Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology 22 (2016) 167 – 173

Procedia Technology

9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Tirgu-Mures, Romania

Studies Regarding Mechanical Properties Improvement of Aluminum Alloy Type $AtSi_5Cu_x$ and Results Validation by Calculating Precision Indicators

Maria Stoicanescu[a,*], Mihaela Smeada[b]

[a] Department of Materials Science, Transylvania University, Brasov, Romania
[b] "Henri Coanda" Air Force Academy, Brasov, Romania

Abstract

Experimental studies performed in order to improve the specific characteristics of materials used by modern technologies have always represented a stringent demand. The current paper presents the results of the experimental researches performed on aluminum alloys, together with their statistical interpretation and data validation by means of precision indicators.
Mechanical vibrations applied to an environment in which aging carries out lead to increasing efficiency of heat treatment due to elastic deformations of the base cell [3,7]. Thus, a significantly growing hardness is obtained as compared to samples subjected to classical treatment [10, 11].

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering

Keywords: aluminum; aging; vibration; precision indicators.

1. Introduction

Using modern lightweight materials with mechanical properties corresponding, not to further eliminate the use of aluminum alloys [7,8,9]. Natural aging are generally characterized by very long periods of holing compare to conventional heat treatment. Purposing of increasing their efficiency, the efforts are remarkable, one of methods

* Corresponding author.
E-mail address: stoican.m@unitbv.ro

2212-0173 © 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the "Petru Maior" University of Tirgu Mures, Faculty of Engineering
doi:10.1016/j.protcy.2016.01.040

being also the aging in vibration field. Following experimental tests, was noticed as first effect, the increasing of diffusion speed to parts that undergo to mechanical vibrations. Hardness as well as the other mechanical properties have significant enhancement [10, 11]. Among the effects on heat treatment active medium, vibrations have also un stimulated effect on metal crystalline lattice [11].

2. Experimental research

Aluminum alloys properties can be improved by heat treatment such as hardenings, tempering's and annealing's, known as age hardening or aging's.

Natural aging take prolonged time, mechanical characteristics being modified very little, the reason why is replaced with artificial aging. Using artificial aging, the total time of aging reduces to several hours, and mechanical characteristics are much improved [3,4,7]. Experimental studies were done in order to study the influence of energy, represented by mechanical vibration on artificial aging phenomenon for aluminum alloys $ATSi_5Cu$.

Experimental researches aimed to apply non-conventional heat treatments, in order to study their influence on the Brinell hardness, on cylindrical samples sized 50x20mm. The heat treatments applied were joined by mechanical vibrations transmitted to the environment. Mechanical vibrations are carried to warm medium, liquid (oil), in which the samples for aging are held, using an elastic lamella excited by an electromagnet.

The experimental device for study the influence of mechanical vibrations on characteristic values of mechanical properties is made of a mechanical exciter actioned by a coil with soft coil, fixed in two points and with free end soaked in hot oil bath and an electric circuit used for activating the excited coil of resonance bar, for which it has been used:

- a power amplifier type LV 103;
- a frequency converter;
- a digital voltmeter with digital display type MULTIMETER V560;
- an electrodynamic exciter type ESE 20.

The general aspect of the installation used to hardening and aging in vibration field is shown in Fig. 1.

Fig. 1. General aspect of installation used at hardening and aging in vibration field [6]

The samples used within the experimental research are cylindrical samples sized 50x20mm, which were quenched and aged artificially, as follows:

- water quenching from a 510°C temperature, with and without applying vibrations;
- artificial aging at a temperature of 170°C, for 1 hour, by applying vibrations.

Following the applying of the heat treatments, we performed hardness measurements by means of the Brinell hardness testing apparatus, having the following characteristics: 5mm diameter steel ball and an applied load of 250kgf / 10s. The impressions measured against samples by means of the Brinell magnifying glass were transformed into Brinell units, by means of value tables, the values presented in tables representing the average of three consecutive measurements done for each sample, in turn.

Measurements were carry out on standardized specimens from aluminum silicon alloys with different content of cooper $ATSi_5Cu_1$, $ATSi_5Cu_2$, $ATSi_5Cu_3$, with chemical composition according to European standard, presented in table 1.

Table 1. Chemical composition of the used specimens [%], [4]

Alloy	Si	Cu	Mg	Al	Others
$ATSi_5Cu_1$ (number samples5)	4.50-5.50	1.00-1.50	0.30-0.60	rest	2.20
$ATSi_5Cu_2$ (number samples6)	4.00-6.00	1.50-3.50	0.20-0.80	rest	2.80
$ATSi_5Cu_3$ (number samples7)	4.00-6.00	2.80-3.50	0.20-0.30	rest	2.00

These aluminum alloys presents the following mechanical characteristics- table 2, according to SR EN 1706 :

Table 2. Mechanical characteristics of casting alloys

Alloy	Symbolization	Symbolization of Heat Treatment	Tensile strength min	Yield min	Elongation %	HB min
$ATSi_5Cu$	$ATSi_5Cu_1$	T_4	170MPa	120	2	80
		T_6	230MPa	200	1	100
	$ATSi_5Cu_2$	-	-	-	-	-
	$ATSi_5Cu_3$	F	140MPa	70	1	60
		T_6	230MPa	200	1	90

In Table 2 the following symbols were used:

- F- crude cast alloy;
- T_4- heat treatment of putting in solution and artificial aging;
- T_6- heat treatment of putting in solution and complete artificial aging.

The hardness values measured on the studied alloys, immediately after quenching, respectively, immediately after the artificial aging for 1 hour, are shown in Table 3.

Table 3. Values of the Brinell hardness after quenching and after artificial aging/1h

Alloy	Brinell Hardness	
	After quenching	After artificial aging/1h
ATSi5Cu1	60…62	82
ATSi5Cu2	65	78
ATSi5Cu3	66	84

Brinell hardness was measured on 6 sets of specimens for each category of aluminum alloys studied, the information obtained being read for validation by calculating precision indicators [5].

For $ATSi_5Cu_1$, and $ATSi_5Cu_2$, aluminum specimens, hardened at 510°C in water, in the absence of vibration and hot oil aging at 170°C for 1 hour, with mechanical energy of vibrations at 50 Hz frequency, there have been obtained the results presented in table 4 and 5:

Table 4. Brinell hardness

Alloy $ATSi_5Cu_1$	HB	HB, medium value
5.2.1.	86	92,33
5.2.2.	104	
5.2.3.	95	
5.2.4.	91	
5.2.5.	88	
5.2.6.	90	

Table 5. Brinell hardness

Alloy $ATSi_5Cu_2$	HB	HB, medium value
6.2.1.	56,6	61,28
6.2.2.	59,6	
6.2.3.	61,3	
6.2.4.	65	
6.2.5.	61,6	
6.2.6.	63,6	

In table 6 there are presented the results obtained in the same experimental conditions for ATSi5Cu3 alloy specimens, and in table 7 there are given for ATSi5Cu1 alloy specimens the values recorded for the second measurements set, when the aluminum specimens were hardened at 510° C in water with vibration applied and aging in the same conditions as in the first case (hot oil at 170° C with overlap of mechanical energy of vibrations at same frequency of 50 Hz.)

Table 6. Brinell hardness [4]

Alloy $ATSi_5Cu_3$	HB	HB, medium value
7.2.1.	68	70,83
7.2.2.	71	
7.2.3.	74	
7.2.4.	71	
7.2.5.	72	
7.2.6.	69	

Table 7. Brinell hardness

Alloy $ATSi_5Cu_1$	HB	HB, medium value
5.1.1.	88	110,33
5.1.2.	124	
5.1.3.	123	
5.1.4.	95	
5.1.5.	114	
5.1.6.	118	

For $ATSi_5Cu_2$ *and* $ATSi_5Cu_3$ alloy specimens, the values recorded for the second measurements set, there are presented in table 8 and 9.

Table 8. Brinell hardness [4]

Alloy $ATSi_5Cu_2$	HB	HB, medium value
6.1.1.	128	90,66
6.1.2.	138	
6.1.3.	76	
6.1.4.	65	
6.1.5.	68	
6.1.6.	69	

Table 9. Brinell hardness [4]

Alloy $ATSi_5Cu_3$	HB	HB, medium value
7.1.1.	123	96,16
7.1.2.	118	
7.1.3.	83	
7.1.4.	77	
7.1.5.	81	
7.1.6.	95	

Comparing the results obtained, may be noticed that carry out measurements are recording higher medium values of Brinell hardness, with mechanical energy of vibration applied both in cooling water, and also in oil bath holding at constant temperature of 170°C.

Experimental research carry out reveal information that have been interpreted with precision indicators, so certainty state that the measurements made are well done, if experimental data are accurate and fall within the margin of accepted error and the recorded deviations are extremely small.

To perform this analysis we calculated the following precision indicators [1, 2, 4]:

- standard swerve of one measurement $s_{D_{ij}}$,
- standard error (average swerve of average value obtained), E ,
- coefficient of variation $CV\%$,
- tolerance T, maximum spread Δ_{max}

The measure of precision determinations or degree of the individual scattering of Brinell hardness values, noted with D, about the medium is represented by the standard deviation of a measurement, calculated with relationship 1. [1;2;4]

$$s_{D_{ij}} = \sqrt{\frac{[vv]}{n-1}} \tag{1}$$

where $[v] \overset{not.}{=} \sum_{j=1}^{n} v_j$ and $[vv] \overset{not.}{=} \sum_{j=1}^{n} v_j^2$ is sum Gauss, $v_j = \overline{D} - D$ represents the apparent corrections calculated as the difference between the medium value and each measurement taken and n - total number of samples.

As an indication of spreading data around the medium value $\overline{D}$ the variation coefficient CV% is calculated using the relation 2. [1; 2; 4]

$$CV\% = \frac{s_{D^i}}{\overline{D}} \cdot 100 \tag{2}$$

Coefficient of variation values can fit: a) between 1…10%;
b) between 10…30%;
c) $> 30\%$ [1; 2; 4].

Since the coefficient of variation takes values in the first period, we define small dispersion, which means that the measurement results indicate a small scattering around the medium value; values that are found in the second intervals, defined the medium dispersion, and if the coefficient of variation takes values greater than 30%, the results indicate a high dispersion.

Bordering coefficient of variation in one of the first two categories, confirm the existence of acceptable measurements statistically, measurements that certifying the experimental data are accurate, the deviations are extremely small.

For values exceeding 30% it is considered that measurements are affected of error too large, so that experimental data shall not be taken into consideration [1, 2, 4] and the set of measurements resumes.

Data referring to carry out measurements are offered and how measurements fall or not in specific tolerance. For this purpose we calculated the value tolerance [1] respectively the maximum spread [1] with the relationship;

$$T = 3s_{D_{ij}} \tag{3}$$

$$\Delta_{max} = D^{max} - D^{min} \tag{4}$$

an then the obtained results were compared.

Maximum spread less than or equal to the tolerance value, indicates that the measurements fall within a range of acceptable values, in other words they are within specific tolerance allowed.

The achievement of condition $\Delta_{max} \leq T$, enables and a statistical study to verify the studying of normal distribution of experimental data obtained. Precision indicators were calculated for all the values recorded in the following measurements, a calculation example being presented in table 10 [1; 2; 4; 5]

Table 10. Precision indicators calculated for samples 5.2.

HB/alloy *ATSi$_5$Cu$_1$*, samples 5.2	v_i	Precision indicators
86	+6,33	$s_D = 6{,}47HB;$ $CV = 7{,}00\%;$ $T = 3s_D = 19{,}41HB$ $\Delta_{max} = 18HB;\quad \Delta_{max} \leq T$
104	-11,67	
95	-2,67	
91	(+1,33); 1,34	
88	(+4,33); 4,34	
90	+2,33	
$\overline{D} = 92{,}33HB;$	(-0,02); 0,00	

alloy *ATSi$_5$Cu$_1$*, samples 5.2:

$$\overline{D} = 92{,}33HB; s_D = 6{,}47HB;$$

$$CV = 7{,}00\%; T = 3s_D = 19{,}41HB$$

$$\Delta_{max} = 18HB; \quad \Delta_{max} \leq T$$

alloy *ATSi$_5$Cu$_1$*, samples 5.1:

$$\overline{D} = 110{,}33HB; s_D = 15{,}19HB;$$

$$CV = 14{,}41\%; T = 3s_D = 45{,}57HB$$

$$\Delta_{max} = 36HB; \quad \Delta_{max} \leq T$$

alloy *ATSi$_5$Cu$_2$*, samples 6.2:

$$\overline{D} = 61{,}28HB; s_D = 2{,}97HB;$$

$$CV = 4{,}84\%; T = 3s_D = 8{,}91HB$$

$$\Delta_{max} = 8{,}4HB; \quad \Delta_{max} \leq T$$

alloy *ATSi$_5$Cu$_2$*, samples 6.1:

$$\overline{D} = 90{,}66HB; s_D = 33{,}14HB;$$

$$CV = 36{,}5\%; T = 3s_D = 99{,}42HB$$

$$\Delta_{max} = 73HB; \quad \Delta_{max} \leq T$$

alloy *ATSi$_5$Cu$_3$*, samples 7.2:

$$\overline{D} = 70{,}83HB; s_D = 2{,}14HB;$$

$$CV = 3{,}00\%; T = 3s_D = 6{,}42HB$$

$$\Delta_{max} = 6HB; \quad \Delta_{max} \leq T$$

alloy *ATSi$_5$Cu$_3$*, samples 7.1:

$$\overline{D} = 96{,}16HB; s_D = 19{,}84HB;$$

$CV = 20{,}6\%; T = 3s_D = 59{,}52HB$

$\Delta_{\max} = 42HB; \quad \Delta_{\max} \leq T$

The achievement of condition $\Delta_{\max} \leq T$ enables a statistical study to verify the studying of normal distribution of experimental data obtained.

For measurements made is noticed that the calculated values of the coefficient of variation generally fall in the first two intervals, which means accurate results with little scattering and medium around average. One single measurement set, the one for alloy $ATSi_5Cu_2$, samples 6.1 causes an coefficient of variation $> 30\%$ (36,5%) which means a large dispersion around the medium value and resuming the corresponding set measurements.

3. Conclusions

The following conclusions are revealed after processing the experimental results:

- the beneficial influence of the mechanical energy over the Brinell hardness values is noticeable; thus, all values recorded on samples quenched in water from a temperature of 510°C, in the presence of vibrations and artificially aged for 1 hour at a temperature of 170°C are higher than the values obtained through classical treatments;
- the overlapping of mechanical vibrations over the thermic energy in artificial aging has beneficial effects on the hardening process; we consider that the supplementary contribution of energy at the level of crystalline net leads to diffusion processes stimulation, processes that determine the strain hardness of the crystalline lattice through the formation of GP zones, respectively of the θ, θ^{I}, θ^{II} phases.
- precision indicators calculation shows that statistically the effectuated measurements were well done, data collected are fall within the margin error, measurement errors being little;
- the diffusion processes are very much activated by supplementary energy carried by mechanical vibrations applied to liquid medium.
- Improving the diffusion coefficient leads to increasing the hardness values and implicit of others mechanical properties.

References

[1] Ghitau D. Processing of geodetic measurements. Topoexim Publishing, Bucharest, 2009.

[2] Munteanu B, Smeada M. Pirnuta O. A. Statistical processing of experimental data in the case of impression diameters of aluminium alloys samples used in aircraft engineering. The Seventh International Congress in Materials Science and Engineering, Iasi, May 28-31, 2009, pg. 73-78.

[3] Preotu O. The construction and calculation of aircraft. Technical Publishing House, Bucharest, 2001.

[4] Smeada M. Studies and researches regarding the improvement of physycal- mechanical properties of the materials used in the aerospace technic, PhD Thesis, Transylvania University of Brasov, 2011.

[5] Smeada M, Stoicănescu M, Munteanu B. Mechanical properties of the aluminium alloys at low temperatures. Statistical processing, ModTech International Conference - New face of TCMR, Chişinău, May 25-27, 2011, pg.1017-1020.

[6] Stoicanescu M. Unconventional heat treatment applied to aluminium alloys. PhD Thesis, 2005.

[7] Stoicanescu M, Smeadă M, Geamăn V. Unconventional heat treatments applied to aluminium alloys used in air force technique. Proceedings of the 1 st International Conference on Advances in Manufacturing Engineering Quality Production Systems (MEQAPS 09),volume II, Braşov, September 24-26, 2009, pg. 440-44.

[8] Giacomelli I, Serban C. Thermic and thermochemical heat treatment nonconventional methods. EVIEC VIII Ben Gurion University, Israel, 1997.

[9] Giacomelli I, Druga L, Samoila C, Bot D. Unconventional technologies with solid state phase transformations. Editura Lux- Libris, 2000.

[10] Vermesan Gh, et al. Special heat treatment processes. Cluj - Napoca, 1990

[11] Iyer KJL. Enhanced activity of austenite resulting from ultrasonic vibration in a low alloy case-hardened steel: Journal of Materials Science 1989; 24(6):2147-2150.