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


Abstract

The aim of this study was the determination of the thermal expansion coefficient $\alpha (T)$ 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 $\alpha (T)$. 

Keywords: Aluminium alloys, thermal expansion coefficient, anisotropy, conventional ingot casting, Direct Cast Casting, Twin Roller Melt Spinning.
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 interatomic forces. However, the determination of the thermal coefficient of linear expansion as a function of temperature, $\alpha(T)$, 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 thermomechanical 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

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>Zn</th>
<th>Mg</th>
<th>Zr</th>
<th>Fe</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pourcentage (%) in weight</td>
<td>90.8</td>
<td>6.0</td>
<td>3.0</td>
<td>0.10</td>
<td>0.01</td>
<td>0.01</td>
</tr>
</tbody>
</table>

- Al-0.5%Mg-0.88%Si

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>Mg</th>
<th>Si</th>
<th>Mn</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pourcentage (%) in weight</td>
<td>97.88</td>
<td>0.50</td>
<td>0.88</td>
<td>0.44</td>
<td>0.30</td>
</tr>
</tbody>
</table>

- Al-1.99%Mn-0.8%Mg

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zr</th>
<th>Fe</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pourcentage (%) in weight</td>
<td>96.1</td>
<td>1.99</td>
<td>0.80</td>
<td>0.60</td>
<td>0.40</td>
<td>0.13</td>
<td>0.05</td>
</tr>
</tbody>
</table>

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
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 (MgZn2), 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

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
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 $\alpha(T)$ along both directions. However, we should note that $\alpha_{\text{radial}} \geq \alpha_{\text{axial}}$, 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 $\beta'$ phase and the equilibrium Mg$_2$Si. These domains are less clearly delineated for the raw sample.

Figure 4. Variation of the thermal expansion coefficient $\alpha(T)$ of:

- a- Raw state
- b- Homogenised state
- c- Homogenised and cold worked state
The Al-1.99%Mn-0.8%Mg alloy, obtained by Twin-Roller Melt Spinning, exhibits a quite strong anisotropy of the $\alpha(T)$ coefficient over the whole temperature range [25-425°C].

We observe, from figure 5, that $\alpha_3(T)$, measured along the direction normal to the rolling plane, is clearly lesser than $\alpha_1(T)$ and $\alpha_2(T)$. 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 $\alpha_1(T)$ and $\alpha_2(T)$ is probably due to the existence of Al$_6$Mn 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 5: Variation of the thermal expansion coefficient $\alpha(T)$ of Al-1.99%Mn-0.8%Mg alloy in the 3 directions](image)

![Figure 6: Al$_6$Mn precipitates](image)
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 $\alpha(T)$ and to better understand the influence of the different thermomechanical 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.

REFERENCES