A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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SEQUENTIAL UPSETTING

SPĘCZANIE SEKWENCYJNE

During forging process considerable pressure should be exerted onto deformed material. This is particularly essential in cold working processes, when preform is characterized by low height to lateral dimensions ratio. It is the reason of applying large energy and large overall dimension machines as well as hot working in high temperatures, in which deformation resistance of material gets smaller.

The upsetting process with upper die divided into three parts is presented in this article. In this method, in distinction to traditional process, pressure is exerted to deformed material sequentially by smaller dimension tools set working progressively. It permits to lower deformation force as well as to control flow of material. In article preliminary investigations of sequential upsetting process are presented.

Podczas kucia lub prasowania trzeba wywierać na odkształcany materiał znaczne naciski. Szczególnie jest to istotne w procesach odkształcania metali na zimno, gdy odkuwka ma małą wysokość w stosunku do wymiarów poprzecznych. Zmusza to do stosowania maszyn przetwórczych o dużych wydatkach energetycznych i dużych gabarytach lub wymusza nagrzewanie materiału do wysokich temperatur, w których opór plastyczny materiału znacznie się zmniejsza.

Propozycją autora artykułu jest zastosowanie nowej metody odkształcania sekwencyjnego. W metodzie tej w odróżnieniu od tradycyjnego procesu, nacisk na kształtowany materiał wywierany jest sekwencyjnie, przez narzędzia o małych wymiarach uruchamiane kolejno. Pozwala to na obniżenie maksymalnej siły kształtowania oraz na kontrolowane płynięcie materiału.

W artykule przedstawiono wstępne badania procesu sekwencyjnego spęczania swobodnego. Badania przeprowadzono na prasie z rejestracją siły nacisku i przemieszczenia suwaka, z zastosowaniem prostego przyrządu.

1. Introduction

Open-die forging is concerned mainly with reducing of the height of a billet. This process is generally realized between two flat dies, although the dies can be simply profiled to impart a specific shape to the ends of the upset forging. Widely used open-die forging operation is an upsetting of a cylindrical billet. The outcome of an upsetting operation, in terms of the shape of the preform, depends on the frictional effects that develop between dies and faces of the billet. The deformation of a billet becomes inhomogeneous and barrelling occurs. The amount of inhomogeneity and barrelling depends on the value of the height/diameter ratio and the reduction in height.

Cold open-die forging of thin preforms, with small height/diameter ratio, needs to apply high unit pressures, that can exceed a die material strength. The reason for this, is high flow resistance of deformed material caused by friction on the die – forging surface and the geometry of deformation region. It makes impossible to cold forging of thin billets. To resolve this problem different press constructions were developed and put into use in engineering industry, for example rotary forging machines. These presses are distinctive in that the upper die is in rocking motion during upsetting operation. As a consequence of that, the die – forging contact area is reduced to a portion of the total face forging area. Thereby, forming forces are reduced to a portion of that, which would be necessary, if deformation force was applied at once to the whole end-face of the forging [1, 2].

Similar idea would proceed when forming die is divided into a few parts. During forming operation component parts of the die are put in motion sequentially. The working surfaces of component dies are a part of the whole die surface. Forming force applied to component dies is lower then one necessary when deformation is realized traditionally.

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2. Experimental work

Experimental investigations concern tests of sequential upsetting using a simple construction divided die. Soft aluminium A0 (EN AW1070A, hardness of 18 Brinell) and PA6 (EN AW-2017A) aluminium alloy (hardness of 63 Brinell) cylinders were used as a specimens' material. Diameter of cylinders was ϕ40 mm and height was ~10 mm (initial height/diameter ratio h_o/d_o » 0.25). The lathe-turned specimens were upset without any special surface preparation. The investigations were carried out on testing machine of 200 kN load capacity and hydraulic press of 1000 kN load capacity.

The tool constructed and performed for test was divided into tree component parts, named die 1, 2 and 3 (Fig. 1). The outer diameters of working surfaces of dies were equal ϕ15 mm, ϕ30 mm and ϕ70 mm respectively. Die 1 and 2 were moved by thrust rings, adequately, 1 and 2 (Fig. 1). During tests sequence of dies movement was 1-2-3 or 3-2-1. Sequence 1-2-3 was performed as follow: – die 1 was indented into specimen at first, by thrust ring 1, onto established depth, – then, thrust ring 2 was set in tool arrangement and die 2 was indented into specimen at the same depth, – the last step was done, after removal thrust rings 1 and 2, by indented die 3 to the moment of equalization the upper surfaces of dies. At sequence 3-2-1, die 3 was indented at first by a thrust ring (not marked at Fig. 1) and then die 2 and 1 were indented respectively (die 2 using thrust rings 2).

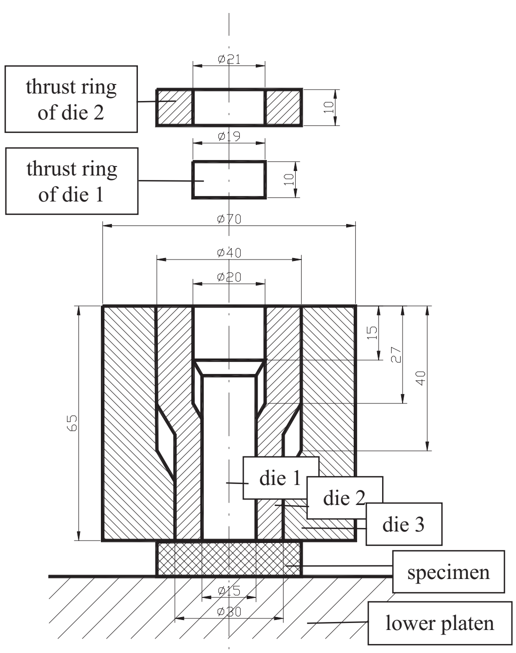

Fig. 1. Tool-specimen set up for sequential upsetting

Preliminary tests concerned upsetting of pure aluminium by sequences 1-2-3. They were performed on 200 kN hydraulic testing machine. This procedure of upsetting was done for three runs of test, with different degrees of total deformation. At last stage of deformation each specimen (in all tests) was compressed with the same maximal press force equal 200 kN. For each step of upsetting compression force and displacement of press ram were measured by gauges and recorded by computer.

Tests of PA6 aluminium alloy were performed by 1-2-3 and 3-2-1 sequential upsetting on 1000 kN hydraulic press. The maximum applied load was limited in respect of the die 1 compression strength.

To compare results obtained during sequential upsetting, conventional upsetting process was performed too. The specimens were upset on 1000 kN hydraulic press.

For evaluation of the feasibility of proposed sequential upsetting method, FEM simulation was carried out. Using an axisymmetric part, three-dimensional FEM simulations of sequential upsetting were performed using MSC.MARC® a commercially available finite element program. The rigid-plastic material behaviour model was assumed for PA6 aluminium alloy. The stress/strain relation of the material and the friction factor were estimated by compression test and used in the finite element simulation.

3. Results and discussion

Example diagrams recorded during preliminary experiments are shown in Fig. 2. There are different ways of deformation when using each component die, so there are differences between curves obtained for particular dies. When die 1 is forced into material, this is an indentation process; deformed material flows at radial outer direction on the bottom surface and upwards on the upper surface of specimen. The process is similar to backward-radial extrusion and the height of specimen increases. When die 2 is forced in, the deformation is almost the same, but material can flow, additionally, at radial inner direction. The recorded displacement of die 2 (Fig. 2) is greater, because of specimen's height increasing during first stage of deformation. Movement of die 3, initially produces deformation process similar to described above for die 2, but finally it is like a conventional upsetting. The mechanism of deformation in these component processes is complicated. It is difficult to estimate the range of deformation in principal directions on this stage of investigations. Similar configurations are described by Balendra and Qin [3]. The most deformed region is laying under the die1- die 2 border edge. It is confirmed by image of microstructure (Fig. 3) and plasticine modelling (not presented at this paper).

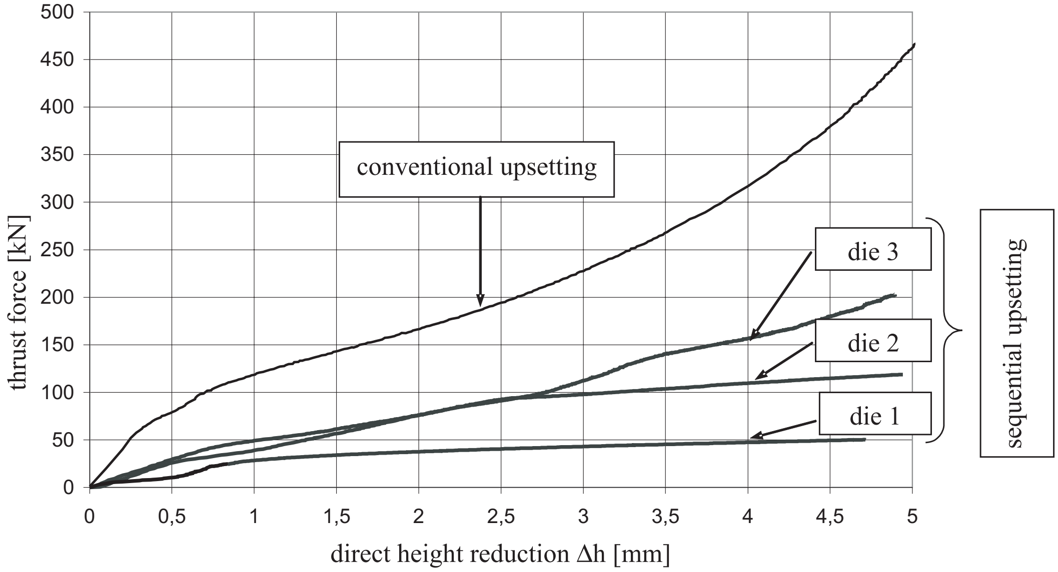

Fig. 2. Deformation force versus height reduction during sequential (1-2-3) and conventional upsetting of aluminium specimen

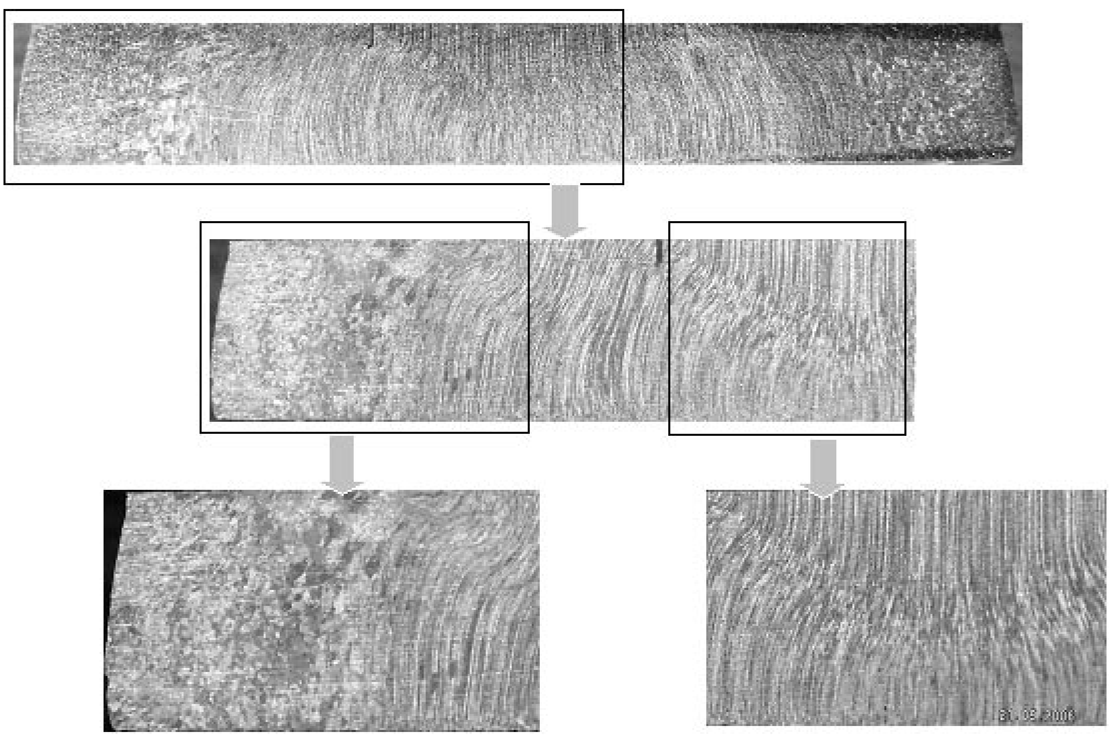

Fig. 3. Macrostructure of aluminium specimen after sequential upsetting (1-2-3) – etched by 30% hydrogen carboxylic acid

The observations of macrostructure of specimen cross-section show the inhomogeneity of deformation. The inhomogeneity is greater in upper region of specimen, laying under segment die, then in bottom region. The great dead zone is visible under die 1; the primary structure of preform is kept up. The deformation at the bottom region of specimen is more homogeneous. The lateral circumferential region of the specimen looks like after recrystallization. This phenomena wasn't investigated. The shuts on the upper surface occur (under the die 1 – 2 border region).

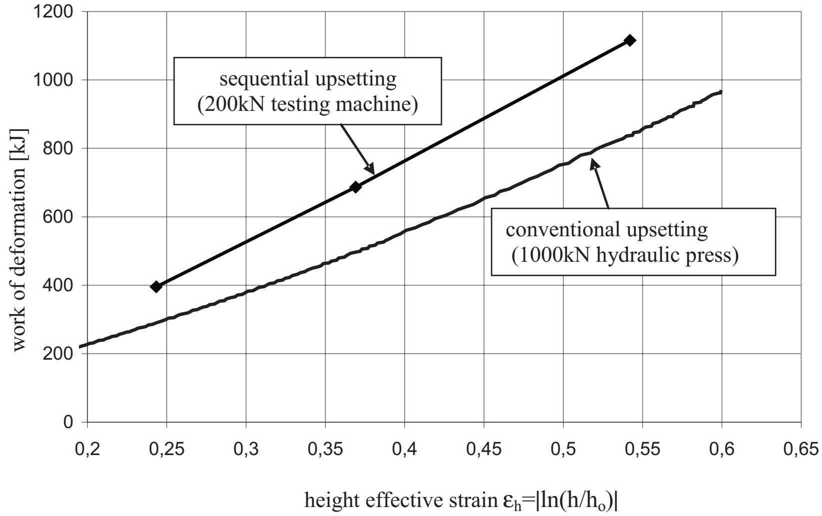

Fig. 4. Work of deformation during sequential upsetting compare with conventional method

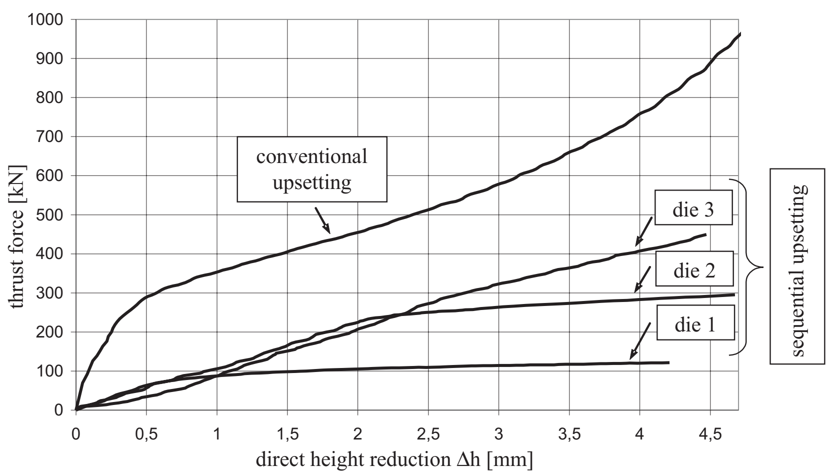

Fig. 5. Deformation force versus height reduction during sequential (1-2-3) and conventional upsetting of PA6 alloy specimen

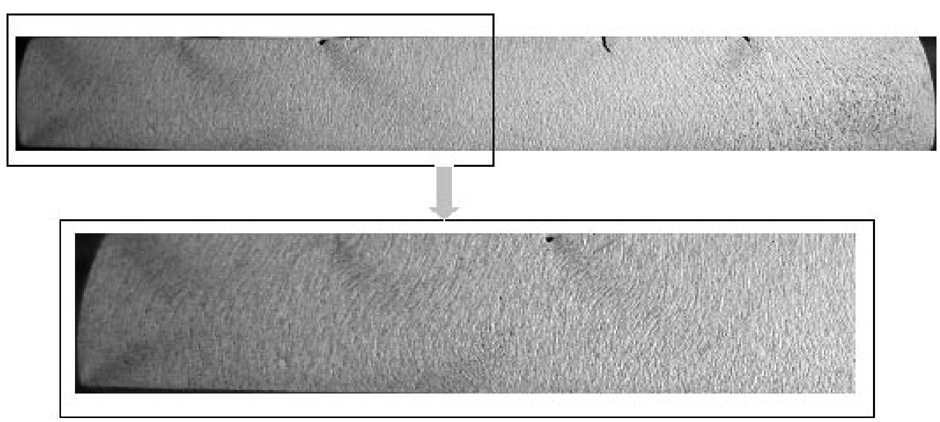

Fig. 6. Cross-section macrostructure of PA6 alloy specimen after sequential upsetting (1-2-3)-etched by 30% hydrogen carboxylic acid

The degree of deformation, when sequential upsetting is applied, can be essentially greater in comparison to conventional upsetting. The maximum logarithmic height reduction in sequential upsetting is almost two times greater then logarithmic height reduction in conventional upsetting. Logarithmic height reduction obtained in tests for aluminium specimens was equal: for sequential upsetting $\varepsilon_h = 0.54$ and for conventional upsetting $\varepsilon_h = 0.29$, when 200 kN thrust force was applied. It results mainly from the fact, that component dies have much smaller working surfaces and small-sized contact surface results in low total friction force and small dimensions of dead zones in deformed material [4]. So, it can be observed decreasing of deformation force or, when force is the same, increasing degree of deformation.

Analysis of load-displacement curves illustrated in Fig. 2 induced to compare deformation work of processes: sequential and conventional upsetting. Work of deformation for sequential process was determined as the sum of areas under load curves recorded for each component die. As it can be seen from Fig. 4 that work of deformation in sequential process is greater then one for conventional process and the same degree of deformation. The reason of this result could be: different flow mechanism of deformed material (as it was shown above) and different friction conditions during component die indentation processes.

For the sake of low hardening properties of aluminium, investigations were performed for PA6 aluminium alloy. The same shape and dimensions specimens were machined from PA6 alloy extruded bars. The results of sequential upsetting 1-2-3 are presented in Fig. 5, 6. They are similar as for aluminium. The force required for height strain $\varepsilon_h = 0.5$ is for sequential upsetting two times lower then one for conventional upsetting (Fig. 5). The deformation inhomogeneity is lower for PA6 alloy then for pure aluminium. The shuts are visible on the upper surface of specimen, under die 1 – 2 and die 2 – 3 border region (Fig. 6).

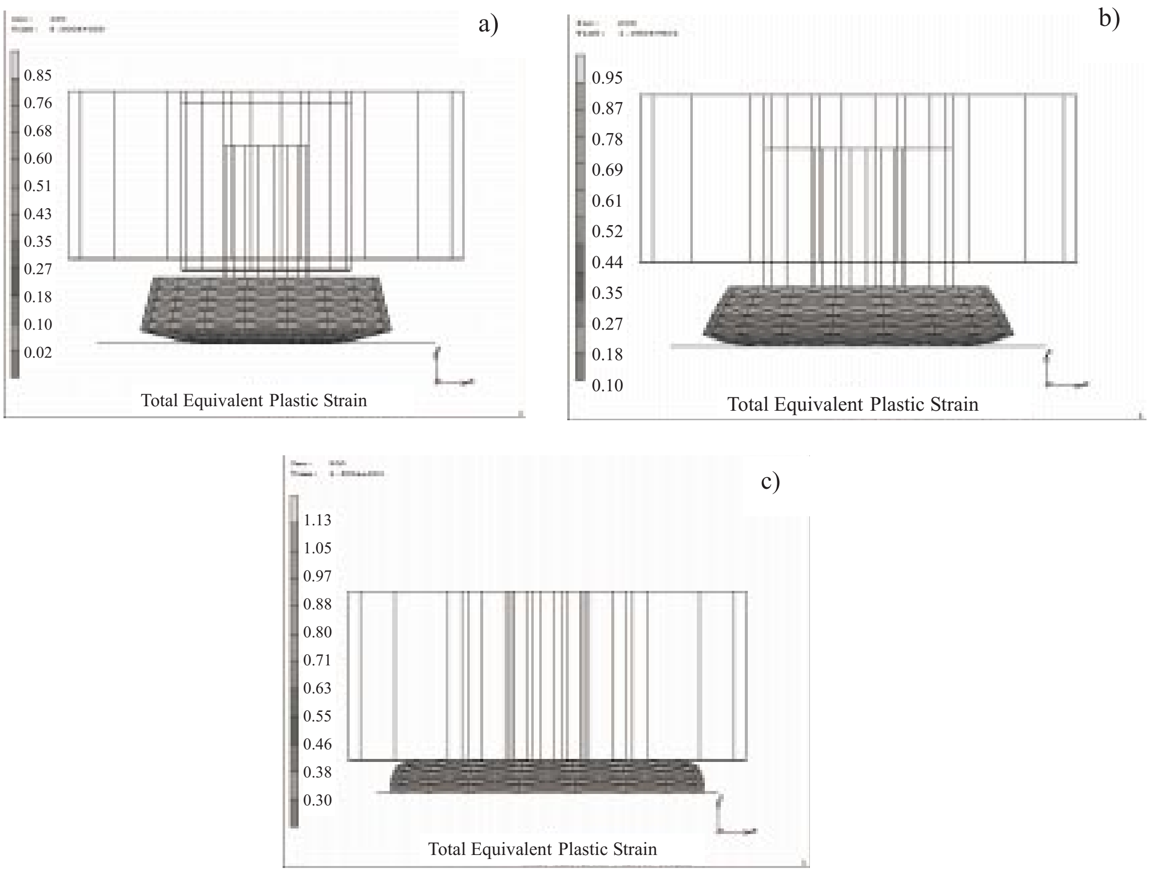

Fig. 7. FE simulation results of 1-2-3 sequential upsetting – deformation of specimen shape: a) step 1 b) step 2 c) step 3

Finite element simulations of sequential upsetting were realized to 50% reduction in specimens height. They confirm the manner of specimen shape deformation on each of three dies movement stages (Fig. 7). As it was observed in real specimens (for pure aluminium and its alloy), lower and upper halves of specimen deform in different modes; the simulated shape of specimen has greater diameter on the bottom surface then on the upper. Diversification of total equivalent plastic strain, observed on the outer specimen surface, is low.

The above presented results concern only one sequence of die movement. As it can be seen from Fig. 1 there are six possible sequences of die movements. Each sequence can cause different manner of deformation and different flow of material. Performed tests included also reverse sequence 3-2-1. This sequence causes more severe state of deformation. In case of PA6 alloy, the cracks appeared on the upper surface of specimen, under die 2-3 border edge (Fig. 8). It is confirmed by the FE simulation results (Fig. 9, 10). Total equivalent plastic strain for the most deformed region, located under the die 2-3 deformed region, is equal almost four, when simulation of 50% reduction in height is performed (Fig. 10). The mode of deformation results in greater diameter of the upper surface than that of the bottom surface. This phenomena is reverse to that observed for 1-2-3 sequential upsetting.

Shapes of specimen in different stages of sequential upsetting obtained in numerical simulations (Fig. 9), let to formulate conclusion that this process can be alternative to impression die or closed-die forging. The working surfaces of component dies, at the end of upsetting process, can form the die cavity such as closed-die cavity. The sequence of dies should provide the proper die cavity filling and required pattern of flow of the material. The essential problem in such sequential device is in resolving the problem of dies movement.

Proposed device for sequential upsetting is shown in Fig. 11. The upsetting die is divided into several parts. The sequence of dies and the range of die movement are established by changing the vertical and radial position of shift threshold. Because this construction is complicated, alternative simplified sequential upsetting machine was designed (Fig. 12).

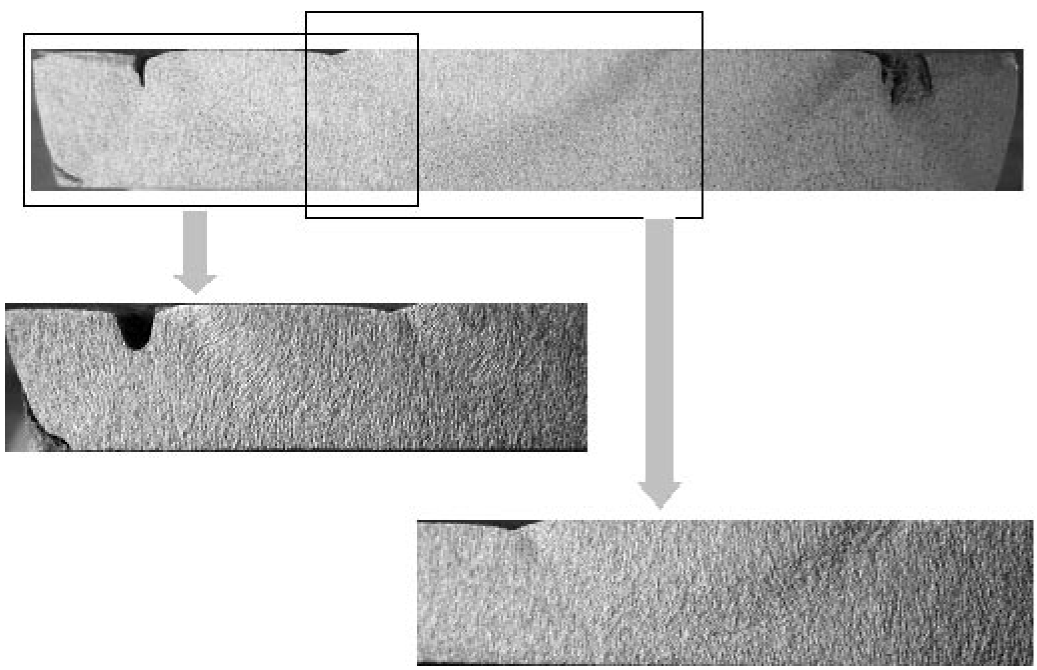

Fig. 8. Cross-section macrostructure of PA6 alloy specimen after sequential upsetting (3-2-1)-etched by 30% hydrogen carboxylic acid

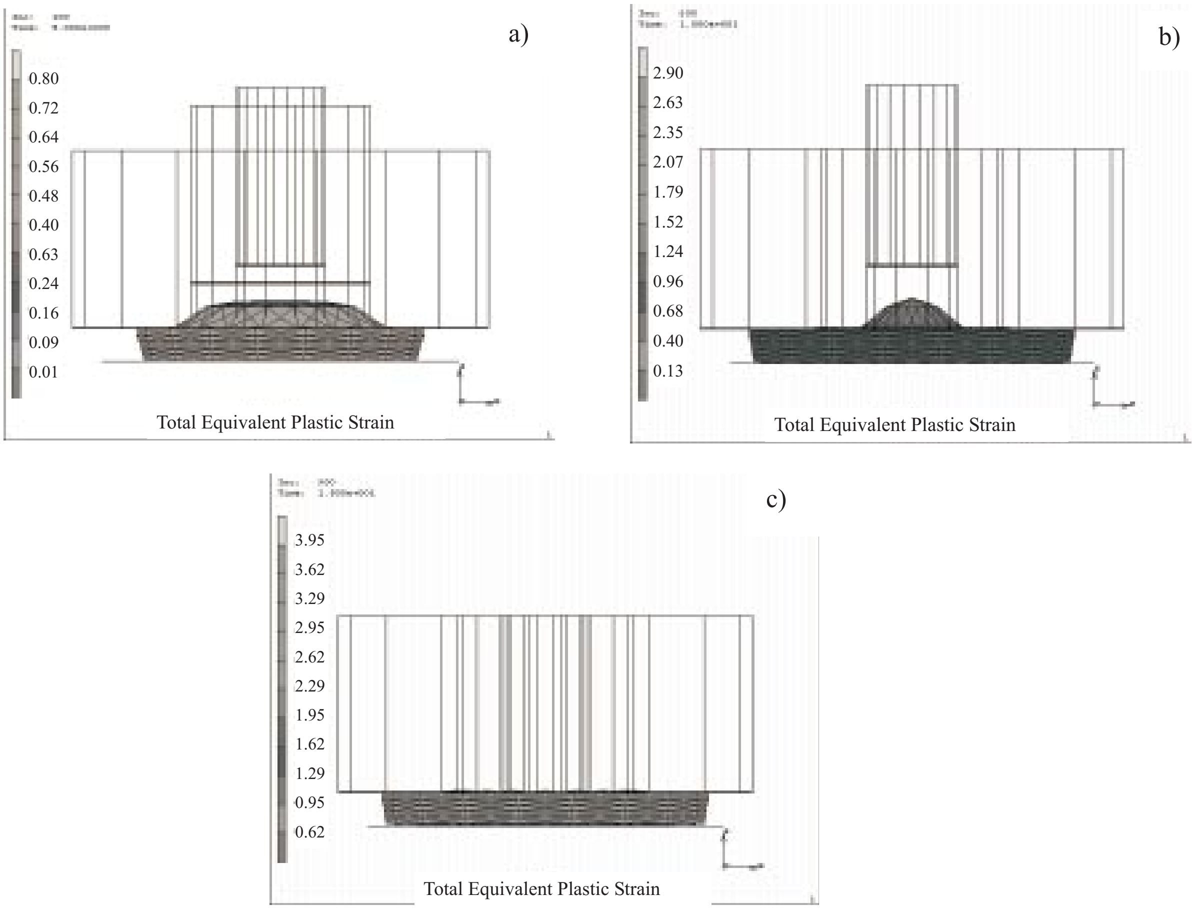

Fig. 9. FE simulation results of 3-2-1 sequential upsetting – deformation of specimen shape: a) step 1 b) step 2 c) step 3

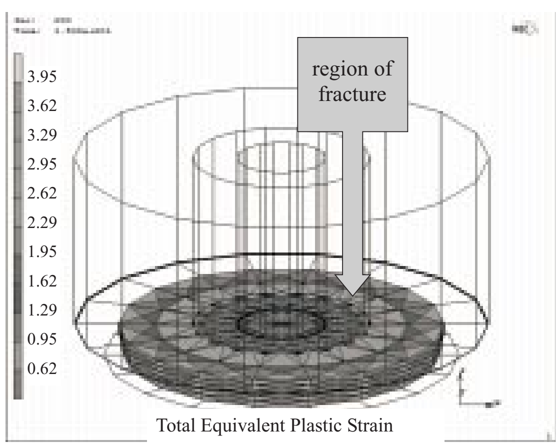

Fig. 10. FE simulation results of 3-2-1 sequential upsetting – upper view

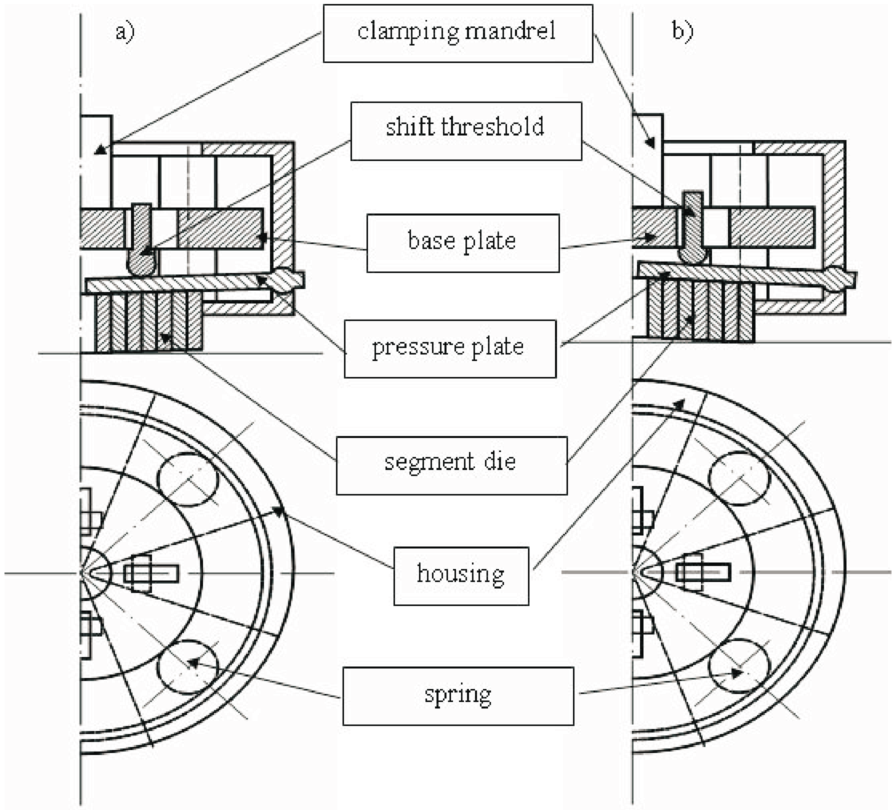

Fig. 11. Schematics of sequential upsetting device design – sequence of tools: a) from the middle to the outside b) from the outside to the middle

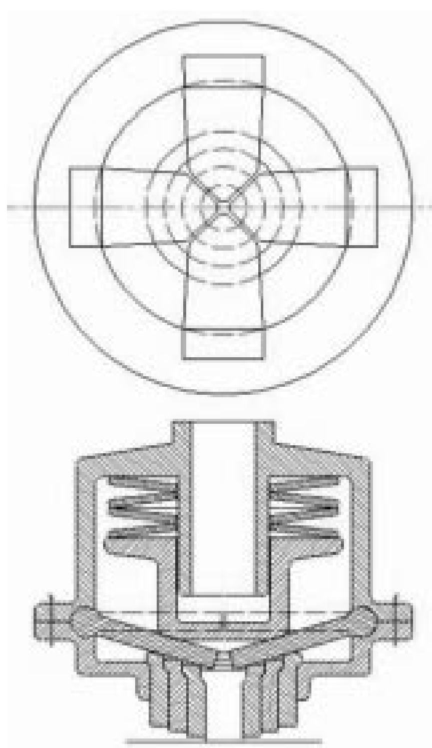

Fig. 12. Simplified design of sequential upsetting device – constant sequence of tools – from the middle to the outside

4. Conclusions

Sequential upsetting, as a method of forging consisting in dividing of the upsetting die into a few component dies set working sequentially, makes possible processing of thin forgings on a low load capacity presses. Dividing the upsetting die into three component dies allowed to twice decreasing of upsetting load. The die sequence "from the outside to middle" produces greater deformations in material then sequence "from the middle to outside", for the same height reduction. On the upper surface of sequential forgings the shut may occur. This may cause necessity of machining of sequentially upset surfaces.

Sequential upsetting can be alternative process for impression die or even closed-die forging. A complex shapes of a drop forging can be obtained by using sequential device with different geometry of component dies.

This innovation needs further investigations. The main problem in industrial applications of this method, is the drive of component dies. Some innovative ideas are considered. The sequential forging device assembled on low load capacity presses could be alternative solution to rotary forging machines.

REFERENCES

[1] Z. Marciniak, A rocking die technique for cold-forming operations. Machinery and Productions Engineering 792-797, 11 November 1970.

[2] W. Johnson, Rotary Forging. The Mechanics of Some Industrial Pressing, Rolling and Forging Processes. PERGAMON PRESS OXFORD and NEW YORK 330-338, 1982.

[3] R. Balendra, Y. Qin, Injection forging: engineering and research. Journal of Materials Processing Technology **145**, 189-206 (2004).

[4] P. Wasiunyk, Teoria procesów kucia i prasowania. WNT, Warszawa 1991.

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