Adding Value Through Metal Casting Innovation

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Company Overview

A W Bell is a global supplier of complex metal parts with high mechanical properties to aerospace, defence, space & biomedical industries.

To be the most innovative and customer-focused supplier of quality casting solutions globally.

Company Vision

AW Bell Group

Outline of Today's Presentation

- Development of High Strength & Ductility in HPDC Al-Si-Mg Alloys from Secondary Sources
- Development of a New High Strength Aluminium Alloy Suitable for Aerospace Applications
- New Aluminum Alloy for High Thermal Conductivity
- A New Initiative: Titanium

Development of High Strength & Ductility in HPDC Al-Si-Mg Alloys from Secondary Sources

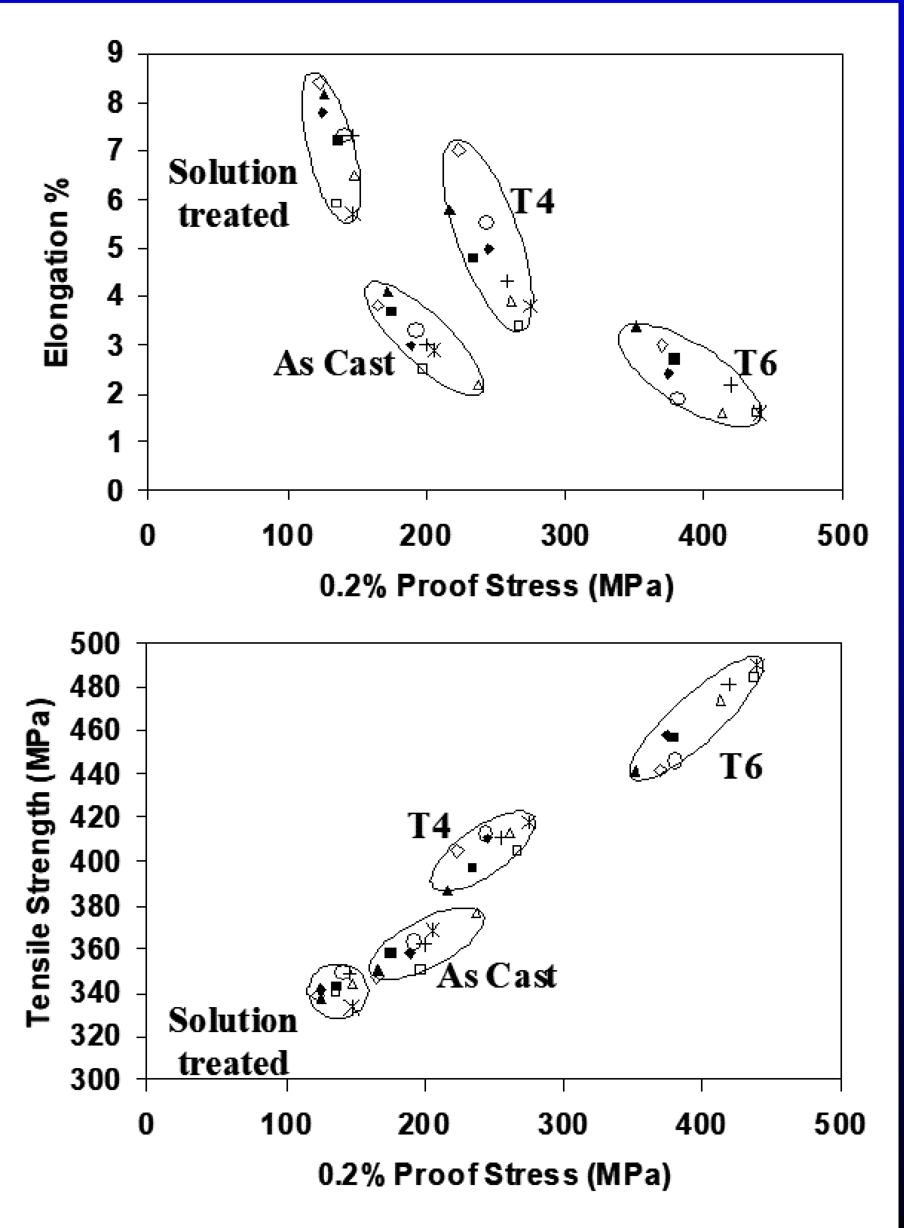
R.N. Lumley, JOM, vol.71,#1, p.382, 2018.

Early Work on Heat Treating Diecastings

Typical behaviour for high pressure diecastings in

As Cast
As solution treated
T4
T6

9 compositions shown
Both commercial and experimental alloys



Lumley et.al. 2005-2010

Basis of the Investigation

- **The price of Troma (shredded wheel scrap) historically is significantly lower than aluminium alloy LME price.**
- **Can wheel scrap be converted into a high quality diecasting and bypass the 40% premium of Aural 2 or Silafont?**

Up to 20 million tons by 2030

Project work conducted 2011

A356 Alloy Compared to the Alloys Tested

Alloy / w%	Si	Fe	Cu	Mn	Mg	Zn	Other each	Other Total
A356 (ranges)	6.5-7.5	0.20 max	0.20 max	0.10 max	0.20-0.45	0.10 max	0.05	0.15
A356 (typical)	7.0	0.15	0.05	0	0.30	0	0.03	<0.1
Alloy 1	7.72	0.39	0.12	0.47	0.20	0.18	--	--
Alloy 2	7.99	0.40	0.10	0.47	0.21	0.38	--	--
Alloy 3	7.73	0.39	0.33	0.47	0.20	0.37	--	--
Alloy 4	7.73	0.38	0.29	0.46	0.40	0.36	--	--
Alloy 5	8.72	0.38	0.39	0.46	0.39	0.53	--	--
Alloy 6	8.75	0.33	0.51	0.46	0.40	1.48	--	--

Ferro Mangnese: 20/80
Ferro Silicon: 25/75
Fe-Si-Mg: ~25/~70/~5

} Makes A356 diecastable.

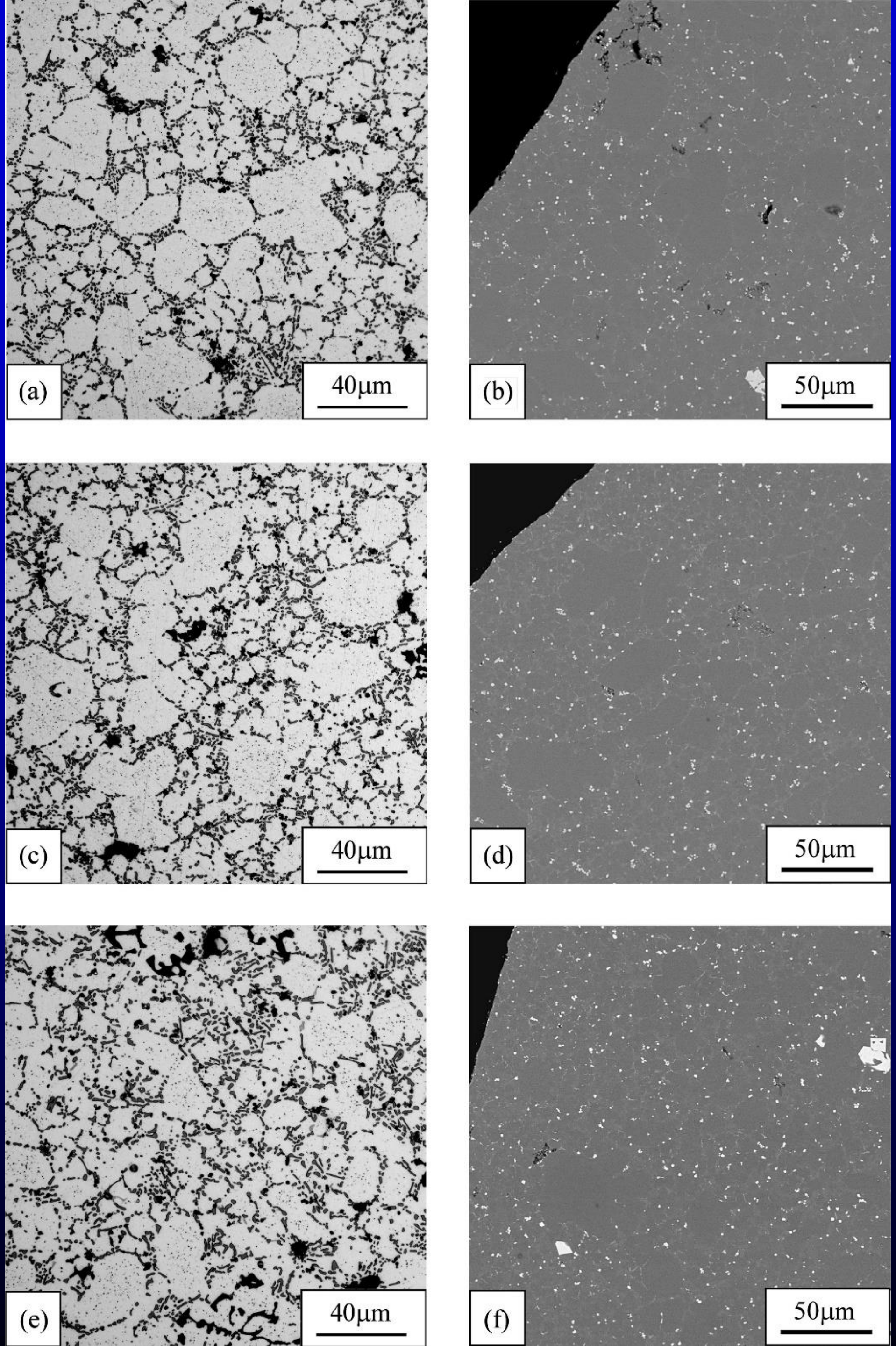
A sludge factor value of 1.2-1.4 was maintained. (SF = 1xFe+2xMn+3xCr)
Cu and Zn was included as a likely contaminant.
FeMn or FeSi can be used to maintain Fe or Mn values.

Typical Properties of Standard Diecasting Alloys Using the Same Casting Parameters

Alloy	0.2% Proof Stress (As Cast)	Tensile Strength (As Cast)	Elongation (%)
A380	172	354	4%
A383	170	338	3.5%
A360	178	310	3.5%

Toshiba 250T Cold Chamber machine (CSIRO). Metal Velocity at the Gate 82 m/s

Distribution of iron bearing phases was fairly homogeneous



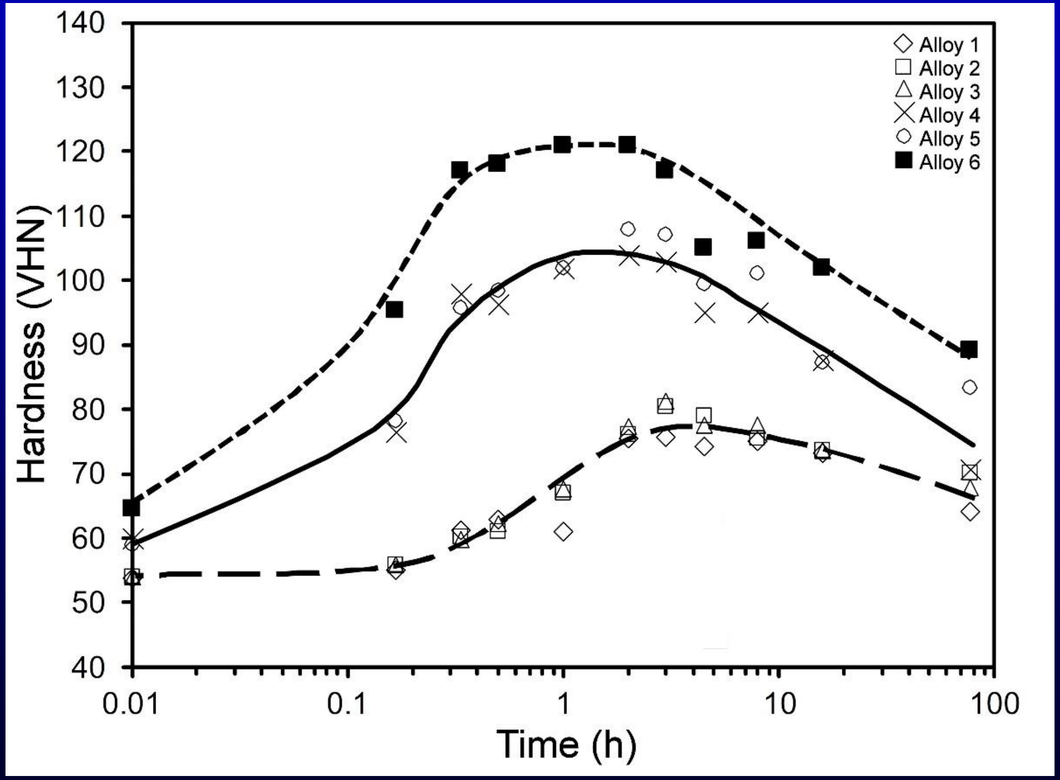
Optical and Backscattered SEM respectively of heat treated microstructures of Alloy 1 (a, b), Alloy 4 (c, d), Alloy 6 (e, f). The optical microstructures (a, c, e) show the morphology and distribution of the Si phase (dark), whereas the SEM images (b, d, f) show the morphology and distribution of the (Fe + Mn) bearing alpha phase $Al_{15}(Mn,Fe)_3Si_2$ (white).

Heat treatment responses.

Solution Treatment 485°C, age at 180°C

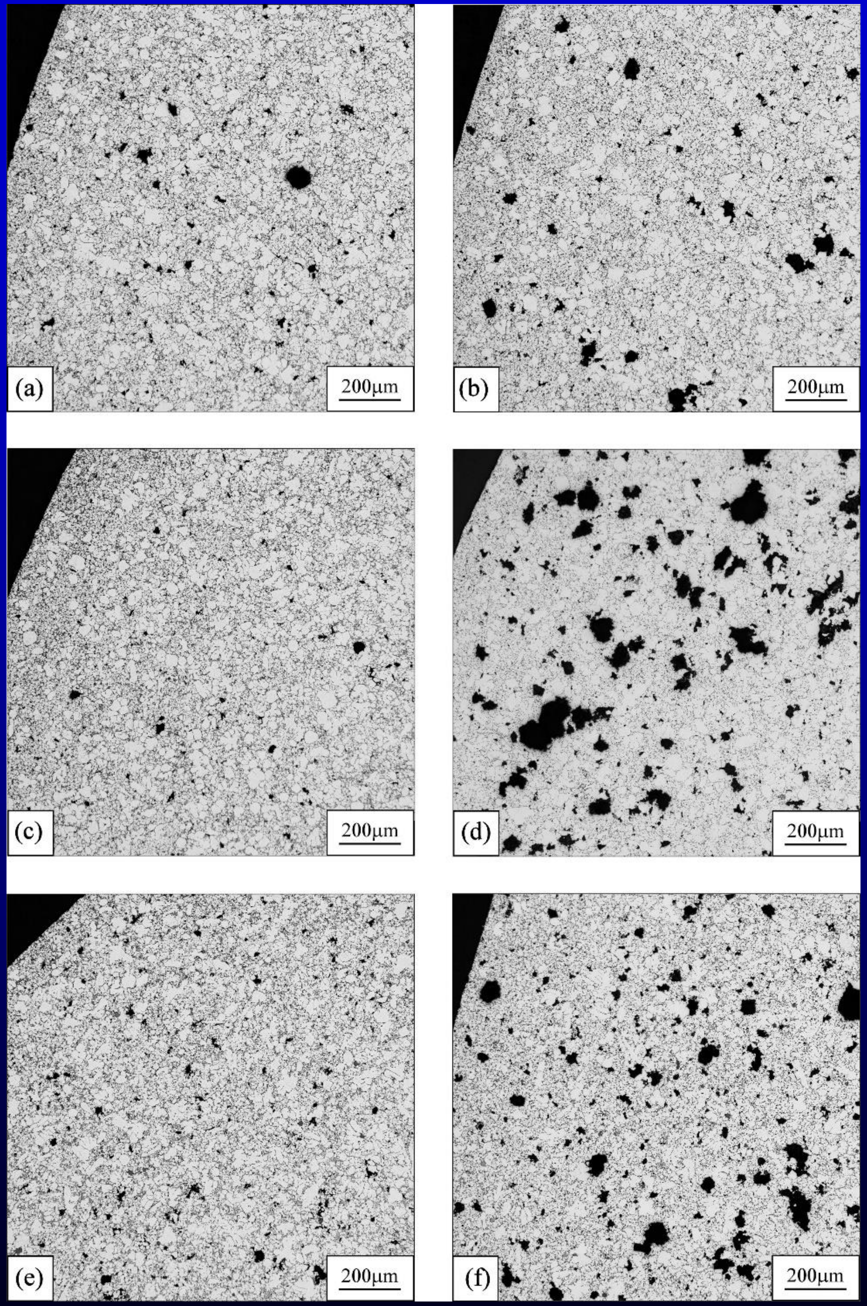
Three Trends

Alloy / w%	Si	Fe	Cu	Mn	Mg	Zn
Alloy 1	7.72	0.39	0.12	0.47	0.20	0.18
Alloy 4	7.73	0.38	0.29	0.46	0.40	0.36
Alloy 6	8.75	0.33	0.51	0.46	0.40	1.48



Effect of Solution Treatment Temperature

Alloy / w%	Si	Fe	Cu	Mn	Mg	Zn
Alloy 1	7.72	0.39	0.12	0.47	0.20	0.18
Alloy 4	7.73	0.38	0.29	0.46	0.40	0.36
Alloy 6	8.75	0.33	0.51	0.46	0.40	1.48



Microstructures near the edge of samples in equivalent positions for:
(a, b) alloy 1 solution treated at 485°C & 545°C, respectively;
(c, d) alloy 4 solution treated at 485°C and 545°C, respectively; (e, f) alloy 6 solution treated at 485°C and 545°C, respectively.

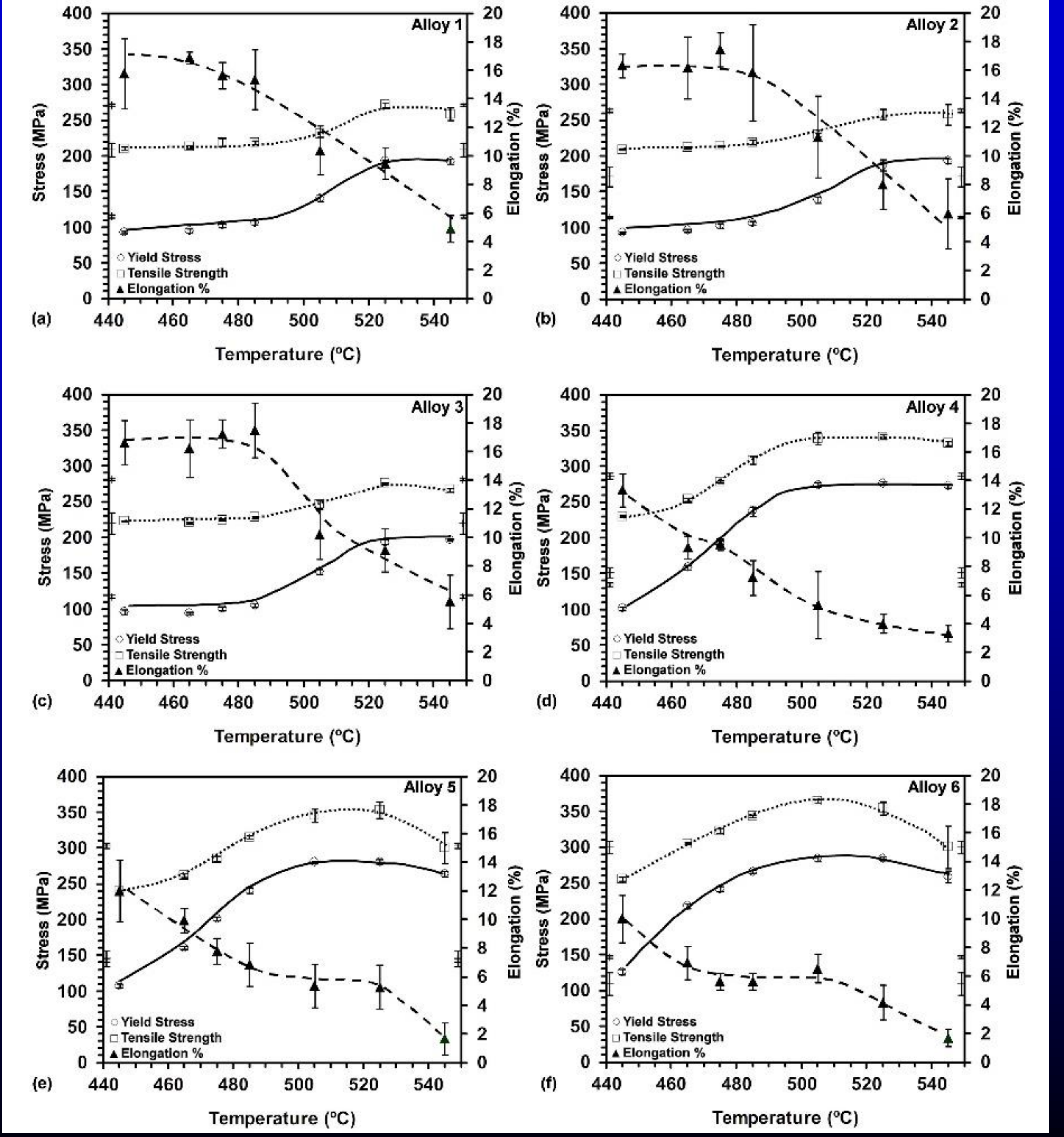
Mechanical properties of the six alloys as-cast or T4 heat treated

Solution Treat 505°C 15 minutes, CWQ, 14d at 25°C

Alloy	0.2% Proof Stress	Tensile Strength	Elongation (%)	notes
A356-T61 minimum*	179	262	5%	Separately cast test bars
356-T6 minimum*	152	228	3%	Separately cast test bars
Alloy 1 as cast	116 (2.1)	272 (1.8)	10.5% (0.45)	Separately cast test bars
Alloy 2 as cast	115 (1.4)	264 (3.0)	8.6% (0.67)	
Alloy 3 as cast	118 (2.1)	282 (1.7)	11% (0.75)	
Alloy 4 as cast	135 (2.5)	286 (4.0)	7.6% (0.35)	
Alloy 5 as cast	143 (1.8)	303 (3.2)	7.3% (0.55)	
Alloy 6 as cast	147 (2.2)	300 (8.4)	5.5% (0.81)	
Alloy 1 T4	97 (3.8)	227 (6.3)	14.3 (4.9)	Separately cast test bars
Alloy 2 T4	98 (0.9)	230 (3.1)	15.7 (2.3)	
Alloy 3 T4	103 (2.3)	244 (2.7)	16.6 (1.9)	
Alloy 4 T4	142 (1.6)	289 (11.5)	13.1 (3.6)	
Alloy 5 T4	141 (1.0)	293 (5.9)	11.6 (1.8)	
Alloy 6 T4	159 (3.1)	313 (2.4)	10.6 (1.1)	

*ASTM B108

Mechanical Properties as a Function of Solution Treatment Temperature for Six Alloys



Solution treatment temperature can be reduced.
High ductility can be developed.
Excellent combinations of mechanical properties.

Note 150/250/10

Conclusions

- Alloys based on scrap A356 alloy (Troma) may be made die-castable by small additions of common foundry additions such as ferro-manganese and ferro-silicon. This allows the alloys to be cast conventionally without die soldering.
- The alloys investigated may show excellent combinations of mechanical properties and potentially be candidates for structural diecastings.
- Some alloys examined may provide excellent combinations of high strength and elongation.
- For example, alloy 6, when solution treated at 505°C and aged 2 h at 180°C, produced average properties of 284 MPa yield strength, 365 MPa tensile strength and 6.5% elongation. Such an alloy and heat treatment combination has equivalent tensile mechanical properties to some grades of aerospace castings.

Sir George Julius Award for Best Paper in Mechanical Engineering

R.N. Lumley, The Development of High Strength and Ductility in High Pressure Diecast Al-Si-Mg Alloys from Secondary Sources, JOM, vol.71,#1, p.382-390, 2018.

Development of a New High Strength Aluminium Alloy Suitable for Aerospace Applications

New Aluminum Alloy

Goals: Y.S. > 380 MPa (55 KSI)
UTS > 450 MPa (65 KSI)
Elongation ≥ 3%

Castability similar to A356 / 357
Low distortion during heat treatment
Low cost to manufacture.

A357 Strength Class 12:
typical Y.S. = 241 MPa (35KSI), UTS = 310 MPa (45KSI), El.=3%

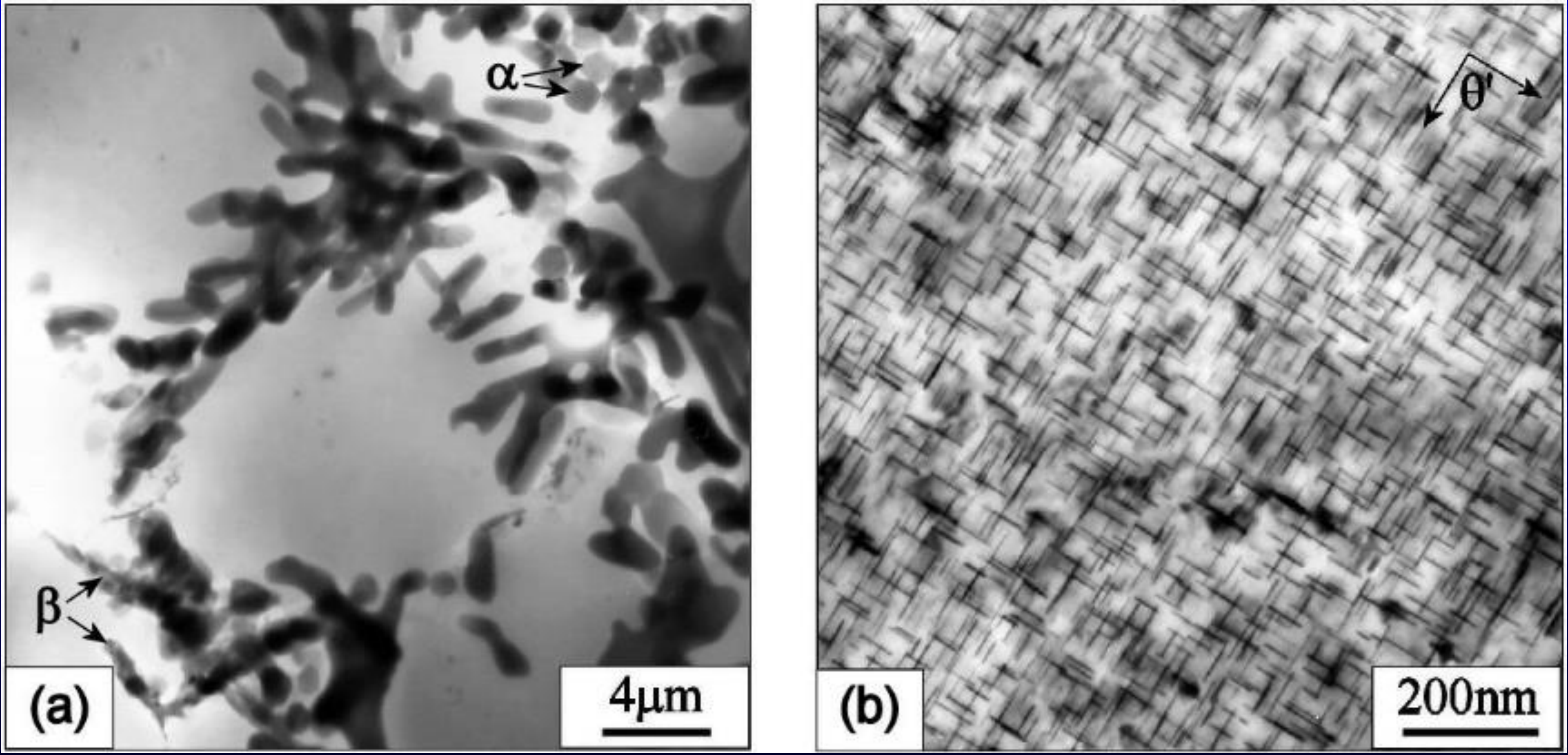
Hypothesis:

Can we produce high strength Al-Si-Cu alloys suitable for investment and sand casting?

Alloys such as A380 and C380 are considered unable to be successfully cast by sand or investment casting and have poor ductility. Heat treated diecastings in this family can however have excellent properties.

Design alloys within the composition ranges that are suitable for the process.
Use a premium investment casting process.

In Al-Si-Cu Alloys Mechanical Properties are Complex, and Compos



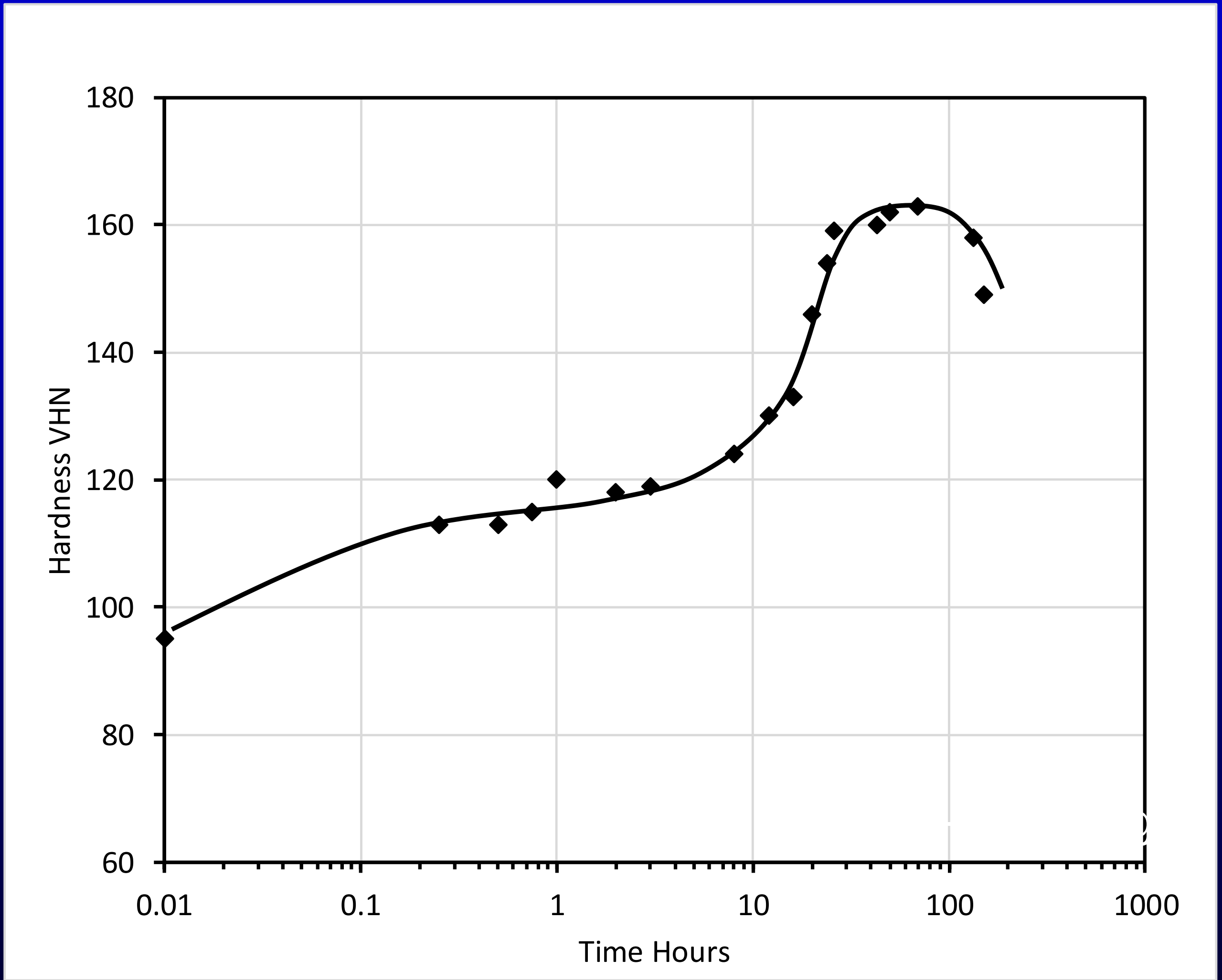
Lumley et. al, 2006

Composition Limits of Some Registered HPDC Alloys

Alloy / w%	Si	Fe	Cu	Mn	Mg	Ni	Zn	Sn	Other total
A380 (US)	7.5 - 9.5	Max 1.3	3.0-4.0	Max 0.5	Max 0.1	Max 0.5	Max 3	Max 0.35	Max 0.5
C380 (US)	7.5 - 9.5	Max 1.3	3.0-4.0	Max 0.5	0.1-0.3	Max 0.5	Max 3	Max 0.35	Max 0.5
A383 (US)	9.5-11.5	Max 1.3	2.0-3.0	Max 0.5	0.1-0.3	Max 0.5	Max 3	Max 0.15	Max 0.5
383 (US)	9.5-11.5	Max 1.3	2.0-3.0	Max 0.5	Max 0.1	Max 0.5	Max 3	Max 0.15	Max 0.5
A384 (US)	10.5-12	Max 1.3	3.0-4.5	Max 0.5	Max 0.1	Max 0.5	Max 1	Max 0.35	Max 0.5
B384 (US)	10.5-12	Max 1.3	3.0-4.5	Max 0.5	0.1-0.3	Max 0.5	Max 1	Max 0.35	Max 0.5

These alloys together make up approximately 60% of the world’s aluminium castings

Age Hardening Response



Solution Treatment 490°C, age 150°C

(A357 peak hardness ~125VHN)

Results: High Si

Condition	Y.S (MPa)	UTS (MPa)	El%
As Cast	174.3 (25KSI)	235.2 (34KSI)	1.9%
T4#1	287.3 (42KSI)	423.3 (61KSI)	7.7%
T6#1	414.2 (60KSI)	483.4 (70KSI)	3.2%
T6#1B	424.5 (62KSI)	496.5 (72KSI)	3.9%
T4#2	284.6 (41KSI)	427.4 (62KSI)	9.3%
T6#2	390.4 (57KSI)	475.6 (69KSI)	4.6%

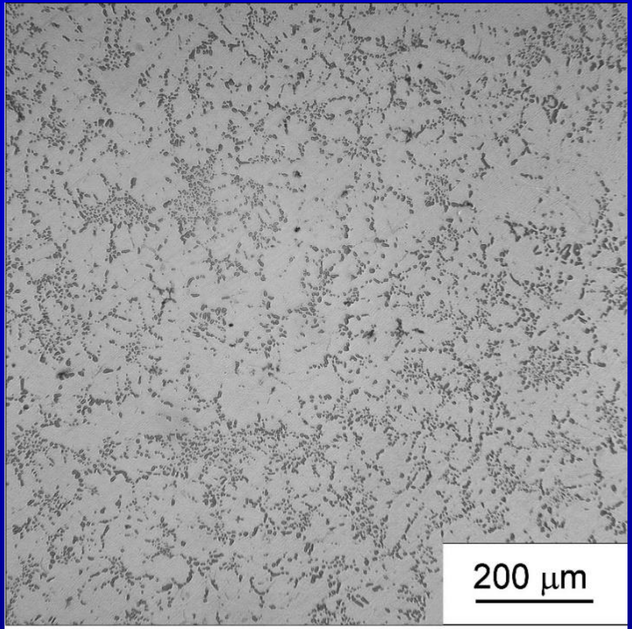
Similar properties to alloy 201-T7, but with the castability of 356/357.

Alloy 1: Al-7.88Si-3.24Cu-0.29Zn-0.24Mg-0.08Ti-0.08Fe-0.02Sr
Alloy 2: Al-7.99Si-3.42Cu-0.25Zn-0.25Mg-0.11Ti-0.08Fe-0.03Sr

C380 alloy.

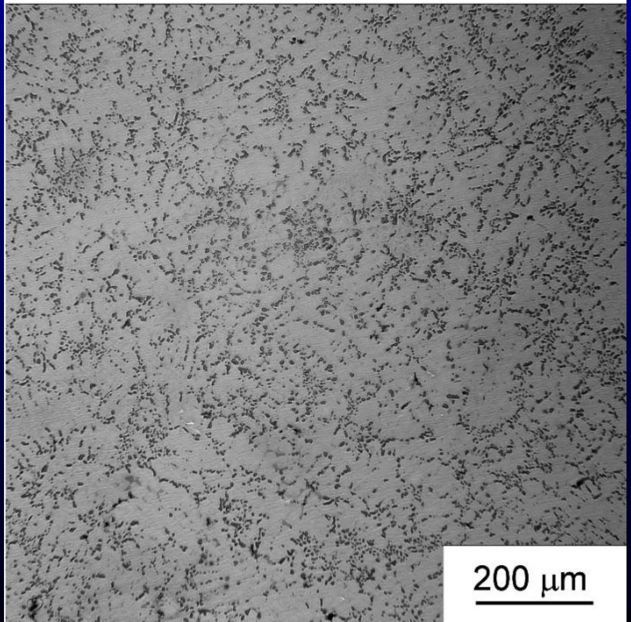
DAS=16.3μm

Alloy 1



DAS=14.4μm

Alloy 2

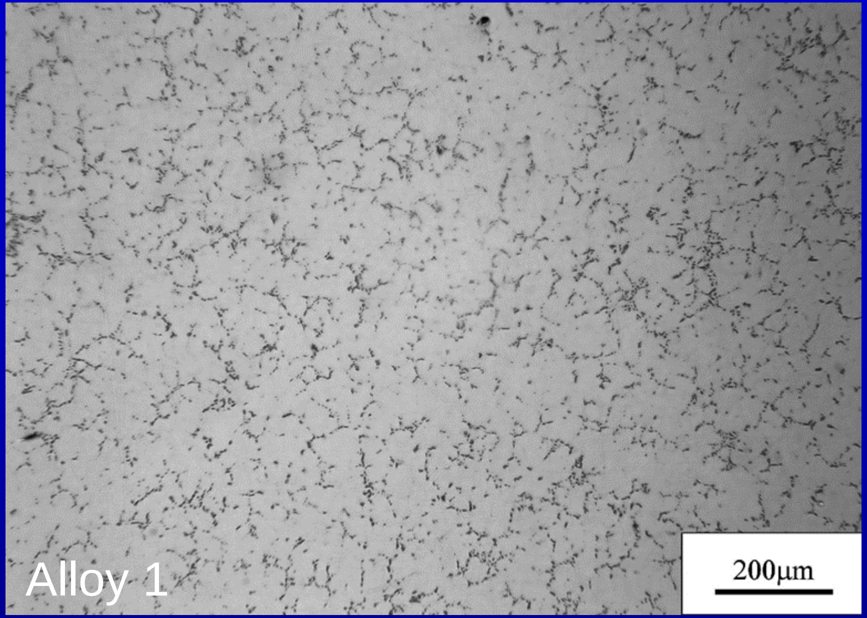


Results: Low Si

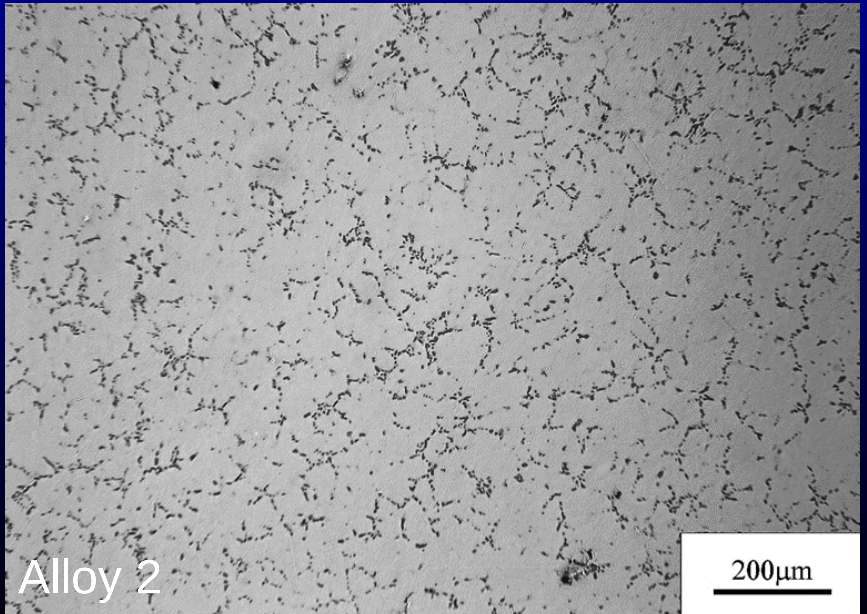
Reduced silicon content to reduce dependence on DAS

Condition	Y.S (MPa)	UTS (MPa)	El%
As Cast Alloy 1	131.7 (19KSI)	236.7 (34KSI)	6.0%
Alloy 1/T4	222.4 (32KSI)	365.1 (53KSI)	14%
Alloy 1/T6	309.5 (45KSI)	412.7 (60KSI)	10.7%
As Cast Alloy2	132.7 (19KSI)	222.1 (32KSI)	4.4%
Alloy 2/T4	252.7 (37KSI)	391.2 (57KSI)	10.6%
Alloy 2/T6	394.5 (57KSI)	451.8 (66KSI)	4.6%

DAS=23.9µm



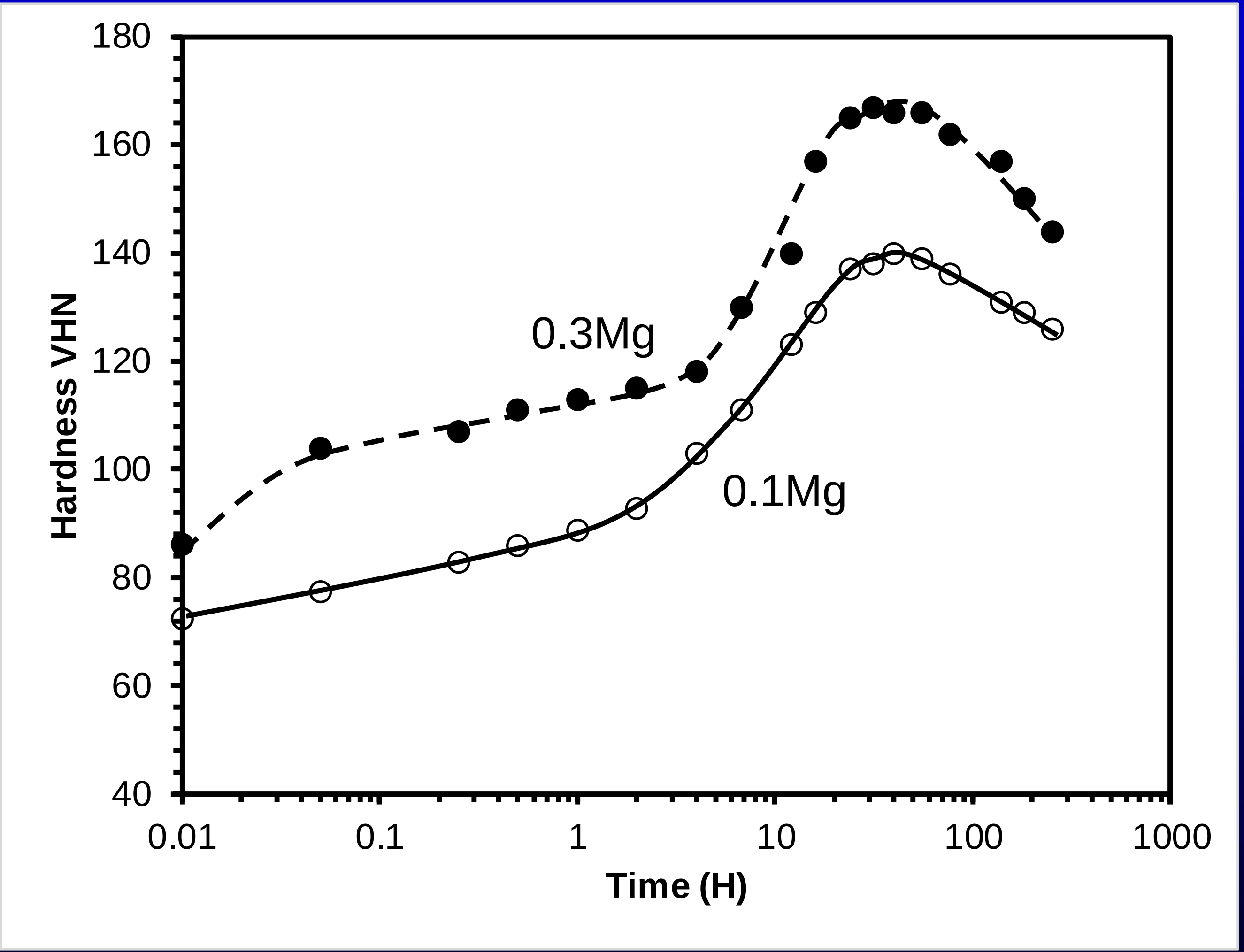
DAS=26.2µm



Alloy 1: Al-4.77Si-3.01Cu-0.19Zn-0.11Mg-0.12Ti-0.06Fe-0.02Sr
Alloy 2: Al-4.60Si-3.48Cu-0.19Zn-0.29Mg-0.13Ti-0.06Fe-0.02Sr

Al-Si5Cu3-(Mg).
Alloy 1 T6 had little change in properties with DAS increase to

Effect of Mg in AlSi5Cu3Mg



Solution Treatment 490°C, age 150°C

Conclusion

- A new family of high strength alloys for aerospace applications has been developed based around Al-Si-Cu.

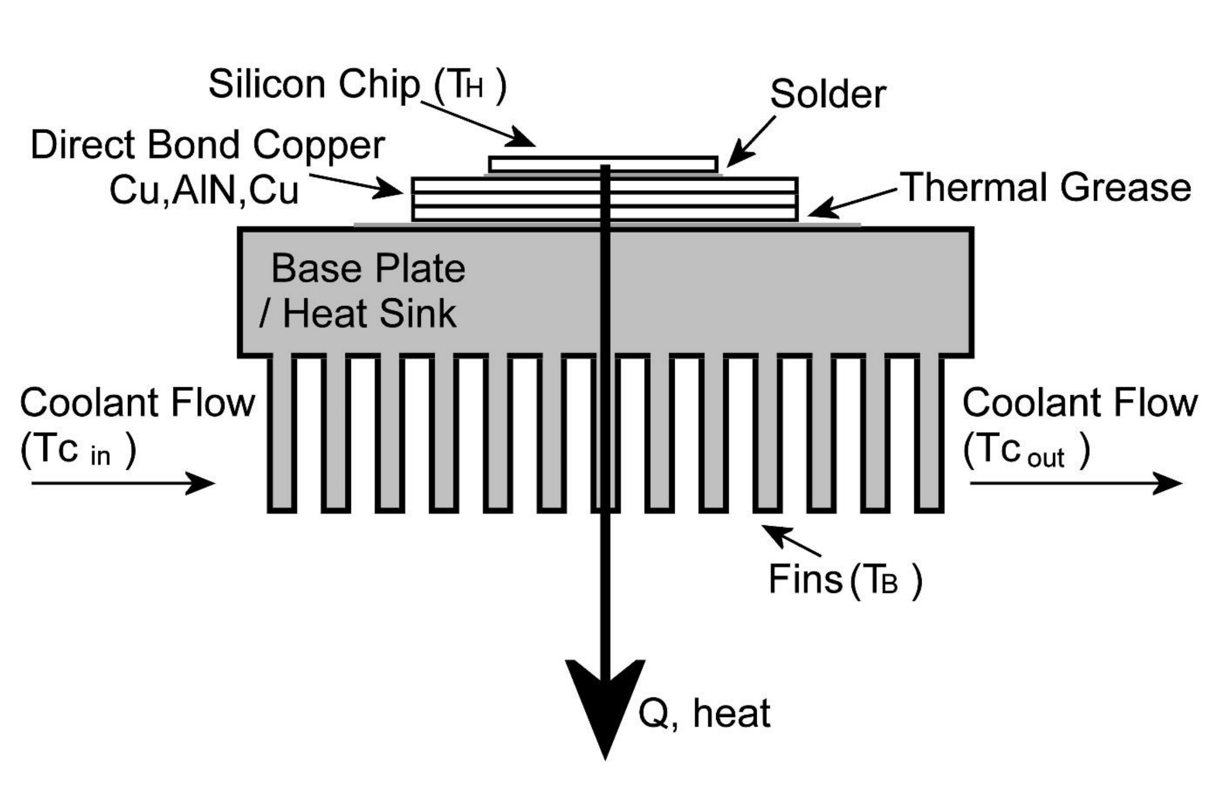
- These alloys significantly outperform current Al-Si-Cu alloys.

- Composition are tailored for investment casting and sand casting. Although these are based on diecasting compositions, the new alloys are not diecastable as they have no Mn and very low Fe. They also may contain Ti and Sr.

- For investment casting a premium investment casting process is required to fully gain benefits.

New Aluminum Alloy for High Thermal Conductivity

Premise: as electronics get smaller and run faster, they also run hotter.
Thermal management is increasingly important in any application related to electronics.



Goals:

>175W.mK at 25°C
Able to be anodized.

Mechanical Properties equivalent to
High Pressure Diecastings or better.

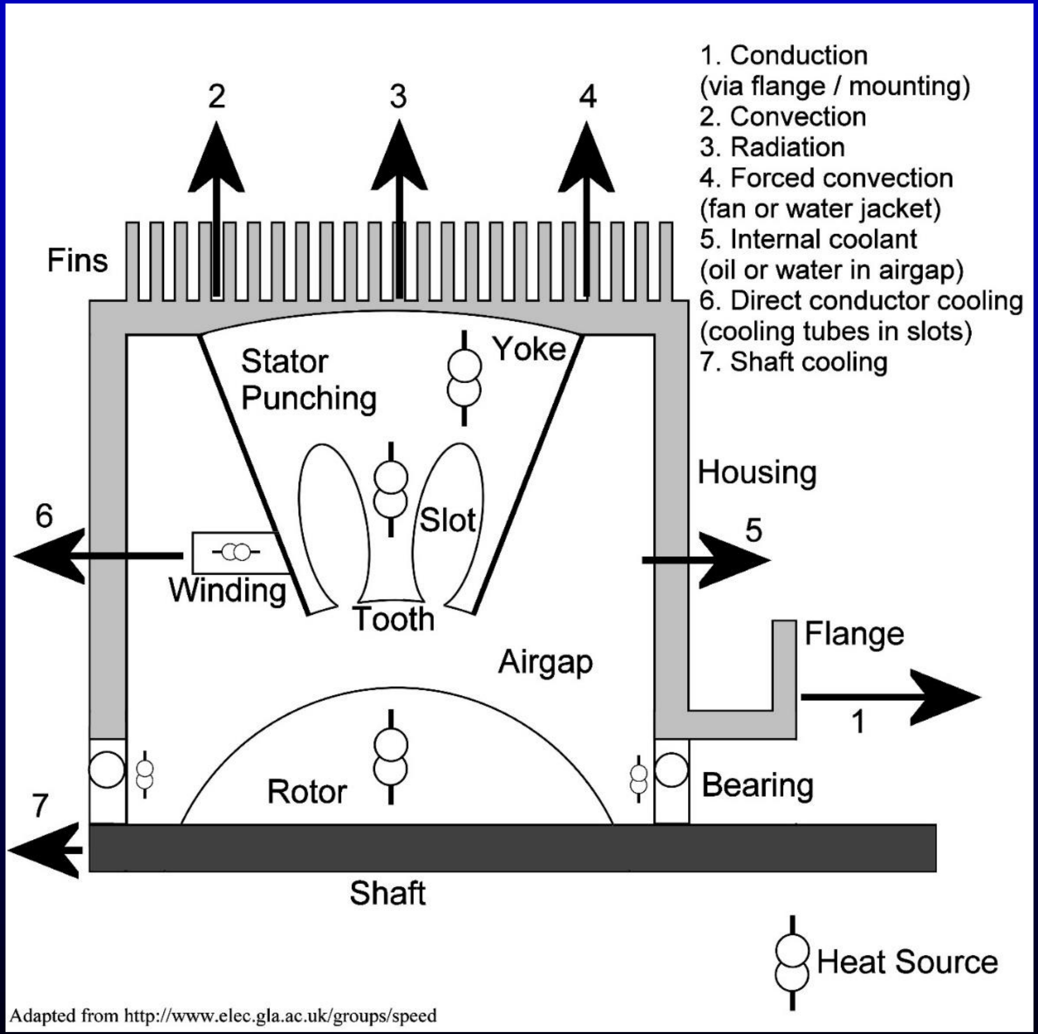
Castability similar to A356 / 357

Low cost to manufacture.

Thermal Conductivity is the rate of heat extraction through the metal, from the source, governed by the thermal diffusivity. Emissivity governs how a material absorbs and emits heat to the atmosphere.

(Example of a simple electric motor)

As electronics get smaller and more powerful, thermal management becomes increasingly important.



Alloy is around 5% Cheaper Than A356 Alloy to Manufacture (Less alloying elements)

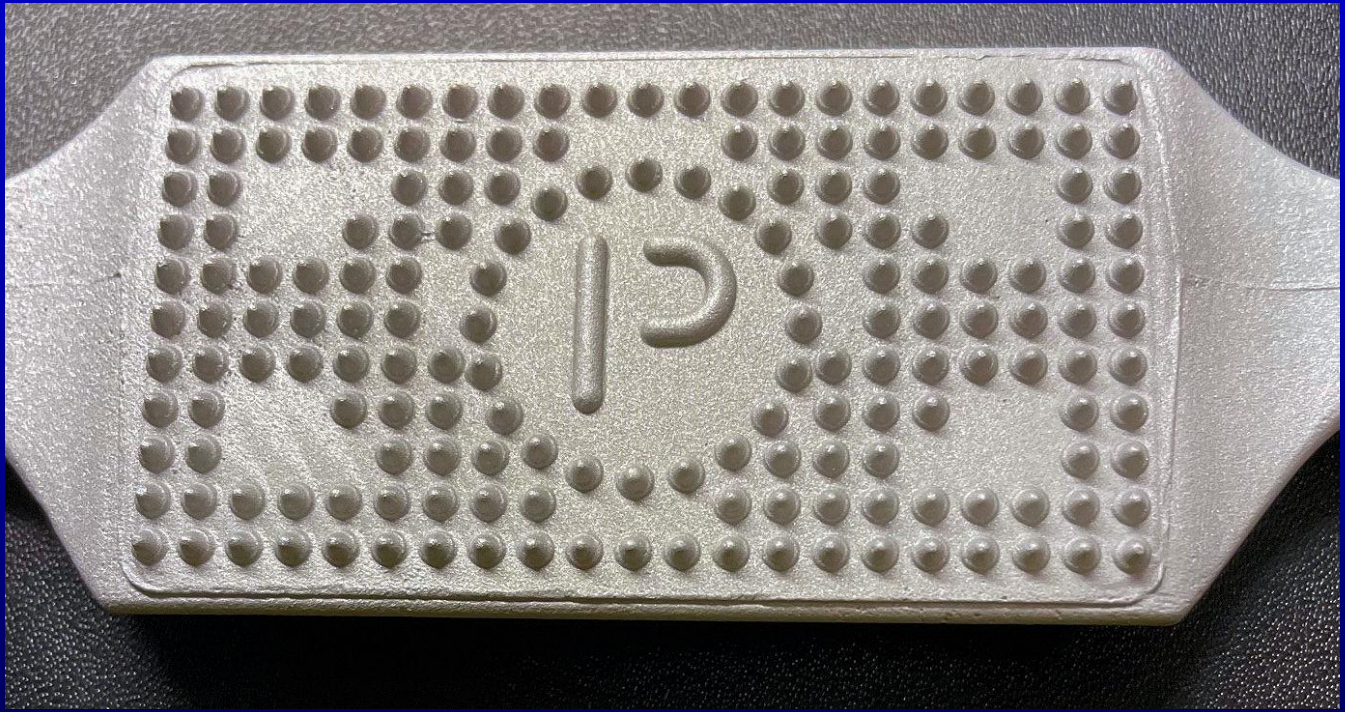
Compositions designed and tested:

1. Al-1.94Si-0.22Mg-0.11Ti-0.06Fe-0.03Sr
2. Al-1.94Si-0.40Mg-0.14Ti-0.08Fe-0.02Sr
3. Al-1.81Si-0.60Mg-0.11Ti-0.06Fe-0.02Sr
4. Al-1.84Si-0.91Mg-0.25Ti-0.06Fe-0.03Sr

Alloys 1& 2 were designed using a predictive model to have Thermal Conductivity of around 180 W/m.K at 23°C

Surface Finish in Sand Castings and Investment Castings is Excellent (~300 RMS)

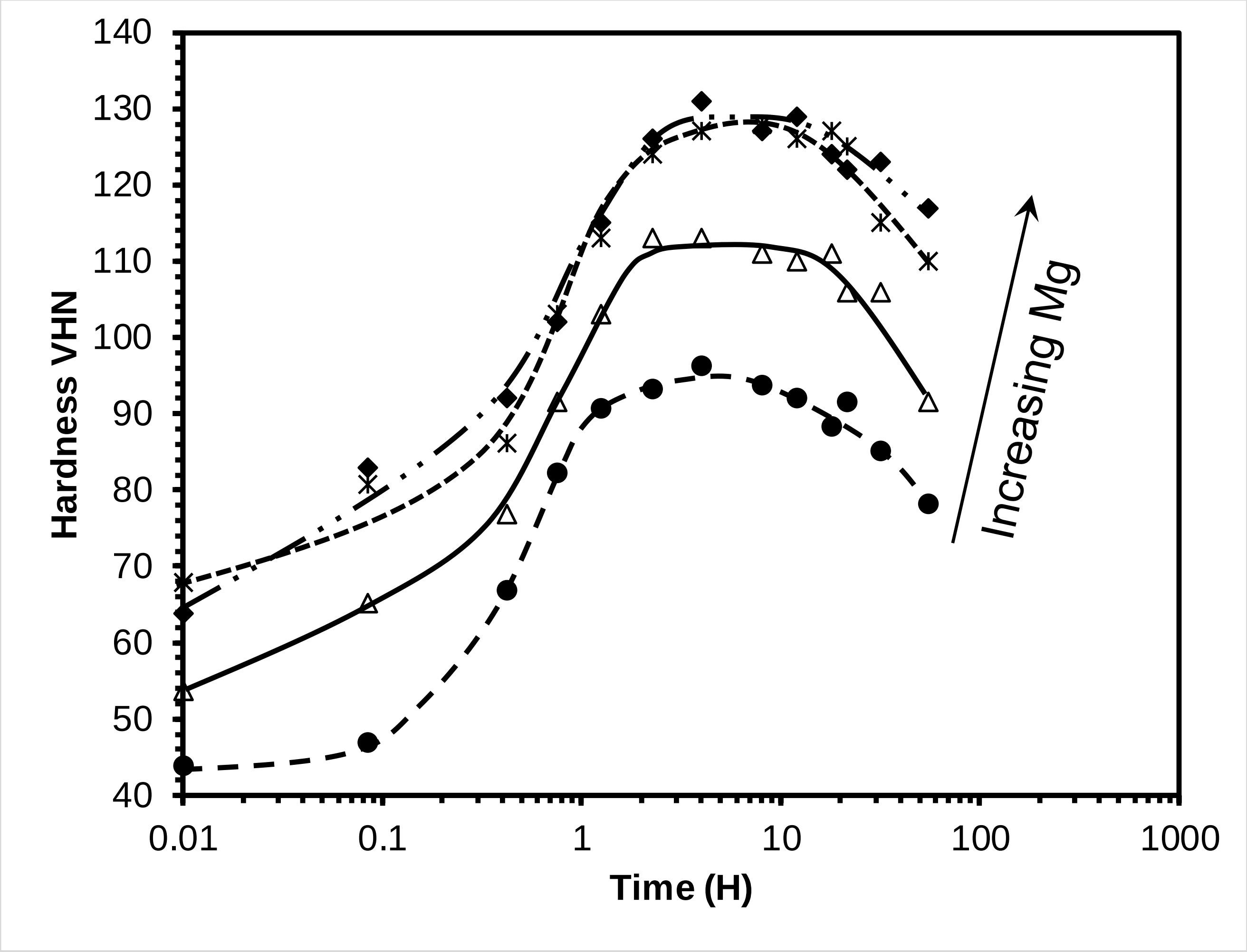
Formation of Dimples / Pins on Investment Casting



Castability is similar to A356

All Four Alloys Display Excellent Age Hardening

T6 tempers at 177°C



No advantage of 0.9 vs. 0.6Mg

Standard T6 Tempers Corresponding to Thermal Conductivity Results

Alloy	Yield Stress (MPa)	UTS (MPa)	Elongation (%)
Alloy 1 T6 (4h)	205.9 (30KSI)	268.3 (39KSI)	16.6%
Alloy 2 T6 (4h)	271.2 (39KSI)	334 (48KSI)	12.8%
Alloy 3 T6 (4h)	318.7 (46KSI)	369 (54KSI)	5.8%
Alloy 4 T6 (4h)	326.8 (47KSI)	359.6 (52KSI)	2.2%

(Investment Castings)

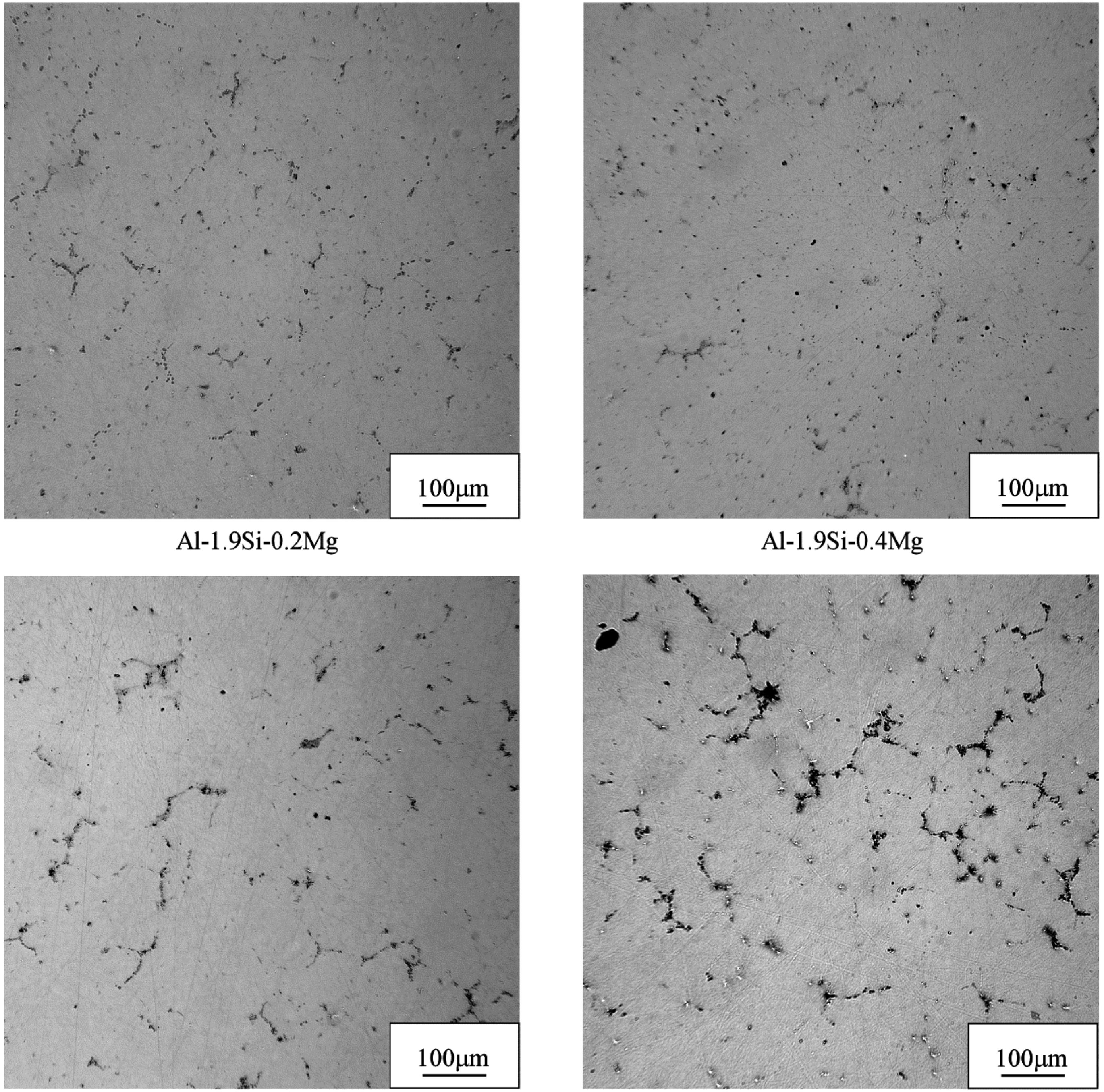
Underaged T6 properties are also excellent

Alloy	Yield Stress (MPa)	UTS (MPa)	Elongation (%)
Alloy 1 T6 (2h)	198.4 (29KSI)	269.7 (39KSI)	19.6%
Alloy 2 T6 (2h)	256.2 (37KSI)	322.2 (47KSI)	12.5%
Alloy 3 T6 (2h)	295.4 (43KSI)	351 (51KSI)	7.9%
Alloy 4 T6 (2h)	299.9 (44KSI)	343 (50KSI)	4.1%
Alloy 1 T6 (1h)	184.9 (27KSI)	258.7 (38KSI)	20.9%
Alloy 2 T6 (1h)	237 (34KSI)	315 (46KSI)	18.6%
Alloy 3 T6 (3h)	293.6 (43KSI)	344.4 (50KSI)	6.2%

Results for sandcastings were also outstanding

Alloy	Yield Stress (MPa)	UTS (MPa)	Elongation (%)
Alloy 1 T6 (4h)	212 (31KSI)	254 (37KSI)	14%
Alloy 2 T6 (4h)	334 (48KSI)	377 (55KSI)	11%
Alloy 3 T6 (4h)	338 (49KSI)	380 (55KSI)	5%
Alloy 4 T6 (4h)	343 (50KSI)	378 (55KSI)	3%

Microstructures of 4 Alloys T6 temper



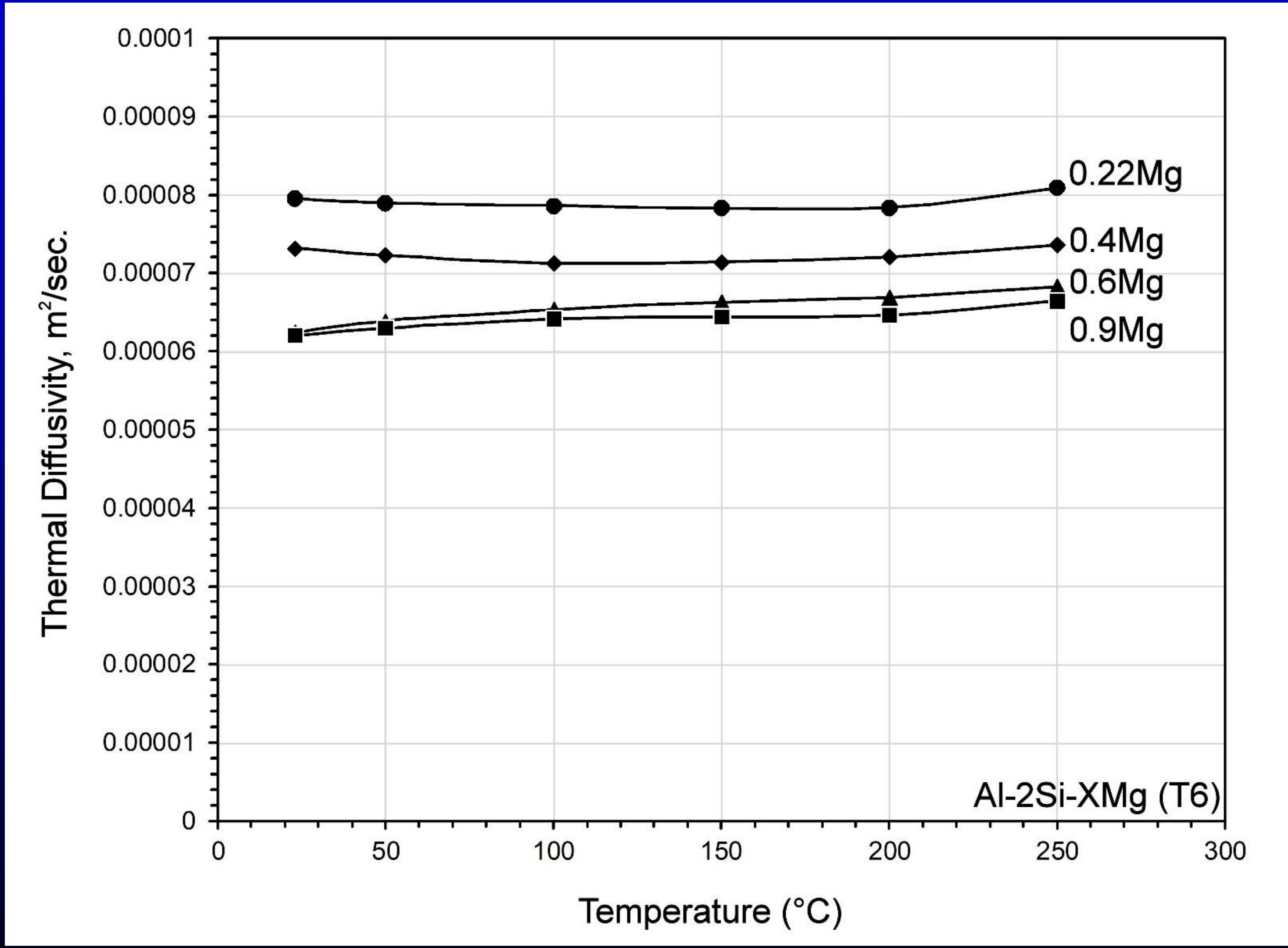
Al-1.9Si-0.2Mg

Al-1.9Si-0.4Mg

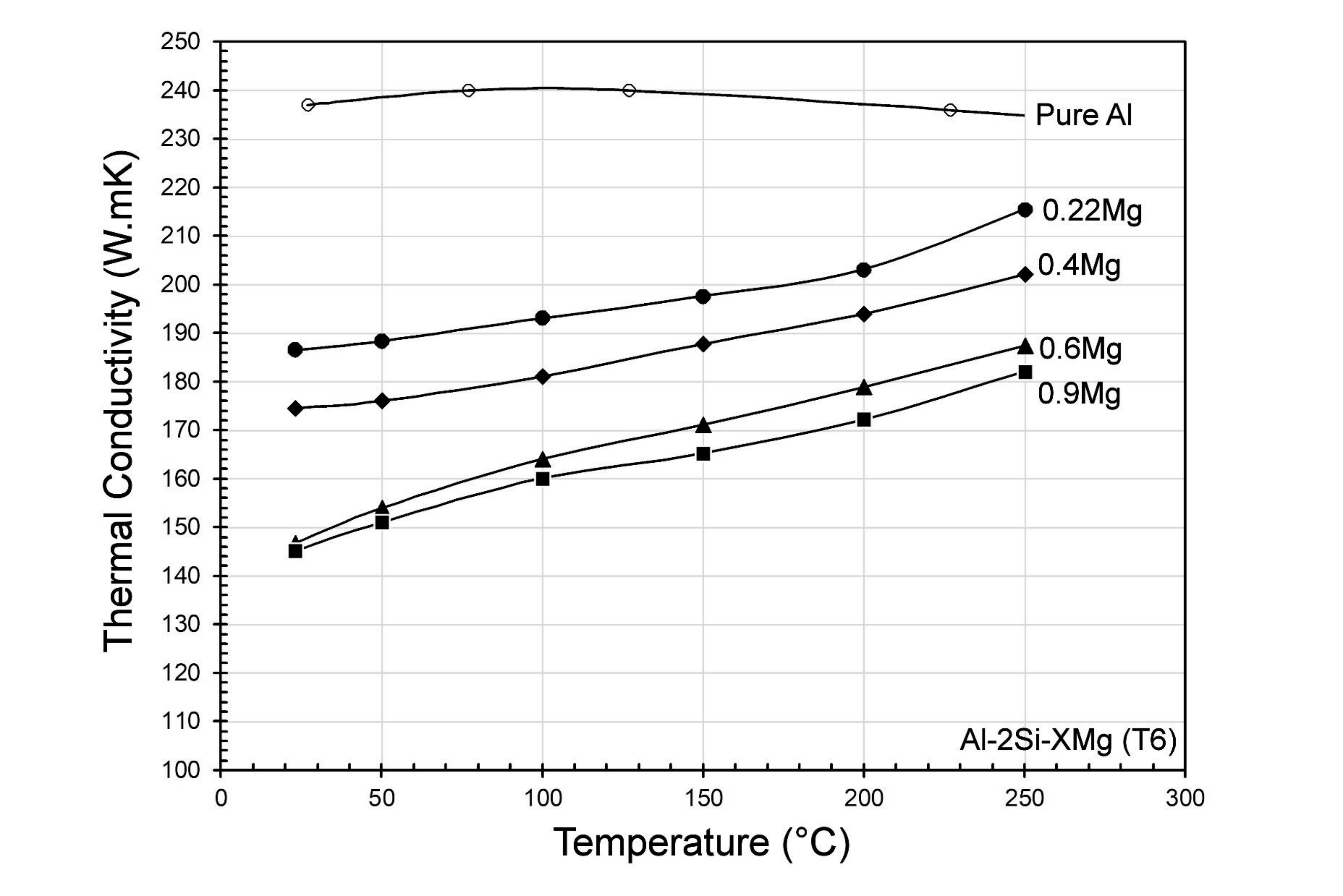
Al-1.8Si-0.6Mg

Al-1.8Si-0.9Mg

Thermal Diffusivity Results T6.

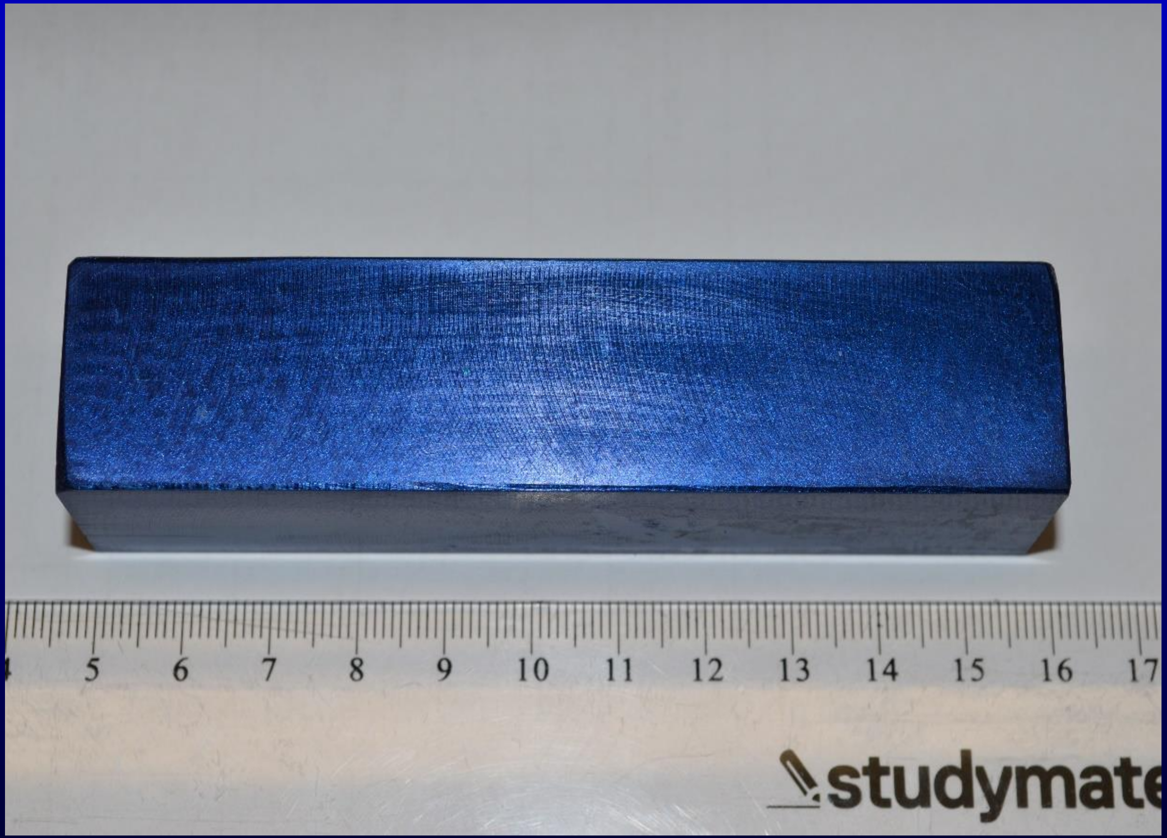


Thermal Conductivity Results T6.



At 23°C
(A356-T6 = 151

Anodizing: All alloys tested were able to be conventionally anodized after investment casting (T6).



Why is Anodizing Important?

Emissivity:

The emissivity of the surface of a material is its effectiveness in emitting energy as thermal radiation.

Emissivity Coefficient (ε) of a Blackbody = 1

Emissivity Coefficient of Polished Aluminium = ~0.05
Emissivity Coefficient of Rough Aluminium = ~0.07

Emissivity Coefficient of Blue or Black Anodized Aluminium >0.85 (~0.9 Typ.)

Conclusions

A new family of alloys developed for high thermal conductivity have been developed, based around Al2Si-XMg, together with optional additions of Sr and Ti.

The alloys are surprisingly easily castable, and weldable.

Alloys with 0.2 or 0.4Mg develop above 175 W/m.K thermal conductivity at 23°C which continues to rise with temperature.

The new alloys are able to be anodized.

Strength properties may be tailored according to requirements, and the mechanical properties are also outstanding.

The high thermal conductivity alloys are not significantly impacted by cooling rate, with equivalent or better properties achievable without rapid cooling.

AWBell Titanium

- **A W Bell is investing in Australia's first titanium investment casting capability.**
- **Project announced by Minister for Defence Industry, Melissa Price on 5/4/22**
- **"The Morrison Government is investing $23 million in 10 Australian businesses whose innovative ideas could strengthen the capability of the Australian Defence Force."**
- **"These contracts awarded through the Defence Innovation Hub will help Defence maintain a capability advantage in our dynamic strategic environment, while boosting the competitiveness of our industry innovation sector."**
- ***$5.88 million contract with Victorian-based company A.W Bell Machinery to develop a world-leading high grade titanium casting system for in-service aircraft.***
- **More to come soon!**

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