Development of NbB_2 for Grain Refining of Aluminium Casting Alloys

CBMM & Partners Mobility Tech Day Workshop

Jack Strong – Engineering Manager - Materials

DEVELOPMENT OF NIOBIUM FOR GRAIN REFINING OF ALUMINIUM CASTING ALLOYS

Todays Presentation Topic

Update from the most recent alloy development project between Grainger & Worrall and CBMM, developing Niobium diboride (NbB_2) as a high performance grain refiner:

- Introduction to Business
- Collaboration Timeline
- Metallurgical Review
- Project Scope
- Project Results
- Conclusions
- Further Opportunities

COMPANY INTRODUCTION – BUSINESS CAPABILITY

Grainger & Worrall (G&W) is a global engineering company, manufacturing high precision sand castings solutions for the automotive, motorsport, energy and wider transport sectors.

Business Profile

- Turnover of £60m
- Founded 1946, Private Ownership
- Based in UK, 1 hour from Birmingham (BHX)
- Representatives in China, USA, Italy, Germany
- 700+ Employees
- Utilising Technologies – Simulation / A.M / C.T

Prototype / Pre-production Supply

300+ NPI's annually

Series

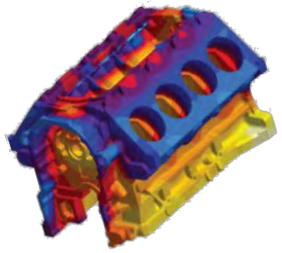
1000-5000 pcs annually

G&W offers a full service solution, from development through to pre-series and low volume, delivering high integral strength alloys:

Aluminium (300 or 200 series) —— **Iron (GI,CGI,SS)**

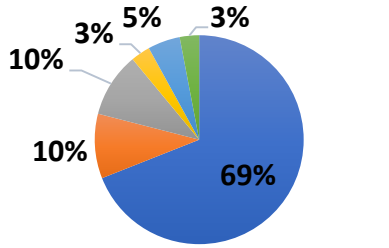
Motorsport

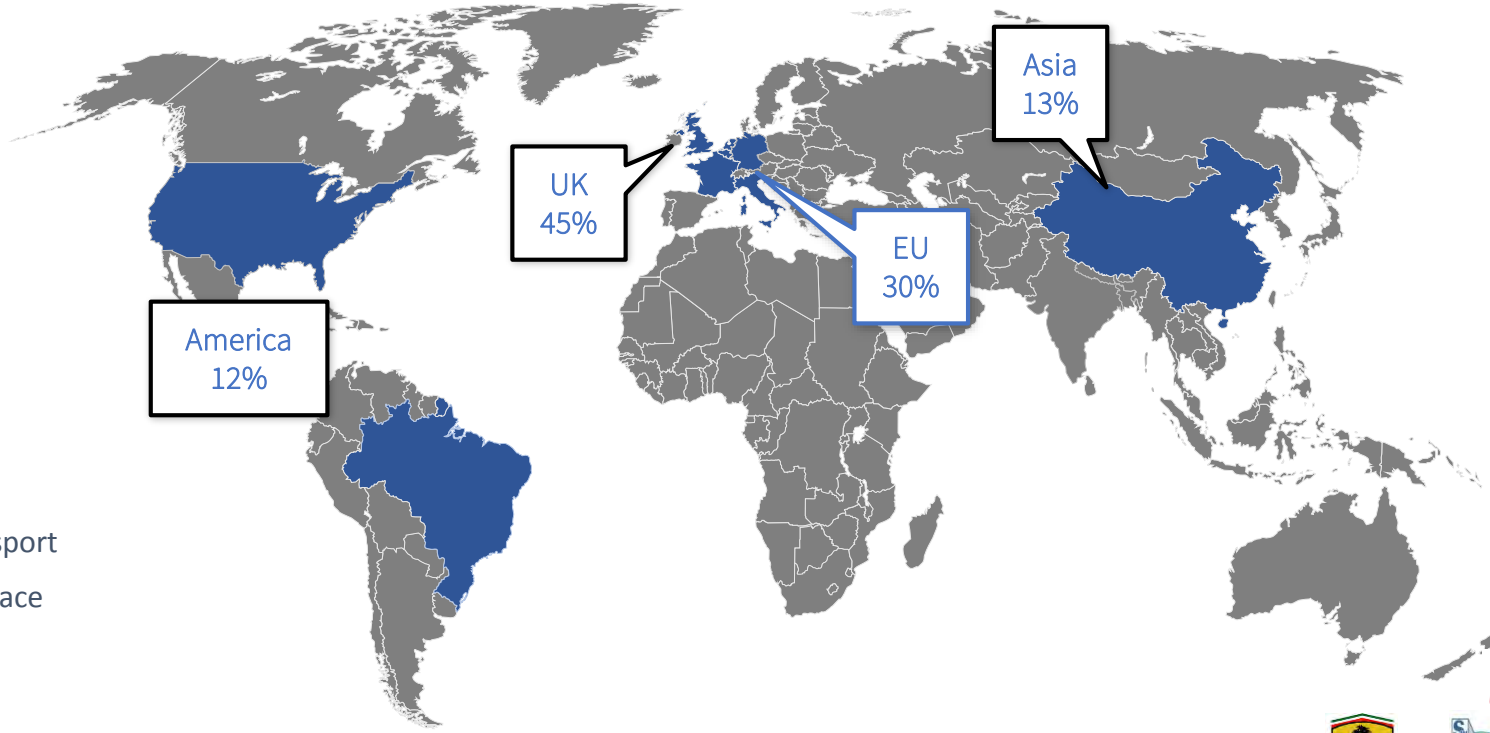
50-500 pcs annually

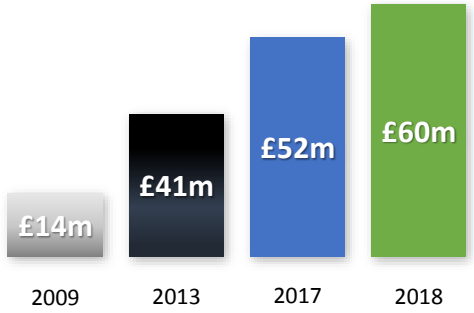
Design Support Engineering	Simulation Prototyping	Tooling Design/Manufacture	Sand Casting Gravity/LP	Validation Geometry/Integrity	Machining Assembly
					

COMPANY INTRODUCTION – GLOBAL AND MARKET SECTORS

G&W's global customer base, supporting the development of emerging technologies and markets.







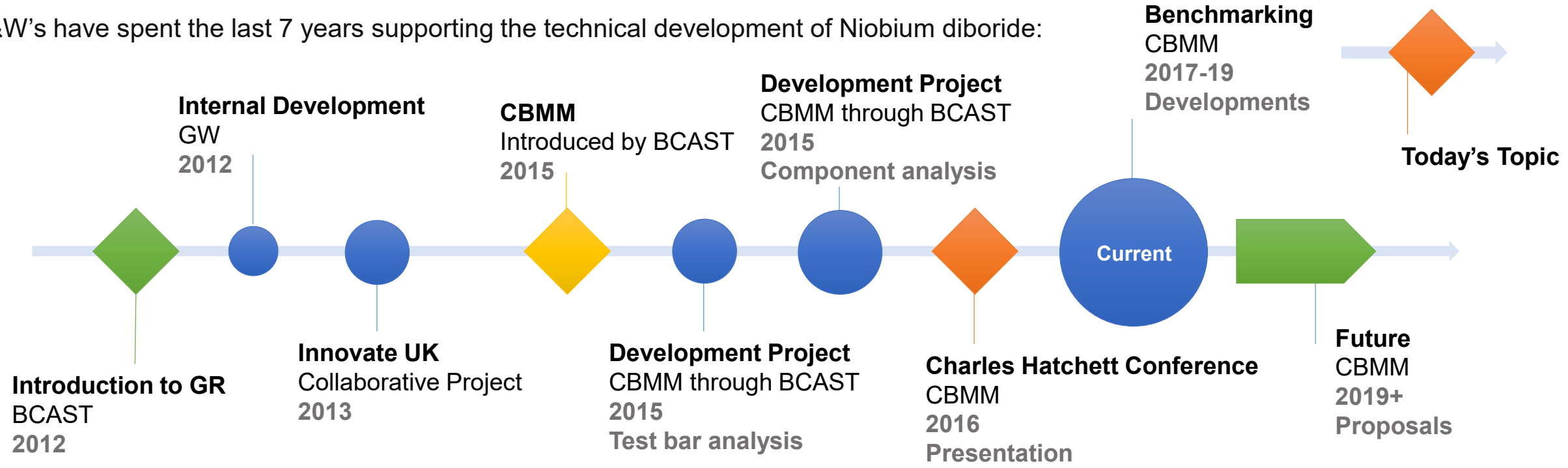
E.V Growth

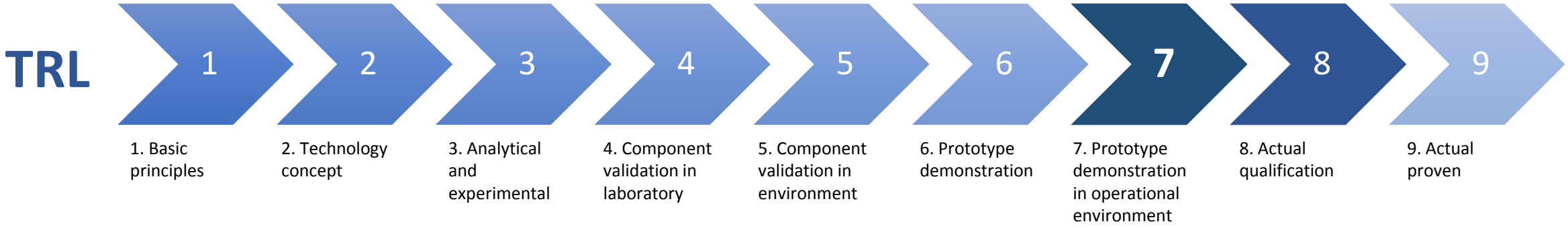
Hard to quantify due to enquiry classification, but based on data:

*Prototype Enquiries

COMPANY INTERACTION WITH NIOBIUM DEVELOPMENT

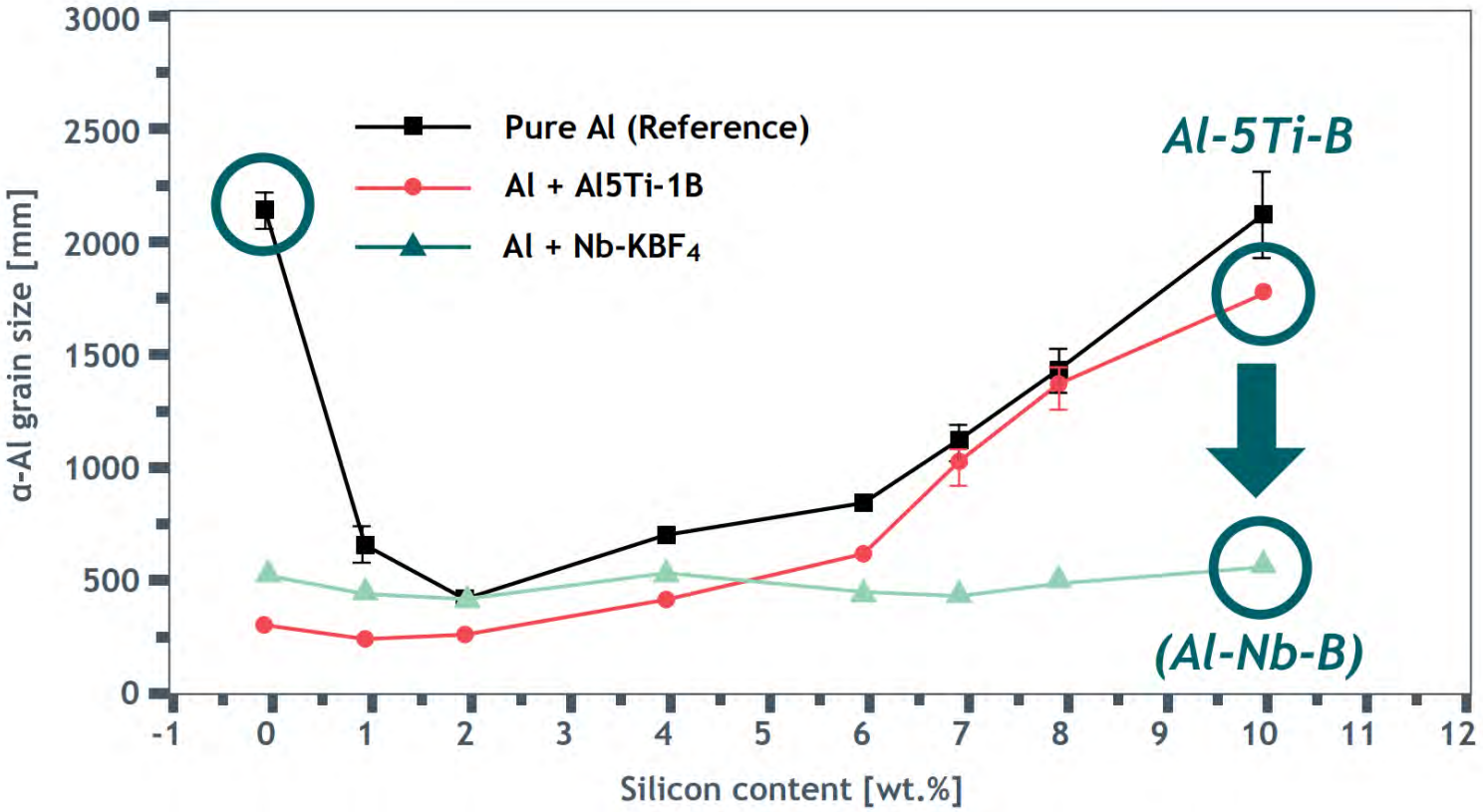
G&W's have spent the last 7 years supporting the technical development of Niobium diboride:





OVERVIEW PROJECT BASIS AND SCOPE

The industrial development of Niobium as a potential grain refiner comes from BCAST academic research.



Extensive research showed Niobium to significantly reduce the grain size in AlSi alloys over industry established Titanium grain refiner.

Reference; M. Nowak, L. Bolzoni , N. Hari Babu. Grain refinement of Al–Si alloys by Nb–B inoculation. Part I: Concept development and effect on binary alloys. Materials and Design 66 (2015) BCAST

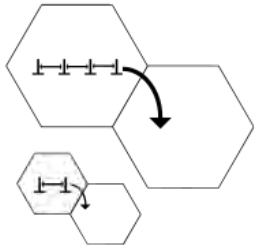
Note

Further reading available through CBMM website; Search ‘Niobium in Aluminium Cast Parts’

REVIEW OF METALLURGICAL PRINCIPLES

Hall Petch

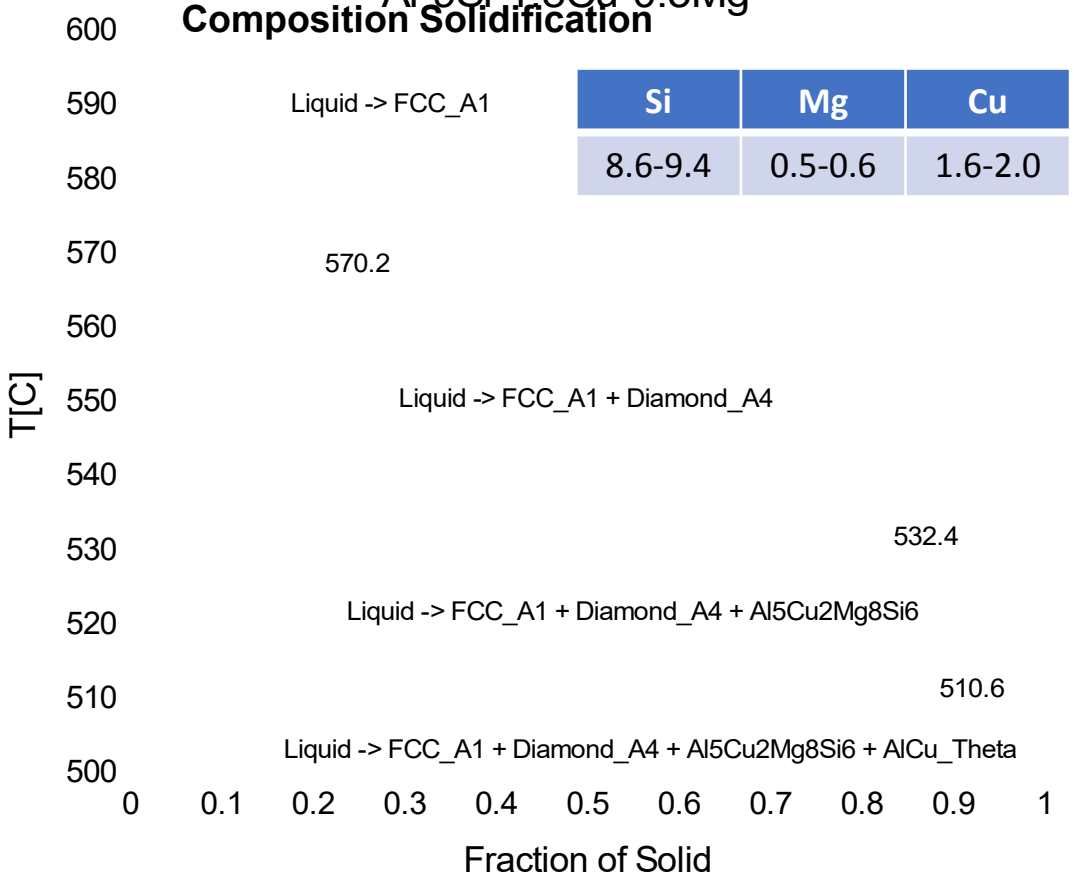
Piling up of dislocations
= larger driving force for slip



A brief introduction of solidification and nucleation of microstructure e.g. A354.

Al-9Si-1.8Cu-0.5Mg

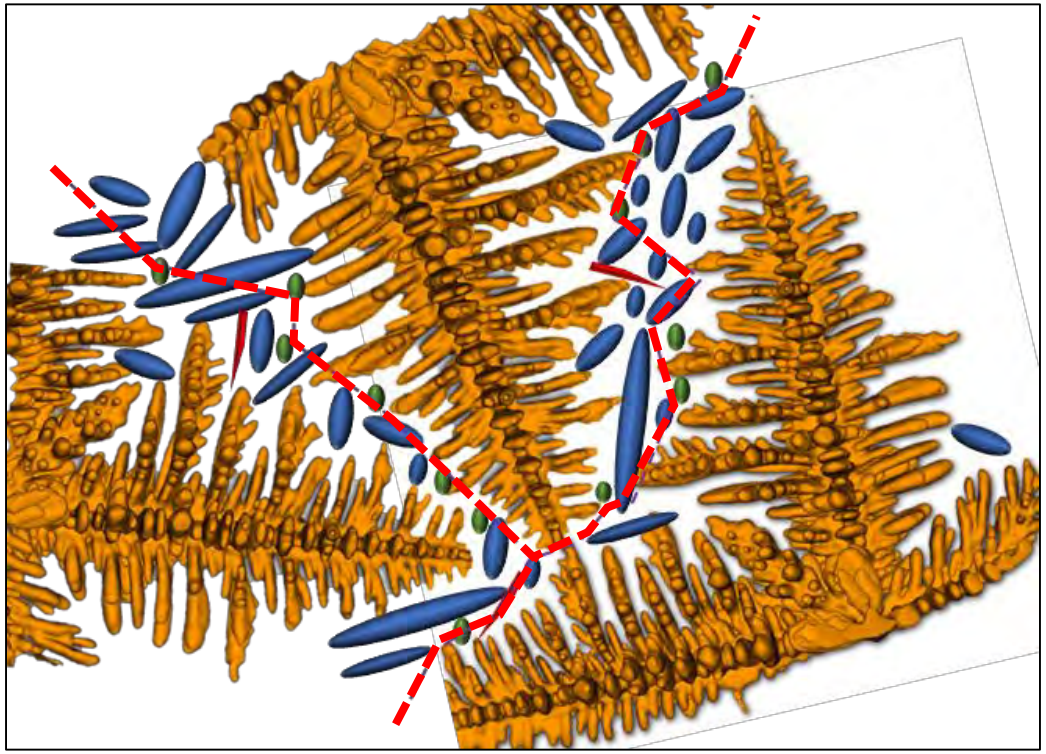
Composition Solidification



Si	Mg	Cu
8.6-9.4	0.5-0.6	1.6-2.0

- Good metal fluidity
- Long freezing range alloy
- High volume fraction of silicon eutectic

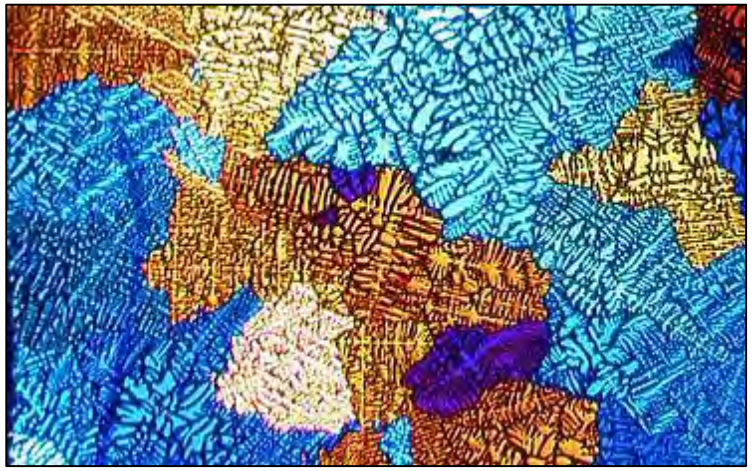
Microstructure Schematic – As Cast



Primary Strengthening Mechanisms

Hall Petch – Grain boundary/size/equiaxed – **NbB_2 reduces Grain Size**
Orowan – Dislocation slip strengthening

REVIEW OF TYPICAL HIGH STRENGTH SAND CASTING ALLOYS

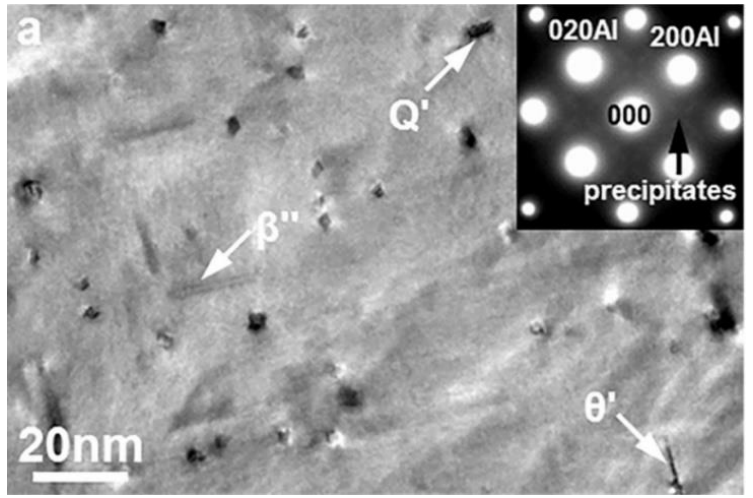


Typical alloys used in the casting industry, suitable for development:

A357 AlSi7Mg0.6 β-Mg2Si

A widely used alloy for automotive structural cast components due to its good strength, moderate ductility in the T6 condition and high thermal conductivity.

Density	2.67	g/cm^3	0.2% proof stress	270 - 300	MPa
Thermal Conductivity	151	W/m-K	UTS	310 - 330	MPa
			Elongation	1 - 7	%



A354 AlSi9Cu2Mg Q-AlSiMgCu, β-Mg2Si, θ (selected for project)

Specified for higher strength applications, especially for elevated temperature performance at compromise of thermal conductivity.

Density	2.71	g/cm^3	0.2% proof stress	290 - 310	MPa
Thermal Conductivity	126	W/m-K	UTS	340 - 360	MPa
			Elongation	1 - 4	%

Notes

Aluminium-silicon alloys are considered heterogeneous, as such will vary their structure/lattice/grains according to local conditions e.g. cooling rate, chemistry (grain refinement) and processing. When nucleation, microstructure and phase growth are controlled you can exploit the intrinsic mechanical properties.

OVERVIEW PROJECT BASIS AND SCOPE

The combination of previous work supported by G&W led to formalising a suitable benchmarking project.

➢ Opportunity

From observed **reduction in grain size** using NbB_2 (previous projects), can G&W increase the properties of large complex high strength castings.

➢ Project Scope

Focussed on exploitation into powertrain, an **i6 cylinder block** was chosen for the basis of comparing NbB_2 to foundry standard TiB2 (5:1). As to determine if Niobium grain refinement was a **direct superseding replacement**.

➢ Aims and Objectives

To understand the effect of the new grain refiner, with respect to measuring key **static/dynamic mechanical properties**.

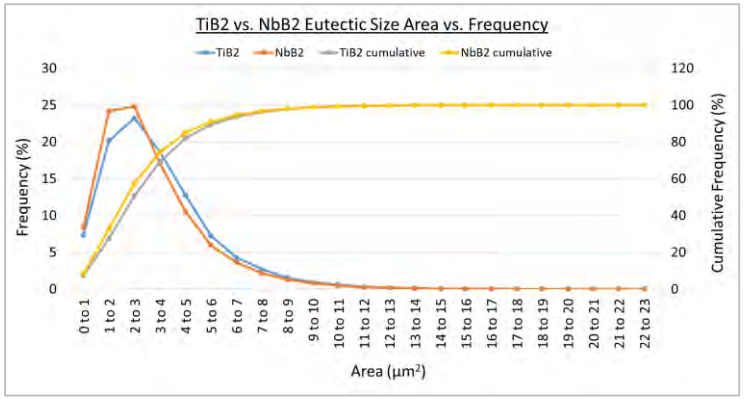
To practically and **quantitively benchmark** the alloys to a high level of control to then draw conclusions from **results/opportunities**.

➢ Deliverables

Following production level practises, **manufacture 5 cylinder blocks/grain refiner**.

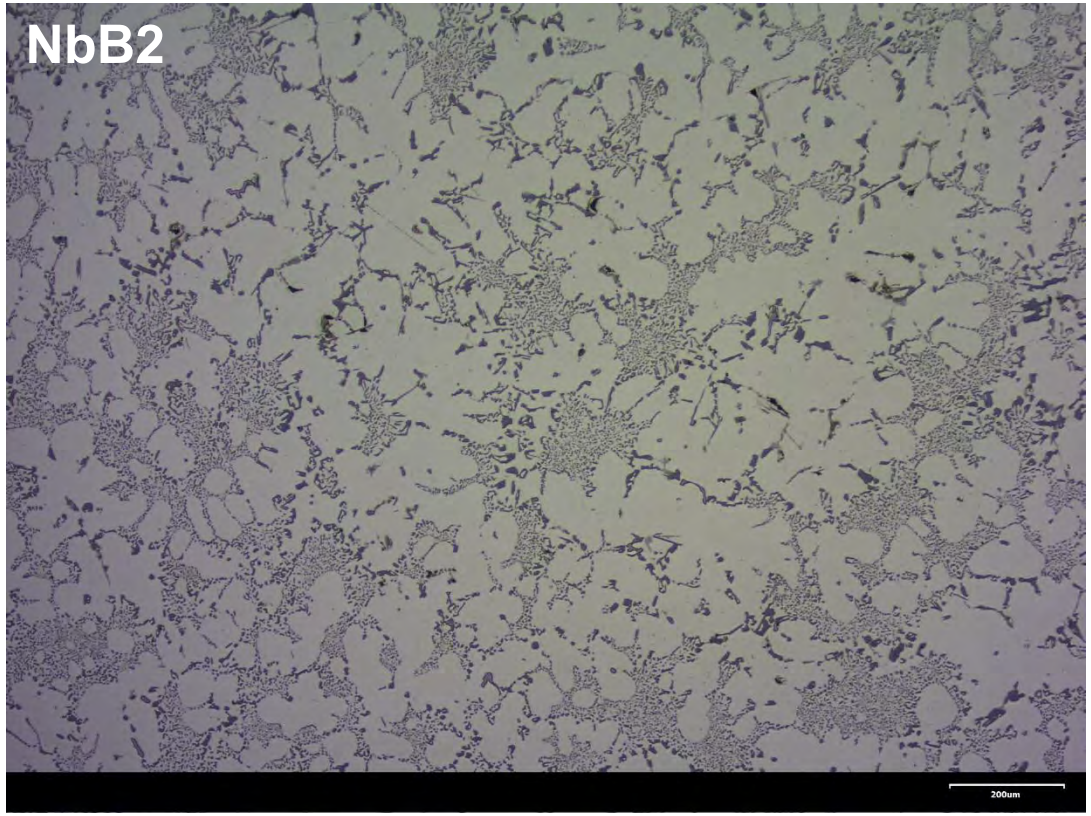
Perform **array of testing** to fully benchmark NbB_2 vs. TiB_2.

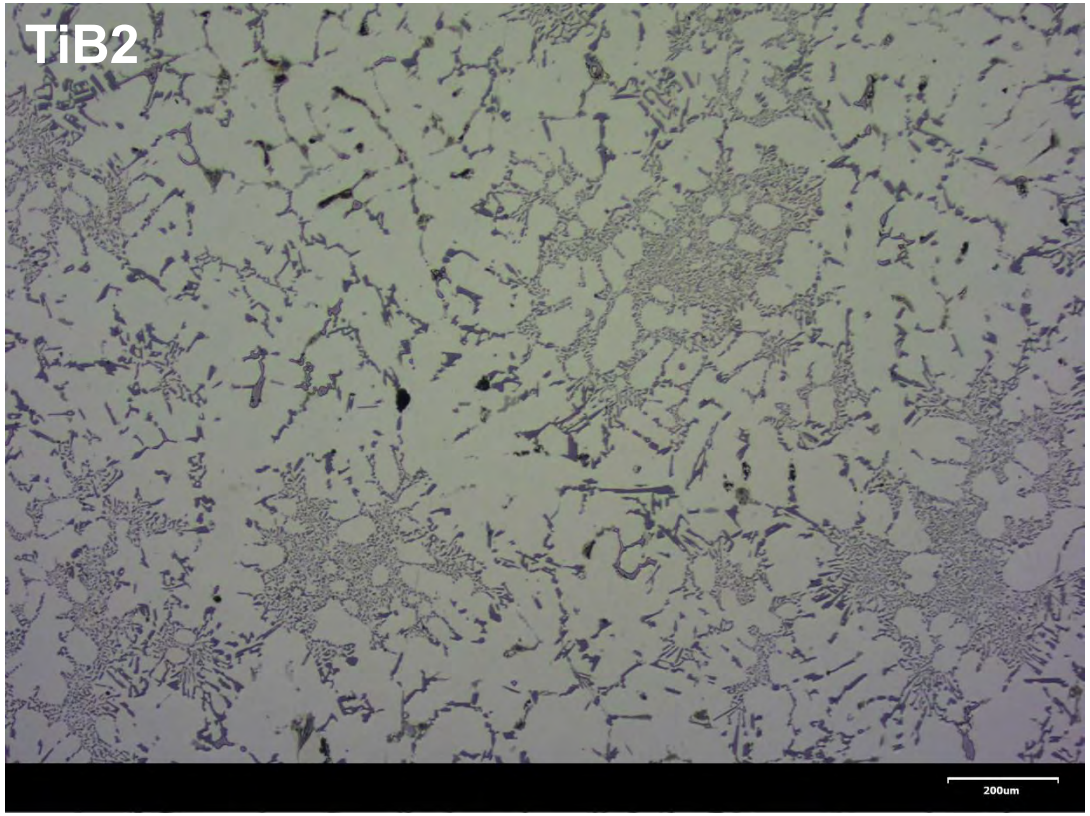
PROJECT RESULTS – MICROSTRUCTURE INSPECTION



Once castings were manufactured and post processed, sections were extracted from a designated high solidification rate area to review the effect of the grain refiners. Results:

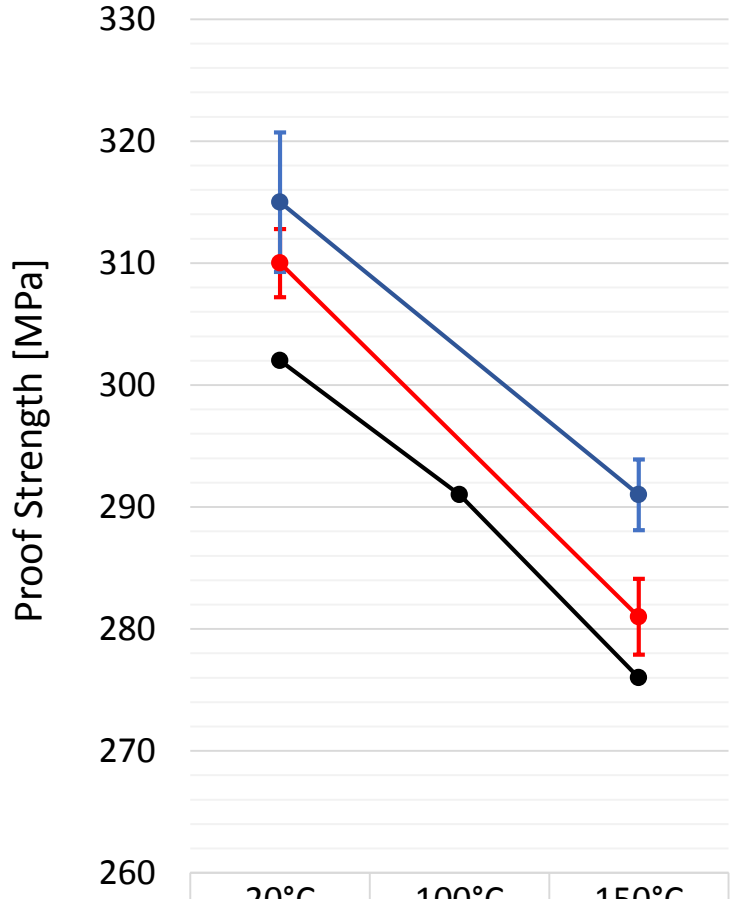
- Grain size - reduction Av. dendrite size ~ 170 mm NbB_2 vs. ~285mm TiB2
- High volume fraction (5%) of smaller silicon eutectic particles in NbB_2



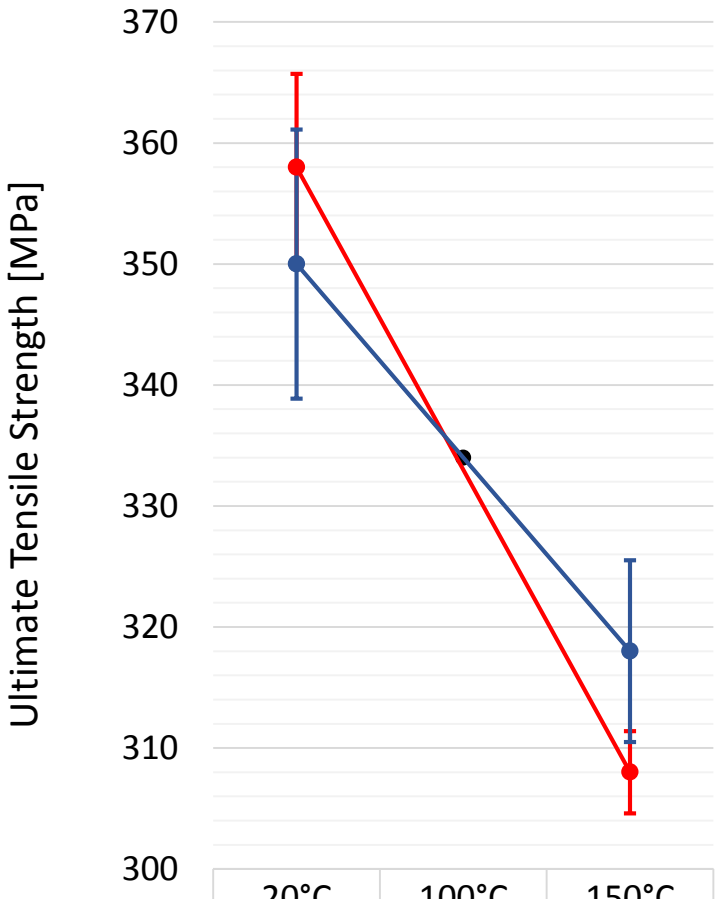


PROJECT RESULTS – MONOTONIC MECHANICAL PROPERTIES

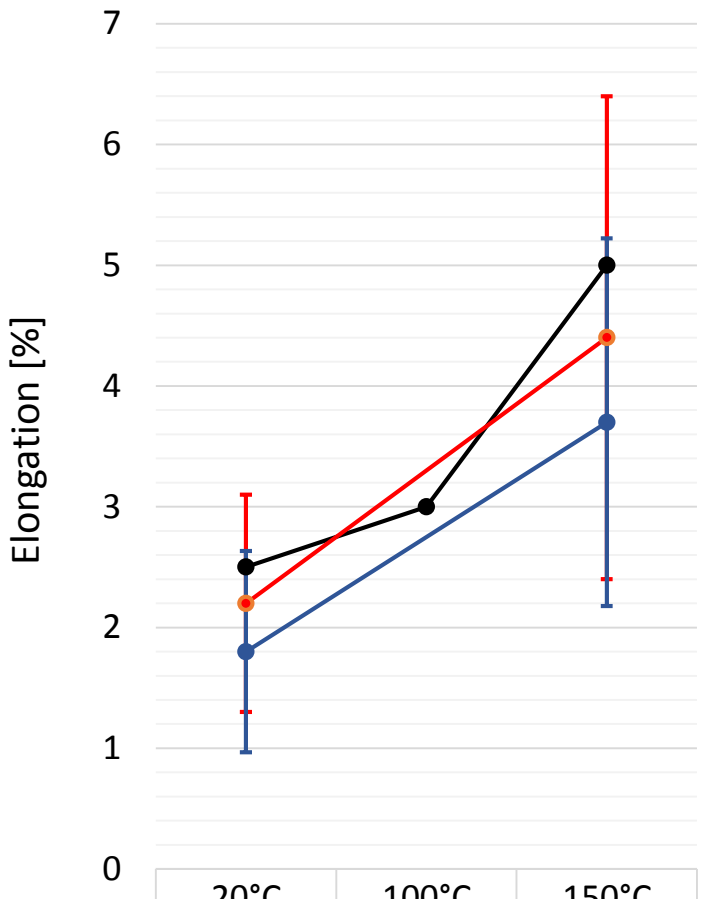
N=10/variant



	20°C	100°C	150°C
Dataset PS	302	291	276
NbB2 PS	310		281
TiB2 PS	315		291



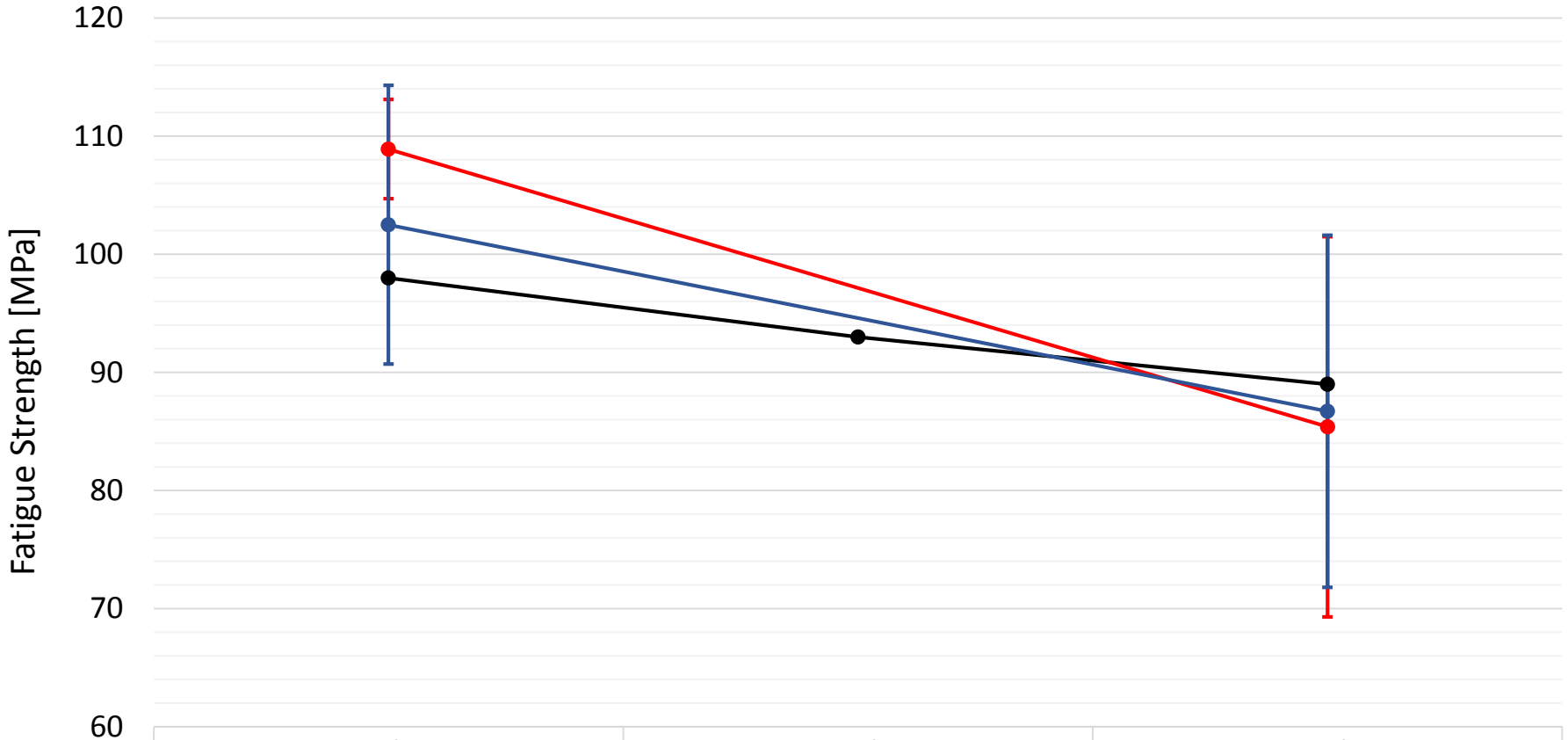
	20°C	100°C	150°C
Dataset UTS	350	334	318
NbB2 UTS	358		308
TiB2 UTS	350		318



	20°C	100°C	150°C
Dataset E	2.5	3	5
NbB2 E	2.2		4.4
TiB2 E	1.8		3.7

PROJECT RESULTS – DYNAMIC MECHANICAL PROPERTIES – ENDURANCE LIMIT

N=15/variant

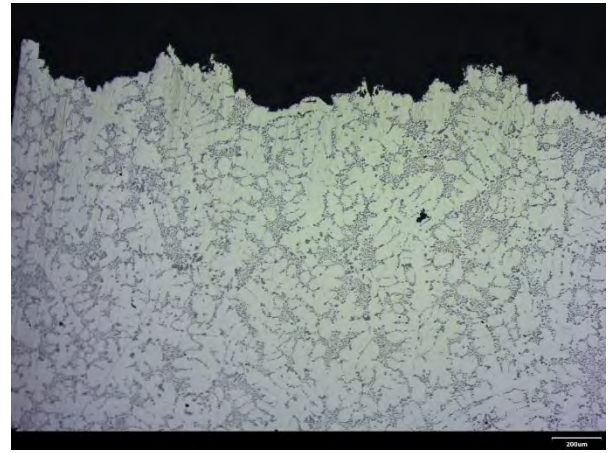


	20°C	100°C	150°C
Dataset FS	98	93	89
NbB2 FS	108.9		85.4
TiB2 FS	102.5		86.7

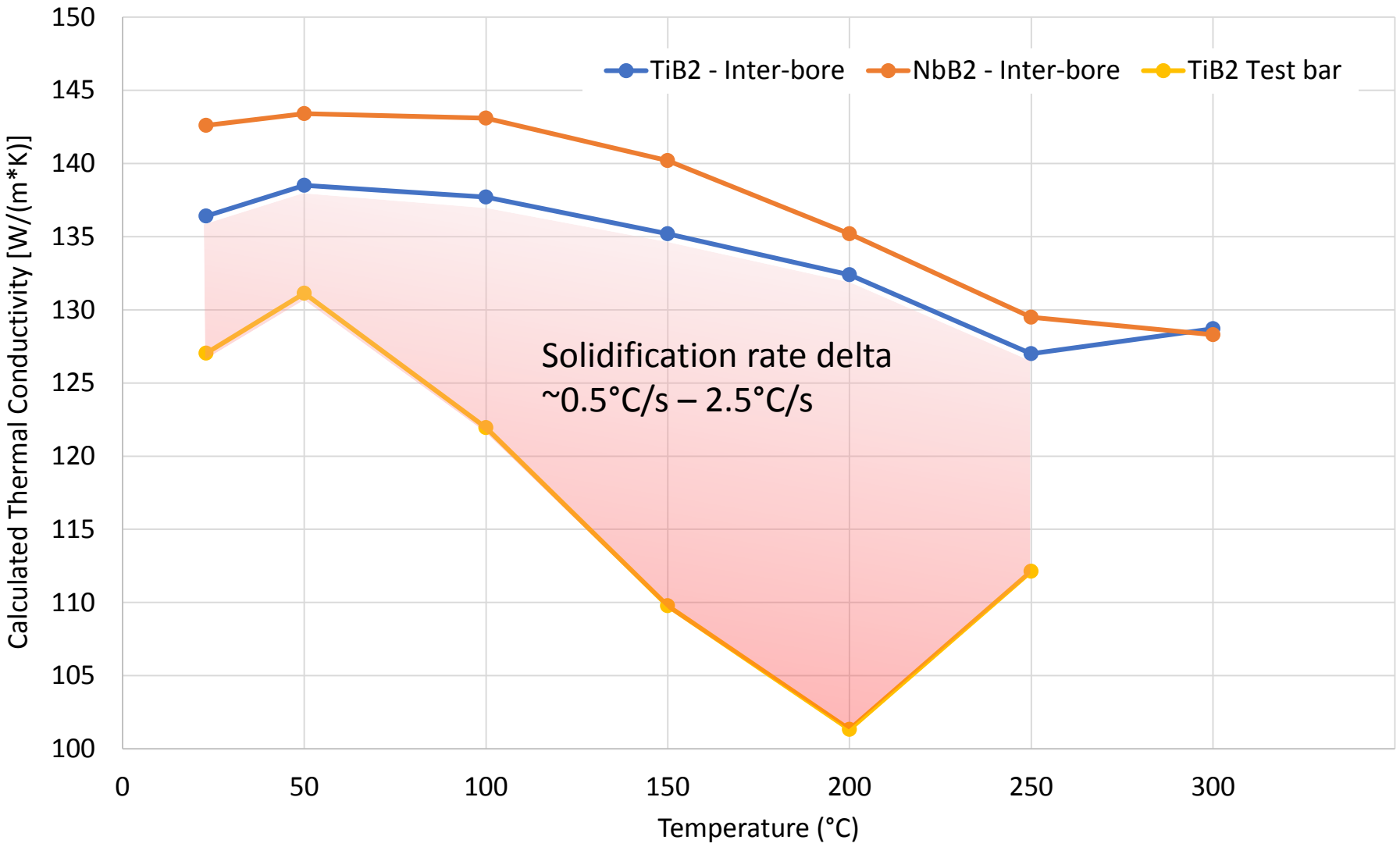
Supporting Measurement

Fractography

Microstructure Analysis



THERMAL RESPONSE RESULTS – THERMAL CONDUCTIVITY



Thermal conductivity was calculated using the thermal diffusivity, density, and heat capacity of the material.

Theoretical/dataset value of 126 W/m.K shown to not be accurate.

Conclusions

5% increase (up to 150°C) in thermal conductivity with NbB_2.

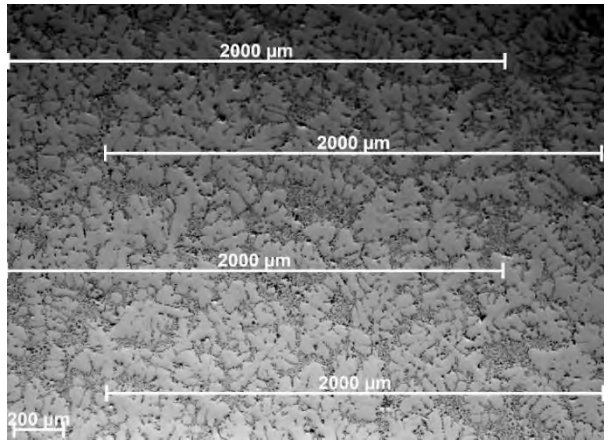
Solidification rate influences thermal conductivity.

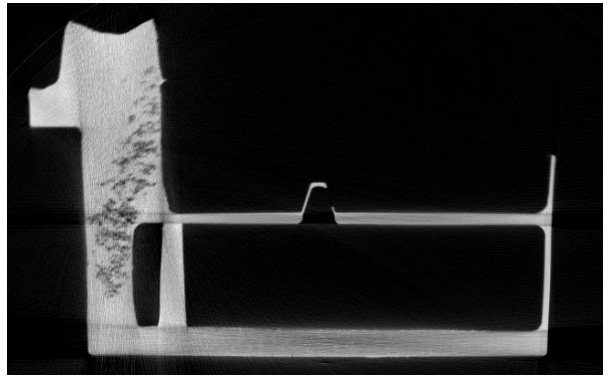
ASSUMPTIONS & CONCLUSIONS

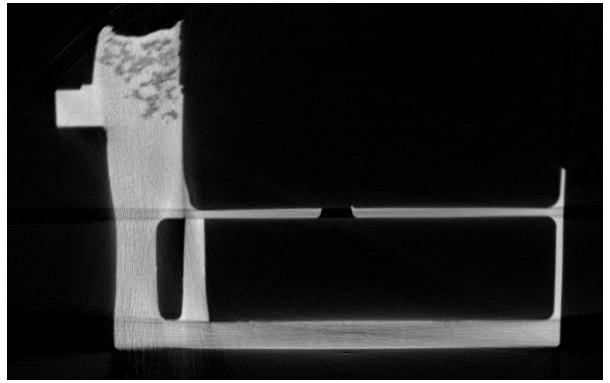
From the work package the following assumptions and conclusions were made.

- Reduced grain size from NbB_2 showed to have some positive/negative effect on mechanical properties, mainly reduction in deviation.
- Increase in thermal conductivity associated to NbB_2 reduction in grain size.
- Currently not able to achieve same mechanical properties as TiB2.
  - Solution/Precipitation response kinetics have changed from having reduced grain size. Finer grain structure needs shorter time for SSSS and longer time for fine precipitation.
  - Further work underway to explore HT effect – Supported by BCAST/CBMM.
- Not realised/measured in study, but feeding efficiency thus material integrity had increased.
- There is a potential advantage of using this grain refiner over existing TiB_2, perhaps not fully realised in this study.

NbB2 is still in development / optimisation phase





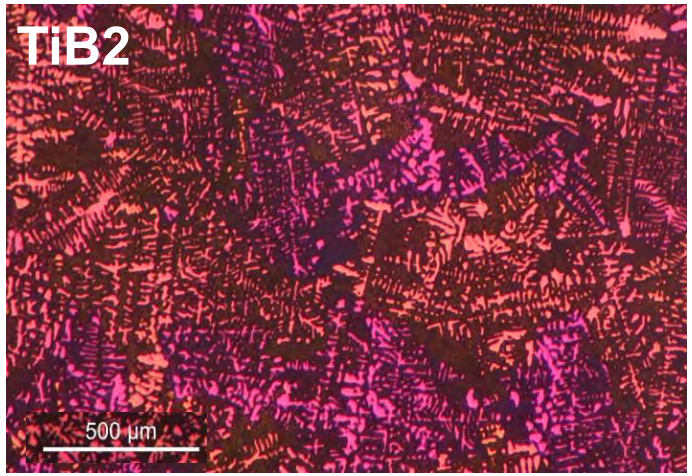


FURTHER DEVELOPMENTS – EXPLOITATION IN OTHER AREAS – CASE STUDY

G&W have also been actively developing NbB_2 internally, with most significant advances made in the following:

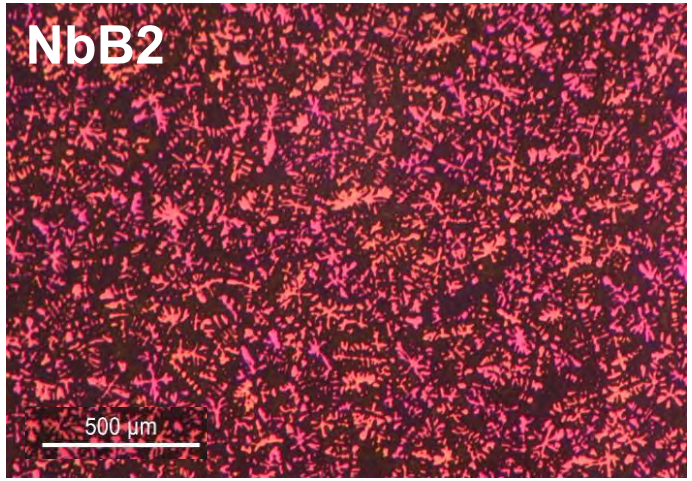
Body in White

Longitudinal BIW castings



Highlights:

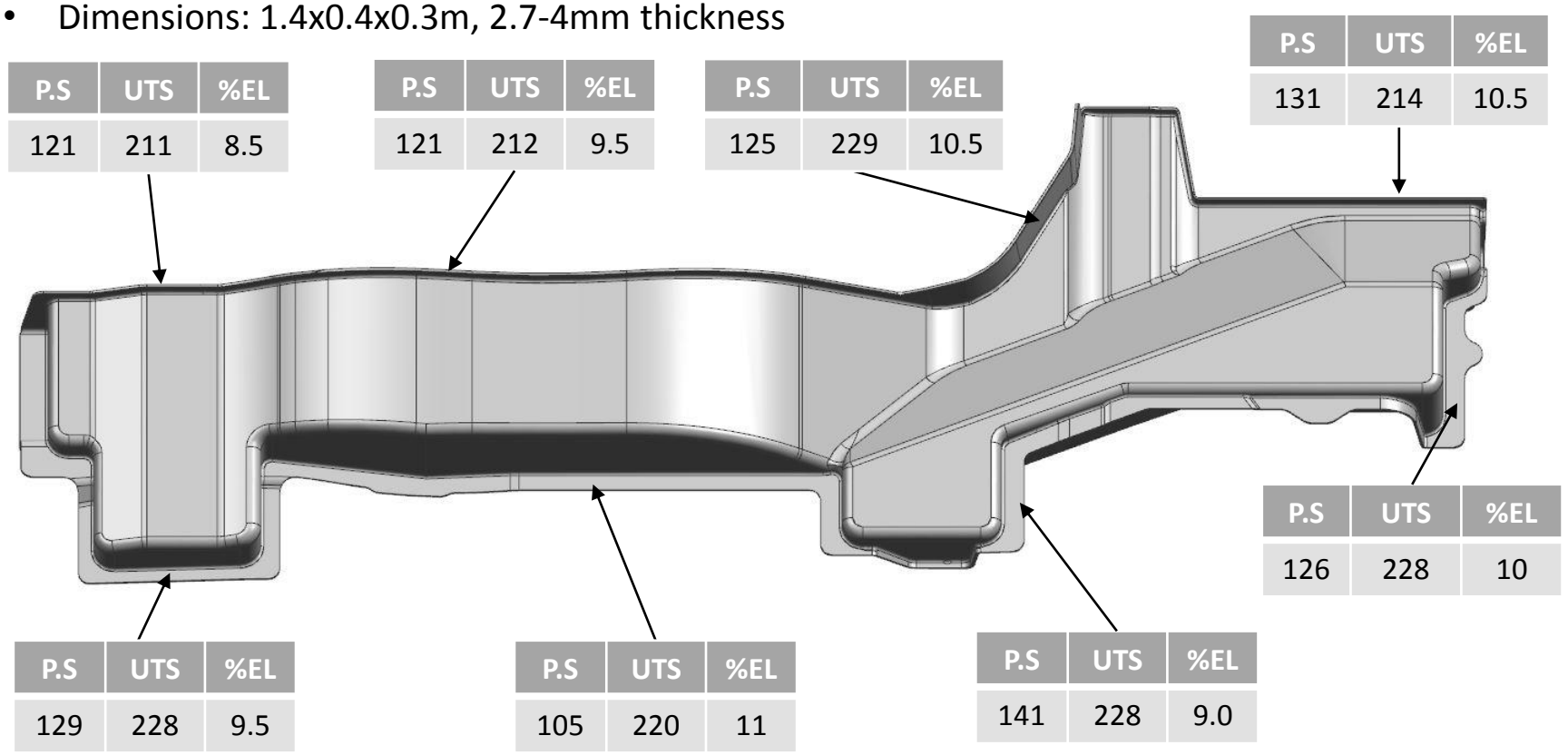
- Developed optimised NbB_2 containing alloy, compositionally similar to HPDC.
- Able to cast thin wall sections, across large distances – currently up to 1.5m.
- Very little post processing required – mitigated influence of heat distortion.
- Potential competitive edge in prototype / low supply market place associated to lead time & representable HPDC properties.
- Currently 6 month confirmed forecast to manufacture ~1600 complex castings.
- Commercially hold NbB_2 as a stock item – G&W were the first customers.



FURTHER DEVELOPMENTS – EXPLOITATION IN OTHER AREAS – CASE STUDY 1

Developments in this area towards manufacturing gravity sand castings with similar properties to HPDC - EN AC-43500:

- Net Weight: 10.5kg
- Dimensions: 1.4x0.4x0.3m, 2.7-4mm thickness



P.S	UTS	%EL
121	211	8.5

P.S	UTS	%EL
121	212	9.5

P.S	UTS	%EL
125	229	10.5

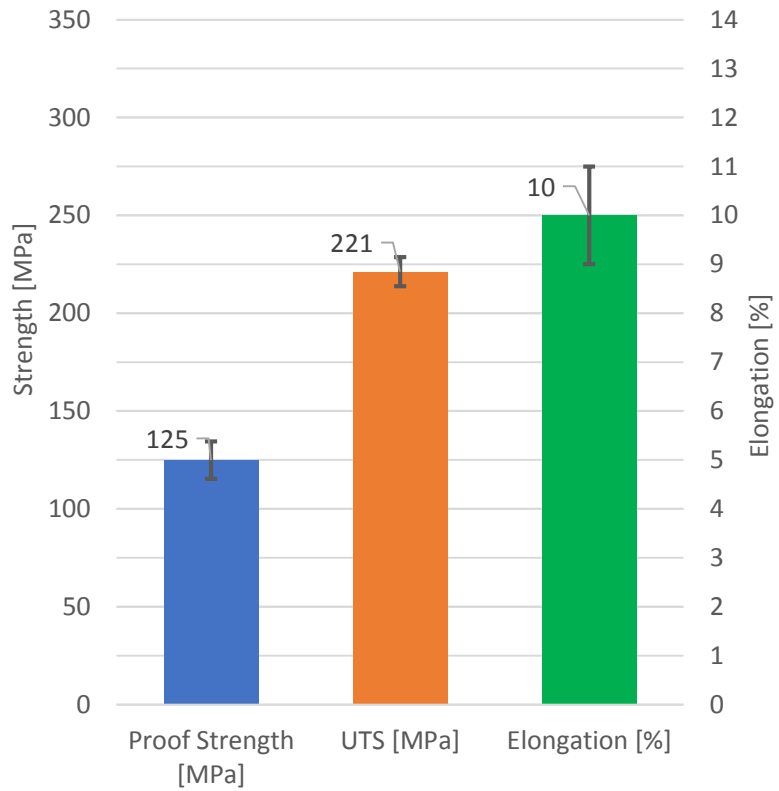
P.S	UTS	%EL
131	214	10.5

P.S	UTS	%EL
126	228	10

P.S	UTS	%EL
129	228	9.5

P.S	UTS	%EL
105	220	11

P.S	UTS	%EL
141	228	9.0



Conclusions

Optimised alloy and process means G&W are able to offer HPDC representable BIW chassis prototype castings to market.

GRAINGER & WORRALL

Thank you for Listening

If you have any enquiries related to technical or supply please contact me;

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