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LIMITING PHENOMENA IN A NEW FORMING PROCESS FOR TWO-RIB PLATES

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This paper presents chosen results of theoretical and experimental research works on a new metal forming process of two-rib plates. The first part of the paper deals with forging technology of such products in a three-slide forging press, assuming two variants of the process: semi-open die forming and closed-die forming. In the further part of the paper, applying software simulations and making experiments for lead, the analysis of the assumed variants with consideration of optimal parameters of forming and present limiting phenomena was conducted. The phenomena disturbing the two-rib plates forging process were discussed in details. They include: plate buckling, overlapping and various types of forging deformation.

Key words: metal forming, forgings with two ribs, three-slide forging press, limiting phenomena, lead

INTRODUCTION

Products with ribs are widely applied in different industrial branches. A lot of these products are made from light metal alloys, which are used by aviation industry [1-3]. For the aviation industry's needs, such elements as: control system brackets, covers, screens, flaps etc. are manufactured. Exemplary aviation parts in the form of plates with two ribs are shown in Figure 1 [4-7].

At present, production of plates with ribs includes such manufacturing techniques as machining and casting. Although these technologies exist, new, competitive solutions are still being searched. Metal forming processes, allowing for forming of products with better mechanical and functional properties, should be taken into consideration [8].

Changing of used so far manufacturing technologies of parts with ribs for metal forming methods would allow for obtaining products of better quality at simultaneous lowering of their manufacturing costs (lowering of labour and material consumption). Because of that, at Lublin University of Technology a new metal forming method of plates with two ribs is being worked on. In this paper, the analysis of the forging process of a plate with two ribs in a three-slide forging machine is presented. On the basis of research results obtained in numerical simulations and in laboratory tests, the influence of the process parameters on limiting phenomena in the analyzed metal forming method was determined.

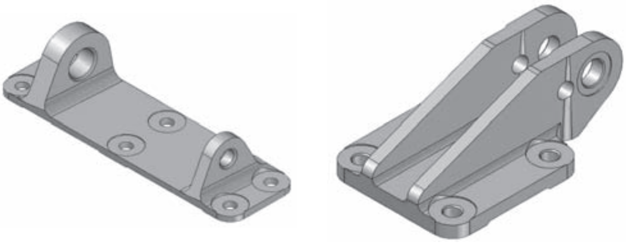

Figure 1 Exemplary plates with two ribs applied in aviation industry [4]

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Issue of plates with two ribs forming process in a three-slide forging press (TSFP)

The schema of the assumed forming process of two-rib plates with marked important dimensions is presented in Figure 2.

It was assumed that forging of two-rib plates would be realized applying the press with three movable tools and with wider technological possibilities in comparison with typical forging machines.

Two variants of the process were assumed: semi-open die forming or closed-die forming.

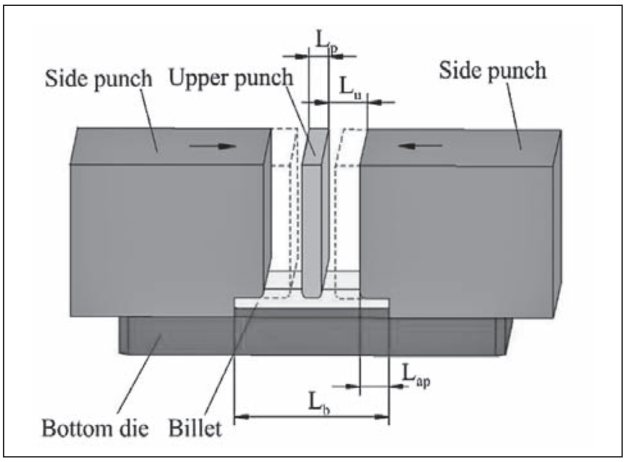


Figure 2 Schema of forming of a plate with two ribs in TSFP

In both variants a semi-finished product in the form of a plate is placed in the bottom die. Next, the upper tool clamps the plate central part and the semi-finished product is upset by side punches, which approaching each other form two ribs. The forging is formed in one working cycle. The time of the process in the case of constant velocity of side punches depends only on the plate upsetting length L_u determined by the equation (1):

$$L_u = \frac{L_b - 2L_{ap} - L_p}{2} \qquad (1)$$

where: L_u - length of upsetting (the punch way), L_b - billet length, L_{ap} - punch working length, L_p - punch width (see Figure 2).

In the variant of closed-die forming side plates were applied, limiting material flow in the direction transverse to the punches movement.

Scope of research

Research works on possibilities of two-rib plate forming in the three-slide forging press were done for lead, which was also used for experimental verification. Theoretical analysis of the assumed two variants of the process (semi-open die forming and in closed impression) was conducted basing on finite element method and applying commercial software Deform 3D. Simulations of the analyzed processes were made considering three dimensional state of strain. The material model was taken from the library of the used software, which flow curves are shown in Figure 3.

It was assumed in calculations that billet is of plate shape with dimensions: height H = 10 mm, width A = 50 mm and length L_b changed within the scope 105 ÷ 140 mm every 1 mm. Constant velocity of side punches v = 6 mm/s was considered. In simulations constant friction model with friction factor at metal-tool surface of contact m = 0,5 was applied.

Exemplary results of numerical simulations, showing products with strains distributions on the surface for both worked out methods are given in Figure 4.

The main aim of the conducted experiments was verification of the chosen results of theoretical research

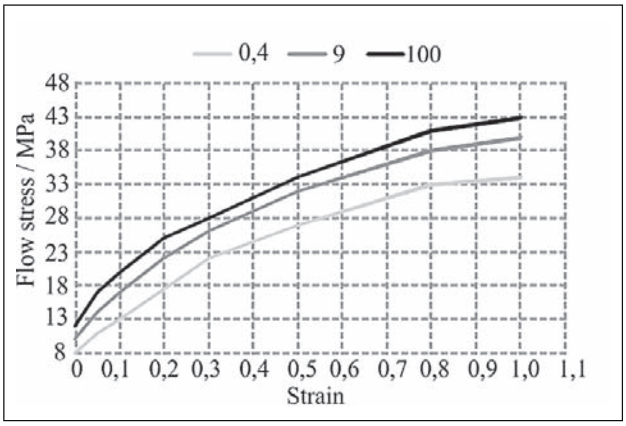


Figure 3 Lead flow curves in the temperature 20 °C taken from material library of the software Deform 3D

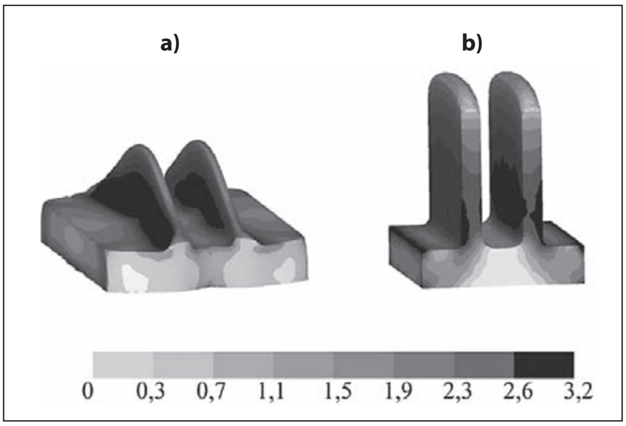


Figure 4 Shape of flat forgings with two ribs obtained in the forging process simulations: a) semi-open die forming, b) closed-die forming

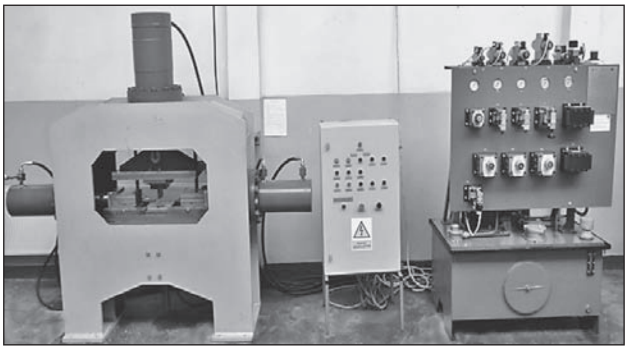


Figure 5 Three-slide forging press applied in experimental research works

works. The obtained results concerning limiting values of the plate upsetting coefficient underwent experimental analysis, this coefficient is described by the equation (2):

$$K = \frac{L_u}{H} \qquad (2)$$

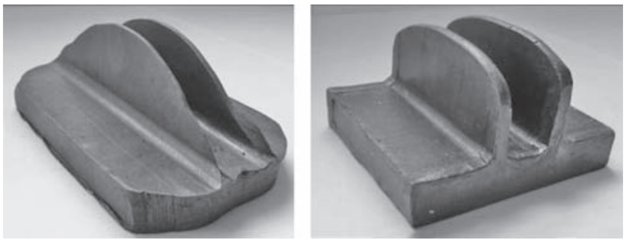
where: K - upsetting coefficient, L_u - upsetting free length, H - billet height.

Experimental research works were done applying three-slide forging press (Figure 5). For the process realization needs, tools for semi-open die forging and for forging in closed impression were designed and manufactured.

RESEARCH RESULTS

On the basis of conducted theoretical and experimental research works, it was stated that in the assumed forging process of two-rib plate in TSFP proper products can be obtained. Figure 6 shows the forging shapes without faults achieved in the experiment.

Inadequate way of the process realization results in obtaining faulty products. The analysis of a wide scope of technological parameters of the two-rib plate forming allowed for identification of limiting phenomena present in the analyzed process, which include: plate buckling, overlapping and various forms of the forging deformation.



a) b)

Figure 6 Shape of flat forgings with two ribs obtained in experimental research works for the process: a) semi-open die forging, b) closed-die forging

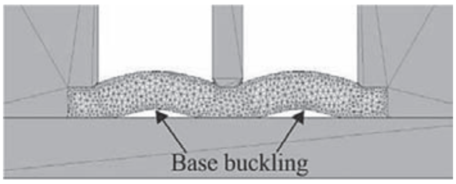


Figure 7 Schema of the buckling presence in the product base - the results of the Finite Element Method

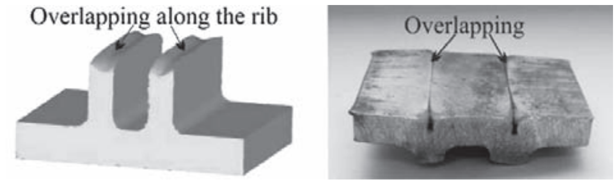
The schema of the buckling appearance - the main limiting phenomenon - is shown in Figure 7. This fault presence depends mainly on the value of upsetting coefficient K, described by the dependency (2).

The authors previous research works connected with determining limiting conditions in the upsetting processes of a plate with one rib showed that simulations results are faulty in some cases [9]. The buckling of theoretical model appears considerably later than in the real process. The cause of such differences are idealized conditions of simulations and larger rigidness of billet. Due to that, the limiting upsetting coefficient should be determined in experiments. The approached value of this coefficient determined in experimental tests at two-rib brackets forming from lead was about 3,0. After exceeding this value of coefficient K billet buckling takes place. Because of that a proper forging of two-rib plate from lead can be achieved for free length of billet 30 mm.

A very unfavorable phenomenon that can appear during forming of the two-rib plate is overlapping. It happens when the limiting value of free length is exceeded. Overlapping can take place along ribs at their upper surface and at the forging base. Overlapping along ribs appears in the result of material upsetting at tools sides (Figure 8a). Overlapping in the product base is the result of buckling phenomenon presence (Figure 8b). Both overlapping along ribs and in the plate base disqualifies the product.

There also exist unfavorable phenomena connected with the forging deformation, which can be eliminated by additional processes improving the product.

The application of additional operations causes, however, lowering of the process effectiveness. One of such phenomena is the product base widening (Figure 9a). This fault appears only during semi-open die forming of plates with two ribs. In this process are not considered tools limiting material flow sideways. In order to obtain a finished part it is necessary to remove material abundance, which increases material consumption and labor consumption of the whole process.



a) b)

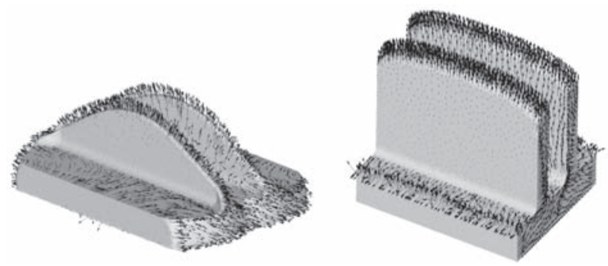
Figure 8 Overlapping present: a) at the rib upper surface, b) in the formed experimentally product base, obtained in Finite Element Method simulations

a) b)

Figure 9 Shape faults of two-rib forging: a) widening of the base and ribs unevenness in the semi-open die forging process, b) ribs unevenness in the forging process in the closed impression

Another shape fault is unevenness of the rib outline. This unevenness is expressed by the difference between the largest and the smallest rib dimension. This difference is, of course, much smaller for the forging formed in the closed die, which ribs have shape close to rectangular (Figure 9b). Ribs formed in the second variant, so semi-open die, have semi-circular shape, hence, the difference of maximal and minimal height is larger (Figure 9a). These unevenness phenomena result from the direction of material flow in the rib area. In the semi-open die forming material flows additionally sideways (Figure 10a) and in the closed die material flows up (Figure 10b).

The next unfavorable phenomenon present in the forming process of two-rib plate is head flash. This is removable fault which requires additional machining. Figure 11 shows forging with head flash caused by material squeezing between tools of closed die.



a) b)

Figure 10 Vectors of material displacement during forming: a) closed, b) semi-open die

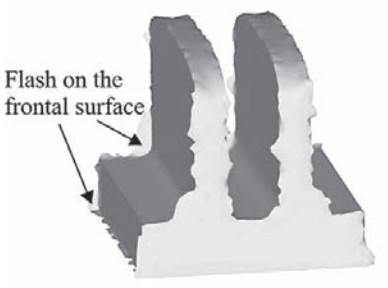


Figure 11 Flash at head surfaces of forgings with two ribs

SUMMARY AND CONCLUSIONS

Conducted theoretical and experimental research works for lead confirmed the possibility of two-rib plates forming in a three-slide forging press, according to the assumed conception. The worked out method can be effectively applied for production of flat parts with thin and high ribs. The basic advantages of the new forming process of plates with two ribs in the three-slide forging press should include: large universality of the method, which can be used for metal forming of various types of metals and their alloys; inconsiderable material loss (small amount of waste for recycling); high productivity of the process due to the possibility of part forging in one working cycle of the press.

The conducted research works confirm the advantages of numerical simulations application, in the result of which it was possible to make a multiple - variant analysis at the designing stage of the process. Finite Element Method usage allowed for precise observation of material flow kinematics and for identification of limiting phenomena present in the analyzed process. This resulted in precise planning of experimental research works and lowering of their costs.

It occurred from the conducted research works that it is possible to form plates with two ribs in the three-slide forging press at the upsetting coefficient $K \leq 3,0$. After exceeding this limiting value of the coefficient, billet buckling and, in the effect, overlapping in the product base, as well as overlapping at ribs upper surface can appear. It should be mentioned that there exist other phenomena limiting the process and connected with shape faults, such as: ribs unevenness, the base widening or head flash. These limitations are, however, of smaller importance as they can be eliminated by additional machining.

Research works on the forging process of plates with two ribs made on lead provided promising results. The main aim of this technology is, by no means, forming of flat forgings with two ribs from non-ferrous metals applied in aviation industry.

Hence, it is fairly justified to conduct further research, which will aim at working out guidelines for designing of forming processes of plates with two ribs in the aspect of future application in the aviation industry.

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