INFLUENCE OF CHEMICAL COMPOSITION ON HARDENING PROCESSES, CORRESPONDING FOR ALUMINUM ALLOYS 2024 USED AT HYDRAULIC EQUIPMENT

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Abstract. *In the case of duralumin complex compounds have been identified as: Mg_2Si, Al_2CuMg, Al_7Cu_2Fe, etc.This indicates structural complexity for duralumin due to the extensive alloying, complexity that generates multiple factors influence the mechanical, functional, tribological properties. This paper studies the influence of alloying compounds in the emergence hardening phases in aluminum alloys 2024, special destinations use.*

Keywords: *aluminum alloys 2024, chemical composition, hardening processes.*

1. Introduction.

Compositional analysis of conventional metallic materials (alloys based on Fe, Al, Cu, Co, Ni, etc.) is almost exclusively taken out by spectrometry OES[1,2,3,4,5]. Compositional analysis of special metal materials incumbent special dosing methods and techniques that ensure quality test results as required the estimation their conformity with requirements related (eg Law 608/2001 and SR EN 573-3/2009 [6,7] for aluminum alloys) and Law 608/2001 ISO 5832-1 conjugated and test standards EN 17025 and EN 13005 [see Table A], [8,9]. Spectrometry OES is the most effective technique for compositional analysis of metal alloys. In fact, more or less intentionally, special metal alloys elemental analysis is performed by analyzing OES, either preliminary or routine testing in order to identify the alloy class (eg 2017 or 2024 dural type) or even conformity assessment related specification alloy composition.

2024 type alloys are produced in S.C.ALPROM S.A. Slatina, they can be used on aircraft, electronics and electrical, hydraulic valves bodies, pistons, bushings, orthopedic structures, etc. In order to ensure that the alloy developed can be used in requested it to be characterized in a complex way, that employment must be assessed ie chemical composition chemical compliance with the provisions of SR EN 573 3: 1994 specifies the compositional limits of the alloys in 2024 in percentage by mass:

Table 1. The chemical composition of the alloy 2024 according to EN 573 3:1994.

Element	Cu	Mg	Zn	Mn	Si	Fe
Composition SR EN 573 3:1994	3,80.. ..4,90	1,20.. .1,80	max 0,250	0,30 ...0,90	max 0.50	max 0,50

Table A.

Aluminum 2024-T4; 2024-T351

Subcategory: 2000 Series Aluminum Alloy; Aluminum Alloy; Metal; Nonferrous Metal

Close Analogs:

Composition Notes:

A Zr + Ti limit of 0.20 percent maximum may be used with this alloy designation for extruded and forged products only, but only when the supplier or producer and the purchaser have mutually so agreed. Agreement may be indicated, for example, by reference to a standard, by letter, by order note, or other means which allow the Zr + Ti limit.

Aluminum content reported is calculated as remainder.
Composition information provided by the Aluminum Association and is not for design.

Key Words: Aluminium 2024-T351; AA2024-T351, Aluminium 2024-T4; UNS A92024; ISO AlCu4Mg1; NF A-U4G1 (France); DIN AlCuMg2; AA2024-T4 ASME SB211; CSA CG42 (Canada)

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	90.7 - 94.7	Mg	1.2 - 1.8	Si	Max 0.5
Cr	Max 0.1	Mn	0.3 - 0.9	Ti	Max 0.15
Cu	3.8 - 4.9	Other, each	Max 0.05	Zn	Max 0.25
Fe	Max 0.5	Other, total	Max 0.15		

Material Notes:

General 2024 characteristics and uses (from Alcoa): Good machinability and surface finish capabilities. A high strength material of adequate workability. Has largely superceded 2017 for structural applications.

Uses: Aircraft fittings, gears and shafts, bolts, clock parts, computer parts, couplings, fuse parts, hydraulic valve bodies, missile parts, munitions, nuts, pistons, rectifier parts, worm gears, fastening devices, veterinary and orthopedic equipment, structures.

Data points with the AA note have been provided by the Aluminum Association, Inc. and are NOT FOR DESIGN.

Physical Properties	Metric	English	Comments
Density	2.78 g/cc	0.1 lb/in³	AA; Typical
Mechanical Properties			
Hardness, Brinell	120	120	AA; Typical; 500 g load; 10 mm ball
Hardness, Knoop	150	150	Converted from Brinell Hardness Value
Hardness, Rockwell A	46.80	46.80	Converted from Brinell Hardness Value
Hardness, Rockwell B	75	75	Converted from Brinell Hardness Value
Hardness, Vickers	137	137	Converted from Brinell Hardness Value
Ultimate Tensile Strength	469 MPa	68000 psi	AA; Typical
Tensile Yield Strength	324 MPa	47000 psi	AA; Typical
Elongation at Break	19 %	19 %	AA; Typical; 1/2 in. (12.7 mm) Diameter
Elongation at Break	20 %	20 %	AA; Typical; 1/16 in. (1.6 mm) Thickness
Modulus of Elasticity	73.1 GPa	10600 ksi	AA; Typical; Average of tension and compression. Compression modulus is about 2% greater than tensile modulus.
Ultimate Bearing Strength	814 MPa	118000 psi	Edge distance/pin diameter = 2.0
Bearing Yield Strength	441 MPa	64000 psi	Edge distance/pin diameter = 2.0
Poisson's Ratio	0.33	0.33	
Fatigue Strength	138 MPa	20000 psi	AA; 500,000,000 cycles completely reversed stress; RR Moore machine/specimen
Fracture Toughness	26 MPa-m½	23.7 ksi-in½	K(IC) in S-L Direction
Fracture Toughness	32 MPa-m½	29.1 ksi-in½	K(IC) in T-L Direction
Fracture Toughness	37 MPa-m½	33.7 ksi-in½	K(IC) in L-T Direction
Machinability	70 %	70 %	0-100 Scale of Aluminum Alloys
Shear Modulus	28 GPa	4060 ksi	
Shear Strength	283 MPa	41000 psi	AA; Typical
Electrical Properties			
Electrical Resistivity	5.82e-006 ohm-cm	5.82e-006 ohm-cm	AA; Typical at 68°F
Thermal Properties			
CTE, linear 68°F	23.2 µm/m-°C	12.9 µin/in-°F	AA; Typical; Average over 68-212°F range.
CTE, linear 250°C	24.7 µm/m-°C	13.7 µin/in-°F	Average over the range 20-300°C
Specific Heat Capacity	0.875 J/g-°C	0.209 BTU/lb-°F	
Thermal Conductivity	121 W/m-K	840 BTU-in/hr-ft²-°F	AA; Typical at 77°F
Melting Point	502 - 638 °C	935 - 1180 °F	AA; Typical range based on typical composition for wrought products 1/4 inch thickness or greater. Eutectic melting is not eliminated by homogenization.
Solidus	502 °C	935 °F	AA; Typical
Liquidus	638 °C	1180 °F	AA; Typical
Processing Properties			
Annealing Temperature	413 °C	775 °F	
Solution Temperature	256 °C	493 °F	

References are available for this material.

Table 2. The chemical composition of the 2024 alloy according to the manufacturer's specifications .

2024 Chemical Analysis											
Percentage	Elements										
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other elements	Total other elements	Al
Val. Min.	-	-	3.8	0.30	1.2	-	-	-	-	-	
Val. Max.	0.50	0.50	4.9	0.9	1.8	0.10	0.25	0.15	0.05	0.15	rest

On the other hand, the alloy composition is not insured for the proper behavior into service of the alloy because the microstructure (grain size) and content of inclusions and compounds affect the mechanical strength, corrosion resistance and wear resistance, including heat ciclaj generated by temperature variations at required regions. This obviously causes, in addition to determining the chemical composition of the alloy candidate for use in industry to require knowledge pertinent to the nature, size and distribution in the matrix alloy of specific compounds or, worse, that non-specific alloy.

2. Detailing matter

The airline industry and the automobile industry, electrical etc, are used mostly hardenable alloys. Al-Cu binary alloys are used rarely in aviation, but also in industry because of their hardening would be provided only Al_2Cu phase (phase θ). Among the many alloys hardened by heat treatment, the most important are those referred duralumin alloy [9,10], which are part of the Al-Cu-Mg alloys with the addition of manganese (and other elements such as Zr, Li, Cr, Be , Ti, Cd, Ag, V).
Conventionally, duralumins are divided into three groups, depending on the content of the main alloying elements according to Table 3:

Table 3. Types of duralumin alloy.

Tip duraluminiu	% Cu	% Mg	% Mn	% Si	% Fe
Slab aliat	2,0-3,5	0,2-0,5	0,2-0,5	$\leq$ 0,7	$\leq$ 0,6
Mediu aliat	2,5-4,5	0,3-0,8	0,3-0,8	$\leq$ 0,5	$\leq$ 0,5
Inalt aliat	3,5-5,0	0,6-1,8	0,6-1,2	$\leq$ 0,5	$\leq$ 0,5

Duralumins alloy mechanical strength increases from the low alloy to the high alloy, but at the expense of a decrease in plasticity.
Alloy with the highest strength achieved till now is chemically very complex, by 10 alloying elements in Table 4:

Table 4. Chemical composition of the aluminum alloy with the high mechanical strength [9].

E	Zn	Mg	Cu	Mn	Ni	Fe	Cr	Zr	B	Y	Al
%	5,5 ÷ 7,5	2,3 ÷ 3,6	2 ÷ 2,6	0,2 ÷ 0,4	0,3 ÷ 0,5	0,4 ÷ 0,8	0,12 ÷ 0,25	0,25 ÷ 1	0,5 ÷ 0,1	0,15 ÷ 0,25	Rest

Besides alloy composition plays an important role heat treatment conditions applied to it (hardening - aging) as treatment influences the behavior of the alloy in use.
Has been found that the rate of hardening has less influence on the mechanical properties and greater influence on the corrosion resistance. Establishing the size of hardening speed is achieved using temperature-time curves - transformation (TTP), similar curves of steels TTT, and built like them.

The physico-chemical and functional duralurilor for hydraulic and not only are dictated by their microstructure and fine structure [11 ÷ 17]. The hardening and increasing the mechanical strength of the alloy is provided by compounds and precipitated which form in the matrix alloy by structural transformations in the solid phase, induced by thermal or thermo-mechanical treatment.
The evaluation phase content in an alloy of this kind is an absolute requirement.
Content estimation of phases involves identifying the nature of the phases and their volume fraction or mass.
On the other hand, the nature and the mass fraction of compounds in a sample are irrelevant, so long as it does not know the size (volume) average phase estimate (compound precipitate, etc.), and distribution of the phases in the volume of the material (matrix). Would be ideal hardening phases to be as small and as evenly dispersed in the matrix so as to achieve a strong bond with their matrix. Practice has shown that not all secondary phases, have a hardened effect, or strengthener effect of the phase depends on the amount (volume concentration) of it to.
Thus, Al-Cu binary alloys, biggest effect strengthener, it has the phase θ (Al_2Cu), which is formed when the concentration of Cu is over 2%. At ambient temperature Cu is dissolved in the matrix of Al in the amount of about 0.1% (by weight). Mg is dissolved better in than Al having a maximum solubility of 17.4% Mg at 450^{0}C and 2% Mg at ambient temperature. The Mn has a solubility of about 0.5% Mn in Al at room temperature and a maximum of 1.5% Mn solubility at 660^{0}C.
In different ways Si to act in the Al, that Si has a maximum solubility of 1.65% into Al and about 580^{0}C and a low solubility at room temperature of about 0.05%. The silicon is more soluble Al than Fe (0.05% Si at ambient temperature) and has a maximum solubility of 1.65% Si at 577^{0}C. The iron does not dissolve in about ambient temperature at 20^{0}C. The maximum solubility of Fe is 0.05% at 653^{0}C. It is known that Fe forms into Al the most likely compound, Al_3Fe, which has a acicular morphology. Al_3Fe compound is formed starting when the Fe content of hundreds of ppm, and he will separate al the grain boundaries. This fact has effect of embrittlement the alloy.
The simultaneous presence of Fe and Si even hundreds of ppm concentrations lead to the formation of AlFeSi compound which is intercrystalline distributed, resulting in a reduction of the formability and reduction in the resistance to corrosion of the alloy. To mitigate the detrimental effects of Fe and Si, of which Si has the highest negative influences by increasing the tendency of cracking in alloy solidification, etc., it is recommended that the ratio of concentrations of Fe and Si to be in the range 1.3% - 1.5%. Also, the effects of Fe into Al can be counteracted by alloying with Mn for the purpose of bind the Fe atoms in the compound Al6 (MnFe).
If the alloy contains Mn, the Fe form together with Al and Cu, the compound (Al7Cu2Fe) which is insoluble in the quenching, which makes the hardening effect of this phase is significant.
Durals alloy corrosion protection is performed classically by flame technically pure Al.

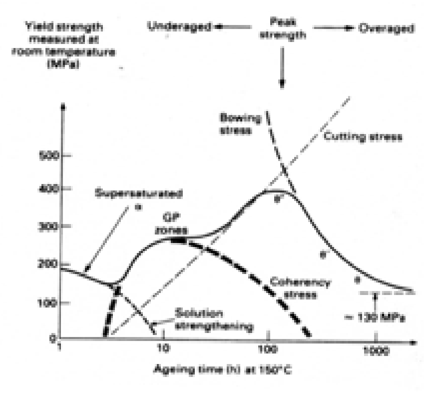


Fig.1. The dependence of the mechanical strength of an alloy of Al-4% Cu during aging at 150^{o}C[21] .

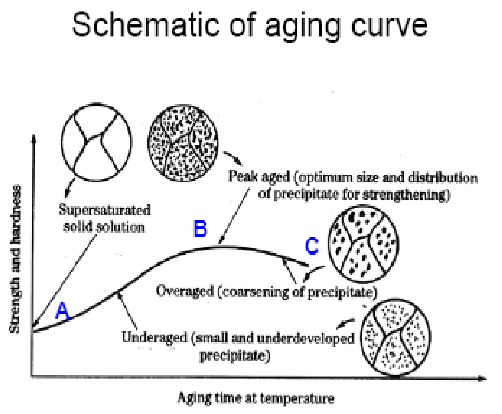


Fig.2.Reprezentation structuring process during TTT[21].

From Figure 1 it follows that, after about 150 hours of aging to achieve the maximum strengthener, and if it exceeds the time, the phenomenon of over-aging occurs, which has the effect lowering the mechanical strength. The hardening mechanisms of complex alloyed dural involving at least two parallel hardening process by forming sequential phase θ and S phase, respectively [18]:

$GP - 1 \rightarrow \theta'' \rightarrow \theta' \rightarrow \theta(Al_2Cu)$ *(1)*

$GP - 1 \rightarrow S'' \rightarrow S' \rightarrow S\ (Al_2CuMg)$ *(2)*

Equilibrium S phase has orthorhombic crystal structure with unit cell parameters: a_0 = 0.40 nm, b0 = 0.923 nm and c_0 = 0.714 nm [18].
Equilibrium θ phase has tetragonal crystal structure with unit cell parameters a0 = b_0 = 0.606 nm, c_0 = 0.4874 nm [12,18].
Phase θ ', is a nonequilibrium phase that has a tetragonal structure with unit cell parameters vary depending on the size of the precipitate (phase). Reference values of unit cell parameters are a_0 = b_0 = 0.404 nm and c_0 = 0.508 nm. Also phase θ '' has the tetragonal crystal structure with lattice parameters a_0 = b_0 = 0.404 nm and c_0 = 0.78 ÷ 0.79 nm [18].

3. Materials and methods

For spectrochemical testing of mentioned samples was used optical emission spectrometer by electric spark type Foundry-Master. This is an automated installation, intended elemental analysis of metallic materials, and operates under the control of a soft. Master Foundry spectrometer consists of four main parts :

1. spectrometry apparatus (Fig. 3),
2. process computer
3. preliminary vacuum system (vorvacuum)
4. spectral argon supply installation,

Figure 3. Optical emission by electric spark spectrometer Foundry-Master.

The distributions of elements or conducted with the electron microprobe JXA 50A that operates as a SEM microscope. Main features of the microprobe are maximum accelerating voltage 60kV, 0.86 min scan area 0,86x0,64 μm ; max 6,5x4.5 μm ; magnification 20 -: -1.4 x10^5x.
In this work the results of structural and compositional investigations carried out on samples taken from batches of aluminum alloys "2024" produced by Alro Slatina. Batch studied has AL1 code. The main objective of the investigation is the assessment under these alloys, type specifications (ie in 2024) [19,20], in terms of chemical composition. Subsequently aims microstructural evaluation under the terms of the grain and the effects of hardening natural or artificial aging by the manufacturer.

4. Experimental results.

4.1. Chemical and structural analysis of the charged AL1. Compositional analysis.
Semi-finished subjected to the expertise is a 50x50mm rectangular bar.
Dosage wet was performed for all elements specified according to EN 515. Since dosing wet prevents estimation uncertainty than by expensive repeating was used optical emission spectrometry determination. Dosage by OSE is extremely important for estimating uncertainties per element and to provide additional control over the exact chemical tests.

To ensure the quality spectrochemical testing (traceability, uncertainty, etc.) spectrochemical testing OES was performed in accordance with standards EN 17025, EN 13005 and EN 515, ie was performed in a laboratory accredited by RENAR to facilitate the estimate in terms of chemical composition / elements, and it was decided that, along with experimental results to be presented the concentrations required by standard EN 1423 mark .
The chemical compositions required, ones wet determined and ones estimated compositions by spectrophotometry are shown in Table 5. Spectrometric compositions are accompanied by uncertainty measurement U (95%), ie 95% confidence level.

Tabelul.5. The reference data and the results dosages.

Concentration	Tip	Cu	Mg	Mn	Si	Fe	Cr	Ti	Zn	other elements
c_r(%)	min	3,80	1,20	0,30	0	0	0	0	0	
c_r(%)	max	4,90	1,80	0,90	0,50	0,50	0,10	0,15	0,25	0,05
c_u(%)		4,27	1,62	0,58	0,16	0,24	0,05	0,04	0,25	0,05
c_s(%)		4,2	1,52	0,55	0,18	0,21	0,07	0,05	0,21	0,04
Us(95%)		0,1	0,08	0,05	0,04	0,04	0,03	0,02	0,04	0,01

In (Fig. 4) are shown modes of framing the concentrations determined in respect of concentrations of imposed on.

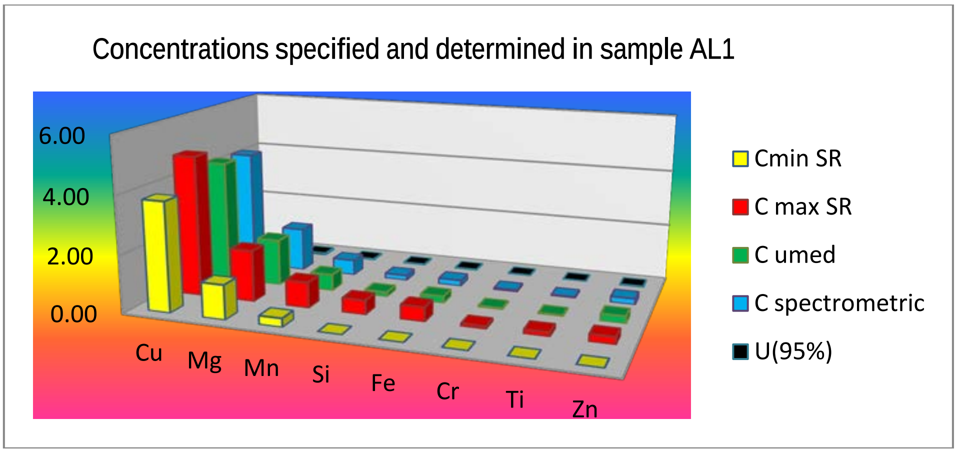
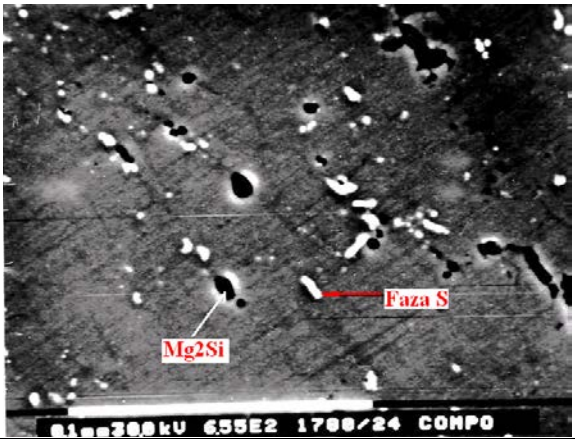


Fig.4. Comparative representation of specified concentrations of SR 1423 and dosed concentrations.

4.2. Morphological and compositional analysis of the batch AL1 by SEM-EDAX investigations.

SEM-EDAX investigations have been carried out according to the above specifications, on the sample AL1. The image in (Fig. 5), (650X magnification) shows an area where compounds are highlighted by shades of gray and by form. Thus the white rods are compounds that contain Fe and Cu, at most likely Al_7Cu_2Fe. Compounds ellipsoidal, or even round, black colored represents strengthener Mg_2Si compound. This compound occurs in isolation, and in the vicinity of S phase (Al2CuMg), which has the appearance of baguette. In some areas, these baguettes are agglomerates, forming laced areas of S phase.
Position Section: cross.

SEM-EDAX test results: SEM image (Fig. 5) Magnification: 650X. Image size 184x136 μm.



a) magnification 650x

b) Right detail central electronic-increased

Fig.5. SEM image of the distribution and morphology of the constituents of the sample AL1.

4. Conclusions
5.

Analyses were performed on batch AL1 highlighted the following conclusions:

- The results of Table 5 and Fig.4 : alloy studied falling from the a compositional point of view in the mark- dural aluminum alloys "2024".
- Microstructure, the fineness of grain, was estimated as corresponding to the type of alloy 2024, by an expert metallurgist.
- batch shows typical class compounds of dural (Mg_2Si, S and S' phases. Al_2CuMg) and atypical type compounds Al_7Cu_2Fe,
- In batch studied, is missing the Al_2Cu equilibrium compound specified at literature as the most important strengthener element. This can be explained by the fact that, in the case of batch investigated a dominant precipitation reaction leading to the formation of S-phase (Al_2CuMg) and / or the phase S 'according to the scheme:

areas G.P → S '→ S (Al2CuMg)

On the basis of the distributions of elements shown in Fig. 6. have identified the phases:

1) Mg_2Si round morphology with apparent diameters in the range 1-10 μm, by "color" black.
2) Phase S (S ') with baguette morphology with lengths of about 15 μm. Also, the phases S and S ' have a the coalescence phenomena around of some Mg_2Si compounds.
3) The compound Al_7Cu_2Fe is morphologically similar to S phase, and the white color in lengths of less than about 10 μm.

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