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

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# Outline

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

# Background

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- **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

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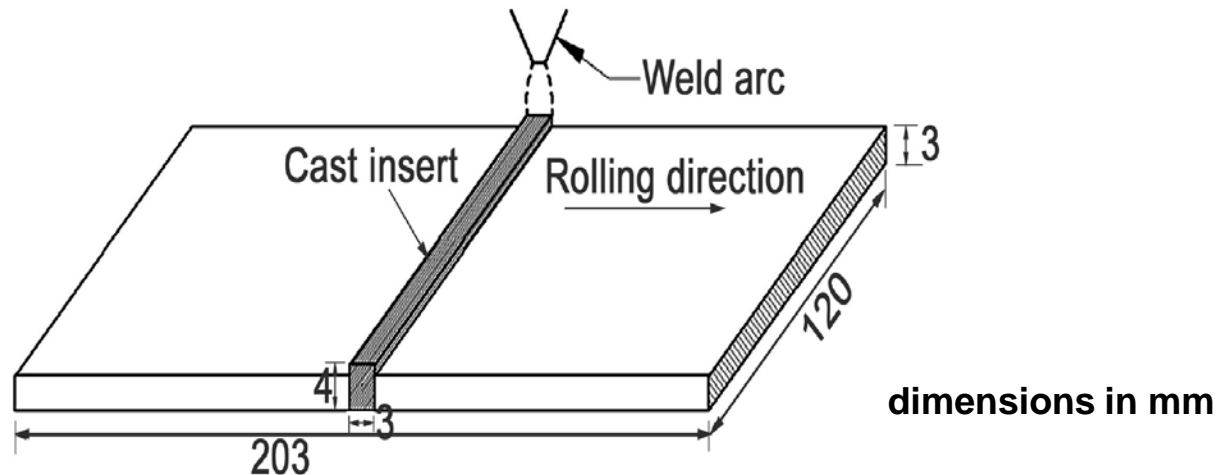
- **Characterize the effect of Al content on AZ31 weld metal:**
  - grain size
  - strength
- **Examine role of Al on grain refinement**

# Approach

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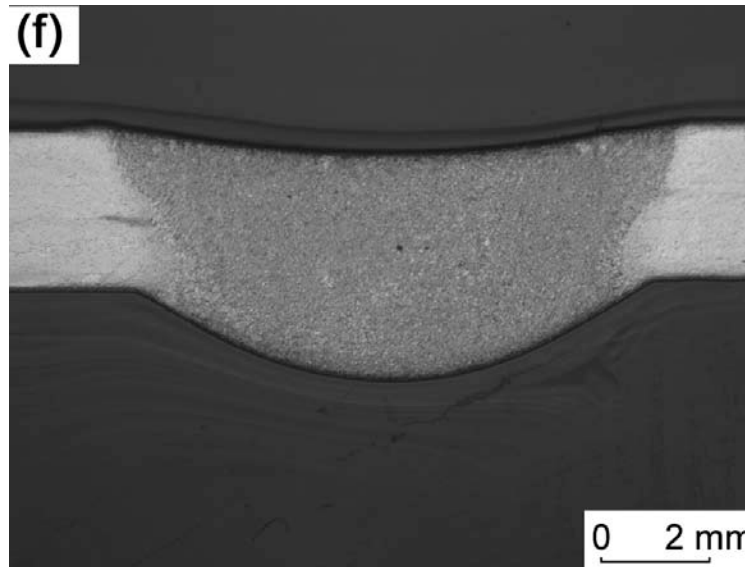
- **Systematically vary the aluminum content of AZ31 weld metal**
- **Measure average grain size in weld metal**
- **Measure cross-weld tensile properties and hardness**

# Experimental



	Al	Zn	Mn	Si	Fe (wt.%)
<b>Base Metal</b>					
AZ31	2.70	0.81	0.30	0.023	0.004
<b>Cast Inserts</b>					
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

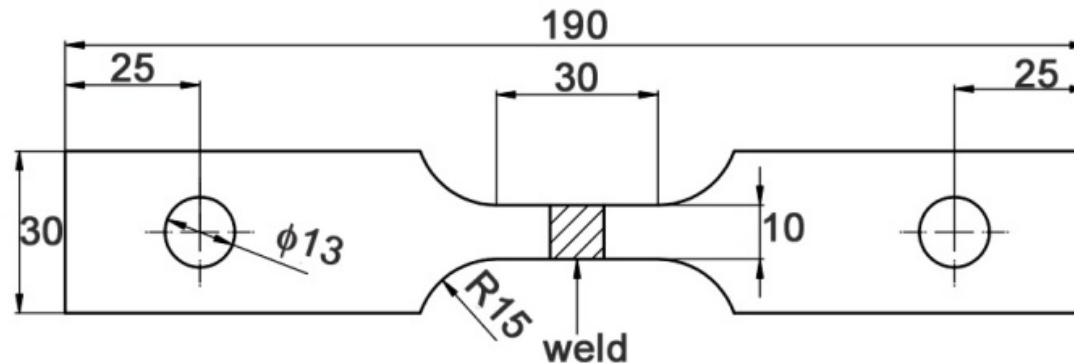
11 V

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

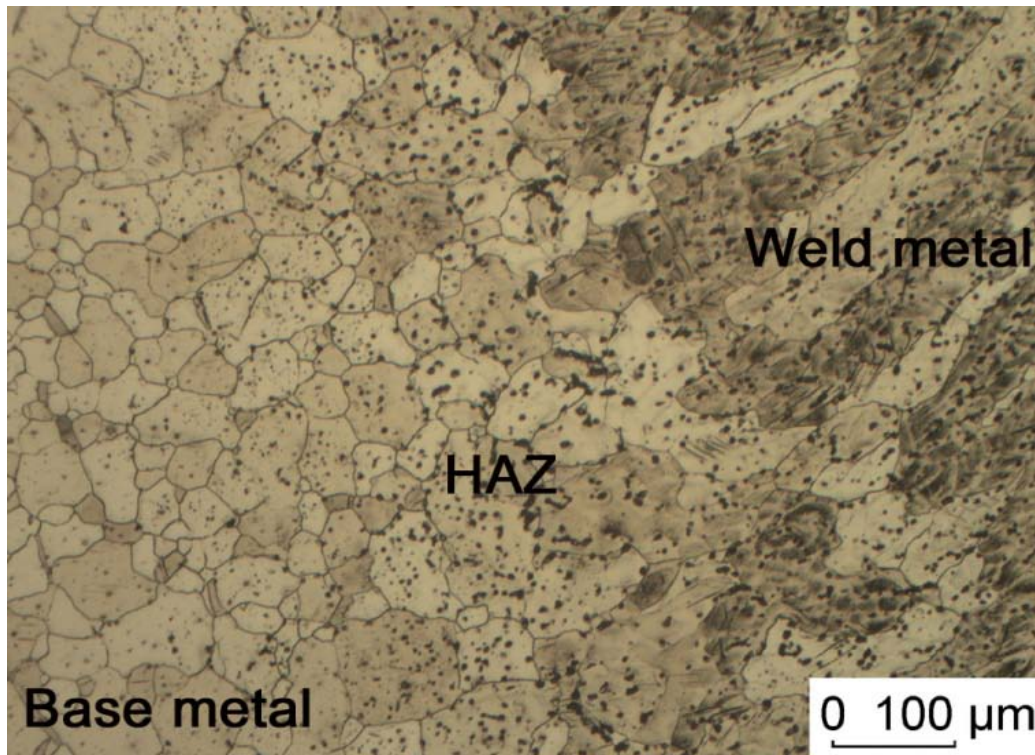
## Microhardness Traverse:

diamond pyramid

1000 g, 15 s

0.05 mm interval

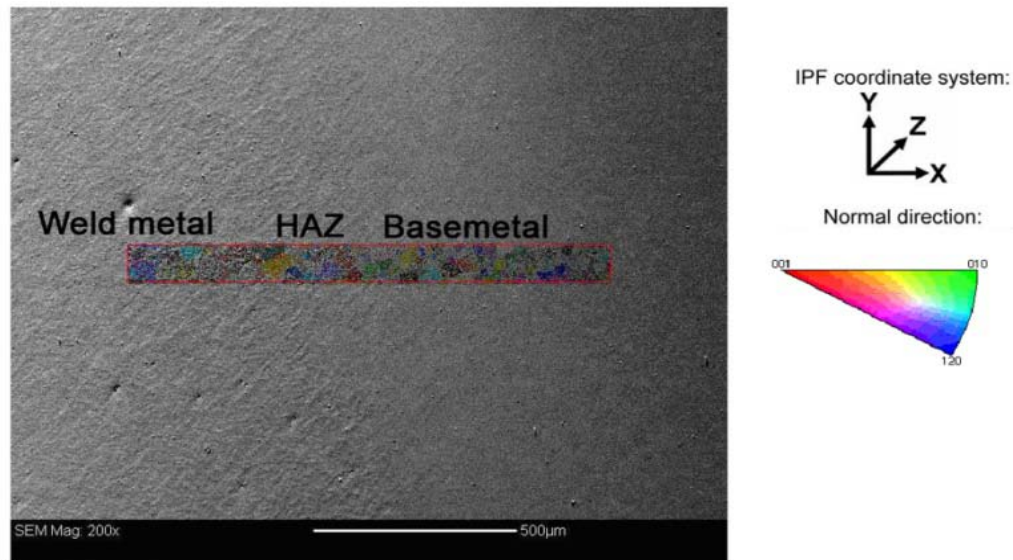
# Results



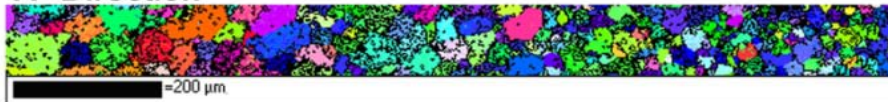
## Weld Microstructure:

- HCP Mg grains
- $\beta$  -  $\text{Mg}_2\text{Al}_3$  eutectic constituent
- $\text{Mn}_5\text{Al}_8$  dispersoids in BM, HAZ

# Results



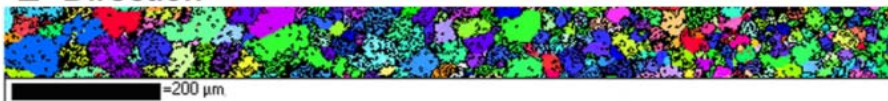
X- Direction



Y- Direction



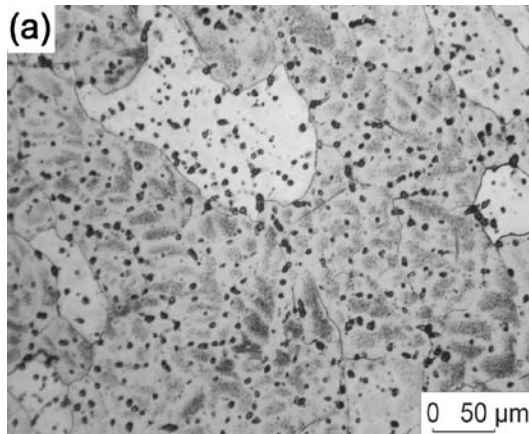
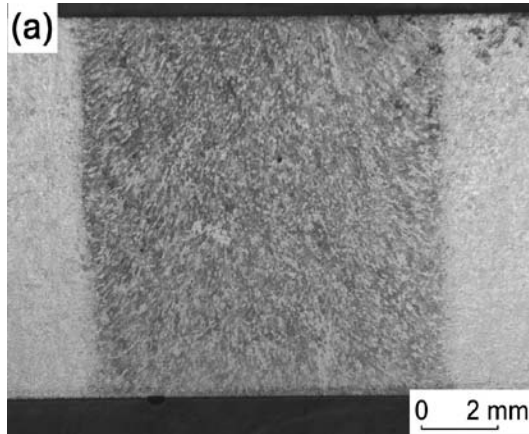
Z- Direction



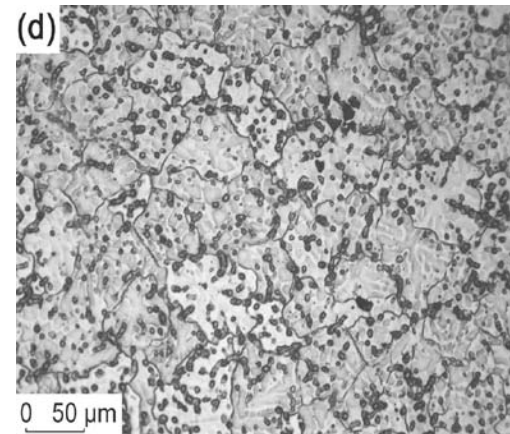
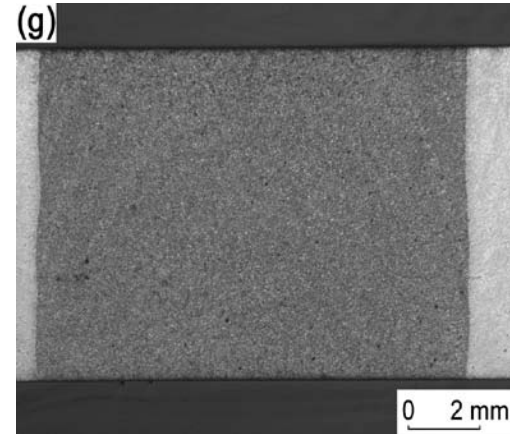
## Weld Texture:

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

# Results



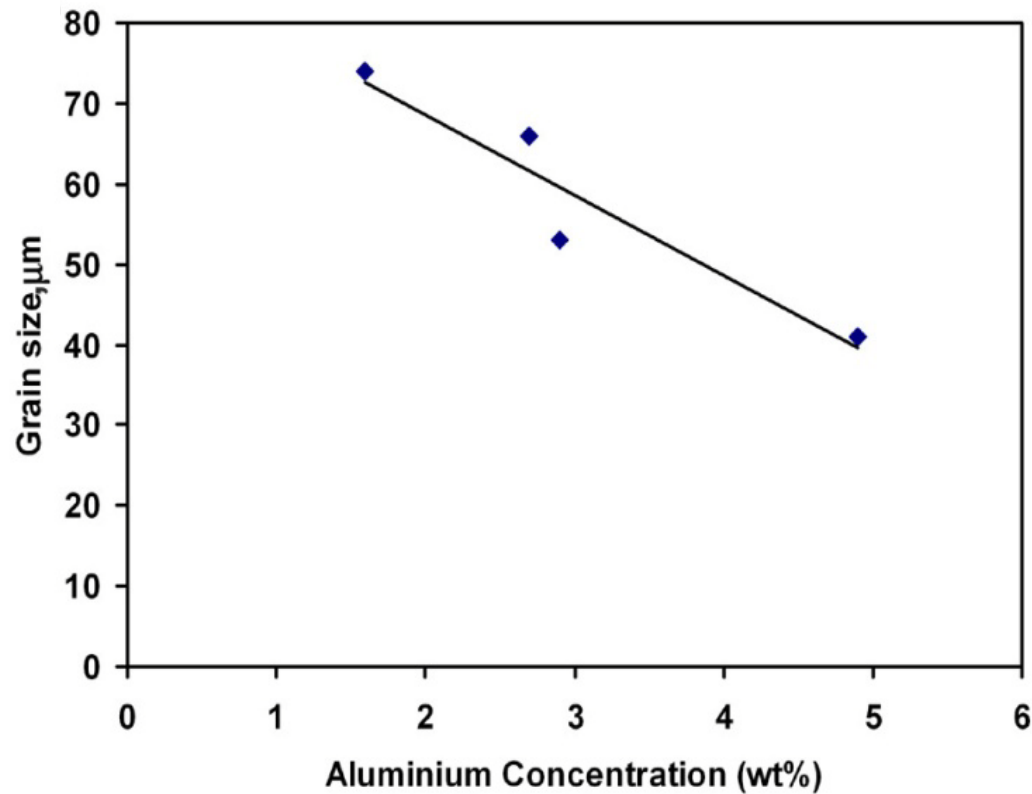
**2.4 wt.% Al in weld metal**



**5.0 wt.% Al in weld metal**

# Results

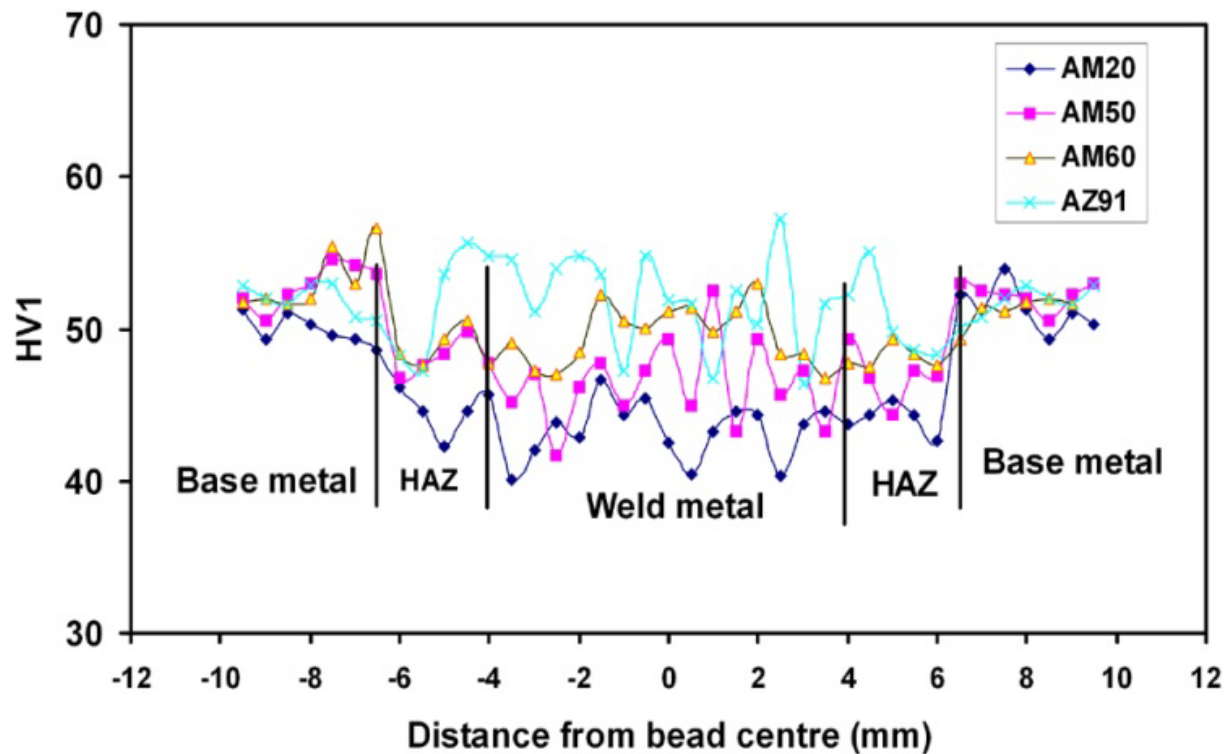
## Grain Refinement by Al





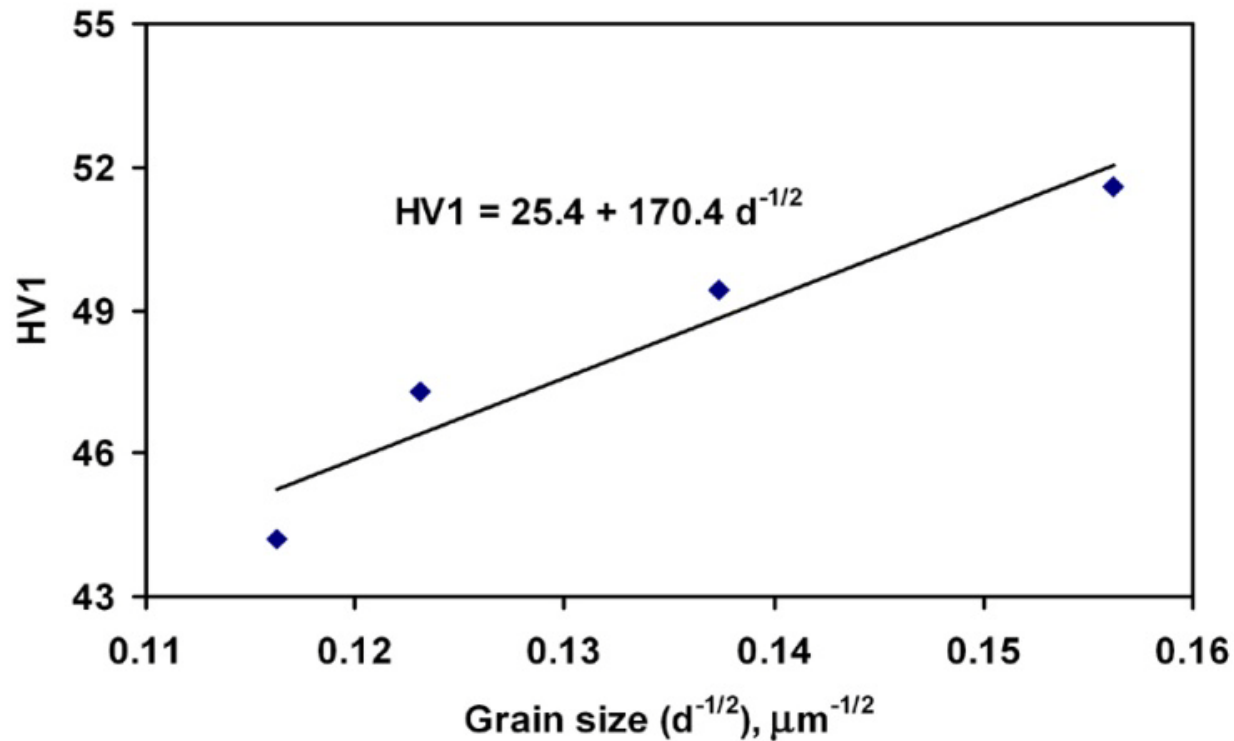
# Results

## Weld Hardness Traverse



# Results

## Hall-Petch Plot



# Results

## Weld Tensile Tests

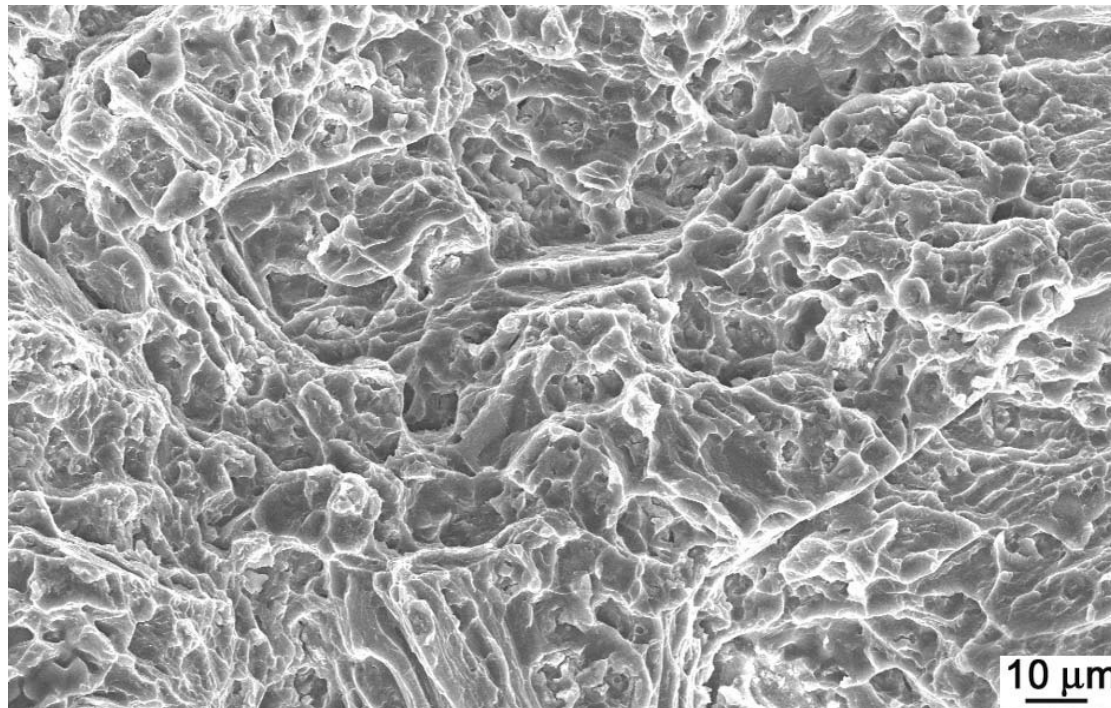
	Al (wt.%)	Ave. G.S. ( $\mu\text{m}$ )	Vick. Hard ( $\text{kg}/\text{mm}^2$ )	Yield Streng. (MPa)	Tens. Streng. (MPa)	Elong. 2" gage (%)	Fail
<b>Base Metal</b>							
AZ31	2.7	23	52	156	251	18	BM
<b>Weld Metal</b>							
AM20	2.4	74	44	70	190	8	WM
AM50	3.3	66	47	87	205	8	WM
AM60	4.3	53	49	105	217	13	WM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



# Results

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## Weld Metal Fractography



# Theory

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

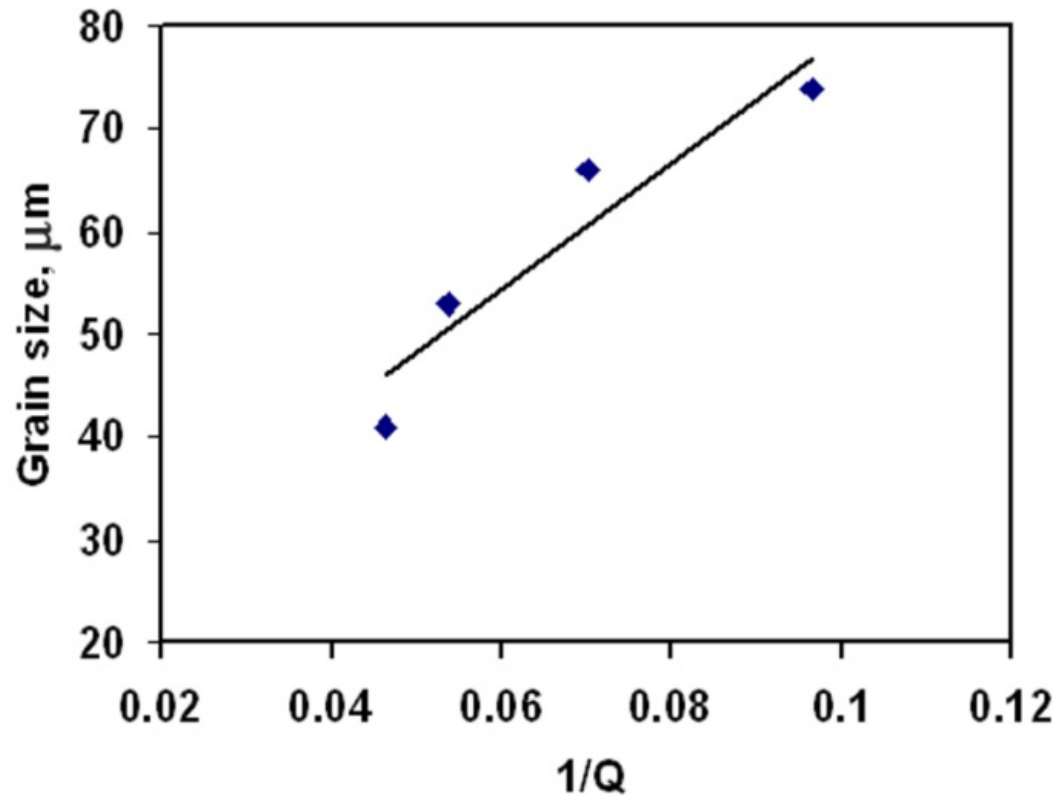
[Easton and St.John, 2005]

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



# Theory

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



# Conclusions

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- **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

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**M. Marten for metallography and**

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