PRODUCING BRASS NARROW STRIPS WITH AN ULTRAFINE-GRAINED STRUCTURE BY ASYMMETRIC ROLLING

Alexander PESIN, Denis PUSTOVOYTOV, Olesya BIRYUKOVA, Anna KOZHEMIAKINA, Kseniya PIVOVAROVA

Nosov Magnitogorsk State Technical University, Magnitogorsk, Russian Federation, EU,

pesin@bk.ru, *pustovoitov_den@mail.ru*

https://doi.org/10.37904/metal.2021.4104

Abstract

Severe plastic deformation is the most efficient method of refining the material structure and producing submicro- and nanocrystalline materials with a unique combination of strength and ductility properties due to a fragmented structure. Upon reaching a definite deformation rate, the fragmentation process is evolving, i.e. a volume of original polycrystalline grains (or monocrystal volume) is broken into mutually disordered areas (fragments). Main methods used to achieve high deformation rates resulting in a visible grain refinement with no sample destruction are equal channel angular pressing and twist extrusion. However, due to rather small finished products, such methods are hardly suitable to produce large-sized structural metal materials, such as, for example, narrow strips. Thus, in recent years highly efficient methods of producing ultrafine-grained materials by asymmetric rolling are widely applied. A fundamental difference between asymmetric and conventional sheet rolling is monotonic deformation in conventional rolling and non-monotonic deformation in asymmetric rolling. Asymmetric rolling in a single deformation schedule combines the processes of rolling (achieved mainly due to a translation component of deformation) and shear (by the rotational deformation). This paper describes the production of narrow strips with an ultrafine-grained structure by asymmetric rolling using L63 alloy grade as an example. Task-specific asymmetry of the process is achieved by mismatching circumferential speeds of rolls, when cold rolling is performed with high contract friction and high single deformations. The scanning electron microscopy was used to study the structure of the samples: before and after asymmetric rolling. It is shown that the deformation by asymmetric rolling with mismatching circumferential speeds of rolls amounting to 50 % and a total percentage reduction of about 70 % results in a fragmented structure and higher performance of the rolling mill due to a reduction in a number of passes, when rolling brass narrow strips from 0.80 to 0.24 mm thick.

Keywords: Asymmetric rolling, severe plastic deformation, brass strips, microstructure

1. INTRODUCTION

The growth rate of the machine-building industry imposes higher and higher demands for the quality of brass mill products not only for sizes or flatness, but also for the structure and mechanical properties, entailing a need for development of new technologies of producing semi-finished and finished products satisfying high performance and operation requirements.

One of the methods of improving the quality of materials is to generate nanostructural (NS) and ultrafine-grained (UFG) states by applying methods of severe plastic deformation (SPD) [1,2] based on large shear deformations under high hydrostatic pressure and at relatively low homologous temperature. By now, it is experimentally showed that SPD methods applied for many metallic materials, including copper alloys, contribute to forming a UFG structure with an average grain size of below 1 µm, mainly containing high-angle grain boundaries due to deformation refining (fragmentation), when achieving a rather high deformation ratio

[3,4]. When performing continuing plastic deformation, an average size of fragments gradually decreases to a minimum size, amounting to, as a rule, about 100-200 nm, including an increase in their mutual disorientation up to large-angle boundaries, namely boundaries of grains of a deformation origin. It is deemed that such fine-grained structures should ensure a high level of ductility and strength parameters due to special strained high-angle grains, entailing generation of entirely new physical and mechanical properties. UFG materials show strength, significantly exceeding strength of the same materials in its coarse-grained state.

As the most common schedules of SPD (equal-channel angular pressing (ECAP) [1-3] and twist extrusion [5]) have significant limitations on their industrial application due to a rather small size of manufactured products, they seem to be hardly suitable for processing structural metal materials of large dimensions, such as sheets, narrow strips or strips. Thus, manufacturing of materials with a UFG structure is a current technological challenge.

One of the most advanced, industrially applicable methods of SPD used to form a UFG structure in thin metal sheets is asymmetric rolling with a high (50 % or more) mismatching of speeds of rolls [6-13], to create a complicated stress state, when severe shear is combined with reduction of a sample characteristic of conventional rolling. Regarding such deformation schedule, a superposition of translation and rotation modes occurs directly during rolling. This results in an additional channel of generating dislocations contributing to a significant increase in a concentration of defects participating in the structure formation. It should be noted that a little research is devoted to studying the effect of asymmetric rolling on changes in the structure. The majority of published research papers [6-17] on this area are devoted to efficiency of impact of mismatched circumferential speeds of work rolls on energy parameters and geometry of rolled strips and narrow strips from various metals and alloys, including brass ones.

The present research is aimed at studying the effect of speed asymmetry on the structure of brass during cold rolling of narrow strips.

2. MATERIALS AND METHODS

The asymmetric rolling due to purposefully created differences in the circumferential speeds of the work rolls is also called "Differential speed rolling". For such process a coefficient of asymmetry K_a is defined as a ratio of circumferential speeds V_1 and V_2 of the work rolls according to Equation (1):

$$\mathrm{K_a} = \frac{\mathrm{V}_1}{\mathrm{V}_2} \qquad (1)$$

where $\mathrm{V}_1 > \mathrm{V}_2$.

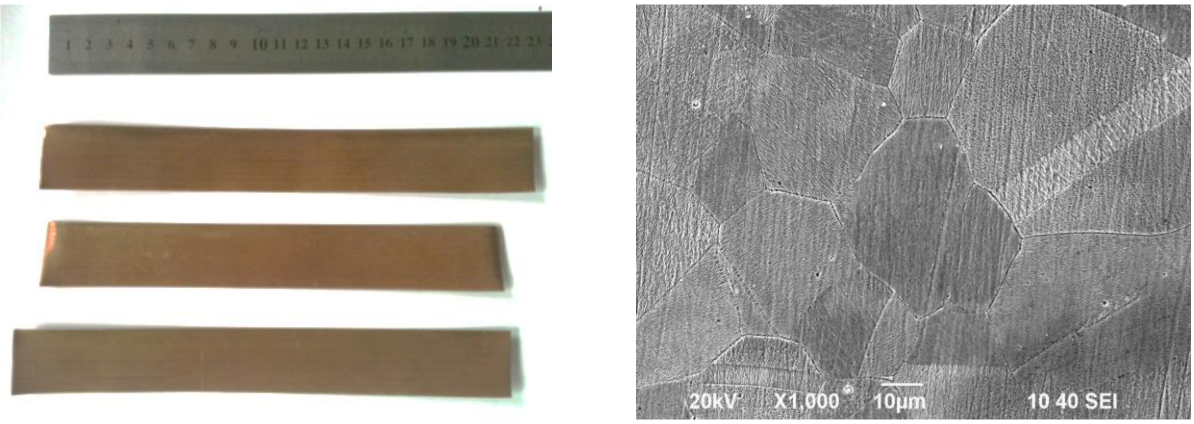
The subject under study is a copper-base alloy brass grade L63. A chemical composition of the alloy under GOST 15527-2004 is given in **Table 1**. Experimental rolling was carried out on two-high reversing mill with individually driven work rolls (**Figure 1**) at the Zhilyaev Laboratory of Mechanics of Gradient Nanomaterials (Nosov Magnitogorsk State Technical University). Symmetric and asymmetric rolling processes were performed without lubrication. Specimens of industrial cold rolled brass narrow strips, 0.80 mm thick and 30 mm wide, were used as blanks (**Figure 2, a**).

Table 1 Elemental chemical composition of brass L63, wt%

Components		Impurity elements (less than)					
Cu	Zn	Pb	Fe	Sb	Bi	P	Total
62.0-65.0	other	0.07	0.2	0.005	0.002	0.07	0.5

Specimens of narrow strips (0.80 mm × 30 mm × 200 mm) were cold rolled at different reduction rates in several passes to achieve a final thickness of 0.24 mm (**Table 2**). Specimen thickness was measured with a micrometer before and after every pass.

Figure 1 Two-high reversing mill with individually driven work rolls



a b

Figure 2 Specimens of brass narrow strips (a) and initial microstructure (b)

Table 2 Reduction schedule of brass narrow strips

Pass No.	**Thickness (mm)**		**Thickness reduction (%)**		**Angular velocity (rev/min)**	
	entry	**exit**	**single**	**total**	**top roll**	**bottom roll**
1	0.80	0.40	50	50	3	6
2	0.40	0.24	40	70	3	6

The microstructures of the specimens before and after rolling were examined with a scanning electron microscope (SEM, JSM-6490LV) at accelerating voltage of 20 kV. A hydrochloric solution of iron (III) chloride was used as an etching solution to determine α and β-phases in brasses.

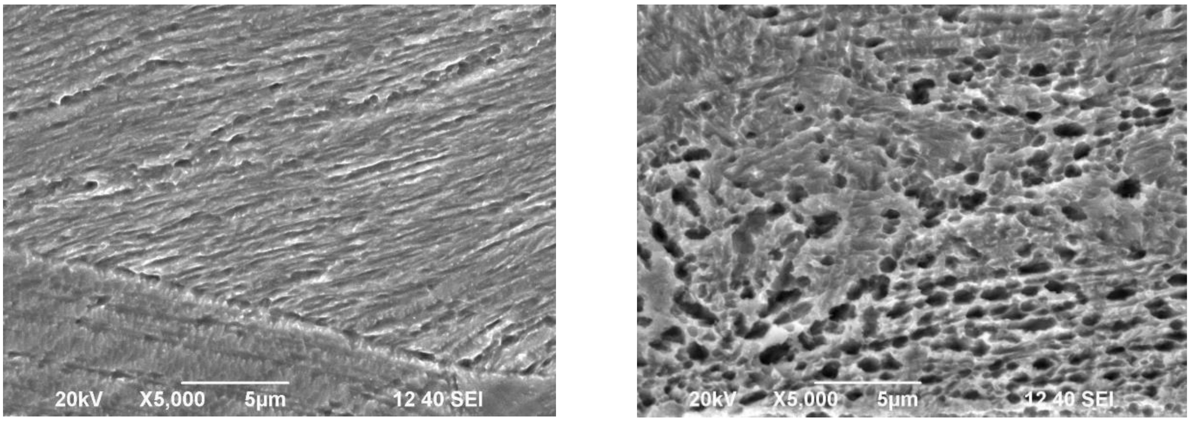
3. RESULTS AND DISSCUSION

The experiment showed that when rolling brass narrow strips with a thickness reduction from 0.80 mm to 0.24 mm, a number of passes decreased in case of asymmetric rolling as compared to symmetric rolling (**Table 3**). Thus, the asymmetric rolling process can be used for reducing the number of rolling passes by increasing the thickness reduction in each pass.

Table 3 Changes in narrow strip thickness by passes during symmetric and asymmetric rolling

Type of rolling	Narrow strip thickness after deformation passes (mm)			
	0	1	2	3
Symmetric rolling	0.80	0.50	0.35	0.24
Asymmetric rolling with K_a = 2	0.80	0.40	0.24	-

The micrographic studies showed that an original state of the structure of brass L63 (**Figure 2, b**) constituted equiaxed grains of α-solid solution of zinc (Zn) in copper (Cu) with a small number of inclusions of excess β-phase along the boundaries.



a b

Figure 3 Microstructure of brass narrow strips after symmetric (a) and asymmetric (b) rolling

As it is shown in **Figure 3, b**, asymmetric rolling with speed asymmetry coefficient K_a = 2.0 (total thickness reduction is 70 %) results in a strong distortion of the structure as compared to symmetrically rolled sample (**Figure 3, a**). The structure consists of heavily deformed grains of α-solid solution as fragments, whose boundaries are non-equilibrium and have complex dislocations, i.e. there is a so-called fragmented structure.

The mechanical properties of the samples before and after cold rolling were investigated by uniaxial tensile test using an AG IC Shimadzu universal testing machine equipped with a 50 kN load cell. The tests were computer controlled registering strain and stress. Tensile samples with a gauge section measuring 30 mm in width and 100 mm in length were cut from the strips along the rolling direction. Tensile tests were carried out at room temperature and a constant cross-head speed of 2 mm/min, which was equivalent to a strain rate of 3.3×10^{-4} s^{-1}. The analysis of the mechanical test results revealed that with augmentation of speed asymmetry coefficient K_a from 1.0 (symmetric rolling) up to 2.0 (asymmetric rolling) the strength properties of brass grade L63 got better and plastic properties remained unchanged. In particular the yield strength increased from 478 MPa (at K_a = 1.0) up to 567 MPa (at K_a = 2.0), and the ultimate tensile strength increased from 509 MPa (at K_a = 1.0) up to 603 MPa (at K_a = 2.0). In case of symmetric and asymmetric rolling with total reduction of 70 % the uniform elongation and elongation to failure were extremely low and did not exceed 2 %.

4. CONCLUSION

The conducted studies showed that asymmetric rolling of brass narrow strips from thickness of 0.80 mm to 0.24 mm from a two-component single-phase alloy, namely brass grade L63, contributed to a heavily fragmented ultrafine-grained structure and higher performance of the rolling mill. To produce the achieved result, asymmetric rolling should be performed with speed asymmetry coefficient K_a = 2.0 and total thickness reduction of about 70 %. The analysis of the mechanical test results revealed that with augmentation of speed asymmetry coefficient K_a from 1.0 to 2.0 the strength properties of brass L63 got better and plastic properties remained unchanged. The ultimate tensile strength increased from 509 MPa up to 603 MPa while elongation to failure remain extremely low and did not exceed 2 % in both cases.

ACKNOWLEDGEMENTS

The study was carried out within the framework of the implementation of the Resolution of the Government of the Russian Federation of April 9, 2010 No. 220 (Contract No. 075-15-2019-869 from May 12, 2019) and it was funded by RFBR (project number 20-38-90097).

REFERENCES

[1] VALIEV, R.Z., LANGDON, T.G. Principles of equal-channel angular pressing as a processing tool for grain refinement. *Progress in Materials Science*. [online]. 2006, vol. 51, pp. 881-981. Available from: https://doi.org/10.1016/j.pmatsci.2006.02.003

[2] SEGAL, V. Review: Modes and Processes of Severe Plastic Deformation (SPD). *Materials*. [online]. 2018, vol 11, pp. 1175. Available from: https://doi.org/10.3390/ma11071175

[3] RADHI, H.N., ALJASSANI, A.M.H., MOHAMMED, M.T. Effect of ECAP on microstructure, mechanical and tribological properties of aluminum and brass alloys: A review. *Materials Today: Proceedings*. [online]. 2020, vol. 26, pp. 2302-2307. Available from: https://doi.org/10.1016/j.matpr.2020.02.497

[4] FIGUEROA, C.G.L., SCHOUWENAARS, R., CORTÉS-PÉREZ, J., PETROV, R., KESTENS, L. Ultrafine gradient microstructure induced by severe plastic deformation under sliding contact conditions in copper. *Materials Characterization*. [online]. 2018, vol. 138, pp. 263-273. Available from: https://doi.org/10.1016/j.matchar.2018.02.017

[5] BEYGELZIMER, Y., PRILEPO, D., KULAGIN, R., GRISHAEV, V., ABRAMOVA, O., VARYUKHIN, V., KULAKOV, M. Planar Twist Extrusion versus Twist Extrusion. *Journal of Materials Processing Technology*. [online]. 2011, vol. 211, pp. 522-529. Available from: https://doi.org/10.1016/j.jmatprotec.2010.11.006

[6] KIM, W.J., WANG, J.Y., CHOI, S.O., CHOI, H.J., SOHN, H.T. Synthesis of ultra high strength Al-Mg-Si alloy sheets by differential speed rolling. *Materials Science and Engineering A*. [online]. 2009, vol. 520, pp. 23-28. Available from: https://doi.org/10.1016/j.msea.2009.05.010

[7] JI, Y.H., PARK, J.J., KIM, W.J. Finite element analysis of severe deformation in Mg-3Al-1Zn sheets through differential-speed rolling with a high speed ratio. *Materials Science and Engineering A*. [online]. 2007, vol. 454-455, pp. 570-574. Available from: https://doi.org/10.1016/j.msea.2006.11.076

[8] LOORENTZ, KO, Y.G. Effect of differential speed rolling strain on microstructure and mechanical properties of nanostructured 5052 Al alloy. *Journal of Alloys and Compounds*. [online]. 2014, vol. 586, pp. 205-209. Available from: https://doi.org/10.1016/j.jallcom.2012.10.128

[9] LOORENTZ, KO, Y.G. Microstructure evolution and mechanical properties of severely deformed Al alloy processed by differential speed rolling. *Journal of Alloys and Compounds*. [online]. 2012, vol. 536, pp. S122-S125. Available from: https://doi.org/10.1016/j.jallcom.2011.12.009

[10] CUI, Q, OHORI, K. Grain refinement of high purity aluminum by asymmetric rolling. *Materials Science and Technology*. [online]. 2000, vol. 16, pp. 1095-1101. Available from: https://doi.org/10.1179/026708300101507019

[11] YU, H., TIEU, K., LU, C. Advanced rolling technologies for producing ultrafine-grain/nanostructured alloys. *Procedia Engineering*. [online]. 2014, vol. 81, pp. 96-101. Available from: https://doi.org/10.1016/j.proeng.2014.09.133

[12] JI, Y.H., PARK, J.J. Development of severe plastic deformation by various asymmetric rolling processes. *Materials Science and Engineering: A*. [online]. 2009, vol. 499, pp. 14-17. Available from: https://doi.org/10.1016/j.msea.2007.11.099

[13] PARK, J.J. Finite-element analysis of severe plastic deformation in differential-speed rolling. *Computational Materials Science*. 2015, vol. 100, pp. 61-66. Available from: https://doi.org/10.1016/j.commatsci.2014.09.010

[14] ZUO, F., JIANG, J., SHAN, A., FANG, J. Shear deformation and grain refinement in pure Al by asymmetric rolling. *Transactions of Nonferrous Metals Society of China*. [online]. 2008, vol. 18, pp. 774-777. Available from: https://doi.org/10.1016/S1003-6326(08)60133-8

[15] BOBOR, K., HEGEDUS, Z., GUBICZA, J., BARKAI, I., PEKKER, P., KRALLICS, G. Microstructure and mechanical properties of Al 7075 alloy processed by differential speed rolling. *Periodica Polytechnica Mechanical Engineering*. [online]. 2012, vol. 56, pp. 111–115. Available from: https://doi.org/10.3311/pp.me.2012-2.06

[16] PESIN, A., KORCHUNOV, A., PUSTOVOYTOV, D., WANG, K., TANG, D., MI, Z. Finite element simulation of shear strain in various asymmetric cold rolling processes. *Vestnik Magnitogorskogo Gosudarstvennogo Tekhnicheskogo Universiteta im. G.I. Nosova [Vestnik of Nosov Magnitogorsk State Technical University].* 2014, no. 4, pp. 32-40.

[17] PESIN, A.M., PUSTOVOYTOV, D.O., SHVEEVA, T.V., STEBLYANKO, V.L., FEDOSEEV, S.A. Simulation of nonmonotonic metal flow during asymmetric sheet rolling with different velocities of the rolls. *Vestnik Magnitogorskogo Gosudarstvennogo Tekhnicheskogo Universiteta im. G.I. Nosova [Vestnik of Nosov Magnitogorsk State Technical University]*. 2017, no. 15, pp. 56-63.