INFLUENCE OF THE THERMAL STRAIN ON THE DILATATIONAL CHARACTERISTICS OF Mg8Li AND Mg10Li ALLOYS

ALEXANDRA RUDAJEVOVÁ[1]*, VIERA GÄRTNEROVÁ[2], ALEŠ JÄGER[2], PAVEL LUKÁČ[2]

The temperature dependence of the relative elongation of Mg8Li and Mg10Li alloys was measured in the temperature range from 20 up to 380 ℃. The changes of the coefficient of thermal expansion, which was calculated from the temperature dependence of the relative elongation, were studied in dependence on the thermal cycles. The thermal strain in both Mg8Li and Mg10Li alloys leads to a drop of the thermal expansion coefficient in a certain temperature range. The influence of the thermal strain on the thermal expansion coefficient in Mg10Li was compared with this effect in Mg12Li-10 vol.% Saffil fibres composite.

Key words: MgLi alloys, thermal strain, thermal expansion

VLIV TEPELNÉ DEFORMACE NA DILATAČNÍ CHARAKTERISTIKY SLITIN Mg8Li A Mg10Li

Teplotní závislost relativního prodloužení slitin Mg8Li a Mg10Li byla měřena v teplotním intervalu 20 až 380 ℃. Koeficient teplotní délkové roztažnosti, který byl stanoven z naměřeného relativního prodloužení, byl sledován v závislosti na počtu několika teplotních cyklů. Tepelná deformace v obou slitinách byla příčinou poklesu koeficientu teplotní délkové roztažnosti v určité teplotní oblasti. Vliv tepelné deformace na koeficient teplotní délkové roztažnosti byl sledován také pro kompozit Mg12Li-10 obj.% safilových krátkých vláken, aby bylo možné porovnat chování tohoto kompozitu s dvoufázovou slitinou Mg10Li.

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[1] Department of Electronic Structures, Charles University, Ke Karlovu 5, 121 16 Prague 2, Czech Republic

[2] Department of Metal Physics, Charles University, Ke Karlovu 5, 121 16 Prague 2, Czech Republic

* corresponding author, e-mail: `rud@met.mff.cuni.cz`

1. Introduction

Mg-Li alloys are perspective alloys for preparation of the ultra light metal composites. Both thermal and mechanical properties of composites are influenced by the differences of the thermal properties of their components, above all by the thermal expansion and thermal conductivity. The internal stresses arising in composites can be important not only in the fabrication of composite but also in determining its subsequent behaviour. Thermal stresses in composite materials may influence the stresses necessary for deformation of the composites [1]. Thermal stresses in composites may cause plastic deformation at the interface between both components in a certain temperature range. This plastic deformation influences the thermal properties of composite materials [2].

It can be seen from the equilibrium diagram that magnesium-lithium alloys exhibit two-phase structures, the α (hcp) up to 5 wt.% Li and β (bcc) above 11 wt.% Li. Both phase structures can be found in alloys between 5 and 11 wt.% Li. The Li content in these alloys changes their thermal properties appreciably. The thermal properties of Mg4Li, Mg8Li and Mg12Li alloys have been published in [3]. The thermal conductivity decreased with an increase in content of Li from 58.7 W/m·K in Mg4Li to 48.1 W/m·K in Mg12Li. The coefficient of the thermal expansion (CTE) at room temperature increased with an increase in Li content (26.5 K^{-1} for Mg4Li, 31.0 K^{-1} for Mg8Li and 37.0 K^{-1} Mg12Li).

In composite materials where the $\mathrm{CTE_S}$ of the components are different, thermal stresses occur at the interface. For an increase in temperature of ΔT, the thermo-elastic stress P is given by [4]:

$$P = -\frac{2(\alpha_2 - \alpha_1)\Delta T E_1 E_2}{2E_2V_2(1-2\nu_1) + 2E_1V_1(1-2\nu_2) + E_1(1+\nu_2)}, \tag{1}$$

where α is the CTE, E is the Young's modulus, ν is Poisson's ratio and V is the volume fraction of the given phase. It was shown in our previous works [5, 6] that these stresses and strains may be released by elastic and plastic mechanisms. The relation (1) was derived for elastic case only.

It has been reported [3] that while the temperature dependence of the CTE for Mg4Li and Mg12Li alloy has a linear character, the CTE of Mg8Li alloy firstly increases with increasing temperature up to 180 ℃, then decreases up to 280 ℃ and increases again. Nonlinear character of this dependence is the consequence of the thermal and residual strain in this alloy. The aim of this work is to investigate both residual and thermal strain changes in Mg8Li and Mg10Li alloys during thermal cycling in order to extend our knowledge of this problem. The results will be compared with the residual and thermal strain in Mg12Li-10 vol.% Saffil fibre composite.

2. Experimental part

Samples of Mg8Li and Mg10Li alloys and Mg12Li-10 vol.% Saffil fibres composites were prepared in the Institute of Materials and Machine Mechanics of the Slovak Academy of Sciences in Bratislava.

The linear thermal expansion of the samples was measured in the argon atmosphere using the Netzsch 402E dilatometer in the temperature range from room temperature to 380 °C at heating and cooling rates of 5 K/min. The thermal expansion samples were 6 mm in diameter and 50 mm in length. The accuracy of the apparatus was determined by comparing measured values of the CTE of pure Mg with those published in literature. The measured values of the CTE are the same as those reported in literature. The thermal expansion curves for alloys and composite were acquired during, at least, three thermal (heating and cooling) cycles (runs). All the materials were studied in the as-cast state. In Mg12Li-10 vol.% Saffil fibres composite the planes of planar randomly distributed short fibres were parallel to the sample axis.

3. Results

Figure 1 shows the temperature dependence of the CTE of Mg4Li, Mg8Li, Mg10Li and Mg12Li alloys for the heating in the first thermal cycle. The alloys composed from only one phase exhibit a linear character of the temperature dependence of the CTE. The two phases alloys Mg8Li and Mg10Li show the drop in the CTE in the temperature range from 180 to 260 °C. The microstructure of

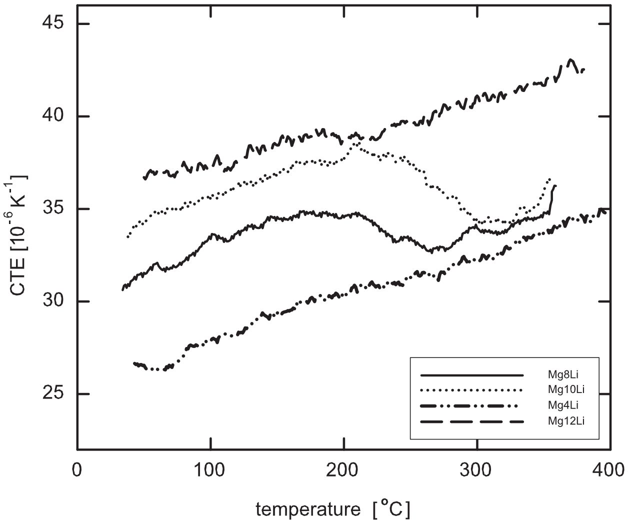

Fig. 1. Temperature dependence of the CTE for the MgLi alloys.

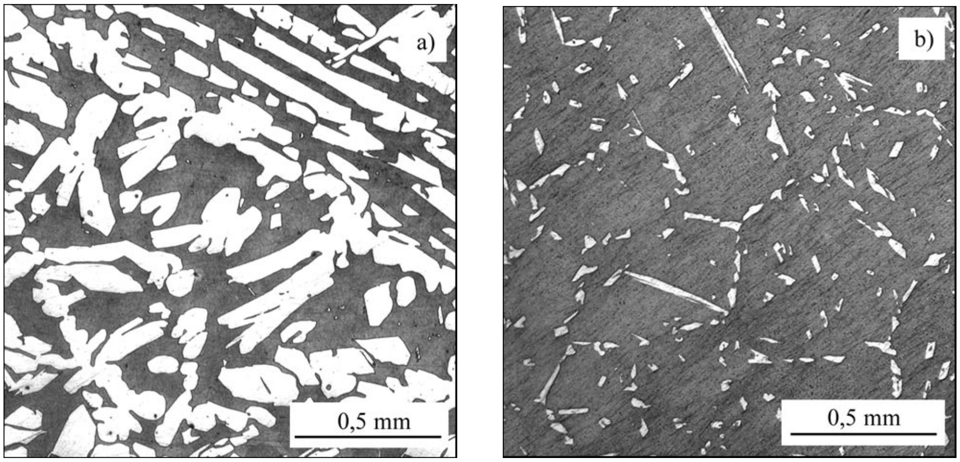

Fig. 2. Microstructure of the Mg8Li (a) and Mg10Li (b) alloys.

both alloys is shown in Fig. 2. Figure 3 shows the temperature dependence of the relative elongation of Mg8Li alloy in the first thermal cycle (the second thermal cycle has nearly the same course) and for Mg10Li alloy in two thermal cycles. While no persistent changes in the sample length were found after the first thermal cycle in Mg8Li alloy, the persistent reduction sample length was perceptible for Mg10Li alloy. After the second thermal cycle the sample length increased in this alloy. The persistent changes in the sample length are presented in Table 1.

Table 1. The persistent changes of the sample length after the thermal cycles in Mg10Li alloy

Cycle number	1	2	3	4
Change of the sample length [μm]	−20	17	23	20

Figure 4 shows the temperature dependence of the CTE of Mg10Li alloy for three different thermal cycles. While the linear part of the temperature dependence of the CTE was found only up to 150 ℃ in the first thermal cycle, in the following thermal cycles this temperature limit was 200 ℃. It can be seen from Fig. 4 that the CTE is different even for the second and third thermal cycle. For Mg8Li alloy the dilatational characteristics were not also quite the same for the individual thermal cycles, but the differences were small.

As mentioned above, the Mg10Li is a mixture of α and β phases. Using the values of density for α and β phases [7] and the density value measured for Mg10Li, one may consider that the Mg10Li alloy is a composite, in which 10 vol.% of α phase is inserted to β phase matrix. The Mg12Li alloy as β phase was reinforced with

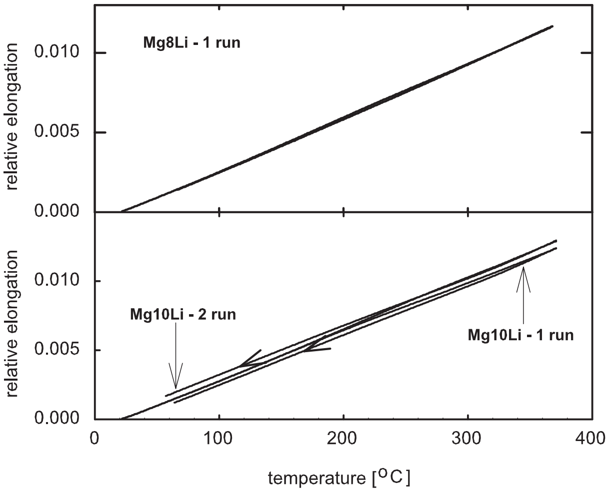

Fig. 3. Relative elongation for Mg8Li and Mg10Li alloys.

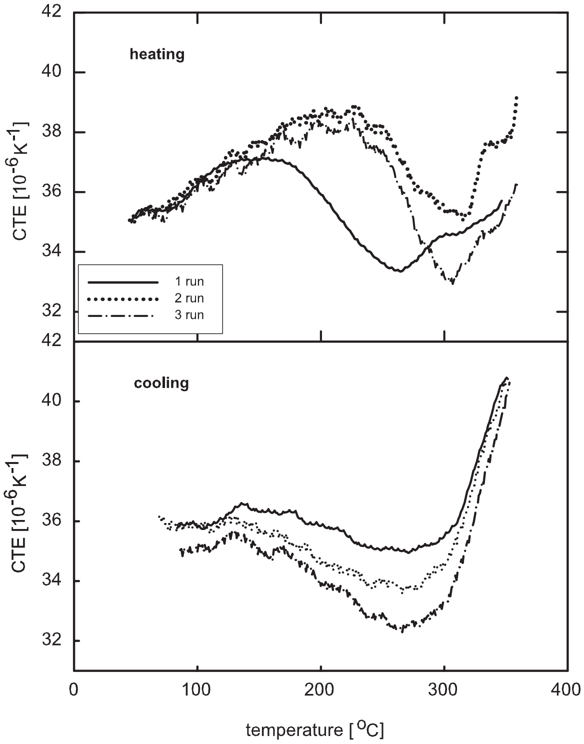

Fig. 4. Temperature dependence of the CTE for three thermal cycles of Mg10Li alloy.

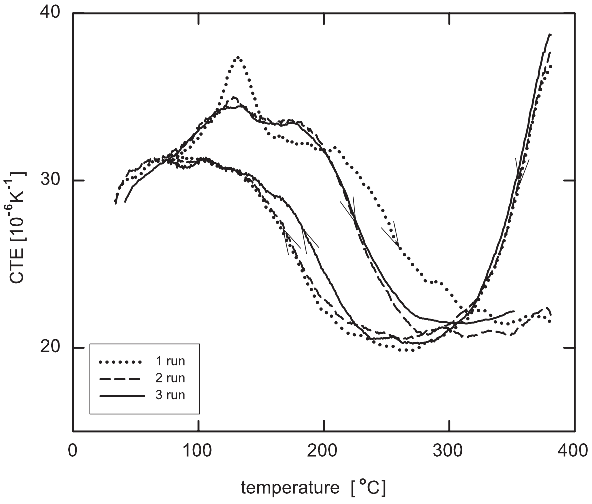

Fig. 5. Temperature dependence of the CTE for Mg12Li-10 vol.% Saffil fibres composite.

10 vol.% of short Saffil fibres. The temperature dependence of the CTE of this composite is presented in Fig. 5.

4. Discussion

The Mg8Li and Mg10Li alloys are a mixture of α and β phases. There is a great difference between the CTEs of both phases. If these alloys are cooled from the manufacturing temperature to room temeperature, the individual phases tend to contract unequally, setting up complex internal stresses (tensile character in the high expansion phase and compressive in the low expansion phase) in each crystallite of the alloy. These stresses are connected with strains which are the largest at room temperature. During heating of the sample the stresses, and with them connected strains, decrease to reach the stress free state at a high temperature (usually 0.8 T_{m} – melting point). The thermal strain is additive with the strain due to lattice thermal vibrations. It means that the total deformation of a composite material, measured by dilatometer, is lower than that when the lattice thermal vibrations would be the only source of the strain.

During heating the thermal stress (strain) at the interface between both phases decreases. At a certain temperature [6] it may reach the yield stress and therefore plastic deformation occurs near the interface. In two phases materials, plastic deformation occurs firstly in the phase with a lower value of the plasticity limit. The values of $\sigma_{0.2} = 5$ MPa at 200 °C for Mg12Li alloy and $\sigma_{0.2} = 30$ MPa for Mg4Li alloy have been reported [8]. In the temperature range where plastic deformation occurs, the thermal strain decreases with increasing temperature more rapidly than in the temperature range before reaching the yield stress. It is supposed that plastic deformation induces the sources of the internal stresses, which modify the elastic field in the given phase. The experimental consequence of this process is a deviation of the temperature dependence of the CTE from the linear course.

Figure 3 shows the changes of the relative elongation with temperature for Mg8Li and Mg10Li alloys. While no persistent changes of the sample length were found in the first run in Mg8Li alloy, negative (only in the first thermal cycle) and positive changes were found for Mg10Li alloy in each thermal cycle studied (seven cycles). In our previous works, dealing with MMC, we called the persistent change length in samples – residual strain. The residual strain depends on the thermal and mechanical history of the material; it is the highest at room temperature and it decreases with increasing temperature. For the composites, we assumed that the thermal residual strain is a consequence of the non-equilibrium cooling during manufacturing or the thermal treatment of the composite material. Mg10Li alloy shows non-stability of the dilatational characteristics as it can be seen from Fig. 4 and Table 1. We assume that the residual strain (persistent changes of the sample length) is connected with plastic deformation in β phase.

In Fig. 5 the temperature dependence of the CTE for Mg12Li-10 vol.% Saffil fibres is shown. We would like to compare the dilatational characteristics of the Mg10Li alloy with Mg12Li-10 vol.% Saffil composite because one may consider both materials as composites with the same matrix but with various kinds of the "reinforcement". The dilatational characteristics Mg12Li alloy reinforced with 10 vol.% Saffil fibres exhibits far higher stability than the mixture of α and β phases even when the phase transition (peak at about 130 °C) [9] occurs in the interface between Saffil fibres and matrix. Using the Eq. (1) for the calculation of the decrease of the thermo-elastic stress at the interface for both composites, then we obtain the 21 MPa for Mg10Li alloy and 86 MPa for Saffil composite for the increase in temperature of 50 °C. In the calculation, we used the same modulus 44 GPa for both α and β phases and 300 GPa for Saffil fibres (these values were obtained only for the temperature range where no plastic deformation occurs). As it can be seen from Figs. 4 and 5, the main drop of the CTE connected with the decrease in the thermal stresses occurs in the range where plastic deformation arose. The decrease in the CTE of Mg12Li-10 vol.% Saffil fibre composite in this range is three times higher than that in the mixture alloy Mg10Li.

5. Conclusions

1. The difference of the CTE in single phase alloys Mg4Li and Mg12Li (α and β phase) induces the thermal stresses at the interface in the mixture alloys (Mg8Li and Mg10Li) composed from these phases. The thermal stresses at the interface may cause deformation of the mixture alloys. The consequence is the drop in the CTE of the alloys. CTE drop in Mg10Li alloy is higher than that in Mg8Li. It is due to the fact that volumetric ratio β to α phase in Mg10Li alloy is higher (9 : 1) than in Mg8Li (1 : 1).

2. The residual strain, i.e. the persistent changes of the sample length after the thermal cycle, was found in Mg10Li alloy after each thermal cycle. No persistent deformation was found in the first thermal cycle in Mg8Li alloy.

3. The thermal strain in Mg12Li-10 vol.% Saffil fibres composite causes higher drop in the temperature dependence of the CTE than in the mixture alloys. The main drop in the CTE during heating in the thermal cycling in the composite as well as in the mixture alloys occurs in the temperature range where plastic strain in β phase is going on.

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