



LOW VOLTAGE ANODES

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Overview



- Low Voltage Anodes – What Are They?
- Motivation for Low Voltage Anodes
 - High Strength Materials
 - Signatures
- Anode Characteristics
- CP Design With LVAs
- Remaining Issues



Modified E_{corr} Anodes

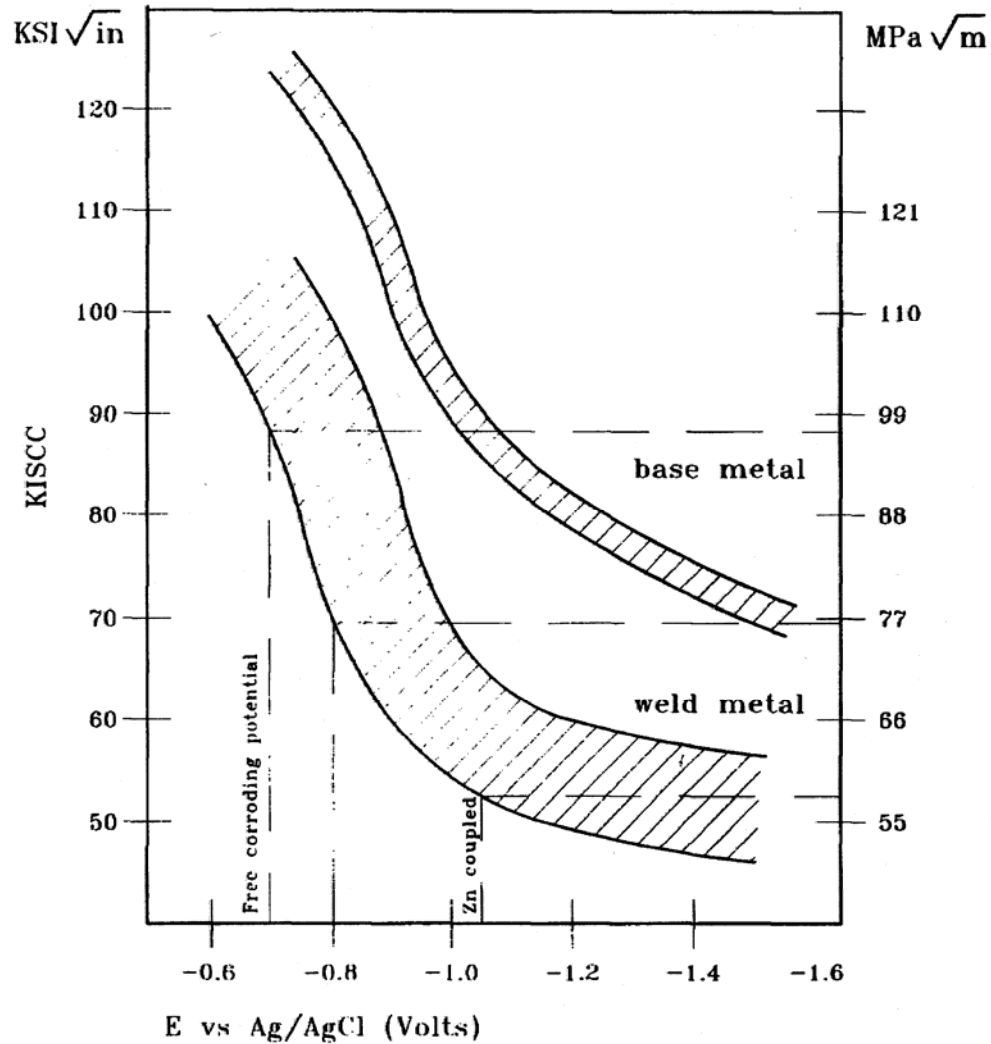


- Pautasso et al.
 - For HY 130, $K_{\text{ISCC}} < 60 \text{ MPa/m}^2$ depending on welding process and parameters
 - KISCC is a function of the applied potential.
 - Ideal cathodic potentials for Ni and C-Mn Alloys was between -0.730 and -0.850 V vs. SCE to provide low corrosion rates and acceptable SCC resistance.
- Conventional Galvanic Anodes have relatively electronegative potentials, by design.
 - MIL –A- 18001 (J) : Zn Anodes $-1.05\text{V vs. Ag/AgCl}$
 - MIL – A –24799(SH): Al Anodes $-1.1 \text{ V vs. Ag/AgCl}$

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Effect of Potential on K_{IEAC} of High Strength Steels





Effect of Anode Compositional Chemistry on Anode Performance

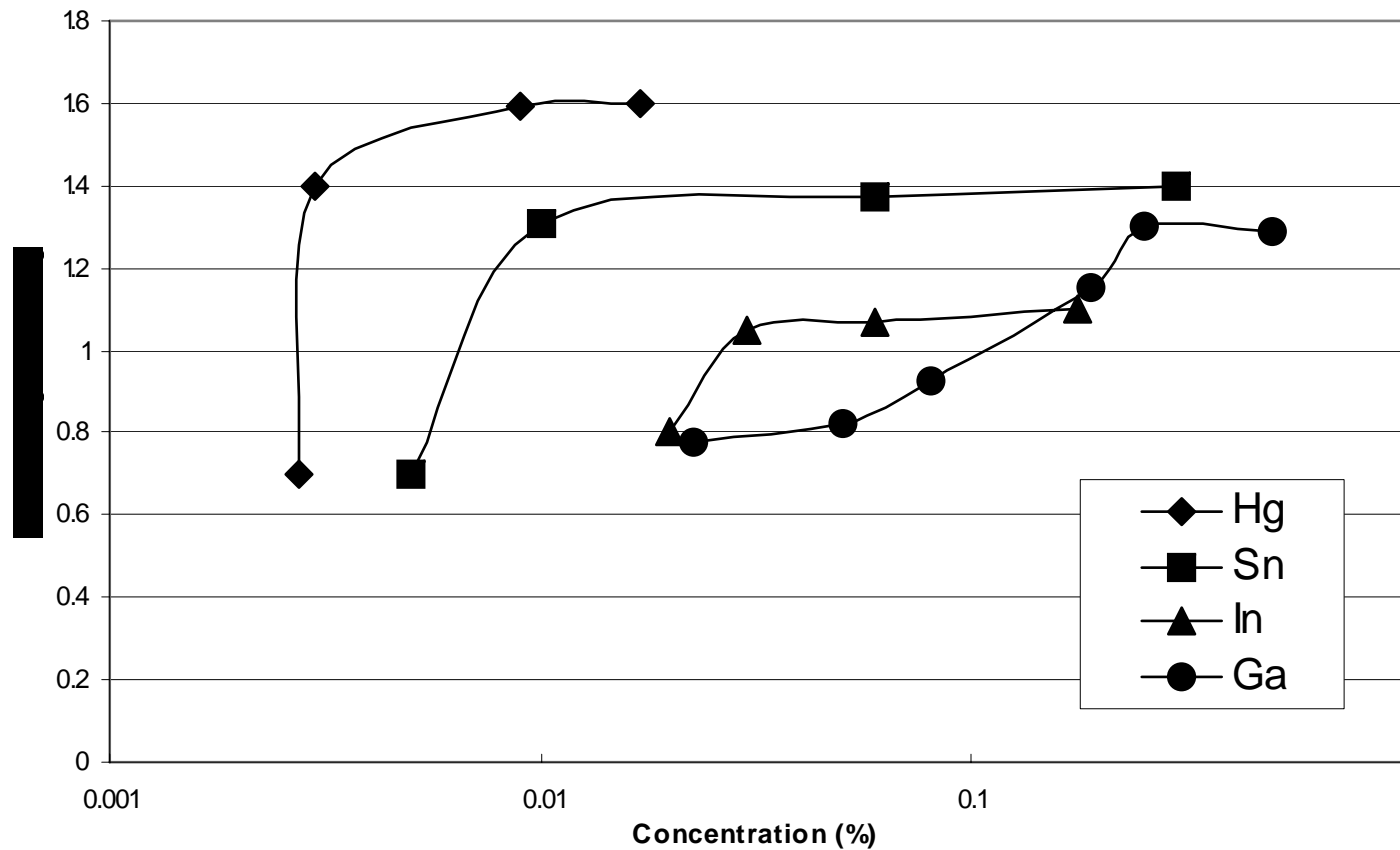


- Elemental Aluminum, which is an active/passive material, is a poor anode.
- Alloying with Zn, Hg, In, Sn, Ga, Bi activates Al and potentials approaching $-1.1V$ vs. Ag/AgCl are achieved
- Important poisons to anode performance and natural impurities in Al alloy anodes are: Fe, Si, Cd, and Cu all of which tend to either passivate the anode or destroy its efficiency.
- Typical Al anode chemistry per MIL-A-24779 (SH)
 - Al/ (4.0-6.5%) Zn / (0.014-0.020%) In
 - Al base (raw) material purity must be $> 99.8\%$

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Effect of Anode Composition on Potential



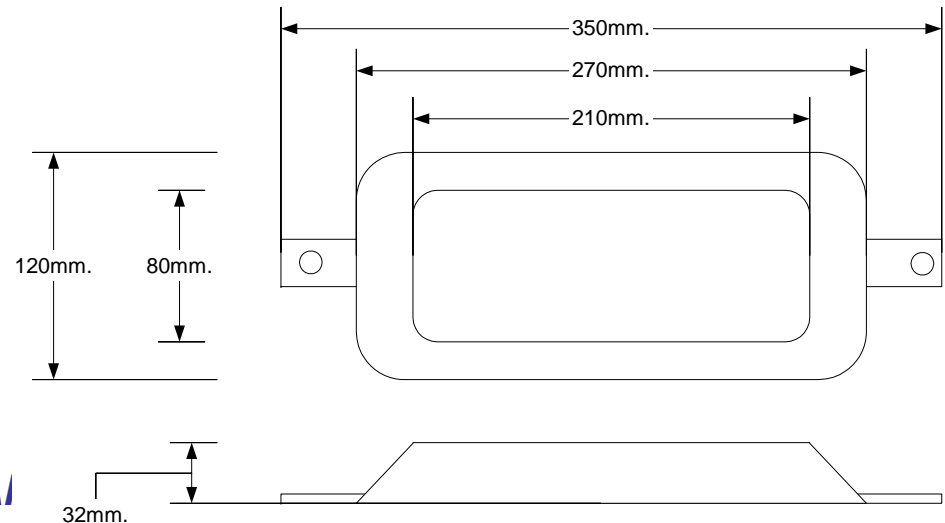
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Test Composition & Form



Anode	Zn	Ga	Si	Cu	Fe	Mg	Al
AG2	0.12	0.010	0.05	-	0.07	-	Bal.
AG2b	<0.10	0.094	0.045	<0.001	0.078	<0.001	Bal.



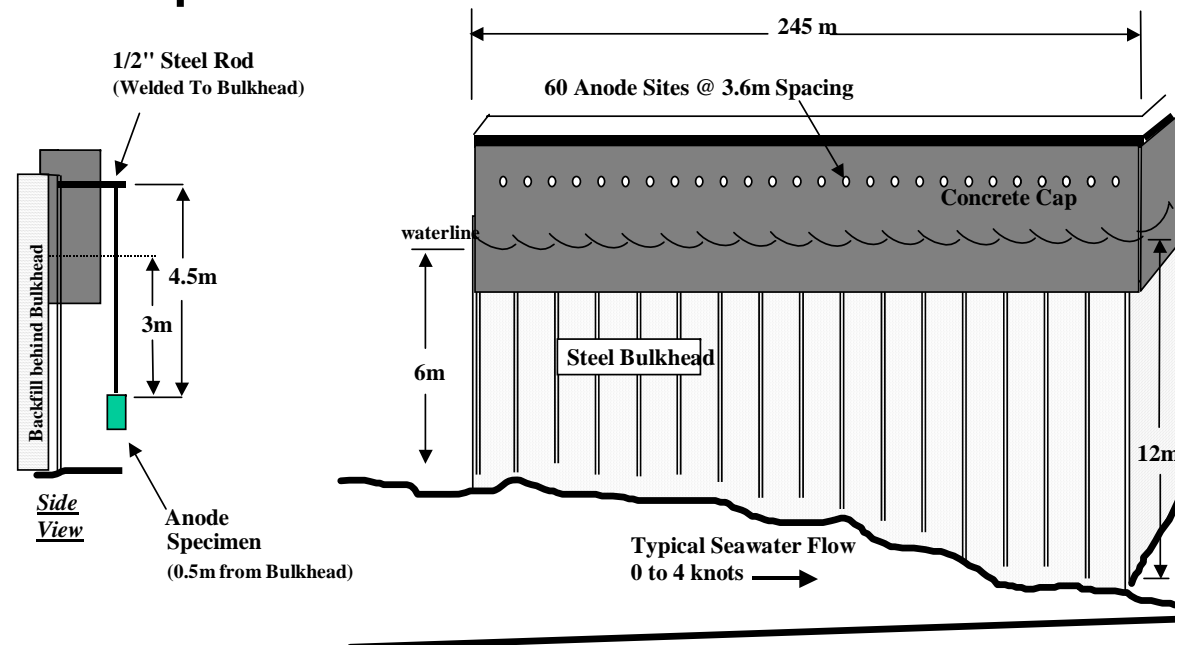
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NRLKW Anode Pier for Long Term Performance Testing



- Anode test site on “semi-infinite” cathode
- Seawall potential polarization is $<10\text{mV}$
- Anode currents monitored weekly
- Anode potentials acquired at start & finish.





Low Voltage Anodes - Attributes



- Potential: More Positive electrochemical potential.
 - $\sim -0.85\text{V}$ vs. Ag/AgCl
 - Zn and conventional Al anodes are -1.0V or lower.
- Composition: Al//0.1%Ga
- Current Capacity: 700-800 Ahr/lb
 - Traditional Al/Zn/In or Al/Zn/Hg is 1000-1100 Ahr/lb
 - Zn anode is 357 Ahr/lb
 - Life span is nearly twice that of Zn
- Efficiency: 55-60%
 - Traditional Al/Zn/In or Al/Zn/Hg is 80-90%
 - Zn anode is 95%
- Deposits: Voluminous

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Corrosion Morphology



Before Cleaning
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Anode 4, station 40



Highlights from Testing



- Alloy showed no sensitivity to temperature in current output.
- Low current density anodes did not passivate
- Working and Open-circuit potential over course of testing, no ennoblement has seen previously.
- Current densities somewhat lower than previous alloys
- Current capacities are significantly lower than previous results with other low voltage alloys.
- Current capacity not degraded by lower current density.
 - Very unusual!!!
 - Espelid et al. only case in literature.

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Design Challenge



- While LVAs are typical in size, shape and weights, normal design rules/values do not apply.
 - Significant decrease in “driving voltage”
 - Resultant decrease in current output and therefore protected area per anode.
- However, Ohm’s Law and Anode Resistance Equation are still valid (as always)
- Note LVAs CANNOT be used in:
 - Conjunction with Zn or traditional Al anode systems
 - ICCP system with the set-potential above -0.800 V vs. Ag/AgCl

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Design Assumptions



- **General Sac. CP Design For HS Steel and / or HE Susceptible Materials Using Low Voltage Anodes.**
 - (1) Use an open circuit potential of -0.83 volt for the LV anode.
 - (2) Use an open circuit potential value of -.6 volt for the combined noble metal / steel surface.
- **General Sac. CP Design For HS Steel and / or HE Susceptible Materials Using Low Voltage Anodes with A Minimal Area of Noble Metals**
 - (1) Use a driving voltage of 150 mV for the low voltage anode.
 - (2) Assume a initial current density of 15 mA/ft² for initial polarization and long term consumption. Allow the use of 10 mA/ft² for surfaces > 180 days continuous immersion.



Design Guidance



Table 5 - Sacrificial Anode Electrical Properties

(f)

Anode Material	Open Circuit Potential v. Ag/AgCl volts	Driving Voltage to Protected Substrate volts	Current Capacity				Anode Consumption		Density	
			Weight Basis		Volume Basis		kg/amp-yr	lb/amp-yr	kg/m ³	lb/in ³
			amp-hr/kg	amp-hr/lb	amp-hr/m ³	amp-hr/in ³				
Zinc [MIL-A-18001]	-1.05	0.20	812	388	5.85 x 10 ⁶	94	11	24	7141	0.258
Aluminum [MIL-A-24779A]	-1.10	0.25	2759	1250	7.58 x 10 ⁶	124	3.2	7.0	2740	0.099
Low Voltage Aluminum [MIL-A-24779A]	-0.83	0.15	1656	750	4.54 x 10 ⁶	74	5.4	12	2740	0.099

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Design Guidance 2



- Current Output of LVA may be increased by 1.53 if noble metal to steel surface area ratio is greater than 1:4.

Anode Style	Dimension (cm)			Current Output (New Anode) - mA		
	Length	Width	Depth	Zinc	Aluminum	L. Volt Aluminum
Z/A/LHC-23	30.5	15.2	3.2	330	410	250
Z/A/LHC-23 (half)	15.2	15.2	3.2	220	280	170
Z/A/LHS-23	30.5	15.2	3.2	330	410	250
Z/A/LHS-23 (half)	15.2	15.2	3.2	220	280	170
Z/A/LSS-12	30.5	7.6	3.2	240	300	180
Z/A/LSS-24	30.5	8.9	6.4	340	430	260
Z/A/LEP (Style B)	5.1	Radius and Thickness	2.5	50	60	40
	7.6		2.5	80	100	60
	10.2		2.5	110	140	80
	12.7		2.5	140	180	110
	15.2		2.5	170	210	130
	22.9		2.5	280	360	210
	27.9		2.5	360	450	270
Z/A/LEP (Style A)	19.1	5.1	5.1	190	240	140
Z/A/LEP (Style A)	15.2	15.2	2.5	200	250	150
Z/A/LHC-42	30.5	15.2	6.4	420	530	320
Z/A/LHS-42	30.5	15.2	6.4	420	530	320
Z/A/LHB-23	30.5	15.2	3.2	330	410	250
Z/A/LHB-23 (half)	15.2	15.2	3.2	220	280	170



Remaining Efforts



- Establish performance in in-service applications.
- Increase knowledgebase in LVA output in cathodic protection of noble metals
- Validate SCC/HE performance with Monel K500 and other susceptible alloys.