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The new dimension in Grain Refinement

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Improving Liquid Metal Cleanliness by Optimized Addition of High Efficiency Grain Refiner

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- Acknowledgement

Introduction

MQP has been engaged in the optimisation of grain refinement for over 20 years

In 2002 MQP began a long association with Opticast Alumium AB a company started by Lennart Backerud, who together with Dr Rein Vainik, invented the Opticast Technology for optimisation of grain refinement

In 2008 Lennart sadly passed away and MQP acquired the assets of Opticast Aluminium AB and the exclusive rights to all the Opticast Technologies

OPTIFINE was developed using MQP's in depth knowledge of grain refinement gained through the introduction and operation of the OPTICAST System and was launched to the aluminium industry in 2009

Today MQP has more than 40 qualified customers worldwide using Optfine high efficiency grain refiner and have successfully cast over 17 million tonnes of aluminium todate

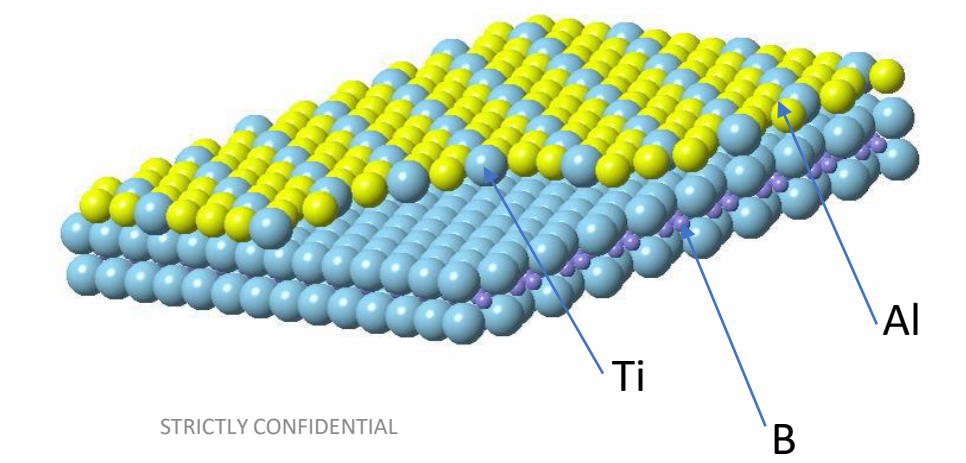
Over 20 international publications on Optifine high efficiency grain refiner and optimisation。

MQP is the only manufacturer to provide on-site technical and optimisation support using OPTICAST technology

Co-operation with BCAST at Brunel University London – Study of the fundamental Mechanism of Nucleation

Objectives:

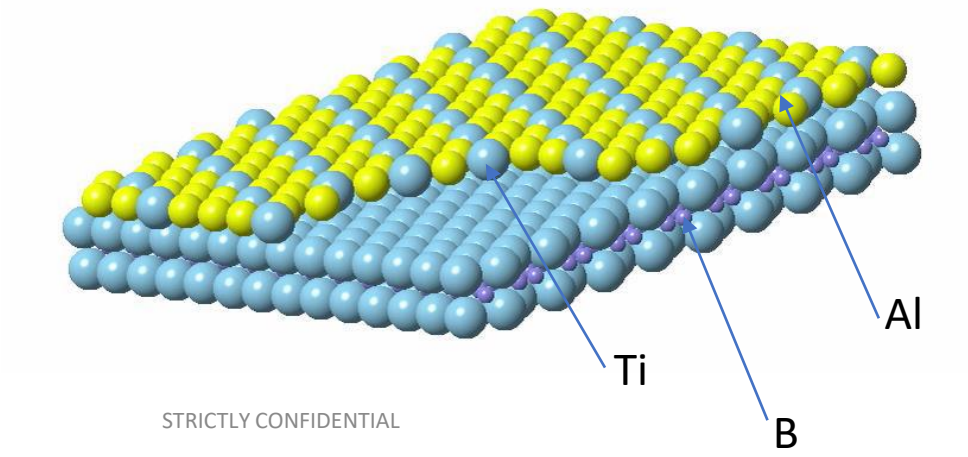
- To reveal the characteristic of TiB_2 particles in the grain refiner with different refinement efficiency and find the relationship between TiB_2 particle morphology and the refinement efficiency.
- To understand why the grain refinement efficiency of produced refiner varies from batch to batch.
- To enable MQP to produce Optifine grain refiner batches with high efficiency.



Co-operation with BCAST at Brunel University London – Study of the fundamental Mechanism of Nucleation

Project Phases:

- Validation of the existence and importance of the Al3Ti monolayer on TiB2 particles
- Study using HR-TEM of the extent of layer formation in samples of grain refiner with 50% and 123% efficiencies
- Study using SEM of the relationship between microstructure and particle size distribution on samples of grain refiner with 50%, 86% and 123% efficiencies



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Phase 1

Validation of the existence and importance of the Al3Ti monolayer on TiB2 particles

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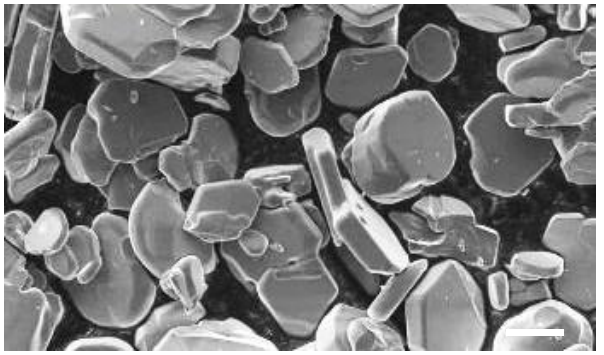
Synthetic TiB_2 has no grain refining ability, even with addition of excess Ti

Number density of the added TiB_2 is equivalent to that of 2ppt addition of commercial Al-5Ti-1B grain refiner.



Synthetic TiB_2, no free Ti

In-situ TiB_2, no free Ti

Synthetic TiB_2 56 ppm free Ti

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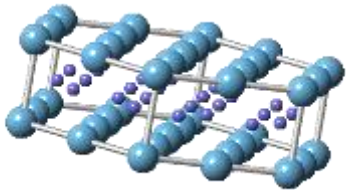
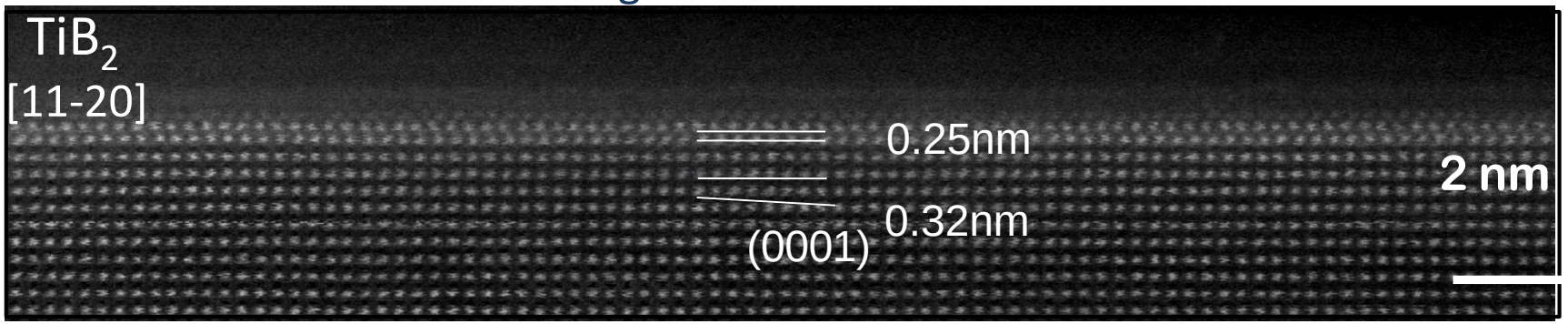
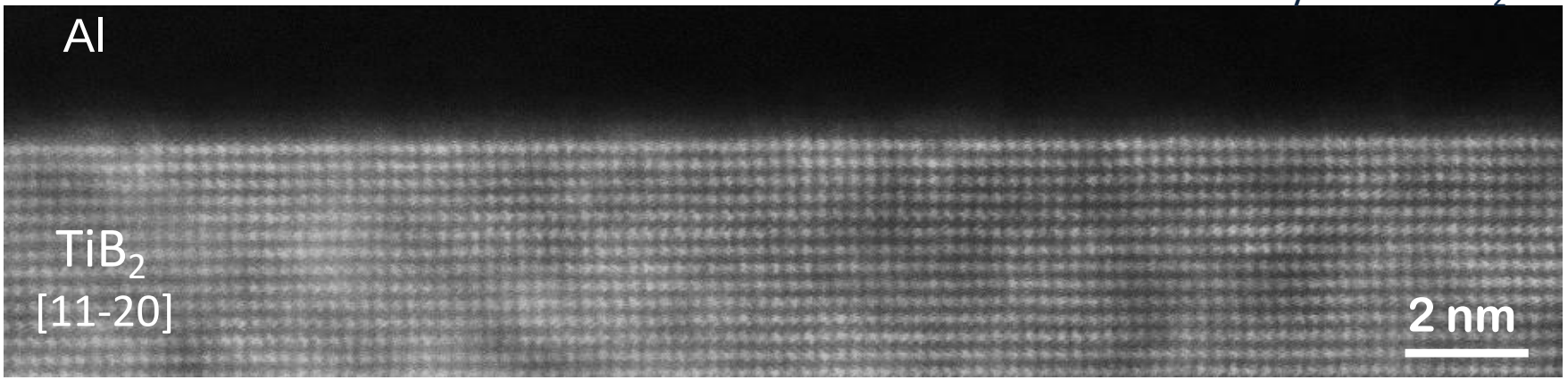
There is an extra atomic layer on (0001) surface of TiB_2 from 5:1 grain refiner



Atomic resolution HRTEM images



Synthetic TiB_2



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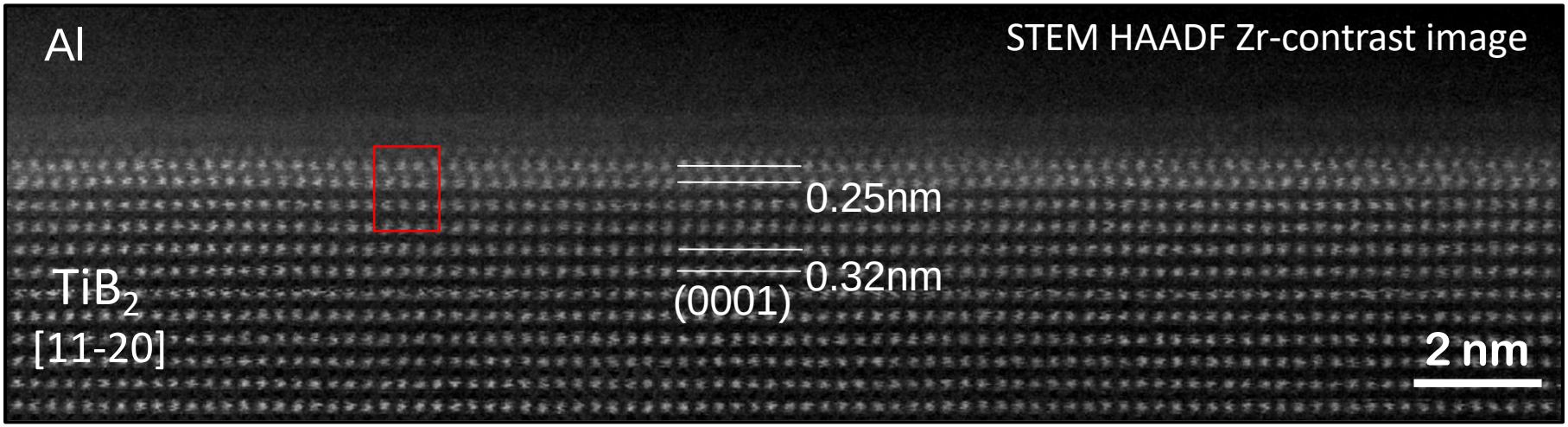
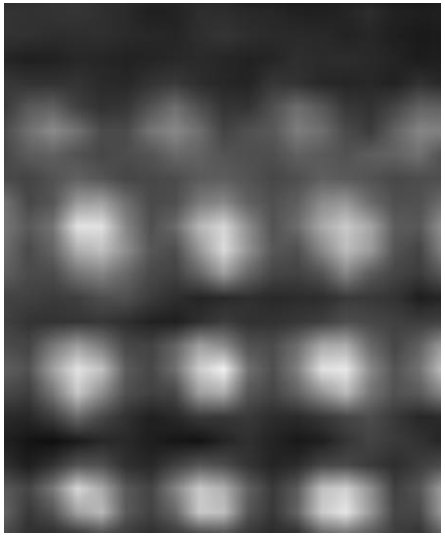
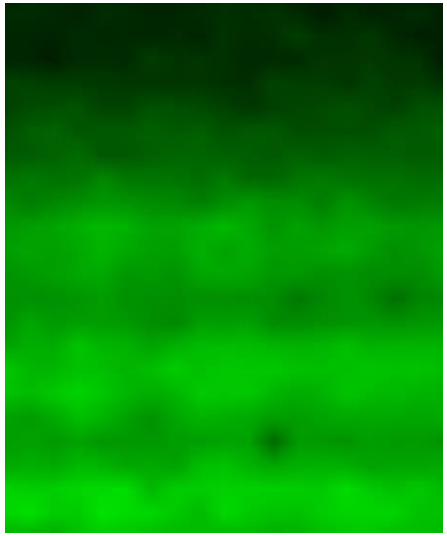
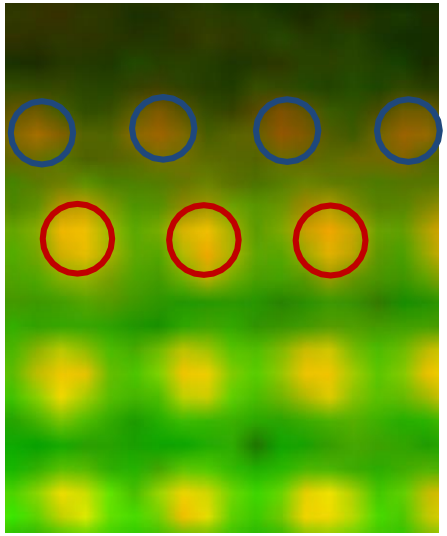




HAADF



Ti L-edge



HAADF and Ti L-edge

Ti-rich column

Ti column (TiB_2)

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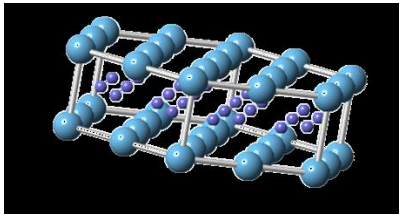
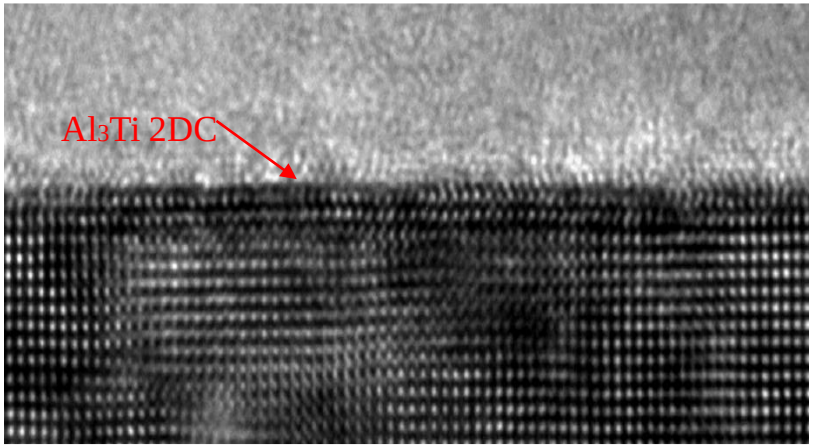
The atomic monolayer

- It is evident that α-aluminium nucleates readily on the aluminide
- The calculated lattice misfit between TiB_2 and the α -Al is –4.22% at 660 C. With the formation of Al3Ti 2DC at the liquid Al/TiB2 interface, the lattice misfit is reduced to 0.09% @ 660℃
- The Atomic monolayer on TiB2is responsible for nucleation of α-aluminiumTiB2





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Phase 2

Study using HR-TEM of the extent of layer formation in samples of grain refiner with 50% and 123% efficiencies

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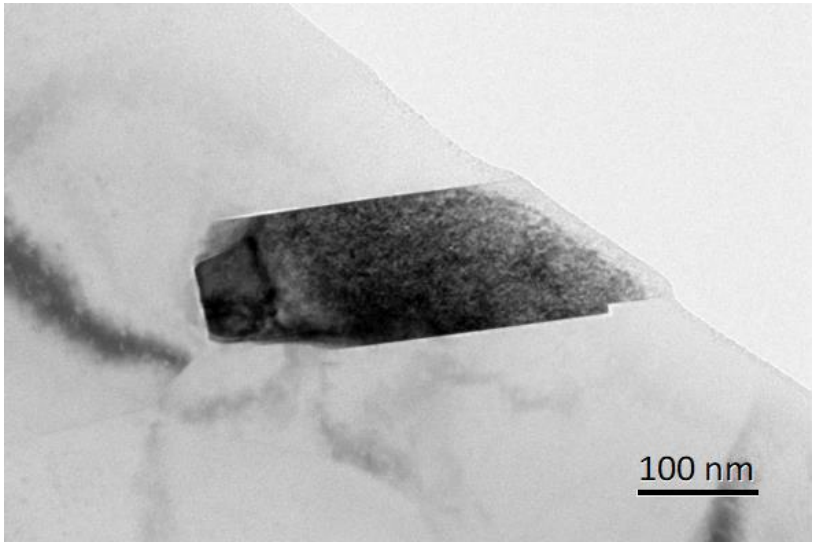
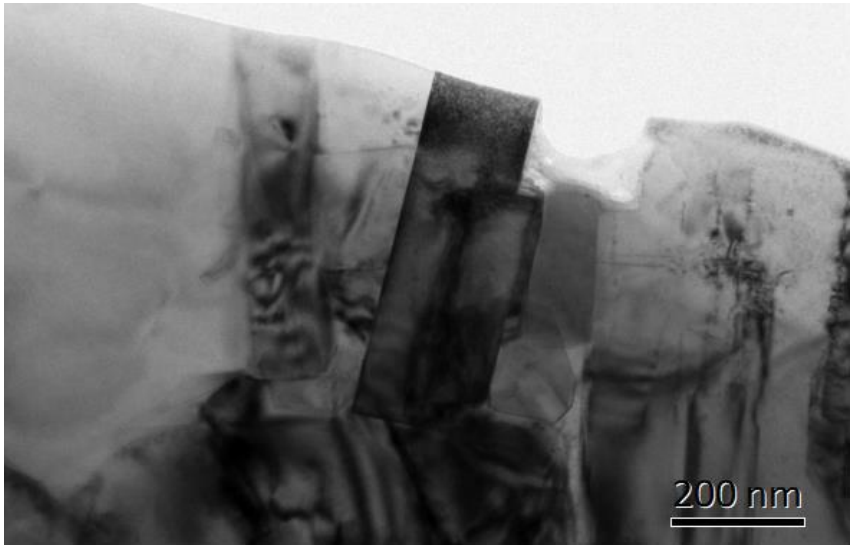
123% efficiency:
7 of the 8 particles are confirmed to have the Al_3Ti 2DC layer.

- So far, a total number of 33 TiB_2 particles were examined for the 123% grain refiner. Among them, 8 particles are electronically thin enough and thus the status of their (0001) surfaces are clarified by HR-TEM.
- 7 of the 8 particles are confirmed to have the Al_3Ti 2DC layer, and one has no Al_3Ti 2DC layer.





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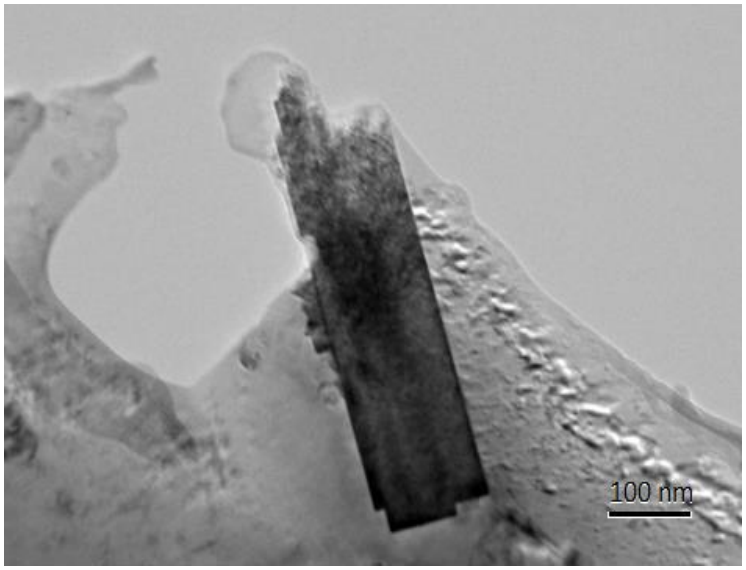
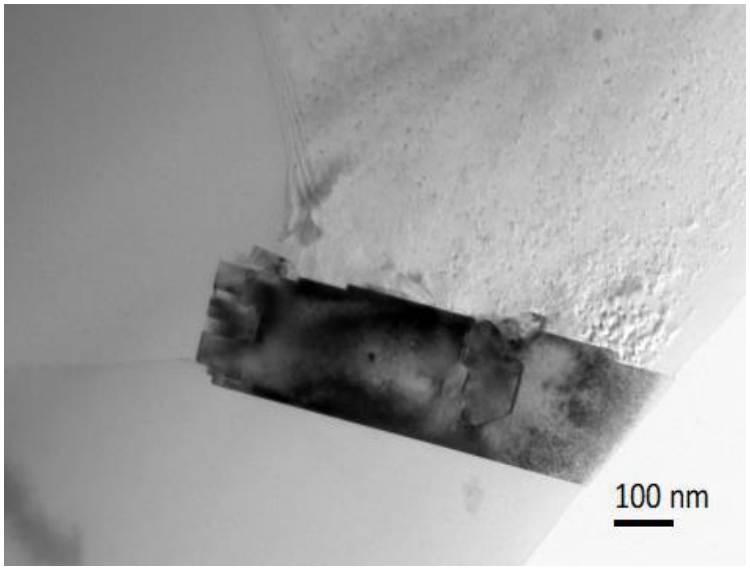
50% efficiency:
5 of the 6 particles have no Al_3Ti 2DC layer, and one has partial Al_3Ti 2DC layer on its basal plane.

- A total number of 37 TiB_2 particles were examined for the 50% efficiency grain refiner. 6 particles were electronically thin enough and thus the status of their (0001) surfaces are clarified decisively by HR-TEM.
- 5 of the 6 particles have no Al_3Ti 2DC layer, and one has partial Al_3Ti 2DC layer on its basal plane.





Conclusions

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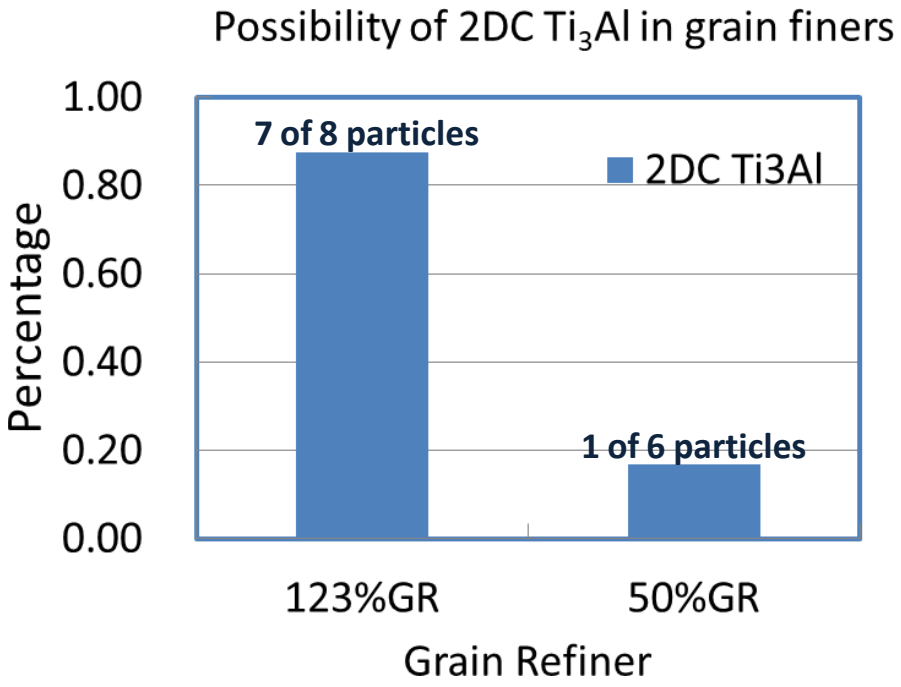
- TEM analysis shows probability of TiB_2 particles which nucleated Al grains are significantly lower in 50% than 123% sample.
- The extent of Al_3Ti 2DC on layer formation on TiB_2 particle is a priority factor in determining the % efficiency.



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Phase 3

Study using SEM of the relationship between microstructure and particle size distribution on samples of grain refiner with 50%, 86% and 123% efficiencies

A percentage of TiB_2 particle size bigger than 2μm is higher in grain refiner of 123%.

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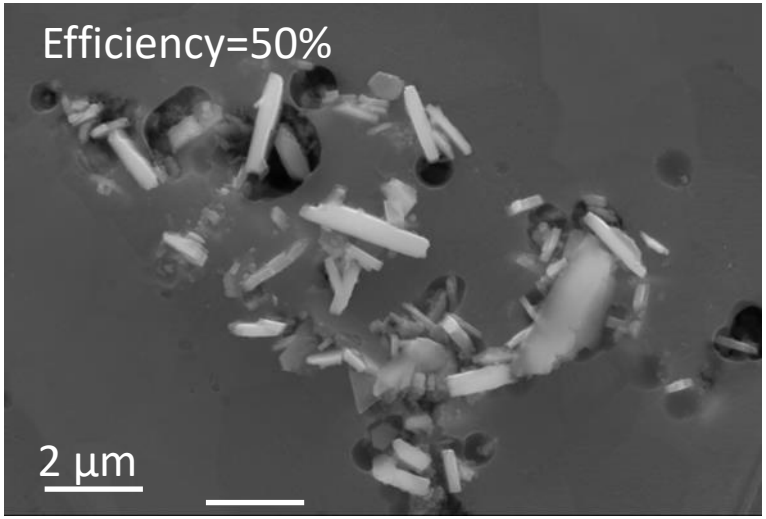

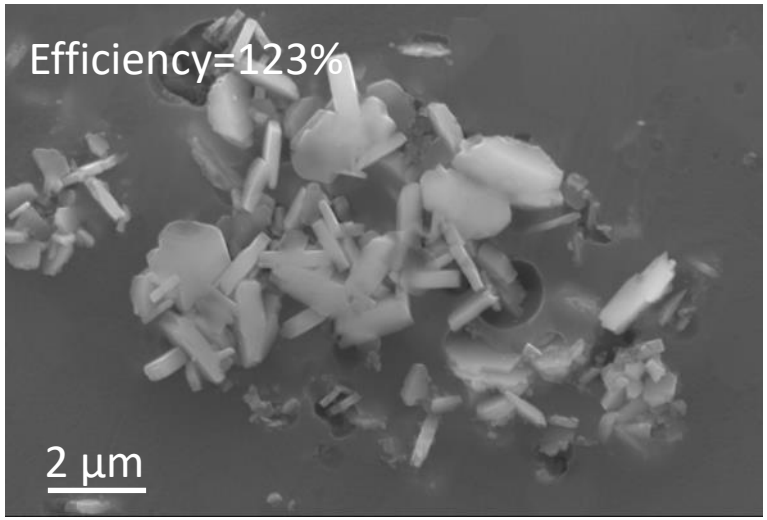

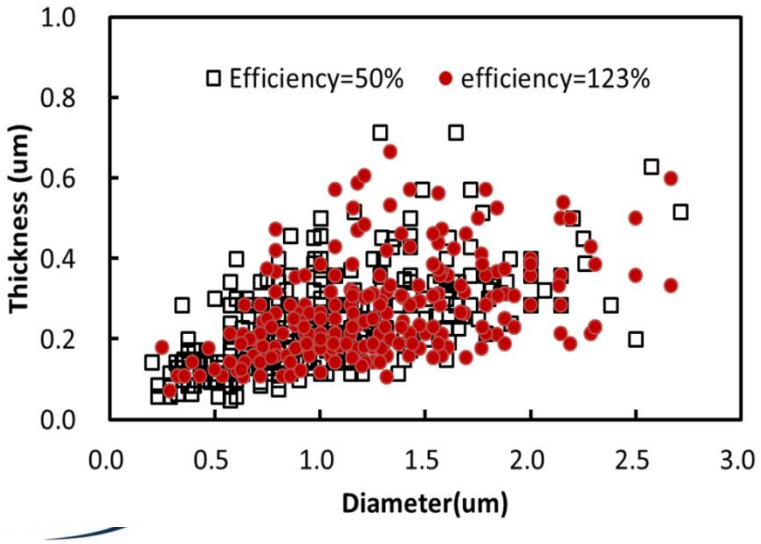

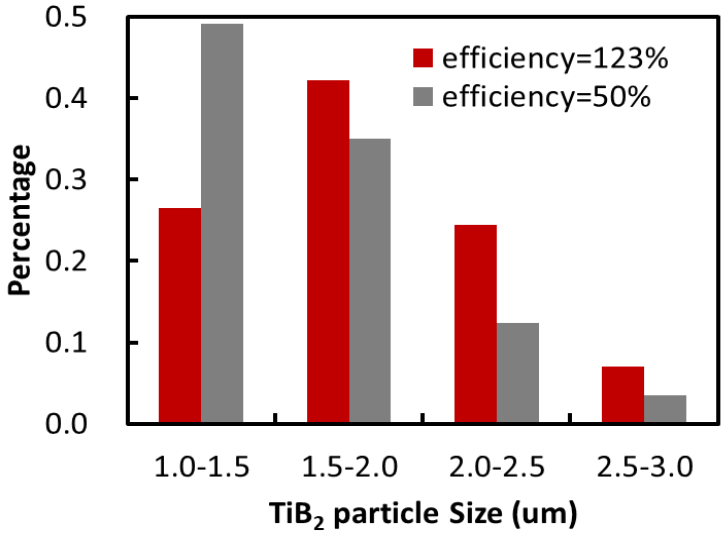

Aluminide

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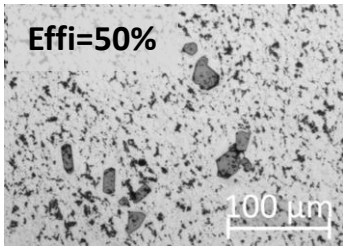
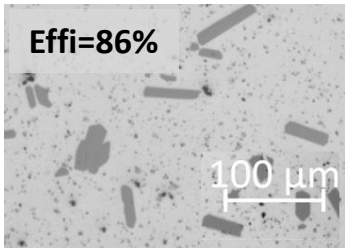
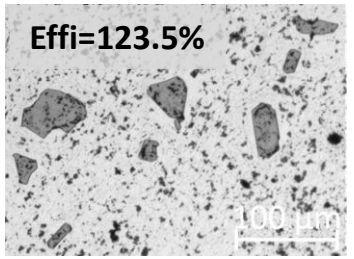
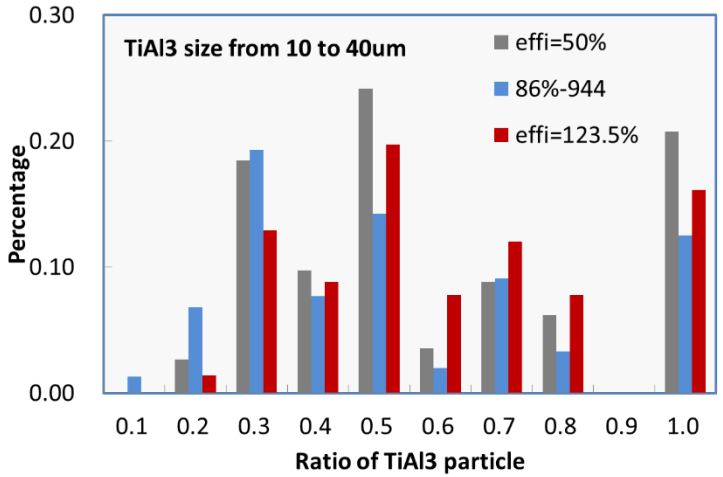
- The dissolution rate depends on particle size and morphology.
- The morphology depends on the titanium content and processing conditions
- **Aluminide morphology: Flakelike, petallike and blocky**
- Al3Ti is not stable in melts with the usual titanium contents of <0·1 %
- **The shape of $TiAl_3$ particle in high efficiency grain refiner tends to have a blocky shape morphology.**
- Blocky aluminide particles dissolve more rapidly and would take less than 1 minute to dissolve at 775 ± 10°C) It is desirable that the TiAl3 particles are well dispersed and in the size range 10-40 µm









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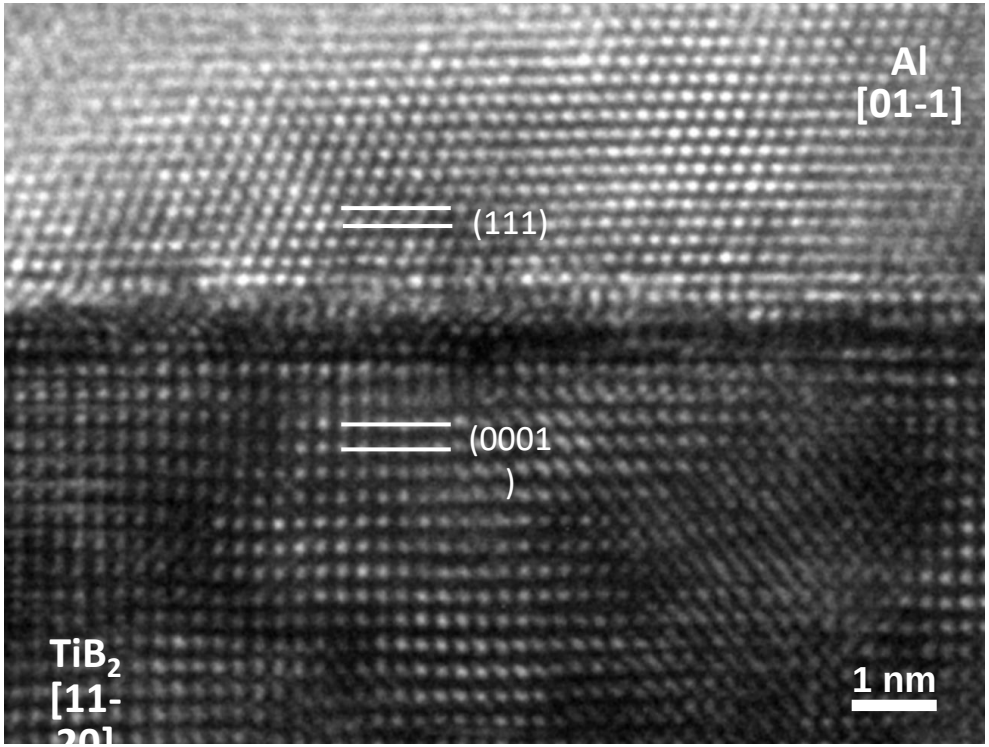
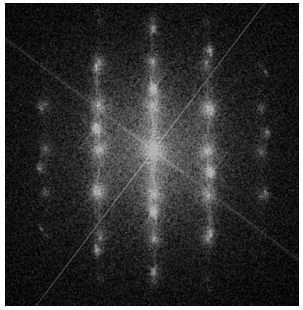
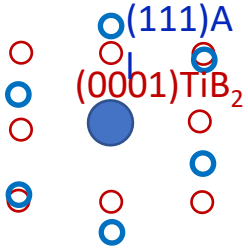
Development of new Super efficiency grain refiner – Optifine 5:1 125

The much expected orientation relationship (OR1) is observed in the Al-5Ti-1B(Optifine 5:1 125), indicating its high grain refining efficiency.

OR1: (0 0 0 1)[1 1 -2 0]TiB_2 // (1 1 1)[0 1 -1]Al







[11-20]TiB_2
// [01-1]Al

125% efficiency:
5 of the 5 particles are confirmed to have the Al_3Ti 2DC layer.

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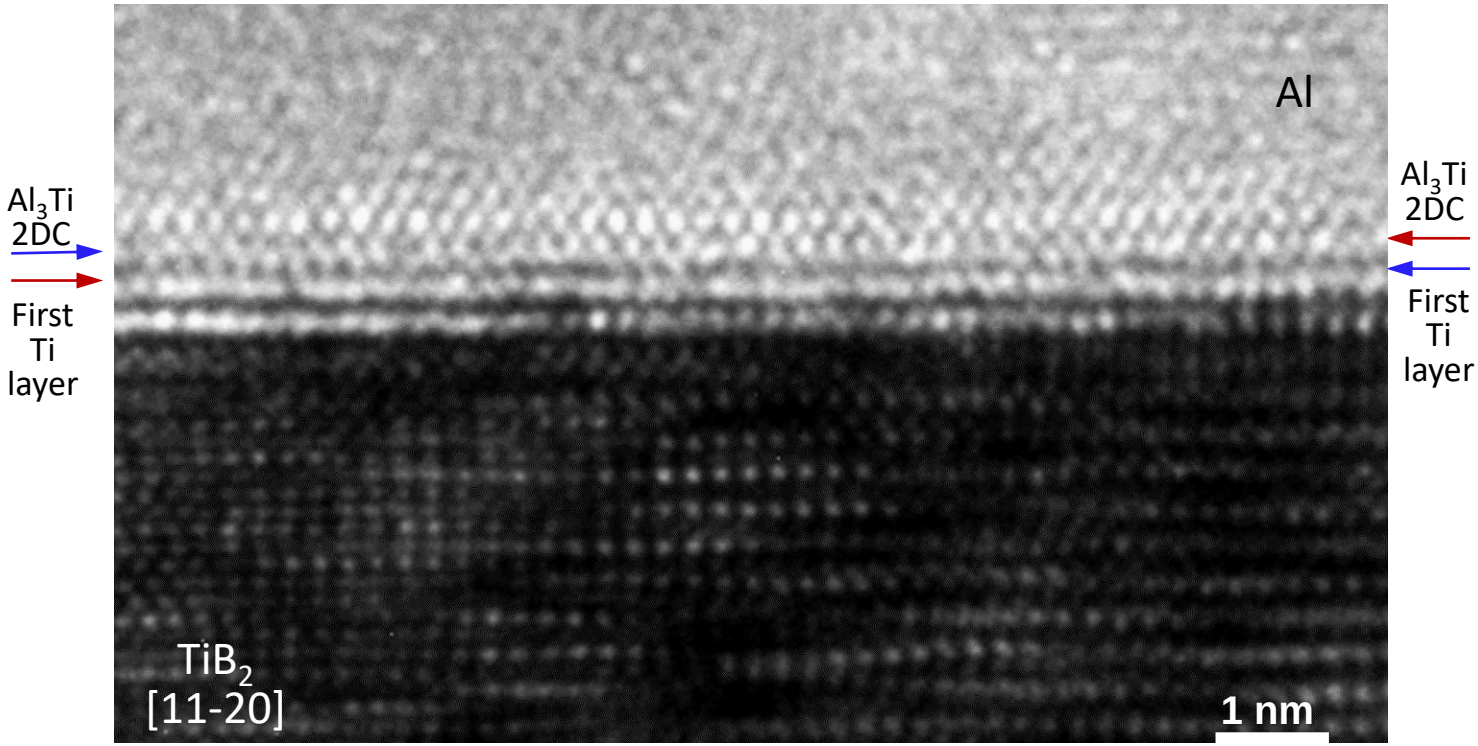

Al_3Ti 2DC layer is readily observed on the basal surface of TiB_2 particles in the Al-5Ti-1B master alloy (Optifine 5:125).

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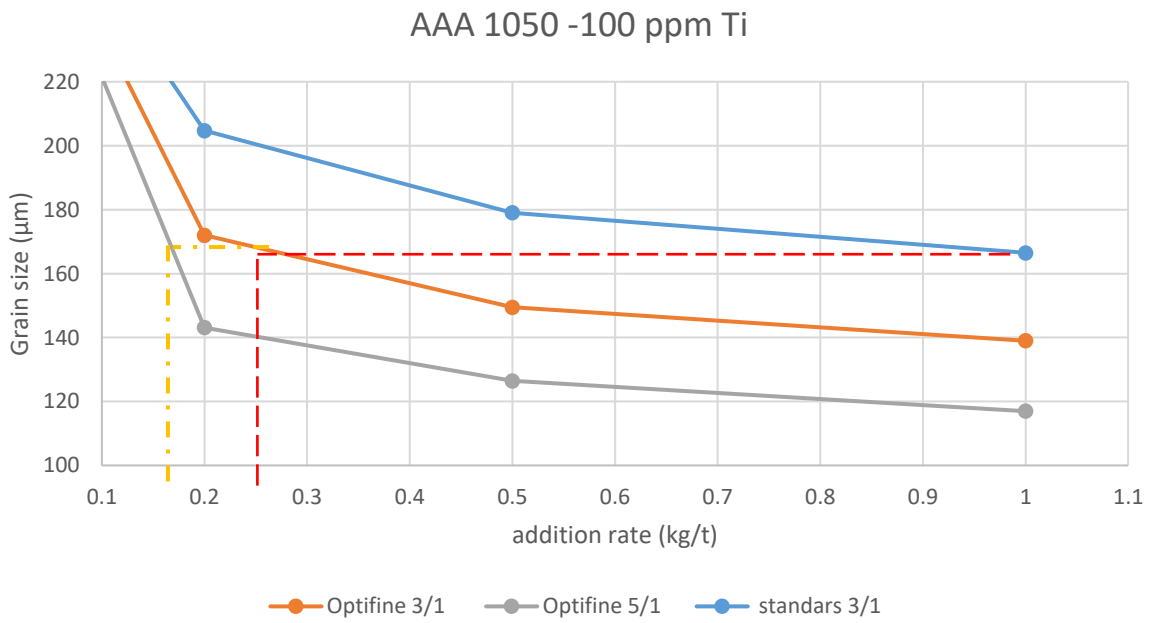
Performance of Optifine 5/1 125 compared to Optifine 3/1 measured in MQP's laboratory in Sweden



Optifine 3:1 gives the same grain size at an addition rate of 0.28 kg/t compared to standard grain refiner, a reduction of 70 % - reducing cost of grain refinement by 50%. Optifine 5:1 125 give the same grain size at an addition rate of 0.15 kg/t compared to the standard grain refiner, a reduction of 85 %, yielding additional cost savings.

Performance of Optifine 5/1 125 measured using Opticast method by a third party

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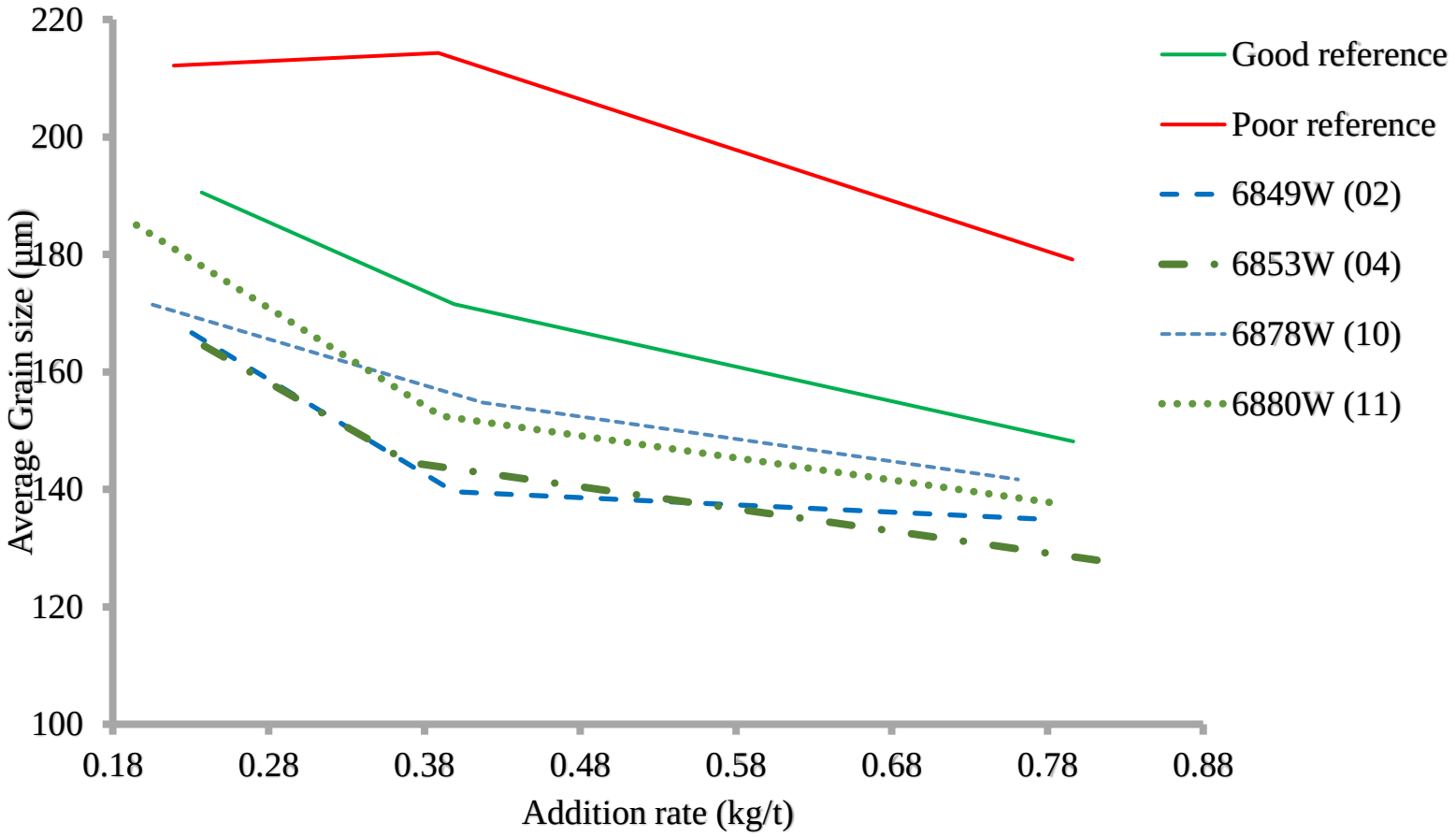

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Effect of reduction of grain refiner addition on particle count in melts

Effect of addition of grain refiner addition on particle count

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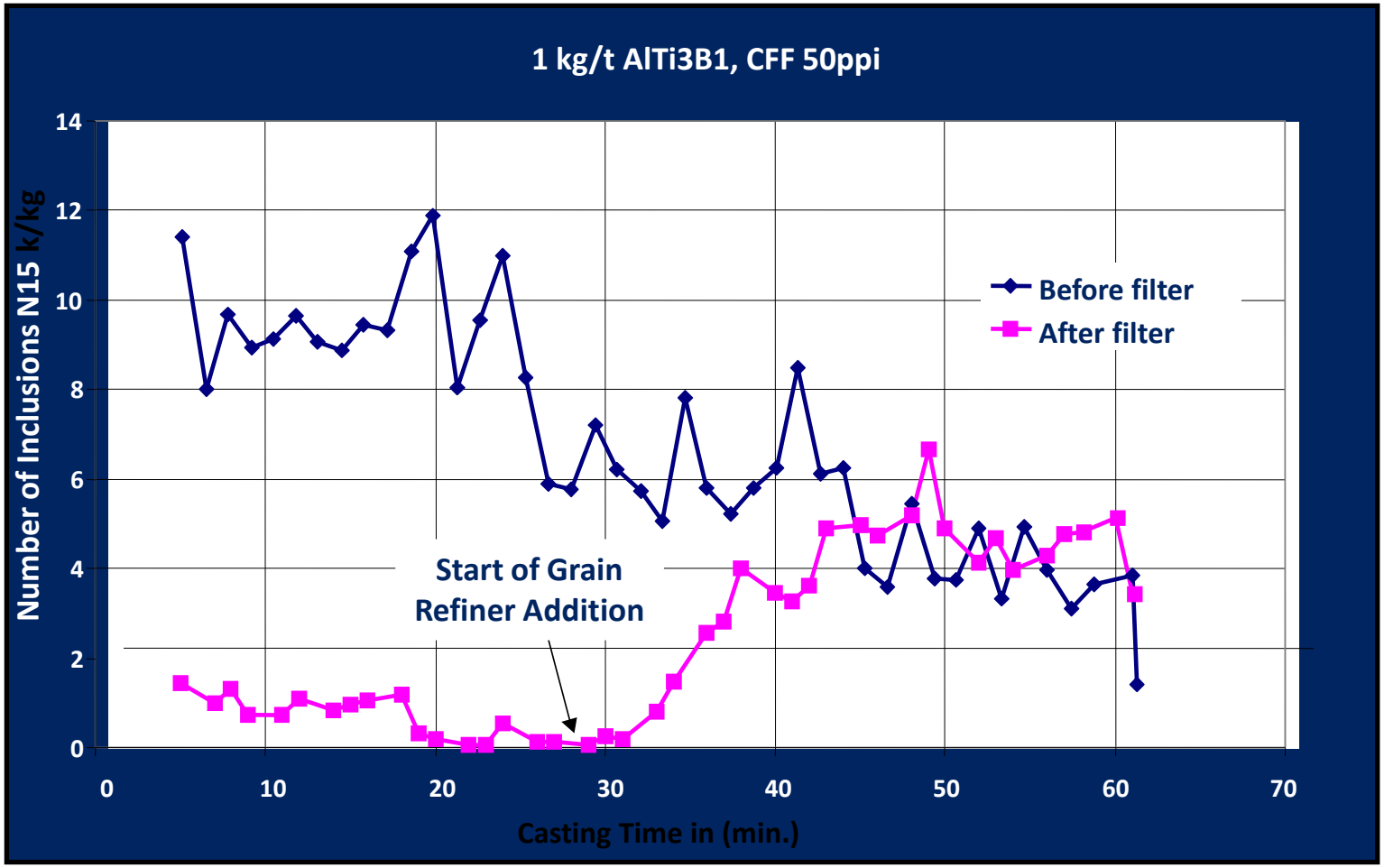

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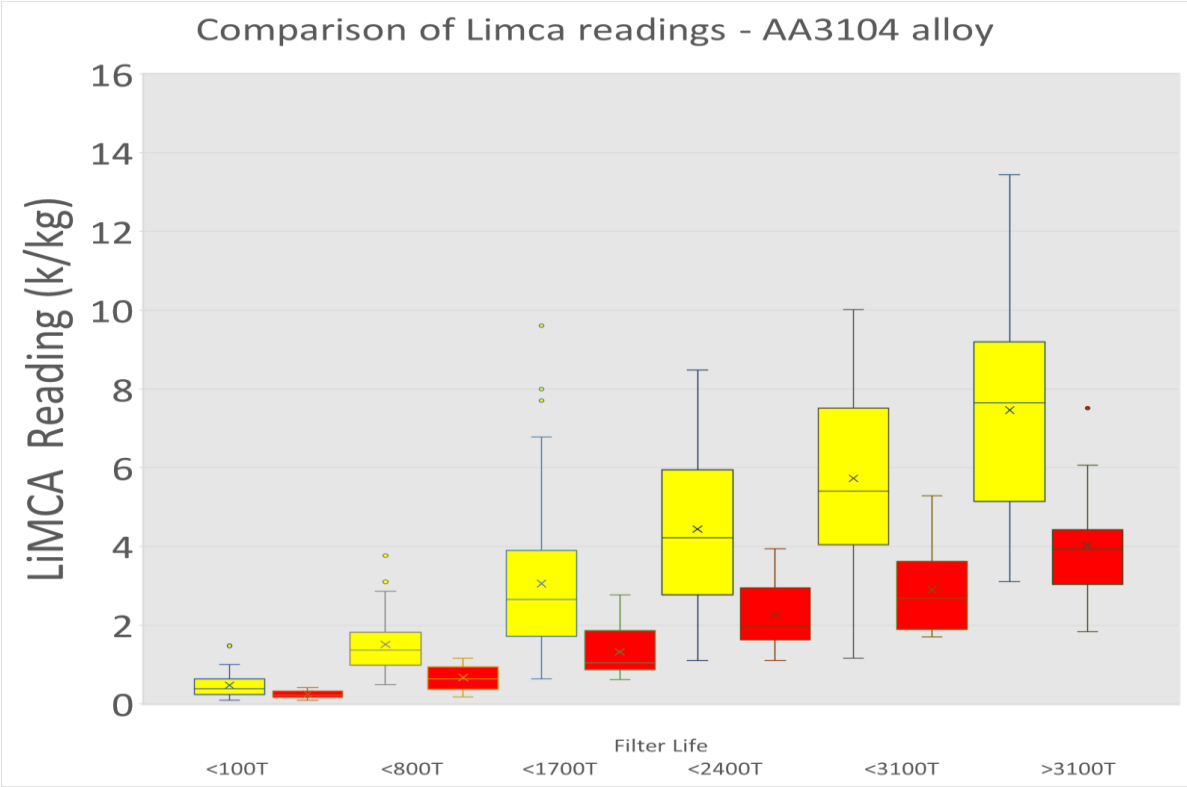
Limca particle counts taken at different stages in tube filter life comparing Optifine vs standard grain refiner

By reducing the amount of grain refiner by 70% the number of particles added to the melt is reduced a similar amount 50% up to 67%, benefiting the metal quality. Evidence for this is shown in this LiMCA data chart



Conclusions

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- Current research at BCAST Brunel University has demonstrated that a monoatomic layer of TiAl3 on the surface of TiB2 particles is a pre requisite for nucleation to occur

- Furthermore HR-TEM examination of grain refiners with varying efficiencies has shown that efficiency is proportional to the extent to which the atomic TiAl3 monolayer has been formed on the TiB2 particles; with a 50% efficiency grain refiner having only 16% of particles coated whilst a grain refiner with 123% shows 87.5% of particles are coated

- From advancements in the understanding of the nucleation mechanism and improvements in manufacturing capability it is now possible to produce a super high efficiency grain refiner, Optifne 5:1 125, in commercial quantities, having an efficiency which is up to 40% higher than that of current high efficiency grain refiners

Conclusions

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- Earlier studies on filtration efficiency have shown that when standard grain refiner at an addition rate of 1kg/t is added in front of a 50ppi ceramic foam filter the Limca particle count at N15 increases by 4000 counts
- Recent work on filter life of rigid media tube filters comparing the use of standard grain refiners versus Optifine have shown that at lives in the range of 2000 heats up to >3100 heats the particle count can be reduced by 50-60% when using high efficiency grain refiner.
- It is postulated that the excess particle count due to grain refiner addition can be reduced from something in the region of 4000 counts to as little as several hundred when super high efficiency grain refiner is applied. Further studies are required and MQP would like to partner with an interested party

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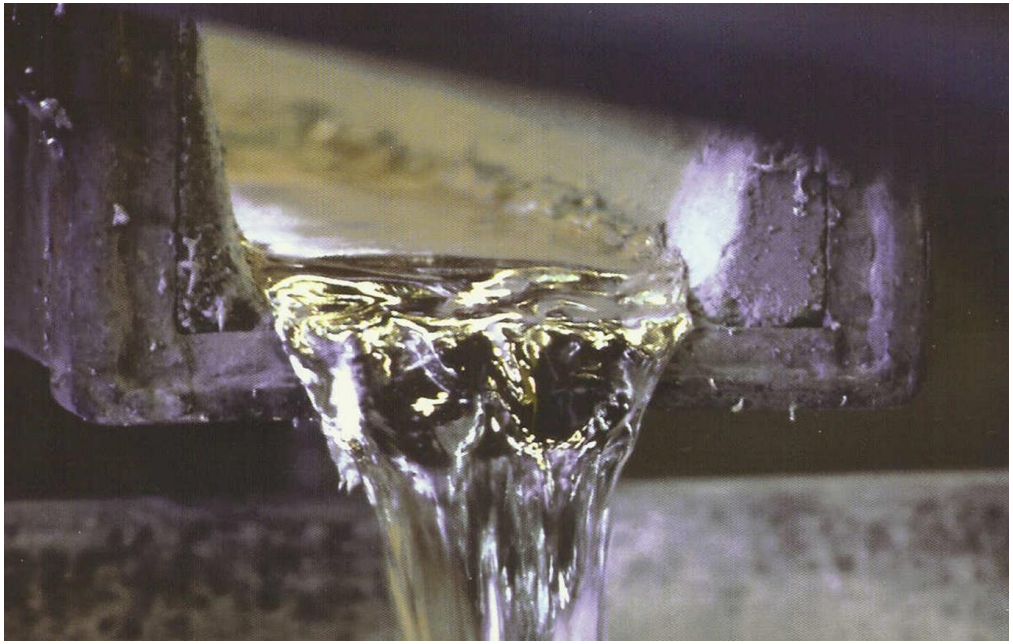
Acknowledgement

The author would like to express his gratitude to Dr Yun Wang and Professor Zhongyun Fan of BCAST at Brunel University London for their pioneering research in this field and for giving their permission for the publication of this material.



Thank you for your attention!