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COMPUTER SIMULATION OF PRELIMINARY HEAT TREATMENT AND RADIAL-SHEAR ROLLING OF BRASS

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ABSTRACT

This paper presents the results of computer modeling of preliminary heat treatment and radial-shear rolling of L63 brass in the Deform program by cellular automata method. Quenching and annealing were simulated as pre-heat treatment modes. Radial-shear rolling consisted of three passes with a compression of 3 mm per pass. The variable parameters were the roll rotation speed (40 rpm, 70 rpm and 100 rpm) and the workpiece heating temperature before rolling (500°C and 700°C). It was found that the most effective mode of preliminary heat treatment of L63 brass is annealing at a temperature of 500°C. The most rational value of the heating temperature of the workpiece before rolling is 500°C, since in this case, at all selected speeds the recrystallization process does not start, which contributes to intensive grain grinding. An increase of roll rotation speed causes additional deformation heating, which contributes to recrystallization and a decrease of grain grinding intensity.

Keywords: *simulation, preliminary heat treatment, radial-shear rolling, microstructure, brass.*

INTRODUCTION

Currently there is no doubt that the use of finite element modeling has undeniable advantages over conducting numerous experiments. When modeling, material and labor costs are repeatedly reduced, it becomes possible to assess the impact of those process parameters that are difficult to vary in real conditions. Also, when considering the calculated model, there is the possibility of a comprehensive assessment of all parameters, whereas in real conditions, specific equipment may be needed to assess individual parameters.

At the same time, when modeling, it is necessary to use a few certain assumptions that can significantly reduce the calculation time. With an increase in the number of such assumptions, the level of error is invariably calculated, therefore it is always necessary to look for a compromise between the calculation time and the accuracy of the model.

At the same time, usually the key factors in modeling are the parameters of the stress-strain state [1, 2]. At the same time, many finite element analysis programs have good tools for modeling the microstructure evolution. However, this parameter is studied much less frequently, since it requires the introduction of additional model constants, the definition of which is a difficult task. In the presence of these constants, the researcher could assess the change in grain size during deformation or heat treatment. Using the mechanism of cellular automata, it is also possible to evaluate changes in the shape of grains [3].

The purpose of this work was computer simulation of the microstructure evolution of L63 brass in the process of preliminary heat treatment (PHT) and subsequent radial-shear rolling (RSR).

EXPERIMENTAL

For computer modeling of the processes of preliminary heat treatment and subsequent radial-shear rolling of L63 brass, it was decided to use the mechanism of cellular automata version 2.0, implemented in the Deform v.13 system. This mechanism allows not only to simulate grain size changes, but also to predict their shape during deformation or thermal processing.

A rod with a diameter of 30 mm and a length of 150 mm was set as the initial workpiece.

The following PHT modes were selected:

- heating up to 500°C, cooling in water (quenching);
- heating up to 500°C, cooling with a furnace (annealing);
- heating up to 800°C, cooling with a furnace (annealing).

Early, a similar simulation of the microstructure evolution for M1 copper alloy was carried out [4]. Then an algorithm was used to calculate the heating time, which is based on the Newton-Richman law and on theoretical and practical studies of the regular thermal regime. In accordance with the calculations in this program, the following values of time intervals were obtained:

- heating to 500°C in 6418 s (106 min), cooling in water in 16 s;
- heating up to 500°C in 6418 sec (106 min), cooling with an oven in 73817 s (≈ 20.5 hours);
- heating to 800°C in 6923 s (116 min), cooling with an oven in 79622 s (≈ 22.1 hours).

The key parameters of the cellular automata algorithm are the input of model constants, the values of which depend on the nature of the material. For brass L63 and its analogues, these constants are considered in [5, 6]. Table 1 shows the values of these constants.

The initial grain size was set to 45 μm, so it was decided to choose a square with a face size of 200 μm as the calculation window, so that it could track the full dimensions of several grains before and after preliminary heat treatment.

RESULTS AND DISCUSSION

The initial structure of L63 brass with an average grain size of 45 μm and after three different PHT is shown in Fig. 1.

After quenching L63 brass at 500°C the initial grain size of 45 μm decreased to about 32 μm, while after annealing at 500°C the initial grain size increased to about 53 μm, and after annealing at 800°C the initial grain size increased to about 68 μm. Based on the results obtained, it can be concluded that the most effective mode of PHT for the purpose of grinding the initial grain size for L63 brass is quenching. However, as is known from the Cu-Zn state diagram, the structure of brass consists of α or α + β' phases, where α-phase is a solid solution of zinc substitution in copper having a HCC lattice, high plasticity, low strength, and hardness values; β' phase is an ordered solid solution based on an intermetallic compound with the crystal lattice of the BCC. This phase is characterized by higher hardness than the α-phase and brittleness and is formed mainly after rapid cooling, i.e. quenching. Since the β-phase embrittles the brass alloy, it is undesirable for further deformation of the samples. Therefore, the most suitable PHT for L63 brass in real production conditions is annealing. To save energy and obtain a finer-grained structure after deformation by radial-shear rolling,

Table 1. Constants of the Cellular Automata 2.0 model.

Material	G, N m^{-2}	b, m	γ, J m^{-2}	δD_{0b}, m^3 s^{-1}	Q_b, kJ mol^{-1}	A_1	n_1	Q_{def}, kJ mol^{-1}
L63 brass	10.5×10^{10}	3.12×10^{-10}	0.346	1.14×10^{-11}	138	3.29×10^{43}	0.146	259

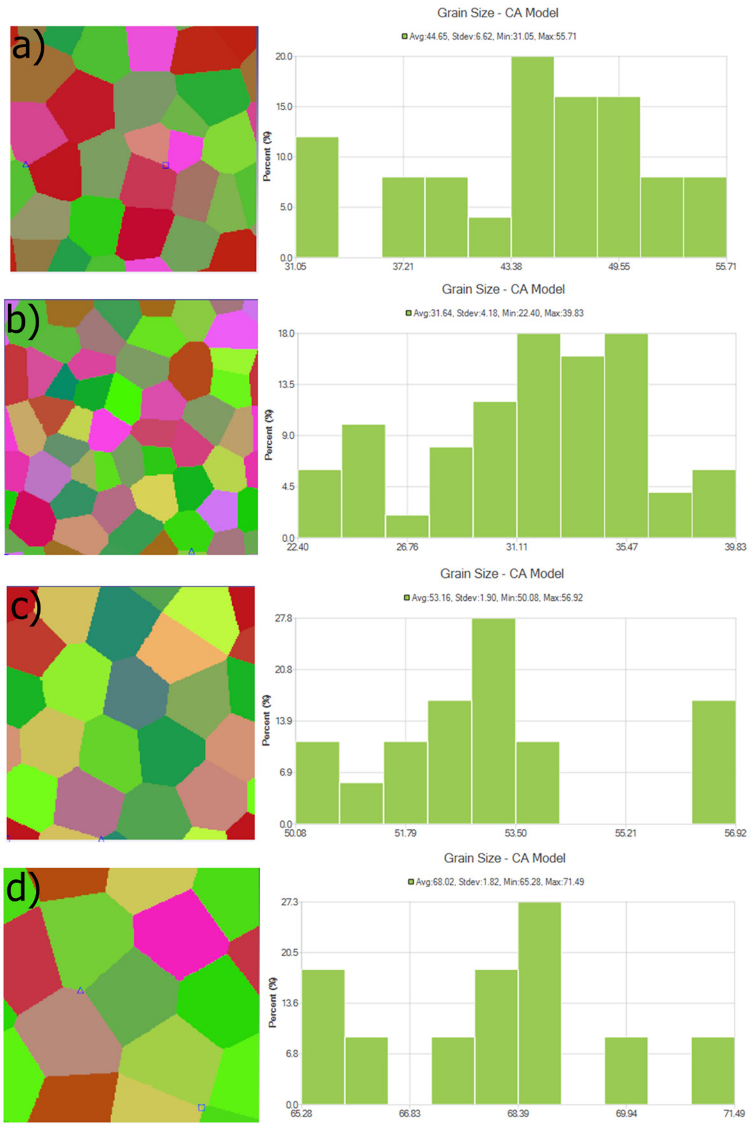

Fig. 1. Structure of L63 brass after various PHT: (a) - initial structure; (b) - after quenching at 500°C; (c) - after annealing at 500°C; (d) - after annealing at 800°C.

annealing at a temperature of 500°C was chosen as a PHT for brass.

To determine the rational speed and temperature parameters of radial-shear rolling in order to obtain an ultrafine-grained structure in brass for a small number of passes, it was decided to conduct three passes with a compression of 3 mm per pass.

As a speed characteristic, which is easy to vary in real conditions, the rolls rotation speed was chosen. The nominal speed was set to 40 rpm, and increased values of 70 rpm and 100 rpm were also adopted to assess the effect of this parameter when changing.

As a temperature characteristic, which is easy to vary in real conditions, the workpiece heating temperature before rolling was chosen. Temperatures of 500°C and 700°C were selected for L63 brass.

Considering the fact that at the stage of modeling of PHT it was found that the most effective mode is annealing, it was decided to use the appropriate heating-cooling modes before the deformation stage. It was also decided to examine the microstructure not only in two different directions (longitudinal and transverse), but also at three different points along the cross section: in the axial zone, in the surface zone (at a distance of 10 mm from the center) and in the peripheral zone (at a distance of about 5 - 6 mm from the center). This is because experimentally it has been repeatedly proved the presence of a gradient distribution of grain size in the cross-section of the workpiece after the RSR and a significant difference in the shape of the grains in different directions.

Fig. 2 - 7 show the results of modeling the microstructure of L63 brass at various speed and temperature parameters. The temperature of the beginning of recrystallization of L63 brass ranges from 250 to 480°C [7]. Therefore, to estimate the theoretically possible maximum level of grain grinding when modeling the microstructure evolution, the value of 480°C was set as the temperature of the recrystallization beginning.

When the L63 brass is heated to 500°C and then deformed, the workpiece cools down to 410 - 420°C after three RSR cycles, considering heat transfer and deformation heating. Such a sharp difference from the copper model at 200°C is explained by a more significant temperature difference between the heated workpiece and the environment with the tool, which leads to a more intense heat transfer. Under the previously set conditions for the start of recrystallization this process is not activated. As a result, the initial grain size, equal to 53 μm after annealing, is intensively refined with a gradient distribution of grain size in the radial direction-from 4 μm in the surface layers to 10 μm in the center. Elongation of grains in the longitudinal direction is clearly noticeable in the central region, on the periphery and surface the level of elongation is insignificant.

During radial-shear rolling with a roll rotation speed of 70 rpm, L63 brass heated to 500°C cools down to 450 - 460°C. As in the previous model, in this case the recrystallization process is not activated. As a result, the initial grain size, equal to 53 μm after annealing, is refined with a gradient distribution of grain size in the radial direction, although less intensively than at a speed of 40 rpm - from 6 μm in the surface layers to 13 μm in the center. The elongation level of grains in the longitudinal direction is most clearly noticeable in the central region, on the periphery the elongation of the grains is insignificant, on the surface the elongation level is almost absent.

During radial-shear rolling with a roll rotation speed of 100 rpm, L63 brass heated to 500°C cools down to 475 - 485°C. In this case, the recrystallization process is only activated. As a result, the initial grain size is crushed with a gradient distribution of grain size in the radial direction with a significantly lower level compared to the initial speed of 40 rpm - from 10 μm in the surface layers to 19 μm in the center. The elongation level of grains in the longitudinal direction in all three zones is insignificant since the elongation intensity is partially annihilated by the recrystallization process.

When the L63 brass is heated to 700°C and then deformed, the workpiece cools down to 580 - 590°C after three RSR cycles, taking into account heat transfer and deformation heating. Under the previously specified conditions of the beginning of recrystallization, in this case, this process is actively taking place in the processed material. As a result, the grinding of the initial grain size of 53 μm is significantly lower due to the intensive recrystallization and grain growth. The surface layer receives the greatest processing (25 μm approximately), while the periphery and center are processed out less-here the grain size is in the range from 30 to 35 μm. Elongation of the grains in the longitudinal direction is not observed under these conditions.

During radial-shear rolling with a roll rotation speed of 70 rpm, L63 brass heated to 700°C cools down to 610 - 615°C. As in the previous model, in this case, the recrystallization process actively proceeds throughout the entire volume of the workpiece being processed. As a result, the initial grain size, equal to 53 μm after annealing, is eventually refined on the surface to 28 μm, on the periphery to 34 μm and in the center to 41 μm. The level of elongation of the grains in the longitudinal direction is absent.

During radial-shear rolling with a roll rotation speed of 100 rpm, L63 brass heated to 700°C cools down to 625 - 630°C. The recrystallization process actively proceeds throughout the entire volume of the workpiece being processed. The initial grain size is 53 μm, eventually crushed on the surface to 31 μm, on the periphery to 35 μm and in the center to 44 μm. The level of elongation of the grains in the longitudinal direction is absent.

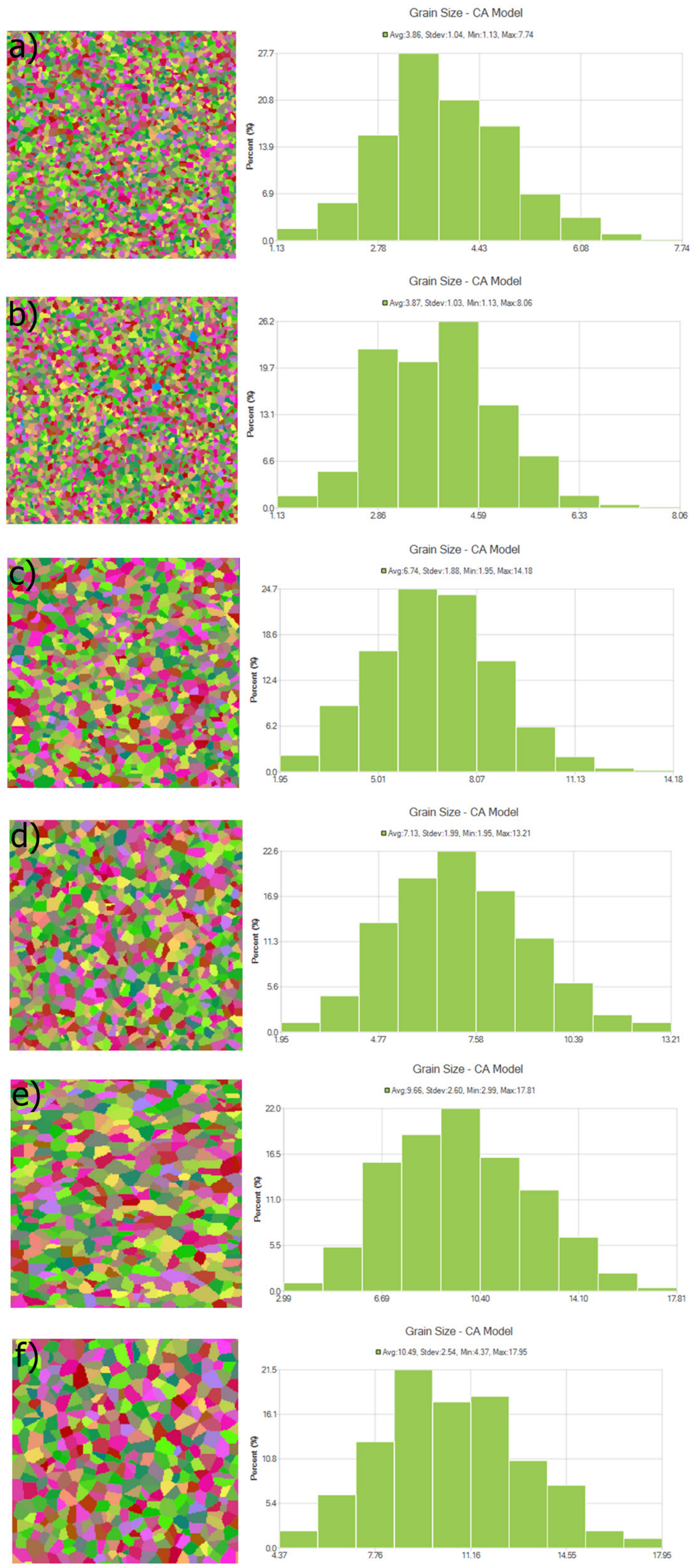

Fig. 2. Structure of L63 brass after annealing, 3 cycles of RSR at the temperature 500°C and the rolls rotation speed 40 rpm: (a) - surface, longitudinal direction; (b) - surface, transverse direction; (c) - periphery, longitudinal direction; (d) - periphery, transverse direction; (e) - center, longitudinal direction; (f) - center, transverse direction.

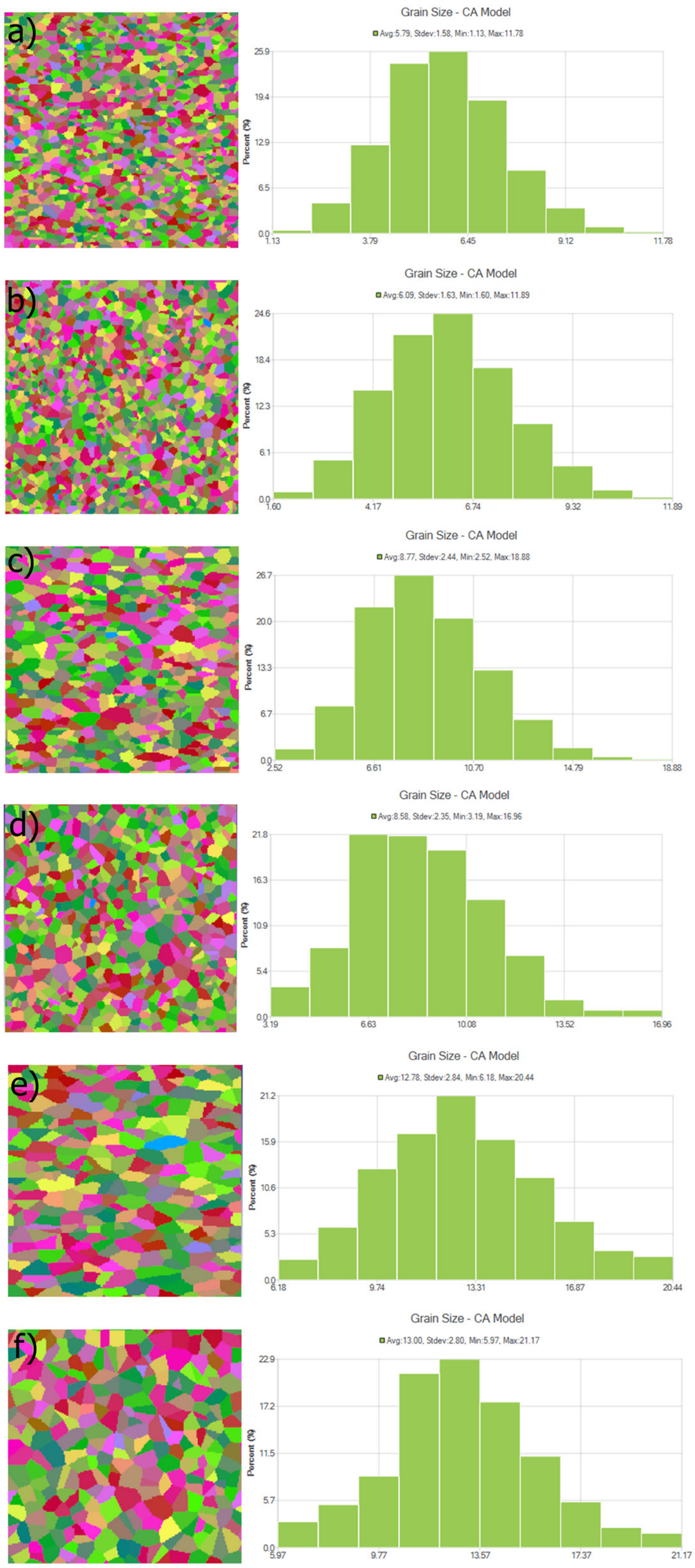

Fig. 3. Structure of L63 brass after annealing, 3 cycles of RSR at the temperature 500°C and the rolls rotation speed 70 rpm: (a) - surface, longitudinal direction; (b) - surface, transverse direction; (c) - periphery, longitudinal direction; (d) - periphery, transverse direction; (e) - center, longitudinal direction; (f) - center, transverse direction.

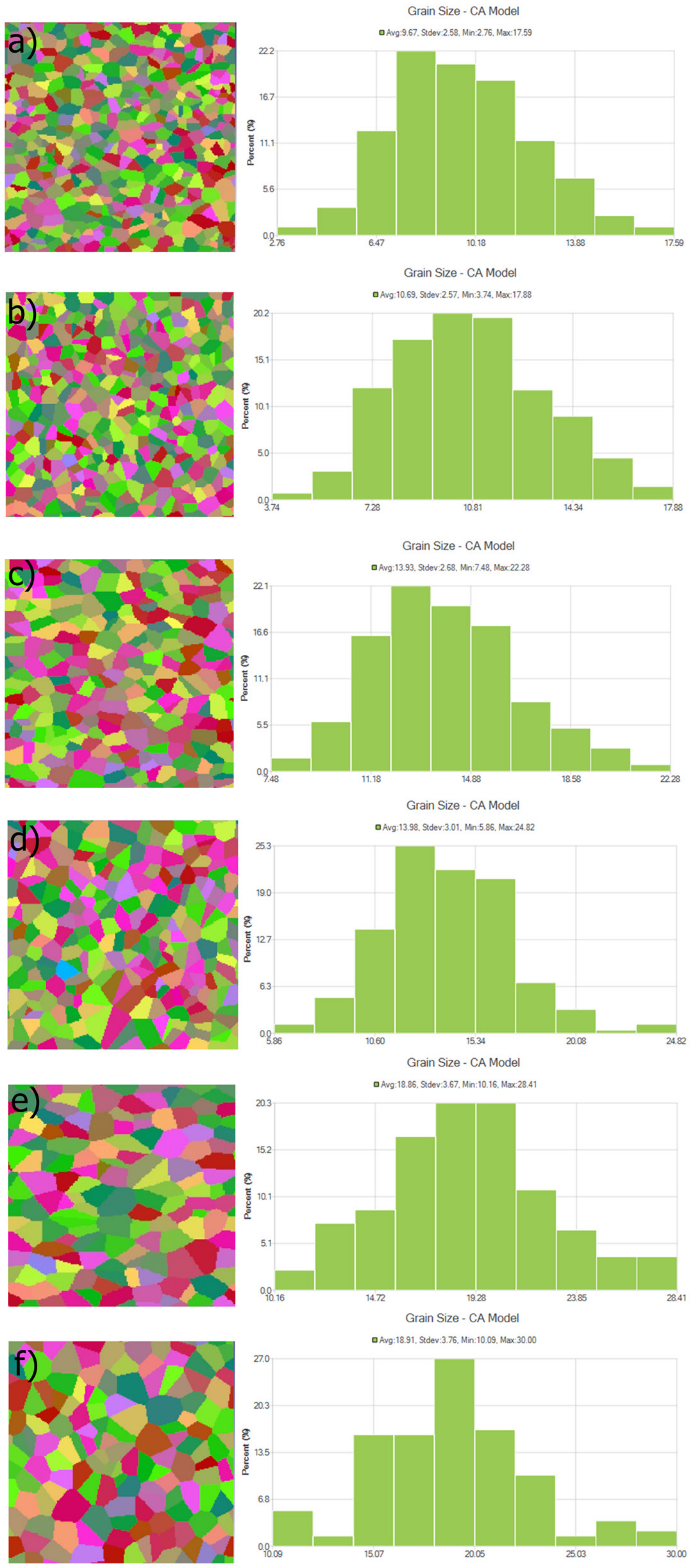

Fig. 4. Structure of L63 brass after annealing, 3 cycles of RSR at the temperature 500°C and the rolls rotation speed 100 rpm:(a) - surface, longitudinal direction; (b) - surface, transverse direction; (c) - periphery, longitudinal direction; (d) - periphery, transverse direction; (e) - center, longitudinal direction; (f) - center, transverse direction.

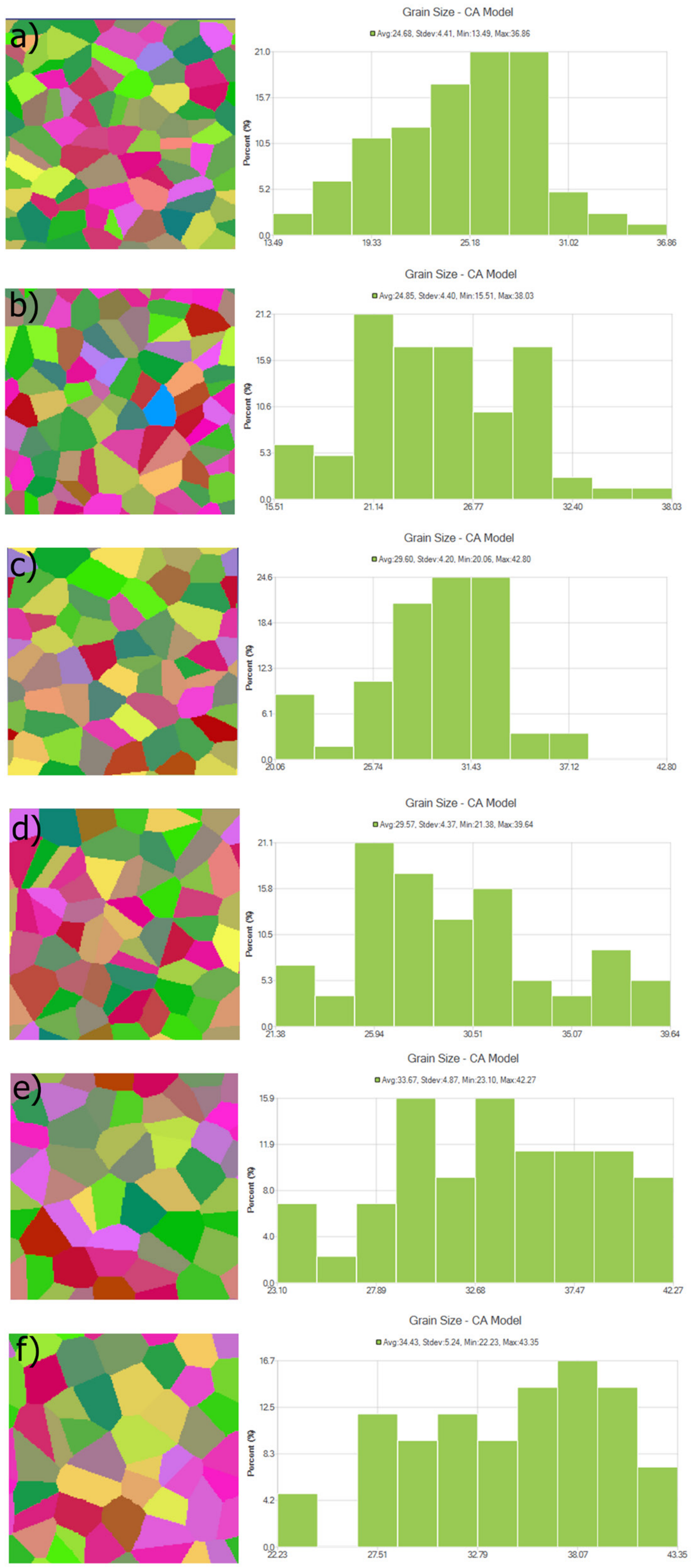

Fig. 5. Structure of L63 brass after annealing, 3 cycles of RSR at the temperature 700°C and the rolls rotation speed 40 rpm: (a) - surface, longitudinal direction; (b) - surface, transverse direction; (c) - periphery, longitudinal direction; (d) - periphery, transverse direction; (e) - center, longitudinal direction; (f) - center, transverse direction.

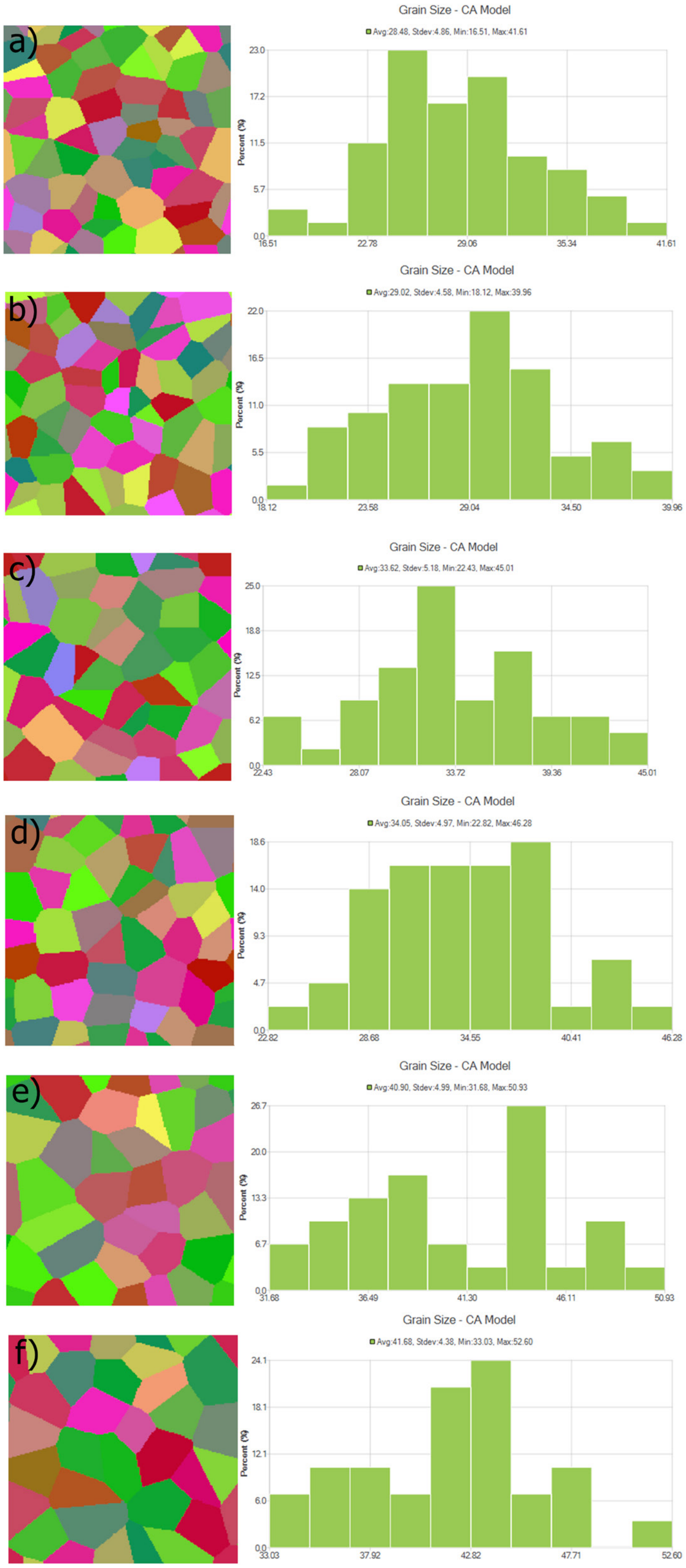

Fig. 6. Structure of L63 brass after annealing, 3 cycles of RSR at the temperature 700°C and the rolls rotation speed 70 rpm: (a) - surface, longitudinal direction; (b) - surface, transverse direction; (c) - periphery, longitudinal direction; (d) - periphery, transverse direction; (e) - center, longitudinal direction; (f) - center, transverse direction.

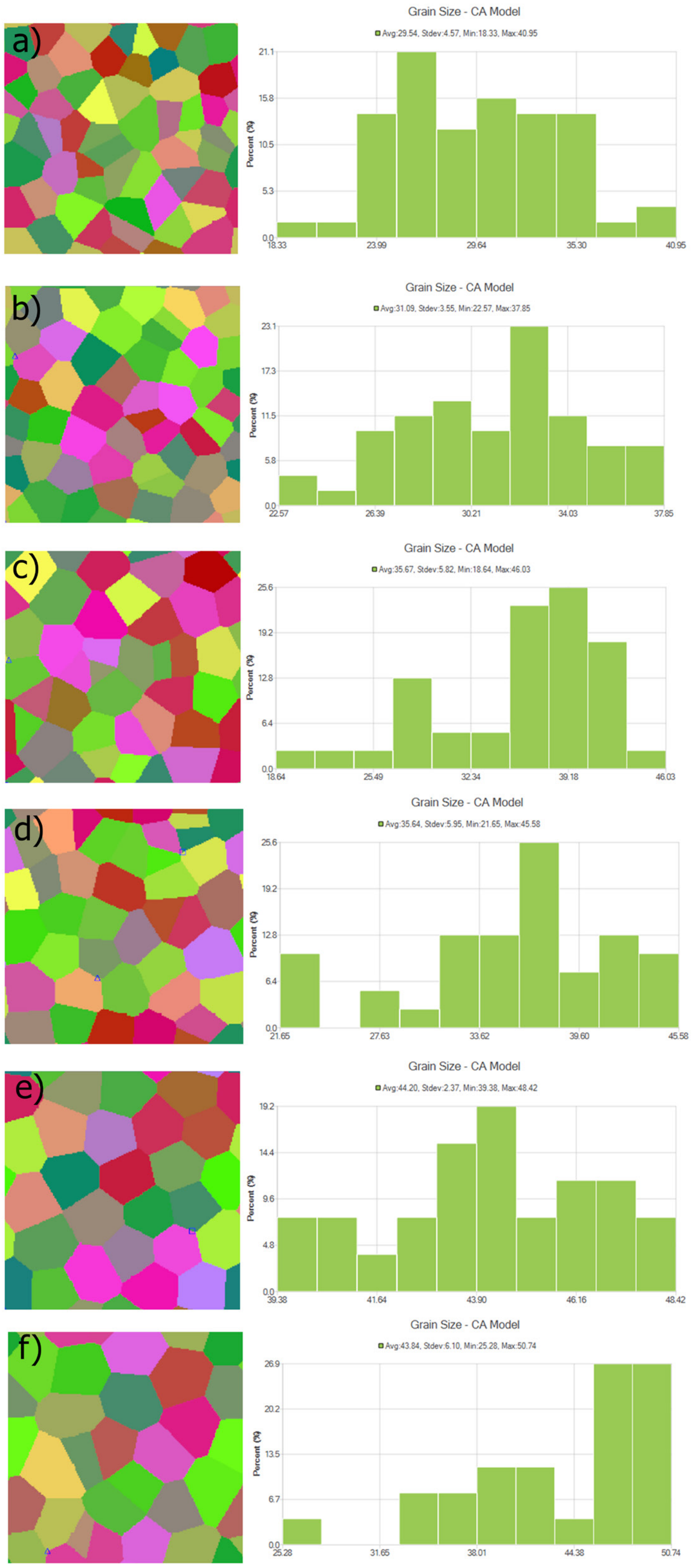

Fig. 7. Structure of L63 brass after annealing, 3 cycles of RSR at the temperature 700°C and the rolls rotation speed 100 rpm: (a) - surface, longitudinal direction; (b) - surface, transverse direction; (c) - periphery, longitudinal direction; (d) - periphery, transverse direction; (e) - center, longitudinal direction; f() - center, transverse direction.

CONCLUSIONS

Based on the results obtained by modeling the evolution of the microstructure of L63 brass, optimal parameters that allow intensify the process of grain refinement after PHT were determined. Heating up to 500°C at the conditional start of recrystallization at 480°C leads to the fact that at all roll rotation speeds, the cooling level of the workpiece is such that the metal temperature is below the set limit. Even rolling at 100 rpm leads only to the initial stage of recrystallization, when this process does not take place in the entire volume of the workpiece. Heating up to 700°C, even considering cooling, promotes rapid recrystallization, therefore this level of heating is not recommended.

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