УДК 621.77.043 DOI: 10.30929/1995-0519.2021.6.79-84

INVESTIGATION OF DIFFERENT DEFORMATION SCHEMES FOR OBTAINING FINE-GRAIN STRUCTURE OF CAST ALUMINUM ALLOY AK 7

N. Zlochevska, A. Lavrinenkov, V. Koreva, V. Pasichnyk
National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»
ORCID: 0000-0002-7252-9566; 0000-0003-3292-7663; 0000-0002-4422-6277

Abstract. The article investigated various schemes of deformation of the workpiece to improve the mechanical properties of the cast aluminum alloy AK 7. The most effective deformation schemes are spiral widening extrusion (SWE) and multi-angle pressing (MAP). Filling of a matrix most completely occurs at the SWE scheme, the degree of filling makes 90–95%. The depth of propagation of plastic deformation in the scheme of SWE is 6–9 mm. The results of numerical simulations correlate with the results obtained experimentally for the SWE matrix. It was experimentally determined that the increase in the accumulated shear deformation causes an increase in the values of microhardness. The magnitude of the accumulated deformation increases along the radial coordinate from the center to the edge of the workpiece. It was found that after the third transition in the central zone, the amount of accumulated deformation is approximately equal to the amount of deformation after the first pass in the edge zone. Mechanical properties, namely strength characteristics are increased. So after the first pass their values increase in relation to the source metal by 15%, after the second treatment by 20%, after the third by 25%.

Keywords: spiral widening extrusion, polygonal pressing, multi-angle pressing, increase of mechanical properties, intensive plastic deformations, back pressure.

ДОСЛІДЖЕННЯ РІЗНИХ СХЕМ ДЕФОРМАЦІЇ ДЛЯ ОТРИМАННЯ ДРІБНОЗЕРНИСТОЇ СТРУКТУРИ ЛИТОГО АЛЮМІНІЄВОГО СПЛАВУ АК 7

Н. Злочевська, А. Лавріненков, В. Корева, В. Пасічник
Національний технічний університет України «Київський політехнічний інститут імені Ігоря Сікорського»
ORCID: 0000-0002-7252-9566; 0000-0003-3292-7663; 0000-0002-4422-6277

У статті досліджено різні схеми деформації заготовки для поліпшення механічних властивостей литого алюмінієвого сплаву АК 7. Найефективнішими схемами деформування є спіральне розширювальне видавлювання (SWE) і багатокутове пресування (MAP). Заповнення матриці найбільш повно відбувається за схемою SWE, ступінь заповнення становить 90–95%. Глибина поширення пластичної деформації за схемою SWE становить 6–9 мм. Результати чисельного моделювання корелюють з результатами, отриманими експериментально для матриці SWE. Експериментально встановлено, що збільшення накопиченої деформації зсуву викликає збільшення значень мікротвердості. Величина накопиченої деформації збільшується по радіальній координаті від центру до краю заготовки. Установлено, що після третього переходу в центральній зоні величина накопиченої деформації приблизно дорівнює величині деформації після першого проходу в крайовій зоні. Підвищуються механічні властивості, а саме характеристики міцності. Так, після першого проходу їх значення збільшуються по відношенню до вихідного металу на 15%, після другої обробки на 20%, після третьої на 25%.

Ключові слова: спіральне розширювальне пресування, полігональне пресування, багатокутове пресування, підвищення механічних властивостей, інтенсивні пластичні деформації, зворотній тиск.

PROBLEM STATEMENT. The use of materials with a fine-grained structure in the modern machine, aircraft construction is promising due to the improved mechanical properties after processing. This is especially true of cast aluminum alloys, which have unstable physical, mechanical and operational properties obtained after casting. It is possible to increase the mechanical properties due to large shear deformations or intense plastic deformations (IPD).

The increase is due to the grinding of the elements of the microstructure without changing the size of the workpiece. A feature of the materials obtained by IPD is the presence of ultrafine-grained structure, which contains mainly polygonal grain boundaries. These materials have a unique structure and properties [1].

There are several requirements for obtaining these materials [2]:

1. Formation of homogeneous mechanical characteristics throughout the volume of the sample, which is necessary to ensure the stability of the properties of the obtained materials.

2. Formation of ultrafine-grained structure having polygonal grain boundaries, only in this case the properties of materials change qualitatively.

3. The samples must be free from mechanical damage or destruction, despite their intense deformation.

At present, the following methods of intense plastic deformation are known all over the world, including equal-channel angular pressing [3–5], torsion under pressure [6], spiral extrusion [7], spiral widening extrusion [8], and others. The analysis of the above methods showed that the IPD methods are fundamentally different from other deformation methods of processing large degrees of deformation without deformation. To ensure the uniformity of the structure throughout the volume for all of the above methods, it is necessary to carry out a sufficient number of processing cycles.

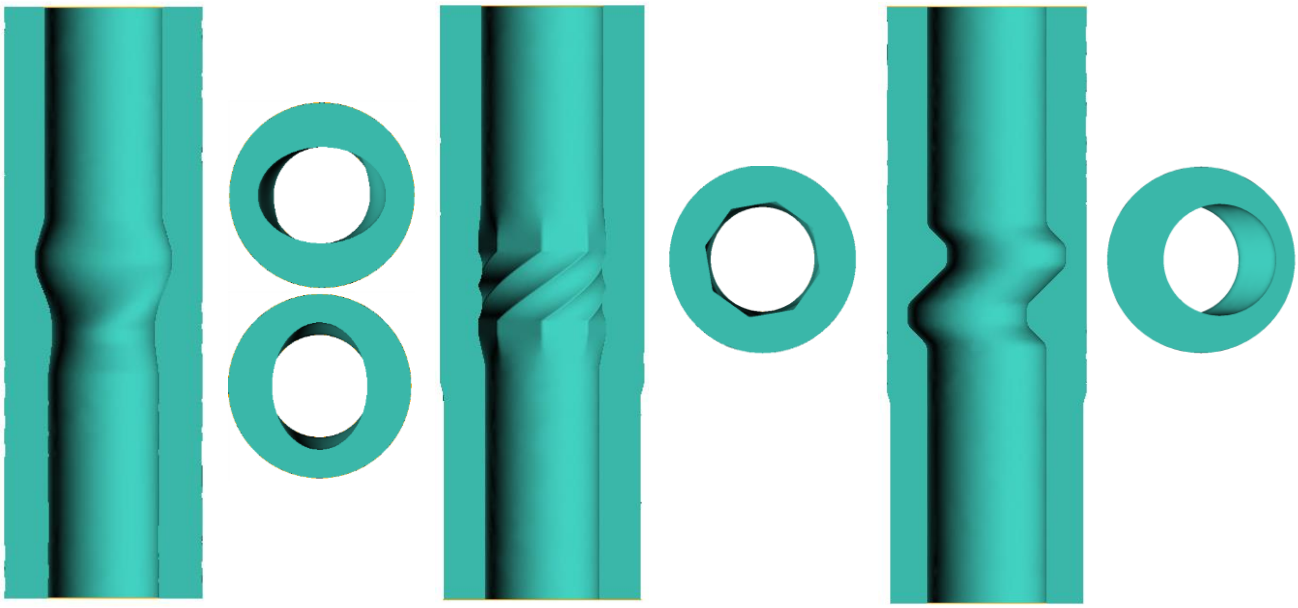
Depending on the pressing scheme, the amount of plastic deformation of the material will be different. Accordingly, the elaboration of the structure of the workpiece material will be different, which in the real process will affect the microstructure of the workpiece.

To investigate and experimentally confirm the influence of different deformation schemes to obtain a fine-grained structure of the material in cast cast alloys AK7.

MATERIAL AND RESULTS. For the experiment, a computerized installation was made, which is mounted on a hydraulic press model PD 476 with a force of 160hp. The samples are made of cast aluminum alloy brand AK7ch with iron impurities in two versions 0,8% and 1,4%. The blanks were obtained by casting in sand molds. Previously obtained blanks (ingots) were processed on a lathe to the dimensions of the original workpiece: diameter Ø29,5 mm, height h=50 mm. The initial blanks had a characteristic cast structure, which consisted of primary dendrites of aluminum solid solution and sections of aluminum-silicon eutectic, as well as plate crystals of iron intermetallic phases.

Before deformation, the workpieces were heated in a furnace. Heating of blanks and equipment was carried out to the same temperature 450–480ºC. The pressing speed was 2 mm/s. Pressing of blanks was performed one after another.

The following pressing schemes were chosen for modeling: spiral widening extrusion (SWE), polygonal pressing (PP) and multi-angle pressing (MAP) (Fig. 1). In Fig. 1 shows cross-sections of the areas of the matrix where intense plastic deformations occur. The simulation was performed by the finite element method (FEM) in the QForm program. Parameters of the modeling process: type of operation - deformation taking into account thermal processes; workpiece material – AK7; billet temperature – 450°C; equipment – hydraulic press with a force of 160 tons; the number of workpieces (except for corner pressing) – two (the second acts as a back pressure).



a) b) c)

Figure 1 – Pressing schemes:
a – SWE; b – PP; c – MAP

The task of modeling was to establish the degree of filling of the matrix channel. To better fill the channel of the die molding of the workpieces is continuous (the previous workpiece acts as a back pressure). The most complete filling occurs at the scheme of SWE. The percentage of filling is 90–95%. In the PP scheme, the filling of the matrix channel was 50–60%. It was not possible to implement the scheme of continuous pressing with the MAP scheme. Plastic deformation occurs at the first angular transition. To fill the second corner transition it is necessary to apply a back pressure by the hydraulic cylinder as the preliminary preparation does not create necessary effort. Given this, the most effective pressing scheme is the SWE.

The results of a numerical study

According to the simulation results (Fig. 2), we can say that the pressing scheme in which the plastic deformation of the maximum volume of metal occurs corresponds to the scheme of SWE.

It is established that in the scheme of PP effective plastic deformation of the material occurs near the workpiece surface. The depth of deformation is 1,5–2,5 mm. At the scheme of SWE it is possible to speak about plastic deformation of material of preparation on all cross section of preparation. The smallest plastic deformation corresponds to the middle of the workpiece. Depth of propagation of plastic deformation is 6–9 mm.

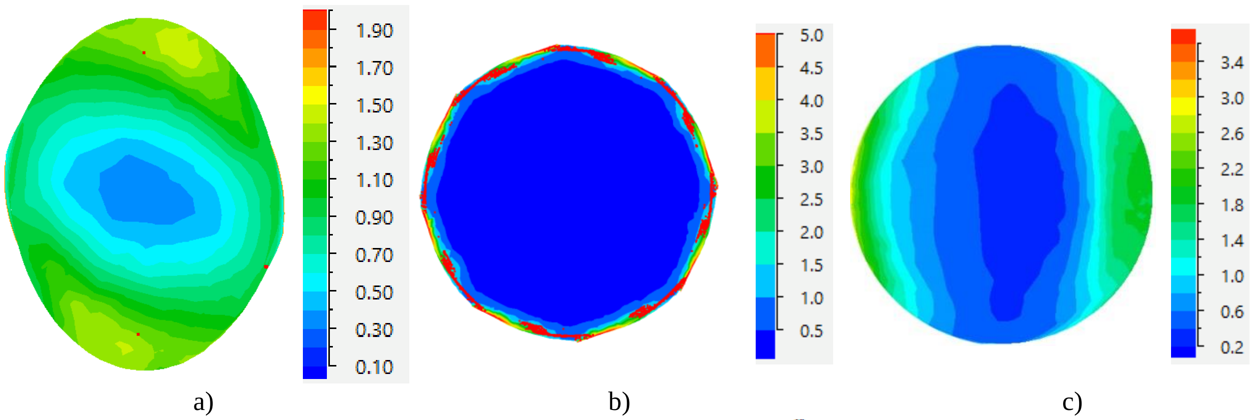


Figure 2 – Distribution of effective plastic deformation e^{p}_{ef} in the center of deformation:
a – SWE; b – PP; c – MAP

But due to the peculiarities of the matrix channel, the intense plastic deformation in the scheme SWE (change the cross section of the matrix circle-ellipse-ellipse (rotation 900C) – circle) processing of the material occurs on both sides of the workpiece, and at an angle corresponding to the angle of the matrix cross section (Fig. 3).

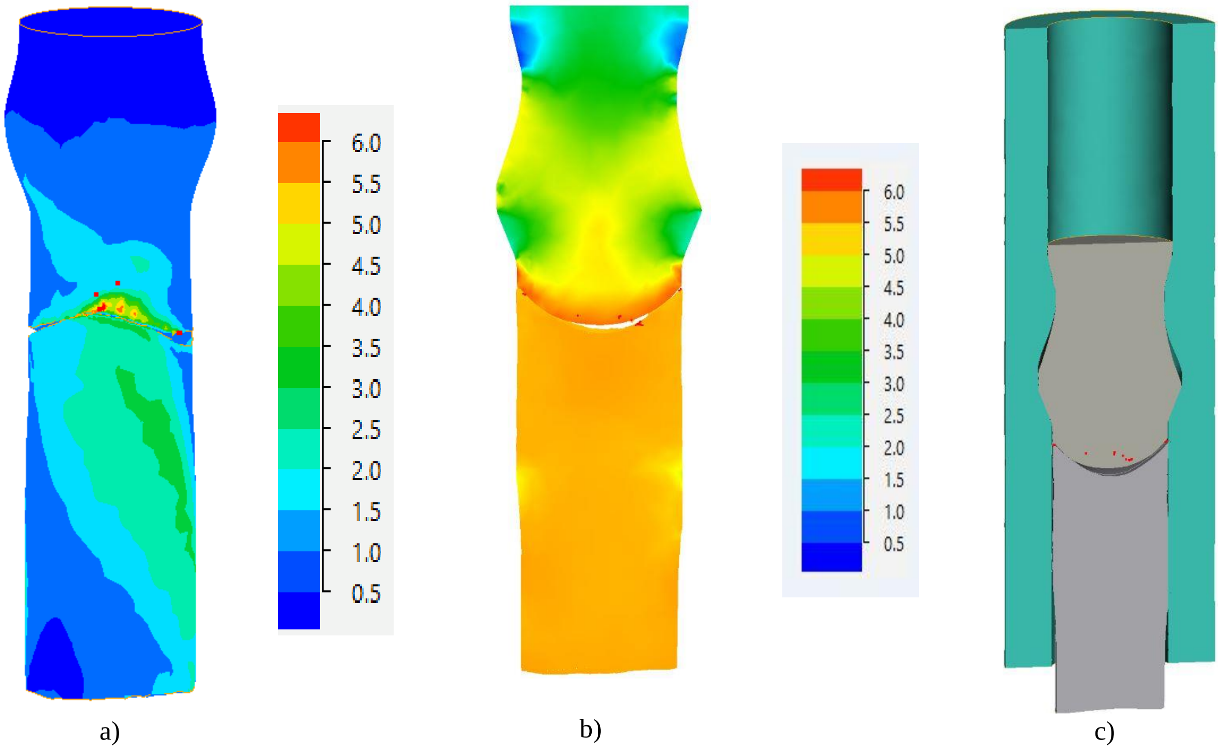


Figure 3 – Plastic deformation of the workpiece according to the scheme of SWE:
a – plastic deformation; b – average stresses; c – filling the matrix

For maximum processing of the workpiece material in order to obtain a crushed microstructure, pressing requires work in two passes. Also, in order not to re-deform the same parts of the workpiece, at the entrance to the matrix, the workpiece must be rotated by 900 relative to the first pass of the workpiece. If this condition is met, the working of the workpiece material during pressing according to the SWE scheme will be maximum. The same condition must be observed when pressing according to the MAP scheme (Fig. 1, c).

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According to the scheme of SWE depth of plastic deformation makes 3–6 mm. But if you implement the complete filling of the material of the two angular transitions of the matrix, then the depth of plastic deformation of the material and the magnitude will be increased. If to compare schemes of pressing on size of plastic deformation the scheme of polygonal pressing, then screw expanding pressing is the most effective. The least effective pressing scheme is a polygonal pressing scheme.

The results of numerical simulations correlate with the results obtained experimentally for the SWE matrix.

The results of the experimental study

To assess the impact of deformation treatment by screw widening compression on the mechanical properties and structure of the material AK7, the workpieces were processed in one and several transitions.

In fig. 4. the dependence of the microhardness of the workpieces on the number of passes during isothermal screw pressing for the alloy AK7 is presented.

The distribution of microhardness, as in previous studies, shows that microhardness increases with increasing degree of accumulated deformation. In fig. 5 shows a comparison of the dependences of microhardness and the degree of deformation depending on the radius of the deformed workpiece after the first pass.

It is shown that an increase in the accumulated shear deformation causes an increase in the values of microhardness. The magnitude of the accumulated deformation increases along the radial coordinate from the center to the edge of the workpiece.

Mechanical properties were determined on the samples during compression experiments in accordance with DSTU 2576-94. In fig. 6 shows the dependences of the value of the yield strength $\sigma_{0,2}$ and the yield strength $\sigma_в$ on the number of passes during isothermal screw pressing of samples from the alloy AK7.

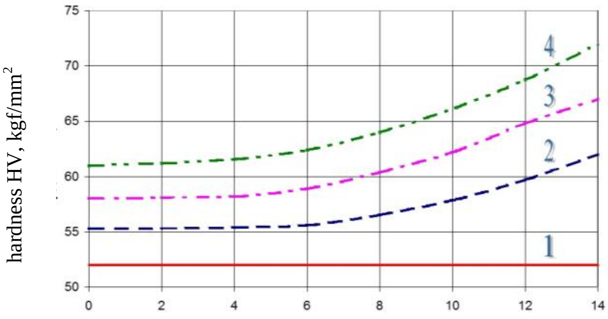
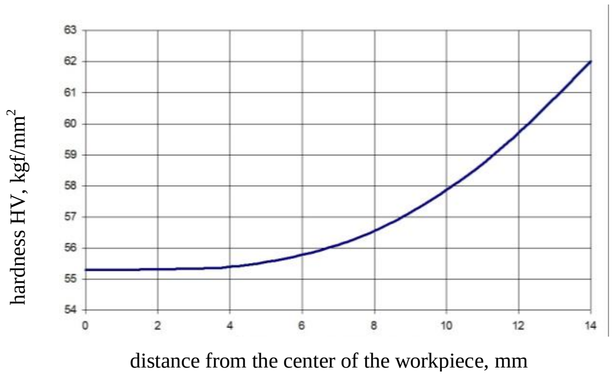
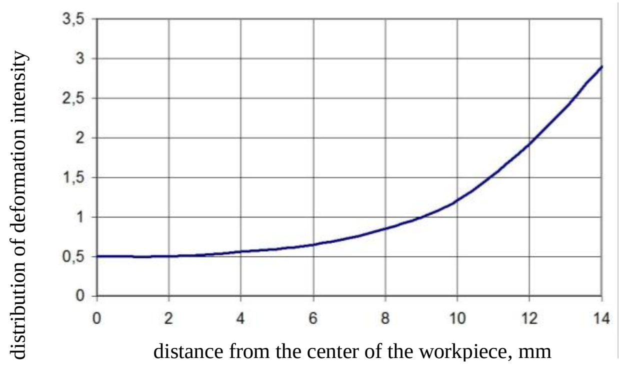


Figure 4 – The dependence of the microhardness of the metal of the workpiece along the radial coordinate after: 1 – without processing; 2 – the first pass; 3 – the second pass; 4 – the third pass



a)



b)

Figure 5 – Comparison of the dependences of microhardness (a) and the degree of accumulated deformation (b) for a sample of AK7 alloy after the first pass

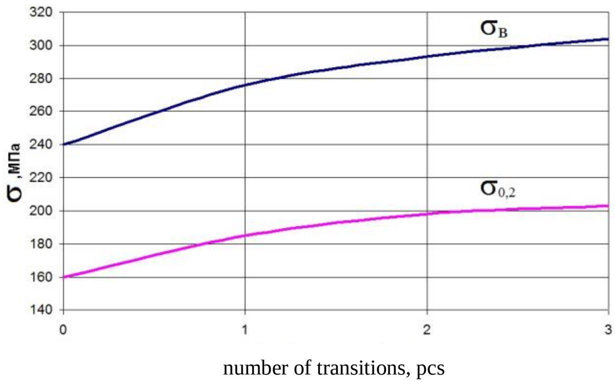


Figure 6 – Dependence of yield strength $\sigma_{0,2}$ and strength limit $\sigma_в$ on the number of passes during isothermal screw pressing of samples from AK7 alloy

The obtained results show that after deformation the strength characteristics increase. So after the first pass their values increase in relation to the source metal by 15%, after the second treatment by 20%, after the third 25%. The relative elongation of the samples in the experiments on uniaxial stretching in accordance with DSTU EN 10002-1: 2006, does not change.

In fig. 7. a comparison of the microstructure of the sample material in the Central and marginal zones depending on the accumulated deformation after several passes.

During the plastic deformation of the cast samples, a significant change in the parameters of the AK7h alloy structure is observed [9]. After a single deformation, the structure of the phase components begins to acquire more compact shapes.

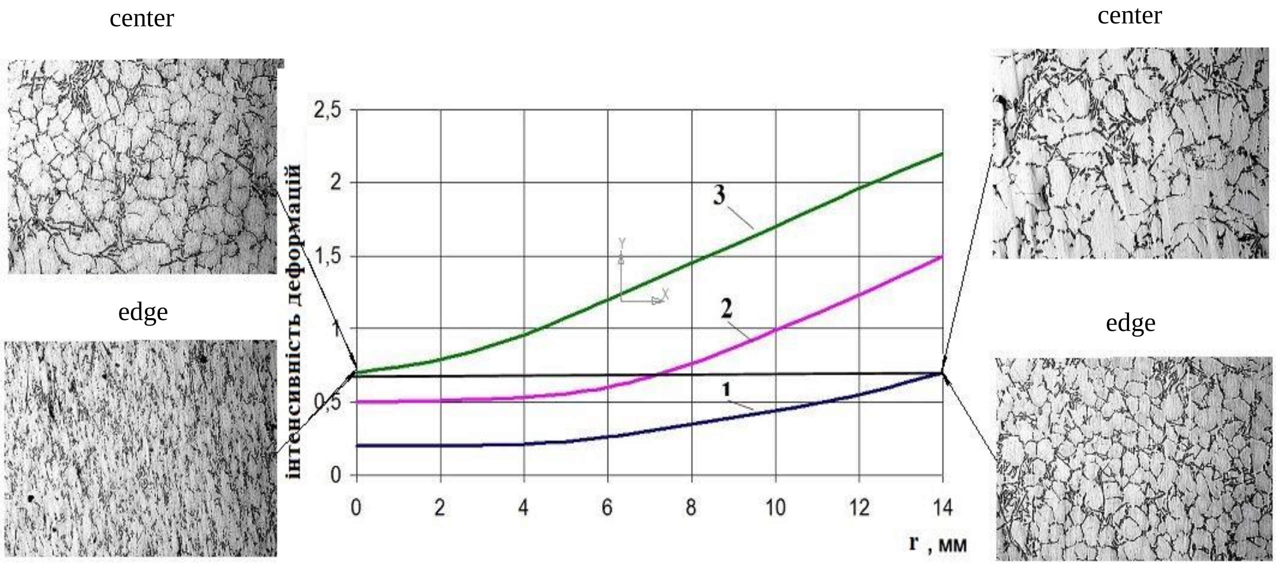


Figure 7 – Comparison of the value of the accumulated deformation intensity for one (1), two (2), three (3) passes and the effect of this deformation on the structure of the workpiece material

As a result of deformation processing there is a grinding of grains, structural components and cleaning of borders. With this method of processing [10], the degree of transformation of the crystal structure increases from the center to the side surface of the sample, where the average grain size is reduced by about half.

It is shown that after the third transition in the central zone the value of the accumulated deformation is approximately equal to the value of the deformation after the first pass in the edge zone. This is confirmed by the results of metallographic analysis.

CONCLUSIONS.

1. It is established that the most complete filling of the matrix occurs in the scheme of SWE. The percentage of filling is 90–95%. In the PP scheme, the filling of the matrix channel was 50–60%.

2. It is established that in the scheme of PP effective plastic deformation of the material occurs near the workpiece surface. The depth of deformation is 1,5–2,5 mm.

3. It is established that at the scheme of SWE the depth of distribution of plastic deformation makes 6–9 mm.

4. It is experimentally established that at the SWE scheme characteristics of durability increase. So after the first pass their values increase in relation to the source metal by 15%, after the second treatment by 20%, after the third 25%. The relative elongation of the samples in the experiments on uniaxial stretching is practically unchanged.

5. It is shown that the increase in the accumulated shear deformation causes an increase in the values of microhardness. The magnitude of the accumulated deformation increases along the radial coordinate from the center to the edge of the workpiece.

6. It is established that for maximum processing of the workpiece material in order to obtain a crushed microstructure, pressing requires work in two or more passes.

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Стаття надійшла 01.12.2021