Application of complementary beam techniques to study deformation mechanisms in heterogeneous materials for automotive industry

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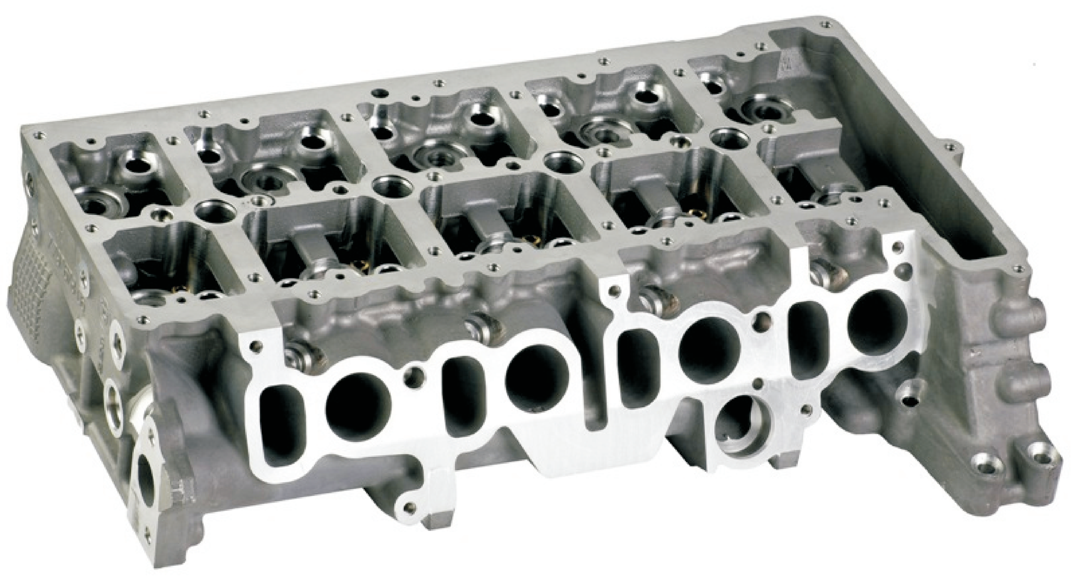
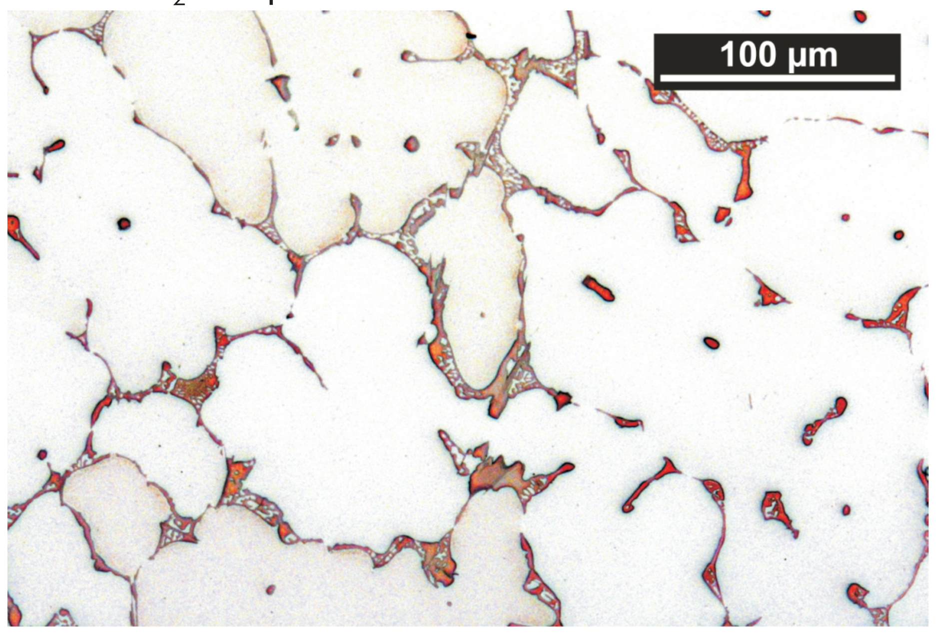
Introduction

In automotive industry the demand on power and efficiency, increases power density in combustion engines significantly. Therefore new materials have to be developed for engine components to withstand thermo-mechanical loads at reduced weight. AlCu alloys combine light weight with good mechanical properties (high temperature strength, creep resistance) due to their composite like micro structure. Micro stresses in between stiff particles and ductile matrix alloy can lead to crack formation and damage under thermo-mechanical load. In this work diffraction and imaging beam techniques were used to identify the phases, evaluate stress evolutions under simulated operation conditions and qualify the damage types i.e. crack formation in the heterogeneous micro structure.



BMW cylinder head by Nemak Linz GmbH

LOM: AlCu7MnZr alloy with bright α-Al, dark Al_2Cu phase and intermetallics



As cast and **T6** (heat treated) condition was investigated.

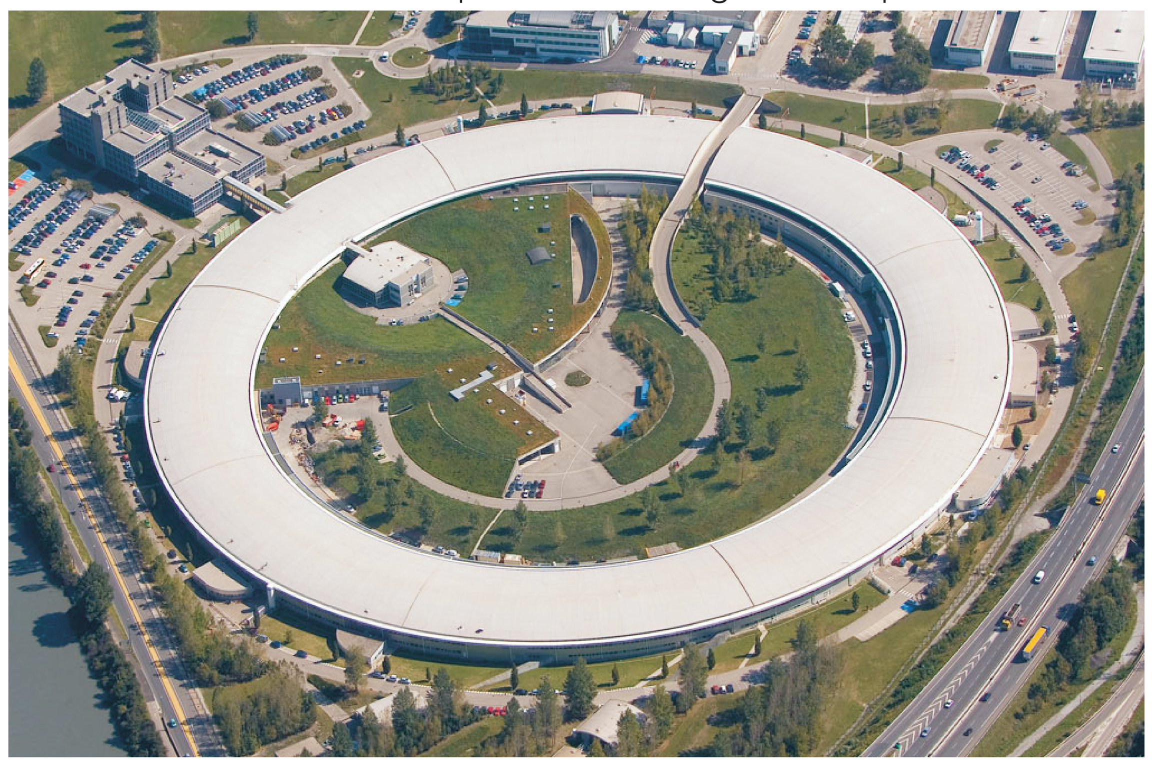
http://www.mlz-garching.de/

FRM2, high flux, continuous neutron source at Garching in Germany

Combined beam techniqhues

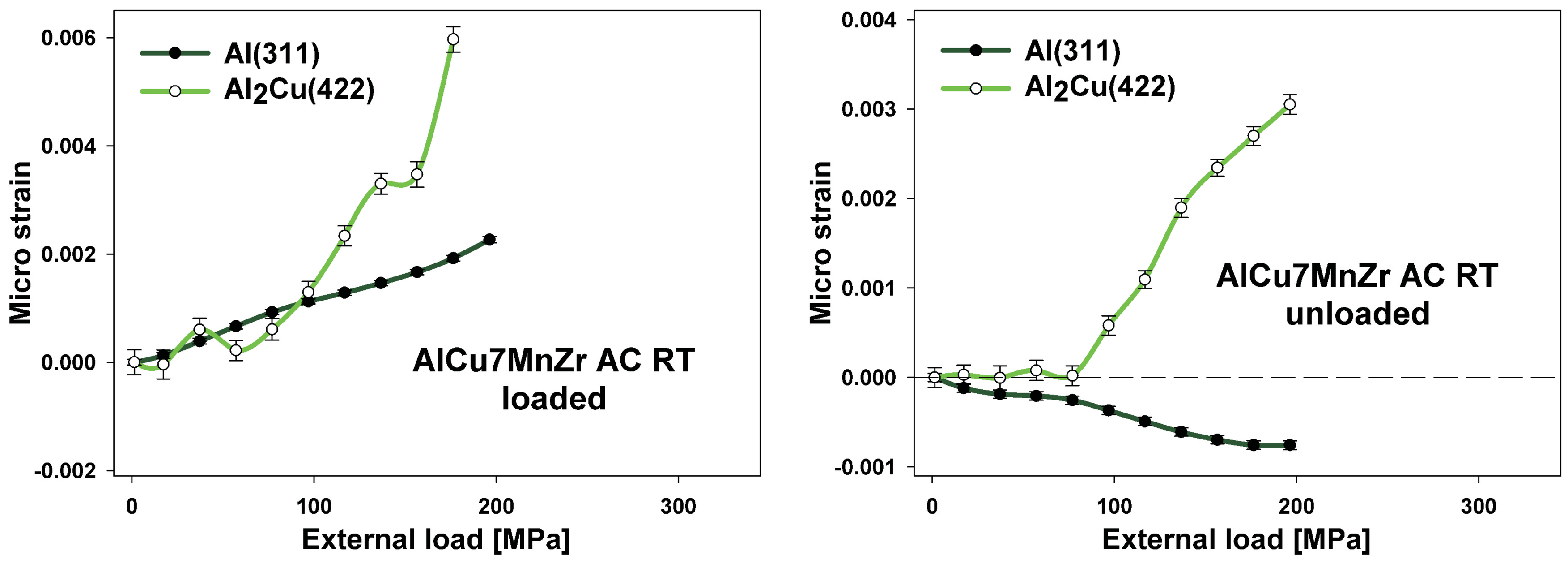
Neutron diffraction was combined with synchrotron tomography to measure strains under simulated thermo-mechanical loads and identify damage by 3D X-ray tomography. Neutrons offer high penetration depths in big gauge volumes, necessary for representative diffraction data. Synchrotron radiation provides good contrast at high spacial resolutions for imaging of cast metals and their 3D microstructure. Additional, high resolution electron microscopy was performed to deliver relevant information on crystal structure and element distribution on nanometer scale.

https://searocksblog.files.wordpress.com/2016/

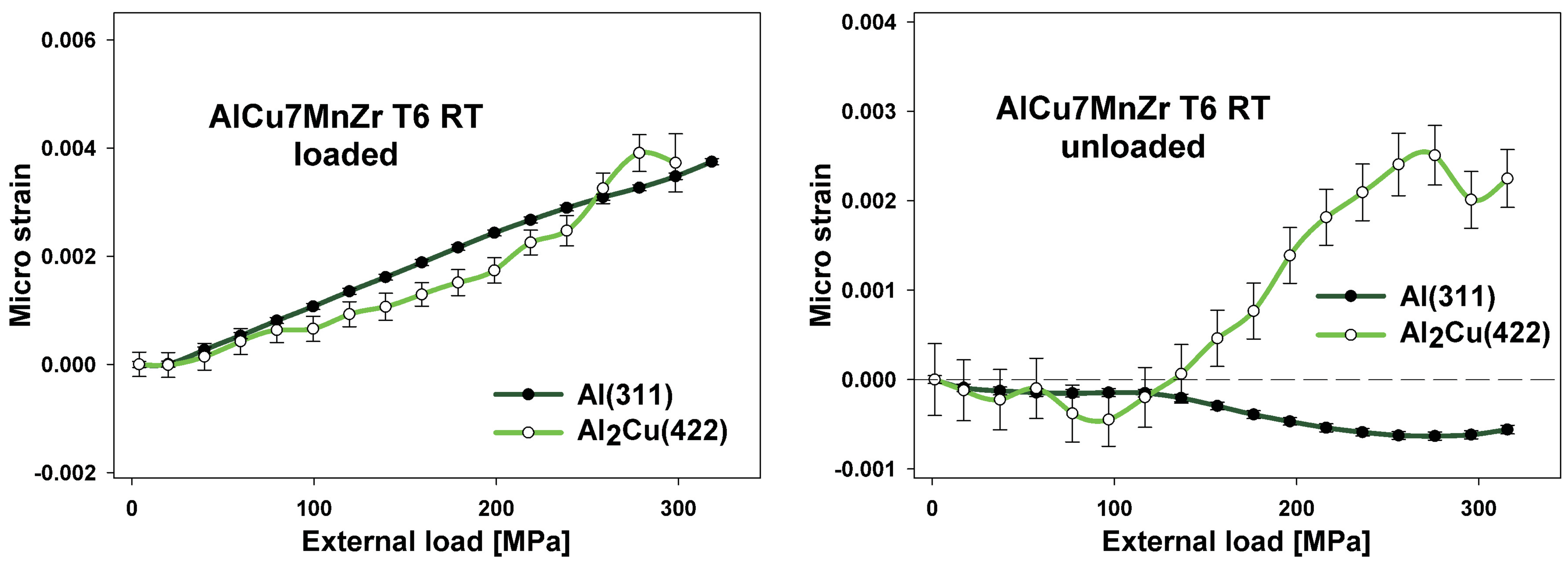


ESRF, electron storage ring, X-ray source at Grenoble in France

In-situ neutron diffraction during tensile testing

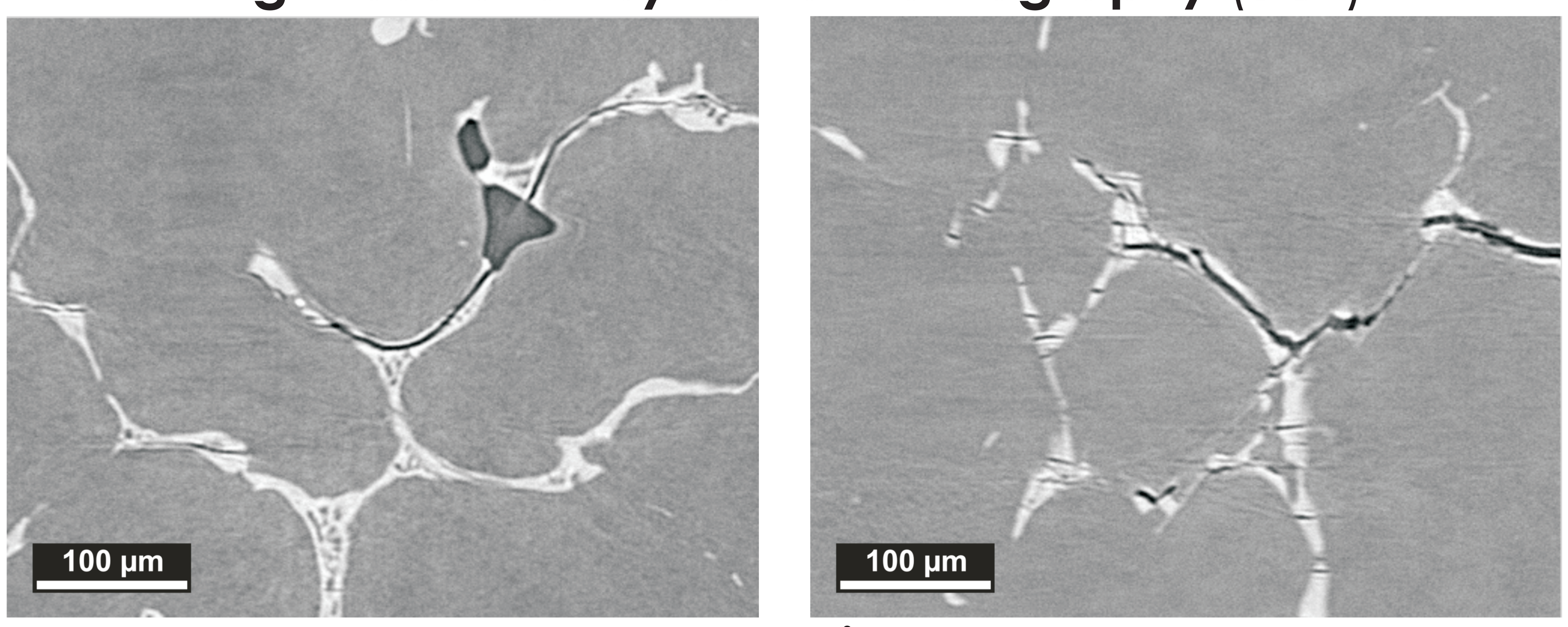


Diffraction at Stress Spec during in-situ tensile testing with a wavelength of 1.6 Å and a acquisition time of 3 min in a 5x5x5 mm^3 gauge volume. Strains in AlCu7MnZr as cast condition under load (left) and after unloading (right). Elastic deformation in α-Al and Al_2Cu until ~ 70 MPa is indicated by equal strains under load (left) and no micro stresses between the two phases (right). Above 70 MPa higher strains can be observed in Al_2Cu then in α-Al (left) going with micro strain increase after unloading (right).



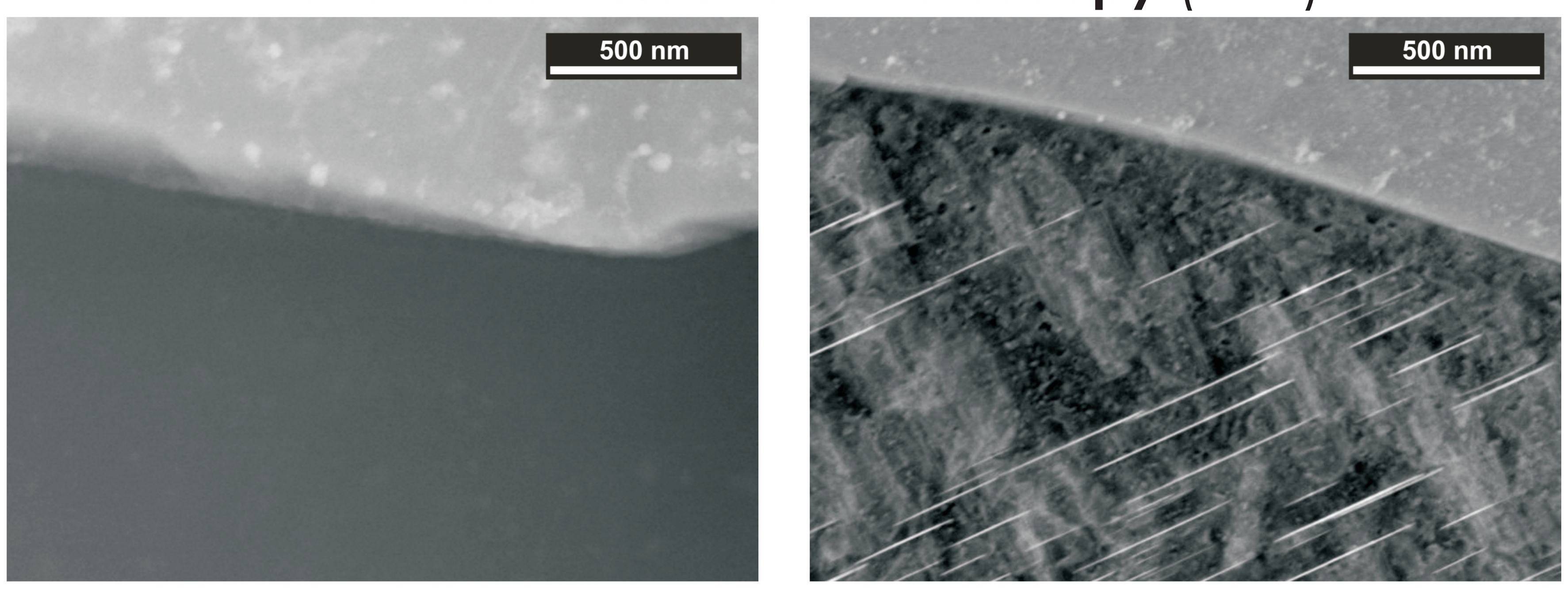
Strain measurement in AlCu7MnZr in T6 condition. Micro stresses and strain distribution shows a significant increase in stress level leading to plastification above ~ 120 MPa and fracture toughness > 300 MPa.

High resolution synchron tomography (SCT)



SCT at ID19 with voxel size of $(0.3\ \mu m)^3$ and a beam energy of 19 keV. AlCu7MnZr as cast (left) and T6 (right) is imaged near fracture surface. Crack indications in the brittle Al_2Cu phase (bright) show ductile α-Al (dark) in the as cast condition compared to a stiff α-Al in the T6 condition.

Transmission electron microscopy (TEM)



TEM bright field imaging at 200 keV, shows AlCu7MnZr in as cast (left) and T6 (right). α-Al (dark) is shown near bright primary Al_2Cu phase. In T6 plates of θ'-Al_2Cu phase are formed within the a-Al.

Conclusions

Mechanical loads lead to elasto-plastic deformation in the heterogeneous micro structure of AlCu7MnZr alloys under service conditions. Strain concentrations in Al_2Cu, proves stiff primary particles acting as reinforcement of the ductile α-Al matrix. Micro cracks are formed in AlCu7MnZr favorable within Al_2Cu particles, more in T6 compared to the as cast condition. In T6 laminar shaped θ'-Al_2Cu precipitates reinforce the α-Al to higher strength, which leads to a significant increase in load transfer into the primary Al_2Cu particles (responsible for the observed micro crack formation).