Report on: Thermal cycling creep behaviour of Al-based reinforced metal matrix composites (MA277)

The following Al-based metal matrix composites (MMCs) were investigated during MA277:

- AlSi12CuMgNi/Al2O3/15s (short fibre reinforced MMC)
- AlSi12/Al2O3/20s (short fibre reinforced MMC)
- 6061/Al2O3/22p (particle reinforced MMC)
- Al99.85/C40MB/65f (continuously reinforced MMC)

The experiments carried out are divided in:

1) Quenching tests: the MMCs were heated up to T_q = 150, 180, 210, 230, 250 and 300°C (one sample per temperature) and held at these temperatures for at least 30min in order to obtain a fully relaxed condition at T_q and then quenched in water. Energy dispersive diffraction was then carried out at RT for every sample. The objective of these experiments was to find the temperature gradient ΔT for which the mismatch between the coefficient of thermal expansion (CTE) of the components of the composites will result in plastification of the matrix.
2) Thermal cycling tests: Energy dispersive diffraction and microtomography were carried out in-situ during thermal cycling for temperatures profiles between RT and 300°C.

Current results

The tomographic study of the continuously reinforced MMC Al99.85/C40MB/65f has been completed at the date. A new method was developed to three dimensionally characterize the microstructure of this composite regarding its reinforcement local distribution and the orientation distribution of the reinforcement [1]. This methodology is not only valid for this specific material but for tomographic reconstructions of all types of continuously reinforced MMCs even if the individual fibres are not fully resolved (see Fig. 1).

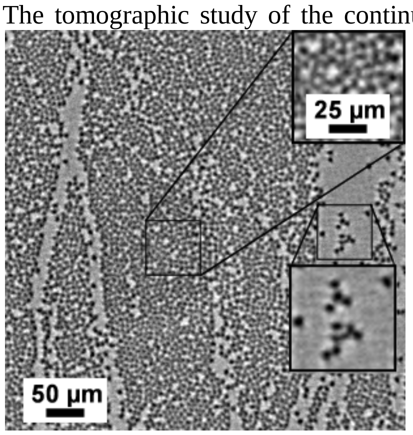

Fig. 1. Portion of a reconstructed µCT slice of the carbon reinforced MMC using a resolution of (1.6 µm)³ (306x306 pixels ~ 490x490 µm²) looking onto the plane perpendicular to the fibres. The lower insert shows individual fibres reflecting their actual diameter (~ 7 µm). The upper insert shows neighbouring fibres with apparent diameters smaller than their actual diameter due to the phase contrast effect.

The variation of the reinforcement LVF is therefore studied using geometric representative area elements (RAEs). The so-called two-point probability function [2] was used to determine the size of the RAE for each composite.

Fig. 2 a) shows the probability of finding REAs with a certain reinforcement volume fraction in regions of 350x550 pixels (~ 0.4 mm²) for 400 slices. The mean reinforcement volume fraction obtained from this distribution is 44.5 vol%, which is in agreement with the value obtained from the grey-value segmentation (44.3 vol%). The distribution has a Gaussian shape with a tail extending to volume fractions down to around 10 vol% where the distribution-function increases again. This increase reflects the presence of matrix channels (fibre-free regions) between the C-fibres bundles. These channels can be observed in the slice shown in Fig. 2 b) where the REAs (white squares) with volume fractions smaller than 10 vol% are shown. The continuity of fibre-free channels along the z-axis (perpendicular to the plane of the figure in Fig. 2 b) was analyzed taking a minimum size of 4 connected facets. The results are shown in Fig. 3 for facet's volume fractions smaller than 20 vol%. The relatively large fibre-free channel shown in Fig. 2 b) is clearly seen and goes through the whole length of the investigated volume. There are some other fibre-free regions with considerable lengths but they are not continuous through the whole volume.

The orientation of the carbon fibres within the composite was also investigated and the results are shown for one slice in Fig. 4. The inhomogeneities in the orientation of the fibres can be visualized in this orientation maps. The fibre-free channels are easily recognisable due to the absence of arrows in these regions (compare with Fig. 2 b). These channels, which in fact separate different fibre bundles, show that the individual bundles have different ϕ orientations but similar variations of θ.

The calculation methods developed in this work will allow to characterize the reinforcement distribution within continuous fibre reinforced materials and thus correlate the results with quality criteria adopted in the stage of development of the materials.

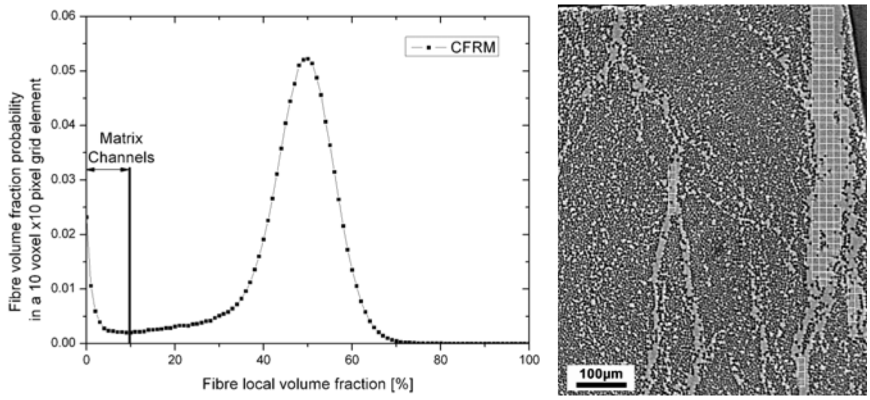

Fig. 2. a) Probability of finding REAs with a certain reinforcement volume. The peak at 0 vol% reflects the presence of matrix channels (fibre-free regions) between the C-fibres bundles. b) Fibre-free channels. The REAs (white squares) with volume fractions smaller than 10 vol% are shown.

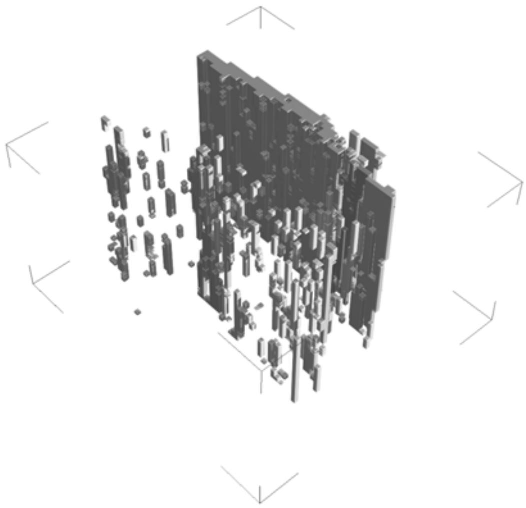

Fig. 3. Continuity of fibre-free channels with a reinforcement volume fraction < 20 vol% in the continuous fibre reinforced MMC along the z-axis for a region of 350x550x400 voxels (~ 0.3 mm³) taking a minimum of 4 connected facets.

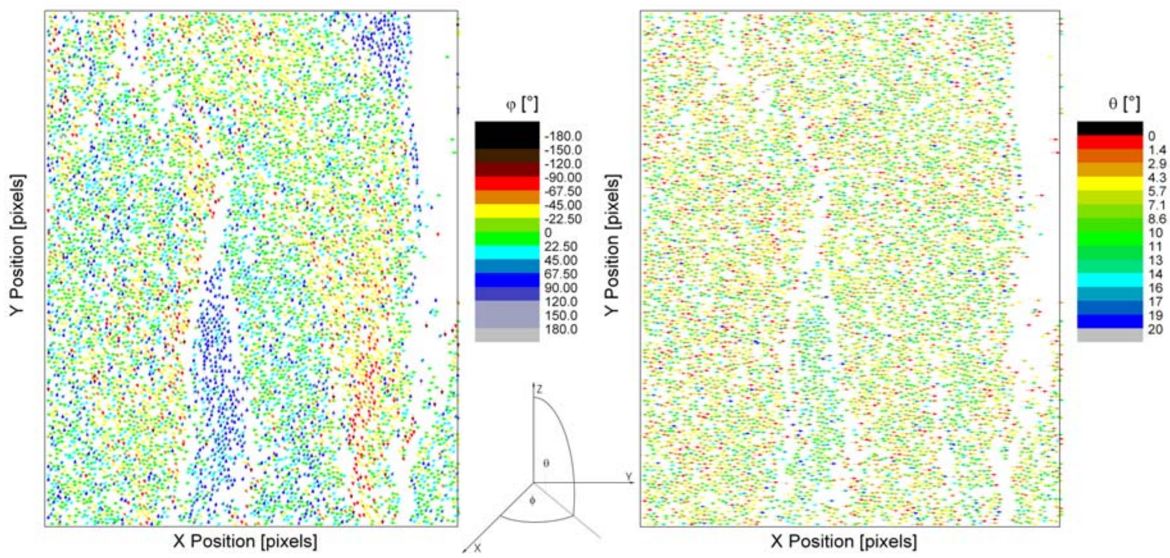

Fig. 4. Orientation of the individual fibres within one layer for a region of 350x550 pixels for the CFRM: a) ϕ and b) θ. The fibre-free channels are easily recognisable due to the absence of arrows in these regions (compare with Fig. 2 b).

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[1] Requena G., Fiedler G., Seiser B., Degischer P., Di Michiel M., Buslaps T., submitted to Composites A.
[2] Torquato S. Random Heterogeneous Materials. New York: Springer Science & Business Media, 2002.