUS*, P. LACKI*, W. WIĘCKOWSKI**

NUMERICAL SIMULATION OF THE FINE BLANKING PROCESS OF SHEET TITANIUM

SYMULACJA NUMERYCZNA PROCESU WYKRAWANIA DOKŁADNEGO BLACH TYTANOWYCH

The present study has been undertaken in order to investigate the new possibilities of improvement in quality of the cut-surface of titanium blanks. For the intended purpose, a number of numerical simulations of the blanking process were carried out.

Fine blanking is one of the most often used methods of finished product manufacturing. Application of blanking with reduced clearance or blanking with material upsetting by V-ring indenter allows for obtaining the high quality cut-surface which does not need further machining. Application of the finite element method (FEM) for numerical simulations allows for effective analysis of the fine blanking processes.

In the paper the results of numerical simulation of fine blanking for a disk made of Grade 2 sheet titanium have been presented. The calculations were carried out using ADINA System v. 8.6 based on FEM. Determination of the effect of clearance between cutting edges, and presence and location of V-ring indenter on the stress and strain distribution in shearing zone was the main goal of the work. The numerical simulations showed the effect of tool geometry on a course of blanking process and consequently on the quality and shape of the cut-surface. Based on the numerical simulation it is only possible to deduce the cut-surface appearance, thus the numerical simulations should be completed with experimental tests.

Keywords: fine blanking, sheet titanium, numerical modelling

Niniejsza praca została wykonana w celu zbadania nowych możliwości poprawy jakości powierzchni przecięcia wykrojek tytanowych. W tym celu wykonano szereg symulacji numerycznych procesu wykrawania.

Wykrawanie dokładne jest najczęściej stosowaną metodą otrzymywania wyrobów gotowych. Zastosowanie wykrawania ze zmniejszonym luzem lub wykrawania ze spęczaniem za pomocą klinowej grani pozwala na otrzymanie wysokiej jakości powierzchni przecięcia, która nie wymaga dalszej obróbki mechanicznej. Wykorzystanie w symulacjach numerycznych metody elementów skończonych (MES) pozwala na efektywną analizę procesów wykrawania dokładnego.

W artykule zaprezentowano wyniki symulacji numerycznej wykrawania dokładnego krążka z blachy tytanowej Grade 2. Obliczenia wykonano przy użyciu programu ADINA System v. 8.6 opartego na MES. Głównym celem pracy było określenie wpływu luzu pomiędzy krawędziami tnącymi oraz obecności klinowej grani na dociskaczu na rozkład naprężeń i odkształceń w obszarze cięcia. Obliczenia numeryczne wykazały wpływ geometrii narzędzi na przebieg procesu wykrawania, a tym samym na jakość i kształt powierzchni przecięcia. Opierając się na symulacjach numerycznych można jedynie wnioskować o wyglądzie powierzchni przecięcia, dlatego symulacje numeryczne powinny być uzupełnione badaniami doświadczalnymi.

1. Introduction

The paper results from explore the new possibilities of increase in quality of the cut-surface of titanium elements, which are generally cut by conventional methods i.e. by two rigid cutting edges (a guillotine or a blanking die). Blanking is not only used as a first step in preparing blanks for further forming but also in manufacturing finished products, which are then ready for assembly without the need for additional machining. Fast production development has lead to an increase in demand for high-quality products. This also concerns shared blanks for which cleanly cut-surface, precise geometry and high dimensional accuracy are very essential. In the case of some elements it is important to keep: surface flatness, identical dimensions through the full thickness of the part and the perpendicularity of the sidewall. In these cases fine blanking can be applied [1-3]. Burrs arising in conventional blanking can cause some surface defects such as scratches and dents on the drawn-parts, which are difficult to eliminate. Moreover, burrs initiate cracks

---

* CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY FACULTY OF CIVIL ENGINEERING, 42-218 CZĘSTOCHOWA, 3 AKADEMICKA STR., POLAND

** CZĘSTOCHOWA UNIVERSITY OF TECHNOLOGY INSTITUTE OF METAL FORMING, QUALITY ENGINEERING AND BIOENGINEERING, 42-200 CZĘSTOCHOWA, 21 ARMII KRAJOWEJ AV., POLAND

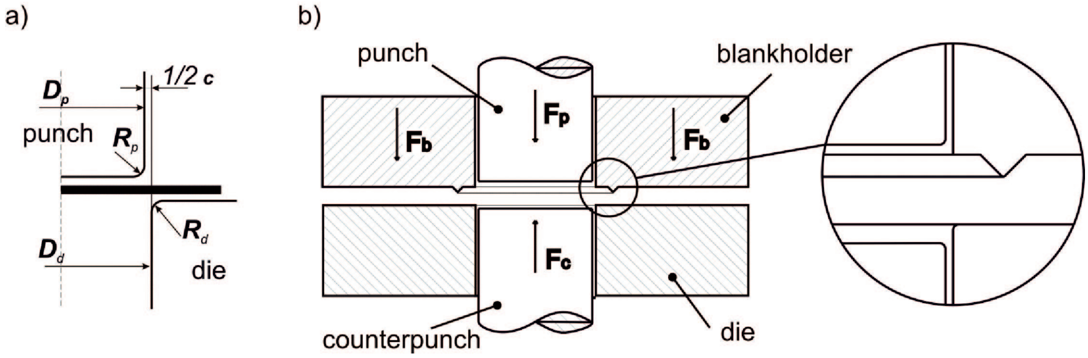

Fig. 1. Conventional (a) and fine blanking with material upsetting (b)

during some stamping operation like flanging. So as to improve the cut-surface quality much experimental research and many numerical simulations have been carried out [4-14]. They have been aimed at determining such parameters as: cutting speed, clearance, tool geometry etc. Unfortunately, the current knowledge of sheet-titanium forming and also shearing of titanium sheets is rather poor. It results from the fact that titanium and its alloys are used in commercial scale of production for a short time. In literature, there are very few works in the range of subject matter [15,16] so the authors decided to carry out numerical simulation of fine blanking process of sheet titanium.

Fine blanking is an industrial manufacturing technique used for achieving near net shape elements. The main characteristic of the process is high quality cut-surface, which does not need further machining. Blanking with reduced clearance or blanking with material upsetting by V-ring indenter (Fig. 1) are the most frequent methods applied for blanking non-ferrous materials. The fundamental nature of these methods is an assurance of a favourable stress and strain state before and during the shearing process, what guarantees the required quality of cut-surface. Tool geometry, which strongly depends on the blanking die construction, and properties of the blanked material are the main factors affecting stress state in shearing zone and consequently the course of fine blanking [1,3,16-20].

Proper choice of the blanking parameters allowing for obtaining high quality elements requires labour-consuming experiments or they can be specified basing on the numerical analysis of blanking process. Application of FEM in simulation of metal forming processes, also blanking, enables analysis of subsequent stages of the process and prediction of the results of the assumed process parameters, and limitation of costly experiments [10,16,20,21].

2. Goal and scope of the numerical analyses

Determination of the influence of:

– clearance between cutting edges of the die and punch,
– application of flat blank-holder or blank-holder with V-ring indenter

on the stress and strain state in cutting zone was the main goal of the numerical simulations of blanking.

In the paper some numerical calculation results of fine blanking for a disk made of 1-milimetre sheet titanium Grade 2 are presented. Fracture initiation and its propagation have been determined. The selection of optimal parameters affecting stress state assures the required cut-surface quality. On the basis of cutting zone shape and material fracture it is possible to deduce the probable appearance of the cut-surface. However, the numerical simulations of fine blanking, which are continuation of research on blanking [15,16] do not allow for full description of cut-surface. Therefore, the experimental investigations should be a complement to numerical modelling [1,6,13,15].

3. Numerical simulation of fine blanking

Geometry of FEM model is presented in Figure 2. A two-dimensional axial-symmetrical model of fine blanking was assumed due to axial symmetry of the problem. The numerical model composed of 5074 4-node square elements and 16015 nodes. Very fine finite element mesh was used in the shearing zone with the aim of getting better calculation precision. The numerical calculations were carried out using the ADINA System v. 8.6 based on finite element mesh (FEM) and allowing for assuming a non-linear description of material hardening and the contact between the tool and sheet metal [22].

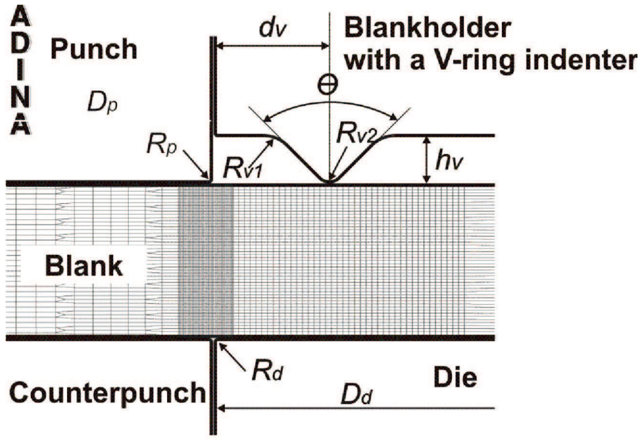

Fig. 2. Discrete model of the fine blanking process

Perfectly rigid material model for blanking tools and isotropic, elastoplastic material model for the blanked sheet-metal (model based on the von Mises criterion associated with the law of plastic flow, using von Mises plasticity function and a principle of isotropic hardening) were assumed in the calculations. Experimentally determined material parameters adopted for the calculations are presented in Table 1.

TABLE 1

Material properties of the sheet EN AW-1070A

Tensile strength R_m [MPa]	Yield strength $R_{0.2}$ [MPa]	Young's modulus E [GPa]	Poisson's ratio ν	σ_p=Kφ^n K[MPa]	n
522	368	110	0.37	822	0.18

A constant die diameter D_d was assumed for the calculation, whereas clearance value c was determined through changing the punch diameter D_P. Simulation of fine blanking with material upsetting was carried out for different locations of V-ring indenter d_V with the same clearance of 1% of the sheet metal thickness. Additionally the simulation of fine blanking without indenter and counter-punch was carried out for variable clearance values. The parameters, which were assumed in the calculations, were presented in Table 2.

Contact phenomenon between mating surfaces of the tool and sheet metal was described using a model of Coulomb friction:

$\tau_f = \mu\sigma_n(1)$

where: τ_f *and* σ_n–shear and normal stress in relation to friction surface, respectively
and μg friction coefficient.

Modelling of blanking process requires employing a fracture criterion for numerical model which allows for analysis of the process due to the course of material separation [1,7,23]. In the numerical simulation of fine blanking process material separation was modelled based on the criterion proposed in [5,18]. It considers appearance of initial cracking at the location where the following formula holds true:

$$\int_0^{\bar{\varepsilon}^f}\left(\frac{\sigma^*}{\bar{\sigma}}\right)d\bar{\varepsilon} = C \qquad (1)$$

where: σ^* – maximum tensile stress, $\bar{\varepsilon}^f$ – ductile-fracture strain, $\bar{\varepsilon}$ – effective strain, $\bar{\sigma}$ – effective stress, C – constant, depending on the material kind.

TABLE 2

Parameters assumed in FEM model for the fine blanking process

Parametr	value
D_d[mm]	31.7
D_p[mm]	31.69; 31.60
$c = D_d - D_p$[mm]	0.01; 0.1
R_p[mm]	0.025
R_d [mm]	0.025
R_{v1}[mm]	0.3
R_{v2}[mm]	0.1
θg°]	90
V-ring indenter position d_v*[mm]*	0.4; 0.7; 1.0
holding down force F_b[N]	64 000
counter-punch force F_c[N]	16 000
V-ring indenter height h_v*[mm]*	0.3
friction coefficient μ	0.15

Assuming that the highest strains occur along the cutting line and the value of stress is constant in blanking operations, the above mentioned criterion can be reduced to the following formula:

$$\int_0^{\bar{\varepsilon}^f} d\bar{\varepsilon} \approx C_1 \qquad (2)$$

finally, it can be assumed that material separation occurs in the location with the given value of the effective strain C_1' :

$$\sum_0^n(\Delta\overline{\varepsilon_e}) \approx C'_1 \qquad (3)$$

where: n – calculation step number, $\Delta\overline{\varepsilon_e}$ – increment of strain in the element.

According to the assumed simplification, a fracture criterion was modelled by determination of a maximal permissible effective plastic strain $\varepsilon_e^p = 0.82$. Value of the effective plastic strain was determined experimentally in tensile test according to the method described in [1]. At the moment when fracture criterion is satisfied at the point of integration of the given element, the element is removed from the numerical model.

4. Numerical simulation results

Blanking with the reduced clearance between cutting edges of the die and punch is the simplest fine blanking method. Calculation results showed the essential influence of clearance on strain and stress values in the shearing zone and consequently on the blanking course and cut-surface shape. The decrease in clearance limits bending moment acting on the blank due to the lateral displacement between cutting edges. Bending moment is responsible for the tensile stresses in shearing zone. A comparison of plastic strain distribution between conventional blanking (*c*=0.10 mm) and blanking with reduced clearance of *c*=0.01 mm for the punch displacement of 0.14 mm is shown in Figure 3. Plastic strains are less intensive for the conventional blanking (Fig.3a) in comparison to the fine blanking (Fig.3b). During fine blanking plasticised zones spreading from the cutting edges of the die and punch, where the plastic deformations initiate, join earlier. Clearance reduction leads to the delay of fracture initiation. All these give smoother cut-surface.

Blanking with reduced clearance and extra upsetting of the blanked material is another very effective fine blanking method. To that end a special construction of the blanking dies, which assures reduction of tensile stresses in shearing zone, are used. Application of flat blank-holder and counter-punch is the simplest method of fine blanking with material compression. In practice neither properly selected clearance nor application of the flat blank-holder are enough effective in elimination of tensile stresses. As it turned out, an important technological breakthrough in the field of tooling for fine blanking was the application of blank-holder with V-ring indenter, which generates favourable changes in strain and stress state in shearing zone. As a consequence high quality cut-surface is produced. The main disadvantage of this method is the necessity for application of the special tools and presses, and therefore higher cost when compared to traditional blanking operations.

Strain distribution in shearing zone during fine blanking with material compression is presented in Figures 4, while stress distribution is presented in Figures 5.

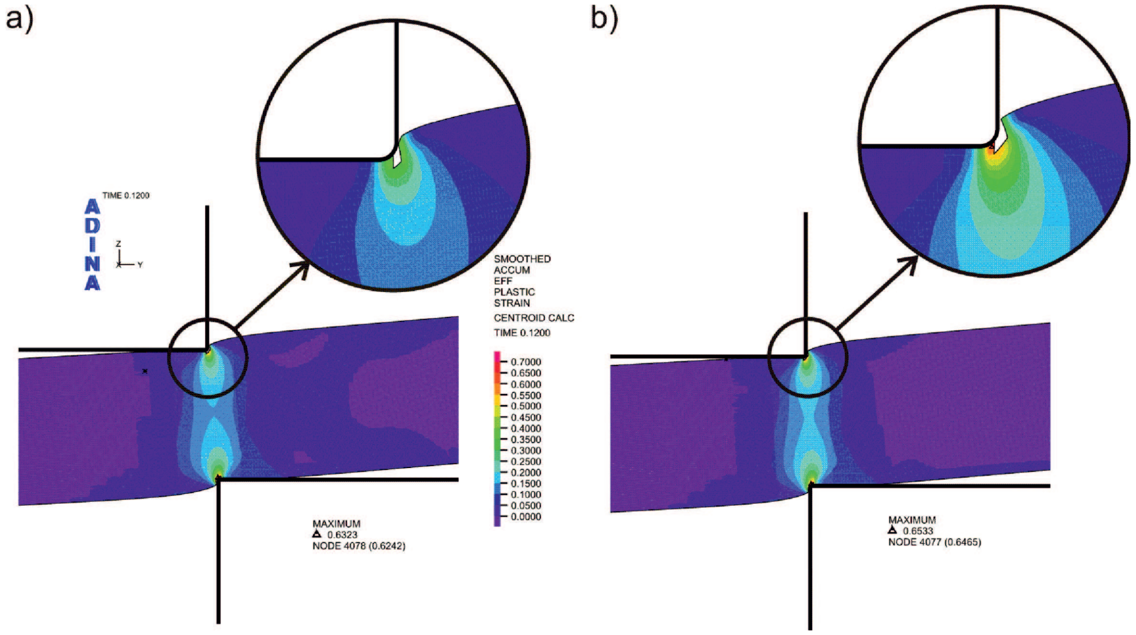

Fig. 3. Plastic strain distribution in shearing zone: a) conventional blanking with clearance of 0.1 mm, b) blanking with decreased clearance of 0.01 mm. Punch displacement: 0.14 mm

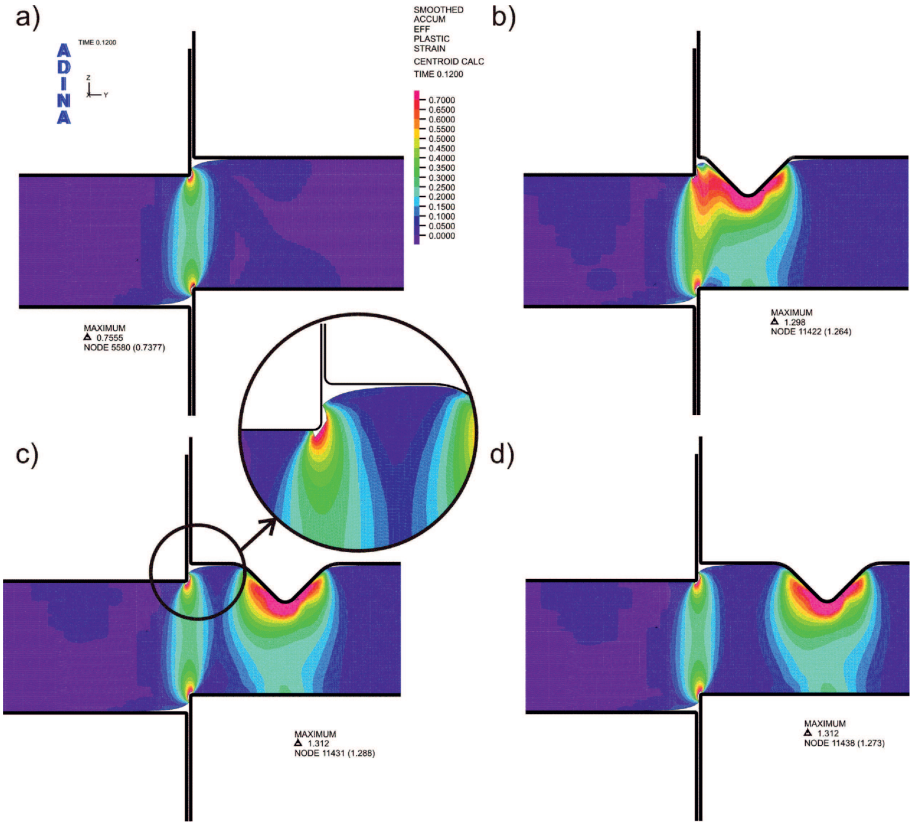

Fig. 4. Distribution of plastic strains in cutting zone for punch displacement of 0.14 mm: a) without indenter, b) d_v=0.4 mm, c) d_v=0.7 mm, d) d_v=1.0 mm

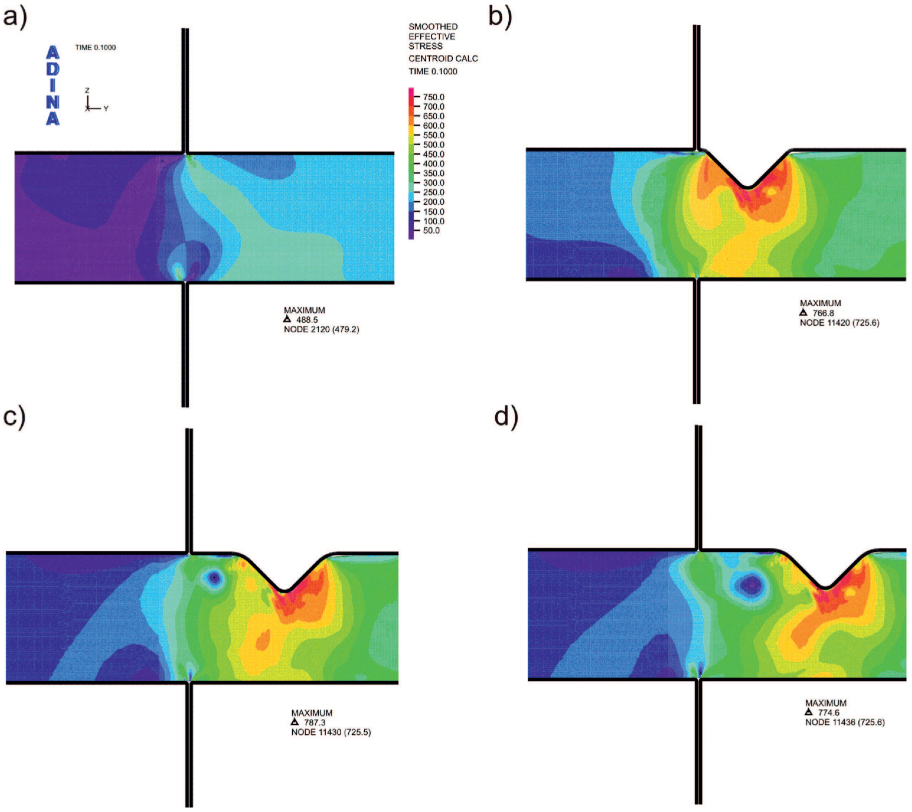

Fig. 5. Effective stress distribution in shearing zone at the moment of blank-holder squeezing into material for different position of V-ring indenter: a) without indenter, b) d_v=0.4 mm, c) d_v=0.7 mm, d) d_v=1.0 mm

Presence of V-ring indenter affects strain state. Additional plastic strains occur in the vicinity of V-ring indenter. As a result material undergoes hardening. Consequently, material being in the direct shearing zone flows rather in cutting direction than away from the punch. The plasticised material affects the material being in the direct zone of cutting line by producing compressive stresses, so the tensile stresses which are conducive to fracture, are reduced. However excessive distance of the indenter limits the effect of material strengthening on plastic strains in direct cutting zone, thereby limits the effect of compensation of tensile stresses, what prevents from achieving the expected effects of fine blanking with upsetting. Value and especially range of plastic strains strongly depends on geometry and location of V-ring indenter. Too low distance of V-ring from rim of blank-holder causes the stresses increase in material along the line between cutting edge of the punch and tip of the indenter, what may contributes to unforeseen loss in material cohesion.

5. Conclusions

The authors collaborate with the firm producing titanium elements. Many of them are made by blanking. Insufficient quality of the cut-surface requires additional machining – grinding, which is very troublesome. Therefore the authors made an attempt at elimination of this operation by using the fine-blanking instead of the conventional one.

Application of FEM in numerical simulation enables analysis of different blanking methods using different initial process parameters (clearance, location of V-ring indenter etc.). Calculation results show the essential influence of the considered geometrical parameters on the blanking course and in consequence on shape of the cut-surface:

- V-ring indenter generates additional plastic strains in its vicinity, which affects material hardening. As a consequence, material being in the direct shearing zone flows rather in cutting direction than away from the punch so a concentration of plastic strains in direct shearing zone and therefore early material separation compared to the process of blanking with flat blank-holder. Value and especially range of plastic strains strongly depends on geometry and location of V-ring indenter,
- excessive distance of the indenter limits the effect of material hardening and the effect of compensation of tensile stresses, what prevents from achieving the expected effects of fine blanking with upsetting,
- too low distance of V-ring from rim of blank-holder causes the stresses increase in material along the line between cutting edge of the punch and tip of the indenter, what may contributes to unforeseen loss in material cohesion,
- the calculation results allow for prediction of material fracture and deduction about the probably shape of blank cut-surface,
- the simulations of the fine blanking process require further experimental verification in order to confirm the legitimacy of the adopted assumptions for the developed numerical model and usefulness of the employed material cracking criterion.
- the carried out numerical simulations allowed the authors for selection the proper geometry of the blanking tools, especially geometry and position of V-ring indenter. The real blanking tool will be made in the nearest future, so the calculation results will be verified experimentally and the results will be presented in further publications.

Acknowledgements

Financial support of Structural Funds in the Operational Programme – Innovative Economy (IE OP) financed from the European Regional Development Fund – Project ”Modern material technologies in aerospace industry”, Nr POIG.01.01.02-00-015/08-00 is gratefully acknowledged.

REFERENCES

[1] S. Kut, An influence of some parameters on quality of fine-blanked products, in Polish: Wpływ wybranych parametrów na jakość wyrobów w procesie wykrawania dokładnego, Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów (2006).

[2] T.C. Lee, L.C. Chan, B.J. Wu, Straining behaviour in blanking process – fine blanking vs. conventional blanking, J. Mater. Process. Technol. **48**, 105-111 (1995).

[3] Z. Polański, Blanking, in Polish: Wykrawanie, WNT, Warszawa (1978).

[4] D. Brokken, W.A.M. Brekelmans, F.P.T. Baaijens, Predicting the shape of blanked products: a finite element approach, J. Mater. Process. Technol. **103**, 51-56 (2000).

[5] F. Faura, A. Gracia, M. Estrem, Finite element analysis of optimum clearance in the blanking process, J. Mater. Process. Technol. **80-81**, 121-125 (1998).

[6] A.M. Goijaerts, Y.W. Stegeman, L.E. Govaert, D. Brokken, W.A.M. Brekelmans, F.P.T. Baaijens, Can a new experimental and numerical study improve metal blanking? J. Mater. Process. Technol. **103**, 44-50 (2000).

[7] R. Hambli, M. Reszka, Fracture criteria identification using an inverse technique method and blank-

ing experiment, Int. J. of Mechanical Sciences **44**, 1349-1361 (2002).

[8] N. Hatanaka, K. Yamaguchi, N. Takakura, Finite element simulation of the shearing mechanism in the blanking of sheet metal, J. Mater. Process. Technol. **139**, 64-70 (2003).

[9] N. Hatanaka, K. Yamaguchi, N. Takakura, T. Iizuka, Simulation of sheared edge formation process in blanking of sheet metals, J. Mater. Process. Technol. **140**, 628-634 (2003).

[10] S.K. Maiti, A.A. Ambekar, U.P. Singh, P.P. Date, K. Narasimhan, Assessment of influence of some process parameters on sheet metal blanking. J. Mater. Process. Technol. **102**, 249-256 (2000).

[11] H. Marouani, A. Ben Ismail, E. Hug, M. Rachik, Numerical investigations on sheet metal blanking with high speed deformation, Materials and Design **30**, 3566-3571 (2009).

[12] H. Marouani, A. Ben Ismail, E. Hug, M. Rachik, Rate-dependent constitutive model for sheet metal blanking investigation, Materials Science and Engineering **A 487**, 162-170 (2008).

[13] Z. Tekiner, M. Nalbant, H. Gürün, An experimental study for the effect of different clearances on burr, smooth-sheared and blanking force on aluminium sheet metal. Materials and Design **27**, 1134-1138 (2006).

[14] M. Jr. Vaz, J. D. Bressan, A computational approach to blanking processes, J. Mater. Process. Technol. **125-126**, 206-212 (2002).

[15] J. Adamus, The Influence of Cutting Methods on the Cut-Surface Quality of Titanium Sheets, Key Engineering Materials **344**, 185-192 (2007).

[16] J. Adamus, P. Lacki, Modelling of blanking process of sheet titanium, in Polish, Hutnik – Wiadomości Hutnicze **76** **(8)**, 552-554 (2009).

[17] T.S. Kwak, Y.J. Kim, W.E. Bae, Finite element analysis on the effect of die clearance on shear planes in fine blanking, J. Mater. Process. Technol. **130-131**, 462-468 (2002).

[18] T.S. Kwak, Y.J. Kim, M.K. Seo, W.B. Bae, The effect of V-ring indenter on the sheared surface in the fine-blanking process of pawl, J. Mater. Process. Technol. **143-144**, 656-661 (2003).

[19] H. Samuel, FEM simulation and experimental analysis of parameters of influence in blanking process, J. Mater. Process. Technol. **84**, 97-106 (1998).

[20] T. Sutasn, J. Masahiko, Investigation mechanism of V-ring indenter geometry in fine-blanking process, Key Engineering Materials **410-411**, 305-312 (2009).

[21] N. Mole, B. Štok, Finite element simulation of sheet fine blanking process, Int. J. Mater. Form., 2 Suppl 1, 551-554 (2009).

[22] ADINA System v. 8.3. Theory and Modelling Guide, vol. I. ADINA R&D, Inc., (2005).

[23] M. Farzin, H.R. Javani, M. Mashayekhi, R. Hambli, Analysis of blanking process using various damage criteria, J. Mater. Process. Technol. **177**, 287-290 (2006).

Received: 10 January 2005.