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PICTURE OF METAL FLOW IN THE PROCESSES OF FORGING OF FLAT WORKPIECES

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ABSTRACT

This article describes the technique of formation the picture of metal flow in the processes of forging of flat workpieces. Specialized software complex is developed, designed to calculate the parameters of the forging processes and to simulate the plastic forming of flat workpiece, which has the following advantages: low performance requirements for computer equipment, high speed of calculations, quick start initial information, quick and easy training of personnel. The possibilities of the developed technique and software complex are considered by an example of calculation of formation of die forging with contoured ribs. With a view to the rapid analysis the forging the picture of metal flow is simulated by using the developed software complex. The results of industrial experiment of stage wise deformation of flat workpiece are presented. The comparison of experimental and calculated data provides the conclusion, that the difference between them does not exceed the engineering error.

Keywords: dividing line, picture of metal flow, flow line, flat workpiece, software complex, forging.

INTRODUCTION

Light alloy forged products with stiffening plates are commonly used in various mechanical engineering branches. They are produced in special departments of steel companies with powerful presses. Such products often have flaws which worsen their macrostructure. Therefore it is urgent to find new techniques of simulating forming processes for forgings with stiffening fins.

It is dificult to make a mathematical model of metal forming processes, which would describe the mode of deformation of metal plastic forming. One way to solve the problem of simulating the metal flow pattern and the spatial pressure profile is the so-called «theory of thin-layer flow» [1]. It is based on the assumptions which simplify the original system of differential equations. Therefore the problem comes to purely geometric tasks and can be solved in terms of the so-called «sand analogy» using the suggested technique [2].

Basic provisions of the developed technique

This technique is based on the following provisions [3, 4]:

1. Principle of the shortest line normal current determines the direction orthogonal to the contour of the forging, which is a sharp change in line thickness (including stiffening ribs or elevations on the web forgings). Then, at the initial stage of deformation, when the same pressure along the boundary contour metal flows move orthogonally contour and stiff metal amount at each point on the boundary defined by the length of the current lines.

2. In the process of deformation the boundary conditions change, and along the contour of the contact pressures are unequal. In this regard, the current lines will be directed at an acute angle to the contour of the forging. However, taking the fact that the spatial diagram of the contact pressure is a ruled surface, the fall line (and hence the current line) is directed orthogonally

to the level curves of the surface. Projecting the three-dimensional picture on plane blade forgings can enter a conditional path along which the contact pressures are equal. Then the flow lines are orthogonal to this conditional loop.

3. In general, the conventional circuit is a rather complicated curve. In accordance with the principle of least perimeter slab tends to take the form of a circle in the plan. Therefore, we can assume that the flow lines directed along the radius of a circular arc. Then conditional contour is a circle, and the flow pattern of metal on the web will be a radial forging.

Note that the radial flow pattern of the metal is more universal than normal. It is also applicable in the initial stage of deformation to the forging circuit which consists of sections of curved lines. Approximating the contour forgings circular arcs, you can apply a radial circuit and at the initial moment of deformation, when the current lines perpendicular to the contour.

4. In view of the above, the spatial diagram of contact pressure is a combination of conical surfaces at any stage of the workpiece deformation than the initial one. Boundary contact pressure while lying in vertical planes intersects these surfaces.

5. The value of the boundary of the contact pressure at any time point for any deformation in the contour depends on several parameters: thickness of the blade forging die cavity size, barb width groove magnitude stiff metal in the cavity. Accounting for all of these parameters it requires the use fairly complex formula to calculate the boundary of the contact pressure.

6. Since the spatial diagram of contact pressure is the surface of the same slope, the line section of metal flow is the locus of points equidistant from the contour forgings. The contour forgings can be approximated by straight lines and circular arcs. Therefore, the problem of constructing a line section of metal flow is reduced to finding the locus of points equidistant from circles and straight lines.

7. Because any multiply connected circuit with sufficient degree of accuracy can be approximated by straight lines and circular arcs, we can assume that the surface of spatial diagram of contact stresses consists of flat and conical sections. Line of their intersection form edges (so-called ridges).

8. Frontal and profile projections of these edges allow determining the volume of diagram of the contact stresses and therefore the force, required for deforming the metal, the horizontal projection (plan view) is a dividing line of metal flow, which characterizes the metal flow distribution on the contact surface.

Description of the software complex

On the basis of the obtained technique a software complex PARSHTAMP is designed, that allows you to construct: contour of the forging, dividing line of metal flow, pattern of the flow metal, profile of stiffener, spatial diagram of contact stresses and to solve the problem of optimizing the combination of technological openings and recesses through which you can control the flow of metal (Fig. 1). Although all of the theoretical issues have been resolved, however the software implementation meets a number of difficulties in connection with which the last three blocks of the program are finalized [5].

The software complex consists of three main programs implementing solution of the static, kinematic and dynamic problems. The solution of the static problem is consistent with the principle of the shortest normal, according to which the metal to the contact plane flows along streamlines directed orthogonally to the contour of the forging. In this case dividing line of the metal flow is equidistant to contour of forging. Th solution of kinematic problem based on the principle of least perimeter, through which the radial flow scheme of metal can be adopted, characterized that streamlines are orthogonally directed to some arbitrary curve, which is a level line on the surface of the contact pressures. Dynamic problem reduces to construction of spatial diagram of contact stresses representing a combination of conical and surfaces of polyhedrons. Moreover, in projection on the plane of contact edge of these surface lines of section of the metal flow are and slope lines - streamlines.

The specialized software complex for calculating parameters of the processes massive forming and forging and simulation of plastic form changing flat workpieces has the following advantages: low performance requirements of computer equipment, high speed calculations, accelerated input initial information, quick and easy training of the staff. Providing these advantages the software complex is achieved by simplifying mathematical model and bringing the initial system of differential equations to the analytical dependences. As a consequence, there is a significant relief software implementation of calculation algorithm, but narrowing

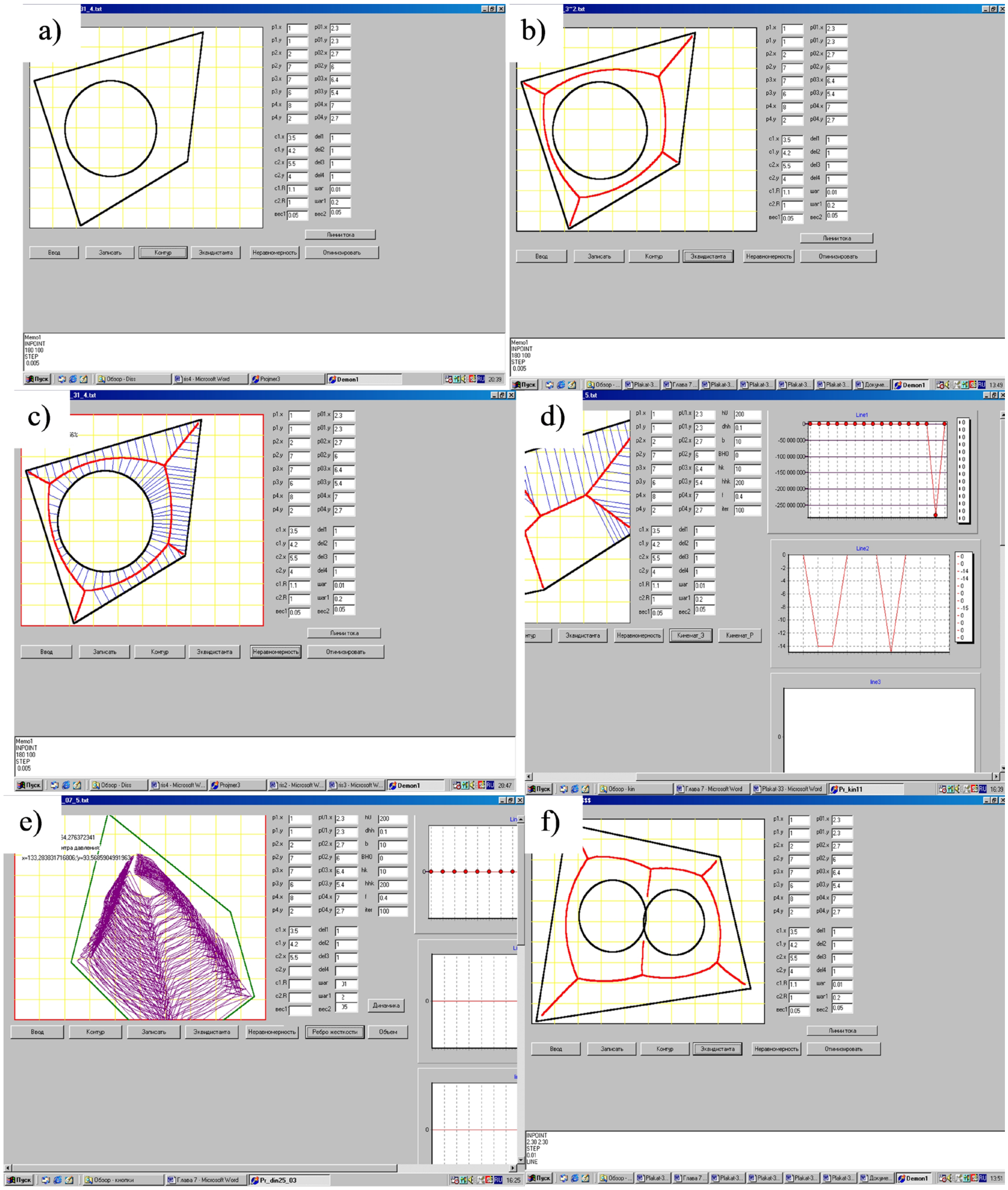

Fig. 1. Abilities of developing software complex.

of the range of tasks. However, where express analysis and fast (albeit approximate) evaluation of the plastic form changing the workpiece are required, such program can be an invaluable assistant.

Computer simulation

The following example of calculating the formation of closed die forging with contour finning shows the capabilities of the developed technique and software package (Fig. 2).

For express analysis of a lug (or a notch) application expediency in the forging, a metal flow pattern with different circle center positions and radiuses has been simulated by means of the developed software complex [6-7]. The end-point analysis shows that the metal outflow to the lug (or the notch) reduces the unevenness of

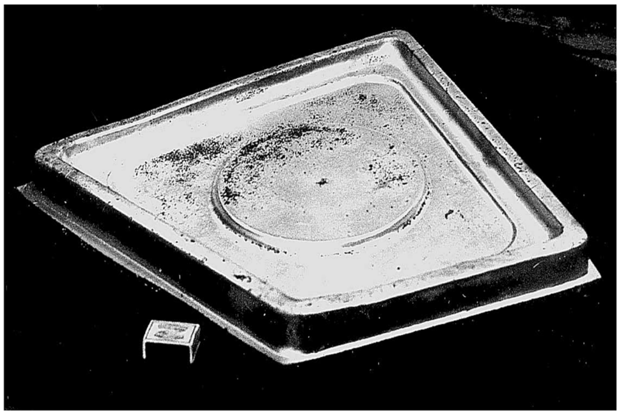

Fig. 2. Forging with contour finning.

metal flow into the die cavity. Therefore its application is advisable.

A program which provides stepwise determination of the amount of metal flow into the die cavity has been used to calculate forging formation.

For simulating process the following requirements should be taken into consideration. We can change only those geometric elements which do not influence the product design, for example, width and height of the groove, the lug radius, initial thickness of the primary blank or upsetting stage. The lug radius belongs to these variables because it should be replaced by a 240 mm hole in the fine product and lug can be removed during machining. In the calculating process the lug size is the controlling factor which allows getting different metal flow patterns on the die impression surface and different contour finning profiles.

The calculation of contour finning profiles with the lug radius of 10 mm and 120 mm may serve as an example. Fig. 3 shows metal flow patterns on forging cloth.

The calculations show that the metal touches the bottom of the die cavity with forging cloth thickness of 22 mm (after 3 upsetting steps) for the lug radius of 10 mm with forging cloth thickness of 21 mm (after 4 upsetting steps) for the lug radius of 120 mm. While angular areas for both variants are nearly similar, central areas of contour finning are greatly different. If we compare profiles 5 and 6 of stiffening fins with different lug radiuses, we can conclude that stiffening fins with the lug radius of 120 mm are formed more evenly than with that of 10 mm. In calculating the height of stiffening fins the difference between two values of lug radiuses is 40 %

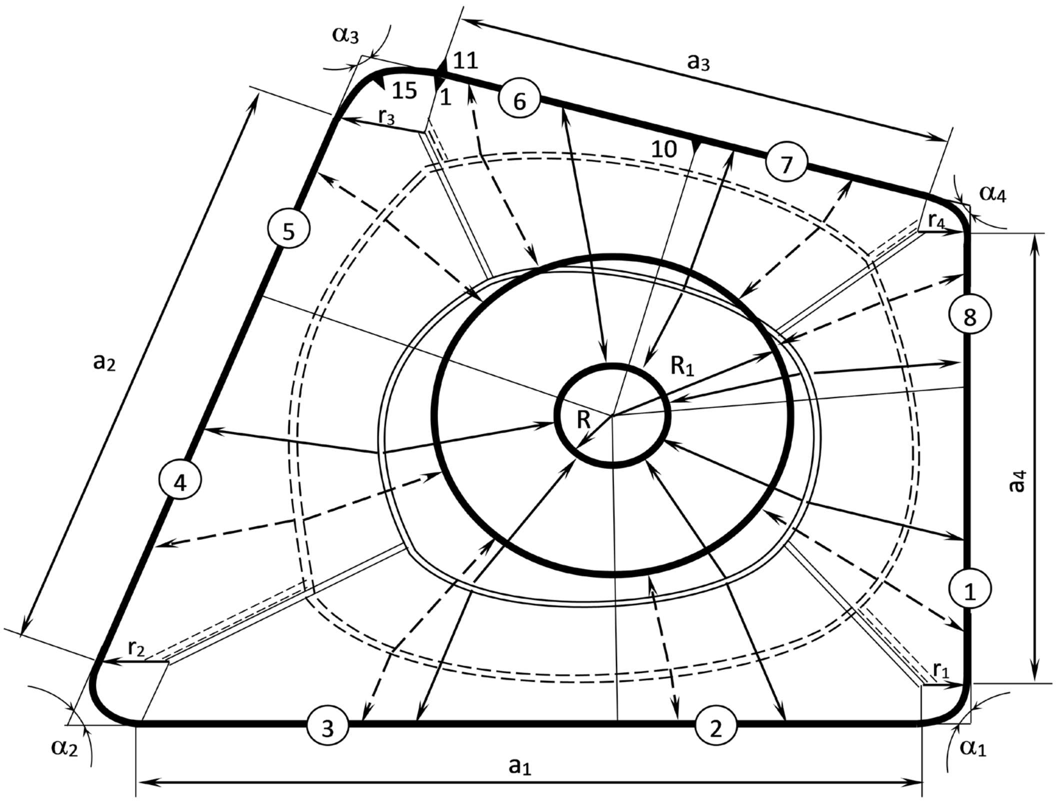

Fig. 3. Picture of metal flow.

in the central area of fin 5 and 60 % in the area of fin 6. At angular points stiffening fins are formed identically.

Industrial experiment

To test the calculation results of forming closed die forging with contour finning an industrial experiment of stepwise upsetting of AK6 alloy flat forged primary blanks by means of a hydraulic press of 150 MN deforming force was made.

There were used trapezoidal primary blanks of maximum 25x500x500 mm overall dimensions, which entirely covered the die impression. The die was heated up to 420^{o}C, the temperature of the primary blanks before stamping was 380 - 400oC. The «Vapor-T» oil with up to 75 % graphite addition was used as grease. The different values of under-forging were obtained by using a set of steel shims on one-plane die base surface. The value of the flat and the die mismatch at each upsetting stage was chosen so that the estimated and experimental values of forging cloth thickness in the area between fins coincided. The lug die cavity had 120 mm radius.

The primary blanks were upset up to the cloth thickness of 24 mm, 23 mm, 22 mm and 21 mm (Fig. 4).

The full forging formation was not achieved because of the low power of the hydraulic press. At the last step of upsetting the lug was entirely formed, whereas the angular areas of stiffening fins did not reach the estimated height (Fig. 4d).

The central areas of stiffening fins are formed much quicker than the angular areas, which results in metal flowing above die cavities under stiffening fins in central areas and worsens the product macrostructure (Fig. 5). The figure shows that the fin was cut from the side of the groove.

The comparison of the estimated and experimental height values was made for fins 5 and 6. Maximum difference in the estimated and experimental values for fins 5 and 6 was identified in their angular areas and made up 16 %; in central areas the difference was approximately the same for both fins and made up 12 %.

The application of the software complex for simulating different technologies in order to obtain the given serial forging served as a proof. As it was stated above, the forging could not be formed by one step with the technique suggested by the factory.

The calculation analysis provided recommendations for the die design and mass production technology. As the use of the lug of a big radius does not eliminate nonuniformity of certain stiffening fins, which may result in flaw forming, it is suggested that die forming

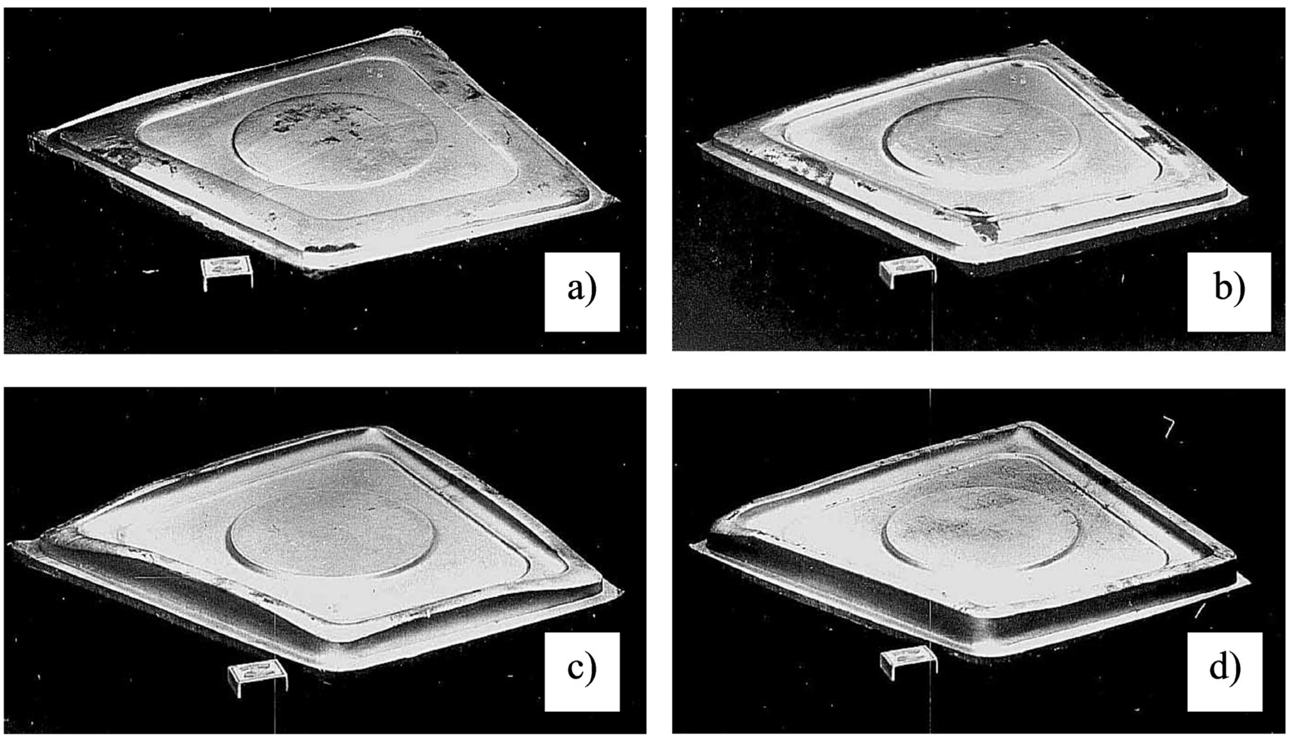

Fig. 4. Deformation of closed die forging.

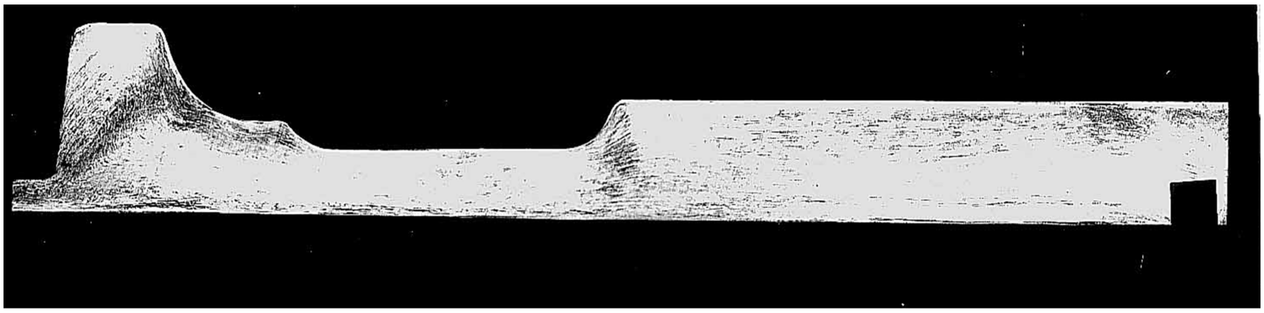

Fig. 5. The macrostructure of one-step forging.

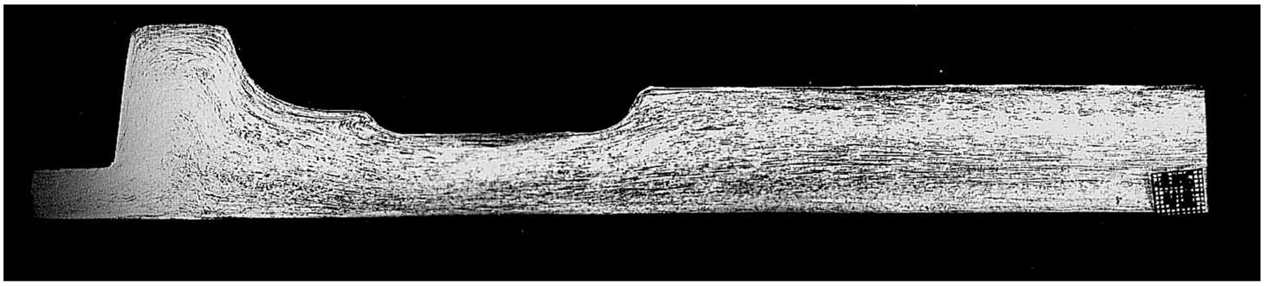

Fig. 6. The macrostructure of two-step forging.

should be performed by two steps in one final die, with cutting a hole of 30 mm radius in the centre of forging after the first step.

Industrial die stamping has proved their appropriateness: the force of the hydraulic press of up to 100 MN power was enough to produce a quality product, whereby the die forging macrostructure was significantly improved (Fig. 6).

CONCLUSIONS

The suggested calculation technique of forming finned forgings with a thin cloth allows automating the design of their production technology. The software complex may perform different functions: express analysis picture of metal flow, calculation of primary blank deformation at each stage. It makes also possible, while examining the values of die impression geometric parameters, to obtain various metal flow patterns and stiffening fin profiles and to select those that provide the most uniform metal flow into the die cavity under the stiffening fins, which ensures flawless product manufacturing.

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