Corrosion Control - Galvanic Table

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Listed below is the latest galvanic table from MIL-STD-889. I have numbered the materials for future discussion of characteristics. However, for any combination of dissimilar metals, the metal with the lower number will act as an anode and will corrode preferentially.

The table is the galvanic series of metals in sea water from Army Missile Command Report RS-TR-67-11, "Practical Galvanic Series."

The Galvanic Table

Active (Anodic)

1. Magnesium
2. Mg alloy AZ-31B
3. Mg alloy HK-31A
4. Zinc (hot-dip, die cast, or plated)
5. Beryllium (hot pressed)
6. Al 7072 clad on 7075
7. Al 2014-T3
8. Al 1160-H14
9. Al 7079-T6
10. **Cadmium (plated)**
11. Uranium
12. Al 218 (die cast)
13. Al 5052-0
14. Al 5052-H12
15. Al 5456-0, H353
16. Al 5052-H32
17. Al 1100-0
18. Al 3003-H25
19. **Al 6061-T6**
20. Al A360 (die cast)
21. Al 7075-T6
22. Al 6061-0
23. Indium
24. Al 2014-0
25. **Al 2024-T4**
26. Al 5052-H16
27. Tin (plated)
28. Stainless steel 430 (active)
29. Lead
30. Steel 1010
31. Iron (cast)
32. Stainless steel 410 (active)
33. **Copper (plated, cast, or wrought)**

34. Nickel (plated)
35. Chromium (Plated)
36. Tantalum
37. AM350 (active)
38. Stainless steel 310 (active)
39. Stainless steel 301 (active)
40. Stainless steel 304 (active)
41. Stainless steel 430 (active)
42. Stainless steel 410 (active)
43. Stainless steel 17-7PH (active)
44. Tungsten
45. Niobium (columbium) 1% Zr
46. Brass, Yellow, 268
47. Uranium 8% Mo.
48. Brass, Naval, 464
49. Yellow Brass
50. Muntz Metal 280
51. Brass (plated)
52. Nickel-silver (18% Ni)
53. Stainless steel 316L (active)
54. Bronze 220
55. Copper 110
56. Red Brass
57. Stainless steel 347 (active)
58. Molybdenum, Commercial pure
59. Copper-nickel 715
60. Admiralty brass
61. Stainless steel 202 (active)
62. Bronze, Phosphor 534 (B-1)
63. Monel 400
64. Stainless steel 201 (active)
65. Carpenter 20 (active)
66. Stainless steel 321 (active)
67. Stainless steel 316 (active)
68. Stainless steel 309 (active)
69. Stainless steel 17-7PH (passive)
70. Silicone Bronze 655
71. Stainless steel 304 (passive)
72. Stainless steel 301 (passive)
73. Stainless steel 321 (passive)
74. Stainless steel 201 (passive)
75. Stainless steel 286 (passive)
76. Stainless steel 316L (passive)
77. AM355 (active)
78. Stainless steel 202 (passive)
79. Carpenter 20 (passive)
80. AM355 (passive)
81. A286 (passive)
82. Titanium 5A1, 2.5 Sn
83. Titanium 13V, 11Cr, 3Al (annealed)
84. Titanium 6Al, 4V (solution treated and aged)

85. Titanium 6Al, 4V (anneal)
86. Titanium 8Mn
87. Titanium 13V, 11Cr 3Al (solution heat treated and aged)
88. Titanium 75A
89. AM350 (passive)
90. Silver
91. Gold
92. Graphite

End - Noble (Less Active, Cathodic)

Notes

AC43.13, starting at Par 247, briefly covers several types of corrosion and corrosion protection. The grouping of materials is an early method of MS33586 which was superseded in 1969 by MIL-STD-889.

More on Galvanic Table (Almost straight from MIL-STD-889)

General

The Galvanic Table lists metals in the order of their relative activity in sea water environment. The list begins with the more active (anodic) metal and proceeds down the to the least active (cathodic) metal of the galvanic series.

A "galvanic series" applies to a particular electrolyte solution; hence for each specific solution which is expected to be encountered for actual use, a different order or series will ensue. The sea water galvanic series is the most complete series that I know and I have not seen another series published by either the Army, Navy, or Air Force. Civilian aircraft encounter moisture and a salt of some kind.

Galvanic series relationships are useful as a guide for selecting metals to be joined, will help the selection of metals having minimal tendency to interact galvanically, or will indicate the need or degree of protection to be applied to lessen the expected potential interactions.

Generally, the closer one metal is to another in the series, the more compatible they will be, i.e., the galvanic effects will be minimal. Conversely, the farther one metal is from another, the greater the corrosion will be.

Notice that graphite is at the bottom of the table. Think of the corrosion potential if you put a big hunk of graphite on a small piece of magnesium.

In a galvanic couple, the metal higher in the series (or the smaller the number I have given it) represents the anode, and will corrode preferentially in the environment.

Types of Protection

Metals widely separated in the galvanic series must be protected if they are to be joined. Appropriate measures should be taken to avoid contact. This can be accomplished by several methods:

1. **Sacrificial** - by applying to the cathodic member a sacrificial coating having a potential similar to or near that of the anodic member. If you are designing for a sacrificial element, the sacrificial element should be on the anodic side and smaller. Cadmium plate (No. 10) on steel bolts (No. 81) holding 2024-T4 (No. 25) plates will sacrifice the cadmium instead of corroding the Aluminum. This is one reason for using new bolts that have the Cad plate intact. **(Don't use Cad plate with Titanium (No. 82 through 88).** But that's another story.**)**
2. **Sealing** - by sealing to insure that faying surfaces are water-tight. (We have "talked" about this before.)
3. **Resistance** - by painting or coating all surfaces to increase the resistance of the electrical circuit. (We have "talked" about this only in terms of primer and sealant on fayed surfaces. There is still more that can be done by design selection.)

The (Non-Aerodynamic) Area Rule

To avoid corrosion, avoid a small anodic area relative to the cathodic area.

Corollary I - Use LARGE ANODE AREA.

Corollary II - The larger the relative anode area, the lower the galvanic current density on the anode, the lesser the attack.

Corollary III - The amount of galvanic corrosion may be considered as proportional to the Cathode/Anode area ratio.

Corollary IV - Design for a SMALL Cathodic/Anodic Ratio (CAR). (When designing, remember your **small CAR**.)

Corollary V - The same metal or more noble (cathodic, higher number in the table) metals should be used for small fasteners and bolts.

Sea Water Environments

Metals exposed to sea water environments shall be corrosion and stress corrosion resistant or shall be processed to resist corrosion and stress-corrosion. Irrespective of metals involved, all exposed edges should be sealed with a suitable sealant material conforming to MIL-S-8802. When non-compatible materials are joined, an interposing material compatible with each shall be used.

Non-Metallic Materials

Material other than true metals, i.e., non-metallic materials which must be considered as metallic materials, unless there is supporting evidence to the contrary. If these material are essentially free of corrosive agents (salts), free of acid or alkaline materials (neutral pH), and free of carbon or metallic particles, not subject to biodeterioration or will not support fungal growth, and do not absorb or wick water, then these may be considered non-metallics suitable for joining to metals.

Many materials classed non-metallic will initiate corrosion of metals to which they are joined, e.g., cellulosic reinforced plastics, carbon or metal loaded resin materials, asbestos-cement composites.

More Precautions for Joining

Where it becomes necessary that relatively incompatible metals must be assembled, the following precautions and joining methods are provided for alleviation of galvanic corrosion.

For Electrical Connection - Select materials which are indicated to be more compatible in accordance with the galvanic series.

Design metal couples so that the area of the cathode is smaller (appreciably) than the area of the anodic metal. For example, bolts or screws of stainless steel for fastening aluminum sheet, but not reverse.

Interpose a compatible metallic gasket or washer between the dissimilar metals prior to fastening.

Plate the cathodic member with a metal compatible to the anode.

Select a electrically conductive sealant. (More on these later.)

Not For Electrical Conductors - Interpose a non-absorbing, inert gasket material or washer between the dissimilar materials prior to connecting them.

Other Approaches

Seal all faying edges to preclude the entrance of liquids.

Apply corrosion-inhibiting pastes or compounds under heads of screws or bolts inserted into dissimilar metal surfaces whether or not the fasteners had been previously plated or otherwise treated. In some instances, it may be feasible to apply an organic coating to the faying surfaces prior to assembly. This would be applicable to joints which are not required to be electrically conductive.

Where practicable or where it will not interfere with the proposed use of the assembly, the external joint should be coated externally with an effective paint system.

EAA Chapter 1000 Home Page

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