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ELIMINATION OF FLOW DEFECTS IN THE FORWARD EXTRUSION PROCESS BY CHANGING FRICTION CONDITIONS

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Abstract

The paper points out possibilities and methods for detection and elimination of material flow defects in forward extrusion process by the application of physical modelling and numerical FEM simulation techniques. Fishskin defects and central burst defects has been analysed in various friction conditions. In physical modelling experiments, plasticine and its mixture were used as model materials. FEM simulations of same process were performed by application of FORGE2 software. Obtained results of physical modelling and numerical simulation are comparable with satisfactory accuracy. It is shown that contact friction conditions have a considerable influence on emergence of defects in forward extrusion process.

Key words: *Contact friction, forward extrusion, physical modelling, FEM simulation*

1. INTRODUCTION

Foreknowledge of material flow in bulk forming processes by application of physical-numerical modelling enables detection of surface defects and especially of internal defects in formed parts that occur due to irregular flow material during its plastic deformation.

Since soft model materials very well illustrate behaviour of real metal material during deformation, contact friction influence on emergence and prevention of defects can be highly successfully monitored by application of physical modelling technique [1]. Beside this, process optimisation with target function for defects elimination can be performed by using the simultaneous numerical simulation, through several numerical experiments by varying contact friction conditions [2,3]. Both modelling techniques are complementary and they give the best results by joint application [4-7].

The possible defects are numerous, as well reasons that lead to their emergence. Arentoft and Wanheim classified defects in bulk forming processes and they determined following influential factors leading to their appearance [8]: tribological conditions, billet shape, tool, machine, workpiece material and process conditions. Due to the base experience and numerous examples of application of physical-numerical modelling of forming processes, they recommended defect matrix for easy detection of eventual reasons of defect emergence.

In this paper, physical modelling of forward extrusion process, using plasticine as model material, has been performed in order to eliminate demonstrated defects by changing of contact friction conditions. Obtained results were quite confirmed via numerical FEM

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simulation, applying the software FORGE2. In this way defects in extrusion process can be eliminated in laboratory conditions and through analysis of virtual models.

2. PHYSICAL MODELLING

Physical modelling of axisymmetrical hot forward extrusion process was performed in laboratory conditions on device with transparent tool surface front that is shown on Figure 1. The device contains easily variable central tool elements, which are used in the modelling of the forward extrusion with different die angle. Figure 2 shows the central parts of tools for forward extrusion.

Figure 1- *Device for physical modelling*

Figure 2 - *Die and inserts for axisyimmetrical modelling of forward extrusion process*

For used model materials (base plasticine and its mixture), the flow curves were determined by the compression test, with optimal lubrication of front surfaces of the cylindrical prepared parts with glycerine, which provides the forming conditions at approximately uniaxial compression. Flow stresses of plasticine and its mixture were determined as the function of strain, strain rate and temperature (T=4, 21 and 28°C, and v_p=10, 100 and 1000 mm/min). Figures 3 and 4 show the comparative diagrams of the flow curves for the green plasticine and mixture M10, with 10% of weight marble powder as additive [1]. Plasticine and its mixture can be used only in the physical modelling of the hot bulk forming processes because of the prominent recrystallisation behaviour at plastic forming. Axis-symmetrical cylindrical specimens were made as two-colour multi-layer, with Ø59x59mm as initial dimensions. All models were cut through, on the tool with wire, along the meridian plane, so that the entire forming process would be recorded in that plane, through the glass tool surface, in the modelling device.

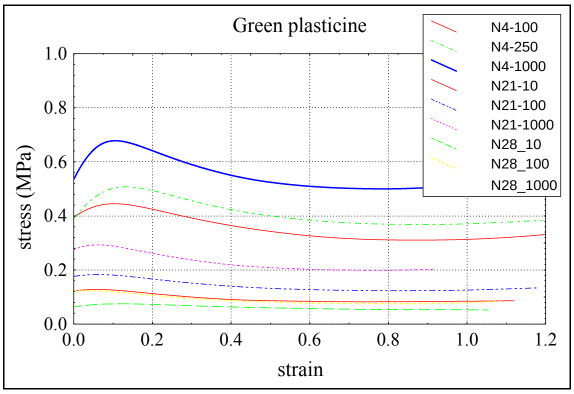

Figure 3 - *Flow curves for green plasticine*

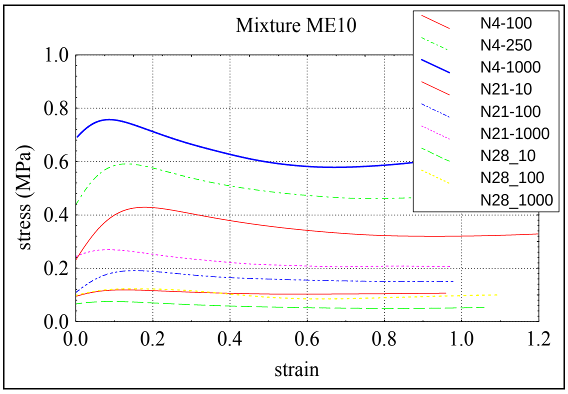

Figure 4 - *Flow curves for ME10 mixture*

By the regression analysis, with use of program package STATISTICA, the high-correlative mathematical models were obtained. For the green plasticine, the mathematical approximate model of flow stress is given with the equation 1, and for the mixture ME10, with the equation 2.

$$\sigma = 0.0228x10^{-10}\varepsilon^{-0.186}\dot{\varepsilon}^{0.184}\exp(\frac{7397.4}{T}) \quad (1)$$

$$\sigma = 0.0164x10^{-10}\,\varepsilon^{-0.160}\,\dot{\varepsilon}^{0.202}\exp(\frac{7538.2}{T}) \quad (2)$$

For the investigation of the contact friction conditions in the modelling experiments, a ring test experiments were done for various tool materials and various lubricants, according to the plan of multi-factor experiment [9,10]. Metal and glass surfaces were selected for the tool material, and talc, vaseline, glycerine and lubricant mixture (50% vaseline and 50% liquid soap) were used as lubricants. In modelling experiments of hot extrusion process, talc was used as a lubricant (*m*=0.8). For contact surfaces of plasticine models and glass front sides of the device, vaseline was used as a lubricant (*m*=0.15), considering that in this way, the influence of friction in contact of meridian plane model and glass tool surface is minimised.

Forward extrusion processes through conical die with output central angle of 60°, 90° and 120° have been modelled, by using cylindrical multicolored models, made from plasticine and mixture ME10. With particular combinations of influential factors, defect in flow material have appeared. For example, when plasticine models were lubricated with ticker layer of talc and contact tool surfaces, as well, central burst defects have been noticed, as shown in figure 5.

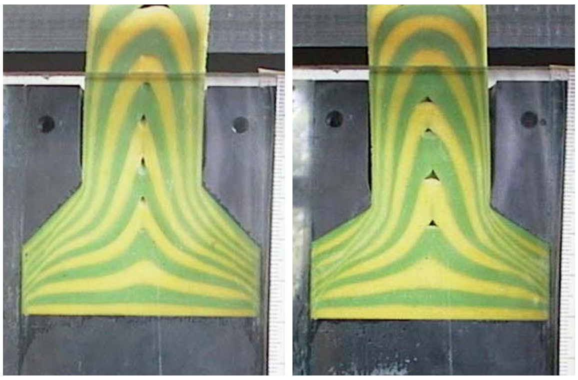

Figure 5 - *Plasticine models with central burst defects, lubrication with ticker layer of talc on the specimen and die*

An emergence of this burst characterizes hydrostatic tensile stress state, i.e. secondary tensile stresses on symmetry axis of extruded specimen. Following factors affect their apperance and size: cone angle of die, reduction and contact friction. Figure 6 illustrates central burst apperance in extrusion, when plastic deformation zones (overshadowed area on figure) do not overlap. Overlapping of these zones and eliminating central burst defects may occur by: increasing of reduction and of influence of contact friction, and decreasing of central cone angle of die. Criterions for eliminating central burst defects, above mentioned, were recommended by Avitzur [11] (see figure 7).

Defects have been eliminated by changing contact friction conditions. Namely, contact friction influence was decreased by lubrication with tinner layer of talc on die surfaces only. Therefore, specimens were unlubricated. In this case, plasticine models without defects were obtained, as shown on Figure 8.

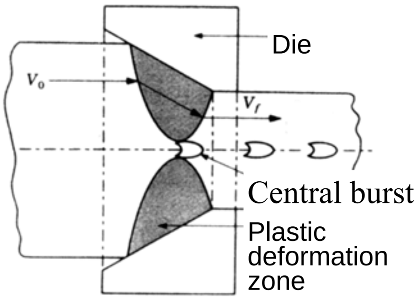

Figure 6 - *Deformation zones in extrusion*

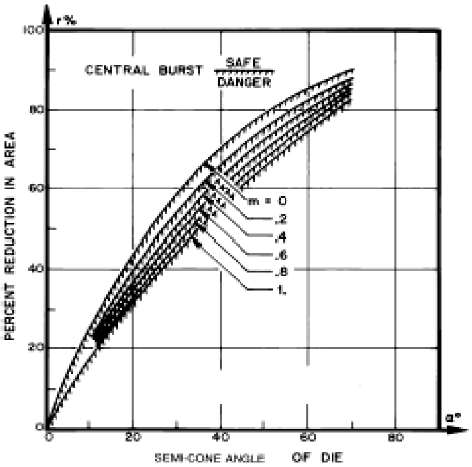

Figure 7 - *Criteria for central burst defects during extrusion [7]*

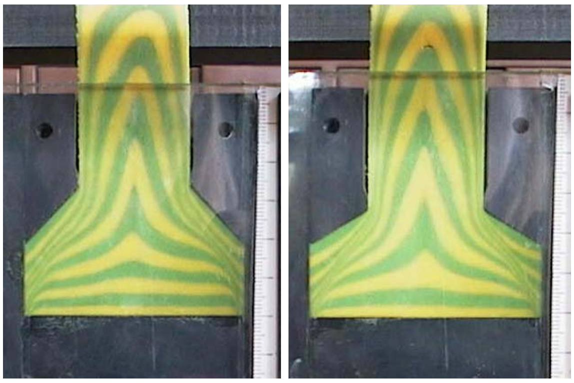

Figure 8 - *Plasticine models without central burst defects, lubrication with tinner layer of talc on die surfaces only*

During extrusion of specimens made from plasticine mixture ME10, with application talc as lubricant (m=0.9), radial cracks on external extrudate surface were occured, so-called fishskin defects (see figure 9). Used mixture has a higher value of strain hardening coefficient, n, than base plasticine (see equations (1) and (2)). In cases when specimen core has considerably greater exit velocity from external layers, i.e. specimen skin, whose flow was obstructed by contact friction, then skin starts to crack and first cracks may be noticed.

Fishskin defects were eliminated by using glycerin as lubricant (m=0.25), whereby influence of contact friction on the output radius of die was decreased, as shown on Figure 10.

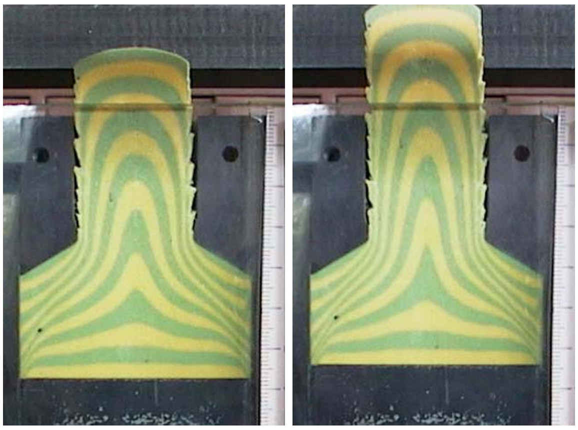

Figure 9 - *Physical models with fishskin defects, ME10 and talc as lubricant*

Figure 9 - *Physical models without fishskin defects, ME10 and glycerine as lubricant*

3. NUMERICAL FEM SIMULATION

Simultaneously with physical modelling of the process, the paper includes the execution of the numerical simulation with same conditions, with application of commercial software package FORGE2 (DIMEG - Italy). The program is intended for the simulation of 2D process by the finite element method, with rigid plastic approach. The objective of this work was to predict the stress and strain distributions in the specimens, and to investigate reasons for defects apperance through Cocroft and Latham ductile fracture criterion distributions.

Six-node triangular mesh elements were used with a coarse mesh and *Fine Print Options* to create a finer mesh on the specimen boundary, as well. In addition, fine mesh has been generated in boxes that were positioned along axis symmetry or external surface of extruded part, because in these zones material fracture was expected. Automatic remeshing occurred when the code was no longer able to perform additional computations due to mesh distortion or mesh penetration into dies [12, 13].

The program enables simulation of rupture in the specimen, with element deletion where the rupture criterion is reached. Latham & Cockroft criterion was computed as follows :

$$\int_0^{\bar{\varepsilon}_f} \sigma_1 d\bar{\varepsilon} = C \tag{3}$$

where C is criterion value. Value of the rupture criterion, which triggers the element deletion, was specified for plasticine as 0.025 and for mixture ME10 as 0.03.

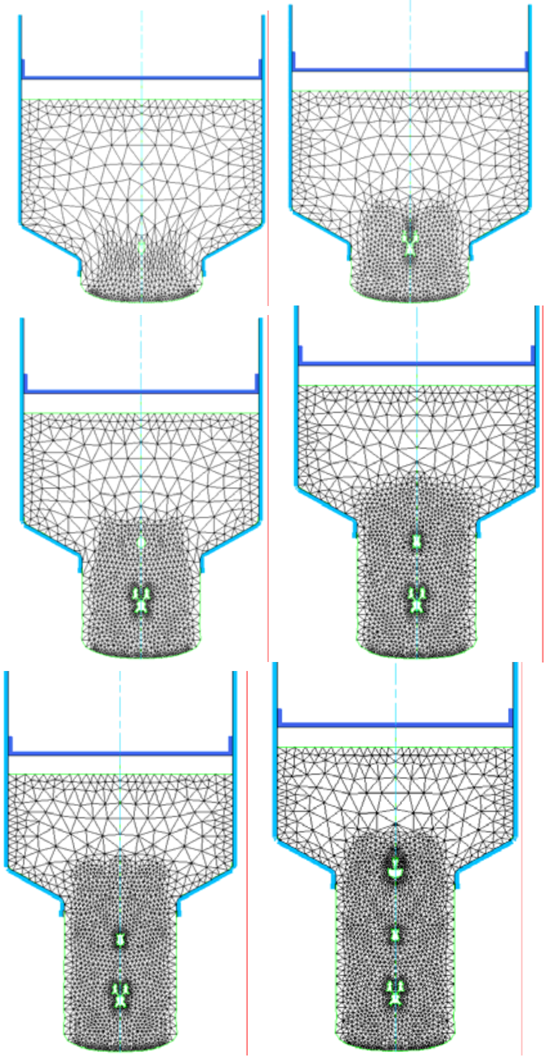

Figure 10 - *FORGE 2 simulation of an emergence and growth of central burst defects*

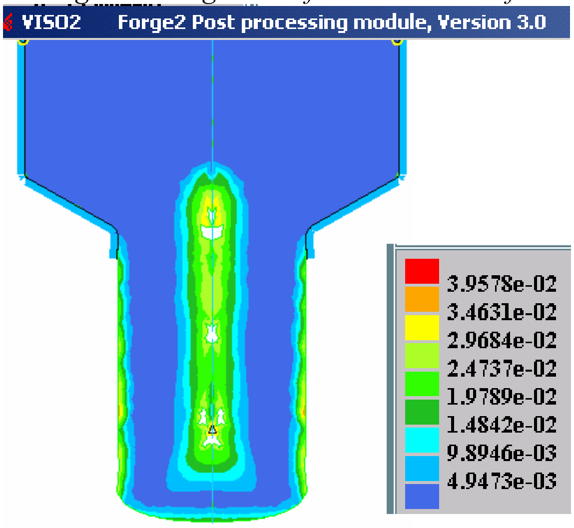

Figure 11 - *Distribution of Cocroft and Latham criterion value for plasticine model with thicker layer of talk*

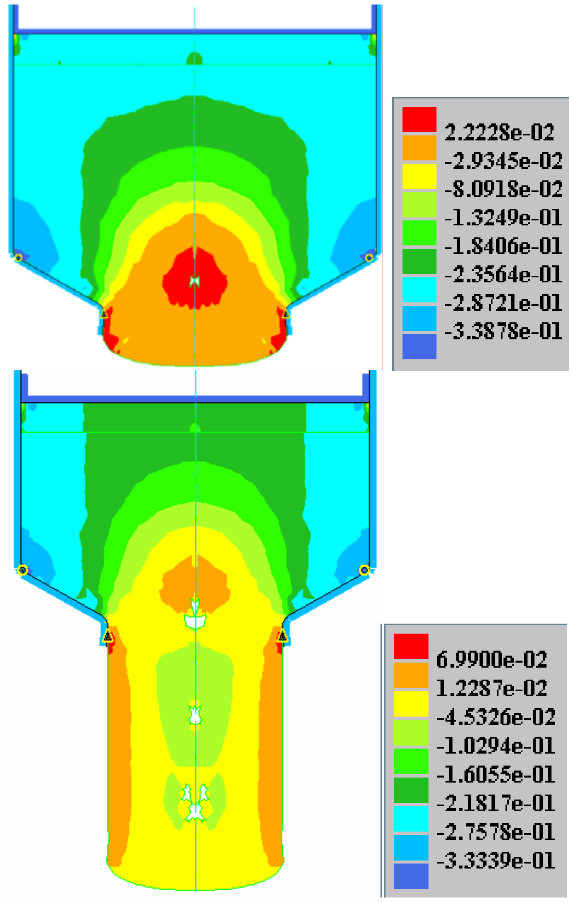

Figure 12- *Axial stress distribution, phase of formation of initial central burst (above) and during process (below)*

Input data for simulations are the same as experimental ones. Young's modulus E is 3 MPa, what is significantly less then for steel.

Figure 10 shows some results of FORGE2 simulation of plasticine extrusion process, and illustrates an emergence and growth of central burst defects. Considering fine accordance of experimental and numerical results, and knowledge of Latham and Cocroft criterion value for certain material, forecast of ductile fracture in advance is possible, at whatsover process.

Distribution of criterion value that is showed on Figure 11 confirms reasons of defects emergence. Namely, C=0.025-0.035 in central zone on the symmetry axis, where central burst defects exist in physical models, as well. In this zone axial stress are tensile and within range of σ_{zz}=0.012-0.06 MPa, as shown on Figure 12. In the moment of formation initial central burst value of this stress is around 0.022 MPa, in the critical zone.

By changing friction conditions, i.e. friction factor value 0.99, at repeated numerical simulation of same process, these defects were eliminated as well as in physical modelling (see figure 13). Herein case criterion values in critical zones are within 0.005-0.01, what is shown on Figure 14. It is evident from physical-numerical results that impairment of friction conditions leads to an enlargement of plastic zones and then to their overlapping and elimination of defects. Distributions of axial stress show less value than the one in the central zone (around 0.0043 MPa), and conditions for formation defects are not accomplished (see Figure 15). In this way, specimen without defects was obtained.

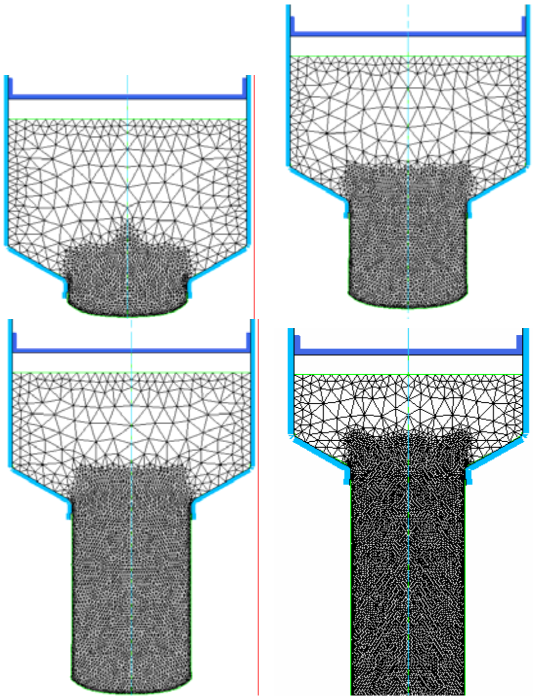

Figure 13 - *FORGE2 simulation of plasticine forward extrusion without defects*

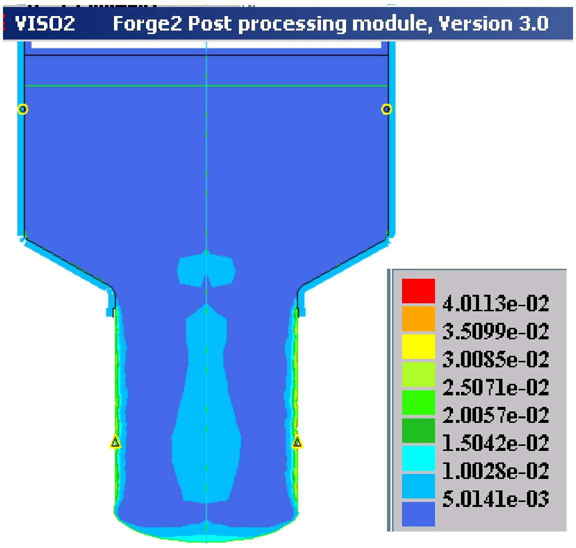

Figure 14 - *Distribution of Cocroft and Latham criterion value for plasticine model with thinner layer of talk on the tool only*

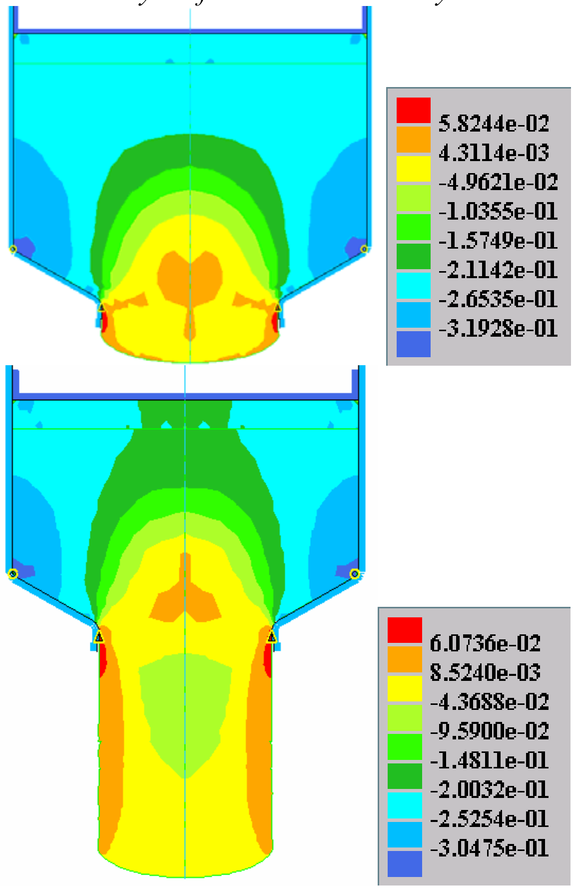

Figure 15 - *Axial stress distribution during plasticine extrusion without defects*

Numerical simulation of extrusion process of specimen made from ME10 plasticine mixture was performed also by using FORGE2 software. At first case, friction factor *m*=0.8, that corresponds to the lubrication with talc, was specified. Radial ruptures on outer surfaces of obtained numerical model occurred, as well as with physical model (see Figure 16). As demonstrated on Figure 17, criterion values on outer surface of specimen are much larger then trigger value (C=0.038-0.067). Stress analysis confirmed appearance of maximal tensile axial stresses in the zone of output radius of die, σ_{zz}= 0.072 MPa, as shown on Figure 18.

Elimination of fishskin defects by changing the lubricant in physical modelling of ME10 extrusion process (glycerine, *m*=0.25) was confirmed by numerical simulation, as shown on Figure 19. Distribution of Cocroft and Latham criterion value on Figure 20 shows less values of fracture criterion value in critical zone (C=0.015-0.03). Since trigger value for deletion of finite elements was less then these values, numerical model was without fishskin defects. In this case, axial tensile stress on the output radius of die was decreased, σ_{zz}= 0.058 MPa, what is around 20% less then at previous case.

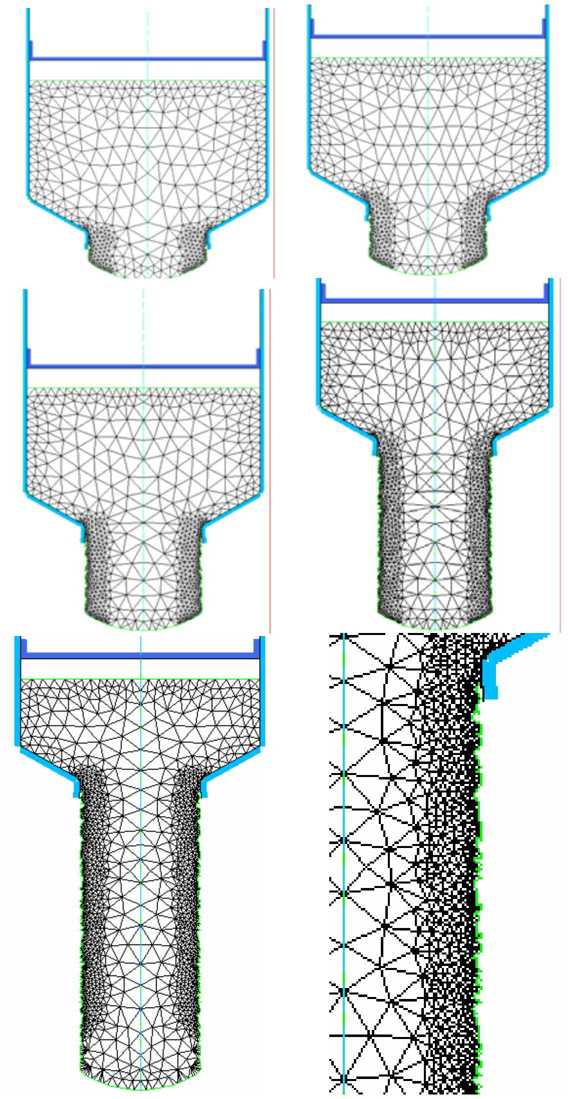

Figure 16 - *FORGE2 simulation of fishskin defects, ME10 mixture with talc*

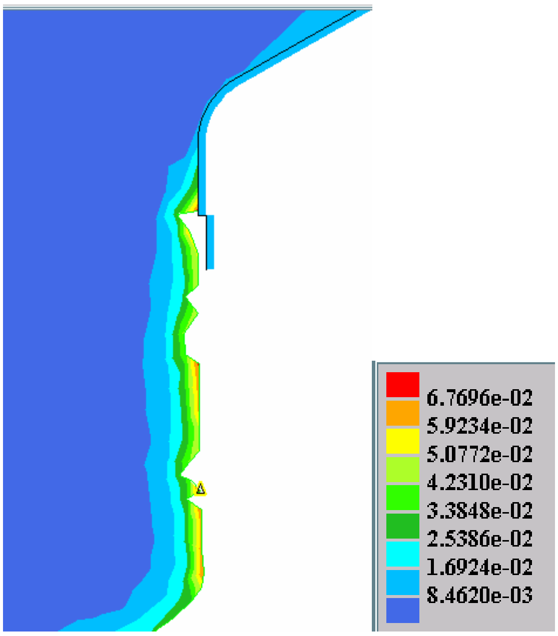

Figure 17 - *Distribution of Cocroft and Latham criterion value for ME10 model with talk as lubricant*

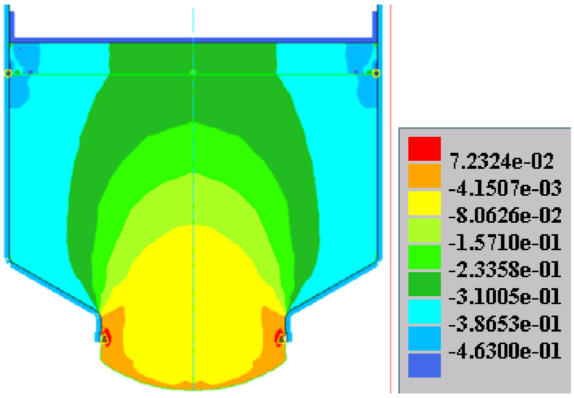

Figure 18 - *Axial stress distribution, ME10 mixture and talk as lubricant*

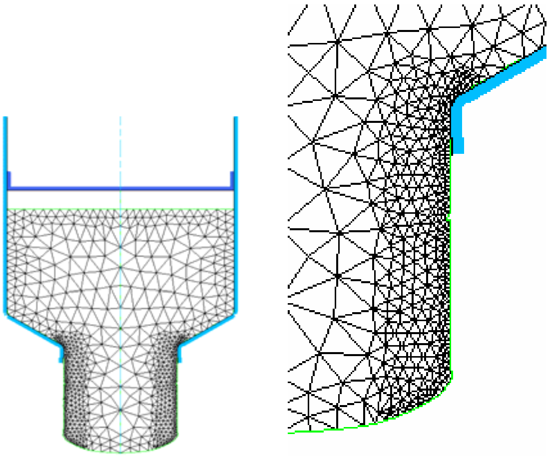

Figure 19 - *FORGE2 simulation of ME10 mixture forward extrusion without defects*

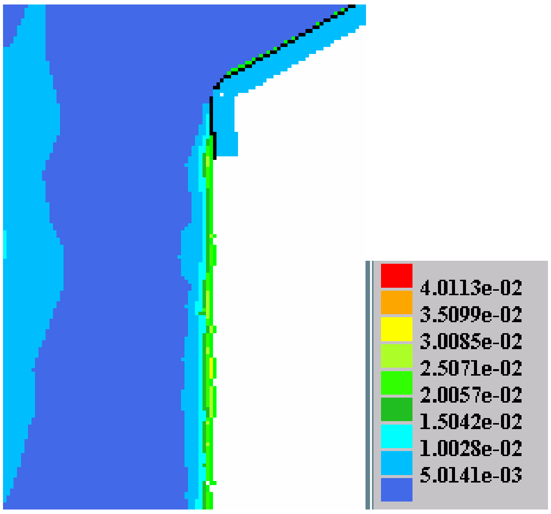

Figure 20 - *Distribution of Cocroft and Latham criterion value for ME10 model with glycerine as lubricant*

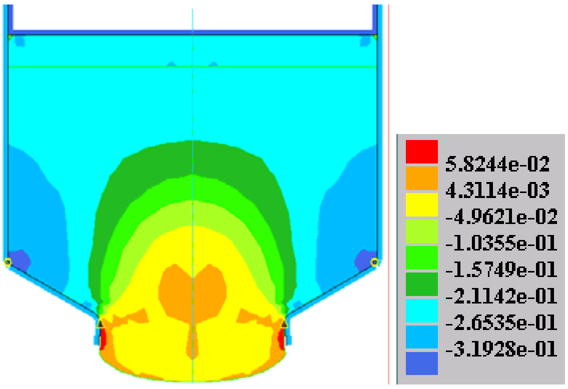

Figure 21 - *Axial stress distribution, ME10 mixture and glycerine as lubricant*

4. CONCLUSIONS

The conclusions derived from the present study may be listed as follows:

1. Physical modelling technique combined with FEM simulation has been used for detection and elimination of internal and external defects, which occurred during extrusion processes.
2. Excellent agreement was obtained when comparing experimental and finite element results for prediction of conditions at which defects occur.
3. Friction conditions are one of the most important factors, which affect the emergence of central burst and fishskin defects in extrusion. Executed investigations shown that by well-conceived changes of friction conditions we can eliminate these defects.
4. Since model materials very well illustrate the behaviour of real material, obtained results and conclusions may be applied on the real process.

Acknowledgements

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5. REFERENCES

[1] V. Mandić, Physical modelling and numerical simulation as basis of new concept in die design of hot bulk forming processes, Ph.D. Thesis, The Faculty of Mechanical Engineering in Kragujevac, 2002.

[2] M.Arentoft, P.Henningsen, N.Bay, T.Wanheim, Simulation of Defects in Metal Forming - An Example, Jour. of Mater. Proc. Tech, 45 (1994), pp. 527-532.

[3] V. Mandić, M. Stefanović, Preventing defects of material flow in the forming processes - physical modelling and FEM simulation, Proc. from 29th Jupiter conference (25. symposium NU-ROBOTI-FTS), Belgrade 2003, pg. 23 (in serbian).

[4] V. Mandić, M. Stefanović, Forging preform design using a finite element simulation, Ohrid 2004, Conf. Manufacturing and Management in 21st century, Ohrid 2004, Proceed. pp. 290-298.

[5] P.F. Bariani, S. Bruschi, S. Masiero, A. Maurizio, F. Zuttion, Optimisation of the hot forging of St70AH turbine blades, Proc. of 7th ICTP, 27-31 October 2002, Yokohama, Japan

[6] V. Mandic, M.Stefanovic, Physical modelling and FEM simulation of the hot bulk forming processes, Journal for Technology of Plasticity, Novi Sad 2002, pp. 41-53.

[7] M. Plančak, D. Vilotić, M. Stefanović, M. Milutinović, V. Mandić, Cold indenting - UBET analysis, FE simulation and experimental verification, Proc. of Conf. Metal Forming 2004, Krakow, pp. 301-305.

[8] M.Arentoft, T.Wanheim, The basis for a design support system to prevent defects in forging, Jour. of Mater. Proc. Tech, 69 (1997), pp. 227-232.

[9] V. Mandić, M. Stefanović, Friction studies utilizing the ring-compression test - Part I, Proc. 8th International Tribology Conference, Belgrade 2003, pp. 44-51.

[10] V. Mandić, M. Stefanović, Friction studies utilizing the ring-compression test - Part II, Proc. 8th International Tribology Conference, Belgrade 2003, pp. 52-58.

[11] B.Avitzur, Handbook of Metal Forming Processes**,** John Wiley & Sons Inc, New York 1983.

[12] N. Nickoletopoulos, M. Hone, Y. Verreman, J. A. Nemes, Validation of the Cockcroft and Latham fracture criterion for cold heading of steel fasteners using drop weight compression testing and finite element modeling, TRANSVALOR literature 2002.

[13] T. Coupez, H. Digonnet, R. Ducloux, Parallel meshing and remeshing, TRANSVALOR literature 2001.