LA-UR-12-22558
Approved for public release; distribution is unlimited.

Title: Influence of Aluminum Content on Grain Refinement and Strength of AZ31 Magnesium GTA Weld Metal

Author(s): Babu, N. Kishore
Cross, Carl E.

Intended for: Trends in Welding Research, 2012-06-04/2012-06-08 (Chicago, Illinois, United States)

Influence of Aluminum Content on Grain Refinement and Strength of AZ31 Magnesium GTA Weld Metal

N. Kishore Babu* and C.E. Cross+

* Singapore Institute of Manufacturing Technology, Singapore

+ Los Alamos National Laboratory, Los Alamos NM, USA

*/+ previously with Federal Inst. of Materials Research & Testing (BAM), Berlin, Germany

Outline

- Background, Goal, Approach
- Experimental
- Results
- Theory
- Conclusions

Background

- Wrought AZ31 (continuous cast/rolled) versus Die Cast
- AZ61 filler wire is commonly used to weld AZ31
- Al content will vary in weld metal depending upon dilution
- Al alloy additions have a strong influence on grain size
- Strength of Mg is strongly influenced by grain size

Goal

- **Characterize the effect of Al content on AZ31 weld metal:**

  - grain size

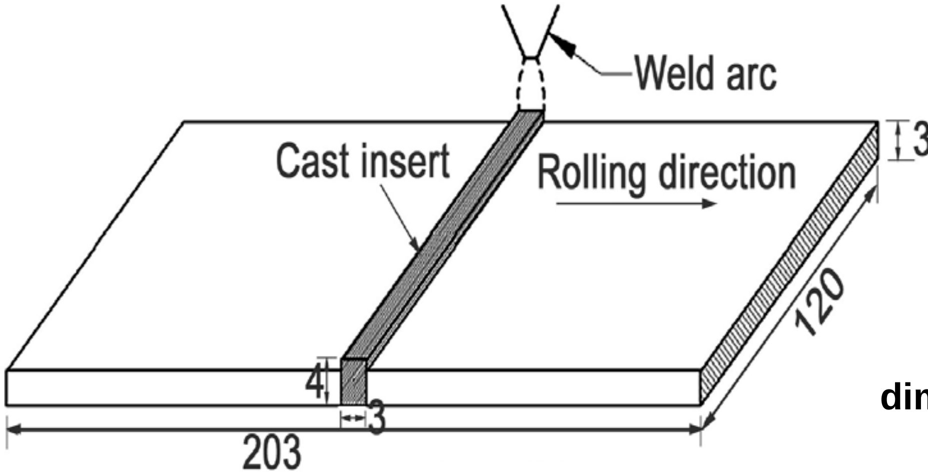
  - strength

- **Examine role of Al on grain refinement**

Approach

- **Systematically vary the aluminum content of AZ31 weld metal**
- **Measure average grain size in weld metal**
- **Measure cross-weld tensile properties and hardness**

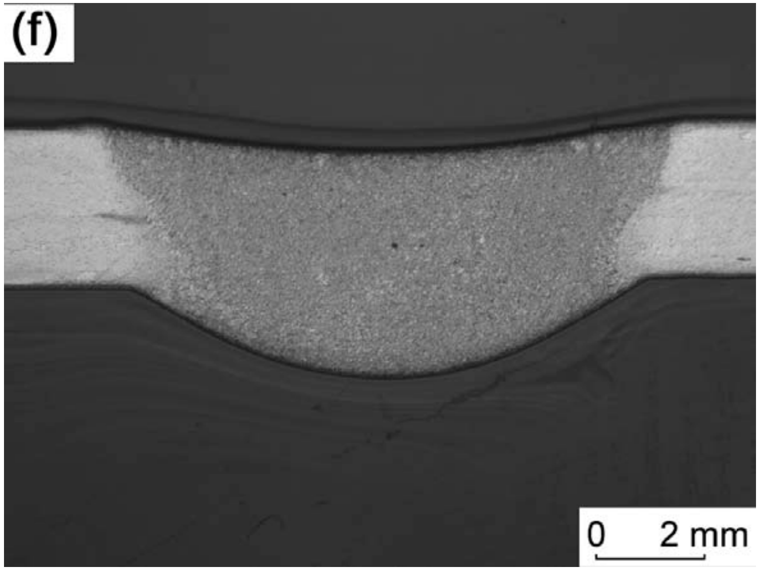
Experimental



dimensions in mm

	Al	Zn	Mn	Si	Fe (wt.%)
Base Metal					
AZ31	2.70	0.81	0.30	0.023	0.004
Cast Inserts					
AM20	2.35	0.002	0.37	0.003	0.006
AM50	4.47	0.002	0.35	0.004	0.001
AM60	5.85	0.002	0.28	0.005	0.001
AZ91	9.21	0.76	0.18	0.008	0.002

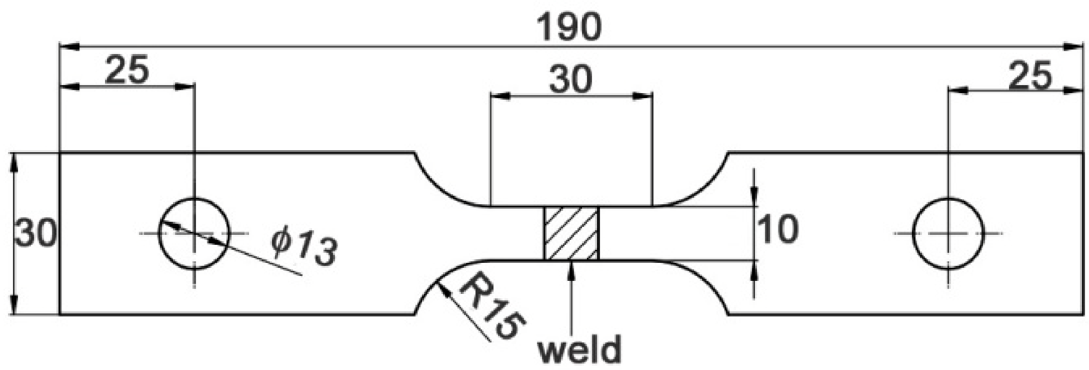
Experimental



Variable Polarity GTAW:

Welding Current	
Electrode Negative	**110 A, 16 ms**
Electrode Positive	**80 A, 4 ms**
Frequency	**50 Hz**
Arc Voltage	**11 V**
Travel Speed	**4.2 mm/s**

Experimental



dimensions in mm

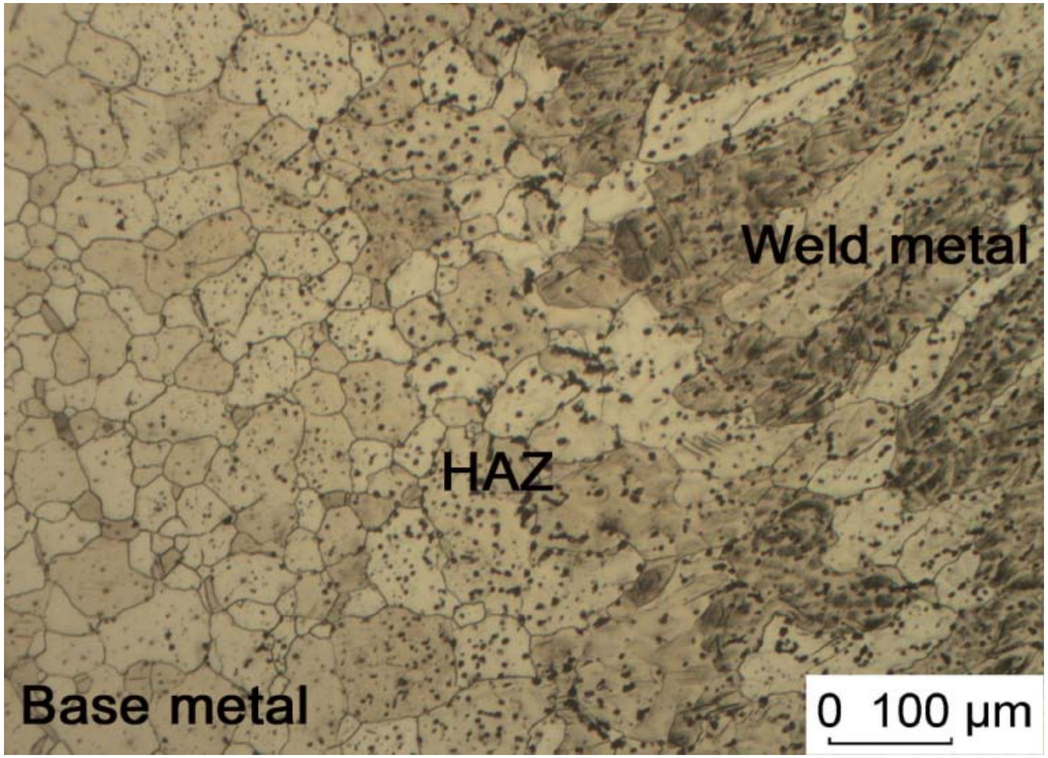
Transverse Tensile Test:

30 mm gage
10 mm bead width
3 mm/min cross-head speed

Microhardness Traverse:

diamond pyramid
1000 g, 15 s
0.05 mm interval

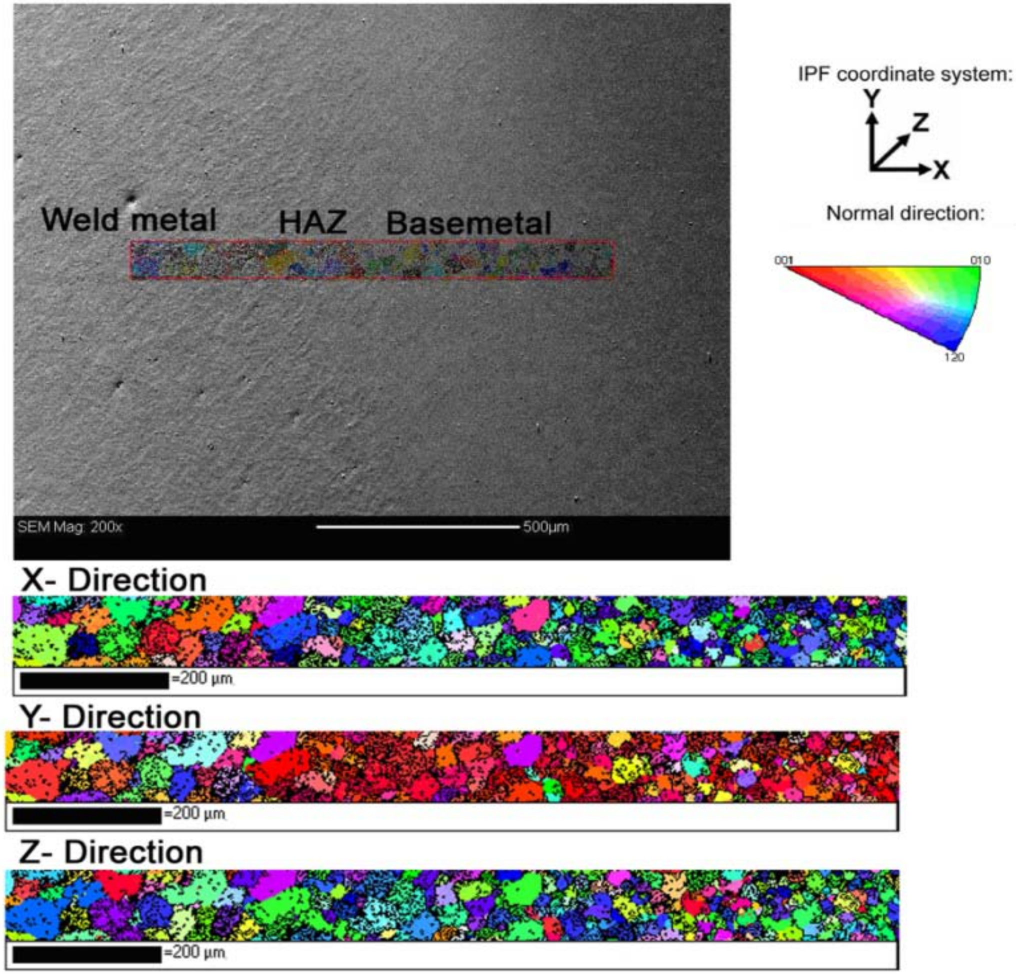
Results



Weld Microstructure:

- HCP Mg grains
- β - Mg_2Al_3 eutectic constituent
- Mn_5Al_8 dispersoids in BM, HAZ

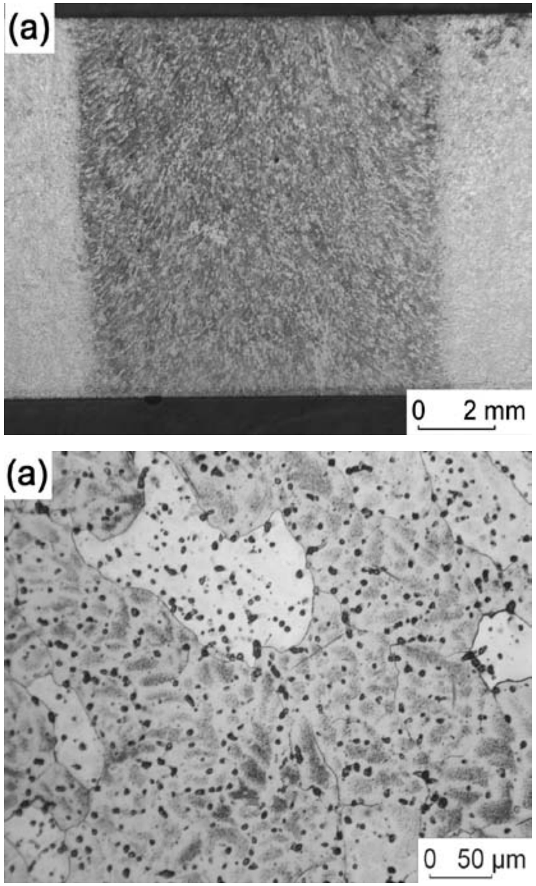
Results



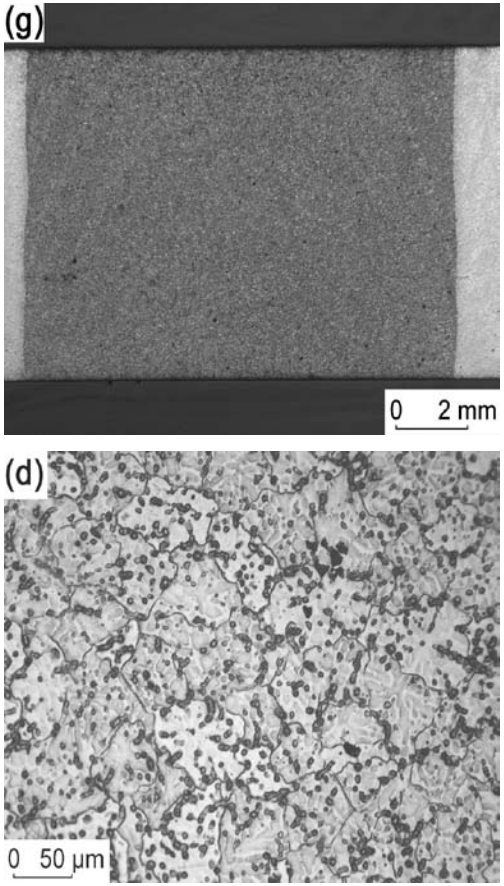
Weld Texture:

- **BM and HAZ basal plane parallel to rolling plane**
- **WM random orientation**

Results



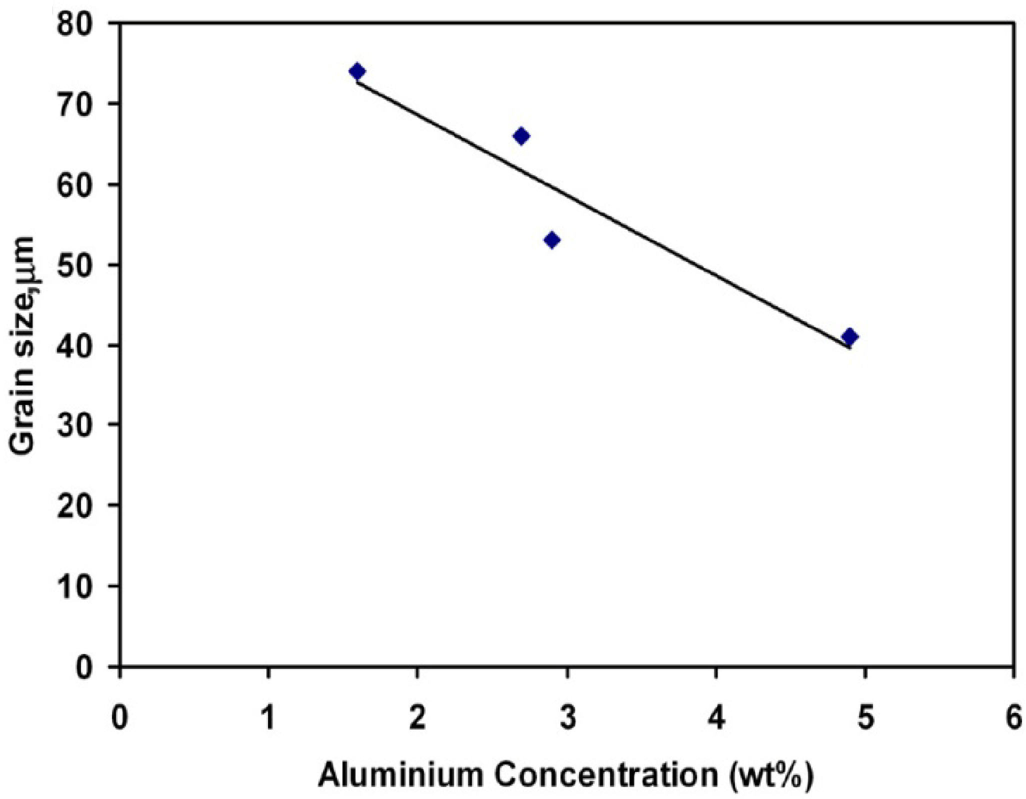
2.4 wt.% Al in weld metal



5.0 wt.% Al in weld metal

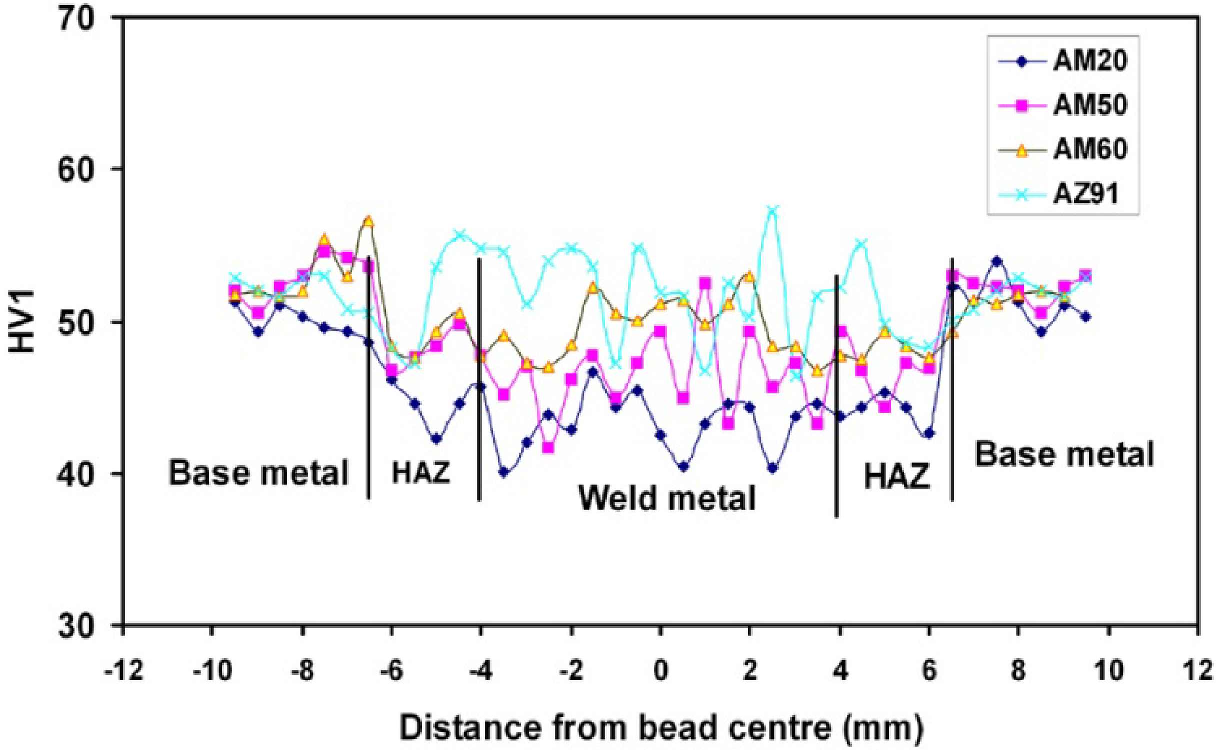
Results

Grain Refinement by Al



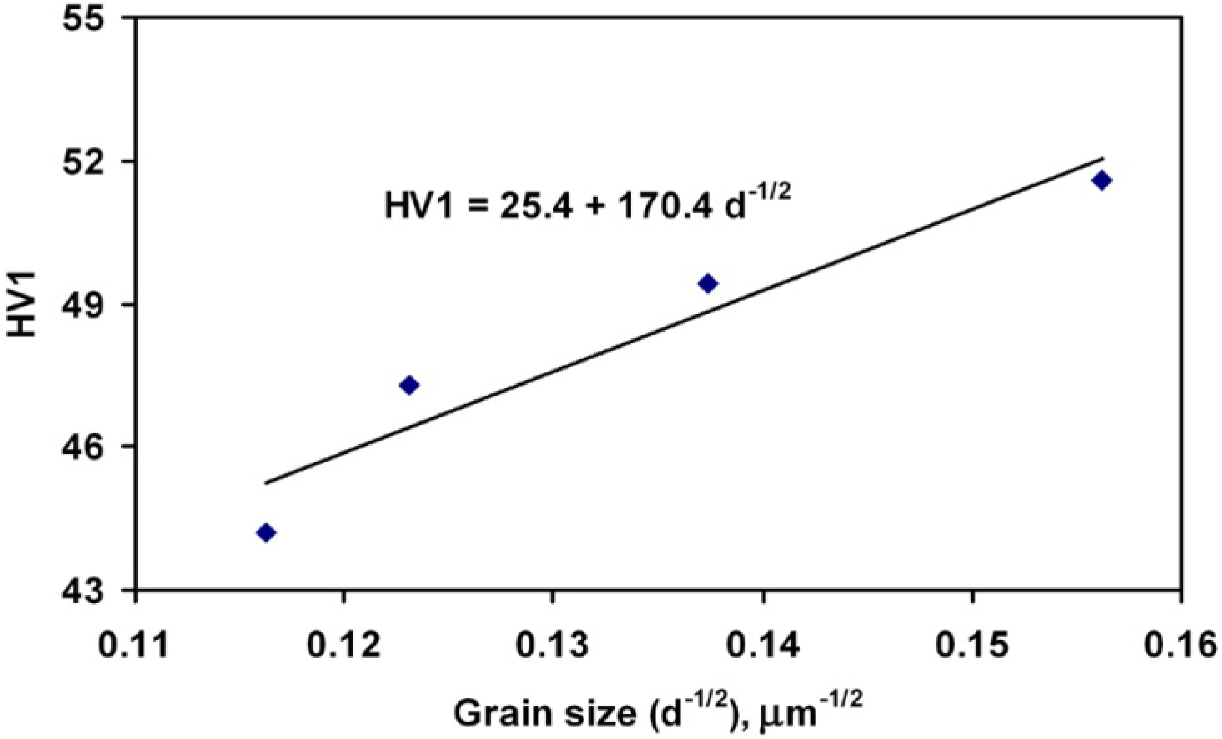
Results

Weld Hardness Traverse



Results

Hall-Petch Plot



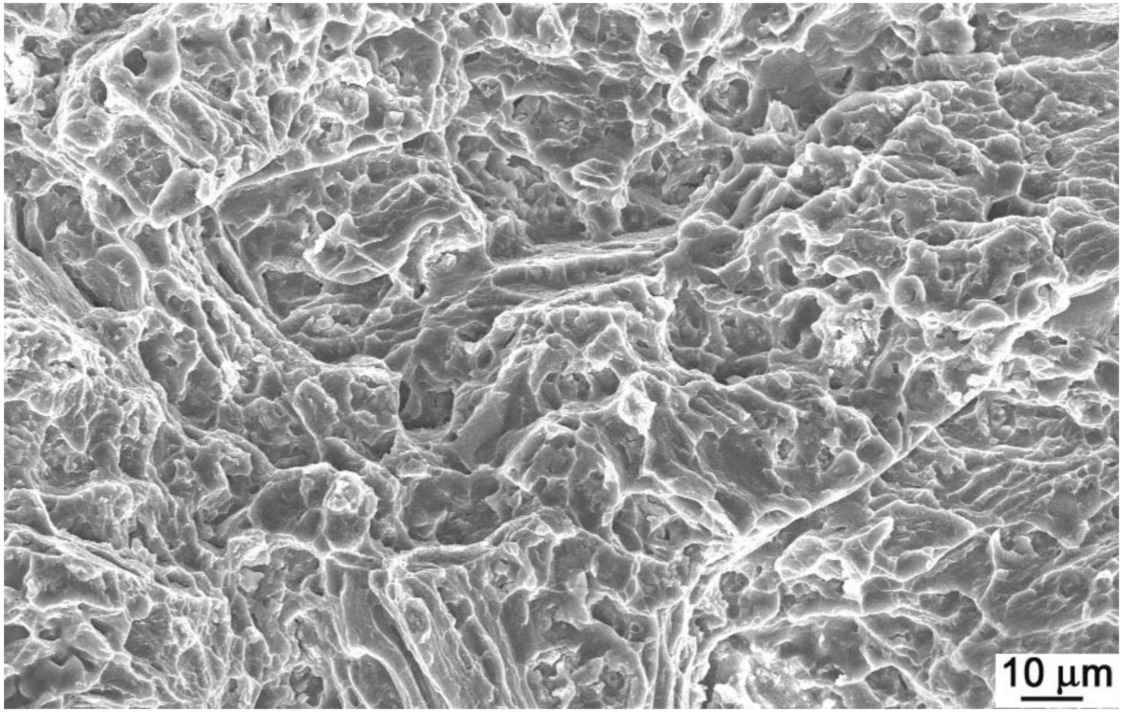
Results

Weld Tensile Tests

	Al (wt.%)	Ave. G.S. (μm)	Vick. Hard (kg/mm²)	Yield Streng. (MPa)	Tens. Streng. (MPa)	Elong. 2"gage (%)	Fail
Base Metal							
AZ31	2.7	23	52	156	251	18	BM
Weld Metal							
AM20	2.4	74	44	70	190	8	WM
AM50	3.3	66	47	87	205	8	WM
AM60	4.3	53	49	105	217	13	WM
AZ91	5.0	41	52	109	231	5	FL

Results

Weld Metal Fractography



Theory

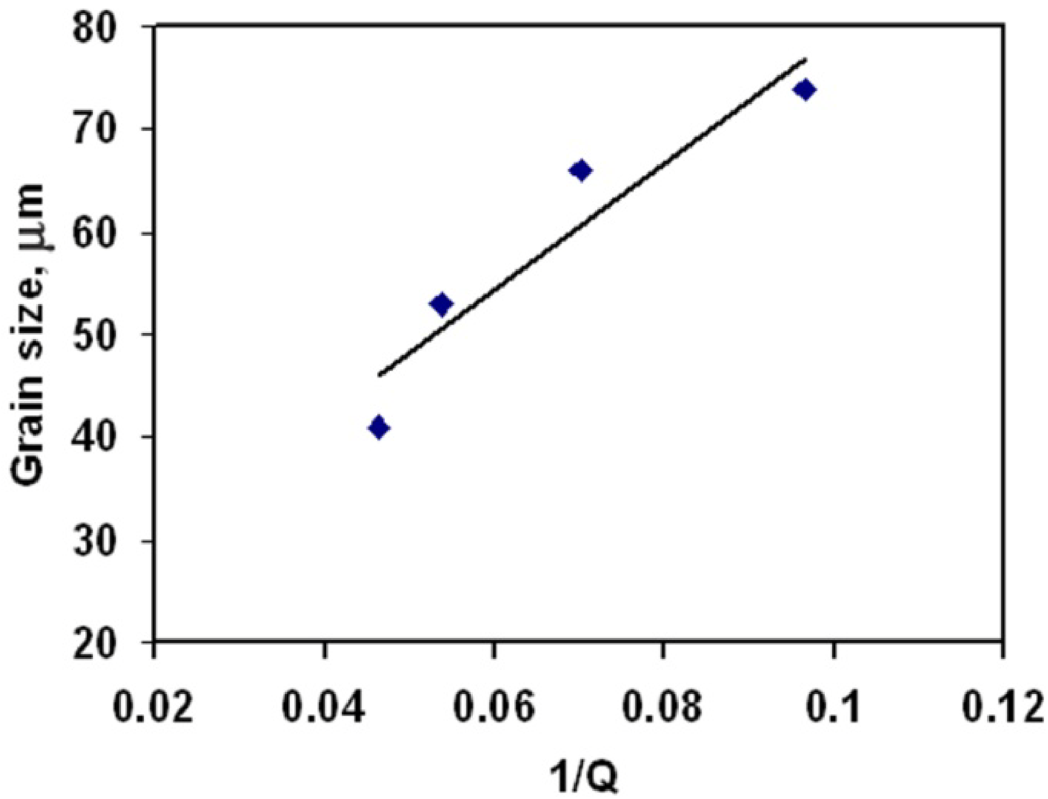
Growth Restriction Factor: $Q = m_L C_0 (k-1)$

[Easton and St.John, 2005]

Element	*m* (ºC/wt.%)	*k*	*Q*, for C_0=1
Zr	6.90	6.55	38.3
Ca	-12.70	0.06	11.9
Si	-9.25	~0.00	9.25
Zn	-6.04	0.12	5.31
Cu	-5.37	0.02	5.28
Al	-6.87	0.37	4.32
Sr	-3.53	0.01	3.51
Ce	-2.86	0.04	2.74
Y	-3.40	0.50	1.70
Sn	-2.41	0.39	1.47

Theory

Grain Size: d = a + b (1/Q)



Conclusions

- **increased Al content in AZ31 weld metal results in grain refinement**
  Reason: higher undercooling during solidification

- **weld metal grain refinement resulted in increased strength & hardness**
  Reason: grain boundary strengthening

- **weld metal strength can be raised to wrought base metal levels**

Acknowledgements

The authors are grateful to BAM (Berlin, Gemany) where this work was performed with funding from an Adolf Martens Fellowship.

Also appreciated was support at BAM from:

M. Marten for metallography and

Th. Michael and S. Brauser for weld development.