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EFFECTS OF THERMOMECHANICAL TREATMENTS ON THE THERMAL EXPANSION COEFFICIENT OF SOME ALUMINIUM ALLOYS

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Résumé

Le but de cette étude est la détermination du cœfficient de dilatation thermique α (T) en fonction de la température des trois alliages suivants:

- Al-6%Zn-3%Mg obtenu par la méthode conventionnelle de coulée en lingot
- Al-0.5%Mg-0.88%Si obtenu par le procédé de Direct Cast Casting
- Al-1.88%Mn-0.8%Mg obtenu par le procédé de Twin Roller Melt Spinning

Ces alliages ont subi, au préalable, de différents traitements thermomécaniques.
Les principaux résultats montrent que l'alliage Al-6%Zn-3%Mg donne une très faible anisotropie, tandis que les deux autres alliages, Al-0.5%Mg-0.88%Si et Al-1.88%Mn-0.8%Mg, montrent, au contraire, une assez forte anisotropie sur les courbes de α (T).

Mots clés: Alliages d'aluminium, cœfficient de dilatation thermique, anisotropie, coulée en lingot, Direct Cast Casting,Twin Roller Melt Spinning.

Abstract

The aim of this study was the determination of the thermal expansion coefficient α (T) in relation to the temperature of the three following aluminium alloys:

- Al-6%Zn-3%Mg obtained by conventional ingot casting
- Al-0.5%Mg-0.88%Si obtained by Direct Cast Casting
- Al-1.88%Mn-0.8%Mg obtained by Twin Roller Melt Spinning

These alloys have undergone various thermal and mechanical conditions.
The main results show that the Al-6%Zn-3%Mg alloy exhibits a very weak anisotropy meanwhile that Al-Mg-Si and Al-Mn-Mg alloys exhibit, on the contrary, a quite strong anisotropy on the curves of α (T).

Keywords: Aluminium alloys, thermal expansion coefficient, anisotropy, conventional ingot casting, Direct Cast Casting, Twin Roller Melt Spinning.

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ملخص

الهدف من هده الدراسة هو تعيين معامل التمدد ف α (T) مع تغيير درجة الحرارة للسبائك التالية
.1 Al- 6%Zn-3%Mgالمحصول عليها بالطريقة المعتادة
. 2 Al-0.5%Mg-0.88%Si الحصول عليها بالطريقة D.C.C
Al-1.99%Mn- المحصول عليها بطريقة التبريد السريع MELT SPINNING
0.8%Mg.3 لقد تمت معالجة هده السبائك حراريا و ميكانيكيا.
النتائج تبين أن السبيكة Al-6%Zn-3%Mg تظهر تغير ضعيف في ألمناح لكن السبيكتين Al- %Mg-0.88%Si
0.5 يظهران تغيرا كبيرا في ألمناح بالنسبة α(T). وAl-1.99%Mn-0.8%Mg

الكلمات المفتاحيــــة: سبائك الألمنيوم، معامل التمدد الحراري، عدم التماثل المناحي، التبريد السريع..

Introduction

In spite of the improvement of their mechanical properties with the introduction of addition elements, the thermal expansion coefficient of aluminium alloys is still quite high. This drawback can be overcome through the use of a rapid solidification process. Together with the grain refinement obtained through hyper-quenching, the addition of transition elements results in the formation of small dispersoids, with a high volume fraction, which are stable at high temperatures because of their low solubility and diffusivity in aluminium.
From another point of view, thermodynamic studies on rapidly solidified aluminium alloys are scarce. One of the physical properties that can give us information on the behaviour of these alloys is the coefficient of thermal expansion, since it is sensitive to the introduction of impurities in the matrix. It is also sensitive to the different phase transformations that could occur and to the inter-atomic forces. However, the determination of the thermal coefficient of linear expansion as a function of temperature, α (T), along different directions for aluminium alloys obtained through rapid solidification techniques, such as Direct Chill Casting (DCC) [1,2] and Twin-Roller Melt Spinning (TRMS) [3,4] , is little known, if not inexistent.
In this work, we set to study the behaviour in dilatometry along different directions in three aluminium alloys prepared with different elaboration processes, to study the anisotropy of their thermal expansion coefficient, and to try to better understand the effect of the different thermo-mechanical treatments on the thermal coefficient of linear expansion.

II. EXPERIMENTAL PROCEDURE

The chemical compositions of the alloys are as follow:
- Al-6%Zn-3%Mg

Elements	Al	Zn	Mg	Zr	Fe	Si
Pourcentage (%) in weight	90.88	6.0	3.0	0.10	0.01	0.01

- Al-0.5%Mg-0.88%Si

Elements	Al	Mg	Si	Mn	Fe
Pourcentage (%) in weight	97.88	0.50	0.88	0.44	0.30

- Al-1.99%Mn-0.8%Mg

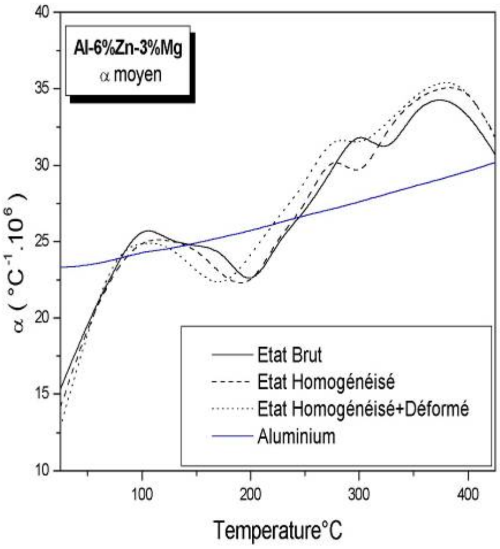
Elements	Al	Mn	Mg	Cr	Zr	Fe	Ti
Pourcentage (%) in weight	96.1	1.99	0.80	0.60	0.40	0.13	0.05

For each alloy, we have prepared a set of samples in three different states: as a raw material, in an homogenized state, and in an homogenized plus cold worked state.
The measurements of the thermal expansion coefficient were done with an Adamel Lhomargy D124 differential dilatometer while a Setaram DSC 111 was used for the calorimetric study of the alloys. The heat flow rate for both procedures was set to 2°/mn.

III. RESULTS

The main results of this research are:
■ The Al-6%Zn-3%Mg alloy, obtained through conventional casting, exhibits a very weak anisotropy.

Figure 1. Effects of thermomechanical treatments on
a- Dilatometric curves
b- Calorimetric curves



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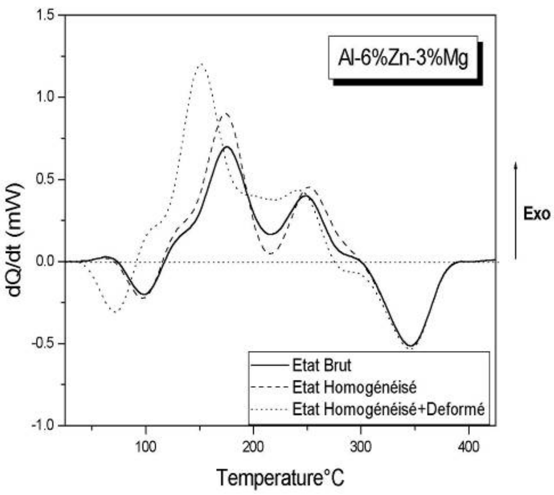
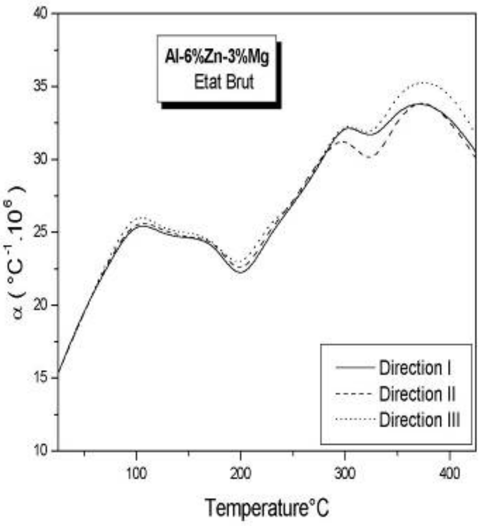


(b)

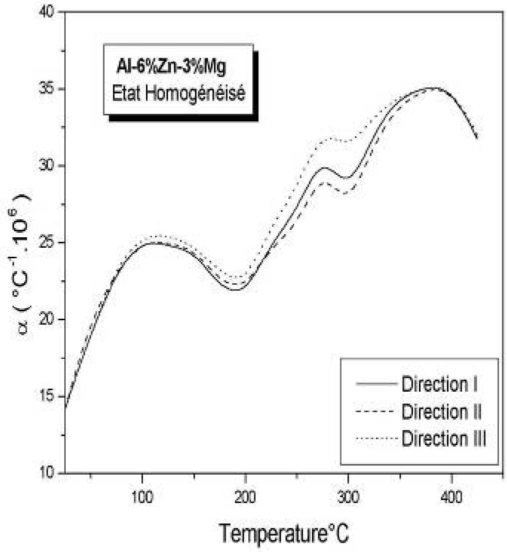
The figure 1.a represents the variation of the thermal expansion coefficient of the Al-6%Zn-3%Mg alloy under different thermomechanical treatments in comparison with pure aluminium. Even if the shape of the 03 curves

seems to be the same, we remark the presence of 04 peaks dues to phase transformations or/and recristallisation phenomena which occurred during the heating of the alloy.
The DSC thermograms (figure1.b) confirm the existence of these transformations and give us more information about their nature [5].
The effect of different thermo-mechanical treatments on α (T) along each of the directions studied brings us to the conclusion that the first three phase transformations, occurring in the temperature range [25-425°C] are more or less influenced by the solution treatment while the fourth, corresponding to the dissolution of the equilibrium η phase ($MgZn_2$), remains practically unaffected. (figure2). On the contrary, this latter transformation occurs at the same temperature for the three directions studied no matter what thermo-mechanical treatment the sample went through.
From another point of view, plastic deformation favours to a higher degree the phase transformations that could occur during the heating of the sample.
This explains the reasons why the phenomena linked to the dissolution of the zones, and to the precipitation of the two phases, η and η ', occur earlier, at lower temperatures, than in the case of raw and/or non-solution treated material.

Figure 2. Variation of the thermal expansion coefficient α (T)
a- Raw state
b- Homogenised state
c- Homogenised and cold worked state



(a)



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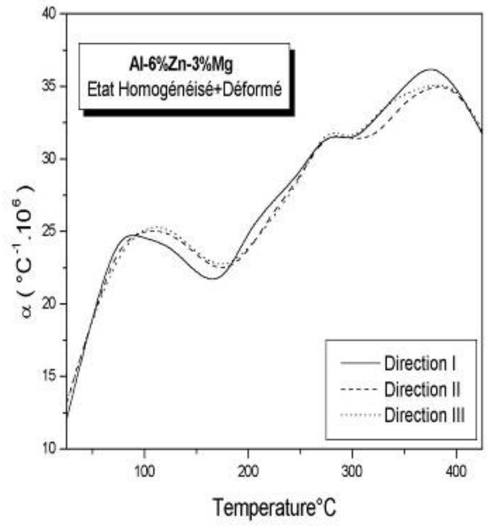
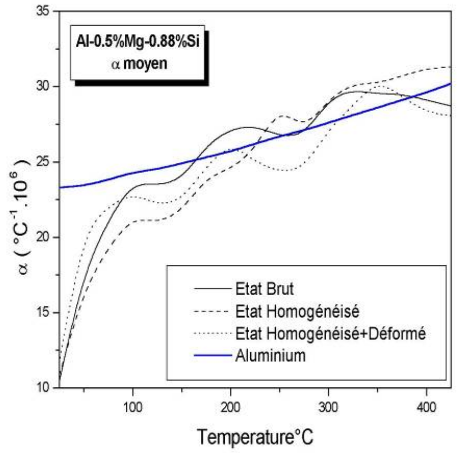


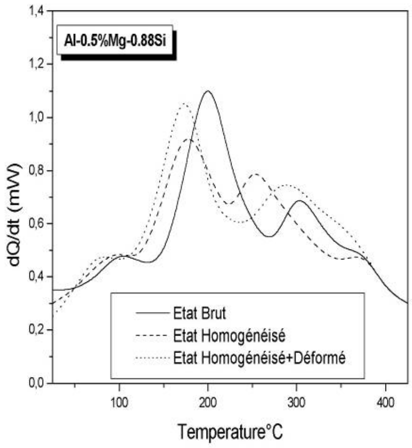
(c)

The Al-0.5%Mg-0.88%Si alloy, obtained by Direct Chill Casting exhibits on the contrary a quite strong anisotropy on the curves of α (T). The effects of the thermomechanical treatments is more visible than it was for the Al-6%Zn-3%Mg alloy, obtained through conventional casting (figure3)

Figure 3. Effects of thermomechanical treatments on
a- Dilatometric curves
b- Calorimetric curves



(a)



(b)

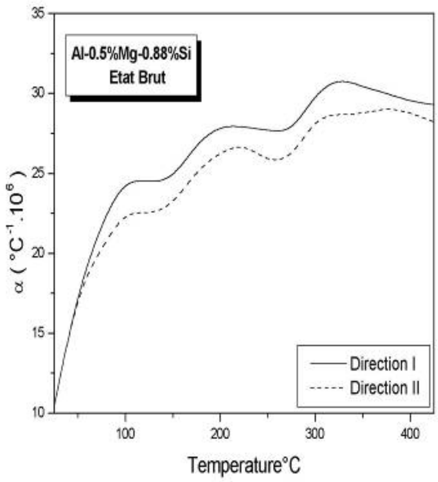
We can observe, from figure 4, very clearly, that while the shapes of the two curves are identical, there appears a quite pronounced anisotropy between the measurements of α (T) along both directions. However, we should note that $\alpha_{radial} \geq \alpha_{axial}$, that is, the thermal coefficient of linear expansion along the radial direction is always greater than that measured along the axial direction in the temperature range [25-425°C]. It is also interesting to note that all the phase transformations occur simultaneously along the two directions [6].

Plastic deformation (cold rolling) along direction I (radial direction) modifies greatly the two dilatation curves, which can no longer be superimposed. The phase transformations do not occur simultaneously along the two directions. Precipitation/dissolution processes occur more quickly along the radial direction.

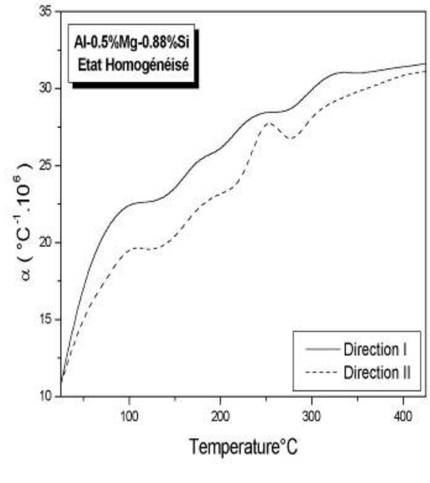
We observe that, along the radial direction, the solution treatment accelerates the kinetics of all the phase transformations, while showing more distinct domains corresponding respectively to the β' phase and the equilibrium Mg_2Si. These domains are less clearly delineated for the raw sample.

Figure 4. Variation of the thermal expansion coefficient α (T) of :

a- Raw state
b- Homogenised state
c- Homogenised and cold worked state



(a)



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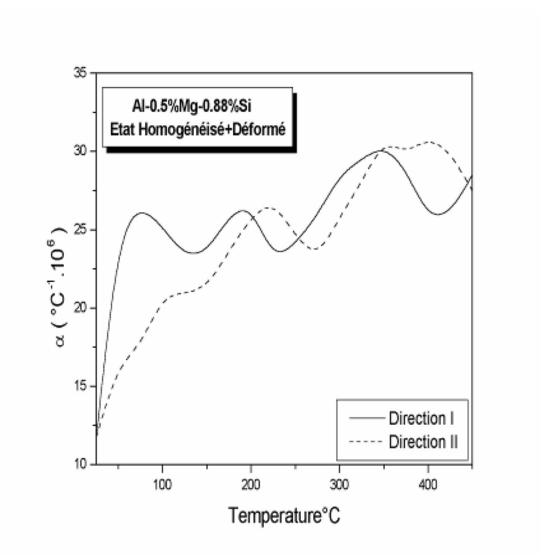

(c)

The Al-1.99%Mn-0.8%Mg alloy, obtained by Twin-Roller Melt Spinning, exhibits a quite strong anisotropy of the α (T) coefficient over the whole temperature range [25-425°C].

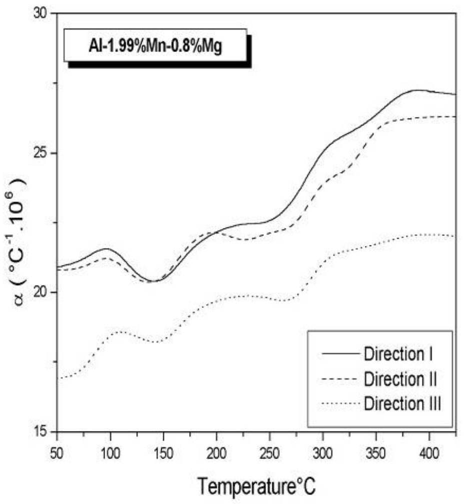

Figure 5: Variation of the thermal expansion coefficient α (T) of

Al-1.99%Mn-0.80%Mg alloy in the 3 directions

We observe, from figure 5, that α_3 (T), measured along the direction normal to the rolling plane, is clearly lesser than α_1(T) and α_2 (T). This behaviour is probably due to the layered structure of the sheet.

The shapes of the curves representing the thermal coefficient of linear expansion along the directions parallel and perpendicular to the rolling direction (in the rolling plane) are practically identical.

The difference between α_1(T) and α_2 (T) is probably due to the existence of Al_6Mn precipitates with a preferential direction coinciding with the rolling direction.

The presence of these precipitates along this direction is certainly due to the unidirectional casting process used (Twin-Roller Melt Spinning [7].

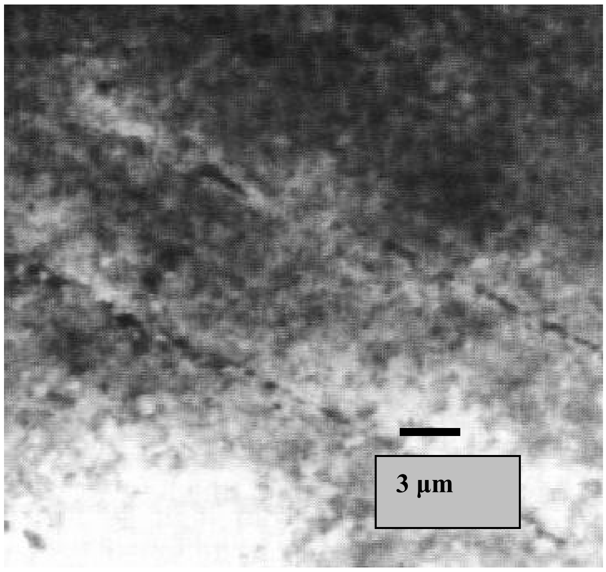

Figure 6: Al_6Mn precipitates

CONCLUSION

The study of these different aluminium alloys, elaborated by different solidification techniques, allowed us to bring a small contribution to the understanding of the different phenomena causing the anisotropy of the thermal coefficient of linear expansion α (T) and to better understand the influence of the different thermo-mechanical treatments on this thermodynamic property.
This anisotropy is due essentially to:

- the mode of elaboration of the alloy,
- the decomposition kinetics of supersaturated solid solution and
- the non-uniform spatial arrangement and size distribution of the precipitating inter-metallic phases.

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