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STRAIN STATE AND MICROSTRUCTURE EVOLUTION OF AISI-316 AUSTENITIC STAINLESS STEEL DURING HIGH-PRESSURE TORSION (HPT) PROCESS IN THE NEW STAMP DESIGN

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The investigation of strain state and microstructure evolution of AISI-316 austenitic stainless steel during high-pressure torsion process in the new stamp design was performed. The study using Deform-3D program was conducted. The deformation was carried out at ambient temperature. The results of strain state study showed that after 4 passes the processed workpiece is obtained the level of equivalent strain more than 5. But the distribution of strain has a gradient view in the cross section. The simulation results of the microstructure evolution showed that after 4 passes of deformation the initial grain size of 12 μm can be reduced up to 0,8 μm. But the distribution of grain size in the cross section also has a non - uniform gradient view.

Keywords: stainless steel, high-pressure torsion, workpiece, strain state, microstructure

INTRODUCTION

High-pressure torsion (HPT) is one of the most well-known developed methods of severe plastic deformation for obtaining bulk ultrafine-grained and nanostructured samples [1-3]. Samples in the form of disks with a diameter of 10 - 20 mm and a thickness of 0,3 - 1 mm are deformed by torsion under conditions of high applied hydrostatic pressure. The sample is placed inside the cavity made in the lower striker, and a high hydrostatic pressure of 1 to 10 GPa is applied to it. Plastic deformation by torsion of the sample is carried out due to the rotation of one of the strikers. Turning the movable anvil at a certain angle allows to achieve different degrees of deformation.

The geometric shape of the sample is such that the bulk of the material is deformed under quasi-hydrostatic compression under the influence of applied pressure and pressure from the outer layers of the sample. As a result, the deformable sample does not damage, despite the high degree of deformation [4].

The high-pressure torsion method is also possible to process the workpiece in the form of a ring, according to the scheme proposed by S. Erbel [5]. This method has been developed and improved in various ways to increase the uniformity of the resulting structure in the center and on the periphery of the sample, the manufacturability and expansion of the types of produced materials.

In the high-pressure torsion process, the movement of the deforming tool consists of two types: translational and rotational. As a working mechanism for the implementation of this method, presses are ideal that allow to create a high hydrostatic pressure during compression. However, the main difficulty is the need to perform a torsion operation along the axis of the workpiece. To do this, it is necessary to communicate a certain torque to the deforming tool, which is often impossible due to the design features of most pressing equipment. Therefore, the possible option in this case is to ensure the torsion of the deforming tool with the constant rectilinear movement of the press punch. The solution of this technical problem can be implemented in practice only in the presence of a composite deforming tool that includes both displacement and rotation blocks.

One of the possible variants of such a scheme can be a double helix system. In this system, periodic spiral grooves of the same shape and size are created on two contacting surfaces. With the mutual movement towards each other and the rotation of at least one body around its axis, the contours of the spiral cutouts begin to mate until full contact. In our case, the rotational motion will be communicated to the idle element due to the sliding friction between the two spiral surfaces.

CREATION OF FINITE ELEMENT MODEL (FEM)

Figure 1 shows a three-dimensional assembly model of the stamp for the implementation of the high-pressure torsion process.

Here, the initial workpiece 1 in the form of a ring is laid in a glass 2, the inner part of which has a step with a width equal to the width of the workpiece. The upper part of the stamp consists of two parts. The punch 3 is fixed on the moving plate of the press and provides the force P, moving translationally. The deforming element

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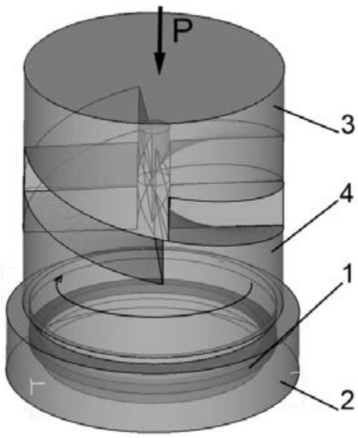

1 – workpiece, 2 – glass, 3 – punch, 4 – deforming element
Figure 1 Model of stamp

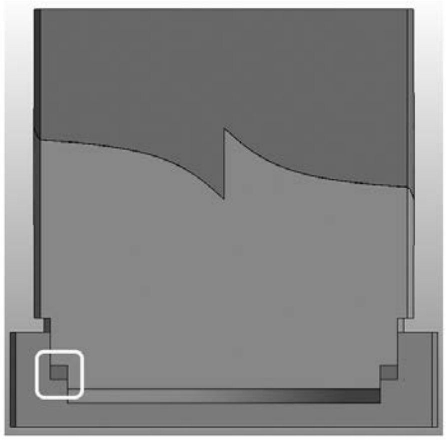

Figure 2 Location of the studied section in the model

4 is the link between the punch and the workpiece. Due to the spiral contact, this element, perceiving the force from the punch, begins to rotate around its axis (in this case, clockwise). Thus, both the force from the punch and a certain torque are transmitted to the workpiece.

The initial workpiece had an annular shape with a diameter of 76 mm, a width of 3,5 mm and a thickness of 3 mm. AISI-316 austenitic stainless steel was chosen as the material of the workpiece. The deformation was carried out at ambient temperature. The speed of the punch was 1,5 mm/sec. For the implementation of shear deformation in this process, a high degree of adhesion of the workpiece to the tool is necessary. Therefore, at the contact of the workpiece with the glass and the deforming element, the value of the coefficient of friction was set to 0,45. No velocity values were reported to the deforming element. Instead, the following boundary condition was set on the axis of the cylindrical rod: free movement in the vertical direction; movement of the axis in the other two directions was disabled. This fixation corresponds to the fact that the rod falls into the cylindrical cutout of the punch and can freely move and rotate in it.

Also for all spiral surfaces of the deforming element, rotation around this axis was allowed. At the same time, the value of the angular velocity of rotation was also not set, instead an extremely small value of the torque of 10^{-6} N·mm was set with the sign opposite to the intended direction of rotation. This method is universal when you want to set an indirect rotation from the action of friction forces. At the contact of the two spiral surfaces, a small value of the coefficient of friction was established, equal to 0,1, which in real conditions is provided by a low level of roughness of both surfaces and the use of lubrication.

During the model calculation, 4 deformation cycles were calculated. Since the shape of the workpiece cross-section does not change during high-pressure torsion, and the deformation process is axisymmetric, it was decided to perform an analysis in the cross-section of the workpiece after each pass. It was considered the left side of the model section, where the top and right side of the workpiece in contact with the rotating tool and the left and bottom faces – with fixed glass (Figure 2).

RESULTS AND DISCUSSION

To study the strain state, the parameter "Equivalent strain" was considered, the value of which is determined by the formula:

$$\varepsilon_{EQV} = \frac{\sqrt{2}}{3}\sqrt{\left(\varepsilon_1-\varepsilon_2\right)^2+\left(\varepsilon_2-\varepsilon_3\right)^2+\left(\varepsilon_3-\varepsilon_1\right)^2} \tag{1}$$

where ε_1, ε_2, ε_3 – main strains.

This parameter includes the main components of strain and characterizes the overall intensity of the material processing. To analyze the level of metal processing, histograms of the percentage distribution of equivalent strain levels over the cross-section of the deformed workpiece were constructed.

After the first pass (Figure 3), the main increase in strain occurs on the inner face of the ring (right side of the section), in the area of contact with the rotating tool. At the same time, the overwhelming cross-sectional area (more than 63 %) is essentially unprocessed, since here the maximum possible level of deformation is 0,75, which is extremely small for SPD processes. The development of strain goes from the contact zone with the tool deep into the section of the workpiece. The maximum level of strain after the first pass is 3,2 – 3,3, while the whole thickness of the ring blanks in the contact zone there is a study to the level of 2,7 – 2,8, decreasing slightly at the edges, which is the result of horizontal facets tools – here the level of strain is about 1,7 – 1,8.

After the second pass (Figure 4), the main increase in strain also occurs on the inner face of the ring (right side of the section), in the area of contact with the rotating tool. However, here it can be clearly seen the influence of the rotating horizontal face of the tool in contact with the upper face of the section, along which the strain also develops. The area of the region [0 ÷ 0,75] is significantly reduced to 46 %, which indicates an increase in the overall level of metal processing in the cross section of the annular workpiece. In contrast to the first pass, at this stage, the trajectory of strain development has a characteristic shape – the main increase in strain occurs in the areas of contact with the rotating faces of the tool. The maximum level of strain after the second pass is 4,8 –

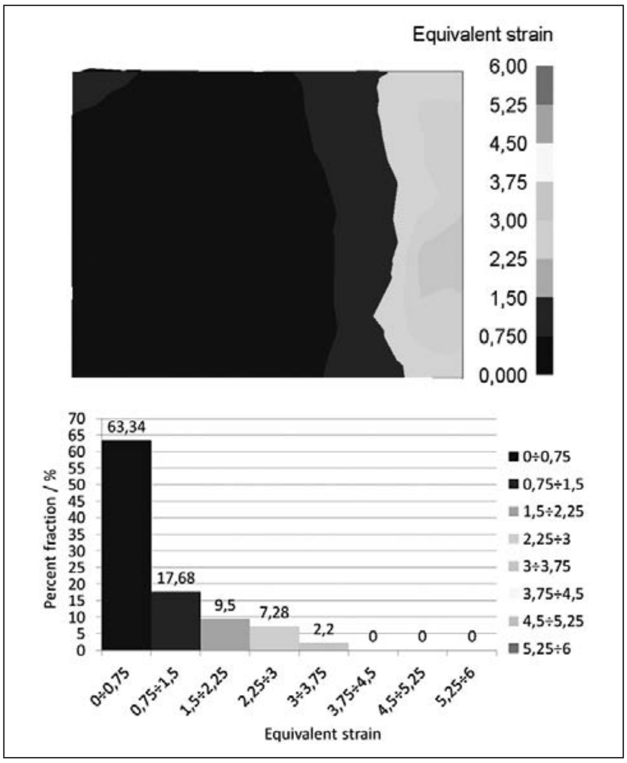

Figure 3 Distribution of the equivalent strain in the cross-section after the 1st pass

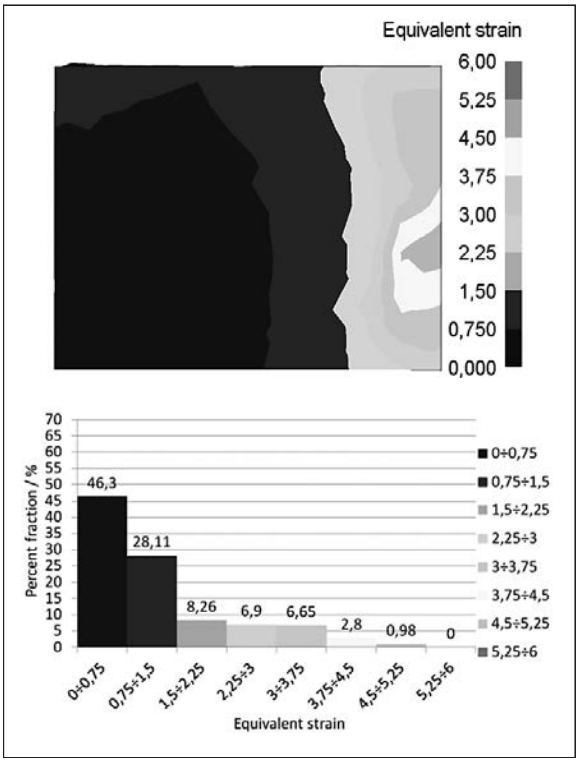

Figure 4 Distribution of the equivalent strain in the cross-section after the 2nd pass

4,9, while the entire thickness of the annular workpiece in the contact zone is worked out to the level of 3,4 – 3,5; at the edges, the level of strain is about 2,6 – 2,7.

After the third pass (Figure 5), the area of the region [0 ÷ 0,75] ceases to be dominant, decreasing to 28 %. The largest part of the cross-section (more than 40 %) is occupied by the zone in which the level of strain is in the range of 1,1 – 1,2. The maximum level of strain after the third pass develops on the inner face of the ring-from 5,3 – 5,4 in the center to 2,8 – 2,9 at the edges.

After the fourth pass (Figure 6), the area of the region [0 ÷ 0,75] is about 7 %. The largest part of the cross-section (more than 40 %) is occupied by the zone in which the level of strain is in the range of 1,3 – 1,4. The maximum level of strain after the fourth pass develops on the inner face of the ring - from 5,8 – 5,9 in the center to 4,6 - 4,7 at the edges.

To simulate the microstructure evolution in the considered high-pressure torsion process, it was decided to conduct a combined simulation. The first method is a classic one, showing a gradient distribution of the grain size, its calculation is carried out during the main calculation of all the energy-power parameters of the process. The second method, called Cellular Automata, shows the calculation result only at certain points. However, in this case, the user can predict not only the size, but also the shape of the grains. The initial grain size was assumed to be 12 μm.

Figure 7 shows the grain size distribution in the cross section of the annular workpiece after the 4th pass. The areas of contact with the rotating faces of the tool get the most processing. At the same time, the grain size decreases on the faces of the workpiece, as it approaches the fixed faces of the glass.

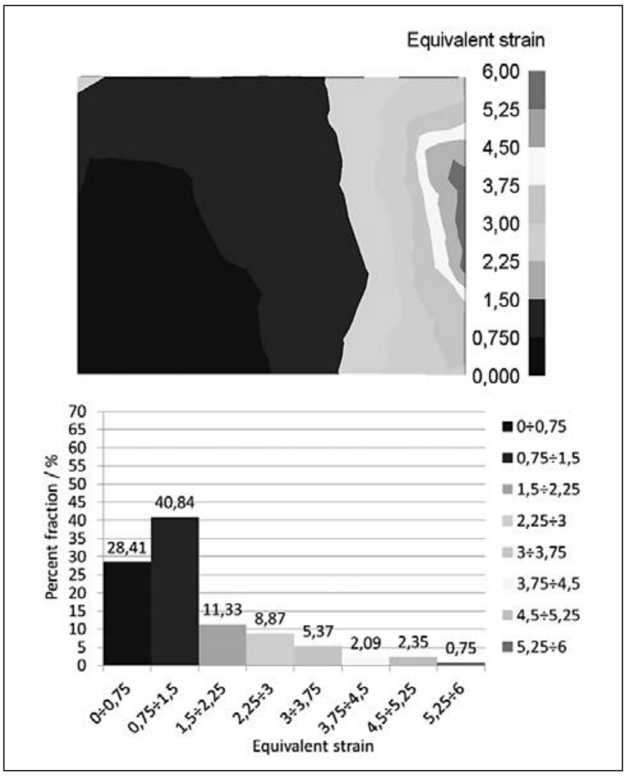

Figure 5 Distribution of the equivalent strain in the cross-section after the 3rd pass

For a detailed analysis, one control point was made on the obtained dimensional zones along the entire width of the workpiece. The calculation in a window with dimensions of 50 x 50 μm was used. The results are shown in Figure 8 and Table 1.

At the same time, it was revealed that individual grains with a size of 0,243 μm were found in zone 8.

Table 1 **Average grain size by zones**

Zone	1	2	3	4	5	6	7	8
Grain size / μm	10,8	9	7,8	6,2	4,5	3,2	2	0,8

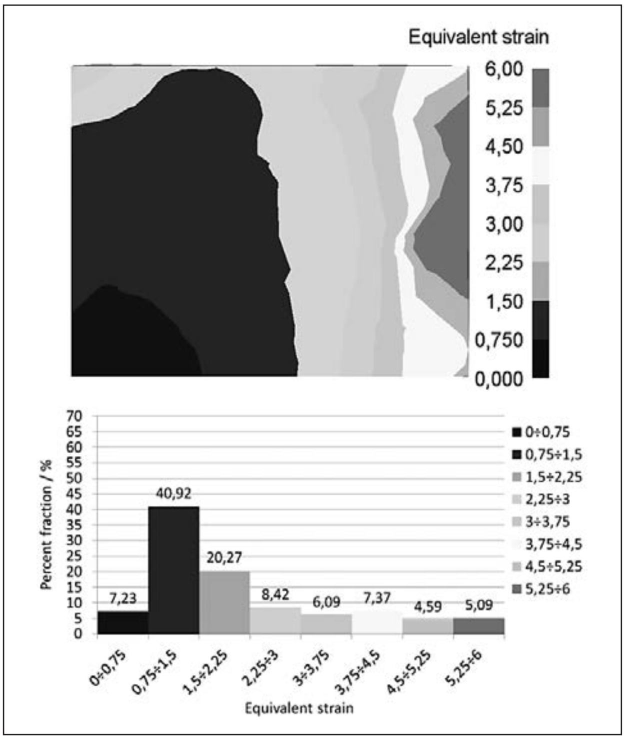

Figure 6 Distribution of the equivalent strain in the cross-section after the 4th pass

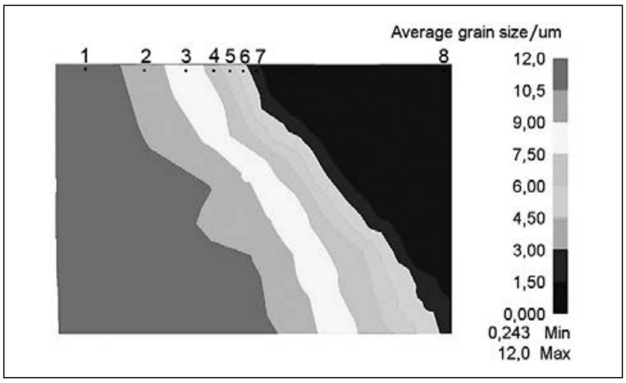

Figure 7 Grain size in the section of the blank after the 4th pass

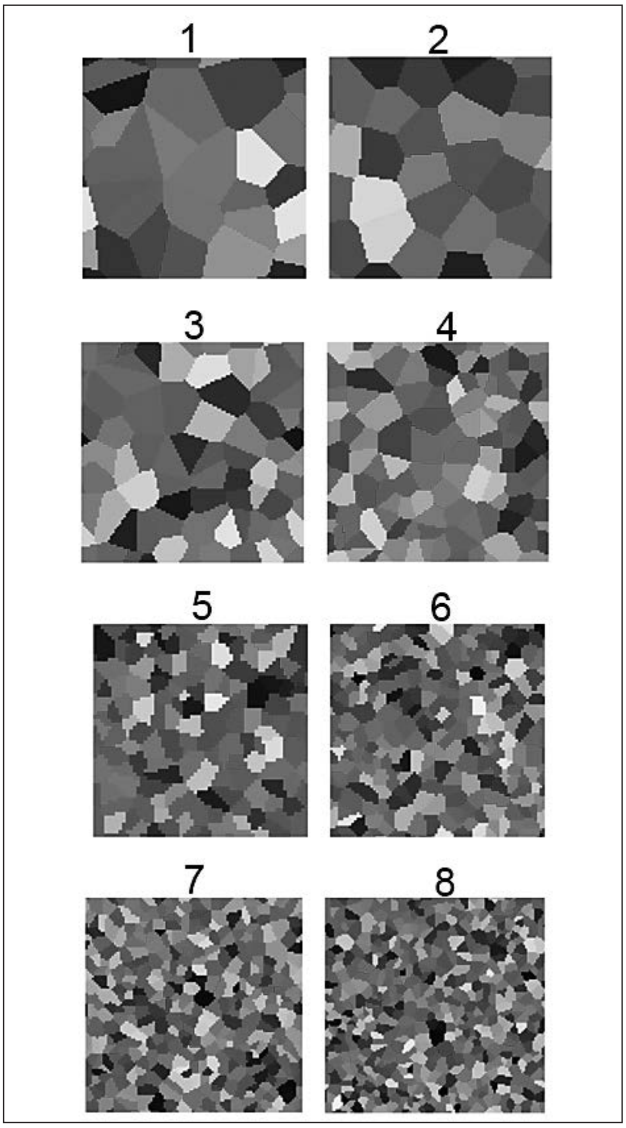

Figure 8 Microstructure evolution

CONCLUSIONS

A special stamp design was developed, which allows to implement the high-pressure torsion process. The investigation of strain state and microstructure evolution at ambient temperature using Deform-3D program was conducted. The results of strain state study showed that after 4 passes the processed workpiece is obtained the level of equivalent strain more than 5. The simulation results of the microstructure evolution showed that after 4 passes of deformation the initial grain size of 12 μm can be reduced up to 0,8 μm. But the distribution of both parameters in the cross section also has a non - uniform gradient view.

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REFERENCES

[1] F. Z. Utyashev, G. I. Raab, Deformation methods for obtaining and processing ultrafine-grained and nanostructured materials, Ufa, Gilem, 2013, 214-222 .

[2] A. P. Zhilyaev, T. G. Langdon, Using high-pressure torsion for metal processing: Fundamentals and applications, Progress in Materials Science 53 (2008), 893-979.

[3] C. Xu, Z. Horita, T. G. Langdon, The evolution of homogeneity in processing by high-pressure torsion, Acta Materialia 55 (2007), 203-212.

[4] O. L. Khasanov, E. S. Dvilis, Z. G. Bikbaeva Methods of compaction and consolidation of nanostructured materials and products, Tomsk: Tomsk Polytechnic University Publishing House, 2008, 82-85.

[5] S. Erbel, Mechanical properties and structure of extremely strain-hardened copper, Metals Technology 6 (1979), 482-486.

Note: Translated by D. Rahimbekova, Temirtau, Kazakhstan