THERMAL EXPANSION OF Al- AND Mg-MATRIX COMPOSITES

Degischer H.P., Lasagni F., Schöbel M., Huber T.*, Aly M.A. **
[Degischer]: hpdegi@pop.tuwien.ac.at
Vienna University of Technology/Austria,
***-currently Siemens VAI/Austria, ** currently Assiut University/Egypt**

Keywords: *MMC, dilatometry, residual stresses, synchrotron diffraction, computed tomography*

1 Introduction

Metal matrix composites (MMC) have been developed to improve the mass related mechanical properties with respect to the matrix metal by embedding ceramic reinforcements [1]. High thermal conductivity and low thermal expansion are the main requirements for thermal management [2] for components in electronics and combustion engines [3]. Ceramic reinforcements reduce the thermal expansion of the MMC, but introduce internal stresses due to the mismatch in the coefficients of thermal expansion (CTE). The CTE of MMC can be estimated by thermo-elastic models [4] on the basis of the elastic constants and the CTE of the constituents. Those predictions fail as soon as the matrix plastifies when thermally induced stresses exceed its yield strength or induce creep. Deviations from the thermo-elastic behavior are detected by dilatometry of particle and fiber reinforced Al and Mg matrices.

2 Experiments

Different architectures of reinforcements in pure Al and Mg, and in some alloys have been selected as listed in Table 1: Al-matrices with different volume fractions of particle reinforcement (p); Al_2O_3-Saffil™ performs with 20vol% short fibers (s) distributed randomly planar and infiltrated mechanically by squeeze casting; continuous Al_2O_3- or C-fiber bundles (f) wound on a mandrel yield unidirectionally (UD) reinforced MMC (CFRM) by gas pressure infiltration. One CFRM contains stapled layers of woven textiles with equal amounts of fibers in 0/90° directions. The Si content of the Al-matrix is considered as an additional constituent [5].

Dilatometry was applied to measure the length change of samples of about 4x 4x 10-17 mm³ during heating and cooling at 3 K/min either from RT or from –50°C to temperatures between 120 and 520°C usually in consecutive cycles. The derivatives of the relative length change with respect to temperature yield the instantaneous, linear coefficient of thermal expansion CTE(T) [6,7].

Table 1. Metal matrix composites investigated

MMC type	Designation: matrix/reinforcement/vol% letter of type	Processing [1]
Particle Reinforced PRM	AlMg1SiCu/Al_2O_3/22p	Stir cast, extruded
	AlSi10Mg/SiC/10-20p	Stir cast, gravity cast
	AlSi7Mg/SiC/55-70p	Gas pressure infiltrated preforms
	AlSi7Mg/R-SiC/85	
	Al99.5/SiC/70p	
Short Fiber Reinforced SFRM	AlSi1.1/Al_2O_3/20s	Saffil™ fiber preforms Infiltrated by squeeze casting
	AlSi7/Al_2O_3/20s	
	AlSi12/Al_2O_3/20s	
	AlSi18/Al_2O_3/20s	
Continuous Fiber Reinforced CFRM	Al99.8/C-M40/70f-UD	Gas pressure infiltrated wound preforms, Stapled fiber weaves
	AlMg1/Al2O3-N610/65f-UD	
	Mg99.8/C-HTA5331/60f-UD	
	MgAlo.6/C-M40/70f-UD	
	MgAlo.2/C-T300/50f-0/90°woven 50:50	

Synchrotron radiation at ESRF/France was applied to yield the temperature dependence of the internal stresses during heating/cooling cycles. Computed tomography was performed at selected conditions of some MMC samples.

3 Results

The PRM, where the particles are mostly surrounded by the matrix (<55 vol% in our case), behave essentially like “diluted” MMC yielding a CTE(T) which can be derived from the properties of the constituents by thermo-elastic models [4]. Some anomalies have been detected which are caused by the Si-content, the solubility of which changes with temperature and thus its atomic volume [5,6].

Densely packed powder preforms as in Al-SiC heat sinks exhibit during each heating from RT a decrease of the CTE(T) between 200 and 400°C as

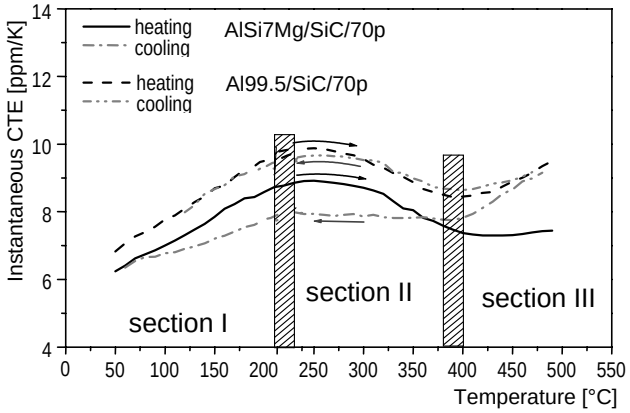

Fig. 1. CTE(T) during thermal cycling of 2 Al-SiC samples: section I elastic, in section II changes the porosity volume, section III partially elastic.

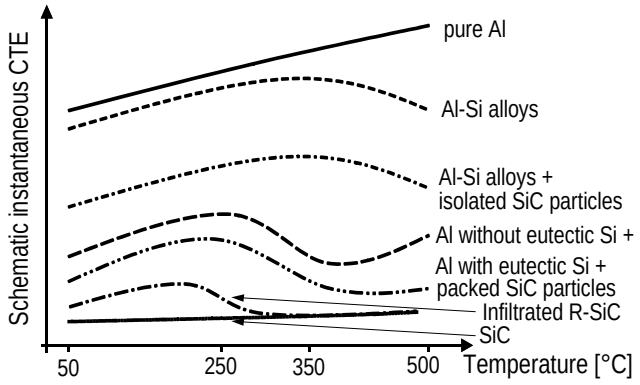

Fig. 2. Schematic comparison of CTE(T) of Al, Al-Si matrix, different Al-SiC versions and SiC.

shown in section II in Fig.1. A more or less reverse effect is observed during cooling. Synchrotron tomography at RT revealed a void content of 0.14 vol% in as delivered samples. The voids of a few µm in diameter shrink during heating yielding at 400°C a fifth of the porosity at RT. The correlated evolution of compressive stresses in the matrix during heating explains the filling of voids by creep, which open again during cooling [6]. Fig.2 compares CTE(T) for Al-PRM, where the CTE(T)-curves depend on the volume fraction of the reinforcement, its architecture and on the Si-content of the matrix.

Similar studies on SFRM reveal the anisotropy of the CTE. Above 350°C, the CTE(T) in the fiber plane approaches that of the reinforcing alumina. Simultaneously, the conservation of volume causes a significant increase of the transverse CTE, which becomes higher than that of the matrix. The rigidity of the percolating reinforcement increases, when the eutectic Si-bridges between the fibers are coarsened by thermal treatments, which reduces the CTE [5].

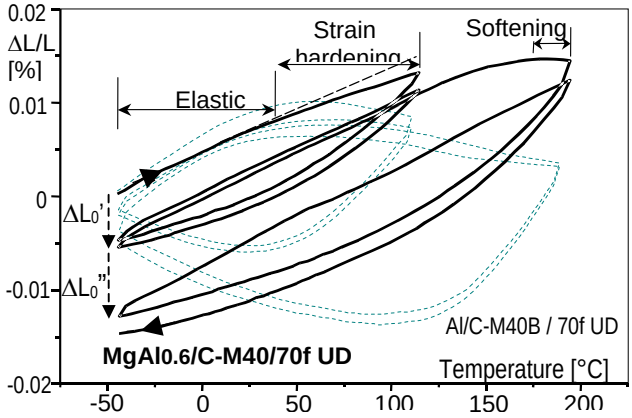

Fig. 3 Thermally induced straining of continuous C-fiber reinforced Al-and Mg-matrices during cycling twice between –50°C and 120°C, then twice up to 200°C. ΔL_0',," indicates the macroscopic shrinkage of the sample after changing T_{max}.

UD and planar orientations of continuous fibers cause a more pronounced anisotropy than that of SFRM. The dimensional changes in the fiber direction are limited by the elastic deformation of the fibers. Fig.3 shows the hysteresis of UD C-fiber reinforced Mg and Al during thermal cycling in the dilatometer. The elastic region of the Mg-matrix extends from -50°C to about 120°C, whereas that of the Al-matrix only up to RT. The CTE(T) curves in fiber direction vary between values according to the thermo-elastic models and those for ideal plasticity of the matrix, where the CTE of the MMC becomes that of the fibers in longitudinal direction [7,8].

4 Conclusions

Dilatometry is a sensitive tool to reveal the transition from thermo-elastic to thermo-plastic or viscous matrix deformation during thermal cycling as well as porosity changes in MMC with interconnected reinforcements. The rigidity of the reinforcement and its anisotropy can be determined.

References

[1] Clyne T.W. *"Metal matrix composites"*, Comprehensive composite materials, ed.by Kelly A. and Zweben C., vol.3, Elsevier, Oxford 2000.
[2] Evans A., San Marchi C., Mortensen A. *"MMC in Industry"*, Kluwer Acad.Publ., Dordrecht 2003.
[3] Zweben C, J.Metal, 44, pp.15-23, 1992.
[4] Balch D.K., et al., Met.Mat.Trans., pp.3700, 1996.
[5] Lasagni F., et al., Kovove Mater, 44, pp 65-73, 2006.
[6] Huber T., et al., Comp.Sci.Techn.., pp2206, 2006.
[7] Aly M., PhD thesis, Vienna Univ. of Technol., 2004.
[8] Böhm H.J., et al., Comp.Eng., 5, pp37-49, 1995.