Influence of combined process “rolling-pressing” on microstructure and mechanical properties of copper

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Abstract

The aim of this work is to study the influences of the combined process of "rolling-pressing” on the microstructure and mechanical properties of copper billets. Laboratory studies were performed of the combined process. In particular, a laboratory experiment was conducted to implement the combined process of "rolling-pressing", whose main purpose was to research the effect of the scheme on the deformation changes in the microstructure and mechanical properties of the original workpieces, made of copper alloy M1. Research of the mechanical properties and microstructure of deformed copper billet by this means found that the implementation of the combined process of "rolling-pressing” increases strength properties of copper, and reduced plastic properties, and the original grain during deformation is reduced.

1. Introduction

Despite the big prospects, until recently the issue of nano-structural metals and alloys use as constructional and functional materials of new generation still remains disputable. Only during last years there was breakthrough outlined in this area, connected with the development of new ways of volumetric nano-structural materials reception as well as with research of fundamental mechanisms leading to achievement of their new properties. Even though currently existing technologies of intensive plastic deformation realization allow the production of
volumetric nano-structural materials, until now the industrial technology of such materials reception did not exist yet – cost price of such production is too high. Therefore the development of new intensive plastic deformation use principles for production of volumetric nano-structural metals with perspective properties is the actual problem currently.

In recent years, a number of new processes of treatment of metals by pressure aimed at obtaining metal with subultra-fine grained structure have been developed in the world, the basic principle of which is the implementation of the simple shift scheme in the process of deformation. This reduces the required deformation force, and increases metal intensity value of shear deformation enough for subultra-fine grained structure. And one of such ways is the billets extrusion in matrixes of different designs, particularly in the channel echelon matrix described by Ashkeev et al. (2005). Although this method of pressing allows to implement intensive plastic deformation without significant the original size changes of the billet cross section in metal, it has the major disadvantage: long billets cannot be deformed using this method, since the length of the billets will be limited by working space blacksmith tools, particularly by the working stroke of a punch on the press. Another disadvantage of this deformation method is the fact that it does not provide the continuity of the pressing process.

2. Investigation of microstructure and mechanical properties

2.1. Scheme of combined process

To solve this task the on the "Treatment of metals by pressure" department of Karaganda state industrial university, the combined process of "rolling-pressing" using the equal-channel echelon matrix proposed by Naizabekov et al. (2013) (Fig. 1) was developed; this process compared to conventional pressing in equal channel stepped matrix partially eliminates restrictions on the billet size and the continuity of the deformation process.

![Fig. 1. Combined process “rolling-pressing”.

The essence of this process is that the deformed billet preliminarily heated to the deformation beginning temperature is moved to rolls which grasp it by means of contact friction forces into rolls throat, and at their output it is pushed through channels of equal channel echelon matrix. At the output of matrix, the front end of the billet, as well due to the forces of the contact friction is captured by second pair rolls which are pull out the billet from matrix. It means that in this case the process of billets pressing in equal channel echelon matrix is realized by the means of
using friction contact forces arising on the surface of metal contacting with rotating rolls. During the implementation of this combined deformation process both flat and calibrated rolls can be applied.

Lezhnev et al. (2008) carried out the research of this combined method; in the research empirical formulas for definition of rolling and pressing force, optimal value of matrix channels joining angle, as well as diameters of rolls at the matrix entry and exit have been calculated. It has been thus proved that it is the most expedient to use calibrated rolls as the working tool carrying out the role of punch and pushing the billet through channels in the matrix.

Panin et al. (2008) have made computer modeling of this process in DEFORM-3D software complex where stress and strain state of the metal and temperature distribution along the sample section were studied, optimal geometrical and technology factors for successful process running were defined.

2.2. Laboratory experiment

This work is devoted to research of new deformation scheme influence on micro-structural changes and mechanical properties’ changes happening in metals and alloys.

Laboratory experiment was carried out at billets with dimensions h x b x l = 16 x 30 x 200mm, made of copper alloy M1, at the simplified facility developed for realization of combined “rolling-pressing” process with the use of flat rolls and equal channel echelon matrix (Fig. 2) on the basis of rolling mill DUO-100. Simplification is connected with current absence of second flat rolls pair. In this case the process of billets deformation at the installation implementing the combined “rolling-pressing” process is designed as follows: billet, preliminarily heated to deformation beginning temperature is supplied to rolls of laboratory mill DUO-100 which by means of contact friction forces grasp it into the rolls throat and push it through channels of equal channel echelon matrix. After the billet completely leaves the rolls throat, next billet is supplied to them, which passes through rolls and comes into the matrix and pushes out the earlier deformed billet from the matrix, and so on. Due to design simplification, in the end of whole batch of billets deformation it was necessary to disassemble matrix and to take out the last billet. Since in the process of rolling, unlike the pressing in equal channels echelon matrix, there is still the change of initial billet dimensions, for implementation of following deformation cycles after each cycle of deformation the rolls throat was reduced and replaced by corresponding size of equal channel echelon matrix.

![Facility for implementation of combined “rolling-pressing” process.](image)

2.3. Results and discussion

Microstructural researches of the copper billets deformed according to the new scheme have shown that in the
initial condition copper has coarse-grained structure with the average size of grain of 90 microns (Fig. 3a). Already after the first cycle of deformation the copper structure is significantly reduced (39 microns) in comparison with initial one.

In the cross section microstructure is rather homogeneous and approximately equiaxial grains prevail. However, the structure has some segregation banding in the radial direction, especially in longitudinal section of billets (Fig. 3b).

In rolling process, after the first cycle of deformation cross-border distances are reduced in the longitudinal and transverse cross-sections. Reduction of cross-border distances happens due to the geometrical deformation, i.e. the compression of the original grain. The formation of new borders at rolling almost does not occur, all fragmenting patterns occur in equal channel stepped matrix during shear deformation by means of twinning. In accordance with Hall-Petch rule rolling on the first passages leads only to increase of the strength characteristics of copper by reducing the distance between the borders in the longitudinal and transverse cross-sections.

It was also found that the second cycle of the rolling-pressing causes the formation of mixed type structure (Fig. 3c). In the study of received patterns grains are of two types were found: small recrystallized and deformed. This structure is caused by implementation of two processes: recrystallization at rolling and fragmentation in equal channel stepped matrix. The presence of two grain types in the structure provides high strength and plasticity. After the third cycle in the structure there is a significant increase in the share of large angle borders (about 59%) due to more active course of dynamic return and recrystallization. It is connected to the fact that with reduction of the grain copper recrystallization beginning temperature is reduced. Grain boundaries become more distinct. Grain size/snippets is about 3.5 microns (Fig. 3 d).

![Fig. 3. Optical photography of copper billets microstructure (a – initial structure; b – after first cycle of deformation; c – after second cycle of deformation; d – after third cycle of deformation).](image-url)
TEM research showed that after the first two cycles elongated structure is formed in the longitudinal microsections, turning into equiaxial one with increasing number of cycles. After the first cycle most of borders were thick and blurred, with the increase of deformation degree thin clear boundaries were formed. With the increasing number of passes the share of large angle borders increases. As a result, after four passages enough equiaxial structure with an average grain size of 3.5 microns (Fig. 4) and the share of large angle borders around 59% is formed. It should be noted that notable difference between the microstructure in different sections was observed.

Also, with the increasing number of passages there is a tendency of the twins amount decrease associated with diminution of the copper grains size, which corresponds to an equation of Hall-Petch for the case of deformation twinning, according to which difficulties of twinning appearing with decreasing size of the grain should be expected.

Based on results of mechanical properties study there were trends built for strength and plasticity properties depending on deformation level (Fig. 5 and 6).
At these trends dependences are presented in the form of four points. The first point located at the axis of ordinates corresponds to parameter of not deformed copper; other three points correspond to parameters after each cycle of deformation. As a result it was revealed that during the deformation of copper billets by combined «rolling-pressing» process strength properties of metal increase, that corresponds to the equation of Hall-Petch, and plastic properties decrease.

3. Conclusions

During the carried out laboratory experiment the influences of the new combined process of deformation “rolling-pressing” on the microstructure and mechanical properties of copper were studied and the following was revealed:

1. At the first cycle of deformation the structure is significantly reduced from 90 microns to 39 microns.
2. The formation of new borders at rolling almost does not occur, all fragmenting of structure occurs in equal channel echelon matrix during shear deformation by means of twinning
3. After the third cycle of deformation structure in cross-section and longitudinal section is becoming almost homogeneous and big angular borders are found. Borders become more accurate that shows processes of dynamic re-crystallization.
4. Strength after 3 cycles of deformation increases from 239 to 485 units, relative lengthening decreases from 22 to 12%, despite this resource of plasticity of the received sample is above the resource of copper plasticity subjected to classical rolling.

These results tell that suggested technology can be recommended for introduction into manufacturing for receiving of billets from non-ferrous and ferrous metals and alloys with sub-ultra fine grain structure and increased level of mechanical properties. Now is already reached the arrangement with “ArcelorMittal Temirtau” JSC about trial approbation of this technology in conditions of Mechanical shop of this company and further introduction of this technology in manufacturing for receiving of high-quality preparations which will be used further for manufacturing of small details of responsible appointment.

References