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INFLUENCE OF ALUMINUM ALLOY CHEMICAL COMPOSITION WITH ULTRAFINE-GRAINED STRUCTURE ON THE MECHANICAL PROPERTIES OF THIN SHEETS

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ABSTRACT

The influence of the chemical composition of aluminum alloy with ultrafine-grained structure on the mechanical properties of thin sheets, rolled by sever eplastic deformation in rolls with corrugated working surface and long itudinal wedge camp. It was established that there crystallized structure of ultrafine primaryre crystallization mechanism isobtained when hot (corrugated rolls) and cold (longitudinally generator mill) rolled sheets of alloys Al-Mg-Si 6082 grade system with comparatively rapid heating to a temperature of 500°C, exposure to 1 hr and then quenching in oil. It is shown that the mechanical properties of ultrafine-grained structure of the alloy increases with the increase of alloying elements such as manganese, magnesium, silicon. Found that by increasing the amount of other alloying elements due toreduced solubility of the impurity decreases ductility of alloys.

Key words: Aluminum alloy, Ultrafine-grained structure, Thin sheets.

INTRODUCTION

Aluminum alloys are widely used in aircraft and rocket construction. During construction the group of requirements determining their working efficiency is imposed[1]. The technological properties of alloys providing low-cost and mass production of semi-finished products and components of required geometry also play significant role. Due to the increasing use of aluminum alloys in different fields of engineering, in particular in automotive (car) industry, technological requirements significantly increase because of mass production, necessity of ensure its cheapness and manufacturing parts with high surface quality. In most cases, for the car bodies aluminum alloys are used as parts produced by cold

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forming from sheets with thickness of 0.8 to 1.5 mm. Therefore, the basic requirement for automobile sheets is the minimum longitudinal and lateral gage interference and flatness, their good formability in combination with sufficient strength characteristics of the final product and a mirror image surface for the external parts.

In the automobile industry for body parts two types of aluminum alloys are used. There are non-heat-treatable alloys of Al-Mn 3000 series, Al-Mg of 5000 series systems and heat-treatable alloys of Al-Cu, Al-Cu-Mg, Al-Mg-Si and Al- Mg-Si-Cu of 2000 and 6000 series[1].

From non-heat-treatable alloys, alloys of 3004 and 5182-0 grades are most commonly used (in the annealed state have a fine grain structure and good stamp)[1]. However, the alloys of 5000 series work harden fast and intent to formLueders line that limits their use as the internal parts of the car body. In these latter daysheat-treatable alloys of the 6000 series take much interest, as sheets from these material are used as the basic material for external parts of the body instead of steel sheet (alloys 6016, 6111, 6061). More than 40 years extra-long-range and bolt-on fuel tanks, bottle, conduit pipes of different modifications aircrafts are made from alloys of this series. For the production of the above listed products alloys of 5000 series are also used. They are less durable, inclined to the formation the porosity in weld seams, less maintainable at cold treatment.

High rates of above listed sheet materials fabricabilityand good quality of the products surface can be obtained by means of the formation of regulated fine grained structure during the primary recrystallization. According to the authors of work[1], grain size of the aluminum alloys sheets should be no more than 50 microns and in the range of 1.5-50 microns.

Lately, technologies of producing nano structured metallic materials with submicro crystalline and ultra-fine grain structures are in intensive development[2]. The technologies of severe plastic deformation (SPD) are widely used to obtain this class of materials. Materials, manufactured by using SPD technologies, have attracted the attention of specialists due to a number of unique properties, many of which have the direct practical application. The prospects of such materials extensive use lead to expansion of our understanding about physical nature of the strength and fracture mechanisms at the different scale levels.

Aluminum alloys of the Al-Mg-Si system are promising materials for automobile designs, because they have low density, sufficiently high elastic modulus and relatively high durability[3-5]. However a number of unresolved issues prevent widespread use of semi-finished alloys of Al-Mg-Si system in mechanical engineering. There are low thermal stability, limited technological plasticity and low service properties in the coarse-grained state, a pronounced anisotropy of mechanical properties. Number of parts of the required quality cannot be produced because of these reasons. It is known that the formation of recrystallized ultra fine-grained structure (UFG) (grain size is less than 10 microns) in aluminum alloys of the Al-Mg-Si system provides to achieve high strength characteristics, high plasticity and crack growth resistance, and most importantly, isotropy of mechanical properties. Another consequence of the formation of an ultra fine-grained structure of semi-finished aluminum alloys is extraordinary increasing of technologic plasticity. It allows both rolling thin sheets from these materials, and produce items of complex shape from these sheets by press forming method in the state of super plasticity. By the time of carrying out this work on the basis of published data and complex laboratory studies, it has been found that the most effective method of UFG structure formation in alloys of Al-Mg-Si system is a severe plastic deformation.

From alloy of 6082 grade, which belongs to alloys of Al-Mg-Si system, the sheets with a thickness of 0.3 mm to 10.5 mm are produced. They are supplied in three states: annealed; hardened and naturally aged; hardened and artificial-aged[1]. At that flow limit of the sheets from 6082 alloy is not specified, but it is an important characteristic for assessment the process ability at the products manufacturing stage and for working efficiency in the construction. The gage interference, flatness and grain size, which determine the workability in cold forming, are not specified as well. However, it is known from practice that semi-finished products of Al-Mg-Si system alloys, including the sheets of 6082 alloy, are prone to gage interference and inequigranularity with pronounced texture of recrystallization, which reduces their ability to deformability (workability) and deteriorates the appearance of products produced by cold forming.

It should be noted that to date, the literature nearly has no data about the complex of functional mechanical properties and thermal stability of aluminum alloy 6082 of the Al-Mg-Si system with UFG structure that restrains the use of the alloy in the industry. It is known that the size of grains in alloys of the Al-Mg-Si system affects the staging of the phase transformations during aging, but their features are not well researched[3-5]. Lack of information requires the carrying a number of additional studies aimed at understanding the structural changes in the alloy of 6082 Al-Mg-Si system in the SPD and, most importantly, at the subsequent heat treatment. The principles of recrystallization at heating for the hardening, as well as mechanisms of influence of UFG structure and chemical composition on the mechanical properties of these alloys have to be known. Structural changes during the plastic deformation and heat treatment of Al-Mg-Si system alloys affect the characteristics of strength and plasticity. Therefore, their detailed research and the establishment of the connection between structure, chemical composition and mechanical properties is not only scientific, but also the great practical importance.

It is known that the formation of fine-grained structure is taking place under nucleation and continuous mechanisms of primary recrystallization[1,6,7].

The main mechanism of formation of recrystallized grains is the formation of surrounded by large-angle boundaries of the section with high structural perfection. Formation and growth of grains takes place due to the initial deformed grains, so-called "eating" the deformed grains which are in recrystallized state already. This mechanism is continuous ("insitu") and consists of a uniform increase of sub-grains[1,6,7].

It is known that continuous recrystallization is more often observed in the hot-deformed semi-finished products with the original poligonized structure[1,6,7]. Structure, obtained by continuous recrystallization method, is characterized by fine equiaxed grains with mutual misorientation of the grain boundaries with angles 8-10 degrees, which contributes to a significant increase the properties of semi-finished products. In recent years, the publications about the research of continuous recrystallization processes in cold rolled sheets of aluminum and its alloys are appeared[1].

The purpose of this work was to study the processes of structure formation of Al-Mg-Si system industrial alloy in the SPD process and the subsequent heat treatment, and to identify the regularities of changes of mechanical properties of the alloy according to the characteristics of the structure and chemical composition.

Equipment, materials and experimental techniques

For the study the mill having rolls with corrugated working surfaces (Fig. 1)[8], as well as the continuous rolling mill for stripsrolling from steel and alloys were used (Fig. 2)[9]. Continuous mill includes working stands, electric motor, clutch, backup non-driven rolls, working drive rolls, shoe, backing plate. Stands, having the drive from alternating-current motor, contain working and backup rolls with constant diameter, but in a tandem stands the diameter of working rolls decreases, and the diameter of the backup rolls increases in the direction of rolling. In this case, the rotation of the rolls is carried out through the individual clutch gearbox, pinion stand and spindles, and the diameters of the work and backup rolls are determined by the formula, respectively:

$$D_{i+1} = \frac{h_i \cdot D_i \cdot n_i}{h_{i+1} \cdot n_{i+1}} \frac{(1+s_i)}{1+s_{i+1}}; \; D_{j-1} = \frac{h_j \cdot D_j \cdot n_j}{h_{j-1} \cdot n_{j-1}} \frac{(1+s_j)}{(1+s_{j-1})}; \; (i = 1, 2, \ldots, \mathrm{N}; j = \mathrm{N}, \ldots 2, 1)$$

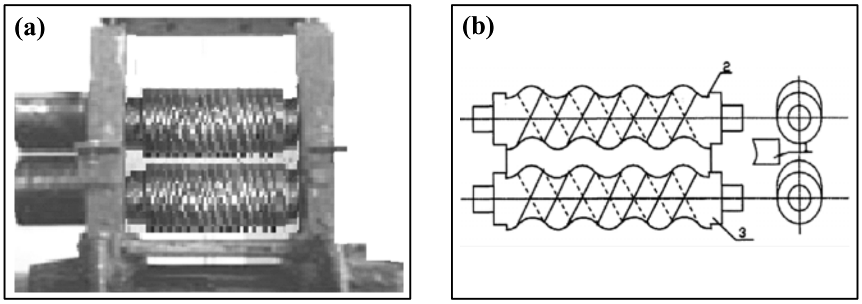
where h_i, h_j – The thickness of the rolled strip in i or j stand

n_iиn_j – Rotation frequency of rolls of i or j stand

N – Sequence number of the stand

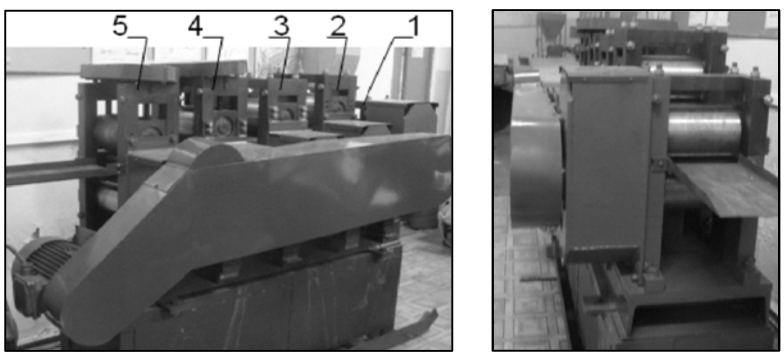
s_iиs_j – Advancing on the output from rolls of i or j stand

D_iиD_j – Diameters of working i and backup j rolls of previous stand



Mill **Rollingpattern**

Fig. 1: Rolling mill DUO with the corrugated rolls: 1-workpiece; 2-drag-over mill; 3-bottom roll



1-two-high mill stand without the screw-down structure; 2, 3-four-high mill stand without the screw-down structure, 4, 5-four-high mill stand with screw-down structure

Fig. 2: Five-stand longitudinal wedge rolling mill

In the proposed mill the horizontal axis of tongue and bottom rolls of the first three mill stands without screw-down mechanism is shifted from the rolling axis in the vertical direction on:

$$\Delta x_i = 0.25 \cdot k_n \cdot D_{pi} \cdot \alpha_i^2$$

Where D_{pi} is a diameter of new working rolls of *i*-th stand, mm;

k_n – Coefficient of resharpening;

α_i – Permissible angle of nip for rollers of *i*-th stand.

It should be noted that the predetermined distance between the working rolls from one stand to another increases by amount of advance.

As the material of the study the industrial aluminum alloy of Al-Mg-Si system of 6082 grade was selected. Severe plastic deformation of the material was carried out in rolls with corrugated working surfaces (Fig. 1), and cold rolling was performed on a continuous longitudinal wedge mill (Fig. 2).

Workpieces of 20 × 150 × 300 mm size were annealed at the temperature of 650°C for 6hours. Rolling was carried out at the temperature of 450°C on the mill with corrugate drolls to a thickness of 5 mm and the cold rolling was generated on the continuous longitudinally wedge mill to a thickness of 1.5 mm. Rolling in the rolls with corrugated working surfaces was performed as follows. Workpiece was supplied into the gap between the upper and lower rolls and by the projections and recesses deform the latter one with following draft $\varepsilon = \Delta h_B / H_o$ and $\varepsilon = 2\Delta h_B / H_o$ (where Δh_B -height of the projection or recesses depth of corrugated work surface; H_o -height of sheet slab before rolling). The resulting sheets were annealed at 300, 400 and 500°C with consequent holding for 1 hour and hardening was carried in oil.

To calculate the stress-strain state (SSS) a specialized standard program MSC. Super Forge was used. A three-dimensional geometric model of the rolled sheet was built in the CAD, Inventor program, and imported into the CAE, MSC. Super Forge program. When creating finite element model of the original workpiece the three-dimensional volume element CTETRA (four-node tetrahedron) was used.

To calculate SSS the technical description of working mill stands of the proposed laboratory mill was used. In MSC. Super Forge tools assumed to be absolutely rigid and provide only the properties of the thermal conduction and heat transfer, i.e. the specific heat conductivity, specific heat capacity and density are taken into account, and mechanical properties are ignored. From materials database SH15 was assigned as a tool material. The program designated by default the density and thermal properties of this material.

The interaction between the hard roll and deformable material of the workpiece is modeled by the contact surfaces, which describe the contact conditions between the surfaces of rolls and the surface of the rolled sheet. During the modeling process contact conditions are constantly updated, reflecting rollers rotation and material deformation, that allows to simulate sliding between the roll and processed workpiece material. The contact between the roller and the sheet was modeled by Coulomb friction; the friction coefficient was adopted 0.3. From a database of materials the alloy 6082 was assigned.

The temperature regime at rolling is consisting of a heat exchange between a roll, sheet and environment, as well as of the heat effect due to the deformation of metal. Rolling process takes place at room temperature, so the initial temperature of the roll was set to 20^oC.

Metallographic analysis was carried out on an optical microscope Axiovert- 200 MAT at magnifications of 200, 500 and 1000-fold. Images processing was carried out by the program Video Test "Metal 1.0", as well as using an energy dispersive spectrometer JNCAENERGY (England), mounted to the electron probe microanalyzer JEOL at an accelerating voltage of 25 kV. The range of the magnifications of JEOL device is from 40 to 40,000-fold. The principle of microanalyzer work: a high-energy (25 keV) narrow (1 mm) beam of electrons directed onto the sample, where is unwrap in the raster (frame), scanning the sample, at that registered the secondary electrons emitted by the sample. The resulting picture is very similar to the optical images, but due to the fact that the electron beam is very thin (≈ 1-2 micron), the depth of focus are much higher than optical images and using enlargement is significantly higher, respectively, smaller structural constituents of the sample can be distinguished.

Quantitative analysis of the parameters of the defect substructure was carried out by standard methods[2]. Specimens for metallographic analysis were prepared by the traditional method on the grinding and polishing circles. Sample for microanalysis were poisoned with a Keller solution.

To study the effect of chemical composition and structure on the quality of the hot-rolled strips samples from aluminum alloy 6082 grade of Al-Mg-Si system were cut.

The chemical composition of study samples was determined by photovoltaic system MFS-8. The work of system is based on the method of emission spectral analysis, which uses dependence of the intensity of spectral lines from the mass fractions of the elements in the sample.

Mechanical tensile testing of the flat samples with size of the working parts 1.5 × 3 × 6 mm was conducted on a universal testing machine MI-20U. At the same time the mechanical properties of the sheets with different types of structures were tested in three directions: longitudinal, lateral and at an angle of 45°. According to the tests results of the samples the yield strength ($\sigma_{0.2}$), tensile strength (σ_t) and relative general (δ) and constant (δ_{const}) relative elongation, coefficient of volume anisotropy and strain hardening were estimated by the methods described in GOST 1497-84 and GOST 9651-84. Mechanical tests at tension cannot give absolute values of stamping, so in the work the depth of the wells during extrusion by Erichsen (H) was determined.

RESULTS AND DISCUSSION

By calculation the optimal mode of compression on mill stands during cold rolling of 1.5 × 150 mm profile was obtained. The profile was made from 6082 grade aluminum alloy of Al-Mg-Si system and tested at semi-industrial longitudinal-wedge mill. Adjustment of the roll gap on adjustable mill stands was carried out by screw-down gear to produce strips with a predetermined thickness, profile and flat form. Degradation of relative compression was performed in the penultimate and the last mill stands of the new mill in order to obtain thin strips with minimum gage interference. In this case the rolling was conducted by the following modes: 1 mill stand: ε = 22%, 2 mill stand: ε = 20%, and 3 mill stand: ε = 20%, 4 mill stand: ε = 10%, 5 mill stand: ε = 5%.

Under laboratory conditions strip flatness defects and gage interference were measured at the free location of the sheet on the control table by an ultrasonic thickness gauge "VZLET UT". Deviation frequency of the strip and tape thickness from the predetermined value was calculated as a result of the study.

Analysis of transverse gage interference of strips showed that their minimum value for 1.5 mm thick strips lies in the range from 0.015 to 0.01 mm. The average value of the transverse gage interference is 0.012 mm.

Transverse gage interference of strips, rolled on the researched mill, meets the requirements of the standards per 100% of the strip length, with the exception of the end sections (96%).

Statistical investigation of the flatness of rolled strips for the proposed continuous mill showed that the average value of the flatness defects amplitude is 2.0 ... 2.8 mm.

Thus, the application of a new semi-industrial rolling mill can reduce transverse gage interference and flatness of strips and thereby to manufacture high-quality strips for further forming.

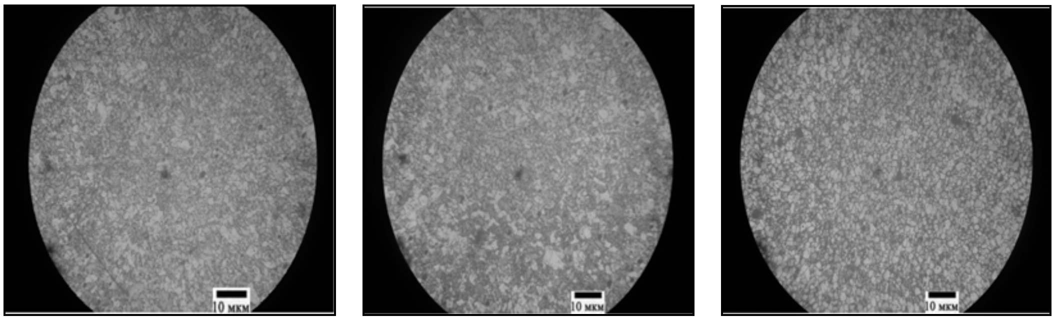
Based on the obtained results of numerical modeling it was found that:

- Proposed a rolling tool having equal dimensions of the projections and recesses of the working surface of the rolls, and protrusions or hollows of the upper roller disposed opposite to the depressions and projections of the lower roll, respectively, with the aforementioned single drafts allows to deform workpiece with a small thickness without changing its dimensions by multiple bending.
- Multiple bending can increase the value of the degree of shear deformation. All this allows to achieve an efficient grinding of alloy structure, i.e. increase the quality of sheets.
- Use small workpiece thickness and alternating bending deformation leads to greater productivity and reduce the complexity of the produced sheets. This reduces the power parameters of the process.
- Tangential and axial stress in the tension zone have a positive sign when rolling in corrugated rolls, as in the compression zone is negative sign. In this case radial stresses on the strip surface are equal to zero, while the thickness has a negative value.
- Displacement of the projections and depressions across the width of the rolled strip occurred during rolling in the working rolls with corrugated surfaces, which creates additional macroscopic shears and the cross section of the preform increases strain rate.
- An increment of deformation intensity value in the case of rolling in rolls with corrugated surfaces twice higher than during rolling in cylindrical rolls (at normal rolling the average intensity deformation value along the section strip is equal to 1.1 ... 1.2, and at rolling in rolls with reverse taper – 2.2...2.6).
- Increase of the deformation intensity will lead to the formation of equiaxial homogeneous ultra-fine grain structure over the strip cross section.
- At rolling in the mill stands of cross-wedge rolling mill the stress and deformation intensity over the cross section of the strip is evenly distributed.

On the base of metallographic analysis it was established that –

- In a cold rolled sheets from 6082 grade aluminum alloy of Al-Mg-Si system at annealing in the temperature range of 300-400^{o}C the non-homogeneous ultra fine-grained structure (average grain size of 2.6 and 2.2 microns) with faint trace of deformation texture (Fig. 3, a and b) was formed.

- Ultra-fine grained homogeneous recrystallized structure (average grain size of 1.5 microns) was obtained in cold-rolled sheets from 6082 grade aluminum alloy of Al-Mg-Si system when heated to 500°C (Fig. 3,C).



(a) **(b)** **(c)**

Fig. 3: Microstructure of cold-rolled sheets of the alloy 6082 annealed at a temp. of 300°C (a), 400°C (b) and 500°C(c)

Table 1 shows the chemical composition of 6082 grade alloy based on the Al-Mg-Si system with a different content of alloying elements, and Table 2 shows the content of impurities.

Table 1: Chemical composition of 6082 grade aluminum alloy

S. No.	**T_o (°C)**	**Fe**	**Si**	**Mn**	**Cr**	**Ti**	**Al**	**Cu**	**Mg**	**Zn**	**Ni**	**Sn**
1	300	0.2	1.2	0.9	0.10	0.06	96.16	0.06	1.2	0.1	0.001	0.002
2	300	0.4	1.0	0.7	0.15	0.08	96.42	0.10	0.8	0.3	0.003	0.001
3	300	0.6	0.7	0.4	0.25	0.09	97.02	0.08	0.6	0.2	0.002	0.002
4	400	0.2	1.2	0.9	0.10	0.06	96.16	0.06	1.2	0.1	0.001	0.002
5	400	0.4	1.0	0.7	0.15	0.08	96.42	0.10	0.8	0.3	0.003	0.001
6	400	0.6	0.7	0.4	0.25	0.09	97.02	0.08	0.6	0.2	0.002	0.002
7	500	0.2	1.2	0.9	0.10	0.06	96.16	0.06	1.2	0.1	0.001	0.002
8	500	0.4	1.0	0.7	0.15	0.08	96.42	0.10	0.8	0.3	0.003	0.001
9	500	0.6	0.7	0.4	0.25	0.09	97.02	0.08	0.6	0.2	0.,002	0.002

Table 2: Contents of impurities in the 6082 grade of aluminum alloy

S. No.	Pb	Be	Zr	V	As	Bi	Sb	B	Cd	Co	Ga
1	0.01	0.0001	0.001	0.001	0.001	0.001	0.003	0.001	0.0002	0.0001	0.003
2	0.03	0.0001	0.002	0.002	0.001	0.003	0.004	0.001	0.0005	0.0002	0.005
3	0.04	0.0002	0.001	0.003	0.001	0.002	0.005	0.001	0.0003	0.0002	0.004
4	0.01	0.0001	0.001	0.001	0.001	0.001	0.003	0.001	0.0002	0.0001	0.003
5	0.03	0.0001	0.002	0.002	0.001	0.003	0.004	0.001	0.0005	0.0002	0.005
6	0.04	0.0002	0.001	0.003	0.001	0.002	0.005	0.001	0.0003	0.0002	0.004
7	0.01	0.0001	0.001	0.001	0.001	0.001	0.003	0.001	0.0002	0.0001	0.003
8	0.03	0.0001	0.002	0.002	0.001	0.003	0.004	0.001	0.0005	0.0002	0.005
9	0.04	0.0002	0.001	0.003	0.001	0.002	0.005	0.001	0.0003	0.0002	0.004

Tensile tests results analysis (Table 3) shows that the sheets from 6082 grade alloy of Al-Mg-Si system with non-homogeneous ultra-fine structure have relatively low values of relative elongation. At the same time the yield point and strength on sheets with homogeneous ultra-fine grain structure in 1.1 ... 1.3 times higher than in the sheets with non-homogeneous ultra-fine-grained structure, with weak traces of deformation texture.

Reduction of relative elongation with simultaneous increasing of the yield stress and strength is observed under the conditions of soaking hardening at temperature of 500^{o}C till 2 minutes (Fig. 4, 5). In our opinion, merging of alloying ingredient that at such holding time and temperatures a dissolution of alloying components does not have enough time to carry out in enough extent, excess phase forms from solid solution, however there is a partial removal of vacancies from solid solution and there is a significant weakening of the intergranular bond. This leads to a decrease of relative elongation. At long heating over 2 mins at 500^{o}C substantially complete dissolution of the alloying phase occurs and excess of vacancies are eliminated, intergranularbonds are strengthened and the maximum level of properties are provides (Figs. 4 and 5).

Best indicators have a homogeneous material with ultra-fine structure by parameters characterizing the fabricability during cold forming (r and n), particularly by level of absolute values and the value of the anisotropy.

Table 3: Mechanical and technological properties of sheets from 6082 grade alloy

S. No.	Direction	σ_t, MPa	$\sigma_{0,2}$, MPa	$\delta_{равн}$, %	δ, %	*r*	n	$\sigma_в/\sigma_{0,2}$	*H*, mm
1	Longitudinal	173.2	94.8	21.2	24.53	0.46	0.237	1.83	8.4
	Lateral	168.8	90.4	20.4	23.92	0.42	0.228	1.87	
	45°	168.9	92.7	22.2	14.56	0.63	0.262	1.82	
2	Longitudinal	162.3	82.7	19.1	22.53	0.41	0.217	1.96	7.9
	Lateral	161.8	79.4	18.8	21.22	0.40	0.206	2.03	
	45°	160.4	80.3	19.4	22.36	0.41	0.216	1.99	
3	Longitudinal	158.3	78.4	17.3	19.68	0.35	0.195	2.02	7.3
	Lateral	156.7	75.3	16.8	19.27	0.34	0.193	2.08	
	45°	153.7	76.8	16.9	19.32	0.35	0.231	2.00	
4	Longitudinal	182.9	103.7	25.6	29.38	0.52	0.274	1.77	8.9
	Lateral	179.3	102.8	23.7	28.62	0.51	0.263	1.75	
	45°	180.2	103.3	24.9	29.12	0.67	0.294	1.74	
5	Longitudinal	173.7	98.2	22.3	25.68	0.48	0.246	1.77	8.7
	Lateral	172.7	96.4	21.4	24.72	0.47	0.243	1.79	
	45°	170.3	92.5	22.8	24.63	0.64	0.289	1.84	
6	Longitudinal	168.7	86.8	20.7	22.53	0.46	0.235	1.95	8.3
	Lateral	167.3	82.9	19.3	21.83	0.49	0.243	2.01	
	45°	169.2	86.2	19.9	23.52	0.63	0.257	1.97	
7	Longitudinal	196.3	108.5	27.4	31.65	0.56	0.294	1.81	9.6
	Lateral	192.8	106.4	26.9	31.24	0.61	0.283	1.78	
	45°	194.8	107.5	27.3	31.47	0.79	0.306	1.82	
8	Longitudinal	187.4	104.7	25.6	28.32	0.52	0.273	1.79	9.1
	Lateral	182.6	102.8	23.8	26.48	0.53	0.271	1.78	
	45°	185.8	100.2	24.2	27.53	0.74	0.301	1.86	
9	Longitudinal	179.8	98.3	23.6	25.83	0.49	0.271	1.83	8.8
	Lateral	174.6	94.6	21.2	24.73	0.52	0.268	1.85	
	45°	178.3	96.8	22.8	24.97	0.71	0.294	1.84	

The total content of alloying elements in alloys of Al-Mg-Si system ranges from 1.5 to 4.5%. Strengthening phase in all alloys is Mg_2Si, and therefore the degree of hardening is in direct dependence on the amount of this phase. Increase of manganese, magnesium and silicon grade of concentration has led to increase of strength and plastic characteristics.

Reduction of plasticity at decrease of the temperature first of all conditioned to the low solubility of impurities at low temperatures and sharp increase of the role of impurities insignificant amount.

Study showed that with increasing content of impurities in a non-homogeneous fine-grained structure, because of the impurities accumulation on the boundaries of relatively large grains, plasticity of alloys decrease. Relatively inequigranular alloy has a relatively small total surface area of the grain boundaries, which leads to a high concentration of intergranular impurities, reaching several and even tens of percent, with a total content of hundredths or thousandths of a percent.

It was established that at ultrafine grain structure, the mechanical properties of investigated alloy increase with increasing such alloying elements as manganese, magnesium and silicon. This is due to hardening and a small decrease in plasticity of the alloy. The increase of other alloying elements amounts leads to a decrease of impurities solubility and thereby to reduction ofalloys plasticity with large amounts of impurities.

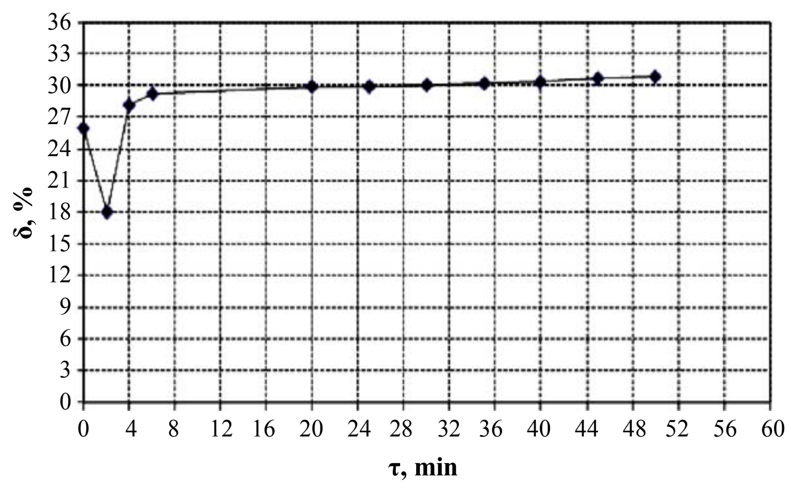


Fig. 4: Effect of hardeningholding timeat 500°C vs. total relative narrowing (δ) of cold-rolled sheets from 6082 grade alloy of Al-Mg-Si system

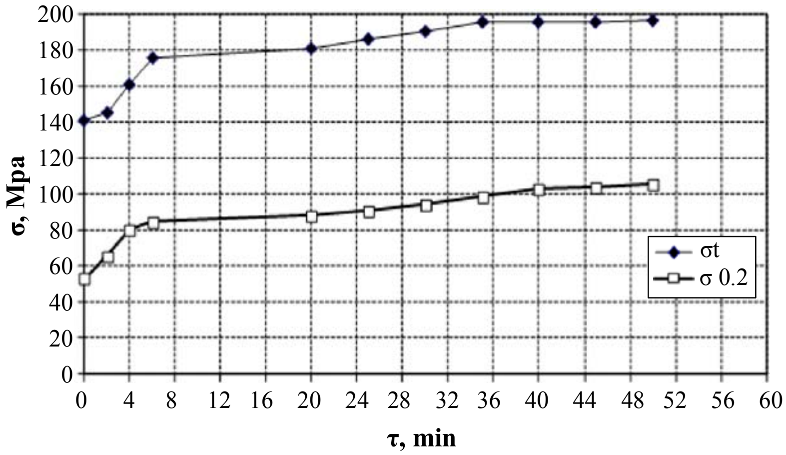


Fig. 5: Effect of holding time for hardening at 500°C vs. tensile strength (σ_t) and yield strength ($\sigma_{0.2}$) of cold-rolled sheets from 6082 grade alloy of Al-Mg-Si system

Thus, to improve the mechanical properties of aluminum alloys measures to promote the production of homogeneous ultrafine grained structure and reduction of harmful impurities amount should be taken.

CONCLUSION

In the hot-(tapered rolls) and cold rolled (longitudinal-wedge mill) sheets from 6082 grade alloys of the Al-Mg-Si system during the annealing in the temperature range of 300-400°C, depending on the composition of primary recrystallization mechanism, irregular equiaxed grains with weak traces of strain texture are formed; Fine grained recrystallized structure by primary recrystallization mechanism was obtained in hot-(corrugated rolls) and cold rolled (longitudinally wedge mill) sheets from 6082 grade alloys of Al-Mg-Si system at relatively fast heating at temperatures up to 500°C, holding time up to 1 hour and then quenched in oil; Sheets from 6082 grade alloys of Al-Mg-Si system at uneven ultra-fine grain structure has relatively low values of relative elongation, at that yield strength on sheets with homogeneous fine structure is 1.1 ... 1.3 times higher than on sheets with uneven fine-grained structure; Both in absolute values and in the value of the anisotropy the best indicators have the material with a homogeneous fine-grained recrystallized structure by the parameters characterizing the fabric ability at cold forming;

At ultra-fine grain structure increase of alloying elements leads to increase of mechanical properties of the alloy and at the same time increase of impurities reduces the material plasticity.

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