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Comparative study of mechanical and structural properties of three different grades of purity of commercial aluminium

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ABSTRACT

The influence of three grades of purity of commercial aluminium on the evolution of the major mechanical characteristics: stress and strain energy, hardness, elongation and stress coefficients, resilience and microstructure have been studied. It was found that the first resistance parameters decrease with the increase in the degree of purity of the chosen material to the disadvantage of the ductility characteristics which rise for the considered states. Furthermore, it is important to note that strain-hardening and annealing lead to considerable hardening and softening respectively. The latter can be respectively associated with an increase in the density of the dislocations and the movement of impurity elements towards the dislocations.

1 Introduction

Our daily environment is populated "with aluminum objects" from simple kitchen utensil to architectural engine blocks ornaments. Common features of all these objects made mostly of aluminum alloys are lightweight, fastness, low melting point, indefinite recyclability, abundance in nature, aesthetics, good reflectance, and high corrosion resistance. The many uses of aluminum and its alloys are related to the qualities of these metals that make outstanding materials. Aluminum alloys are "magic metals" because of their remarkable characteristics. Their metallurgical properties and the advantages they offer, both in terms of processing and their applications, make these materials the most versatile. The exploitation of these alloys were developed in surprising proportions for technical and economic reasons. There are many technical reasons (low density, good conductors, etc.) while economic reasons are diverse (low cost, whether in the construction, building, road, transport,

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packaging and automotive sectors ... etc). Aluminum and its alloys have and will therefore have a positive impact on the quality of life for all of us [1-4].

Commercial aluminum has very reduced properties that prohibit its use for some applications [5-7]. The present study consists in determining the essential role of the variation of the purity on the evolution of the mechanical characteristics of traction, Brinell hardness, Vickers microhardness, resilience and structural of aluminum, for this it is possible to significantly improve its properties by adding elements thus forming alloys that change more or less deeply the microstructure. Three types of commercial aluminum materials (Al-99,0%, Al-99,5% and Al-99,8%) were chosen to perform the study. The studied materials were developed by casting in metal shells. After their elaboration, three structural states were considered, reference state, designated by casting: F, homogenization, annealing and dissolving at a temperature of 540°C with maintaining for 10h followed by cooling in the oven, designated state: O and strain hardening with 25% deformation in 3 passes, designated state: H1/4. The mechanical characteristics were determined using a traction machine with low deformation speed and at room temperature.

At the same time, hardness, microhardness, resilience, and microstructural measurements were taken. For the three states considered of the commercial aluminum chosen, we followed the evolution of the variations of the elastic limit, of the tensile and breaking strengths of the Young and shear moduli of the different free energies of deformation, necking, Poisson and Lamé coefficients, elongation and necking, resilience, Brinell HB hardness, Vickers Hv0,1 microhardness and the structure versus the purity of the material studied. The values of these characteristics represent an average of 5 measurements.

Once the treatments are carried out, the material will be subjected to quasi-static tests of uni-axial traction at low loads and speeds of Brinell hardness of microhardness and quasi-dynamic of resilience to quantify the different characteristics of resistances and ductility, necessary for the different calculations that the design engineer needs at the design office level. The microstructure will complete the study to fully identify the material.

To verify the elastic tensile properties, the study is followed by the nondestructive ultrasonic test.

2 Chemical composition of the commercial aluminum

The tables below present the chemical compositions of commercial aluminum considered according to standard NF A.57-702 and according to the actual analyzes carried out by National Companies of the Household Appliances and Electro Industries of Fréha. The compositions below correspond to the composition tolerances in the shell castings. The alloys used in these tolerances composition, suitably prepared and optionally heat-treated, give test pieces having at least well-defined mechanical characteristics.

2.1 Chemical composition according to standard NF A.57.702

This chemical composition correspond to the composition tolerances in gravity cast parts is summarized in the following table:

Tableau 1 – Chemical composition according to standard NF A.57.702

Chemical elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
% Mass.	-	-	0,10	0,30	0,30	0,10	0,10	0,08	99,0 (1200A)
% Mass.	0,25	0,40	0,05	0,05	0,05	0,06	0,07	0,05	99,5 (1050A)
% Mass.	0,15	0,15	0,03	0,02	0,02	0,03	0,06	0,02	99,8 (1080A)

2.2 Composition of ingots of commercial aluminum delivered by French aluminum

The following table summarises the chemical composition of commercial aluminium. These ingots make it easier to achieve the required composition in the parts (23 – 28).

Tableau 2 – Composition of commercial aluminium ingots delivered by French company Pechiney.

Chemical constituents	Si	Fe	Cu	Mn	Mg	Zn	Ti	Ga	V	Al
% Mass.	0,20	0,30	0,05	0,03	0,03	0,20-0,50	0,03	-	-	99,0
% Mass.	0,25	0,40	0,05	0,05	0,05	0,05	0,03	-	0,05	99,5
% Mass.	0,15	0,15	0,03	0,02	0,02	0,03	0,03	0,03	0,05	99,8

3 Material under investigation

The materials employed are graciously provided by the national companies SNVI of Rouïba and Electro - Industries of Fréha. They are three types of commercial aluminium with different grades of purity (Al-99,0%, Al-99,5% and Al-99,8%) which were chosen to carry out our study. After analysis of the gravity die-cast specimens, the following chemical composition was obtained

Table 3 – Chemical composition of commercial aluminium

Chemical constituents	Fe	Si	Cu	Zn	Ti	Al
% Mass.	0,60	0,40	0,02	0,08	0,03	99,0
% Mass.	0,40	0,16	0,02	0,06	0,03	99,5
% Mass.	0,12	0,10	0,01	0,04	0,03	99,8

4 Production of commercial aluminium

Commercial aluminium production is divided into three stages as follows [4, 8]:

4.1 Casting

Melting is done in a gas furnace tilting from front to back, comprising a graphite crucible with a capacity of 350Kg whose charge is composed approximately $\approx 100\%$ of new commercial aluminium ingots of standard dimensions. Once the total melt has become liquid at about 700°C, it undergoes a degassing, deslagging and covering treatment in the furnace.

Then the metal is poured into a specially prepared 50 kg preheating ladle which is then transported by a hoist to fill the 150 kg holding-heat furnace, which has been properly adjusted. A ladle is used to fill the preheated and carefully prepared single shell mould from the holding-heat furnace, which is then used to carry out the refining operations. The parts can be cast in the single metal mould, so that the reference specimens are referred to as raw castings, denoted: F.

In order to further increase the strength characteristics of the F-stage, the two materials with different grades of purity will be subjected to specific tempering and strain-hardening treatments.

4.2 Shell casting

In this method of moulding, the mould consists of two steel clevises (5% chromium), whose role is to maintain the impressions. These clevises, separated by a parting line, must be prepared and heated to a temperature of $(200 \div 300)^\circ\text{C}$ if necessary.

After casting, the specimens cast in a metal mould by gravity will be divided into three identical batches each consisting of 5 tensile specimens, one prismatic specimen for ultrasound, 5 impact strength specimens and 2 specimens for micrographic observation, considering three states: as-cast noted: F, annealed noted: O and cold worked noted: H1/4.

4.3 Treatments of (36-39)

- Annealing: heating and solution annealing with homogenisation at 540°C for 10 hours followed by cooling in the furnace when switched off.

Hardening: 25% deformation in 3 passes with a 6-roll rolling mill.

Once the treatments have been carried out, the material will be subjected to the quasi-static tests of uni-axial tensile strength at low loads and speeds, Brinell hardness and quasi-dynamic resilience to quantify the different characteristics, resistances and ductility, necessary for the various calculations required by the design engineer at the engineering office level. The microstructure will complete the study to completely identify the material and the ultrasound to check the elastic tensile properties.

5 Experimental procedure

In order to determine the behaviour of the material in relation to the various stresses it may encounter during use, these stresses are reproduced by means of static or dynamic tests, generally carried out on standardised specimens in order to determine the material's numerical characteristics. Five techniques are used: tensile to identify the various stresses, Brinell hardness HB and Vickers microhardness $H_{V0,1}$ for the stress field, Kcv impact strength to provide information on fracture mode, brittleness and impact resistance, ultrasound to check the tensile elastic properties and microstructure to identify the various structures [9-13].

In the following we will describe and present in detail the main mechanical and microstructural characteristics obtained from the material under study.

6 Results and discussion

The average values of the mechanical tensile, ultrasonic, hardness, microhardness and impact strength characteristics of the three states of commercial aluminium are those given by means of 5 identical specimens for each of the respective cases and are shown in figures 6 to 36 below.

Influence of the degree of purity on the evolution of the mechanical characteristics of the three states of commercial aluminium

6.1 Average resistances

For the three considered states of the selected commercial aluminium, we followed the evolution of the variations of the main strength and ductility characteristics: the different stresses and strain energies, the hardness and microhardness, the Young's and shear moduli, the strain, Poisson and Lamé coefficients, the elongations and stress coefficients, the resilience and the microstructure versus the purity of the studied material.

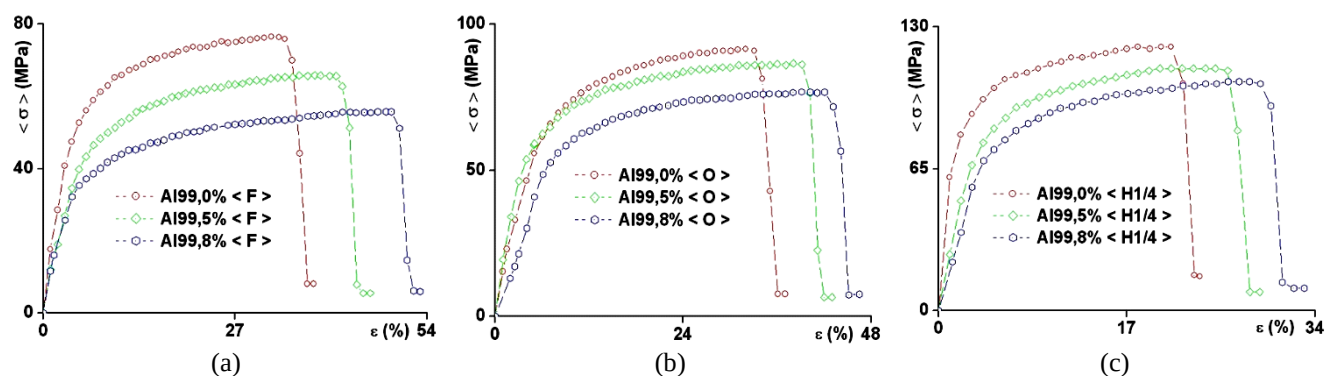


Fig. 1 - Grouping of tensile curves (stress-strain) comparing commercial aluminium in the states: (a) - rough casting noted: $\langle F \rangle$, (b) - annealed noted: $\langle O \rangle$ and cold worked noted: (c) - $\langle H1/4 \rangle$ of three different purities (Al-99,0%, Al-99,5% and Al-99,8%).

Figures (6 – 15) show that the average histograms of the ten mechanical strength characteristics of the three states under consideration decrease with increasing purity at the expense of the different deformation energies figures (16 – 22) and

ductility characteristics figures (23 – 26), however the rate of decrease varies differently depending on the mechanical characteristic and the state under consideration.

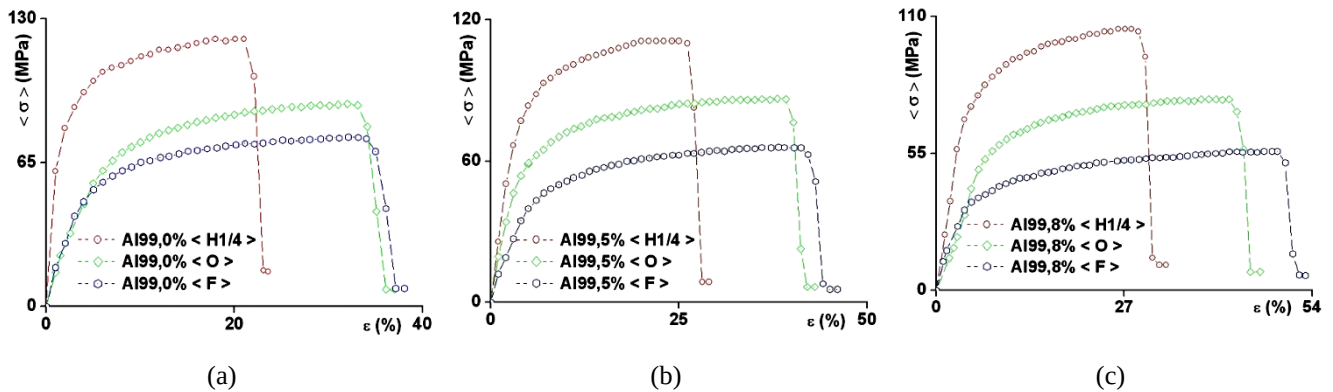


Fig. 2 – Grouping of tensile curves (stress-strain) comparing commercial aluminium of the three different purities respectively of the three states: (a) - Al-99,0 %, (< H1/4 >, < O >, < F >), (b) - Al-99,5 % (< H1/4 >, < O >, < F >) and (c) - Al-99,8 % (< H1/4 >, < O >, < F >).

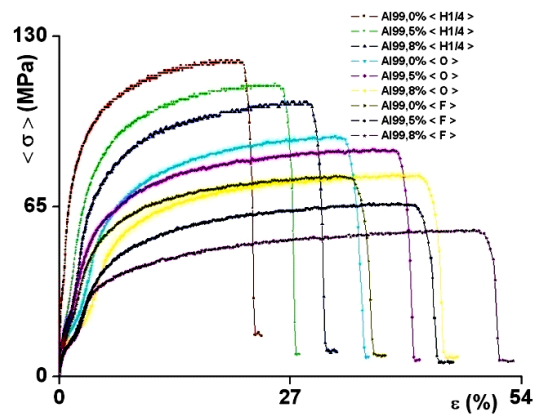


Fig. 3 - Grouping of tensile curves (stress-strain) comparing commercial aluminium of the three different purities of the three states.

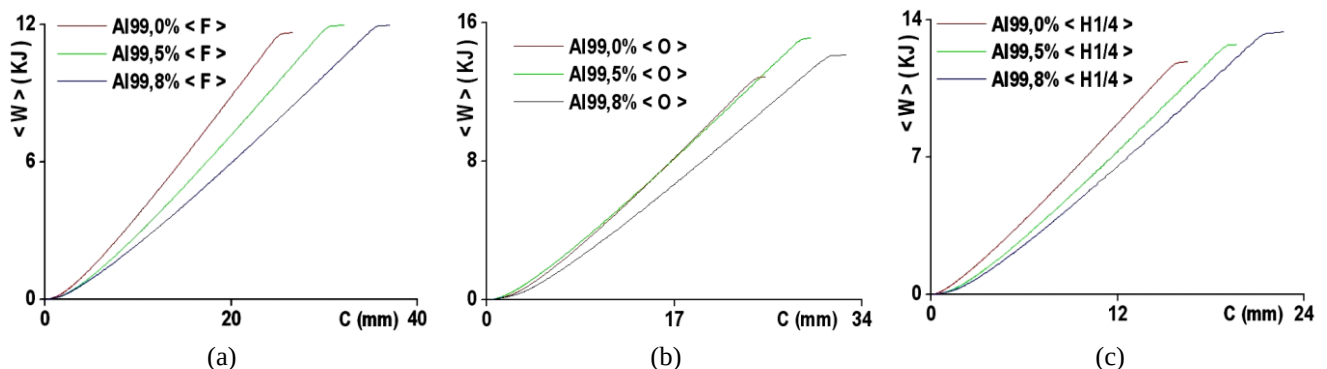


Fig. 4 – Grouping of curves (free energy of deformation - stroke) for comparison of the three types of purity in the same respective state.

In addition, the average histograms of the resistance characteristics of the H1/4 state are well above those of the annealed state, which are themselves above those of the as-cast state.

Regardless of the condition under consideration, the average curves (stress-strain) (Fig. 1) and (free strain energy-stroke) (Fig. 4) for Al99,0% purity are above those for Al99,5%, which are themselves above Al99,8% at maximum ductility.

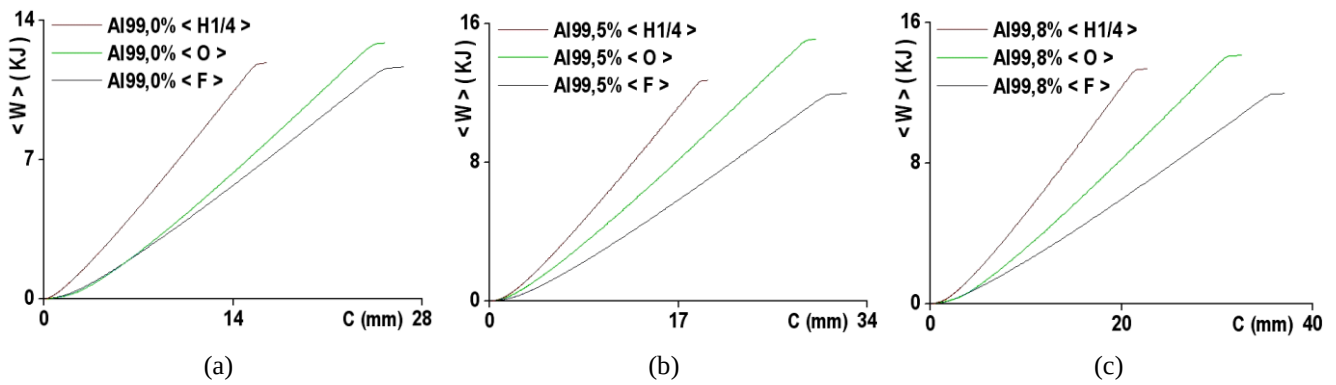


Fig. 5 – Grouping of curves (free energy of deformation - stroke) comparing the three types of aluminium of the same purity in the three respective states.

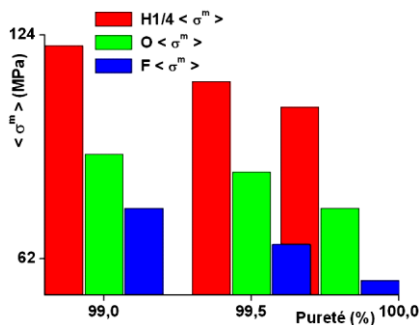


Fig. 6 – Maximum stress versus Purity

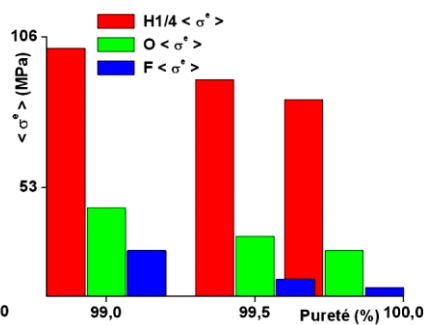


Fig. 7 – Elasticity stress versus Purity

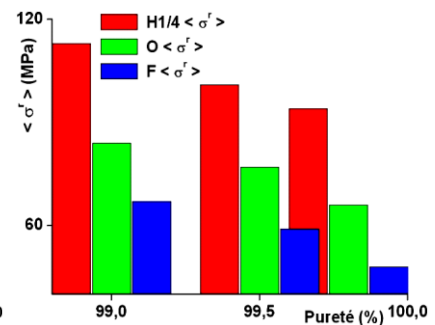


Fig. 8 – Breaking stress versus Purity

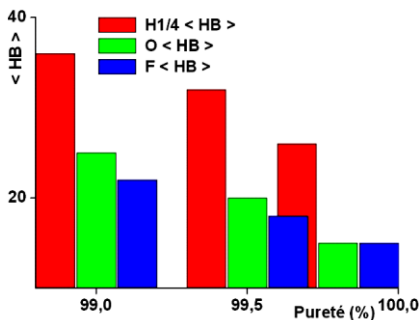


Fig. 9 – Brinell hardness versus Purity

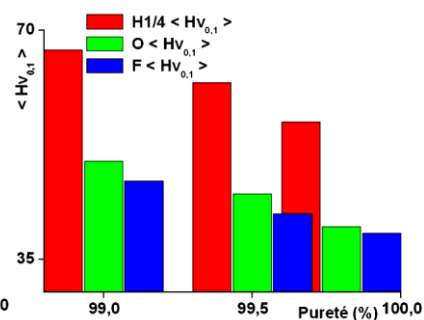


Fig. 10 – Vickers microhardness versus Purity

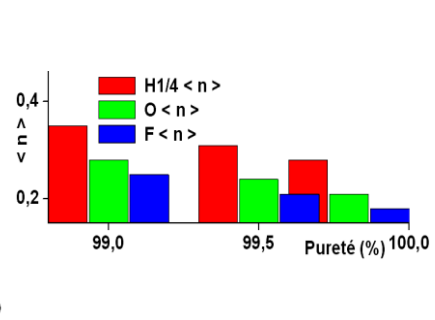


Fig. 11 – Hardening coefficient versus Purity

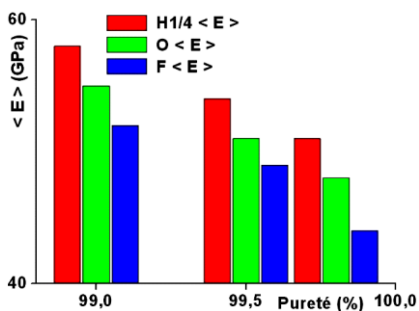


Fig. 12 – Young's modulus versus Purity

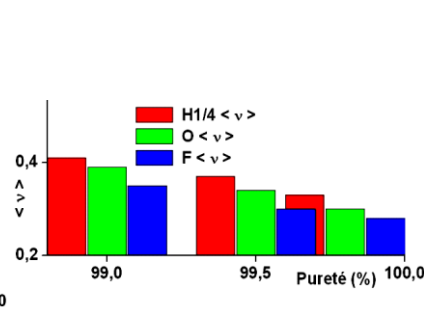


Fig. 13 – Poisson's ratio versus Purity

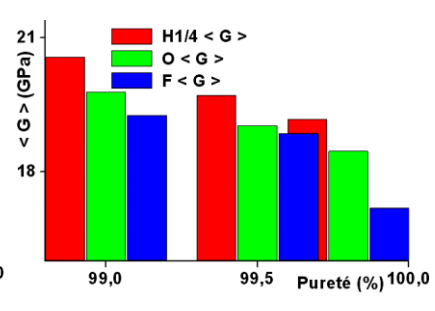


Fig. 14 – Shear modulus versus Purity

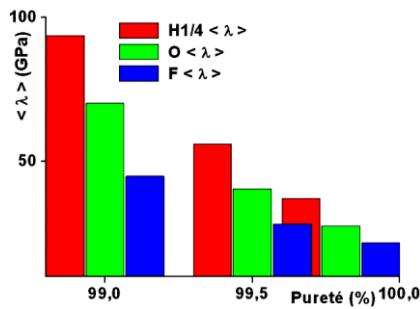


Fig. 15 – Lamé Coefficient versus Purity

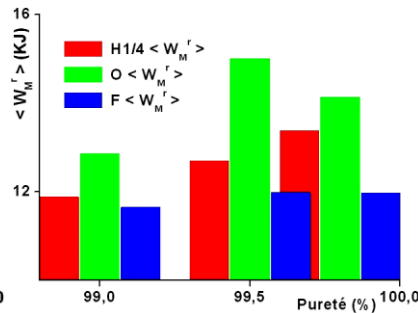


Fig. 16 – Maximum total deformation energy versus Purity

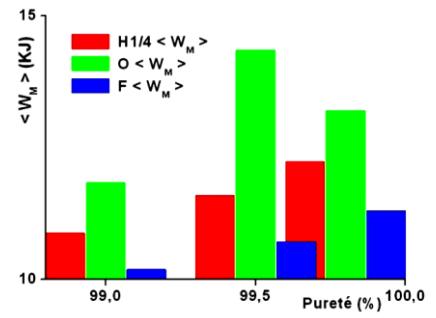


Fig. 17 – Maximum deformation energy versus Purity

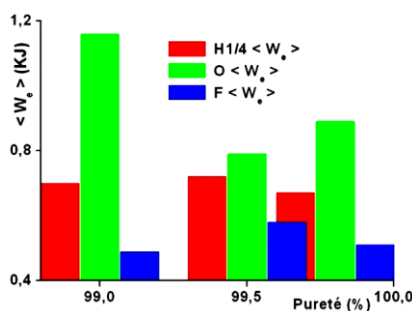


Fig. 18 – Elastic deformation energy versus Purity

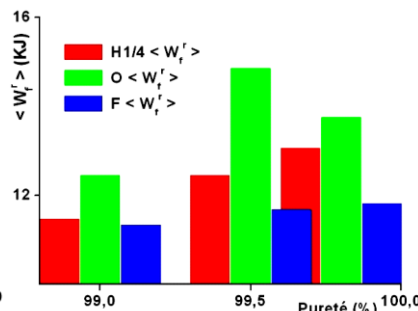


Fig. 19 – Total deformation energy of cracking versus Purity

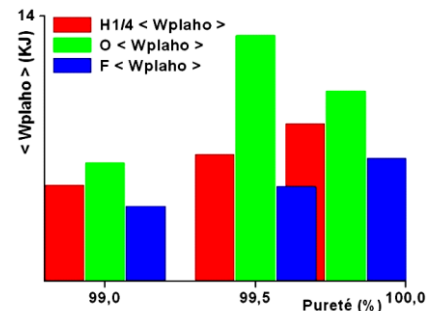


Fig. 20 – Homogeneous plastic deformation energy versus Purity

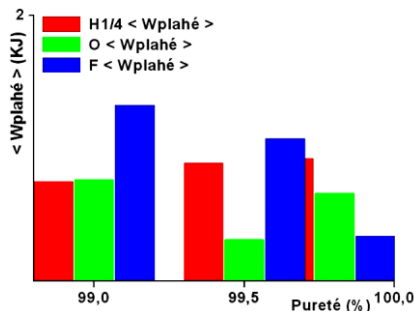


Fig. 21 – Heterogeneous plastic deformation energy versus Purity

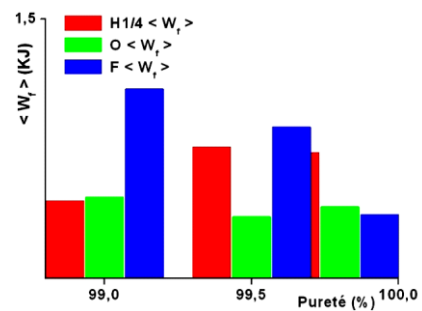


Fig. 22 – Crack deformation energy versus Purity

It can also be seen that the average curves (stress-strain) (Fig. 2) and (energy free from strain - stroke) (Fig. 5) for the cold worked condition are too high above those for the annealed condition, which are themselves just above those for the as-cast condition F at maximum ductility, whatever the purity considered.

Figure 3 shows us that the curve for the H1/4 state and Al99,0% purity is much higher than the other states, whatever the purity considered, to the detriment of the maximum ductility in the F state of Al99,8% purity.

6.2 Average Ductility

Similarly, for the three considered states of the selected commercial aluminium, we also monitored the evolution of variations in the four main ductility characteristics: mean elongation $\langle A \% \rangle$, mean stress coefficient $\langle Z \% \rangle$, mean stress elongation $\langle Z_u \% \rangle$ and mean resilience $\langle K_{cv} \rangle$ versus the purity of the studied material.

Figures (23 – 26) show that the four mechanical ductility characteristics of the three states considered grow with increasing purity at the expense of strength characteristics, however the growth rate varies differently depending on the mechanical characteristic and state considered.

It can also be seen that the average histograms of the four ductility characteristics of the work-hardened condition are too far below those of the annealed condition, which are themselves below those of the as-cast condition.

figures (1-5)(a-b-c) represent respectively the average tensile curves (stress-strain) and (energy free of strain-stroke) of five specimens of **commercial aluminium** for the three states which are: a – rough casing noted: $\langle F \rangle$, b - annealed noted: $\langle O \rangle$ and cold worked noted: c - $\langle H1/4 \rangle$ of the three purities considered: (**Al-99,0%, Al-99,5% and Al-99,8%**).

The study of the previously mentioned curves allowed us to determine the mechanical characteristics of each state according to the three purities.

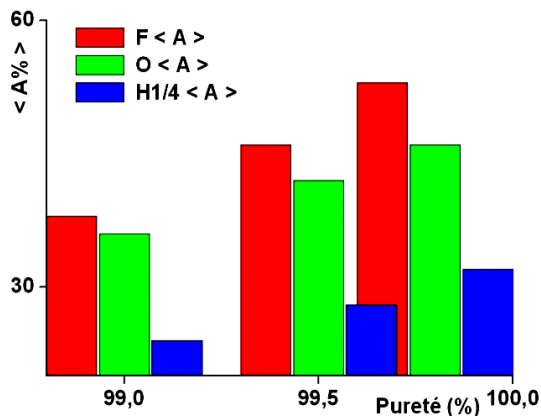


Fig. 23 – Elongation versus Purity

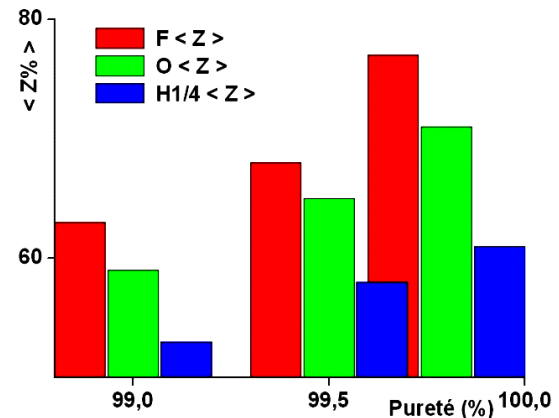


Fig. 24 – Shrinkage coefficient versus Purity

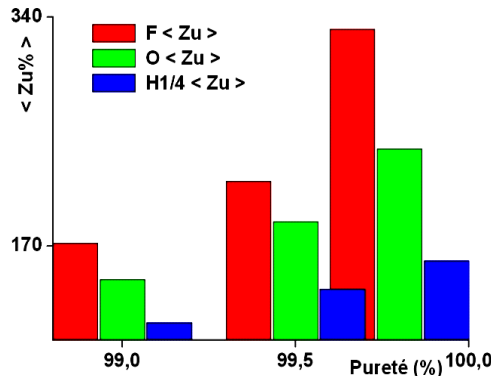


Fig. 25 – Stress elongation versus Purity

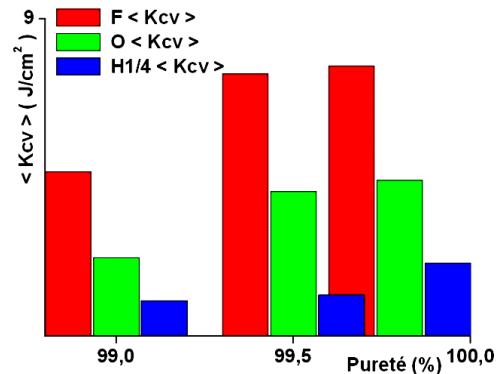


Fig. 26 – Resilience versus Purity

Figures (6 - 26) represent the different results obtained during our study of the different mechanical properties of the three purity states of **commercial aluminium**.

Whatever the condition under consideration, the respective curves (stress-strain) (fig.1-a-b-c) and (strain-free energy - stroke) (fig. 3-a-b-c) of the Al-99,0% purity are above those of Al-99,5%, which in turn are above those of Al-99,8% to the detriment of the elongations $\langle A\% \rangle$.

The respective curves (stress-strain) (Fig. 2-a-b-c) and (strain-free energy-stroke) (Fig. 4-a-b-c) of the work-hardened condition ($\langle H1/4 \rangle$) are above those of the annealed condition, irrespective of the purity: $\langle O \rangle$, which are themselves above those of the as-cast condition: $\langle F \rangle$, to the detriment of the elongations $\langle A\% \rangle$.

All the curves (Figs. 1, 2 and 3) obtained can be interpreted as follows and show almost the same speed, which can be distinguished by three different regions (46 – 52):

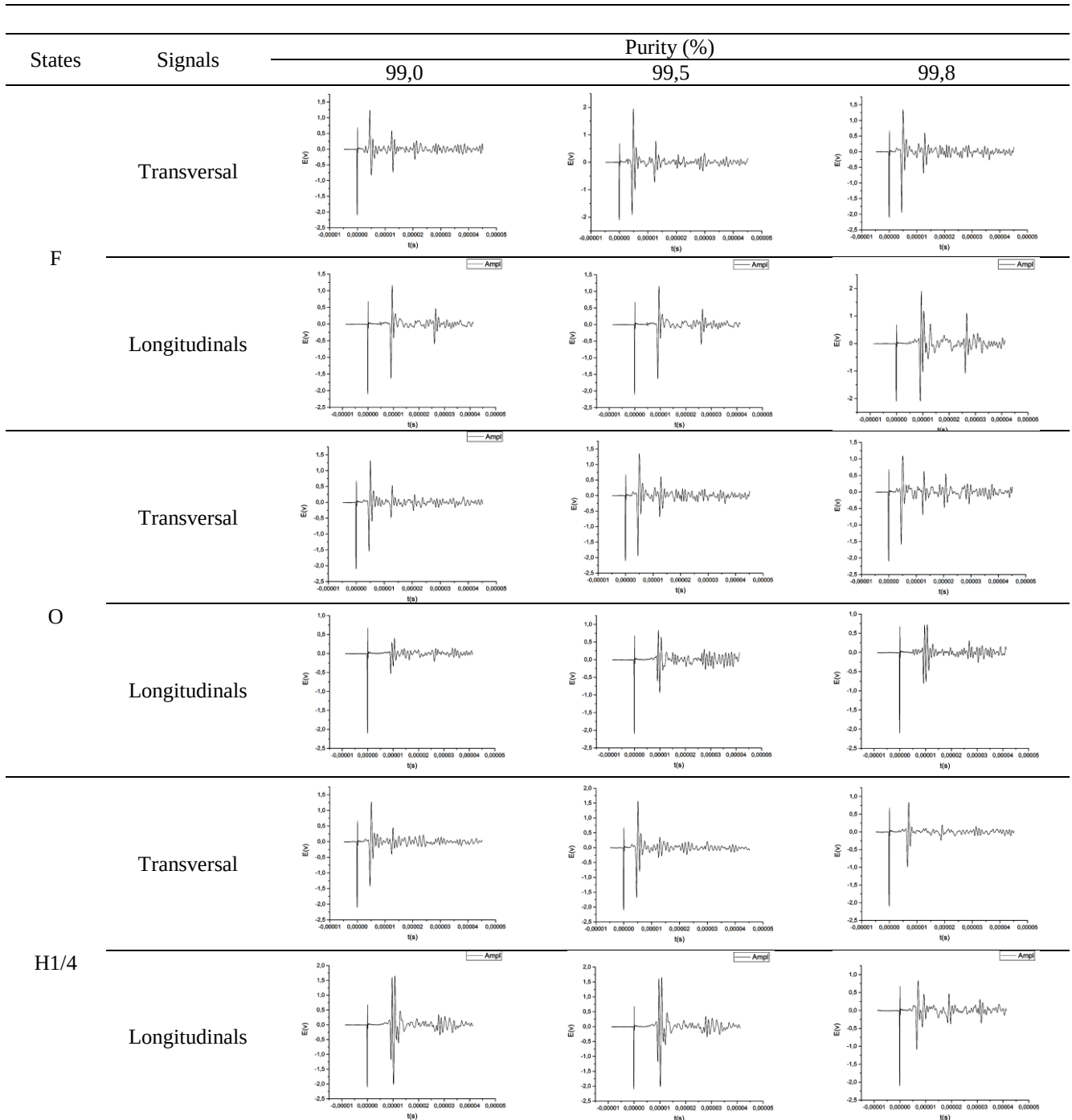


Fig. 27 – Signals recorded on 28 mm wide prismatic ultrasonic specimens of the three states of commercial aluminium in the as-cast: F and matured states: < M12h > and < M24h >.

- **A small linear elastic range:** Below the elastic stress σ^e (MPa), the deformations are elastic. When the force is removed, the specimen returns to its original shape, resulting in the reversible deformation defined by the Young's modulus.
- **A second large homogeneous plastic domain:** Above the elastic stress σ^e (MPa) up to the maximum stress σ^m (MPa), the deformation becomes homogeneous plastic. After the force has been removed, an irreversible permanent deformation occurs on the curve. The increase in plastic deformation requires an increase in the applied force. This phenomenon is called strain-hardening and is defined by a strain-hardening coefficient n . This phenomenon is interpreted by the movement of the dislocations.
- **A third plastic domain, this time heterogeneous and very restricted:** Beyond the maximum stress σ^m (MPa), damage occurs in two stages, the first is the appearance of microcracks on a defect and their coalescence with the appearance of striction and the second is their propagation throughout the entire section of the specimen.

For this reason the mode of rupture is similar to a ductile rupture for the following six main reasons:

The elongations at break: $A\% \gg 5\%$ (figs. 1, 2,3 and 23), the values of the stress coefficients $Z \gg 0.1$ (fig. 24), the very high *resilience* (fig. 26), the various deformation energies W are large (16 – 21), the crack deformation energy $W_f > 0,51\text{KJ}$ (Fig. 22) and the tensile fracture faces are cup-shaped (Fig. 41) show us that the fracture is ductile and has a matt to grainy appearance (Fig. 41).

The mean curves (stress-strain) in Figs. (1 – 3) show three domains, one small elastic domain and another very large homogeneous plastic with a third very small heterogeneous plastic domain, as the damage occurred gradually and along a straight line with a small slope, where the instantaneous damage begins with the specimen being stressed, with the microcrack appearing and spreading over a defect. In this case, we are probably dealing with the superimposition of the type II and type III fracture modes with instantaneous displacement of the two straight slides and screws to obtain a fracture surface inclined at approximately 45° (Fig. 42).

Under load, the shear stress is at its maximum on planes inclined at 45° to the line of applied force. On the other hand, the movement of a dislocation is simplest in the direction of the planes furthest apart. This crystallographic slip is due to critical shear, the value at which the first slippage or critical shear stress takes place, characterising the transition from elastic to plastic behaviour.

In the as-cast state $< F >$ (**Al-99, 0%, Al-99, 5% and Al-99, 8%**) (Fig.37, 40), the distribution of the content of different impurity elements is non-uniform in the **commercial aluminium** studied. This leads to the formation of structural and local heterogeneities that generate a stress field that varies from one point to another in **commercial aluminium**. In order to improve the mechanical characteristics of the as-cast condition, annealing heat treatments and mechanical hardening treatments were applied (Figs. 38, 39), revealing on the one hand a homogeneous distribution of matrix atoms and impurities and on the other hand dislocations of the same nature in the aluminium which impede the movement of dislocations.

When loaded, the atoms of the Al matrix and the different impurity elements of the three structural states have atoms of smaller or larger radii which can be in solid solution respectively insertion or substitution, create lattice distortions with a stress field due to the size difference between the solute and solvent atoms (tension in the case of insertion and compression in the case of substitution).

There are three factors that cause the movement of dislocations to be blocked:

- The interaction between this stress field and the dislocations makes them difficult to move,
- Dislocations anchored by these atoms of impurity and network.

Two mechanisms can then occur during the passage of a dislocation at these atoms:

- Shearing or bypassing of these atoms respectively by dislocation and creation of defects,
- Interaction crystal.

But in any case, more energy is required at dislocation to reach the high level, which increases the values of the resistance characteristics of commercial aluminium.

Figures (6 – 15) show that the histograms of stress, Brinell hardness, microhardness, Young's and shear modulus, Poisson, Lamé and consolidation coefficients of the three states under consideration decrease with increasing purity at the expense of the ductility characteristics shown in figures (23 – 26), although the rate of decrease varies differently depending on the mechanical characteristic and the state under consideration. It can be seen that the extrinsic values of fracture strength, tensile strength, yield strength, Brinell hardness, Vickers microhardness, Young's modulus, shear modulus, consolidation coefficient, Lamé and poisson's modulus Figs (6 – 15) of the hardened condition are higher than those of the annealed condition, which in turn are higher than those of the as-cast condition, irrespective of the percentage of purity.

6.3 Determination of the average elastic properties by ultrasound of the three states of commercial aluminium

6.3.1 Recorded signals

The following table represent the various recorded signals:

6.3.2 – Elastic properties

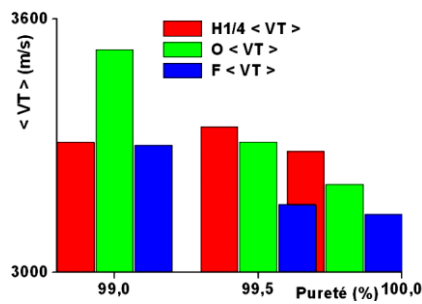


Fig. 28 – Transversal velocity versus Purity

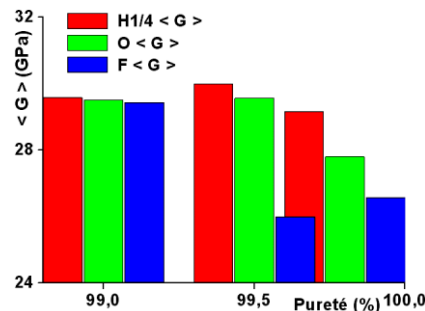


Fig. 29 – Shear modulus versus Purity

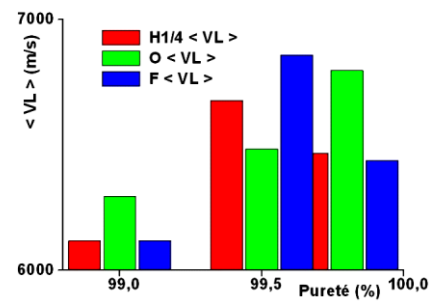


Fig. 30 – Longitudinal velocity versus Purity

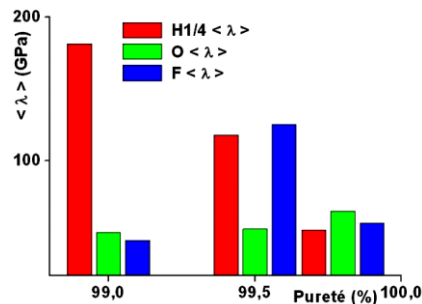


Fig. 31 – Lamé Coefficient versus Purity

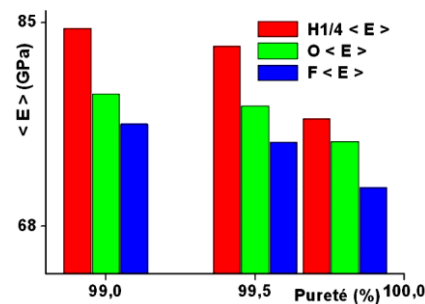


Fig. 32 – Young's modulus versus Purity

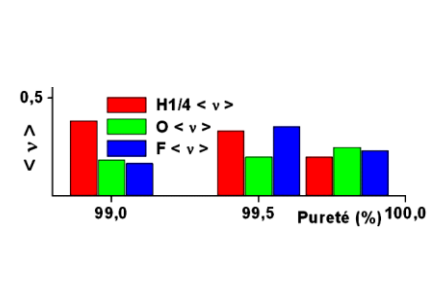


Fig. 33 – Poisson's ratio versus Purity

Figures (27 – 33) show that in all three states, the elastic properties decrease with increasing purity, but the rate of decrease varies differently depending on the elastic characteristic and the state under consideration. The extrinsic values of Young's modulus, shear modulus, Poisson's and Lamé coefficients of the hardened state are higher than those of the annealed state, and are even higher than those of the as-cast state regardless of the percentage of purity.

The evolution of the elastic strength characteristics given by the non-destructive ultrasonic method are on the one hand more reliable and on the other hand verify those given by the destructive tensile method.

All the data obtained by ultrasound comply with the AFNOR standard.

6.4 - Comparative study of the maximum elastic H1/4 tensile and ultrasonic properties of the three states of commercial aluminium

A comparative study of the four common maximum elastic properties of the H1/4 states is considered in Figs. (34-37): The Young's and shear moduli, Lamé and Poisson coefficients obtained by ultrasound and tensile testing versus purity decrease with increasing purity, however, the rate of decrease varies differently depending on the elastic characteristics and state under consideration. The histograms of the properties obtained by tensile testing are far below those of ultrasound.

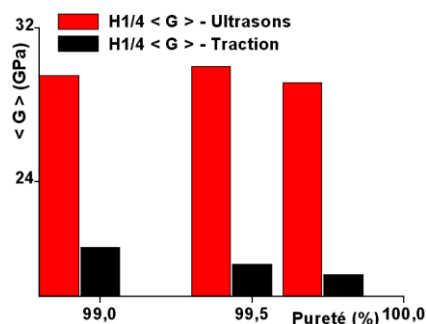


Fig. 34 – Shear modulus versus Purity

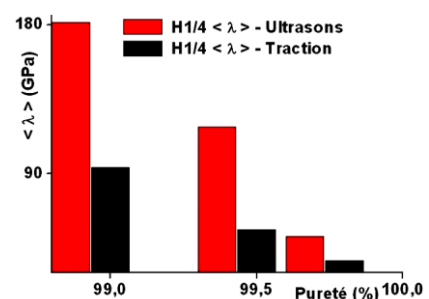


Fig. 35 – Lamé Coefficient versus Purity

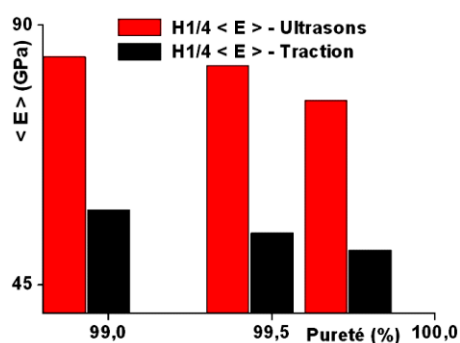


Fig. 36 – Young's modulus versus Purity

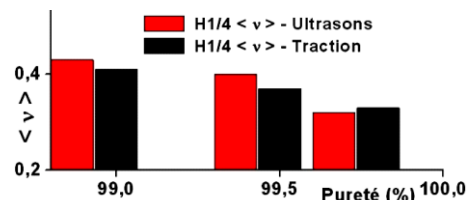
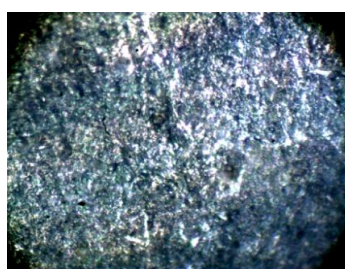


Fig. 37 – Poisson Coefficient versus Purity

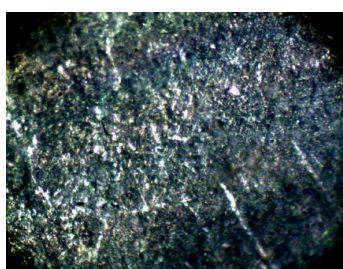
Regardless of the purity considered, the elastic characteristics of ultrasound are considerably greater than those obtained by traction.

The results of the common elastic properties obtained by the ultrasonic method are reliable and conform to the AFNOR standard. On the other hand, the destructive tensile method is erroneous, but the latter has a great advantage as it allows the complete characterisation of materials: elastic, homogeneous and heterogeneous plastics, stress- and breakage properties.

7 Microstructure of the three structural states of commercial aluminium



(a) < F > (Al-99,0%) x200

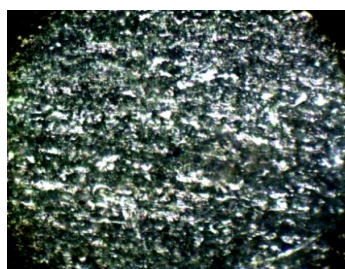


(b) < F > (Al-99,5%) x200

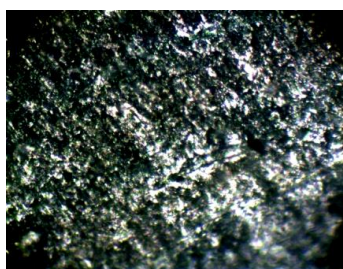


(c) < F > (Al-99,8%) x200

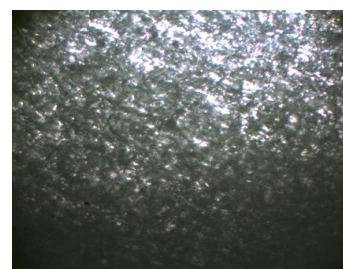
Fig. 38 – Micrographic structures of commercial aluminium in the < F > state.



(a) < O > (Al-99,0%) x200

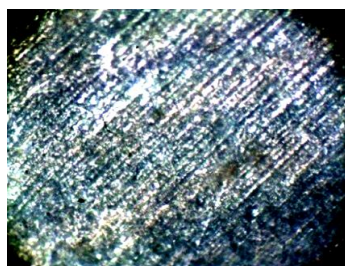


(b) < O > (Al-99,5%) x200

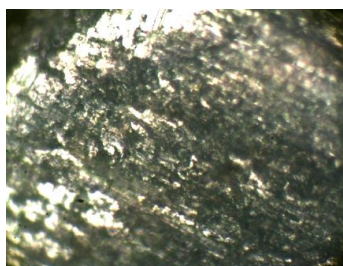


(c) < O > (Al-99,8%) x200

Fig. 39 – Micrographic structures of commercial aluminium in the < O > state.



(a) < H1/4 > (Al-99,0%) x200

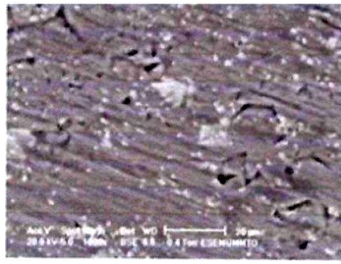
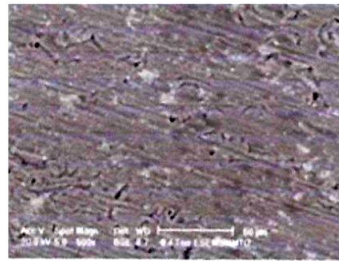
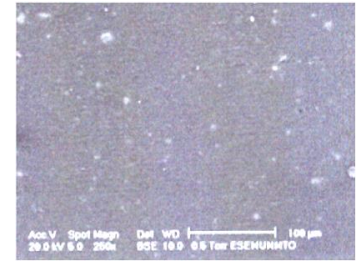
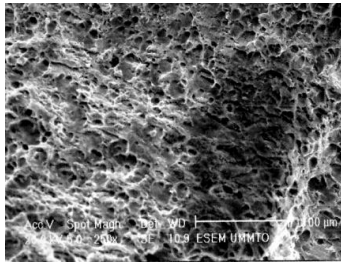
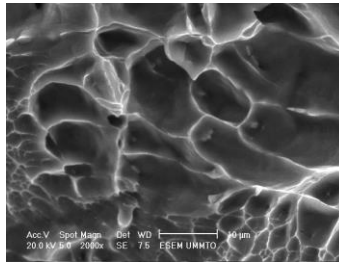
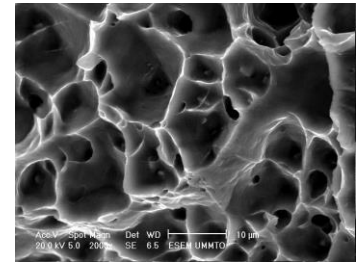
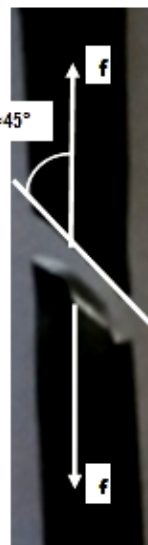


(b) < H1/4 > (Al-99,5%) x200



(c) < H1/4 > (Al-99,8%) x200

Fig.40 – Micrographic structures of commercial aluminium in the < H1/4 > state

(a) $\langle F \rangle$ (Al-99, 0%)(b) $\langle F \rangle$ (Al-99, 5%)(c) $\langle F \rangle$ (Al-99, 8%)**Fig. 41 – SEM microstructures of commercial aluminium in the $\langle F \rangle$ state.**(a) $\langle O \rangle$ (Al-99, 0%)(b) $\langle O \rangle$ (Al-99, 0%)(c) $\langle H1/4 \rangle$ (Al-99, 0%)**Fig. 42 – Ductile fracture toughness in tension cups obtained with SEM of commercial aluminium of purity (Al-99, 0 %) in the states $\langle F \rangle$, $\langle O \rangle$ and $\langle H1/4 \rangle$.**(a) $\langle F \rangle$ (Al-99, 0%)(b) $\langle O \rangle$ (Al-99, 0%)(c) $\langle H1/4 \rangle$ (Al-99, 0%)**Fig. 43 – Ductile fractures at 45° of commercial aluminium of purity (Al-99, 0%) in the states (a) $\langle F \rangle$, (b) $\langle O \rangle$ and (c) $\langle H1/4 \rangle$ with f - tensile stress**

Commercial aluminium in the as-cast condition (fig.38 - (a) $\langle F \rangle$ (Al-99,0%), (b) $\langle F \rangle$ (Al-99,5%) and (c) $\langle F \rangle$ (Al-99,8%)) has a heterogeneous structure with low strength properties. As the purity increases, there is a decrease in the percentage of impurities whose distribution is random. Their microstructure shows us a white coloured phase immersed in the dark aluminium matrix with the presence of pores. To eliminate them, it is necessary to monitor the refining process.

In order to make the heterogeneous structure of commercial aluminium in the as-cast condition homogeneous, an annealing treatment with heating, solutionizing, homogenizing and cooling in the quenched furnace is often carried out (Fig.39 - (a) $\langle O \rangle$ (Al-99,0%), (b) $\langle O \rangle$ (Al-99,5%) and (c) $\langle O \rangle$ (Al-99,8%)). The annealing under consideration certainly causes a migration of the impurity atoms or lattice to dislocations as the material under study hardens. This leads us to a clear improvement in the resistance characteristics of the $\langle F \rangle$ states.

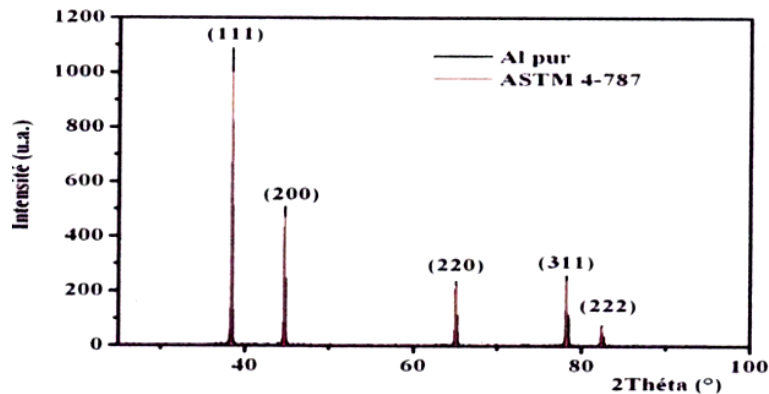


Fig. 44 - DRX of commercial aluminium in the $\langle F \rangle$ state (Al-99,5 %)

The microstructures (Fig.40 - (a) $\langle H1/4 \rangle$ (Al-99,0%), (b) $\langle H1/4 \rangle$ (Al-99,5%) and (c) $\langle H1/4 \rangle$ (Al-99,8%)) reveal sliding planes oriented at 45° . During strain-hardening, the dislocations introduced either block the movement of other moving dislocations or they become mobile and interact with other obstacles. In both cases, a hardening of the commercial aluminium in the as-cast condition occurs, which allows a noticeable increase in strength characteristics.

Figure 44 shows the DRX diagram of the intensity (A.U.) versus angle 2θ ($^\circ$) of commercial as-cast aluminium noted: F and 99,5% purity and shows a cubic structure with ductile centred faces.

8 Conclusion

This investigation of the tensile, free strain energy, Brinell hardness, microhardness, resilience and structural characteristics of commercial aluminium has demonstrated that strain-hardening causes a delay in the beginning of dislocation motion, but accelerates the fracture process and also leads to considerable hardening and a simultaneous loss of plasticity. In the annealed state, the material hardens, but this hardening is weaker than in the work-hardened state. In addition, during this annealing process, a high plasticity of the material appears. The poor mechanical characteristics of the material in the as-cast state can be associated with the occurrence of heterogeneities. Increasing the degree of purity leads to the softening of the material.

Commercial aluminium is a ductile material: it can withstand large plastic deformations without brutal rupture.

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