Journal of Materials and Engineering Structures

Research Paper

Elastic characterization by Ultrasonic waves of the unstandardized polycrystalline alloy 42500

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ARTICLE INFO

Article history :

Received : 11 February 2017

Revised : 5 May 2017

Accepted : 10 May 2017

Keywords:

Al-Si

Ultrasound

Elasticity

Hardness

Resilience

ABSTRACT

The objective of this work is to determine the impact of the temper heat treatment (150, 160, 170, 180, 190, 200,220 and 240) °C on the evolution of the main elastic and structural properties of the alloy foundry AlSi7Zn3Cu2Mg (42500). This alloy will be subjected to precipitation hardening. This is one of the most successful methods to considerably improve the mechanical properties of the alloy, this allows choosing the compromise of high resistances while maintaining satisfactory ductility. The mechanical properties are governed by the combination of four factors: heat treatments, molding process, chemical composition and the shape of the specimen used. We used mainly four techniques namely: The ultrasonic method for the determination of the elastic characteristics, the Brinell hardness HB and the micro hardness Hv to identify the stress field, the Kcv resilience to provides information on fracture mode, brittleness and the impact resistance, and finally to completely identify the alloy, it will be followed by its metallography, microstructure and fracture surface in resilience.

The purpose of this work is to study the structural hardening of the alloy AlSi7Zn3Cu2Mg (42500) by considering ten states: crude of casting noted: F taken as reference state. To improve the mechanical characteristics obtained from the crude of castingstate, a structural hardening heat treatment is carried out, the addition of magnesium is necessary in order to make the alloy sensitive to this specific heat treatment T46.

1 Introduction

The study investigates the impact of some commonly used Engineering materials to mechanical properties when diffused to the microstructure of Al [1] – [3].The addition of 7% mass. Si-3% mass; Zn-2% mass; Cu and Mg (0.20 to

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e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

0.70)% mass respectively to Aluminium followed by specific heat treatments show precipitates of different genres that hinder dislocation motion [2].The foundry alloy $AlSi_7Zn_3Cu_2Mg$ is obtained using the sand molding by gravitation process. This molding is composed of two half-marks left by the model in the packed sand. This industrial process has been considered to make improvements in mechanical properties particularly in the presence of Si where it gives strong ability in casting [3- 5]. Zn increases the corrosion resistance, Cu improves thermal and electrical conductivity resistance characteristics and Mg is the main agent for improving the mechanical characteristics such as structural hardening [4].

These additional elements go into solution by occupying lattice points (substitutional) or interstices (interstitial) and may also be present in the form of inter-metallic phases. If their size is smaller or larger than the aluminium atom the disruption caused on the network becomes more difficult to deform. The induced effect is similar to the network strain difficulty that causes hardening. The hardness of aluminium will increase due to these disturbances. The composition of these phases forms a uniform distribution aluminium matrix if fused by solid diffusion. This enhances intrinsic fragility and stability of heat treatments to follow in order to obtain final properties of the alloy [4; 6].

The unalloyed aluminium has limited properties that suit only a few working conditions. [1; 2] it is possible to improve its properties by adding four elements (7% Si, 3% Zn, 2% Cu and ≤1%Mg) which when diffused into Al change the physical, metallurgical and mechanical properties in the microstructure. This gives an $AlSi_7Zn_3Cu_2Mg$chemicaldesignationofcasting alloy.

2 Materials

The material used is an aluminium alloy containing 7% silicon, 3% zinc, 2% copper and an amount of magnesium of less than 1% (mass percentage). It is made the S.N.V.I. (National Company of industrial vehicles in Algeria) and contains some traces of impurities. Silicon gives it very good properties to enhance excellent foundry applications. It is used for parts with complex shapes that require with maximum mechanical strength on thin sand sections. The chemical analysis of cast pieces depicted the composition shown in Table 1.

Table. 1 - Chemical Composition of the $AlSi_7Zn_3Cu_2Mg$ Alloy

Chemical Elements	Si	Zn	Cu	Mg
% Mass Percentage	6,83	3	1,85	0,62

3 Studies and experimental techniques

3.1 Study 1

Metal fusion is made in a production as oven, a350Kg graphite crucible with filler material around 40% of new ingot and 60%ofthe casting jets of mixture and return (feed appendages, evacuation, regulation, defective parts and scrap) AlSi7Mg, to which is added 3% Zn and 2% Cu. The mass liquefied at about 700°C, at which the first scrub and skimming was done using a plump and ladle. Then, a first spectrometry test piece is taken for an immediate chemical analysis.

The result of this analysis of the liquid mass is then subjected to a degassing treatment, followed by a second cover and deslagging in the furnace. Then, the metal is poured into a preheating pocket where there finements and deslagging operations are carried out. A second test is performed to verify the correction effect. If the results of analysis of this second test are in compliance, the casting process can proceed. Thus, reference [12] test pieces are referred to as cast (denoted: F). In order to improve the resistance characteristics of this state F, increase in yield stress and modulus of rigidity while reducing deformations, the material (digital 425000 and chemical $AlSi_7Zn_3Cu_2Mg$ designation) is subjected to specific treatments T46.

3.2 Study 2

This is to study the influence of heat treatment on the evolution of the main elastic characteristics, strength, ductility and structural alloy of AlSi7Zn3Cu2Mg foundry sand cast by gravity. These treatments generate significant micro-structural changes, usually curing by varying tempering temperatures in increments of 10 and 20°C. These characteristics are determined in the three directions of each test piece, dimensions (200x150x20) mm3, through ultrasonic method. The latter is based on acoustic or elastic waves whose the ultra sound is presented as one of the most interesting research methods. For consistency, the properties of resilience, hardness, micro hardness and structural strength are evaluated, respectively, by destructive or non-destructive methods.

The ability to $AlSi_7Zn_3Cu_2Mg$ alloy hardening is studied by considering ten states (the cast state, denoted F, is taken as a reference state). The improvement in mechanical characteristics of the cast state is conditioned by a heat treatment hardening. The addition of magnesium is thus necessary to make the alloy sensitive to this specific heat treatment which is conducted as follows:

i. Solution heat treatment followed by homogenization. This generates a diffusion of carbon in solid insertion and substitution solution. It is made in a tempering furnace at a temperature of around 500°C.

ii. Holding for 8hrs, before quenching in water at room temperature (20-25°C).

iii. Maturation for 17 hours in ambient air.

iv. Tempering at (150, 160, 170, 180, 190, 200, 220 and 240°C) for 20 h in an income oven in which the specimens are left to cool.

3.3 Experimental Techniques

Four experimental techniques and methods are used

3.3.1 Application of the Ultrasonic Method

The two main modes, used in industrial control, concerning longitudinal waves (called compression waves or dilation waves in the theory of elasticity) and the transverse waves (shear waves). Longitudinal waves are characterized by the fact that the direction of vibration is the same as of the propagation. The transverse waves propagate in a perpendicular direction to that of the mechanical vibration. The continuum mechanics (elastic materials) provides transverse and longitudinal waves speeds equations [7] - [11]. These speed (transverse velocity: V_T (m/s), and longitudinal speed V_L (m/s)) are connected to the mechanical characteristics of the isotropic material, and are given by the relationships (1) and (2).

$$V_T = (\mu / \rho)^{1/2} = \sqrt{\frac{\mu}{\rho}} \tag{1}$$

$$V_L = ((\lambda + 2\mu)/ \rho)^{1/2} = \sqrt{\frac{2\mu+\lambda}{\rho}} \tag{2}$$

ρ (Kg/m^3) is the density of the AlSi7Zn3Cu2Mg alloy, G is the shear modulus, μ and λ are the Lamé coefficients. The Young's modulus E (GPa), the Poisson's coefficient νand the shear modulus μ = G (GPa) are respectively given by equations (3 to 5).

$$E = \frac{\mu(3\lambda + 2\mu)}{\lambda + \mu} \tag{3}$$

$$\nu = \frac{\lambda}{2(\lambda + \mu)} \tag{4}$$

$$\mu = \frac{1}{2}\frac{E}{(1+\nu)} = G \tag{5}$$

The ultrasonic velocities were measured in five (5) identical Al specimens plates of dimensions 200x150x20mm for each respective case of tests. The measurement is performed in transmission mode using two ultrasound transducers; one as transmitter and the other as a receiver. A longitudinal wave transducer and a transverse wave transducer, of 2.25MHZ centre frequency, are used to measure the speed in the three directions (length, width and thickness) of each plate. The experimental setup is shown in Fig. 1.

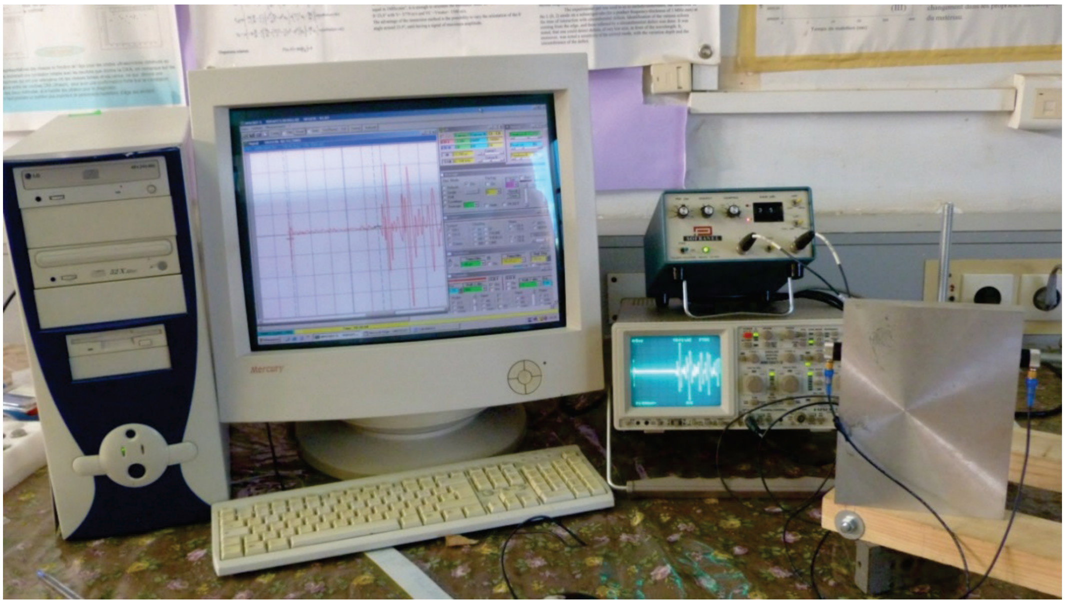
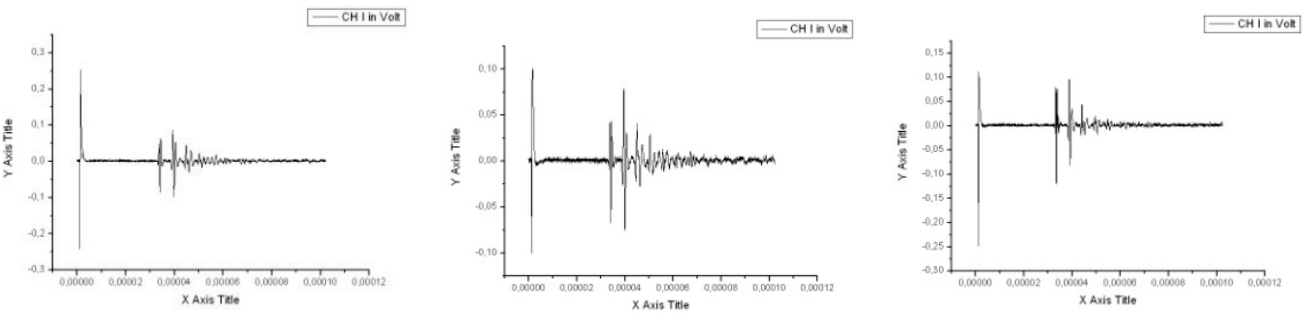


Fig. 1- Experimental setup for the measurement of longitudinal and transverse velocities (Support, Transmitter and receiver transducers, Aluminium plate, Oscilloscope, Generator pulse, Acquisition Computer).

Non-destructive ultrasonic technique is an adequate tool to characterize materials. The ultrasonic wave velocity measurements are used to determine the different characteristic constants of material: Young's modulus, shear modulus, Poisson's ratio, Lamé coefficients, hydrostatic compression modulus and coefficient of linear thermal expansion. The test specimens made up for this purpose, are metal parts, cast in sand and then machined to the dimensions X = 200, Y = 150 and Z = 20 mm. The main mechanical characteristics obtained for the $AlSi_7Zn_3Cu_2Mg$ chemical material composition are detailed in the following.

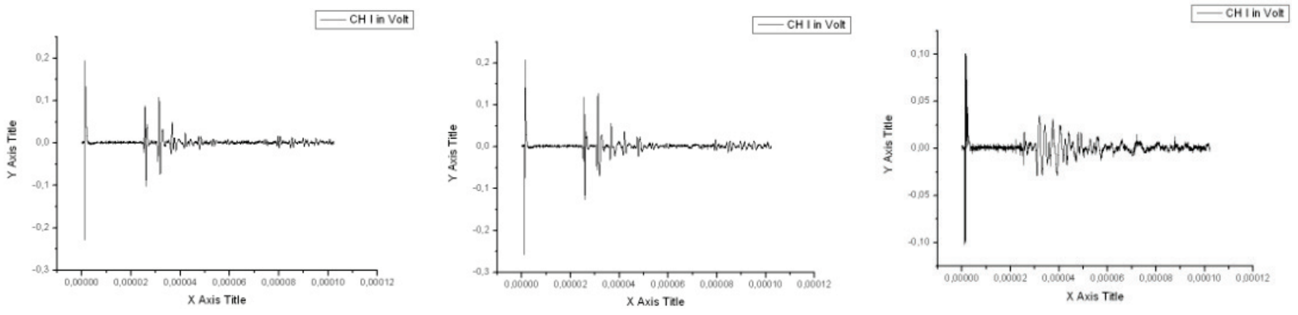
3.3.2 Echoes in the three directions

The elastic characteristics are determined in the three directions of each test piece (length; X =200mm, width; Y =150mm and thickness; Z =20mm). The evaluation of the isotropy (or not) of the material is performed by the ultrasonic method described above. Figures 2 to4 provide the received signals in the three directions X, Y and Z of the specimens tested at the income compromise temperature; noted: Rv=170°C.



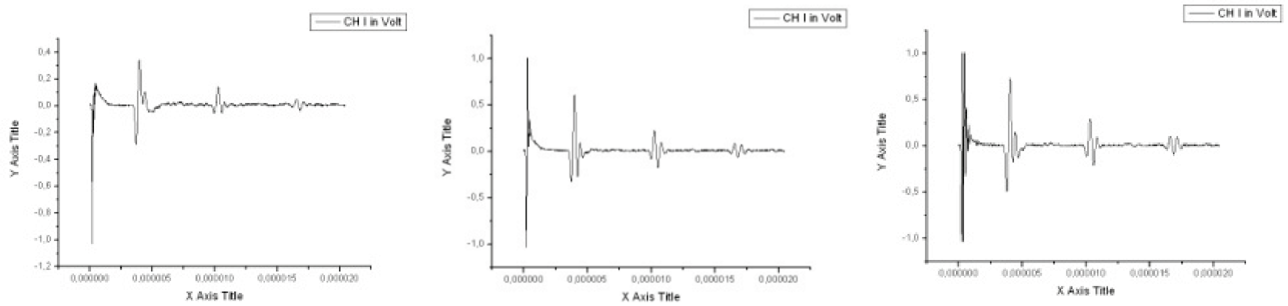
- a - - b - - c -

Fig.2– Echoes according to X direction (X=X1=X2=X3= 200mm) of $AlSi_7Zn_3Cu_2Mg$ alloy recorded to revenue compromise temperature (Rv=170°C) with: a- echoes according to the direction X1, b- echoes according to X2 direction, and c- echoes in the direction X3.



- a - - b - - c -

Fig. 3– Echoes according to Y direction (Y= Y1= Y2= Y3= 150mm) of $AlSi_7Zn_3Cu_2Mg$ alloy recorded to revenue compromise temperature (Rv=170°C) with: a- echoes according to the direction Y1, b- echoes according to Y2 direction, and c- echoes in the direction Y3.



- a - - b - - c -

Fig.4 – Echoes according to Z direction (Z= Z1= Z2= Z3= 20mm) of $AlSi_7Zn_3Cu_2Mg$ alloy recorded to revenue compromise temperature (Rv=170°C)with: a- echoes according to the direction Z1, b- echoes according to Z2 direction, and c- echoes in the direction Z3.

3.3.3 Procedure for Mechanical Tests

This section is devoted to the presentation of the different experimental methods and techniques used [1; 2; 7; 8; 9; 10]. Four techniques have been used:

- The nondestructive testing ultrasonic method for the determination of elastic characteristics,
- Brinell HB hardness and micro hardness to identify the strength of the stress field,
- Kcvresilienceprovides information on fracture mode, fragility and impact resistance,
- Metallography and microstructure to identify the different structures.

Brinell hardness

The test consists of printing in the test part a ball of hardened steel (HBS hardness) or tungsten carbide (HBW hardness) of diameter D (mm) under a load F, and measuring the diameter d of the cavity left on the surface after removal of the load F. The print is a spherical cap of diameter d, averaged by two orthogonal diameters measured using an appropriate optical device. The test load F (N) is chosen from a standardized range adapted to D and to the material tested.

The Brinell hardness HB, is a number proportional to the F/S ratio and can be expressed as follows

$$HB = \frac{0,102 \times 2F}{\pi D \left(D - \sqrt{D^2 - d^2} \right)}$$

F(N) – test load, D (mm) - ball diameter, d (mm) – diameter of the cavity.

Vickers Hardness

The test consists in printing a pyramidal diamond penetrator a square base and apex angle of 136 ° in the part to be tested, under a load F and measuring the diagonal d of the impression left on the surface S after removal of the load. The cavity is a recessed pyramid with an average diagonal d, the average of the two diagonals of the base square, measured using an appropriate optical device. The test load F is selected from a standardized range. Vickers test is used for harder parts than the Brinell test and can be of small thickness.

The Vickers hardness is proportional to the F/S ratio as shown in the relationship below

$$H_V = \frac{0{,}189 \times F}{d^2}$$

avec F(N) – test load, d (mm) - diagonale de l'empreinte.

We also used two types of microscopy

Optical microscopy

This is used to determine the granular structure and texture of materials studied (Grains, grain boundaries, phases ...).

Scanning electron microscopy (SEM)

It is used to observe finely the surface state of materials and to visualize the coarse precipitates present in the various materials. The principle of SEM imaging consists in composing a surface image from the secondary electrons ejected from the material under the effect of the primary beam. The energy of these electrons depends directly on the energy of the primary electrons and on the atomic number of the element that interacts with the primary beam.

The tests were carried out and the results obtained are shown and discussed in the next section

4 Results and discussions

The mechanical characteristics of elasticity, hardness, micro hardnessandresilienceAlSi7Zn3Cu2Mgalloy are the average results of five identical specimens for each of the respective cases. They are represented in Figures 2 to 15. It is then shown the influence of the variation of the tempering temperature on the evolution of mechanical properties.

4.1 Elastic characteristics in the three direct

Figures (5) – (9) show the evolution of the longitudinal and transverse speeds, Young's and shear modulus and Poisson coefficients.

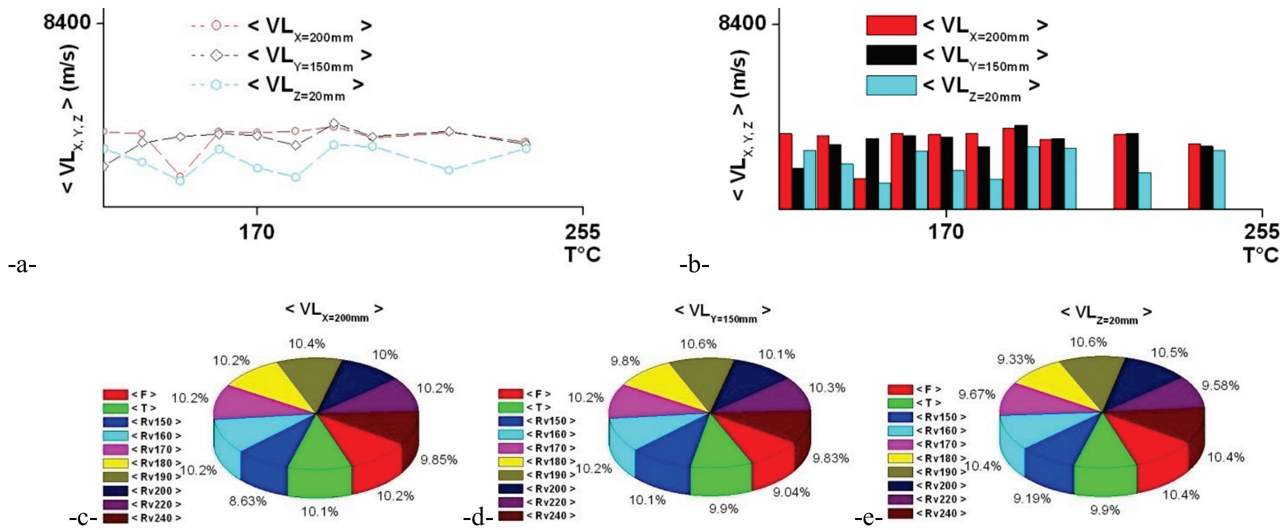


Fig.5 – Average longitudinal speed < VL> at different states: casting(F), tempered (T), and revenue temperatures ; 150, 160, 170, 180, 190, 200, 220 and 240°C (a-graphs, b- histograms, c- sector <VL_X>, d- <VL_Y>, e-<VL_Z>).

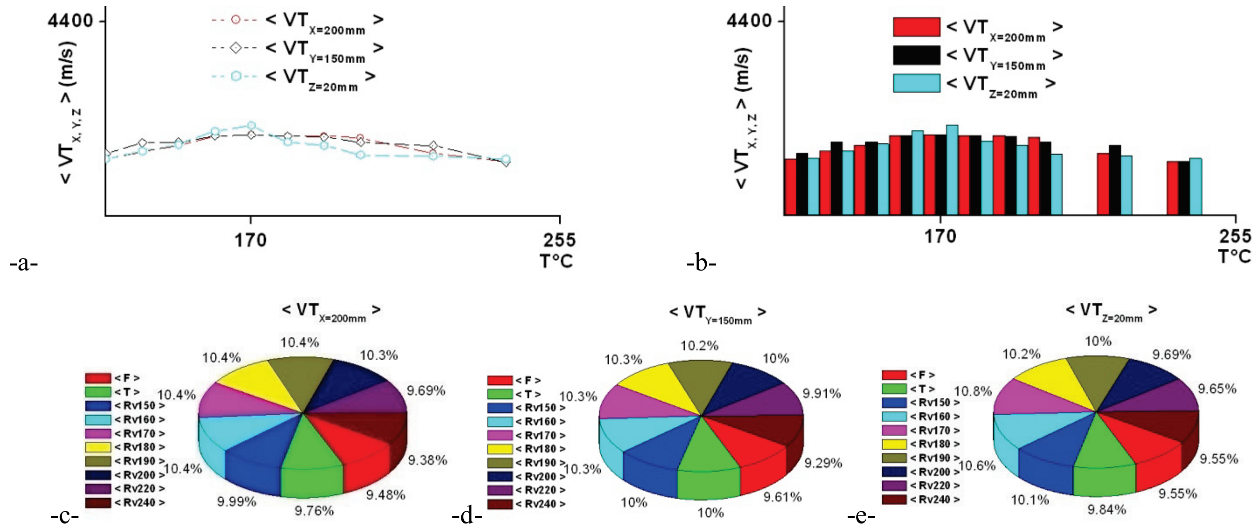


Fig.6 – Average transverse speed < VT> of $AlSi_7Zn_3Cu_2Mg$ cast alloy in the sand at different states: casting(F), tempered(T), and revenue temperatures; 150, 160, 170, 180, 190, 200, 220 and 240°C (a-graphs, b-histograms, c-sector <VT_X>, d-<VT_Y>, e-<VT_Z>).

They are a function of tempering temperatures, and are determined in the three directions (X =200 mm, Y =150 mm and Z =20 mm). They are almost confounded for each respective state. These five elastic characteristics of the $AlSi_7Zn_3Cu_2Mg$ alloy are almost invariant and all the graphs have horizontal lines patterns; which shows that this alloy is isotropic.

The elastic properties (longitudinal and transverse speeds, Young's modulus, shear modulus and Poisson's ratio), determined by the ultra-sonic method for the $AlSi_7Zn_3Cu_2Mg$ foundry alloy, are usually intrinsic. They only depend on the type of bond and atomic architecture. These properties are closely related to longitudinal and transverse velocities. Figures (7 and 8) show that the rigidity modulus is maximal in the state: Rv 170°C.

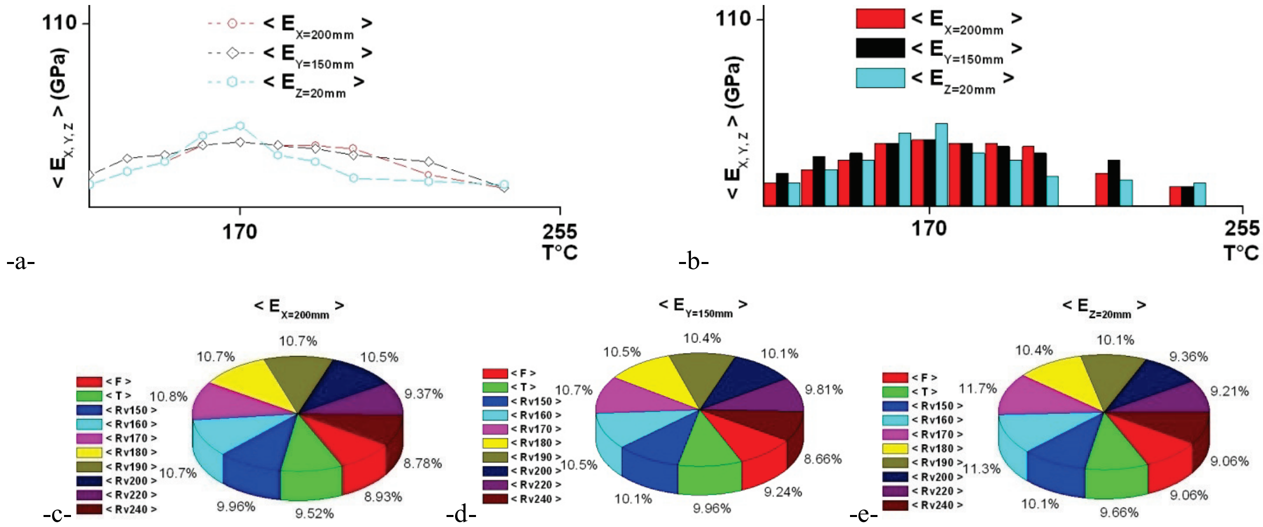


Fig.7 – Average Young's Modulus < E > of $AlSi_7Zn_3Cu_2Mg$ at different states: casting(F), tempered (T), and revenue temperatures ; 150, 160, 170, 180, 190, 200, 220 and 240°C (a-graphs, b-histograms, c-sector <E_X>, d- < E_Y >, e-< E_Z >).

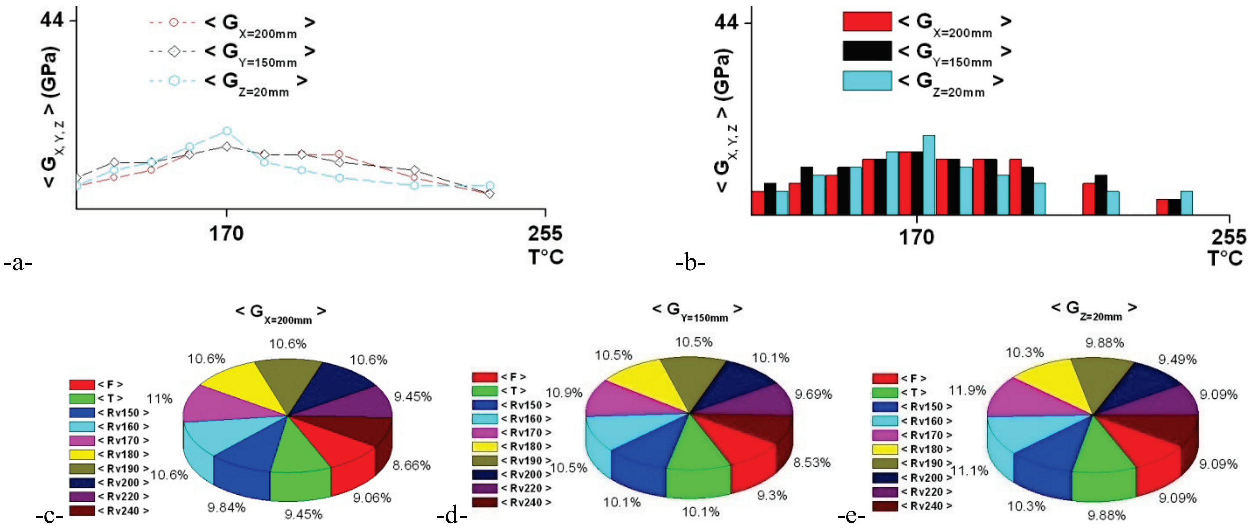


Fig.8 – Average shear modulus <G> of AlSi7Zn3Cu2Mg cast alloy in the sand at different states: casting(F), tempered(T), and revenue temperatures; 150, 160, 170, 180, 190, 200, 220 and 240°C (a-graphs, b-histograms, c-sector <GX>, d- <GY>, e- <GZ>).

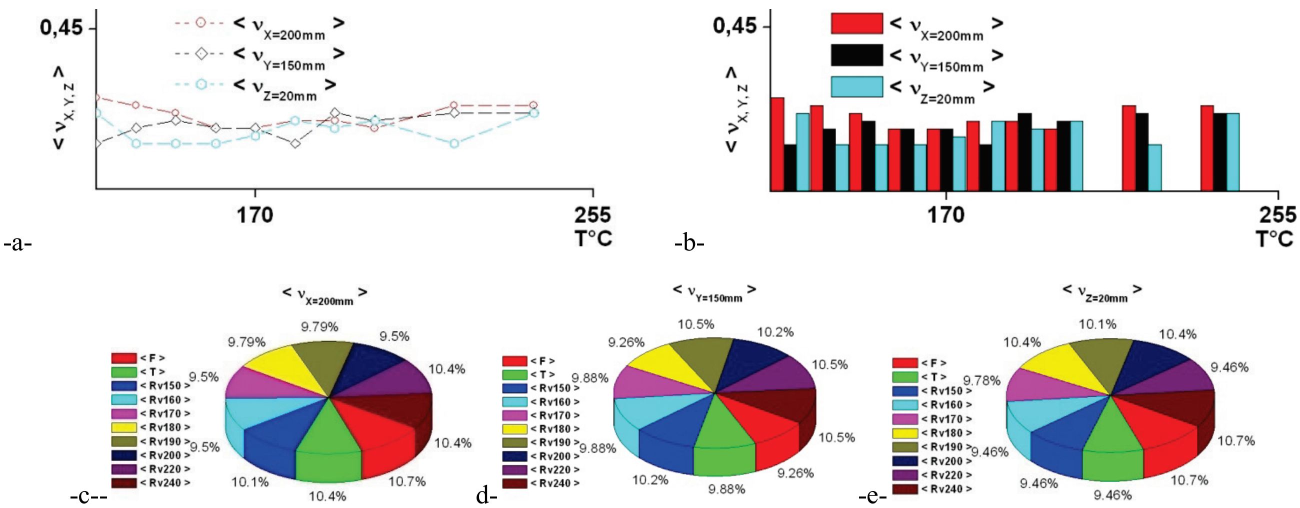


Fig.9 – Average Poisson's Ratio <ν> of AlSi7Zn3Cu2Mg cast alloy in the sand at different states: casting(F), tempered(T), and revenue temperatures; 150, 160, 170, 180, 190, 200, 220 and 240°C (a-graphs, b-histograms, c-sector <νX >, d- <νY >, e-<νZ >).

4.2 HB Brinell hardness, Vickers $Hv_{0;1}$ micro-hardness and resilience

Figures (10) and (11) show that the HB hardness characteristics and micro-hardness graphs of the two areas, black and white, and their average, grow up the cast condition (F) to Rv170°C state (with maximum properties).They decrease in the final state Rv240°C. In Figure 11, the black area micro-hardness graph is well above that of the white area micro-hardness graph, and this whatever the considered states. The black area is the solid solution of aluminium, zinc and copper in the silicon. By cons, the white area is that of silicon, zinc and copper in aluminium. Resilience (see Fig. 12) decreases from the state F to state Rv170°C (minimum properties) then; believed to Rv240°C. Speed growth or decay is faster and different from one property to another.

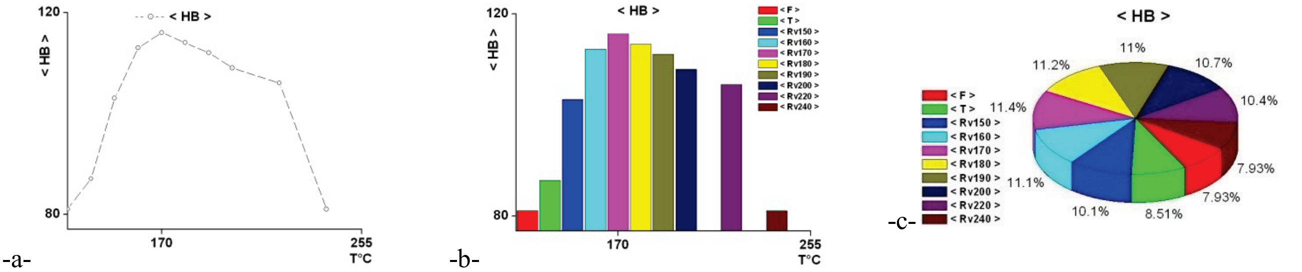


Fig.10 – HB Brinell hardness: a- graph, b- histogram, c-average Brinell hardness <HB> (as cast statements; F, soaked; T and revenues temperatures: 150, 160, 170, 180, 190,200, 220 and 240°C).

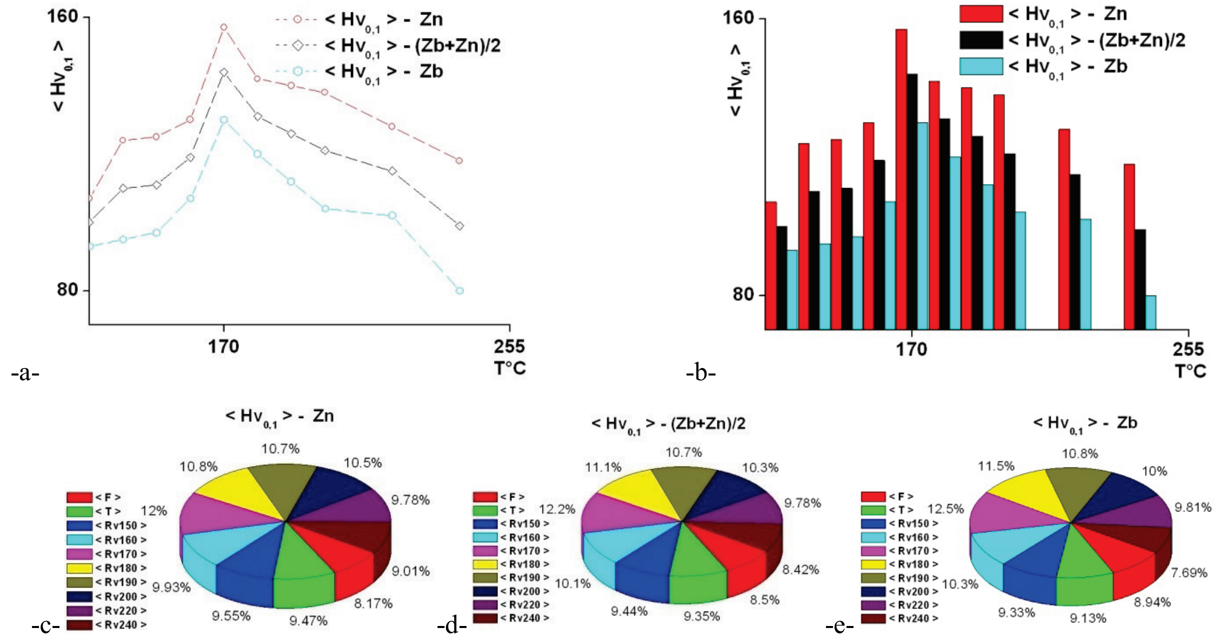


Fig.11 – $Hv_{0;1}$ Vickers micro hardness of the white and black areas, and their average (< $Hv_{0,1}$>): a- graph, b- histogram, c-<$Hv_{0,1}$> - Zn sector, d- <$Hv_{0,1}$> - (Zb+Zn)/2 sector, e- <$Hv_{0,1}$> - Zb sector, (cast statements; F, soaked; T, and revenues temperatures: 150, 160, 170, 180, 190,200, 220 and 240°C).

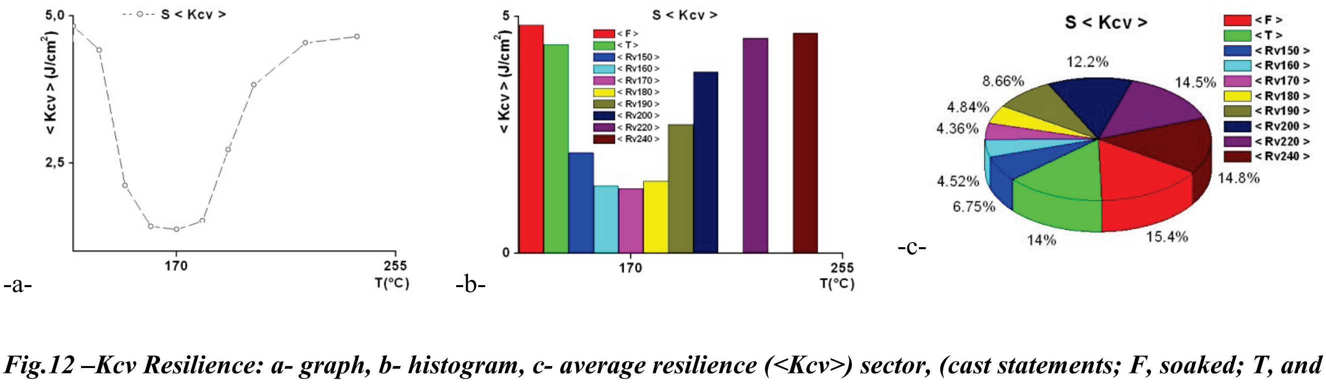


Fig.12 –Kcv Resilience: a- graph, b- histogram, c- average resilience (<Kcv>) sector, (cast statements; F, soaked; T, and revenues temperatures: 150, 160, 170, 180, 190,200, 220 and 240°C).

4.3 SEM observations (micro-structural characteristics)

A cast condition; denoted F, heterogeneous with large grains without hurry. And, are venue state to 170°C; denoted Rv170, homogeneous and fine-grained with clear precipitates. The failure mode of this AlSi7Zn3Cu2Mg hypo-eutectic alloy casting is rather semi-brittle. This can be explainedby the fact that the Kcv resilience is very low (see Fig. 12), the fracture surfaces are intra-granular with cleavage, and take a mirror polish grained (seefig.15). The break is probably of type I with severe and perpendicular loading to the crack plan.

-a- -b-

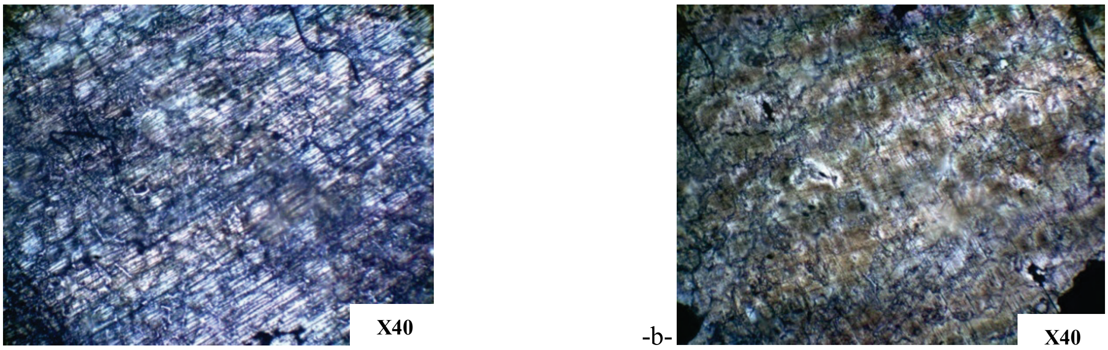


Fig.13 –Metallographic Structures of AlSi7Zn3Cu2Mg alloy cast in sand to states: (a)- cast (noted: F), (b)- revenue at 170°C (noted: Rv170).

-a- -b

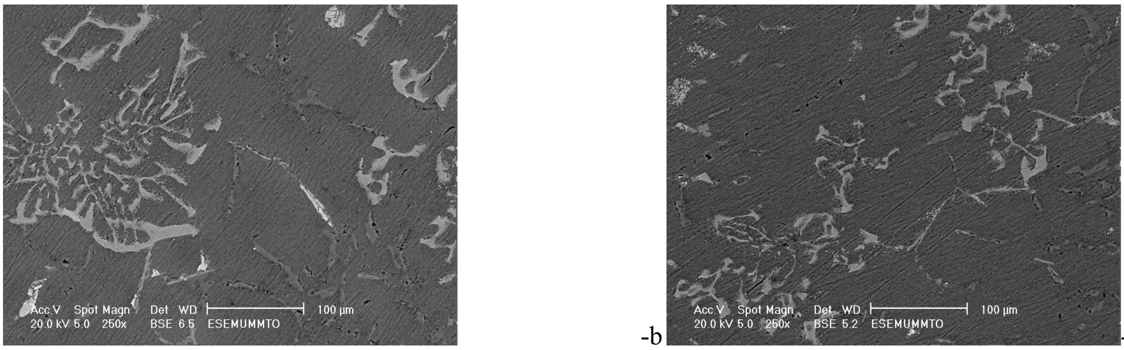


Fig.14 – Microstructures obtained by SEM of AlSi7Zn3Cu2Mg alloy cast in sand to states: (a)- cast (noted: F), (b)- revenue at 170°C (noted: Rv170).

-a- -b-

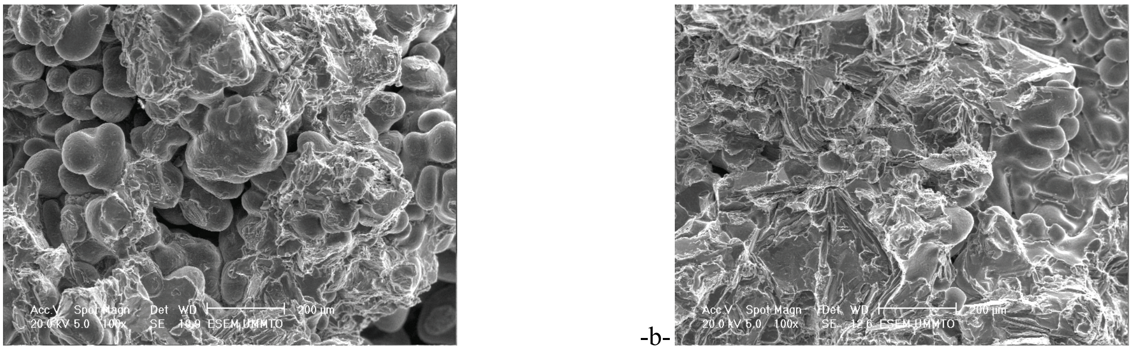


Fig.15 – Resilient fracture toughness obtained from the SEM of the AlSi7Zn3Cu2Mg alloy sand cast in the following states: (a) - Casting stock: F and (b) - Income at 170 ° C noted: Rv170

The material properties are improved by the interaction between the stress field and dislocations make them difficult to move. Similarly atoms in solid solution tend to diffuse to dislocations and to regroup around them so as to reduce global strain energy; dislocations anchored by these atoms. The marked improvement in mechanical properties of hardness and micro-hardness of the alloy in the state Rv170°C is mainly due to these two types of changes in the structure of the material. The HB hardness, micro-hardness of the two areas (black, white, and their respective average) and $AlSi_7Zn_3Cu_2Mg$ foundry alloy resilience are usually extrinsic. They depend on the type of microstructure produced and the defects density introduced in the material structure. To change the mechanical properties of non-alloy aluminium (whose characteristics are poor), foreign elements in the Al matrix were added: 7% mass. Si, 3% mass. Zn, 2% mass. Cu, and traces of Mg (≤ 1%)). This leads to the $AlSi_7Zn_3Cu_2Mg$ casting alloy. Applied heat treatments allow structural hardening; which provides a finer structure with precipitates of different genres (Mg_2Si, Al_2Cu, Al_2CuMg, etc.) that impede dislocation movement. In addition, the four added elements have atoms of smaller or larger radius; they can be in solid solution insertion or substitution, and thus create distortions network. This results in a stress field due to the difference in size between atoms of the solute and solvent (tension in the case of insertion, and compression in the case of substitution).

5 Conclusion

The ultrasonic wave velocity measurements give valuable results, qualitatively and quantitatively, on the behaviour of the studied material. This technique permit to determine the different $AlSi_7Zn_3Cu_2Mg$foundry alloy mechanical characteristics: Young's modulus, shear modulus, Poisson's ratio, Lamé’s coefficient, hydrostatic compression modulus and coefficient of linear thermal expansion. The tested specimens are cast in sand, then; milled of dimensions X =200, Y =150 and Z =20mm. This non-destructive technique is, indeed, a satisfactory tool to characterize this type of material. The elasticity and resistance mechanical characteristics are maximum at Rv170 and whatever the considered statements.

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