Report on: Void kinetics in diamond reinforced aluminium MMC during thermal cycling

The following Al-based metal matrix composites (MMCs) were investigated during IN607:

- Al/CD/60p (particle reinforced) monomodal diamond particles ~25µm size as cast
- Al/CD/60p (particle reinforced) monomodal diamond particles~25µm size heat treated (640°C/5h)

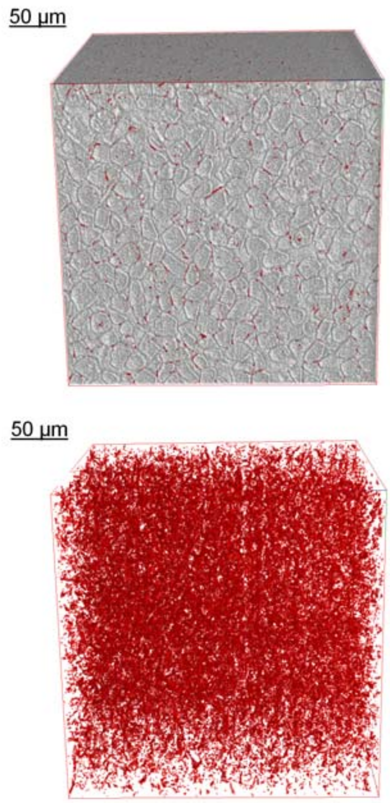
The experiments carried out are divided in:

1) Thermal cycling tests: High resolution tomography images were made during thermal cycling. The MMC was cycled two times up to soldering temperature (350°C). Changes in void volume fraction show the thermal expansion behaviour of the matrix between the particles. Two cyles were made to show the LCF behaviour in the second cycle. Debonding and damage in the matrix will be visualized. Images with absorption contrast at $(0.7µm)^3$voxel were made. Short exposal times are necessary to achieve in situ results of the behaviour in the ductile Al matrix at high temperatures.
2) Quenching experiments: High resolution tomography at $(0.3µm)^3$ was made at room temperature after quenching from 350° (the worst case scenario) to show delamination at the interfaces. Debonding caused by matrix shrinkage will be shown.

Current results

The tomography experiments were done to analyze the void volume fractions during thermal cycling. Voids are formed during cooling after infiltration of the Al/CD/60p MMC. A 3D image of the Al/CD/60p is shown in Figure 1. The voids in the Al matrix between the diamonds could be separated from the volume. An initial volume fraction of 0.7vol% could be identified in the MMC. These infiltration voids and shrinkage pores are arranged at the interfaces between the particles and the matrix. In situ evaluation of the volume fractions at different temperatures show the void kinetics during cycling. These experiments were made comparable to earlier ID15A investigations on an Al/SiC/70p MMC (MA57). The results show the differences in reinforcement architectures of these two comparable systems and their effects on the thermal fatigue behaviour. High resolution microtomography at ID19 enabled the identification of debonding at the interfaces.

Figure 1:

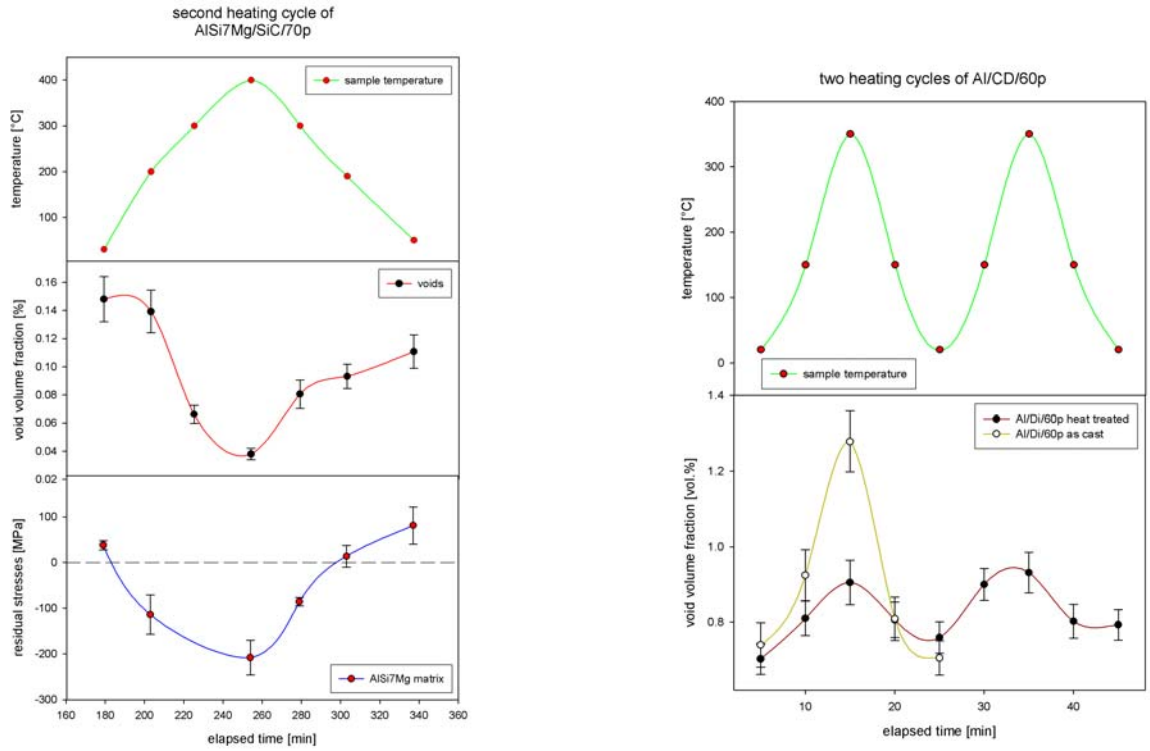


A Al/CD/60p cube with $(200x200x200)µm^3$ with a particle size of ~25µm. The voids are segmented in the volume (red).

In the AlCD system the void volume fraction increases during heating as shown in Fig.2. For the heat treated AlCD MMC a lower increase can be observed which results from better bonding quality achieved by carbide formation at the interfaces. The void kinetics show an inverse behaviour compared to the AlSiC system (Fig.2). A high amount of residual stresses during cycling in AlSiC induce diffusion in the matrix by plastic deformation. During heating compressive stresses close the voids and tensile stresses during cooling reopen these voids again. This behaviour can be explained by a connected network of SiC particles with Si bridges embedding the AlSi7Mg matrix. The inverse behaviour of AlCD is caused by a different internal architecture of isolated particles in an Al matrix. These two types of reinforcement structures influence the thermal fatigue behaviour of these MMC under application conditions fundamentally. In the AlSiC debonding can be expected during cooling by shrinkage of the matrix. In the AlCD system debonding during heating and cooling can be expected. The regenerating compression stresses in the AlSiC cannot be expected in the AlCD system.

The quenching experiments show debonding at the interfaces between the particles and the matrix. High resolution tomography was done on an as cast and a heat treated AlCD MMC after quenching from 350°C to RT. The absorbtion contrast images show voids caused by debonding at the interfaces (Fig.3). In the as cast structure the particles are almost completely debonded from the matrix. Voids are arranged over big regions at the interfaces. In the heat treated material (640°C / 5h) the interface quality is better and a lower volume content is produced after quenching (as shown in Fig.3). The effects of carbide formation on the bonding quality could be visualized in the 3D projections of the voids.

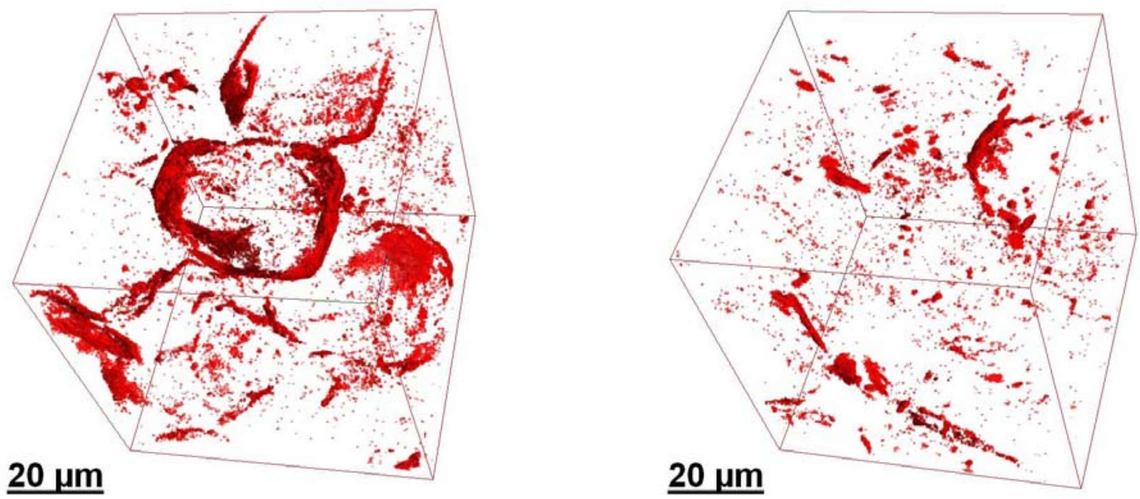
Figure 2:



On the left the void volume fraction and he residual stresses in the AlSi7Mg matrix of an AlSiC MMC during one heating cycle is shown. On the riht the void kinetics in an AlCD MMC behave inverse compared to AlSiC during thermal cycling. The void volume increase during heating is stronger for the as cast AlCD MMC caused by weaker bonding at the interfaces.

The influence of Si bridges on the internal architecture of particle reinforced composites has to be studied. In situ residual stress measurements as well as tomography has to be done on diamond reinforced composites with varying Si content in the Al matrix. First neutron experiments have been done on AlCD MMC with different Si content show promising results. High resolution tomography as well as neutron diffraction are planned to investigate the void kinetics in SiC and CD reinforced AlSi matrix composites.

Figure 3:



A as cast AlCD cube with a size of (60x60x60)µm³ on the left and a heat treated (640°C/5h) cube with the same size on the right. The voids at the interfaces (red) are formed after quenching from 350°C to RT.