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DEVELOPMENT OF THE TECHNOLOGICAL PROCESS OF ROLLING BARS IN THE NEW DESIGN RADIAL SHEAR MILL BY USING PHYSICAL MODELING

Abstract. A new design radial shear mill (RSM) which allows us obtaining high quality rods and wires by combining rolling and pressing is presented in this article. Physical modeling of the technological process of rolling rods and wires at RSM with various processing modes was performed by using STD 812 torsion plastometer.

The change in the structure of aluminum alloy A5083 during multi-stage compression at various temperatures and strain rates is described with a single position. The impact of temperature-deformation processing conditions on the microstructure and micro-hardness of aluminum alloy A5083 while rolling at RSM is analyzed. Kinetics of growth and grain grinding are considered; the conditions for forming the fine-grained structure are mentioned. It is established that in the deformation temperature range of 200 ÷ 300 °C and strain rates of 1.0 and 30 s^{-1}, dynamic and static recrystallization proceeds in the structure of the aluminum alloy A5083, depending on the temperature-deformation processing conditions. In the article, it is proved that it is necessary to perform rolling of the workpieces on a RSM at a rolling temperature of 280-320 °C in order to ensure a fine-grained structure in bars out of A5083 alloy.

Key words: tensile torsion, torsion, experiment, structure, grains, mill, rolls, hardening, softening, recrystallization.

Introduction. Nowadays, it is common that various industries produce a certain amount of press products out of non-ferrous metals and alloys with small geometric dimensions (various profiles, rods, pipes, wires, etc.). With the purpose of producing such types of products, most of the technically developed countries produce and implement radial-shear rolling (RSP) [1,2], methods of continuous pressing of a new generation of Conform, Extrolling, Linex, as well as the methods of continuous casting, rolling and pressing of Castex and Caster [3-5] at a good scientific level. Furthermore, it should be noted that the equipment used in these technological processes own high mobility, flexibility, and relatively high productivity while manufacturing products of various nomenclatures despite the large number of changes in the technological process.

According to the authors of the article [6-9], a well-studied continuous process is the method of combined rolling and pressing (CRP). This opinion occurred due to the fact that the development of CRP installations with an optimal design and testing of rational modes of manufacturing bars and profiles out of non-ferrous metals and alloys were performed by studying this method in laboratory and industrial conditions. It should be noted that it is advantageous to use a continuous combined process of casting, rolling and pressing in the production [10-13] in order to decrease the number of metallurgical processes and reduce energy costs. Later, these methods might become innovative processes in mini-factories for the production of small batches of press products.

Thus, the analysis of technological processes of manufacturing press products indicated that they are effective according to both technological and economic indicators. However, most of the above mentioned methods were not used and implemented properly in the industry, since the proposed technical solutions did not provide the industry with a stable process and did not create the necessary pressure for extruding the metal. At the same time, powerful shear deformations of the metal are not developed along the section of the workpiece, and, consequently, does not create conditions for a good investigation of the metal structure and for its property improvement.

It is known [14-17] that a set of experimental and industrial studies is required in order to develop a technology with the optimal temperature-deformation processing intervals. In this case, a certain amount of time is spent and certain materials are consumed. Therefore, for developing a technological process it is necessary to study and investigate various processing modes by using physical modeling and find rational modes that make it possible to manufacture products with a fine-grained structure as well as with high mechanical properties. The implementation of physical modeling can minimize the resource and time costs of the study in a significant way. Subsequently, physical modeling allows us to determine the rational temperature-deformation modes of rolling and pressing by a resource-saving way.

The objective set in our work was to develop a rational technology for hot pressing of rods out of aluminum alloy on a new design radial-shear mill (RSM) by using physical modeling.

Materials and methods of research. In this article, a new design of RSM was presented [18]. At this mill, the combination of hot screw rolling and pressing produces metal rods of small diameters or wire with a fine-grained structure.

Physical modeling was used for developing a rational technology for the hot deformation of rods and wires on a new design radial-shear mill. Operations of torsion and tensile torsion were implemented for physical modeling due to the fact that combined rolling and pressing processes in the proposed mill is carried out by rotational-translational movement of the workpiece. The impact of the temperature-strain parameters of the above mentioned combined process on the evolution of the grain structure of the aluminum alloy A5083 was investigated by using these operations.

STD 812 torsion plastometer was implemented for the physical modeling of hot plastic deformation of rods and wires on a new design radial-shear mill [19,20]. The samples were heated in an inductor. Aluminum alloy A5083 was chosen as the workpiece material. With the purpose of producing samples with a homogeneous and relatively coarse-grained structure, the initial bar stock with a diameter of 10 mm was subjected to homogenization annealing at the temperature of 470 °C and kept in this position for 30 hours.

In the manufacture of bars and wires at radial-shear mill, the main changing technological parameter is regarded to be the feed angle and the rolling angle. These indicators affect both speed and degree of deformation, as well as the processing temperature. Therefore, samples with the size of Ø16 × 210 mm manufactured out of annealed rods (length of the deformation zone is 60 mm) were deformed by torsion and tensile torsion at various strain rates. Testing procedure of the samples was carried out in vacuum. The samples were heated until the temperature reached 200, 300, and 400 °C at a rate of 5 °C/s and kept at this temperature for 250 s, then they were tested at a strain rate of 1.0 and 30 s^{-1}. After deformation, the samples were cooled at a rate of 20 °/s.

A universal microscope Neophot 32 (Karl Zeiss, Jena) (Germany) was used for conducting metallographic analysis. The Neophot 32 microscope is designed for metallographic microscopy and for making photographs.

The measurement of micro-hardness of the samples was performed according to the Vickers HV method on an automated micro-hardness tester of the American company INSTRON at a working load of 2.942 H and holding time of 10 seconds at the particular load.

Results and discussions. In this article, the obtained image of the microstructure of aluminum alloy A5083 in the cross section of the deformed rod was presented and demonstrated in Figures 1-4.

Based on the study of the microstructures of aluminum alloy A5083, it was established that:

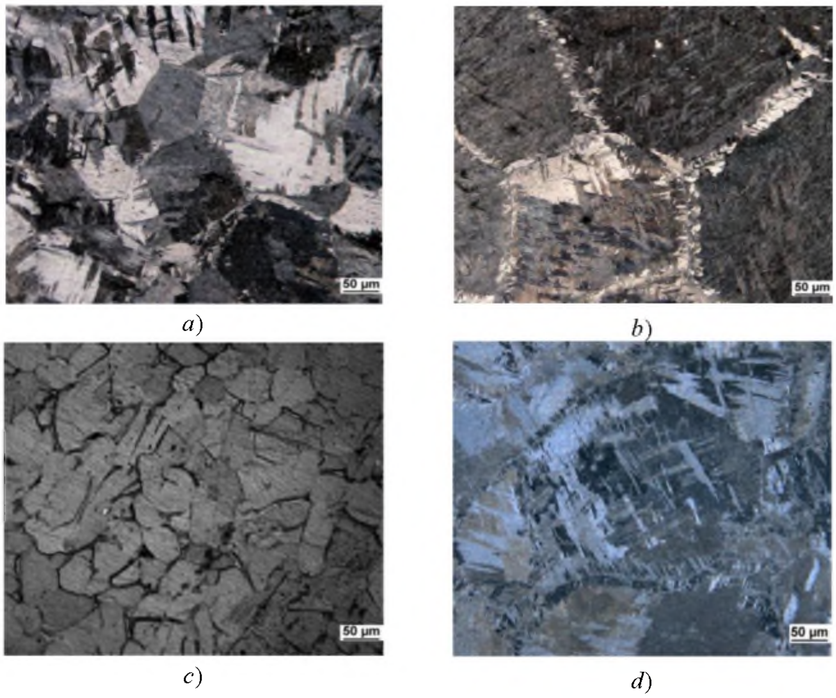
- the initial structure has relatively unevenly distributed large grains with an average size of ~ 368 microns;

- samples deformed by the torsion with a strain rate of 1 s^{-1} at temperatures of 200 °C had a relatively coarse-grained structure in the central and surface zones of the sample (figure 1, a, b). The average grain size varied from 163 microns to 315 microns;

- an increase in the strain rate to 30 s^{-1} at a testing temperature of 200 °C led to an intensive decrease in grain sizes in the surface zone of the workpiece, while it had a relatively coarse-grained structure in the central zone (figure 1, c,d). In these cases, the average grain size in the surface zone was 52 µm, and 253 µm in the central layers;

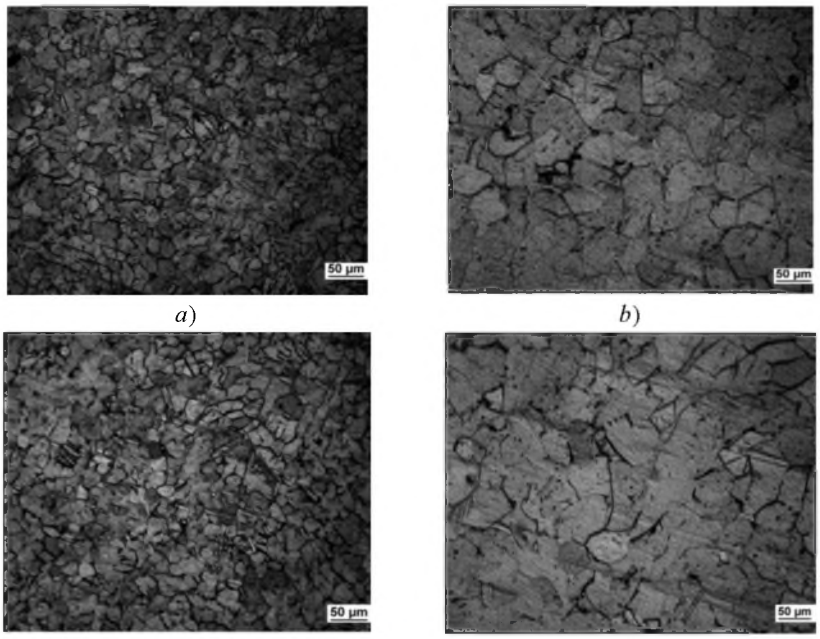
- torsion of the samples with a strain rate of 1 s^{-1} at a temperature of 300 °C also led to the formation of a different-grain structure (figure 2, a,b). The average grain size in the surface zone was 28 µm, and 57 µm in the central layers;
- testing the samples at the temperature of 300 °C, but with a strain rate of 30 s^{-1}, also contributed to the formation of a relatively different-grain structure (figure 2, c, d) with a change in the average grain size from 34 µm (surface zone) to 69 µm (central zone);
- deformation of samples at the temperature of 400 °C and with a strain rate of 1 and 30 s^{-1} led to the formation of a relatively coarse-grained structure (figure 3, a, b) with a range of grain sizes ranging from 263–271 µm (surface layer of the sample) and 293–302 µm (central zone of the sample);
- deformation of samples by the tensile torsion at the temperature of 200 °C with a strain rate of 1 s^{-1} led to the formation of a homogeneous and relatively coarse-grained structure with an average grain size of 62 µm (figure 4, a);
- an increase in the temperature to 200 °C and deformation at a speed of 30 s^{-1} made it possible to obtain a homogeneous and relatively fine-grained structure over the entire cross section of sample which is under testing with a grain size of 73 µm (figure 4, b);
- tensile torsion with a strain rate of 1 s^{-1} allowed us to obtain more homogeneous and relatively fine-grained structure in samples deformed at a temperature of 300 °C a with a grain size of 36 µm (figure 4, c);
- twisting tension at a temperature of 300 °C and deformation at the rate of 30 s^{-1} resulted in a homogeneous and relatively fine-grained structure over the entire cross section of the sample under testing. In this case, the average grain size was 18 µm (figure 4, d);
- tension with a torsion at the temperature of 400 °C and strain rates of 1 and 30 s^{-1} led to the formation of a relatively homogeneous and coarse-grained structure with a range of grain sizes from 182 - 211 µm across the sample cross section (figure 4, d).

By comparing the obtained images of the structures, it can be seen that the strain by the torsion did not allow us to obtain a homogeneous refinement of the structure in the cross section of the rod. In the majority of cases, there are areas with a fine-grained structure in the surface layer of the sample, and larger grains which are visible in the central zones. We believe that the reason behind fragmentation of surface zones and preservation of coarse-grained structure in the center of the workpiece is the concentration of deformation degree in the surface zone of the workpiece during the deformation of sample by torsion.



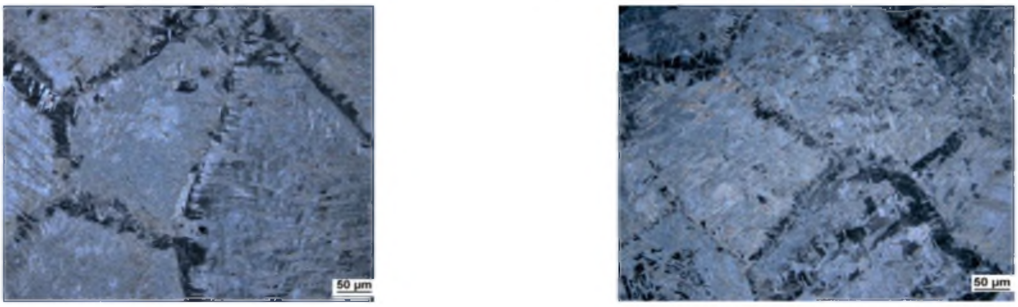
a) *b*) *c*) *d*)

Figure 1 – Microstructure of the surface and central zones of samples deformed by the torsion at the temperature of 200 °C.
a - surface zone, 1 s^{-1};
b - central zone, 1 s^{-1};
c - surface zone, 30 s^{-1};
d - central zone, 30 s^{-1}



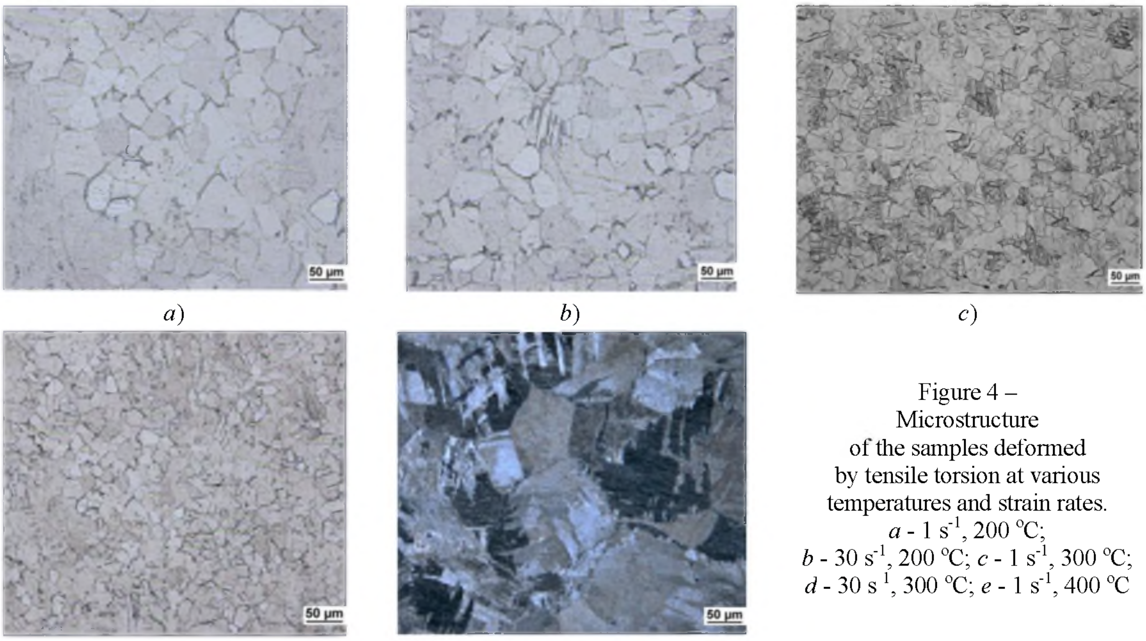
a) *b*) *c*) *d*)

Figure 2 – Microstructure of the surface and central zones of samples deformed by the torsion at the temperature of 300 °C.
a - surface zone, 1 s^{-1};
b - central zone, 1 s^{-1};
c - surface zone, 30 s^{-1};
d - central zone, 30 s^{-1}



a) *b*)

Figure 3 – Microstructure of the surface and central zones of samples deformed by torsion with a strain rate of 1 s^{-1} (a) and 30 s^{-1} (b) at the temperature of 400 °C



a) *b*) *c*) *d*) *e*)

Figure 4 – Microstructure of the samples deformed by tensile torsion at various temperatures and strain rates.
a - 1 s^{-1}, 200 °C;
b - 30 s^{-1}, 200 °C; *c* - 1 s^{-1}, 300 °C;
d - 30 s^{1}, 300 °C; *e* - 1 s^{-1}, 400 °C

It should be noted that such a difference in the formation of structures is particularly evident when samples are deformed by torsion with a strain rate of 1 s^{-1} at a testing temperature of 200 °C. The results of the experiment indicated that torsion of the samples under demonstrated temperature-strain conditions leads to a small thermal effect of plastic deformation. The temperature of the working part of the sample increases by 250 °C while compared to its initial temperature.

The results of metallographic studies indicated that hardening and softening processes take place mainly by the return and polygonization mechanism during a rise in temperature in the structure of the central zone of the sample. At the initial stage of deformation, a dynamic return occurs in the metal structure of the workpiece, and polygonization occurs with a continuous increase in stresses. Furthermore, unsteady polygonization takes place in the metal structure. Due to the unsteady process of polygonization in the metal structure, unequal grains and subgrains are formed in the sample with relatively large sizes. It should be noted that this temperature-velocity condition of deformation provides unsteady dynamic recrystallization taking place on the surface of the sample and structure which is formed with an average grain size.

The above mentioned research results indicate that structure is formed during the deformation of samples by torsion with temperature-speed conditions both at the temperature of 200 °C with a strain rate of 30 s^{-1}, and at the temperature of 300 °C with strain rates of 1 and 30 s^{-1} according to the above-described law. However, torsion of the sample at the temperature of 200 °C with a strain rate of 30 s^{-1} led to the greatest thermal effect of plastic deformation. The maximum temperature recorded in the working area of the sample was 530 °C. Based on these data, it can be noted that the temperature of the working area of the sample was increased by 330 °C. Such increase in temperature led to the occurrence of steady-state polygonization and recrystallization in the structure of the central and surface zones of the sample, respectively. We believe that the established polygonization and recrystallization took place in the structure of the central and surface zones of the sample in the case of torsional stress at a temperature of 300 °C with strain rates of 1 and 30 s^{-1} respectively. The occurrence of established polygonization and recrystallization at these temperature-strain rate deformations led to the formation of fine-grained structure in the surface zone of the workpiece and a medium-grained structure in the central zone of the workpiece.

It should be noted that the samples deformed by tensile torsion with a strain rate of 1 and 30 s^{-1} received a relatively large fragmentation of grains. Therefore, the microstructure of samples deformed by this type of deformation at the temperature of 200 and 300 °C has more finer-grained structure in comparison with samples deformed by torsion under the same temperature and speed conditions of testing. The reason behind the greater fragmentation of grains when tensile torsion is applied to the sample is the action on the rod of the torsion and additional tensile stress. The actions of such complex stress state lead to a more uniform distribution of the degree of deformation. It is known that a uniform distribution of the deformation degree leads to the formation of a homogeneous structure in the metal.

By analyzing the above mentioned data, it becomes clear that, regardless of the applied load, an increase in the testing temperature up to 400 °C leads to the formation of a coarse-grained structure due to the occurrence of secondary (collective) recrystallization.

Investigation of the micro-hardness of A5083 aluminum alloy deformed by the torsion and tensile torsion indicated that the hardness of the material in the surface layer is higher than on the rod axis. At the same time, the study of the laws of the distribution of micro-hardness in the cross section of samples deformed by the torsion or tensile torsion at various temperatures and strain rates indicated that the smaller the size of the fragmented grains of the structure, the greater the micro-hardness of the metal. Conversely, the larger the grain size, the lower the micro-hardness of the sample.

It should be noted that deformation of samples by the torsion or tensile torsion at the temperature of 400 °C led to the decrease in micro-hardness over the entire cross section of the sample, which is associated with the passage of secondary (collective) recrystallization in the metal structure.

Based on the obtained results, it can be concluded that the rolling should be carried out in the temperature range of 280 - 320 °C with a strain rate of 1 – 30 s^{-1} in order to obtain a fine-grained structure in bars or wires out of aluminum alloy A5083, deformed on a RSM of a new design. Furthermore, in the proposed mill, it is necessary to produce a load conducive to develop tensile or compressive torsion in the deformation zone. The load which facilitates deformation of the workpiece with the tensile torsion can be created by installing a coiler in front of the die. At the same time, the load allowing the workpiece being deformed by compressive torsion can be produced by increasing the flow velocity of the rolled metal in the rolls, i.e. by backing up the metal in front of the matrix.

Conclusion. The combination of rolling and pressing on a new design radial-shear mill allows us to obtain uniform micro-hardness and fine-grained structure over the entire cross section of a cylindrical workpiece in the case of production of load contributing to the development of tensile or compressive torsion in the deformation zone.

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ҚҰРЫЛЫМЫ ЖАҢА РАДИАЛЬДЫ-ЫҒЫСТЫРУ ОРНАҒЫНДА ШЫБЫҚ ИЛЕМДЕУДІҢ ТЕХНОЛОГИЯЛЫҚ ҮДЕРІСІН ФИЗИКАЛЫҚ МОДЕЛЬДЕУ АРҚЫЛЫ ЖАСАУ

Аннотация. Мақалада құрылымы жаңа радиалды-ығыстыру орнағы (РЫО) ұсынылған. Шыбықтар мен сымтемірлерді баспақтау үшін қолданылатын радиальды-ығыстыру орнағы басты жетектен, жұмысшы қапастан, пішінбілік торабынан жэне баспақ-ұяқалыбынан тұрады. РЫО-ның үш пішінбілігі бар жұмысшы қапасы тұғырдың ішіне орналастырған. Осы тұғырдың ойығына 120° бұрышпен жұмысшы пішінбіліктердің торабы жинақталған. Жұмысшы пішінбіліктер жастыққа жинақталған. Пішінбіліктерге айналу моменті біліктер арқылы электрқозғылтқыштардан беріледі. Осы орнақтың пішінбіліктері дайындаманы қарпитын жэне жаншитын толқынды-консуты бөлімге жэне мөлшерлейтін бөлімге иемденген. Толқынды-консуты бөлімнің шығыңқы жэне ойыңқы жерлері бұрандалы сызықпен орындалғаны жайында айта кеткен жөн. Осы кезде шығыңқы жэне ойыңқы жерлердің геометриялық өлшемі илемдеу бағытына қарай біртіндеп азаяды. Осы орнақта илемдеу мен баспақтауды біріктіру жолымен жоғары сапалы шыбықтар мен сымдарды алуға болады. STD 812 торсионды пластометрін қолдана отырып, РЫО шыбықтар мен сымдарды түрлі режимдермен өңдеудің технологиялық үдерісі физикалық модельдеу арқылы жасалды. Мақалада нақты позициямен түрлі температурада көптеген деформация жылдамдығымен A5083 алюминий қорытпасынан жасалған дайындаманы көпсатылы жаншығанда қорытпа құрылымындағы түйіршіктер өлшемінің өзгеру заңдылығы сипатталған. РЫО-да A5083 алюминий қорытпасынан жасалған шыбықтарды илемдеген кезде осы қорытпаның микроқұрылымына температура-деформацияның өңдеу режімі қандай заңдылықпен эсер ететіндігі талданған. Құрылым түйіршіктерінің өсуі мен майдалау кинетикасы жұмыста қарастырылған, ұсақ түйіршікті құрылымның қалыптасу жағдайы көрсетілген. 200-300 °С деформация температурасы мен 1,0 жэне 30 $с^{-1}$ деформация жылдамдығы диапазонында A5083 алюминий қорытпасынан жасалған шыбықты илемдегенде, температура-деформациялық өңдеу режіміне байланысты шыбық құрылымында динамикалық жэне статикалық қайта кристалданатыны анықталды. Жұмыста A5083 алюминий қорытпасынан жасалған шыбықта ұсақ түйіршігі құрылымды алу үшін оның дайындамасын РЫО-да 280-320 °С температура аралығында илемдеу қажеттігі дэлелденді. Осы жұмыста түрлі температура мен деформация жылдамдығы аралығында үлгілерді бұрау немесе созып бұраумен деформацияланғанда олардың көлденең қимасында микроқаттылықтың таралу заңдылықтары зерттелді. Металл құрылымның бөлшектелген түйіршіктерінің мөлшері неғұрлым кіші болса, металл микроқаттылығы да соғұрлым жоғары болатындығы мақалада көрсетілді. Жұмыста A5083 қорытпасынан жасалған бұйымдарда ұсақтүйіршікті құрылымды алуды қамтамасыз ету үшін оларды 280-320 ° С температура аралығында РЫО-да деформациялау қажеттілігі дэлелденді.

Түйін сөздер: созып бұрау, бұрау, тэжірибе, құрылым, түйіршік, орнақ, пішінбілік, беріктік, беріксіздік, қайтакристалдану, полигондау.

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РАЗРАБОТКА ТЕХНОЛОГИЧЕСКОГО ПРОЦЕССА ПРОКАТКИ ПРУТКОВ НА РАДИАЛЬНО-СДВИГОВОМ СТАНЕ НОВОЙ КОНСТРУКЦИИ С ПОМОЩЬЮ ФИЗИЧЕСКОГО МОДЕЛИРОВАНИЯ

Аннотация. В данной статье предложен радиально-сдвиговый стан (РСС) новой конструкции, позволяющий совмещением прокатки и прессования получать прутки и проволоку высокого качества. РСС для прессования прутков и проволоки содержит главный привод, рабочую клеть, валковый узел и пресс-матрицу. Трехвалковая рабочая клеть РСС состоит из станины, в расточках которой через 120° смонтированы узлы рабочих валков. Рабочие валки смонтированы на подушках. Крутящий момент к валкам передается через шпиндели от электродвигателей. Валки данного стана имеют волнисто-конусообразные участки захвата и обжатия и калибрующий участок. Заметим, что выступы и впадины волнисто-конусообразных участков выполнены по винтовой линии. При этом геометрические размеры выступов и впадин постепенно уменьшаются в направлении прокатки. С использованием торсионного пластометра STD 812 произведено физическое моделирование технологического процесса прокатки прутков и проволоки на РСС новой конструкции с различными режимами обработки. С единой позиции описано изменение структуры алюминиевого сплава А5083 при многоступенчатом обжатии при различных температурах и скоростях деформирования. Проанализировано влияние температурно-деформационных режимов обработки на микроструктуру алюминиевого сплава А5083 при прокатке на РСС. Рассмотрена кинетика роста и измельчения зерен, отмечены условия образования мелкозернистой структуры. Установлено, что в диапазоне температур деформаций 200 ÷ 300 °С и скоростях деформации 1,0 и 30 $с^{-1}$ в структуре алюминиевого сплава А5083 протекает динамическая и статическая рекристаллизация в зависимости от температурно-деформационных режимов обработки. В работе доказано, что для обеспечения мелкозернистой структуры прокатку заготовки из сплава А5083 на РСС необходимо производить при температуре прокатки 280-320°С. В работе изучены закономерности распределения микротвердости в поперечном сечении образцов, деформированных кручением или растягивающим кручением при различных температурах и скоростях деформации. Показано, что чем меньше размер фрагментированных зерен структуры, тем больше микротвердость металла. В работе доказано, что для обеспечения мелкозернистой структуры в прутках из сплава А5083 необходимо прокатку заготовок производить на РСС при температуре прокатки 280-320 °С.

Ключевые слова: растягивающее кручение, кручение, эксперимент, структура, зерна, стан, валки упрочнение, разупрочнение, рекристаллизация.

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