Influence Of The Coherent Diffraction Areas Sizes On The Mechanical Properties And Formability Of Aluminium Alloys Al - 10% Mg And Al - 5% Cu - 2% Mg (2024)

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Abstract: Actuality of work associated with fine-grained structure obtaining in aluminum alloys for production goods by sheet stamping methods. The problem of establishing the influence of the grain structure dispersion on the mechanical and technological properties of high-alloyed aluminum alloys blanks is solved in the article. Plastic deformation and low-temperature annealing of Al-10% Mg and Al-5% Cu - 2% Mg (2024) flat samples are carried out. Their mechanical properties (tensile strength, yield strength, relative elongation) were identified by static uniaxial tension. The graphs of dependence of true tension and deformations are constructed. Evaluation of the grain structure dispersion was carried out by the coherent diffraction areas changing on the basis of X-ray diffraction analysis results. The graphs of dependence of mechanical and technological properties of the coherent diffraction areas size in these alloys are constructed. Microstructures of samples in the annealed condition were considered. The assessment of technological effectiveness of alloys Al-10% Mg and 2024 in operations of sheet stamping by stamping coefficient estimation is carried out. The sizes of crystallites for obtaining favorable strength, plasticity and technological effectiveness of alloys in operations of sheet stamping are revealed. It was established that grain size obtaining less than 1.8 microns in alloy 2024 and 4.3 microns in the alloy Al-10% Mg while cold rolling and interoperational annealing is impractical for subsequent stamping operations

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1. Introduction

It is known that increasing of grain structure dispersion and decreasing of irregularity of grain size impact on strength and technological properties of alloys [Gubernatorov et al, 2006; Huang and Humphreys, 2012]. Often receiving and determination of the grain size and its uniformity in aluminum alloys represents a separate task. On the one hand, the quality of the resulting structure depends on the etchant composition and etching conditions. In some alloys, for example Al-Cu-Mg or Al-Mg-Si systems, this question has no definite answer. On the other hand, the grain shape is such that it is impossible to determine its size, for example, if it disorientation, blocking or twisting. The using of the X-ray diffraction analysis allows estimating the areas of coherent diffraction [Aruldoss et al, 2007; Bryukhovetsky et al, 2010]. They represent volumes or grain parts which crystallographic planes coherently reflect X-ray bunches. When the size of these areas is less than (1...1.5) x0.1 micron the effect of erosion and the broadening of the interference lines on radiographs is observed [Brandon and Kaplan, 2004]. The increase of crystal lattice defects quantity leads to increase of specific volume of structural components, including the areas of coherent diffraction. At the same time, the considerable plastic deformations implemented by rolling and pressing, lead to the appearance of dislocation walls and loops of different shapes within the grains, which affects the appearance of new areas of coherent diffraction [Galevskii et al, 2007].

When the deformed metal heating to temperatures of prerecrystallization annealing at a stage of refreshment the main structural changes consist in reduction of pint defects concentration, and density of dislocations decreases very little therefore hardening from deformation generally remains. If poligonization associated with the formation and consolidation of subgrains decontaminating their volume from dislocations, develops at prerecrystallization annealing, the size of coherent diffraction areas changes, although the grains size changes slightly. Thus strength properties can significantly decrease [Shan and Zhen, 2012; Li and Ghosh, 2004]. The period during which the specified transformations proceed, depends on degree of preliminary cold-hardening, temperature of heating and endurance duration of annealing.

In practice the obtaining the specified size of grain is described by recrystallization diagrams in coordinates “grain size - the degree of deformation - the heating temperature”. Duration of heating and endurance in these diagrams isn't considered and depends generally from the massiveness of processed products, the principle of heating devices operation and other factors. In turn, the yield strength is related to the diameter of subgrains by the Hall-Petch correlation [Gusev, 2009]: $\sigma_{0.2} = \sigma_0 + k/\sqrt{d_{cp}}$, where $\sigma_0 = 2.5 \cdot 10^{-4} G$ - Payerls tension; k - Petch coefficient; d_{cp} – the average size of subgrain, Å, G - shear modulus, MPa.

Petch coefficient calculated by the formula [Gusev, 2009]: $k = 1.6G\sqrt{b\Theta'}/(2\pi(1-\nu))$, where b - Byurgers vector modulus, Å; [theta] - disorientation angle of adjacent subgrains, rad; [nu] - Poisson's ratio [Gusev, 2009].

Plasticity factors during annealing after cold deformation generally vary inversely with strength properties change: in recover area they relatively little increase, then greatly increased in primary recrystallization, when the most part of hardening is removed, and changes little during collecting recrystallization. The maximum plasticity is reached in some interval of temperatures in the stage of collecting recrystallization. The secondary recrystallization giving very large grain, and also inequigranular reduce of plasticity factors [Dharmendra Singh et al, 2013; Deschamps et al, 2011]. The presence of high plasticity is not yet good the technological effectiveness, for example, in operations of sheet stamping. So, technical aluminum and low-elemented alloys having high rates of relative elongation and low resistance to deformation can be intensively thinned because of anisotropy properties, stick to the tool, form corrugations and festoons [Wenk el al, 1997; Sidor et al, 2010]. That demonstrates a low technological effectiveness.

Thus, the properties intensively change at different behaviors of deformation and annealing, and therefore, strongly depend on the structural transformations completeness connected with change of grain. A specific electric resistance is one of the characteristics that keeps sensitive to structural transformations. As a rule, the electrical resistivity starts to drop during the annealing before the tensile strength will decrease, since the electrical resistivity can be greatly reduced because of the decrease of concentration of pint defects in the recover, and the intensive tensile strength drop becomes possible only when the dislocation density decreases sharply [Styles et al, 2012; Hadianfard et al, 2008]. Aluminum alloys have a low electrical resistance, which causes difficulty in establishing its characteristics through the contact and contactless methods. Therefore structural changes diagnose associated with replacements at grain may be best conducted by detecting coherent scattering regions.

The aim of this work was to establish the influence of the coherent diffraction areas size on the mechanical and technological properties of the alloys Al-10% Mg and 2024. The choice of these alloys is connected with wide use of the alloy 2024 for production of aircraft details by methods of sheet stamping. In turn the alloy with the raised content of magnesium Al-10%Mg was developed as replacement for the stamped steel type A 620 and A 622 for automotive industry [Kuziak et al, 2008] and now its properties and structural changes during receiving sheet semi-finished products are insufficiently studied. The effect of increased magnesium content on the ability of aluminum alloys for grain refinement during recrystallization is interesting. Besides, it is required to estimate the grain structure of nanoscale dispersion values positive role in the ability of alloys to operations of sheet stamping. Thus considerable hardening of alloys from grain size reduction can result in fast wear of the tool and need of use of more power-intensive equipment.

2. Materials and Methods

The chemical composition of studied alloys was defined by energy-dispersive accessory of raster electronic microscope Tescan Vega and presented in table 1.

Table 1. Mass fraction of elements in studied alloys

Alloys	Mass fraction of elements, %										
	Al	Mg	Zr	Be	Ti	B	Cu	Co	Mn	Fe	Ni	Zn
Al-10%Mg	89.3	10.5	0.11	0.08	0.018	0.01	0.001	0.015				
2024	85.02	1.54					5.97		0.33	0.64	0.39	0.36

Samples were cut from the middle part of cold-rolled annealed sheets having a thickness of 1 mm in the rolling direction. For obtaining various values of the grain size they were subjected to uniaxial stretching in several stages before achievement of the maximum uniform deformation. Values of deformations are presented in table 2.

Table 2. Values of samples deformations

Alloys	ε1, %	ε2, %	ε3, %	ε4, %	ε5, %	ε6, %
Al-10%Mg	13	17	21	24	27	30
2024	9.5	14	18	22	26	30

For both alloys most uniform elongation was 30%. The samples were then annealed at 373 K for 3, 5, 7 and 9 minutes. Cooling was carried out in water for fixing of the obtained structure.

The obtained samples were tested for uniaxial tensile by testing machine Testometric. For the calculations used logarithmic strain, as it obeys the laws of summation [May et al, 2010].

Values of true (logarithmic) deformation calculated by the formula [May et al, 2010]:

$$\varepsilon_i = \ln(l_k/l_0)\cdot 100\% \quad (1)$$

where ε_i - true deformation, %; l_0 - initial length of sample, mm; l_k - final length of sample, mm.

The true tension in the test part of the sample is determined by the formula [May et al, 2010]:

$$\sigma_i = P/F \quad (2)$$

where P - stretchable force, N; F – cross section area of sample, mm^2.

For assessment of coherent diffraction areas X-ray diffraction research of samples in the plane of sheet in the direction of rolling was conducted on the X-ray diffractometer "DRON-7" using the cobalt anode in the characteristic radiation k [alpha] (wave length [lambda] = 1.54056Å) and the nickel filter [beta] - lines. The diffraction method based on the analysis of width of diffraction lines was applied. The behavior X-ray shootings 2[theta]-[theta] (to the scheme Bragg - Brentano), tension is 40 kV, current 20 мA, scanning step 2 [theta] =0.01-0.02°, range of scanning angles 2 [theta] =25-140°, exposition 3-4 sec.

Researches of alloys Al-10% Mg and 2024 microstructure in the recrystallized condition with different durations of annealing performed on metalographic instrumental microscope METAM PB. For microstructure research one of surfaces of flat samples, after annealing, was grind, then was polished and exposed to etching. The etchant composition consisted of hydrofluoric acid HF – 2%, nitric acid HNO_3 – 3% and water H_2O – 95%, etching duration – 10 sec.

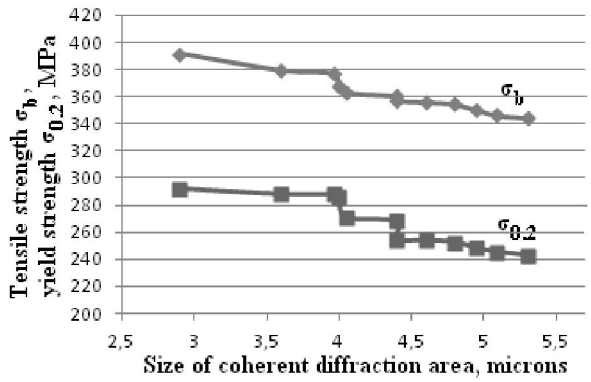
Technological effectiveness of alloys Al - 10% Mg and 2024 in operations of sheet stamping was estimated by means of stamping coefficient determined by the formula: [May et al, 2010]:

$$K = \sigma_{0.2}/\sigma_b \quad (3)$$

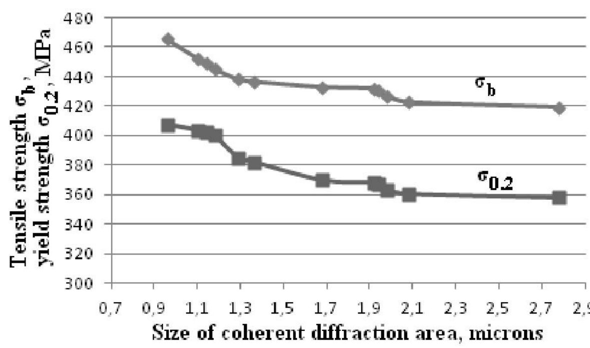
where $\sigma_{0.2}$ - yield strength, MPa; σ_b - tensile strength, MPa.

3. Results

Dependences of tensile strength, yield strength, stamping coefficient and relative elongation from coherent diffraction area size in alloys Al-10%Mg and 2024 are presented in figures 1 and 2 respectively.



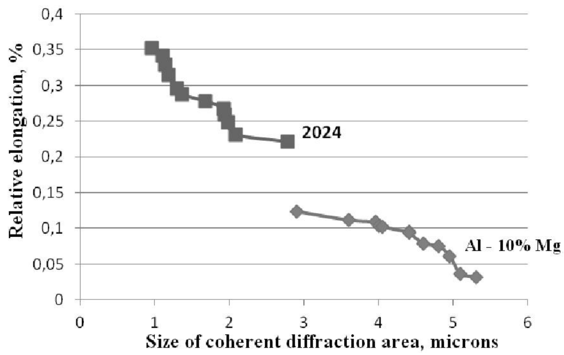
a)



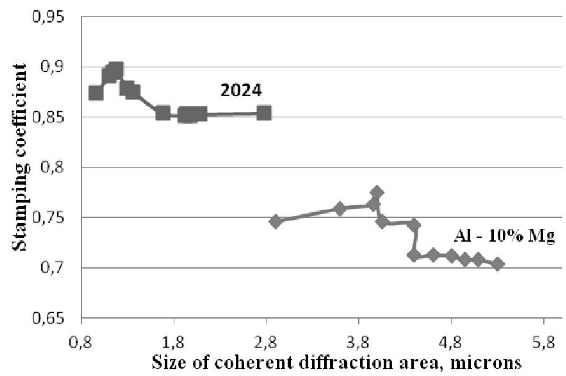
b)

Fig. 1. Dependencies of tensile strength (σ_b) and yield strength ($\sigma_{0.2}$) from size of coherent diffraction area in alloys Al-10% Mg (a) and 2024 (b)

The size of coherent diffraction areas decreases from 2.78 to 0.96 microns with growth of preliminary degree of deformation in the alloy Al-10%Mg. While the tensile strength increased with 419 to 466 MPa and the yield strength - from 248 to 288 MPa, the relative elongation - from 3.2% to 12.4%. Hall-Petch dependence has the form: $\sigma_{0.2} = 101 + 324/\sqrt{d}$. The stamping coefficient increases at values of the sizes of coherent diffraction areas is less than 4.3 microns.



a



b

Fig. 2. Dependencies of relative elongation (a) and stamping coefficient (b) from size of coherent diffraction area in alloys Al-10% Mg and 2024

In the alloy 2024 with growth of preliminary degree of deformation the size of coherent diffraction areas decreases from 5.3 to 2.9 microns. Thus the tensile strength increases from 344 to 392 MPa, the yield strength – from 358 to 407 MPa, the relative elongation – from 22.1% to 35.2%. Hall-Petch dependence has the form: $\sigma_{0,2} = 287 + 118/\sqrt{d}$. The stamping coefficient at quite large size of coherent diffraction area influences slightly, but at values less than 1.8 microns (for the alloy 2024) and 4.2 microns (for the alloy Al-10%Mg) it increases.

In figure 3 shows graphs of dependence of true tension from true deformation in alloys Al-10% Mg and 2024 in the annealed condition.

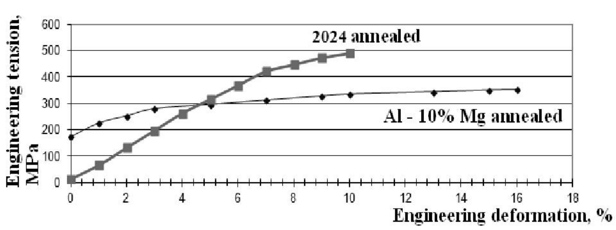
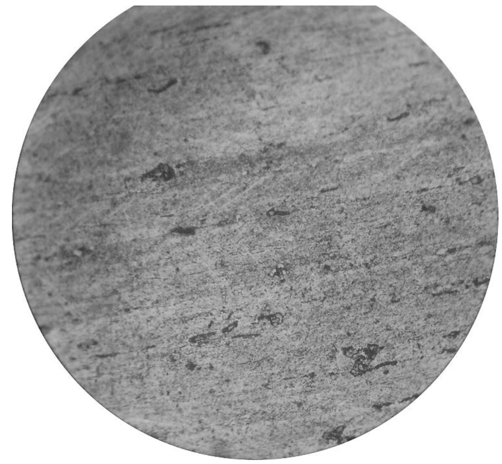


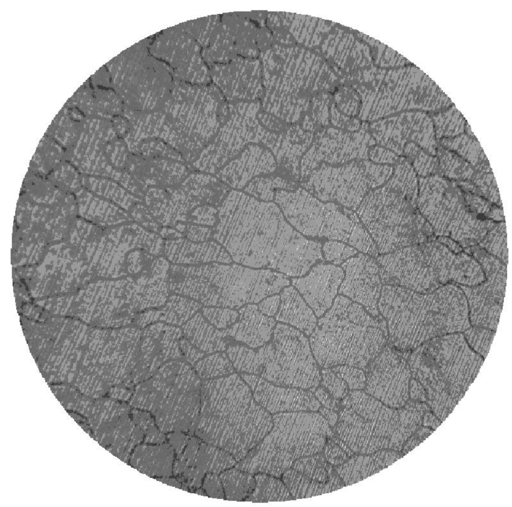
Fig. 3. Dependences of engineering tension from engineering deformation in alloys Al - 10% Mg and 2024 in the annealed condition

Hardening nature of alloys 2024 and Al - 10% Mg in the annealed condition has power dependence, the degree of hardening decreases with increase tension.

Figure 4 shows the microstructure of the alloy after deformation and low temperature annealing.



a)



b)

Figure 4 - The microstructure of alloys 2024 (a) and the Al-10% Mg (b) after deformation 26-27% and annealing, for 9 minutes, x500

From Figure 4 it may be seen that alloy 2024 has less grain than the alloy Al - 10% Mg. Thus [beta] - phase in the alloy Al - 10% Mg is allocated generally on grain boundaries while at the alloy 2024 [theta] - phase is distributed on all area of grain.

4. Discussions

The received results show that during the deformation by stretching and followed annealing at rather lower temperatures it is possible to obtain the crystallite (coherent diffraction areas) with sizes from 2.8 to 5.5 microns in the alloy Al-10%Mg and 0.9-2.8 microns in the alloy 2024.

Increase of dispersion of structure leads to increase in factors of strength, which agrees well with the Hall-Petch law [Gmoshinski et al, 2013]. Simultaneously with hardening and ductility increases, although in most cases these dependences are reversed. High ductility can be explained to that the mechanism of plastic deformation can occur not due to dislocation glide, and grain boundary sliding, as with significant dispersion the specific volume of the grain boundary structure is increased. Dislocations can't overcome these obstacles due to disintegration reactions, increasing thereby strength of the crystallite. Therefore grain boundaries and coherent diffraction areas has a lower strength than the grain body [Huang et al, 2012]..

The stamping coefficient as assessment of alloys suitability to operations of sheet stamping has the reverse character i.e. it's increase shows an decrease in ability of shaping. Such dependence is explained by the following. while stamping indicator is going down, the interspace of tensions bekomes wider for possible plastic shaping without destruction of workpieces. Comparing curves in figures 1 and 2 shows that stamping of the alloy 2024 is lower than that Al-10% Mg, thus intensive hardening of the alloy Al-10% Mg flows in the interspace 180-360 MPa, and the alloy 2024 - in the interspace 390-500 MPa (Figure 3).. Although factors of elongation of the alloy 2024 are higher, its high resistance to deformation requires more powerful presses, for example, for holding stitched shells of sheet. Fall of ability to a deep drawing of material can be also caused by the increased speed of cooling after annealing. In this case ductility of material can be lowered to 25% that depends in turn on degree of impurities solubility [Deschamps et al, 2011, Styles et al, 2012]. On the other hand, decrease of crystallites size may decrease ability to a deep drawing due to intensive hardening.

Thus the volume of grains at chosen temperatures of annealing commonly doesn't change, leading only to their fragmentation due to refreshment and poligonization processes. So, completion of full process of deformed aluminum recrystallization requires endurance at a temperature 200º for several years while at a temperature 600º enough 2-3 min. The alloying elements which are present at considered alloys, undoubtedly, effect on factors of recrystallization edge and demand durance. But as a rule, these values in alloys is higher, than in pure metals [Metals and Alloys in the Unified Numbering System (UNS), 2012].

Larger grains and the the coherent difraction areas size in the alloy Al-10% Mg can be attributed of elevated levels of the crystal lattice distortion due to the significant presence of magnesium (see table 1). This leads to an increase of internal stresses in the alloy, and hence a large driving forces in the process of the recrystallization, which promotes greater distance of the boundary migration.

5. Conclusion

The sizes of coherent diffraction areas for alloys Al-10% Mg and 2024 in polygonized condition are determined. It is established that with increasing exposure time at an annealing temperature near 100ºC the sizes of coherent diffraction areas in the alloy 2024 decrease, it shows to decrease in density of pointwise and linear defects in grains and their fragments.

The results of the investigations have revealed patterns of change of strength, plastic, technological properties and coherent diffraction areas depending on the behavior of heat treatment of alloys Al-10% Mg and 2024. It is established that with increasing grain size for the alloy Al-10% Mg from 2.9 to 5.3 microns the tensile strength changes from 392 to 344 MPa, the yield strength changes from 292 to 243 MPa, the relative elongation falls from 0.124 to 0.032; for alloy 2024 from 0.96 to 2.78 microns the tensile strength changes from 466 to 419 MPa, the yield strength changes from 407 to 358 MPa, the relative elongation from 0.352 to 0.221.

The alloy 2024 possesses smaller values of coherent diffraction areas in comparison with the alloy Al-10% Mg, with decreasing of the grain size the tensile strength, the yield strength and the relative elongation are increased, and the technological properties of alloys 2024 and Al-10% Mg reduced at high dispersion of the grain structure. Therefore obtaining of grain size less than 1.8 microns in the alloy 2024 and 4.3 microns in the alloy Al-10% Mg in step of cold rolling and interoperational annealing is inexpedient.

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