

GALVANIC ANODE SPECIFICATIONS – A MANUFACTURER’S PERSPECTIVE

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SUMMARY: Galvanic anode specifications provide a framework within which manufacturers must operate in order to produce anodes which comply with the design requirements and provide adequate protection to the given structure. This paper will discuss the purpose and value of each of the manufacturing and quality control criteria which make up a galvanic anode specification.

This paper will include some examples at both extremes. i.e. specifications which are so short on guidelines that quality requirements are all but non-existent for the manufacturer, allowing for second rate casting practices and short cuts, which inevitably lead to insufficient protection of the structure.

At the other extreme, some organisations have a generic galvanic anode specification, which over many years of accumulated additions, becomes extremely cumbersome, unnecessarily complicated and in some cases impossible to comply with.

This paper will also review some of the criteria outlined in commonly used standards, why they are used and how they are complied with in an anode manufacturing foundry.

Keywords: Galvanic, Anode, Technical Specification, Manufacture

1. INTRODUCTION

This paper is for engineers who are involved with the preparation of Galvanic Anode Specifications. It is not about galvanic anode design parameters, when to select different alloys or what type of anodes to choose, as this is the domain of the Corrosion Engineer. It is about the key aspects of a Galvanic Anode Specification from the perspective of a manufacturer.

Since commencing manufacturing in 1984, Cathodic Diecasting has accumulated substantial casting experience and reviewed a diverse range of technical specifications and international standards. Using this knowledge, this paper will discuss the purpose and value of each of the following elements and outline what we believe to be best practice.

- Aluminium Anode Alloys
- Casting Tolerances
- Anode Traceability
- Electrochemical Testing
- Anode-To-Core Resistance Testing
- Steel Inserts

This paper will conclude with some examples which support the key points presented in this paper.

2. ALUMINIUM ANODE ALLOYS

Aluminium based alloys, as opposed to Zinc and Magnesium, make up the majority of technical specifications we receive, so this part of the paper will focus on some of the aluminium alloys, with particular emphasis on those specified in Australia and New Zealand.

2.1 DNV-RP-B401/ NACE SP0607/ NORSOK M-503

As table 1 illustrates, this group of alloys are almost identical. They were developed for use in the North Sea and the Gulf of Mexico. We have seen a gradual increase in the use of these alloys in Australia and New Zealand over the past two or three years. We assume that this is because engineers as well as organisations from the North Sea and the Gulf of Mexico are operating in greater numbers on Australian and New Zealand projects.

Table 1. DNV-RP-B401/NACE SP0607/NORSOK M-503 Alloy Compositions

Alloy	Zn	In	Cd	Si	Fe	Cu	Other		Al
							Each	Tot.	
DNV-RP-B401 (2005)	2.5 – 5.75	0.015 – 0.040	0.002 max	0.12 max	0.09 max	0.003 max	-	-	Bal
NACE SP0607 (2007)	2.5 – 5.75	0.016 – 0.040	0.002 max	0.12 max	0.09 max	0.003 max	0.02 max	-	Bal
Norsok M-503 (2003)	2.5 – 5.75	0.015 – 0.040	-	0.10 max	0.09 max	0.003 max	-	-	Bal

Note that each of these 3 alloys has a maximum Iron concentration of 0.09%. The Iron level is usually the key element which determines the grade of primary ingot to purchase.

As a general rule our foundry allows for a 0.02% buffer for Iron as a safeguard against Iron that may be picked up during the manufacturing process. No matter how meticulously clean the foundry or how stringent the manufacturing procedures, there is still a chance of picking up some Iron during casting. When casting any of the alloys in table 1, we would purchase primary ingot which has an Iron concentration of no higher than 0.07%, leaving a buffer of 0.02%.

2.2 AS2239 A1

A1 is one of the most commonly used Aluminium Anode alloys in Australia and New Zealand. The alloy composition has changed little since it was introduced in the first issue of AS2239 in 1979.

Table 2. AS2239 A1 Alloy Composition

Alloy	Zn	In	Cd	Si	Fe	Cu	Other		Al
							Each	Tot.	
AS2239 A1	2.1 – 2.7	0.017 – 0.025	0.008 – 0.012	0.20 max	0.12 max	0.006 max	0.02 max	0.05	Bal

A1 is an interesting alloy, in that it has a minimum and a maximum value for Cadmium. Few alloys use both Cadmium and Indium as the activators against self passivation. Most alloys rely on indium alone as the activator.

2.3 GALVALUM®III/AS2239 A6

There has been a lot of conjecture surrounding the use of the Galvalum®III alloy. A brief look at its history and a comparison with the AS2239 A6 alloy and other recognised alloys should clear up a number of misconceptions.

In the US during the 1950's, 60's and 70's the Dow Chemical Company developed a number of Aluminium based alloys for use as Aluminium Anodes for corrosion protection. Their research and field trials resulted in the development of an Al-Zn-In alloy composition that performed well in a number of marine environments. The Dow Chemical Company patented this alloy and called it "Galvalum®III".

Table 3. Galvalum®III Alloy Composition

Alloy	Zn	In	Cd	Si	Fe	Cu	Other		Al
							Each	Tot.	
Galvalum®III	2.00 – 6.00	0.01 – 0.02	-	0.08 – 0.20	0.13 max	0.006 max	0.02 max	-	Bal

The Galvalum name is the exclusive trademark of Cathodic Protection Technology Pte Ltd

The worldwide patent on this chemical composition expired in the late 1990's and became public domain. Subsequently, Cathodic Protection Technology Pte Ltd (anode manufacturer based in Singapore and Malaysia), registered the trade mark name "Galvalum", **but not the chemistry**. This remains public domain.

When the patent **on the chemistry** expired, a number of reputable foundries used this proven chemistry as the basis for similar alloys, refer to table 4. A brief comparison between table 3 and table 4 illustrates the similarities.

Table 4. Impalloy III, Galvotec III and Defender G3 Alloy Compositions

Alloy	Zn	In	Cd	Si	Fe	Cu	Ti	Other		Al
								Each	Tot.	
Impalloy: Impalloy III	2.8 – 6.5	0.01 – 0.02	0.002 max	0.12 max	0.12 max	0.006 max	0.025 max	0.02 max	0.05	Bal
Galvotec: Galvotec III	2.8 – 6.5	0.010 – 0.02	0.002 max	0.08 – 0.2	0.120 max	0.006 max	-	0.02 max	0.05	Bal
Aberdeen Foundries: Defender G3	2.8 – 6.5	0.01 – 0.02	-	0.08 - 0.21	0.12 max	0.006 max	-	0.02 max	-	Bal

The Australian version of this alloy was included in the 2003 revision of AS2239 as designation A6 (refer to table 5). A direct comparison of the two alloys shows that Zinc, Indium and Copper are in the same proportions, while Silicon, Iron and Cadmium are more tightly controlled in A6.

It is important to point out that **by complying with A6, the alloy also complies with Galvalum®III**. Also, the tighter tolerances of the A6 alloy means that the anode is more likely to operate more efficiently.

Table 5. Galvalum®III and AS2239 A6 Alloy Compositions Comparison

Alloy	Zn	In	Cd	Si	Fe	Cu	Mg	Ti	Sn	Other		Al
										Each	Tot.	
Galvalum®III	2.00 – 6.00	0.01 – 0.02	-	0.08 – 0.20	0.13 max	0.006 max	-	-	-	0.02 max	-	Bal
AS2239 A6	2.0 – 6.0	0.01 – 0.02	0.005 max	0.08 – 0.12	0.12 max	0.006 max	0.02 max	0.02 max	0.02 max	0.02 max	0.05	Bal

Galvalum®III/A6 is widely specified in Australia and New Zealand. Some engineers specify Galvalum®III, but will not accept A6, even though it is quite clear that the percentages of all elements within A6 comply with Galvalum®III.

2.4 CHALLENGE FOR THE FUTURE

Engineers and manufacturers are facing new challenges as oil and gas infrastructure moves into deeper water. Anode alloys designed for shallow water are not always suitable for deep water. NACE published a report early last year addressing this subject, titled **“Cathodic Protection Design Considerations for Deep Water Projects”**.

In terms of Galvanic Anodes, this report indicates that in deep water:

- Temperature
- pH
- Salinity
- Current velocity
- Pressure
- Dissolved oxygen
- Seasonal variations
- Degree of fouling at various depths

all have an effect on the rate of corrosion. At this stage there has been no definitive studies conducted on these variables and how they relate to each other.

Shell Petroleum has developed a widely accepted alloy for deep water applications (refer to table 6), which has been replicated by a number of reputable foundries. Note the very low Iron level (0.06% max) is critical in ensuring that the anode will not passivate.

Table 6. Shell Deep Water Alloy Composition

Alloy	Zn	In	Cd	Si	Fe	Cu	Other		Al
							Each	Tot.	
Shell DEP 37.81.20.31	4.75 – 5.75	0.016 – 0.020	0.002 max	0.08 – 0.12	0.060 max	0.0030 max	0.02 max	0.05	Bal

It is most likely that the composition of these alloys will evolve as our knowledge of deep water conditions improves.

3. CASTING TOLERANCES

Most international standards and casting specifications have detailed casting tolerances. These usually cover:

- | | |
|---|--|
| <ul style="list-style-type: none"> • Anode dimensions • Nett and gross weight • Anode straightness • Insert position • Shrinkage depressions | <ul style="list-style-type: none"> • Inclusions • Cold shuts • Sharp edges • Bending • Cracking |
|---|--|

Over the years the author has reviewed many standards and technical specifications with a wide spectrum of casting tolerances. Some of these tolerances are possible to achieve, but at a very high cost for little benefit. Others have tolerances that are too loose and allow for poor workmanship by second rate manufacturers.

From our research, the standard which strikes a really good balance between being stringent enough to prevent poor workmanship, and providing a realistic range of tolerances which can be achieved by reputable anode manufacturers is **NACE SP0387(2006) “Metallurgical and Inspection Requirements for Cast Galvanic Anodes for Offshore Applications”**.

3.1 ANODES THAT CRACK

From a manufacturer’s point of view, the most challenging castings are when the combination of steel insert, anode cross section and anode alloy combine to produce an anode which is likely to crack.

It is important to keep in mind that cracking in aluminium anodes is a direct result of the metallurgical properties of the alloy. The performance criteria of these alloys have been designed for their electrochemical properties, such as potential and current capacity, rather than for ease of casting, structural integrity or corrosion resistance, as with other aluminium based alloys.

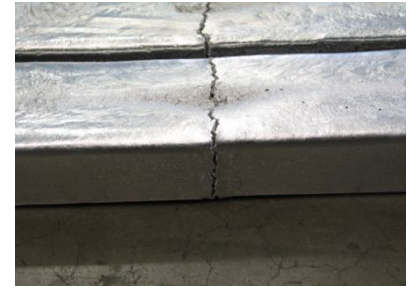


Figure 1: Cracked Anode

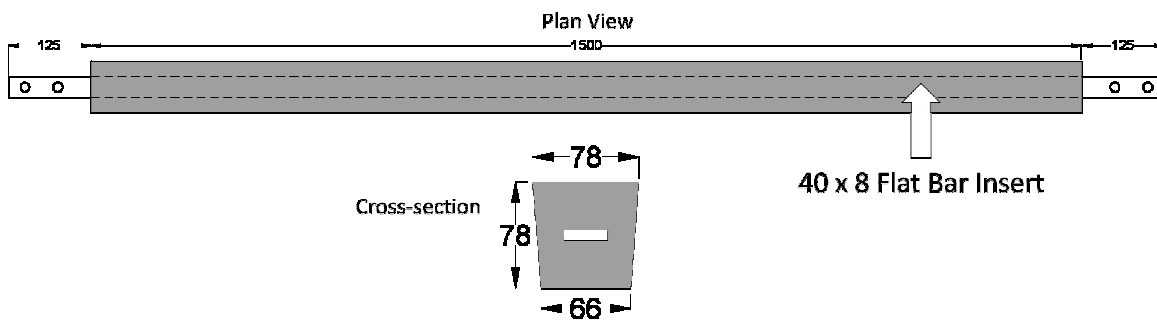


Figure 2: Anode Prone to Cracking

Figure 2 is typical of an anode that would be prone to cracking. Notice the small cross section of the anode material compared to the cross section of the insert, which is relatively large for an anode of this size.

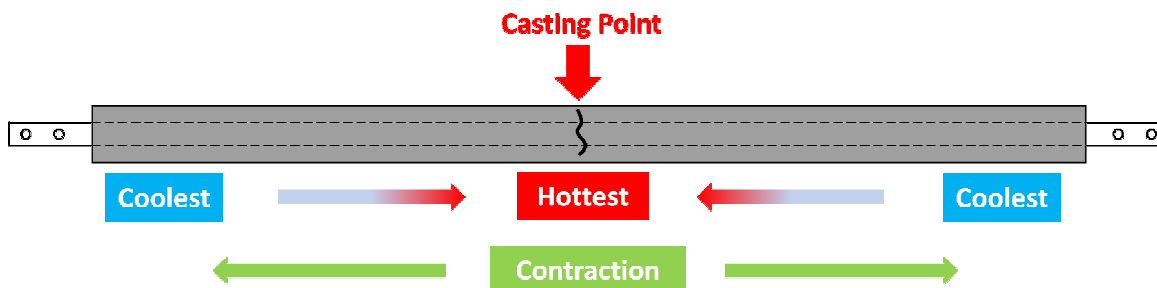


Figure 3: Why Cracking Occurs

As illustrated in Figure 3, the anode is cast in the central part of the mould resulting in a concentrated hot zone in both the anode and the mould material. As the molten metal at the ends of the mould cools and solidifies, it pulls away from the hottest part of the casting which is still molten. This is the primary cause of full circumferential cracking, which does not meet most recognised standards and technical specifications.

There are numerous casting techniques that can be employed to reduce or eliminate cracking, but they can be time consuming and costly. Often the simplest solution is to change the insert configuration at the design stage.

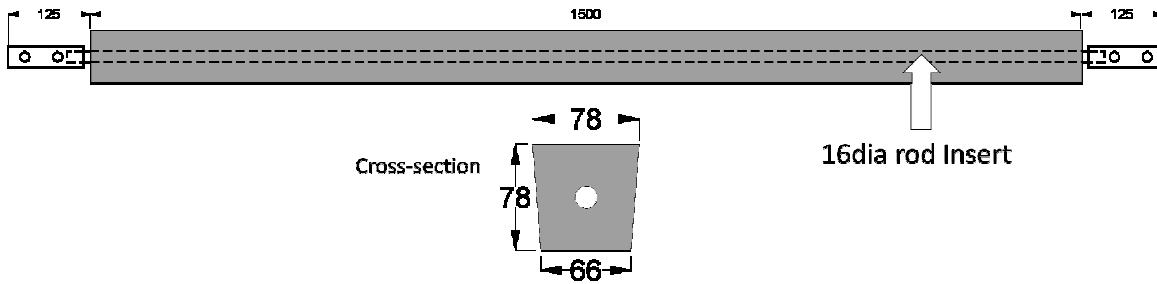


Figure 4: Alternative design which is unlikely to crack

As shown in Figure 4, the solution would be to replace the 32x8 flat bar with a 16mm diameter rod and weld the 32x8mm flat bar tabs onto the ends. The 16mm diameter rod has a smaller cross sectional area, this results in a thicker section of anode material between the insert and the mould. The thicker anode material section results in a lesser capacity for the molten metal to pull away from the hottest part of the casting while it cools.

3.2 CONSULT WITH A MANUFACTURER AT THE DESIGN STAGE

Consultation between the design engineer and the manufacturer at the design stage can eliminate a range of casting issues, such as cracking. A brief discussion at the design stage can eliminate costly technical engineering design changes that may go undetected right up until the procurement stage.

4. TRACEABILITY

If an anode is not working effectively, the link back to the chemical composition of the anode is vitally important.

Our internal procedure states, *“Aluminium anodes are traceable via the heat number, which is hard stamped on the face of the anode. This heat number is also recorded on the disc sample, which links it to the spectrometer analysis and the customer job number.”*

It is most important for the client to have a clear understanding of how the manufacturer links the anodes back to their chemical analysis reports. If this is not a clearly defined process, it may suggest that the foundry has poor house-keeping practices.

Hard stamping of the heat number on the anode ensures traceability to the point of installation. The concern is that once the anodes start to corrode, the heat number disappears quite rapidly. Some contractors and installers record the heat number of each anode and its GPS location, so that even when the heat number disappears the anode is still traceable to its chemical analysis.

5. ELECTROCHEMICAL TESTING

Laboratory based Electrochemical testing is an accelerated corrosion test, where the rate of corrosion is measured over a short period of time. The test gives an indication that the anode will corrode at the desired rate when in service.

The author recently reviewed three of the most commonly specified electrochemical test methods. They were:

1. NACE TM0190
2. AS2239
3. DNV-RP-B401

5.1 NACE TM0190

This standard includes two test methods, Hydrogen Capture and Mass Loss.



Figure 5: DNV-RP-B401 Electrochemical Testing Baths

Hydrogen Capture Method: This test is quick to set up and easy to conduct but some reports suggest that it consistently over-estimates the current capacity by as much as 100 – 200 A-hrs/kg, possibly due to not all of the hydrogen being captured.

Mass Loss Method: Uses the same principle as the DNV-RP-B401 method, (discussed later in this paper), but the test period is 14 days. Given the commercial pressure to release the anodes, this is too long.

5.2 AS2239

The Australian Standard AS2239 Annex D is frequently specified, but it lacks detail in the set-up method and is open to interpretation. There is also some confusion with regard to acceptable limits for the consumption rate. It is also restricted to only testing Aluminium Anode Alloys and the test period is 10 days.

AS2239 is due for revision soon. As an industry, we need to decide whether to revise this part of the Australian Standard or adopt an existing International standard.

5.3 DNV-RP-B401

The DNV-RP-B401 standard is easy to follow, easy to set-up and most importantly has little room for misinterpretation. The other major benefit of this standard is that it applies to both Aluminium and Zinc anode alloys.

From a commercial perspective, the test period is four days, which in comparison to NACETM0190 and AS2239, significantly reduces the lag time between casting the anodes and releasing them to the customer.

We receive far and away more technical specifications requesting electrochemical testing according to the DNV-RP-B401 standard than any other. It has become the industry standard in Australia and New Zealand.

Figure 6 represents the DNV-RP-B401 set-up for consumption rate testing. Figure 7 represents the DNV-RP-B401 set-up for Closed Circuit Potential testing.

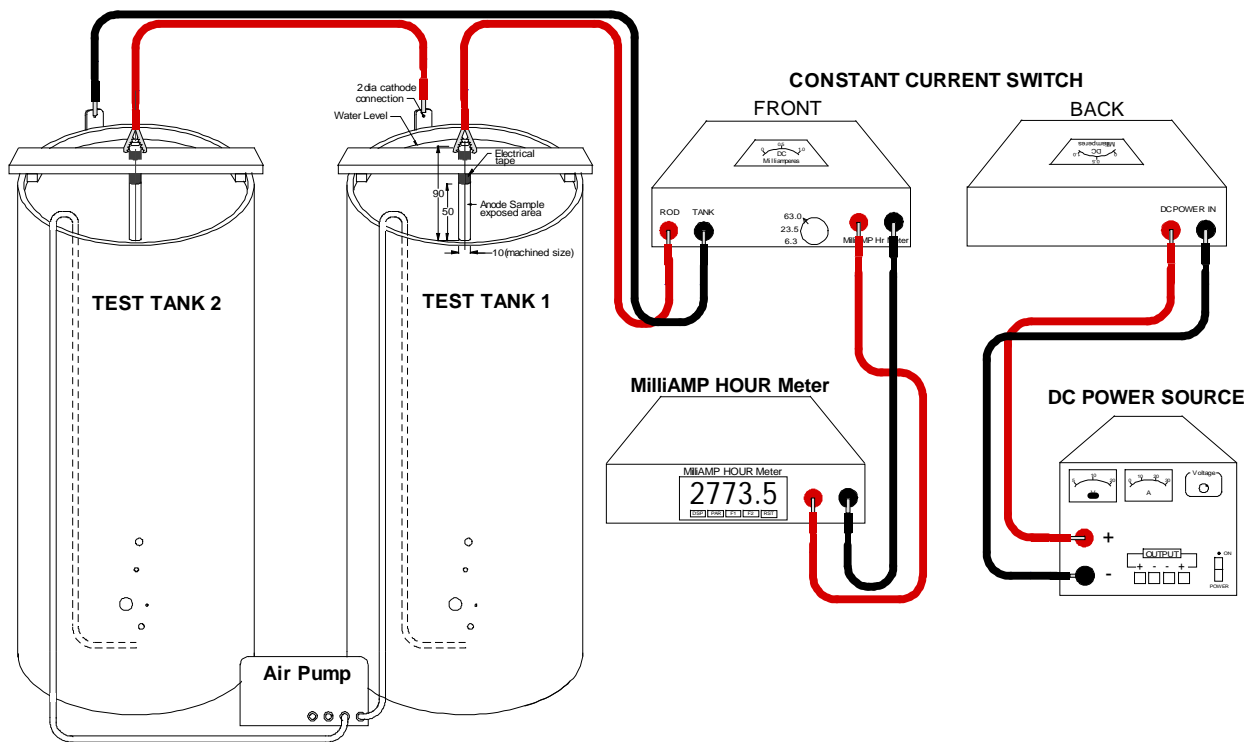


Figure 6: DNV-RP-B401 Consumption Rate Testing

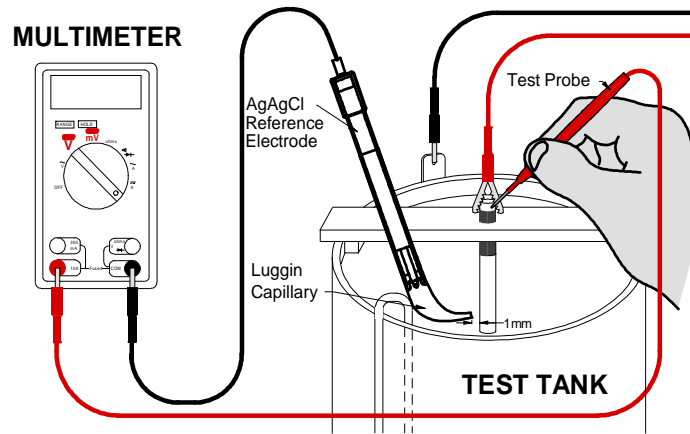


Figure 7: DNV-RP-B401 Closed Circuit Potential Testing

5.4 IS ELECTROCHEMICAL TESTING WORTHWHILE?

There are two opposing arguments for laboratory based Electrochemical Testing:

1. It provides an indication of the expected performance of the anode and provides confidence that the anode will offer suitable protection once installed.
2. If the alloy composition of the anode meets the requirements of the designated specification, then the anode will operate effectively. Why conduct expensive and time consuming laboratory based testing when it does not accurately represent the “in service” performance of the anode?

This argument prompts the question; **Is there more to an anode than just the alloy composition?**

Some recent electrochemical testing indicates that, in some cases, there is more to an anode than just the alloy composition. In one test, we spectrographically analysed an Aluminium anode; it complied with the designated alloy composition. Electrochemical testing was then conducted on the same anode, which yielded very inconsistent results.

The equipment and the circuit were checked, which were working effectively. The electrochemical tests were conducted again. The results were inconsistent yet again.

The results were puzzling, so further investigation involved conducting multiple spectrographic tests from various positions and at various depths within the anode. Most of the spectrographic readings complied with the alloy specification, but there was a lot of variation in the readings. The conclusion was that the alloy composition was not homogenous and this was the reason for the inconsistent electrochemical behaviour of the anode.

Further testing is needed in order to draw more solid conclusions, but we are confident that homogeneity of the alloy is an important factor in anode performance. In the test above, electrochemical testing identified the issue, which would not have occurred with Spectrographic testing alone. So for this reason electrochemical testing is worthwhile and there is more to an anode than just the spectrographic analysis results.

5.5 HOMOGENEITY, FURNACE TYPE AND CASTING PRACTICES

The type of furnace and the casting procedures in place in the foundry can affect the homogeneity of the alloy.

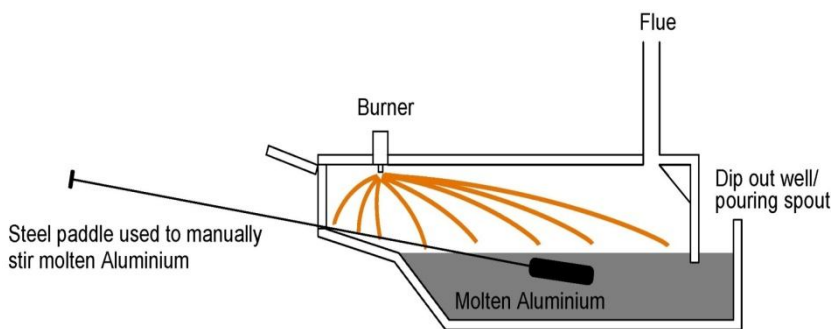


Figure 8: Gas Fired Furnace Requires Manual Stirring

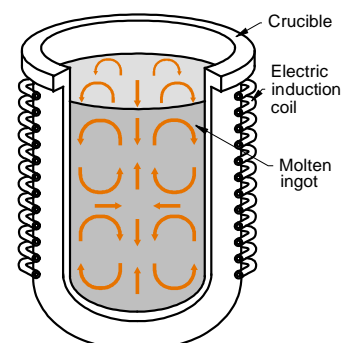


Figure 9: Electric Resistance Furnace

Many gas fired furnaces can only be stirred manually (see Figure 8) and as soon as the furnace is not being stirred, the heavier elements which are added to the alloy to improve anode efficiency such as Zinc and Indium as well as impurities such as Iron and Lead start to sink to the bottom of the furnace. If stirring is carried out on an ad-hoc basis, the heavier elements sink causing the anodes cast from the bottom of the furnace to have a different alloy composition from the anodes cast from the top. Or, as the previous example illustrates, the alloy composition can vary within a single anode.

The electromagnetic field in Electric induction furnaces (Figure 9), creates a natural stirring action, where the molten metal continually circulates throughout the molten bath up until the anodes are cast, ensuring that the anodes are homogenous.

6. ANODE-TO-CORE RESISTANCE TESTING

The purpose of Anode-to-Core Resistance Testing is to check that there is minimal electrical resistance between the anode material and its steel core.

Australian Standard AS2239 Annex C has a clearly defined procedure for testing anode-to-core resistance. Figure 10 is from our internal procedure. In summary, a 5 amp current is applied through the anode, then a millivolt reading is taken with one probe on the anode and the other probe on the steel insert. To calculate the total resistance, divide the millivolt reading by the ampere reading.

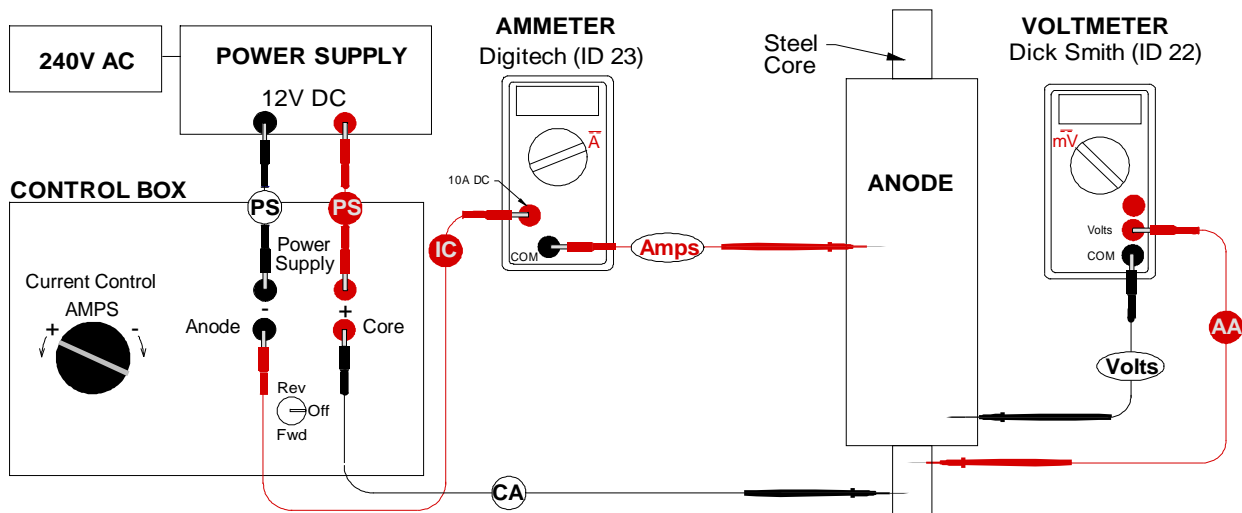


Figure 10: AS2239 Anode-To-Core Resistance Test

AS2239 specifies that the electrical resistance of the anode-to-core “shall be not greater than 0.01 Ohms for the life of the anode”. Our readings are typically 0.0003 Ohms or less.

6.1 CORRODED STEEL ANODE-TO-CORE RESISTANCE TEST

To check the worth of this test, we set up a trial to see what result would be achieved casting a Zinc anode onto a corroded steel insert (refer to Figure 11 and 12).



Figure 11: Casting zinc onto a corroded steel insert

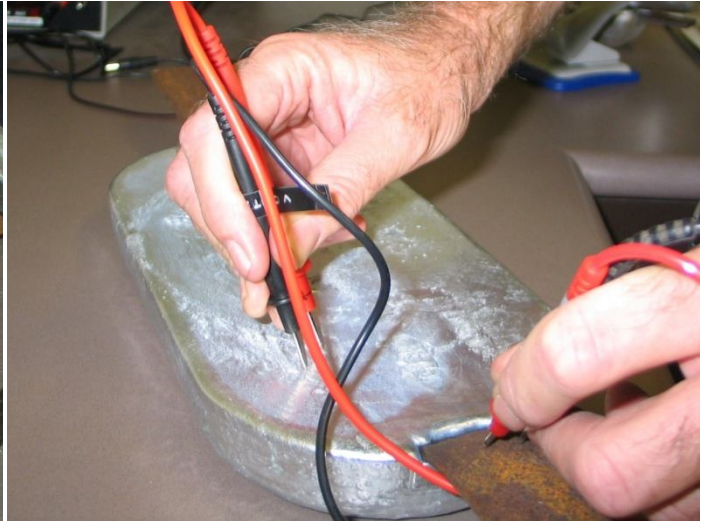


Figure 12: Anode-To-Core test with a corroded steel insert

The reading for this test was 0.0004 ohms. As you can see, even a heavily corroded insert is well and truly below the 0.01 ohm maximum specified in AS2239.

This result brings into question the value of conducting this test.

Anode-to-Core resistance testing is not common in international standards and is not commonly requested in technical specifications. This may be because the test does not provide any real benefit.

The most effective and most widely specified method of ensuring the integrity of the electrical continuity between the anode and the steel core is to specify:

1. Inserts are abrasive blast cleaned to a recognised standard (eg AS1627.4 class 2.5 or ISO 8501-1 SA2.5).
2. Blasting is done within a defined time frame prior to casting, usually 12-24hrs. Ensure that blast certificates are requested as part of the Manufacturers Data Report.
3. Destructive testing. Destructive testing involves cutting the anode at various points along the length of the anode. This test clearly show any disbondment or voids adjacent to the steel core. A destructive test is also useful to check that the insert is central within the anode.

The anode with the corroded steel insert (see Figure 13) was sectioned. Note the void on the upper side of the insert. Gas was still trying to escape from the steel core as the molten alloy solidified, trapping the gas at the surface of the insert.



Figure 13: Destructive Test of Anode with Corroded Steel Insert

6. STEEL INSERTS

It is most important to specify the steel grade and request steel certificates from traceable batch numbers. If there is no specification, steel suppliers can supply cheap low grade steel, which can result in cracking when the inserts are being bent, or while the anodes are being installed or at some time after installation.

We do not see many technical specifications that do not clearly define the grade of steel that is required. This requirement is frequently skipped for smaller jobs that are required at short notice.

7. CONCLUSION/KEY POINTS

The following four points are the most important elements to be considered by engineers when putting together a Galvanic Anode Technical Specification.

7.1 USE RECOGNISED STANDARDS AS A GUIDE

Use recognised standards as a guide, this will eliminate most pitfalls. There are numerous standards which can be used, some include:

- AS2239 (2003)
- AS2832 series
- NACE RP0387 (2006)
- DNV-RP-B401 (2005)

These standards are easy to follow and ensure that engineers and manufacturers are clear on what is required.

7.2 PROVIDE SUFFICIENT INFORMATION

The best way to explain the importance of this point is to provide an example.

Last year we received a request for quote for a 95,000kg job for a major piece of marine infrastructure. The scope of work document was a single A4 page. A tender of this size should include a sizable technical specification comprising stringent casting tolerances, detailed inspection and testing requirements, comprehensive back-up documentation and possibly a site inspection.

There was no requirement for:

- Spectrographic analysis
- Steel grade for the inserts
- Abrasive blasting of inserts
- Weight and dimensions check
- Destructive testing
- Traceability of alloy batches
- Electrochemical testing
- Inspection and test plan
- Manufacturers data report

Each of these requirements serves a specific purpose in ensuring that anodes will offer sufficient protection. To ignore or exclude any of these requirements could result in manufacturers taking short cuts and ultimately risking the protection of the structure.

7.3 PROVIDE CLEAR INFORMATION

Some organisations have a generic specification which over many years of accumulated additions, becomes extremely cumbersome, unnecessarily complicated and in some cases impossible to comply with.

A good example of this was a section in a recent technical specification which stated:

“The basis for the anode material specification is AS2239”

The next paragraph stated:

“The material shall be Galvalum III or approved equivalent...”

Later in the same paragraph was a table with a completely different alloy composition again, which in no way reflected any of the AS2239 alloys or Galvalum®III.

In this instance, clarification was needed from the client. Often, seeking clarification can be time consuming, as the client must go to their client and so on up the chain until a decision is forthcoming.

7.4 CONSULT WITH A MANUFACTURER AT THE DESIGN STAGE

Finally and most importantly, consult with a manufacturer at the design stage. A brief discussion can save a lot of time and expense in re-designing at the procurement stage.

REFERENCES

Standard	1. DNV-RP-B401 (2005) Cathodic Protection Design
Standard	2. NACE SP0607 (2007) Petroleum and Natural Gas Industries – Cathodic Protection of Pipeline Transportation Systems
Standard	3. Norsok M-503(2007) Cathodic Protection
Standard	4. AS2239 (2003) Galvanic (sacrificial) anodes for cathodic protection
Standard	5. NACE SPO387 (2006) Metallurgical and Inspection Requirements for Cast Galvanic Anodes for Offshore Applications
Standard	6. NACE TM0190 (2006) Impressed Current Laboratory Testing of Aluminium Alloy Anodes
Standard	7. AS1627.4 (2005) Metal finishing – Preparation and pretreatment of surfaces – Abrasive blast cleaning of steel
Standard	8. ISO 8501-1 (2007) Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness – Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings
Standard	9. AS2832.1 (2004) Cathodic Protection of Metals – Pipes and Cables
Standard	10. AS2832.2 (2003) Cathodic Protection of Metals – Compact Buried Structures
Standard	11. AS2832.3 (2005) Cathodic Protection of Metals – Fixed Immersed Structures
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AUTHOR DETAILS



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