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Abstract

The results of the study of the stressed and strained state of metal during turning the billet in the “rolling-extrusion” joint process using the equichanneled step die and grooved rolls are given in this work. The study of the process was made with the help of computer modeling in the DEFORM complex program. During the study of the stressed state there was studied the distribution of the equivalent stress in the main sites of origen for metal strain – in the rolls and in the areas of joint of the die channels. During the study of the strained state there was studied the distribution of the accumulated strain in various billet cross-sections in the process of the strain. It was found that turning of the billet not only has a positive effect on the distribution of the accumulated strain and equivalent stress in the billet but also provides the recovery of the initial cross-section form which is very important in a number of cases.

Keywords: “rolling-extrusion”, joint process, grooved rolls, computer modeling, equichanneled step die

1. INTRODUCTION

In spite of great prospects the problem of use of nanostructural (NS) metals and alloys as structural and functional new generation materials has been disputable until lately. A breakthrough in this field connected with both the development of new ways of making solid NS materials and the study of fundamental mechanisms resulting in the appearance of new properties has taken shape in the latter years. Though present-day high-rate plastic deformation technologies allow to obtain solid nanostructural materials there has nit been an industrial technique of making such materials until recently because of its very high manufacturing cost. That is why the development of new concepts of using high-rate plastic deformation (HRPD) for making solid NS metals with promising properties is now a real challenge.

In their works (1-4) the authors proposed a new technique for realization of high-rate plastic deformation in the deforming process, namely the “rolling – extrusion” joint process with the use of the equichanneled step die (fig. 1), and described the advantages of this process.

The essence of this process consists in the fact that the billet pre-heated to the temperature of the beginning of deformation is fed to the rolls which grip it into the roll gap at the cost of contact friction forces and on leaving the roll gap they push it through the channels of the equichanneled step die. When the billet leaves the roll gap completely another billet is fed which having passed through the rolls and entering the die pushes out the previously deformed billet from the die. That means that in – this case the billet extrusion in the equichanneled step die is realized at the cost of using contact friction forces emerging on the surface of the contact of metal with the spinning rolls. Both plain and grooved rolls can be used during realization of the joint deformation process. Besides it was proved that it is highly expedient to use grooved rolls as a working tool acting like a punch and pushing the billet through the die channels [1].
It is from work [5] that in order to produce sub-ultrafine-grained structure and moreover, nanocrystal structure using conventional step extrusion it is necessary to make not less than 10-12 deformation cycles. In the “rolling-extrusion” process scheme the number of cycles is reduced to 8-9 at the cost of extra deformation of the billet in the grooved rolls, and this number is still big. That is why the main and most important trend of the further development of this deformation technique is reduction of the number of deformation cycles necessary for producing sub – ultrafine-grained structure and increasing its output.

Proceeding from the above at the chair of metal forming of Karaganda state industrial university there has been proposed the following trend of the development of this deformation scheme, namely turning of the billet. The essence of this method consists in the fact that after the second pair of rolls has drawn out the billet from the die it is turned by 90° and is again fed into the first pair of rolls. Thus, shear deformations will be realized not only along the width but also along the thickness of the billet which will result in the reduction of the required number of deformation cycles.

In order to evaluate the effect of the billet turning on the stressed and strained state of the metal during realization of the “rolling – extrusion” joint process modeling of the process in the program complex DEFORM-3D was made. The model used in works [2-3] for studying stressed and strained state was assumed as the prototype.

The following parameters were studied for the analysis of the stressed and strained state:

- equivalent stress $\sigma_{eqv}$
- equivalent strain $\varepsilon_{eqv}$

These parameters were studied sequentially, at first after the first pass when the billet completely left the second pair of rolls (fig.2, a-c), then it was turned by 90° and fed into the first pair of rolls again, was deformed in the die and drawn out from it by the second pair of rolls (fig.3,a-b).
Fig. 2. Stages of the first pass
Fig.2 and 3 illustrate the distribution of the equivalent strain along the length of the deformed billet. One can see that after rolling in the second pair of rolls the distribution of strain is uniform. That is why the strained state was studied along with the distribution of the stored strain in the billet cross-section. With this view there were made sections in the following parts of the made billet model (fig.4):

- section 1-1 – at the entrance to the first pair of rolls;
- section 2-2 – at the exit from the first pair of rolls;
- section 3-3 – in the centre of the entrance channel;
- section 4-4 – in the centre of the intermediate channel;
- section 5-5 – in the centre of the exit channel;
- section 6-6 – at the entrance to the second pair of rolls;
- section 7-7 – at the exit from the second pair of rolls;

As a result the following patterns of the equivalent strain distribution were obtained (table 1).
It is obvious from table 1 that the distribution of the stored strain in all the sections is uniform after the first pass with the exception of the surface portions where the value of the equivalent strain is a little higher. This is explained by extra shear strains arising because of the friction of the billet on the rolls surface and the die. The average value of the equivalent strain equals to:

- in section 1-1=0 in the central and surface layers of the billet;
- in section 2-2=0,2-0,27 in the central layers of the billet and 0,3 – 0,38 in the surface ones;
- in section 3-3=0,23-0,28 in the central layers of the billet and 0,32-0,4 in the surface ones;
- in section 4-4=0,4-0,5 in the central layers of the billet and 0,44-0,6 in the surface ones;
- in section 5-5=0,6-0,7 in the central layers of the billet and 0,65-0,75 in the surface ones;
- in section 6-6=0,62-0,72 in the central layers of the billet and 0,92-0,97 in the surface ones.

After turning the billet and its second pass the value of the equivalent strain grows, except section 1-1 in which the equivalent strain value is equal to the value in section 7-7 after the first pass:

- in section 1-1=0,9-0,95 in the central layers of the billet and 0,92-0,97 in the surface ones;
- in section 2-2=1,05-1,09 in the central layers of the billet and 1,07-1,1 in the surface ones;
- in section 3-3=1,07-1,1 in the central layers of the billet and 1,08-1,13 in the surface ones;
- in section 4-4=1,15-1,2 in the central layers of the billet and 1,4-1,5 in the surface ones;
- in section 5-5=1,4-1,5 in the central layers of the billet and 1,7-1,8 in the surface ones;
- in section 6-6=1,42-1,54 in the central layers of the billet and 1,73-1,85 in the surface ones;
- in section 7-7=1,6-1,7 in the central layers of the billet and 1,9-2,0 in the surface ones;
Table 1 Distribution of stored strain on cross-sections

<table>
<thead>
<tr>
<th>Section number</th>
<th>Distribution of $\varepsilon_{eq}$ after the 1-st pass</th>
<th>Distribution of $\varepsilon_{eq}$ after the 2-nd pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
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<td>5-5</td>
<td><img src="image9" alt="Image" /></td>
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Besides the growing value of the equivalent strain there was found another advantage of billet turning. The initial cross-section of the billet was square. After the first pass it became rectangular. But by turning and by further deformation along the width and not along the height the cross-section approaches a square form again. Thus realization of turning during the “rolling - extrusion” joint process makes it possible to deform billets without sufficient changing of initial dimensions of the cross-sections.

Along with the study of the strain state there was studied the strain distribution simultaneously on the billet at the moment it was in the first and the second pair of rolls because in this case there was a possibility to study the stressed state both in the die and in both pairs of rolls.

During the first pass when the front end of the billet was gripped by the second pair of grooved rolls and its rear end was still being rolled in the first pair the following pattern of the equivalent stress distribution was obtained (fig.5).

**Fig.5.** Distribution of the equivalent stress in the first pass
It is seen from fig. 5 that during realization of the joint process there appear three places of strain, with the rolling strain places having sharp boundaries while the die strain place having elongated boundaries on the billet surface layers which can be explained by the tensioning made by both pairs of rolls. This tensioning arises because of the difference of rolling rates in both pairs of rolls. Which values are chosen into the program according to the force calculation [5]. Creation of tensioning is a necessary condition of the normal course of the process because a seizure will take place at the arising of a prop. The average value of the equivalent stress equals to 70-80 MPa.

While analyzing the main stresses it was found that both in the first and in the second pass of the billet there prevail compressive stresses except $\sigma_1$ where tensile stresses prevails over compressive ones reaching 142 MPa due to the tensile forces acting along the billet length which emerge because of the tension made by rolls. However the data of the tensile stress do not excess the permissible 260 MPa which is equal to the yield strength of the chosen steel 35. The patterns of distribution of the main stresses are given in table 2.

It is known from work [6] that in order to get a solid nanocrystal structure in metal it is necessary to develop in it stored strain $\varepsilon_{\text{eqv}} \geq 4$. Modeling went on in order to get this value of equivalent strain. It was found as a result that after the third pass $\varepsilon_{\text{eqv}}$ value reaches 3.05 and after the fourth one $\varepsilon_{\text{eqv}}$ value reaches 4.08. Thus in order to make billets with solid nanocrystal structure during realization of the rolling – extrusion joint process using an equichanneled die it is necessary to make as minimum four deformation cycles turning the billet by 90° after each cycle.

2. CONCLUSIONS

Modeling of the “rolling-extrusion” process using grooved rolls and equichanneled die to reveal the degree of the effect of billet turning on the stressed and strained state of metal was made. It was found that the realization of the sample turning not only has a positive effect on the distribution of the stored strain and the equivalent stress in the billet but also facilitates to recover the initial form of the cross-section which can be very important in a number of cases.
Table 2 Distribution of the main stresses

<table>
<thead>
<tr>
<th>No</th>
<th>After the 1-st pass</th>
<th>After the 2-nd pass</th>
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<tbody>
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LITERATURE


