

Dilatometric Study of Two based Aluminium Sheets

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Abstract

The aim of the present work is dilatometric study, within the range from room temperature to 550°C, of two aluminum based sheets containing some alloying elements in different proportions. The level of the Mn concentration in sheet 1 is higher than that in the sheet 2. But, the Fe concentration in the latter sheet is important compared to that of former one. The different proportions of alloying elements could be the origin of the remarkable difference in the thermal expansion behavior of the two studied sheets. It is important to note that both sheets are anisotropic. The thermal expansion coefficient measured along the perpendicular direction to the rolling plane of the sheet 1 containing a considerable amount of Mn, as a function of temperature, is 3.5 times less than that of the sheet 2 containing a considerable amount of Fe. The observed weak thermal expansion coefficient in the case of the sheet 1 is explained by the strengthening of the interatomic bonds and the interaction forces. The use of complementary techniques of investigations such as Transmission electron Microscopy (TEM), scanning electron microscopy (SEM) and energy dispersive (EDS) chemical analysis reveal the presence of thermally stable particles, especially, in sheet 1.

Keywords: Dilatometry; Calorimetry; Anisotropy; Dispersoids; Phases transitions

Introduction

Among the targets of the scientific community is to improve the understanding of the physical phenomena which present new products and especially those that underwent different stresses. This knowledge could help for getting new materials with very interesting dynamic and thermodynamic characteristics [1].

The introduction of alloying elements in aluminium could be the origin of significant changes in its physical and, especially, thermodynamic properties. The addition of Si and Mg to aluminium with suitable teneurs could significantly improve the mechanical properties of the obtained products [2-8]. AlMgSi alloys are widely used in the automotive industry due to the compromise between weight reduction and improved mechanical properties [2]. The Mg/Si ratio plays a predominant role on the precipitation sequence in these alloys. Although, these systems have been extensively studied, there are still some ambiguities which justify new approaches and detailed studies. Thus, several alloys were subjected to several research works published in different journals. However, the anisotropy detected, by dilatometry technique, along the three different directions of the studied sheets, was very little studied. Only few dilatometric studies have been conducted on aluminium sheets [9-11]. It has been showed that the thermal expansion coefficient changes as a function of temperature depends upon the direction along which the measure has been performed. The purpose of the present work is to understand deeply the behavior of the AlMgSi sheets in point of view dilatometric approaches along three directions.

Experimental Procedure

The chemical compositions of the studied two sheets are summarized in the following Table 1. We emphasize that both sheets contain the same alloying elements, except the level of some of them varies from one sheet to another. For example, the concentration of manganese in sheet 1 is higher than that in sheet 2. Also, the latter material contains more Mn than that of the former one.

The thickness of the studied sheets is about 1.35 mm. For dilatometric study, samples have been taken from each sheet as follow:

- Three samples have been taken along the direction parallel to the rolling direction (X direction);

- Three other specimens have been taken along the direction perpendicular to the rolling direction in rolling plane (Y direction);

- The last three specimens have been taken along the direction perpendicular to the rolling plane (Z direction).

The thermal expansion coefficient $\alpha(T)$ measurements were performed in the temperature range 20-550°C, using a dilatometer Netzsch 402C. The $\alpha(T)$ curves versus temperature were obtained with a precision of about $10^{-7} \text{ }^\circ\text{C}^{-1}$. Scanning electron microscopy (SEM) study has been carried out using a Philips 505 operating at 20 keV, equipped with an energy dispersive X-ray detector (EDS). Transmission electron microscopy (TEM) study has been carried out using a Philips EM 400T TEM operating at 120keV. Samples for TEM study were prepared by jet electropolishing technique using a Struers Tenupol Unit using a solution of nitric acid-methanol (1:3) at -30°C and a voltage of 15V.

Results and Discussions

Thermal expansion coefficients changes of samples of the sheet 1 versus temperature, measured along X, Y and Z directions, are shown in Figure 1.

It is important to note that the thermal expansion coefficient $\alpha(T)$ curves of the studied materials showed different dilatometric behavior depending upon the direction along which the analysed sample has

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Sheet	Si	Mg	Cu	Fe	Mn	Cr	Ni	Ti	V	Zn	Zr	Al
01	0.520	1.080	0.300	0.300	0.120	0.210	0.011	0.024	0.006	0.011	0.001	Balance
02	0.540	1.030	0.340	0.420	0.050	0.210	0.014	0.016	0.006	0.016	0.001	Balance

Table 1: Chemical compositions of the two studied sheets.

been taken. The shape of the thermal expansion coefficients curves of for samples taken along X and Y directions appear to be similar, as they present similar dilatometric anomalous which correspond to different reactions of the precipitation sequences of this alloy as reported in the literature [12-16] are as follows:



where α (SSS) is the supersaturated solid solution; GP zones are generally spherical clusters with unknown structure; β'' precipitates are fine needle shaped zones with monoclinic structure and are generally present in Al alloys aged to the maximum hardness; β' is rod shaped precipitates with hexagonal structure and are found in the over aged specimens. The β (Mg₂Si) is an equilibrium phase in the precipitation sequence.

The shift of the peak reaction, attributed to the GP zones formation, towards higher temperatures for the samples taken from X and Y directions is the unique remark that can be seen from the corresponding curves. For example, the difference in temperature between the two maxima seen in the curves of the samples corresponding to X and Y directions (Figure 1) is about 30°C. This difference in temperature between these two maxima could be related to the presence of a preferred orientation, as these materials have been cold and hot rolled during the fabrication process. Because, the presence of defects favour the formation of precipitates [10,11]. We note that the X direction coincides with the rolling direction. The peak corresponding to the GP zones formation for samples taken from Z direction is located in the same temperature range as those of the two others. It is important to note that the thermal expansion coefficient changes of the sample taken along Z direction is substantially lower than those corresponding to the samples corresponding to the two other directions. The height of its GP zones formation peak, is estimated to be less than half compared to those obtained from samples taken from X and Y directions.

Figure 2 shows that the thermal expansion coefficient curves, corresponding to samples taken from the three directions, appear to be similar. The different dilatometric anomalous are practically located in the same temperature range, whether measured along Z direction or along the two other directions. Moreover, the heights of the first peak corresponding to the zone GP formation of the thermal expansion coefficient (in the case of samples taken from X and Y directions), which appear to be equal. Whereas, the thermal expansion coefficient measured along Z direction, $\alpha_z(T)$, is significantly larger than those measured along X and Y directions, denoted $\alpha_x(T)$ and $\alpha_y(T)$, respectively. This suggests the presence of a strong anisotropy in this material along this direction. While, $\alpha_x(T)$ and $\alpha_y(T)$ are practically overlapped over the entire temperature range. This result is very important compared to those observed for the samples measured along X and Y directions. It is probably attributed to the presence of clusters of Mg or Si and/or the co-clusters of Mg and Si along this direction. The presence of dilatometric anisotropy in the two studied sheets is due to the rolling process, which is responsible for the creation of a high level of defects.

The next section is reserved to a comparative study of the thermal

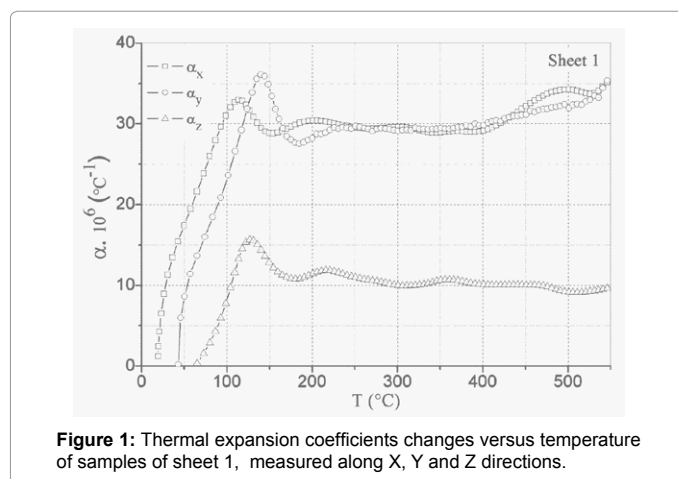


Figure 1: Thermal expansion coefficients changes versus temperature of samples of sheet 1, measured along X, Y and Z directions.

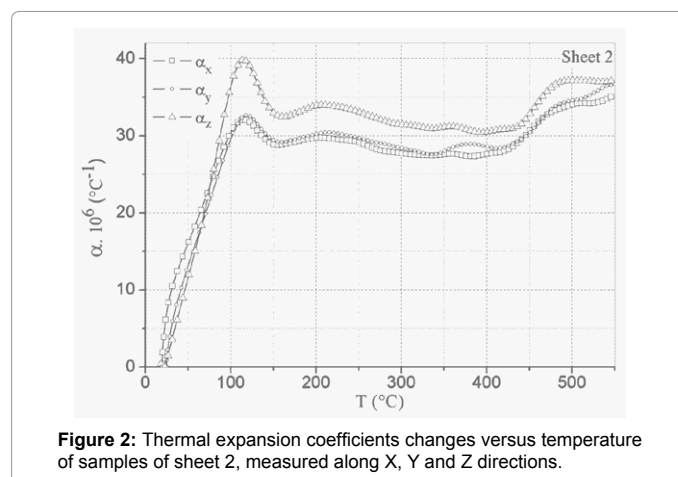


Figure 2: Thermal expansion coefficients changes versus temperature of samples of sheet 2, measured along X, Y and Z directions.

expansion coefficient changes of the two sheets measured along Z direction.

Dilatometric measurements of the two sheets along the direction perpendicular to the rolling plan (Z direction) showed that the thermal expansion coefficient of the sheet 1, $\alpha_{z1}(T)$, is less compared to that of the sheet 2, $\alpha_{z2}(T)$, over the entire temperature range. One can see a weak peak at around 40°C, in the case of $\alpha_{z1}(T)$ curve which does not appear in the case of the $\alpha_{z2}(T)$ curve. This is probably due to the easy formation of clusters of solute in sheet 1 compared to that in sheet 2 [17,18]. At 120°C, the height of the dilatometric peak for the case of sheet 2, is 4 times higher than that of the sheet 1. Beyond 200°C, $\alpha_{z1}(T)$ curve appears almost linear and does not exceed $10 \cdot 10^{-6} \text{C}^{-1}$. Whereas, the $\alpha_{z2}(T)$ curve, which is linear too, is clearly higher than $35 \cdot 10^{-6} \text{C}^{-1}$. The dilatometric peak located at around 500°C, in the case of sheet 1, is probably due to the coarsening and/or dissolution of the phase and other particles.

At 550°C, we can see that the ratio $[\alpha_{z2}(T)/\alpha_{z1}(T)]$ is about 4. The observed weak expansion along Z direction in the case of the sheet

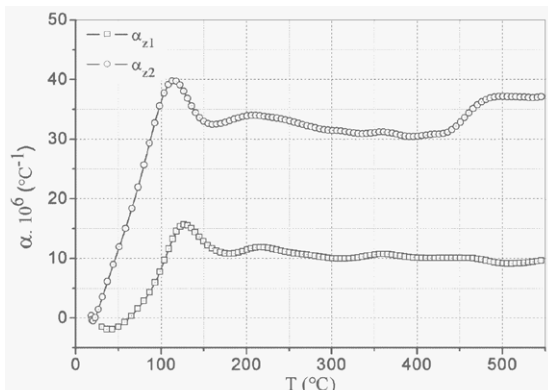


Figure 3: Thermal expansion coefficient changes, measured along Z direction, of the two sheets versus temperature.



Figure 4: A Typical SEM micrograph showing the distribution of particles present in the as received sheets.

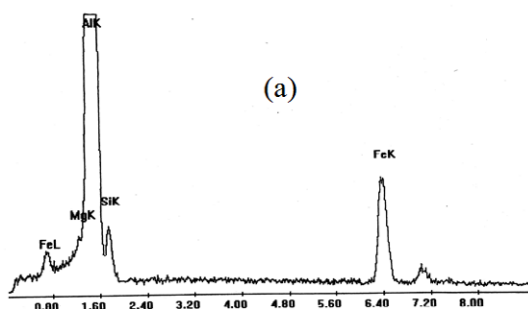


Figure 5a: EDS Spectrum obtained from particles seen by SEM in the as received sheets: Particles containing Fe and Si.

1 compared to that of the sheet 2 is attributed to different levels of transition elements present in the studied two sheets. The presence of the bearing located between 250-550°C in the case of $\alpha_{z1}(T)$ curve showed a good resistance to thermal shock of sheet 1 compared to sheet 2, (Figure 3).

SEM observations of both of the as received sheets revealed the presence of particles, (Figure 4). Chemical analysis using X-ray energy dispersive (EDS) of the particles observed by SEM microscope showed the presence of particles, containing Fe and Si, in sheet 2 (with 0.42wt.% Fe), (Figure 5a). While, sheet 1 (with 0.12wt.% Mn) contains a relatively low volume fraction of these particles. This mean of investigation reveals, also, the presence of particles containing Fe

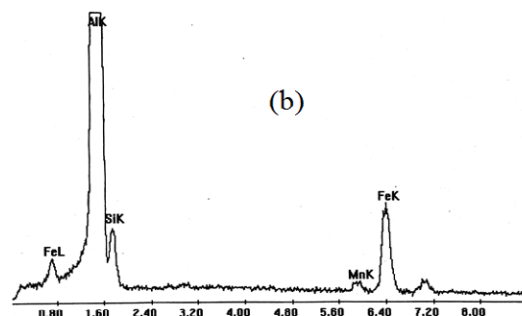


Figure 5b: EDS Spectrum obtained from particles seen by SEM in the as received sheets: Particles containing Fe, Mn and Si

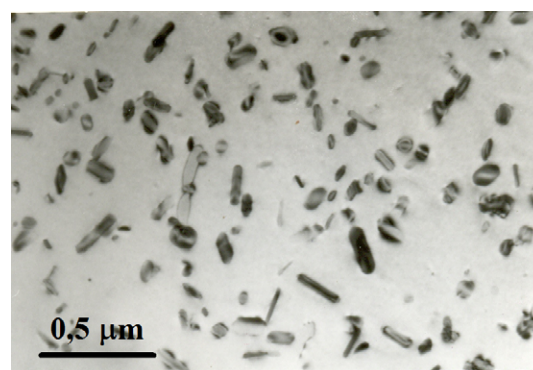


Figure 6: TEM Micrograph of the as received sheet 1 showing plate like particles containing Mn, Fe and Si with the other one that does not contain Mn.

and Mn in addition to Si, (Figure 5b). The particles containing Mn, Fe in addition to Si, appear to be stable at high temperatures and could improve the mechanical properties of the material.

Transmission electron microscope investigation of the as received sheets revealed the presence of plate like particles which contain Fe and Mn transition elements in addition to Si and another type of particles which does not contain Mn, (Figure 6). This result is consistent with that found by SEM technique and previous results reported by other workers [12,13,17]. Moreover, these authors added that the presence of particles, which contain Mn and Fe transition elements in addition to Si, improves the mechanical properties of the material compared to the non containing Fe particles.

Conclusion

The thermal expansion coefficients changes versus temperature showed that the sheet which contains a relatively high level of Manganese expands less compared to the other sheet containing a high level of iron. A detailed analysis of the dilatometric curves suggests that the sheet 1 is more anisotropic than the other sheet. The latter material expands considerably along the perpendicular direction to the rolling plane (Z direction) compared to the former. The study of both materials by SEM and TEM techniques revealed the presence of thermally stable precipitates in sheet 1. The presence of particles containing Mn, in addition to Fe and Si, justifies the good behavior of the corresponding material with temperature changes and also the improved mechanical properties of sheet 1 compared to that of sheet 2.

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