U. MURZAKHMETOVA, L. KURMANGALIYEVA, N. SMAGULOVA

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ULTRAFINEGRAINED STRUCTURE OF D16 ALUMINIUM ALLOY AFTER ROLLING IN THE CORRUGATED ROLLS AND ON THE LONGITUDINAL-WEDGE MILL

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The article explains the influence of number of passes on the parameters of the microstructure of D16 aluminium alloy during rolling in the corrugated rolls, and the impact of the drafts while rolling of the strips on the longitudinal wedge mill. A comparative evaluation of the grain size of the ultrafine grained structure was conducted after rolling strips in the corrugated rolls by various passes, and after rolling on the longitudinal wedge mill at deformation temperature of 320 °C. It is shown that the sheet material of D16 aluminium alloy ensures uniform formation of an ultrafine grain structure with the size of about 220 - 240 *nm*, which leads to increased strength properties of the alloy and preserve good ductility.

Keywords: aluminium, rolling, strip, severe plastic deformation, ultrafine grained structure

INTRODUCTION

The role of aluminium alloys as structural materials of modern technology is increasing all the time, it applies to the areas related to the development of energy-saving and other high technologies, as well as the solution of environmental problems [1].

It should be noted that the widespread use of semi-finished products made from alloys are hampered by a number of unresolved issues, which include low thermal stability, limited technological plasticity, low service properties in the coarse-grained state, and a pronounced anisotropy of mechanical properties.

It is known that the formation of the recrystallized ultrafine grained (UFG) structure (grain size less than 10 microns) in aluminium alloys provides a high performance strength, ductility and crack resistance, and, most importantly, isotropic mechanical properties. Another consequence of the formation of UFG structure in semi-finished products from aluminium alloys is an extraordinary increase in the technological plasticity that allows them to roll out thin sheets, as well as manufacturing of complex configuration details from these sheets by using method of pressure forming in a state of superplasticity (SP).

Currently, to obtain materials with ultrafine structure (nanostructure), without significant changes in their size, the methods of severe plastic deformation (SPD) is used, which is mainly realising macro share strain with the total level of more than 2 – 3 [2]. Macro share deformations cause changes in the structure of the metal due to intercrystalline slip, which does not depend on the orientation of the crystal grains. The result of these changes is the increase of the level of uniformity of the mechanical properties of the metal, as well as reducing their anisotropy.

Intensive macro share during sheet rolling may be provided by different technological and constructive ways [3,4]: use of multiple sequential alternating bending, preforms and rolls with a wavy or corrugated surface, asymmetric rolling, uneven cooling-down of the peal through its thickness and width, etc. The authors of [3] note that in all these cases, intensive macro share is achieved as a result of local deformation effects on the rolled metal.

The aim of the research is to study the evolution of the structure of D16 aluminium alloy during rolling of the strips in the corrugated rolls and on longitudinal-wedge mill (LWM).

EQUIPMENT, MATERIALS AND METHOD OF THE EXPERIMENT

Among the known methods of SPD, the method of rolled foil is widespread in practice. However, there is a little use of it for subsequent forming operations because of the small cross-section of the foil. In order to to produce semi-finished products with UFG structure, a tool with corrugated working surface of the rolls was developed (Figure 1) [5]. The developed tool implements the SPD without significant changes of their

A. Mashekova, A. Turdaliev, S. Mashekov, U. Murzakhmetova, L. Kurmangaliyeva, N. Smagulova, Institute of Industrial Engineering, Kazakh National Research Technical University after K. Satpayev, Almaty, Kazakhstan. A. Kawalek, Czestochowa University of Technology, Czestochowa, Poland.

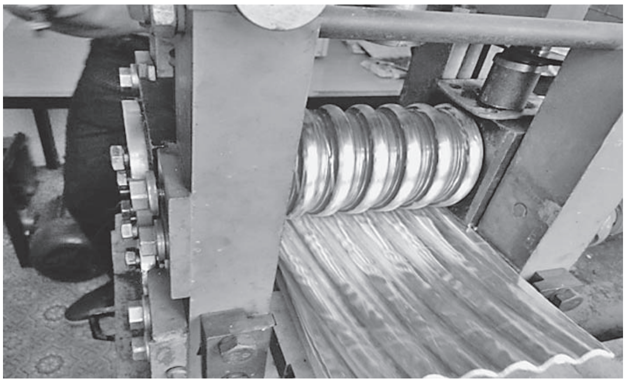


Figure 1 Duo rolling mill with the corrugated rolls

original shape and size. In addition, 5-stand LWM [6] for rolling strips of a given workpiece was designed.

D16 aluminium alloy was selected as the work piece material. The size of the work piece was equal to 6 × 150 × 400 mm. Rolling was run according to the following modes:

- Mode 1. Heating temperature was 320 °C, soaking for 2 hours, rolling by 4 passes in the corrugated rolls while the width of the work peice reaches 5.4 mm. Then warming-up at a temperature of 320 °C, soaking for 30 minutes, rolling by 4 passes till the width of the work piece touches up 5.0 mm. After that, warming-up at a temperature of 320 °C, soaking for 30 minutes, after that rolling on the 5-stand LWM till the width of 1.5 mm.
- Mode 2. Heating up to 320 °C, soaking for 2 hours, and rolling by 8 passes in the corrugated rolls till the width of 5.4 mm. Following by warming-up to a temperature of 320 °C, soaking for 2 hours, and rolling by 8 passes in the corrugated rolls till the width reaches 5.0 mm. After that heating at 320 °C, soaking for 2 hours, and rolling on the 5-stand LWM till the width of 1.5 mm.

The preform was deformed by the projections and depressions of the rolls with a single compression $\varepsilon = \Delta h_B / H_o$ in the first pass and with the compression unit $\varepsilon = 2\Delta h_B / H_o$ in the subsequent passes.

Metallographic analysis was performed using energy dispersive spectrometer JNC ENERGY (England), which was mounted on the electron probe microanalyzer JEOL (Dzheol) at an accelerating voltage of 25 kV. Magnification range of JEOL instrument is 40 to 40 000 times.

Mechanical tests on stretching of the flat samples were conducted on the Universal Test System «Instron 5882». Yield strength (R_e), tensile strength (R_m) and elongation (A) were evaluated based on the test results of the samples and by using the methods, described in the State Standardы GOST 1497-84 and GOST 9651-84, respectively.

Before testing on stretching, samples were subjected to heat treatment (HT), consisting of a hardening and subsequent aging. The heating temperature for quenching was 450 °C, holding at this temperature was 2 hours, cooling was conducted in oil. Aging was performed at 120 °C for 5 hours.

RESULTS AND DISCUSSION

At the initial state the billet, made of D16 aluminium alloy, had a non-uniform microstructure, which consisted of large unrecrystallized grains with an average size of about 246 μm in the longitudinal and ~ 223 μm in the transverse directions. Besides there were small grains with the size of ~ 30-35 μm, spaced along its boundaries.

The study of the structural state of work piece after rolling in the corrugated rolls by 4 passes show that:

- the microstrip structural state forms in the cross-section, that is perpendicular to the rolling plane;
- the density of intragranular dislocations increases, and shear bands evolves with the width up to 10 - 12 μm;
- the deformation in the form of shear bands mainly took place within the large grains. Most likely values of the microbands widths with high-angle boundaries are in the range of 8 to 10 μm at maximum (very rarely observed) values of ~ 14 μm;
- width of microbands with low-angle boundaries varies 1 – 3 μm at the most likely value of about 2 μm;
- additional refinement occures and as a result grain-subgrain structure have been formed. The size of some grains has reached 8 – 10 μm.

Whereas rolling in the corrugated rolls by 8 passes lead to:

- the reduction of the microbands width;
- the formation of finer shear bands on the boundaries of the initial broad microbands;
- occurrence of a pronounced banded structure in the cross-section of the strip, with the distance between the boundaries not exceeding 1 – 5 μm at the most probable values of 2 – 3 μm;
- the formation of the uniform and equiaxed structure in the longitudinal and transverse cross-sections of the work piece;
- further grinding of grain-subgrain structure;
- formation of polygonized or recrystallization structure occure, due to softening processes. An average grain size throughout the volume is 1 - 3 μm;
- in the border areas of the grains the high-angle boundaries formed.

The dislocation density is very high and its value cannot be calculated based on the image of the structure.

Thus, when rolling in the corrugated rolls the action of alternating deformation mechanism provides fragmentation and reorientation of the crystal lattice. In this case the high-angles boundaries are formed with high density in the transverse direction of the billet [7-9].

To investigate the effect of rolling on LWM on the microstructure formation of D16 aluminium alloy, strips, rolled in the corrugated rolls, further were processed on LWM at a temperature of 320 °C (Figure 2). It is seen that rolling at a temperature of 320 °C greatly affects on the microstructure of the alloy. The microstructure of D16 aluminium alloy, that was rolled twice by 4 passes in the corrugated rolls, and then rolled on LWM, characterized by existence of subgrains, formed inside the former strain bands (Figure 2, *a*). The average size of subgrains is 870 – 940 nm.

Rolling of the blank on LWM, that was deformed twice by 8 passes in the corrugated rolls, leads to the formation of the UFG structure. As a result of softening processes, the structure in a range of ultrafine size was formed and the grains was equal to 220 - 240 nm along the entire volume of the rolling strips (Figure 2, *b*). The resulting ultrafine grain structure is characterized by the uniformity of the grain size throughout the volume of the material. The images of the microstructure show a clear picture of the grain boundaries after rolling by mode 2. Type of the microstructure indicates the formation of grains with predominantly high-angle boundaries.

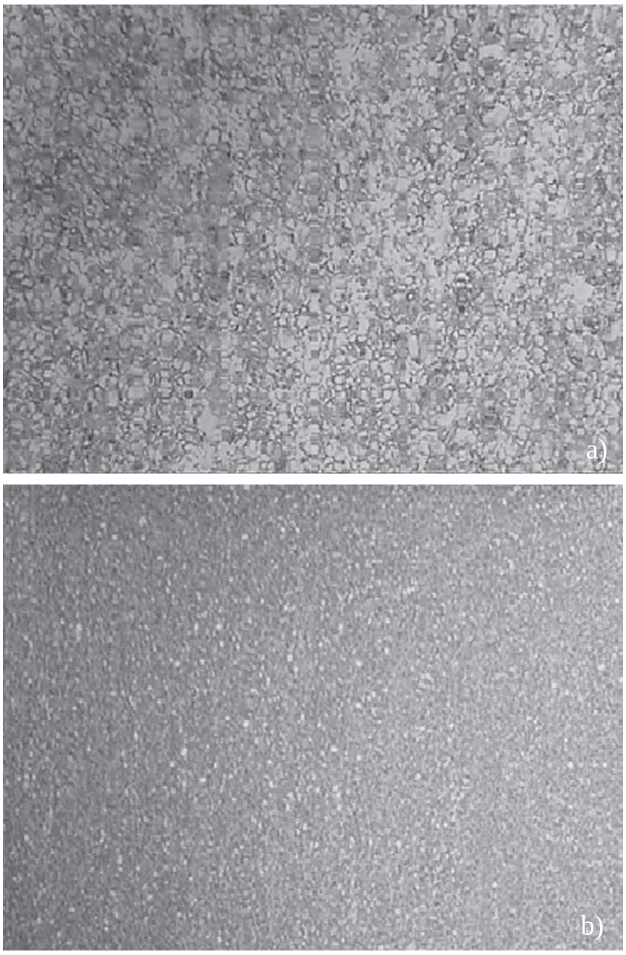
Table 1 shows the results of strength and ductility parameters evaluation of D16 alloy after rolling in the corrugated rolls and on LWM. It should be noted that on the strength properties of the UFG material influence not only the mean grain size, but, mostly, the nature, size and distribution of the dispersed particles. Additionally, conducted energy dispersive spectrum mapping of the surface by elements composition showed that sheet-like *S*-phase (Al2CuMg) separates out at the grain boundaries of D16 alloy. This reduces the effects of aging. These particles grow as the aging process progress, and coherent particles of strengthening *T*-phase dissolve, these particles are distributed uniformly in the body of grains, and all these lead to a drop in a strength. High strength is achieved if *T*-phase with the coherent boundaries is homogeneously released along the volume of the grain.

The alloy, deformed by mode 1, demonstrates lower levels of strength and ductility than after rolling by mode 2. This is due to the fact that the structure of the alloy, after deformation by 4 passes in the corrugated rolls and rolling on LWM, consists of larger grains and contains stitch accumulation of *S*-phase, angled 45° to the stretching axis, i.e. they coincide with the direction of maximum shear stresses action. Draft of alloy strength characteristics after rolling in the corrugated rolls by 8 passes associated with the increasing of *S*-phase volume fraction.

It is shown that D16 alloy shows the highest mechanical properties after rolling by mode 2. Apparently, this is due to the optimum combination of structural strengthening, associated with the size of grains and precipitation hardening, connected mainly with coherent particles in the body of the *T*-phase grains.

Table 1. **The mechanical properties of D16 alloy (at room temperature) after rolling in the corrugated rolls and on the LWM**

State of D16 alloy	R_e / MPa	R_m / MPa	*A* / %
Allong the rolling direction			
Rolling in rolls by 4 pass + LWM + HT	291	442	10,0
Rolling in rolls by 8 pass + LWM + HT	298	481	10,4
Across the rolling direction			
Rolling in rolls by 4 pass + LWM + HT	291	446	10,0
Rolling in rolls by 8 pass + LWM + HT	308	498	10,2



a – rolling according to mode 1; *b* – rolling according to mode 2

Figure 2 The microstructure of D16 aluminium alloy after rolling in the corrugated rolls and on LWM, ´ 3500.

CONCLUSION

- Results of the long work pieces microstructure evolution research have shown the possibility of obtaining bands with ultrafine structure by using intensive plastic deformation.
- Saving of enough ductility of aluminium, rolled in corrugated rolls, allows to run shaping operations on LWM, which contribute to a further refinement of the grain structure of the work piece, and formation of the high dislocation density.
- The preposed technology allow to get an ultrafine grain structure with a size of about 220 - 240 nm in the sheet material of D16 aluminium alloy. It leads

to increased strength properties of the alloy and preserve good ductility.

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Note: Translated by A. Omarbekova, Almaty, Kazakhstan