Prediction of samples failure during severe plastic deformation by multiple extrusion

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Abstract. A method of obtaining a hardened semi-intensive plastic deformation by extrusion is considered. The results of simulation process at different stages of extrusion are given. Conclusions are drawn about the applicability of the simulation results to obtain the axisymmetric products. The results of sample study are given according to the method of determining the criterion of damage $\Psi$.

1. Introduction

Significant refinement of metals and alloys structure until the occurrence of nanostructured states can be provided by severe plastic deformation (SPD).

Special schemes of mechanical deformation are known and studied, such as intensive torsion under high pressure torsion disc blanks on the Bridgman anvils, equal channel angular pressing (ECAP), comprehensive forging etc. Recently, a number of new technological SPD schemes have appeared: “hourglass” [1], screw extrusion, in which intense shear deformation is achieved by hydromechanical pressing prismatic billet through a matrix with a screw channel, which cross section is orthogonal to the axis of extrusion and continuously along this axis [2].

The above mentioned technological scheme of SPD has a number of advantages. First, it is possible to make massive samples for mechanical testing. Secondly, residual porosity, obtained from powder materials, can be substantially reduced. Thirdly, these methods can be used to obtain ultra fine-textured patterns not only in modeling, but also in industrial alloys that can lead to the prospects of industrial applications. A promising method of SPD metals processing by expression for grinding structures can be rated among these methods [3].

2. The Main Part

The basic technological stages of this method are shown in figure 1.
Figure 1. The process diagram of SPD by expression:
(a) initial state; b) backward extrusion of “glass”; c) formation of the initial shape of the radial extrusion of “glass”; d) backward rod extrusion with thickening; e) formation of the initial shape of the radial extrusion of the rod with thickening; 1 – blank; 2 – matrix; 3 – plate washer; 4 – solid punch; 5 – hollow punch; \( P_1 \) – \( P_3 \) – extrusion power at different stages; \( P_n \) – back-pressure power (\( 0 \leq P_n < P_2, 0 \leq P_n < P_3 \)); \( D, d \) – diameters of the punches; \( v_1, v_2 \) – tools speed

The workpiece 1 is placed in the matrix 2, mounted on a special plate 3. The height of the matrix exceeds the height of the workpiece. A solid 4 and a hollow 5 punches are put on the workpiece, which alternately carry out the deformation.

Figure 2 presents the algorithm, showing various combinations of deformation in SPD expression.

Figure 2. The algorithm of SPD process by extrusion

Based on the developed algorithm the matrix of different variants was formed (table 1) of SPD process by extrusion, where 0 and 1 are Boolean variables corresponding to the execution of deformation of 1, or not performing to 0.

The process may begin with a backward extrusion of “glass” (deformation by tool 4) or rod with a thickening (deformation by tool 5). Then the deformation is carried out by tool 5 or by tool 4, up to obtaining the initial contour of workpiece (for example, options 1 and 2 in table 1).
Table 1. Morphological matrix of SPD variants by extrusion SDI

| Variant | Initial contour of workpiece | Backward extrusion of “glass” | Backward extrusion of a rod with a thickening | Radial extrusion with the receipt of the original form | Casting-off |
|---------|-----------------------------|-------------------------------|---------------------------------------------|---------------------------------------------------|------------|
| 1       | 1                           | 1                             | 0                                           | 1                                                 | 0          |
| 2       | 1                           | 0                             | 1                                           | 1                                                 | 0          |
| 3       | 1                           | 1                             | 0                                           | 1                                                 | 1          |
| 4       | 1                           | 0                             | 1                                           | 1                                                 | 1          |
| 5       | 1                           | 1                             | 0                                           | 1                                                 | 1          |
| 6       | 1                           | 0                             | 1                                           | 1                                                 | 1          |
| 7       | 1                           | 1                             | 0                                           | 1                                                 | 1          |
| 8       | 1                           | 0                             | 1                                           | 1                                                 | 1          |

Structure formation and strain hardening during the transition to intensive plastic deformation, were first observed and systematically studied in the works of V.I. Trefilov, Y.I. Milman and S.A. Firstov [4-8]. With the growth of strain in the material a qualitatively new type of dislocation structure is formed that are strongly misoriented cells. Their main feature is the continuous increase of misorientation angles with strain increasing at a weak reduction in the transverse dimensions. This pattern evolution is inherent to other metals. V.I. Trefilov with employees suggested to evaluate strain hardening during intensive deformation from the standpoint of the reduction of grain size in the extreme case up to size of strongly misoriented cells. His point of view about the radical changes in the mechanism of hardening received numerous confirmations and is now recognized by many scientists. Directed and continuously occurred motion of disclinations in the process of plastic deformation should lead to the fragmentation patterns of the metal, i.e. breaking it up into microregions, on misoriented angles of the order of several degrees. The more the degree of plastic deformation, the smaller should be the fragments and more is the turn relative to each other [9].

3. Experimental part
To establish the effect of the method on the stress-strain state (SSS) and determine the optimal deformation variants lead to the investigation of SPD process by extrusion in the QForm 7.2 environment. The simulation was performed sequentially according to the variant matrix (table 1). Material of the workpiece is alloy AD1, the temperature of the workpiece is 20°C, the temperature of the tool is 20°C, graphite grease. Strain rate is 1 mm/s. For easier comparison of the obtained results the scale of plastic deformation is he same in different extrusion variants and are graded from 0 to 20. The simulation results at different extrusion variants are summarized in table 2. The table is formed based on the algorithm shown in figure 3.

Figure 3. The algorithm of summary table formation of results (table 2): (a) workpiece with accumulated deformation rate after the implementation of one embodiment of the extrusion; (b) semi-finished type of “glass”; (c) semi-finished type of "stud with thickening"
To define the parameters of SSS based on the interaction of the software for simulation of forming processes, and software that allows you to perform mathematical calculations in Excel and MathCAD environments, in areas where destruction is likely to occur, the history of deformation is traced. Next, this information in the form of numerical tables is passed to the software for mathematical calculations, where method of determining the criterion of damage $\Psi$ is implemented. Further, there will be a check on the well-known V. L. Kolmogorov condition

$$\Psi = \int \frac{dE}{\varepsilon} (\eta) < 1$$

After a preliminary simulation of extrusion options of variants 1 and 2 (table 1), several areas were identified in workpieces where the destruction is possible. The traced points are placed in these zones (figure 4). The first zone includes points 2, 4, 5, 6, 7, 8, 9 and 10, which are located in the peripheral area of the workpiece, i.e., those points that are in the process of deformation directly interact with the tool and the matrix. The second zone includes points 1, 3, 11, 12, 13, 14, 15 and 16 – points inside the tested workpiece.
Figure 4. The location of the traced points after extrusion for option No. 1

Figure 5. Changing of the used plasticity resource in the course of deformation for option No. 1

In points No. 12 and No. 3 (figure 5) plasticity resource is exhausted and we can expect the formation of defects. In general, after extrusion for option No. 1, an adequate supply of plasticity is present to continue the accumulation of deformation with the purpose of increasing the strength of the workpiece.

4. Conclusions
The discussed method is promising for the implementation of SPD in large-sized workpieces, including intermetallic compounds, and other materials.

SSS allows to provide intensive plastic deformation of workpieces without damage and defects.

The simulation results and SSS in the workpieces with the possible application of these results to obtain blanks or semi-finished products are compared.

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