Fibre reinforced AlSi12CuMgNi alloy under compression

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Kurzfassung

Typically, the near-eutectic Al-Si alloys consist of highly interconnected three-dimensional network of the eutectic Silicon (Si) and intermetallics embedded into Aluminium (Al) matrix. For further improvement of the mechanical properties of such alloys, often, one single ceramic reinforcement phase, e.g. silicon carbide (SiC) or aluminium oxide (Al_2O_3) in the form of fibres or particles is added. However, hybrid reinforcements (fibres and particles) can further improve wear resistance and fracture toughness, and additionally, reduce anisotropy of the material. The engineering of metal matrix composites (MMC) for specific application requirements benefits from a comprehensive knowledge of the failure behaviour. Therefore, damage evolution under compression was investigated on:

- pure near-eutectic AlSi12CuMgNi matrix alloy
- type I: matrix reinforced with random-planar oriented Al_2O_3 short fibres (15 vol.%)
- type II: matrix reinforced with random-planar oriented Al_2O_3 short fibres (7 vol.%) and additional SiC particles (15 vol.%)

The analysis of damage mechanism was carried out in two rather independent but complementary studies. First, selected sister samples of every material were exposed to quasi-static compression (traverse control). The compression tests were interrupted at different strain levels. Miniature cylinders with a diameter of 1mm were extracted from the pre-strained samples and investigated by synchrotron computed tomography (SX-µCT) with a spatial resolution of about 0.7 µm. For the pure matrix alloy, microcracks are confined to the intermetallic particles and to the eutectic Si, hence no damage was observed in the Aluminium. The composite type II revealed a more effective strain accumulation (less damage) than type I at low plastic strain (up to 5 %), but a more catastrophic damage development due to cracking of the SiC clusters at higher strain levels.

The second approach to study the damage initiation and accumulation in the materials subjected to compressive load was Acoustic Emission (AE) analysis. In this case the in-situ monitoring of the acoustic emission signal was performed during compression tests on specimens with dimension of several mm. For all three material types, AE activity set at 2% strain. Differences in AE behaviour of the three materials was proven based on AE hitrate, signal peak amplitudes as well as weighted peak frequencies (WPF). Future work focuses on combination of AE and SX-µCT aiming for more detailed knowledge on damage mechanism of metal matrix composites.

Sicherheit in Technik und Chemie

BAM
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ACOUSTIC EMISSION OF FIBRE REINFORCED AlSi12CuMgNi ALLOY UNDER COMPRESSION

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1

Introduction

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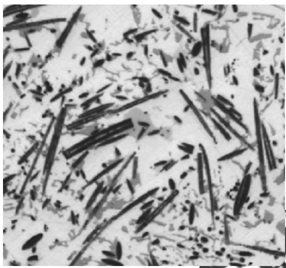
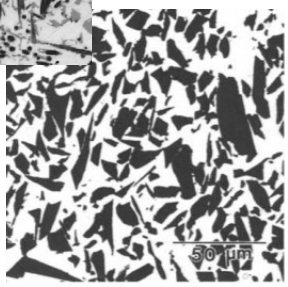
Metal matrix composites (MMCs):
- Light weight material Al-Si alloys
- High temperature strength by Ni, Cu

→ Automotive and aerospace industry





Most MMCs are produced with single ceramic reinforcement phase (fibres/whiskers or particles)

Hybrid reinforcement can improve wear resistance and fracture toughness and reduce anisotropy of the material.

2

Motivation

MMC’s micromechanical behavior under load

Microstructure
- 3D network of eutectic Si
- Intermetallics
- 1 or 2 ceramic phases

Load partition
Evolution of the phase-specific stresses

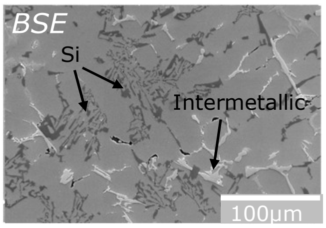
Damage mechanism
- Cracks initiation
- Damage evolution
- Amount of induced damage

NDT
- Computed tomography
- Acoustic emission

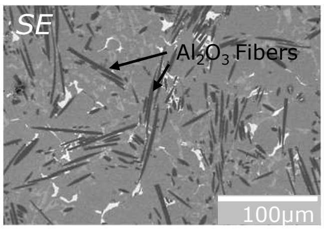
3

Materials under investigation

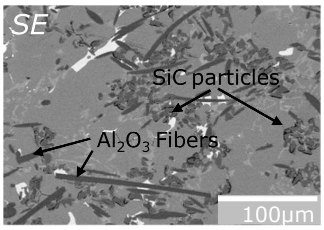
Matrix



Type I



Type II



AlSi12CuMgNi alloy

AlSi12CuMgNi alloy
+ 15% vol.
Al_2O_3 fibers*

AlSi12CuMgNi alloy
+ 7% vol.
Al_2O_3 fibers*
+ 15% vol.
SiC particles

** random-planar oriented*

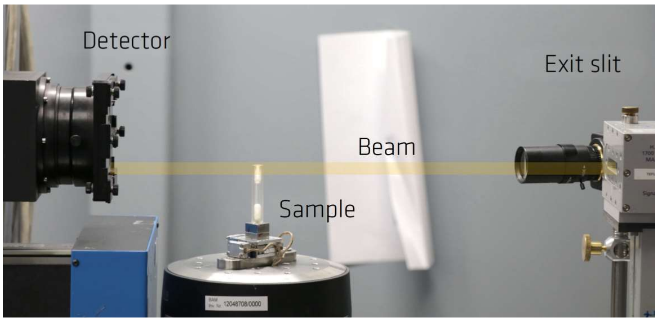
BSE Back scattered electron image
SE Secondary electron image

4

Test setup
Synchrotron X-ray computed tomography (SX-CT)

Synchrotron BESSY II, Berlin

BAMline



- Sample diameter: 1mm
- Effective pixel size: 0.44µm
- Spatial resolution: <1µm

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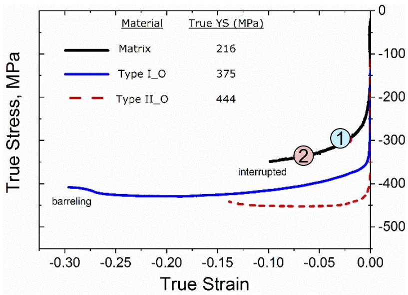
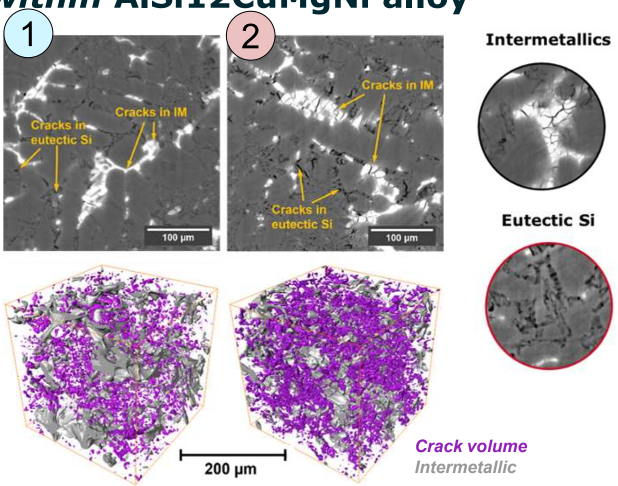
5

5

Micro-Tomographic analysis
Damage accumulation within AlSi12CuMgNi alloy

- Microcracks: Intermetallic (IM), Silicon (Si)
- No damage observed: Aluminium (Al)





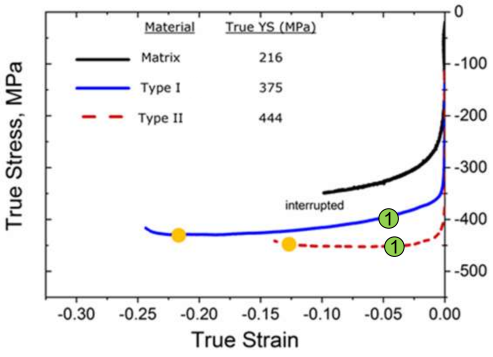
Volume Fraction of cracks

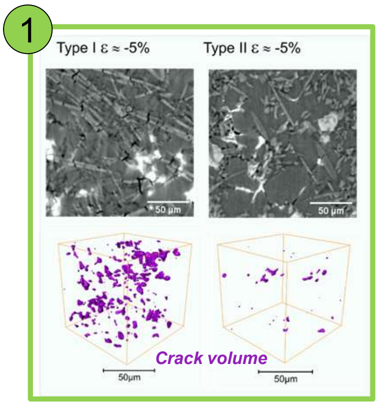
VF_{cracks} = 1.6±0.1% VF_{cracks} = 3.4±0.1%

6

Micro-Tomographic analysis
Damage accumulation within type I and II

- Type II generated less crack volume at low plastic strain than Type I
- No damage in Al of I & II

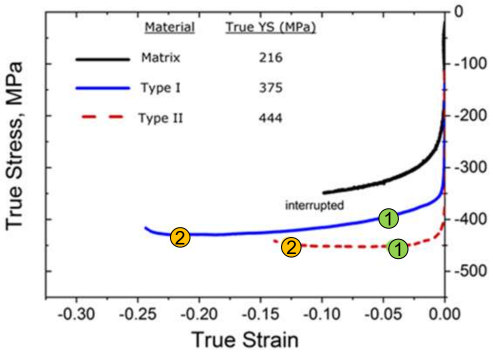


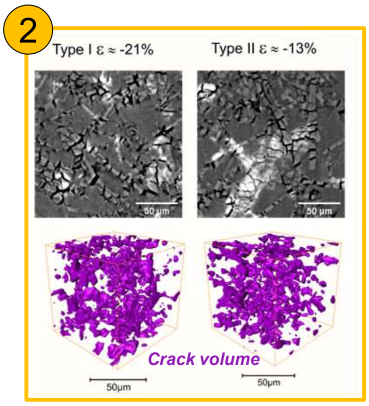


7

Micro-Tomographic analysis
Damage accumulation within type I and II

- A more catastrophic damage development in Type II due cracking in SiC clusters
- No damage in Al of I & II





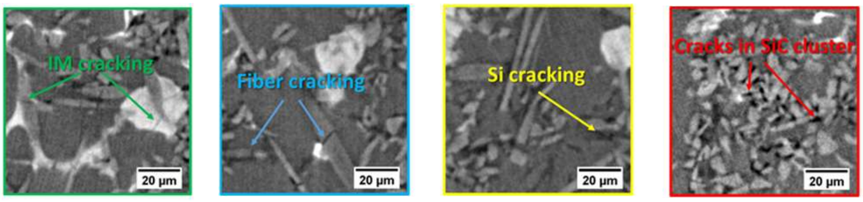
8

Micro-Tomographic analysis
Damage types in fibre reinforced MMC's

Dimension of components:

Damage types in material:

Cracking of	Matrix	Type I	Type II
Si	x	x	x
IM	x	x	x
Fibres		x	x
SiC, SiC particles, SiC clusters			x



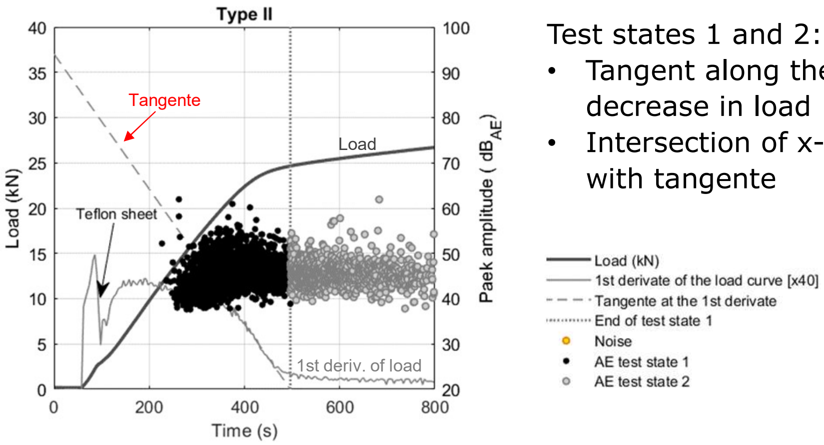
9

Test setup
AE measurement during compression test

- 2 specimens of each type (8 x 8 x 16 [mm³])
- Test with/without Teflon sheets btw. sample and holding device
- Testing device Instron 4505, compression with 100µm/min traverse speed
- AE sensor PICO S/N 5259 (PAC, Ø 5 mm x H 4 mm)
- AMSY6, continuous mode, threshold-free, sampling rate 5 MHz, digital Filter: 120 kHz … 1 MHz

10

Acoustic emission analysis
Definition of 2 testing states



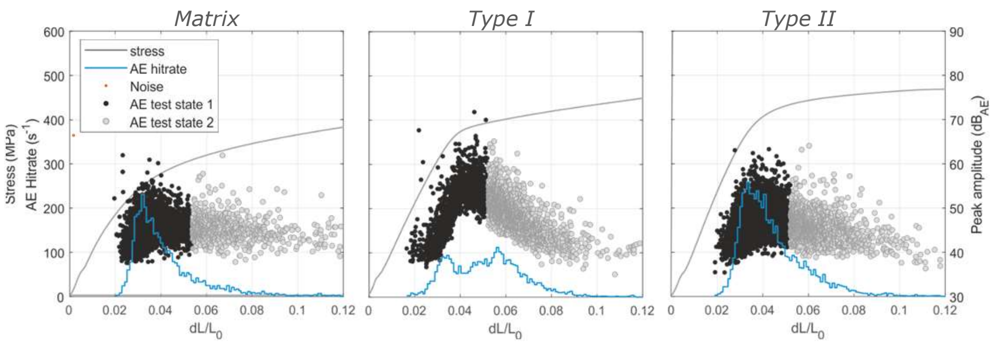
Test states 1 and 2:

- Tangent along the decrease in load
- Intersection of x-axis with tangente

11

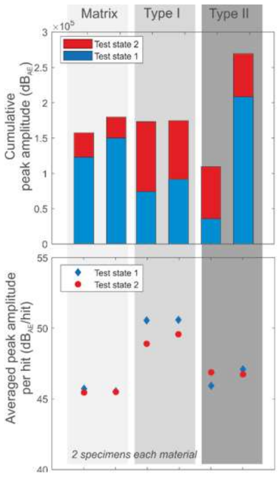
Acoustic emission analysis
Hits vs. strain

- AE activity starts at 2% strain for all materials
- Test state 1: peak in hitrate for matrix and type > 200 hits/sec
  flat peak in hitrate for type I with ca. 100 hits/sec
- Test state 2: lowest hitrate at 6% strain for matrix, decreasing peak amplitdue



12

Acoustic emission analysis
Total AE activity



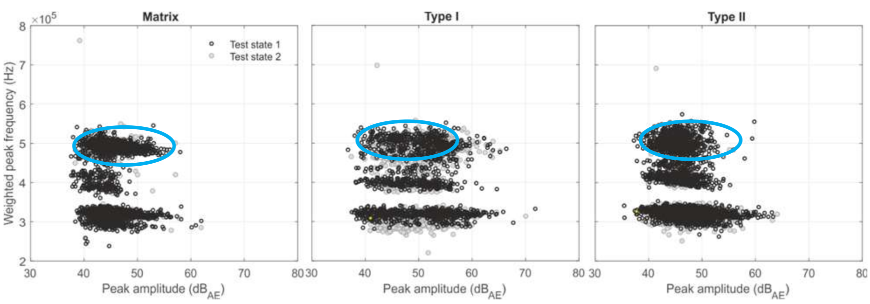
- Outlier in cumulative peak amplitude

  → sample 1 of type II underwent early failure
- Cumulative peak amplitude:
  - Low for type I in test state 1
  - Similar for matrix & type I in test state 2
- Highest averaged peak amplitude per hit found for type I (test state 1 > test state 2)
- Averaged peak amplitude for matrix similar to type II
- Few, but „larger" AE hits in type I
- Many „small" AE hits in type II

13

Acoustic emission analysis
Weighted peak frequency

- Detected signals range from 300 kHz to 550 kHz
- 3(4) clusters are formed in weighted peak frequency (WPF) vs. Peak amplitude for each material
- Differences in the scatters for each material, f.e. above 450 kHz (WPF)



14

Acoustic emission analysis
Weighted peak frequency

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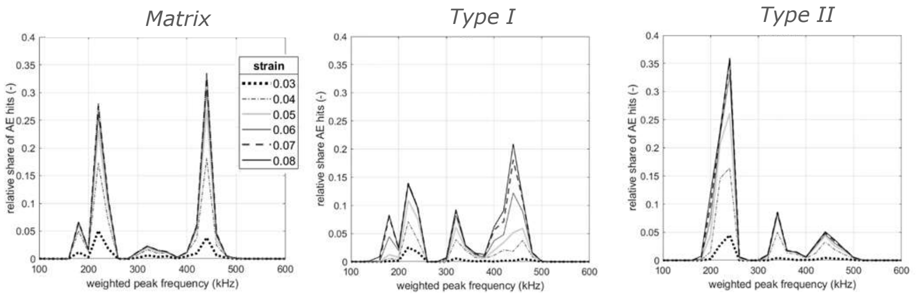
Matrix: signals with WPF of 220 kHz or 440 kHz at 3% strain, ~30% of hits with WPF 220 kHz, ~30% of hits with WPF 440 kHz

Type I: 15% of hits with 220 kHz WPF, additional peak in hits with 320 kHz WFP , increase in hits with 450 kHz WPF at strain >6%

Type II: >30% of hits with 230 kHz WPF



15

Conclusion

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- The here presented study is rather levelled to a pre-test.
- Materials: Matrix → AlSi12CuMgNi matrix
  Type I → Matrix +15%vol. Al_2O_3 fibers
  Type II → Matrix + 7%vol. Al_2O_3 fibers + 15%vol. SiC particles
- Computed tomography (CT) and Acoustic Emission (AE) were not performed for the same specimen, yet. Therefore, a more precise testing setup is required.
- Based on tomograms, crack types are identified.
- Differences in AE behaviour of the three materials are observed. AE sources (damage types) need to be identified. → **NEW Setup AE+CT**
- NDT detection limit regarding damage of MMC's ? (Modelling)

16