

Magnesium

Galvanic Corrosion in the Automotive Industry

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Why Use Magnesium

- **Mass reduction / efficiency**
 - Density is **~1.7 g/cc** (about $\frac{3}{4}$ the density of aluminum and $\frac{1}{4}$ of steel).
 - Big weight savings in seat frames, steering wheels, instrument panels, transmission cases, brackets, etc.
 - Less mass → **better fuel economy / EV range**, lower CO₂ over vehicle life.
- **High specific strength & stiffness**
 - Absolute strength is lower than steel, but **strength-to-weight** can be very good when designs are optimized.
 - Works well for **stiff, lightweight castings** where wall thickness can be controlled.
- **Excellent castability & design freedom**
 - Flows well in **high-pressure die casting**, filling thin sections and complex geometries.
 - Enables **part consolidation** (one Mg casting instead of multiple steel stampings + fasteners), simplifying assembly.
- **NVH and functional properties**
 - Good **vibration damping**; helps reduce noise and harshness in interior structures.
 - Good **EMI shielding**, useful for housings and electronics enclosures.
- **Recyclability**
 - Like aluminum, Mg alloys are **recyclable**, supporting circular material strategies



Where Used on Vehicles Today

- **Body / closures / exterior**
 - **Liftgates / tailgates** (inner structure or full assembly) for SUVs and crossovers (Chrysler Pacifica).
 - **Roof frames / roof bows** (C6 Corvette)
 - **Door inners / window frames** (Porsche Panamera)
 - **Front-end modules** (F150 Rad Support)
- **Interior / cabin**
 - **Instrument panel / cross-car beams (IP beams)** – common high-volume Mg casting application (e.g., JLR Defender cockpit structure and GMC Savana Van)
 - **Steering wheel frames** (classic Mg application since late '80s; typically AM50/AM60).
 - **Seat frames and recliner structures** (Mercedes Benz 500SEL).
 - **Center console frames, armrest structures, brackets** in luxury vehicles (Audi A8, Volvo, Hongqi, etc.).
 - Various **brackets, mounts, and housings** inside the cabin (column shrouds, display frames, HVAC case components).



Where Used on Vehicles Today

- **Powertrain**

- **Transmission / gearbox housings and transfer case housings** – long-standing Mg use (VW Beetle, many modern AT/DCT units).
- **Engine front covers, cam covers, some engine cradles / subframes** (e.g., HPDC Mg engine cradle on high-performance models like Corvette variants).

- **Chassis / suspension**

- **Cross-members / engine cradles** (C6 Corvette)
- Select **steering column housing** (C7 Corvette).

- **Wheels and specialty parts**

- **Wheels** (historically in racing and specialty road cars; now more niche due to corrosion and cost).
- **Handrails, seat frames in buses, LED lamp housings, electronics enclosures** where EMI shielding + weight matter.

Average Content for Light Weight Materials Today

- Aluminum:**

- About **10–13% of vehicle mass** (~340–460 lb Al on a 3,600–3,800 lb vehicle).
- Forecast to grow toward **~16%** (~560 lb) by late decade as more closures/BIW parts go Al.

- Magnesium:**

- Around **0.2–0.5% of vehicle mass** (~10–15 lb on a ~3,800 lb vehicle).
- Analyses describe current vehicles as using “**less than 1% magnesium on average.**”

- Carbon fiber (CFRP):**

- Essentially 0% on a fleet-average basis** (well under **0.1% of mass**)
- CF is confined to a small number of premium performance/EV models.
- On CF-intensive niche vehicles (e.g., i3, supercars).



Galvanic Corrosion Fundamentals

- **Conditions required:**

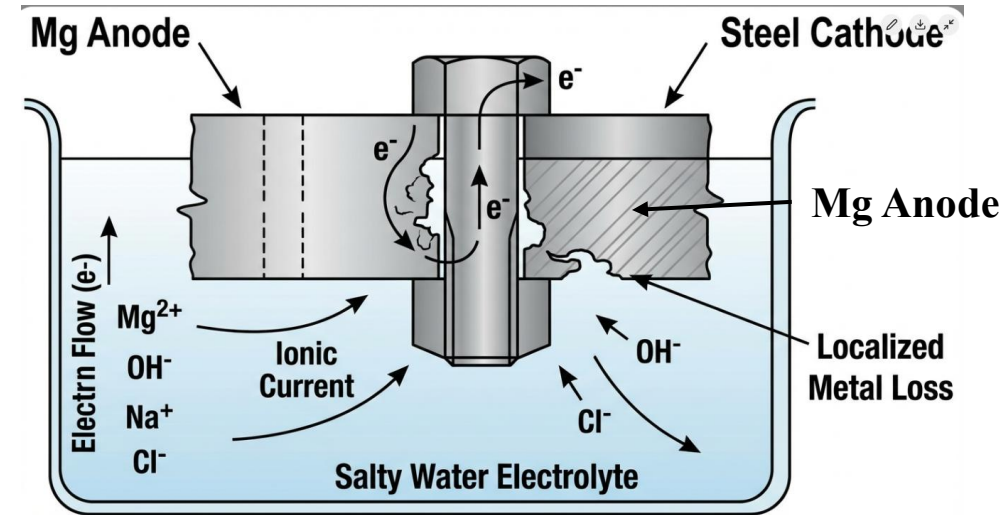
- Two **electrically connected dissimilar metals**
- Presence of an **electrolyte** (e.g., road salt, humidity, condensate)
- Sufficient **potential difference** between metals

- **What happens:**

- More active metal (anode) **corrodes faster** than it would alone.
- More noble metal (cathode) is **protected**.
- Attack is often **highly localized** near joints, fasteners, and crevices.

- **Key accelerants:**

- Chlorides (road salt), standing water, dirt/poultice
- Large cathode / small anode **area ratio**
- Poor drainage and trapped electrolyte



Magnesium is High-Risk in Mixed-Metal Joints

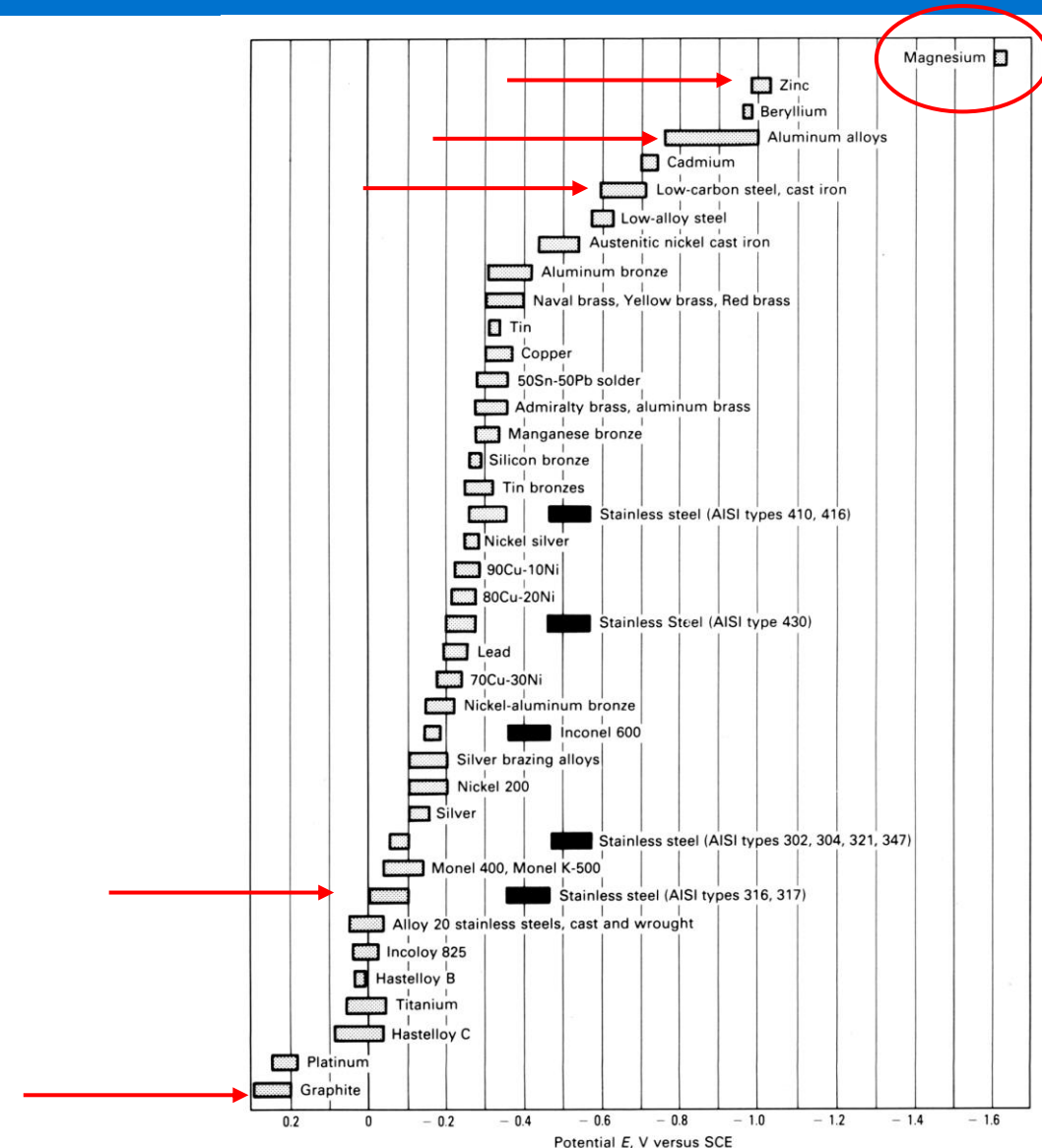
Galvanic Series alone:

- Mg & Mg alloys → **most active**
- Zn-coated steels
- Al alloys (5xxx, 6xxx)
- Carbon steels
- Stainless steels
- Carbon fiber (CFRP) → **very cathodic**

Mg is one of the **most anodic** structural metals used in vehicles. It is not compatible with many other metals, however it can be used with some Aluminum Alloys due to Cathodic Polarization.

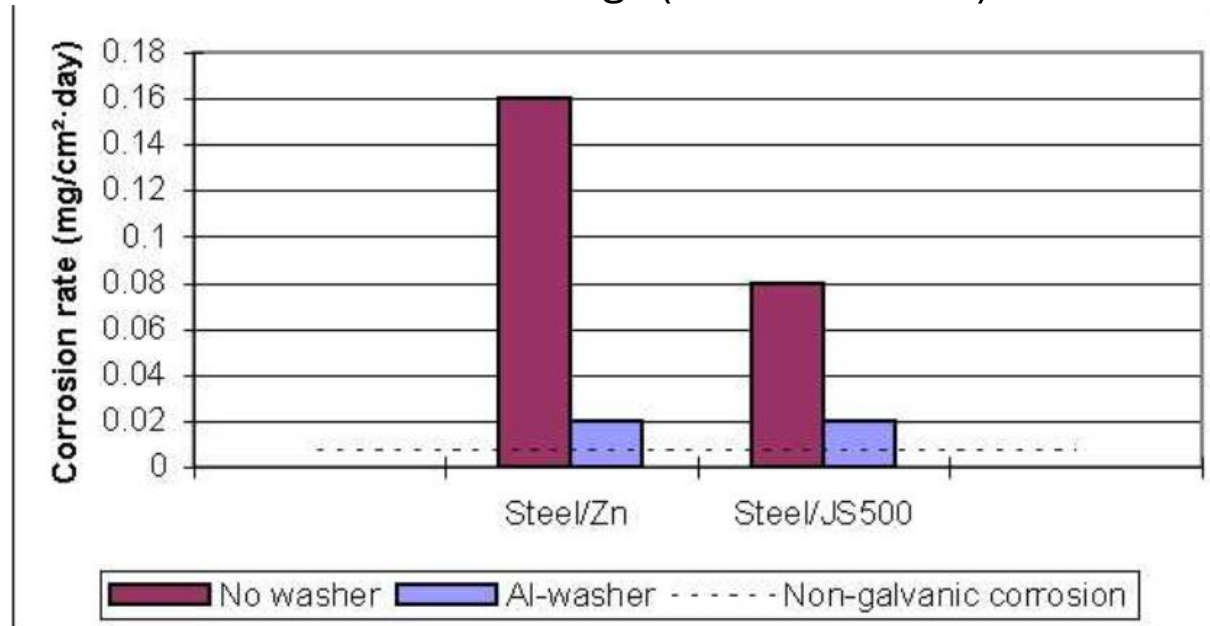
First consideration is a review of the stack up between Magnesium and the adjoining alloy by checking the Galvanic Series.

Second consideration would be a review of the Polarization behavior of Mg and the mating material.

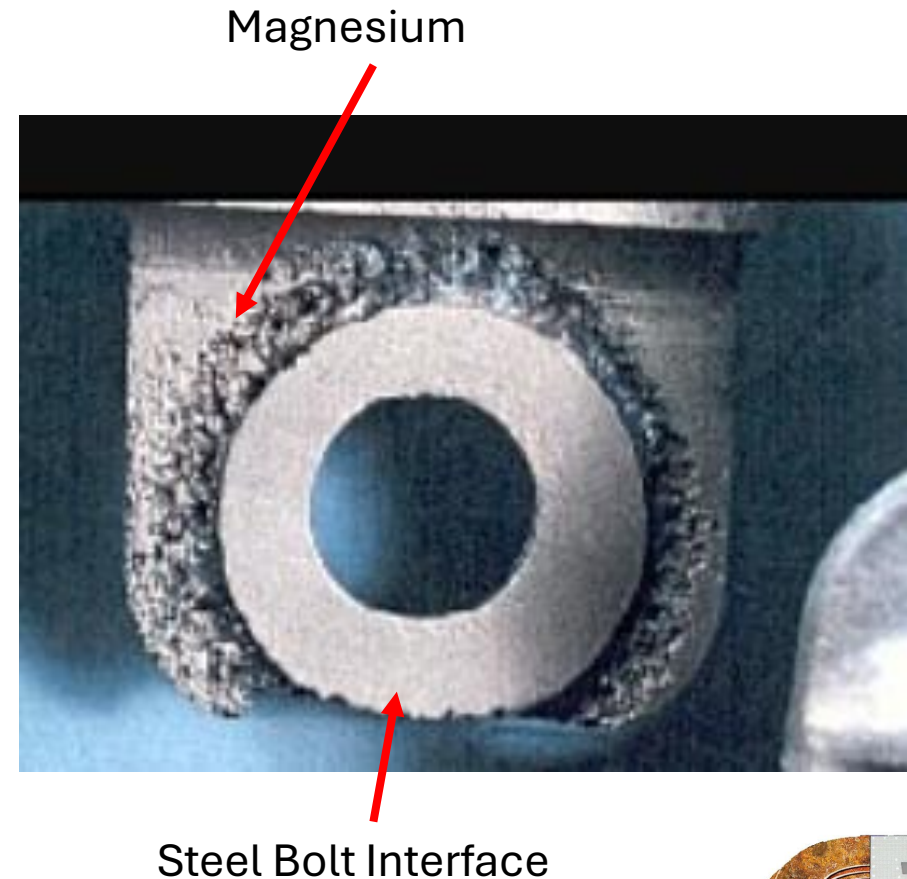


Critical Mixed-Material Combinations with Magnesium

- **Mg–Steel (carbon-steel or Zn-Ni coated)**
 - Very large potential difference; **severe attack** on Mg around bolts, brackets, and sleeves,
 - Through-bolts, exposed tips, and unsealed interfaces are especially vulnerable.
 - High rate of Mg base metal attack with Steel/Zn coating as well as Steel/PTFE coating. (Al washer note).



Galvanic corrosion of magnesium with zinc and JS500 plated steel bolts, exposed per GM9540P for 80 days. The washers were 3 mm thick, with an external diameter of 20 mm.
 JS500 - Xylan-type PTFE coating



Other Critical Mixed Material Combinations with Magnesium

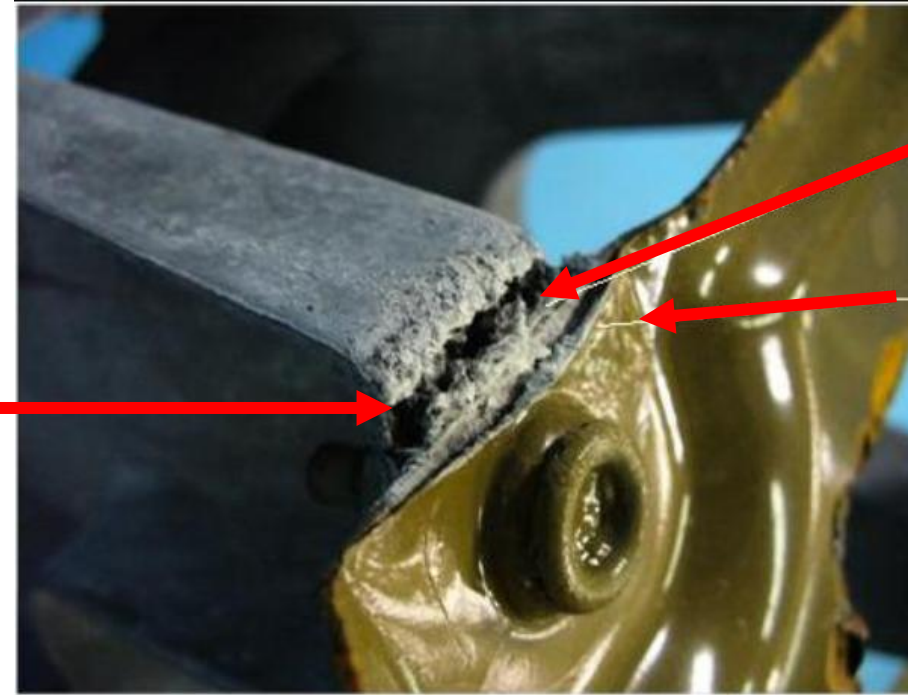
- **Mg–Aluminum (5xxx/6xxx)**
 - Lower driving force than Mg–steel, but still significant in **salt environments**.
 - High risk at **cast Mg to wrought Al** interfaces and mixed-metal cradles, brackets, and shields.
- **Mg–CFRP / Mg–Stainless**
 - CFRP and stainless act as strong cathodes.
 - Risk of **deep localized pitting** and **joint softening** if Mg is the only anodic path.
- **Compounding effects:**
 - **Crevices** (gaps under washers, clips, sleeves) trap electrolyte and amplify galvanic attack.
 - **Area ratio:** small Mg region coupled to larger Al/steel/CFRP surface accelerates Mg loss.



Typical Failure Modes & Field/Validation Observations

- **Common observations in testing and field:**

- **Ring-shaped pits** around steel or Zn-Ni fasteners in Mg and brackets.
- **Section loss** under washers or at bolt tips where steel and bare Mg are in direct contact.
- Localized attack at **interfaces to aluminum torque boxes, shields, and brackets** if isolation or coating breaks down.
- In extreme cases, **loss of clamp load** or cracking of thin Mg sections near joints.



Significant
Corrosion of Mg
Brkt at Interface

E-Coated Steel
Brkt

- **Where problems concentrate:**

- Underbody and wheel-well environments (high chloride, wet/dry cycling).
- Areas with **poor drainage** or dirt/poultice accumulation.

Design and Coating Strategies to Control Mg Galvanic Corrosion

- **Metal Compatibility** – Use **Aluminum washers, cups, and sleeves** between Mg and steel parts. Aluminum washer thickness and diameter are critical to lengthen electrolyte path between anode and cathode.



Design and Coating Strategies to Control Mg Galvanic Corrosion

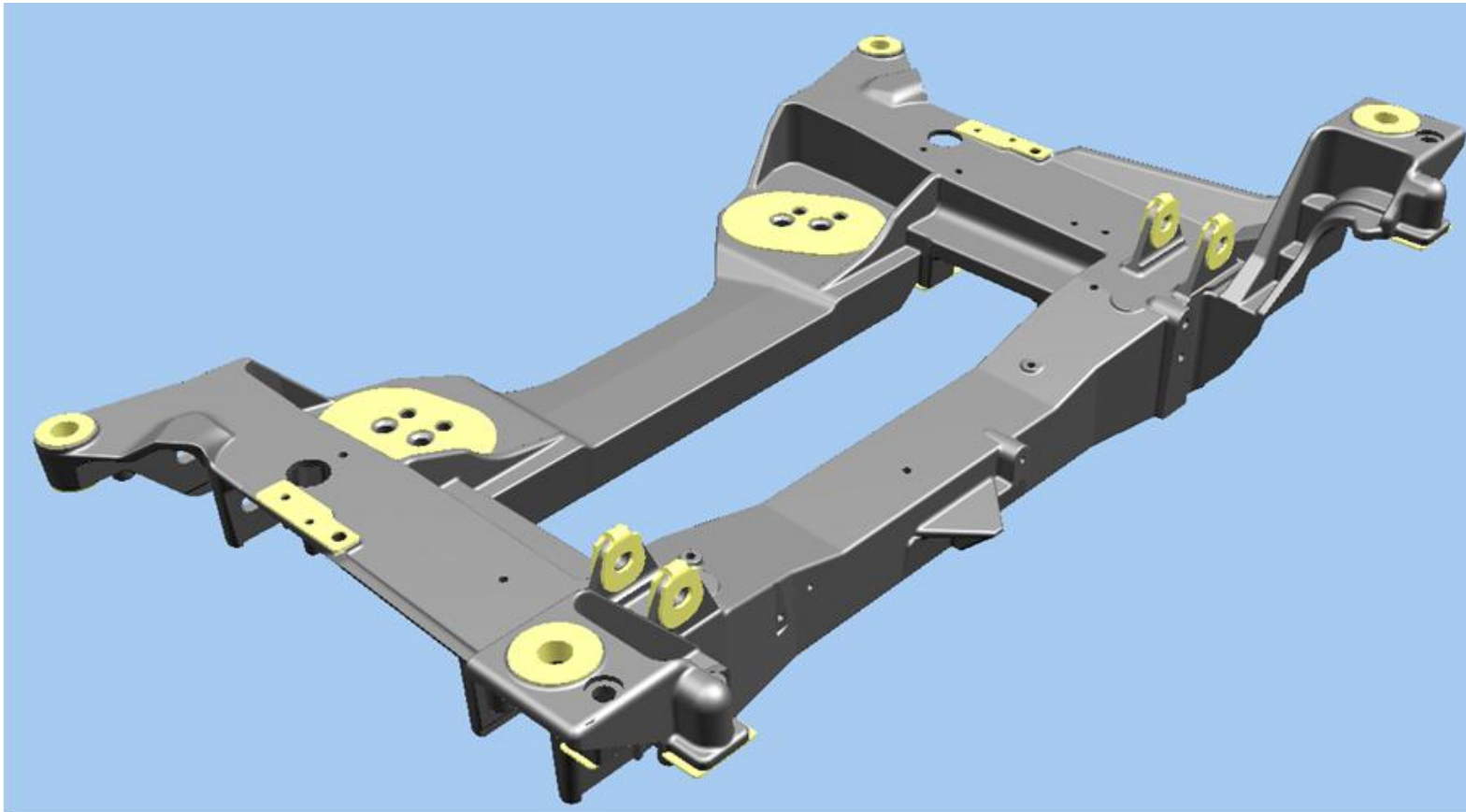
- **Metal Compatibility** – Use washers, cups, and sleeves between Mg and steel parts.
 - Below is the use of a cup style washer. This design maximizes electrolyte path but applications are limited to avoid cup washer filling up with electrolyte.



Aluminum Cup Washer

Design and Coating Strategies to Control Mg Galvanic Corrosion

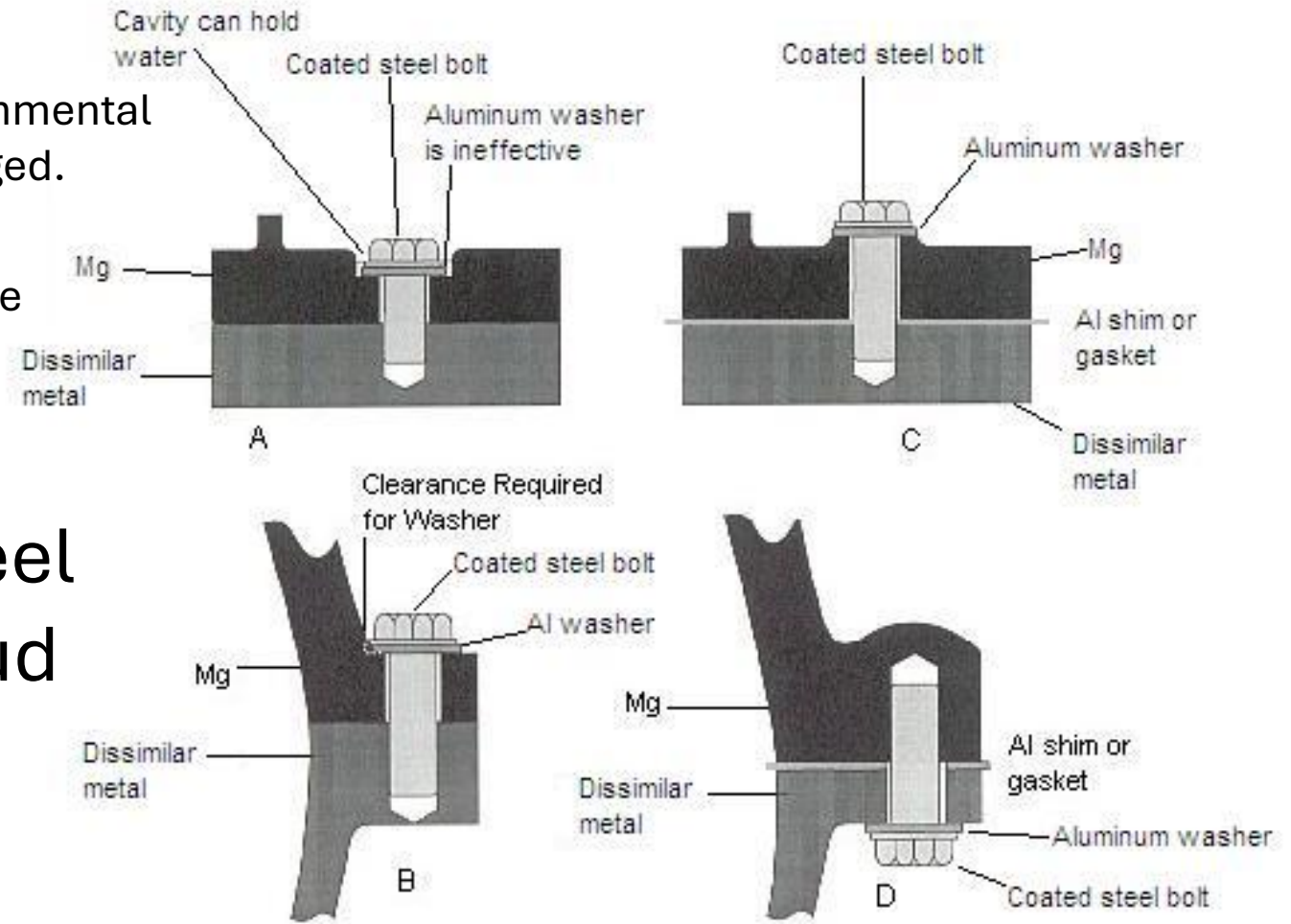
- **Metal Compatibility** – Use **washers, cups, and sleeves** between Mg and steel parts.
 - Yellow portions below are compatible aluminum pads, sleeves, and washers.



Design and Coating Strategies to Control Mg Galvanic Corrosion

• Material & geometry choices

- Whenever possible, design **blind holes** rather than through-holes to prevent environmental exposure where threads have now been damaged.
- Avoid Cavity or recessed areas.
- Use of Aluminum Washer to provide distance between Mg & Steel Bolt head, stud, etc.

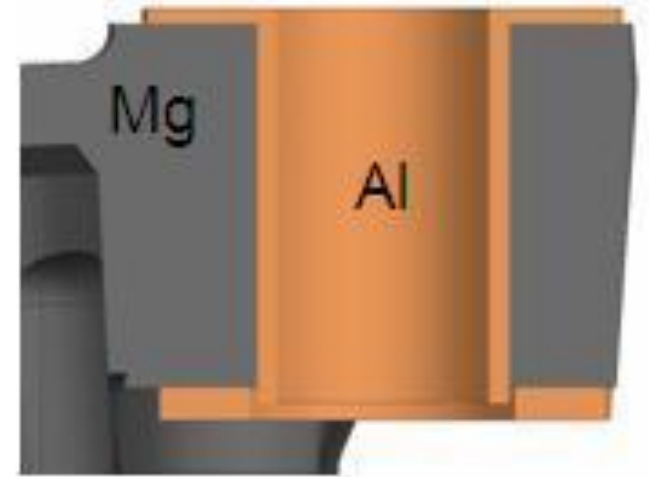


A and B represent poor design. C and D represent improved design.

Design and Coating Strategies to Control Mg Galvanic Corrosion

- **Material & geometry choices**

- Avoid Mg in locations with **persistent wetting** if robust isolation cannot be guaranteed.
- Favor joints where Mg is the **larger area** and more noble metal is smaller (reduces anodic current density).
- Add **bushings or gaskets** to break metal-to-metal contact at brackets and fasteners.
- Use **Aluminum Sleeves** in joints to step down the Galvanic couple when steel substrate fasteners are required.

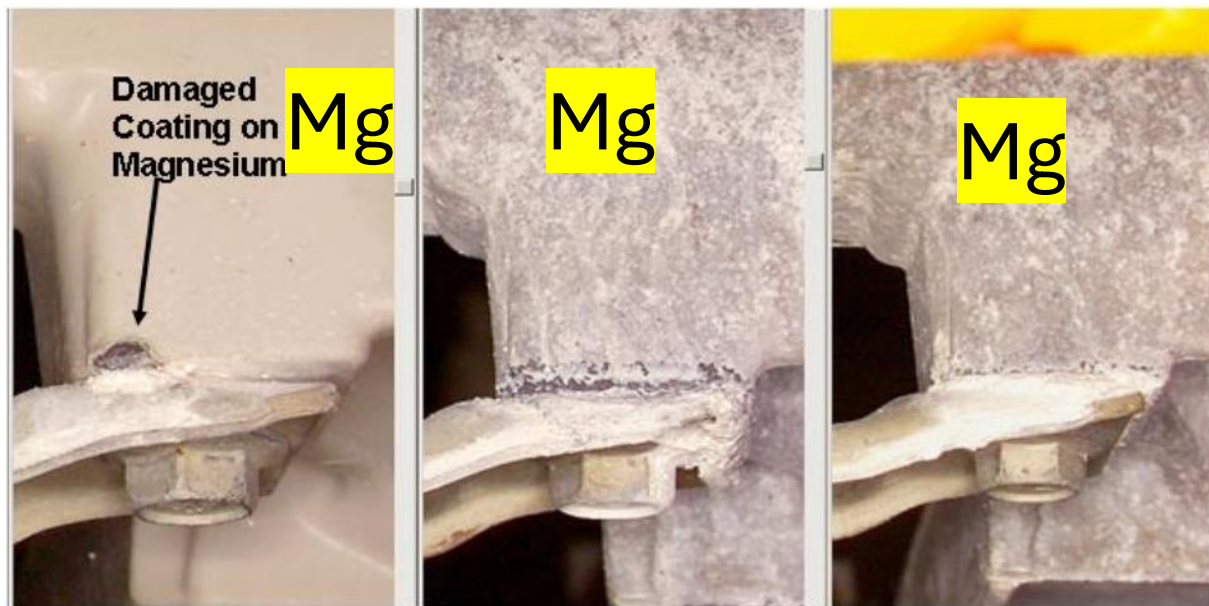


Aluminum Sleeved Joint
for Steel substrate Bolt
(Bolt not shown)

Design and Coating Strategies to Control Mg Galvanic Corrosion

- **Coating strategy**

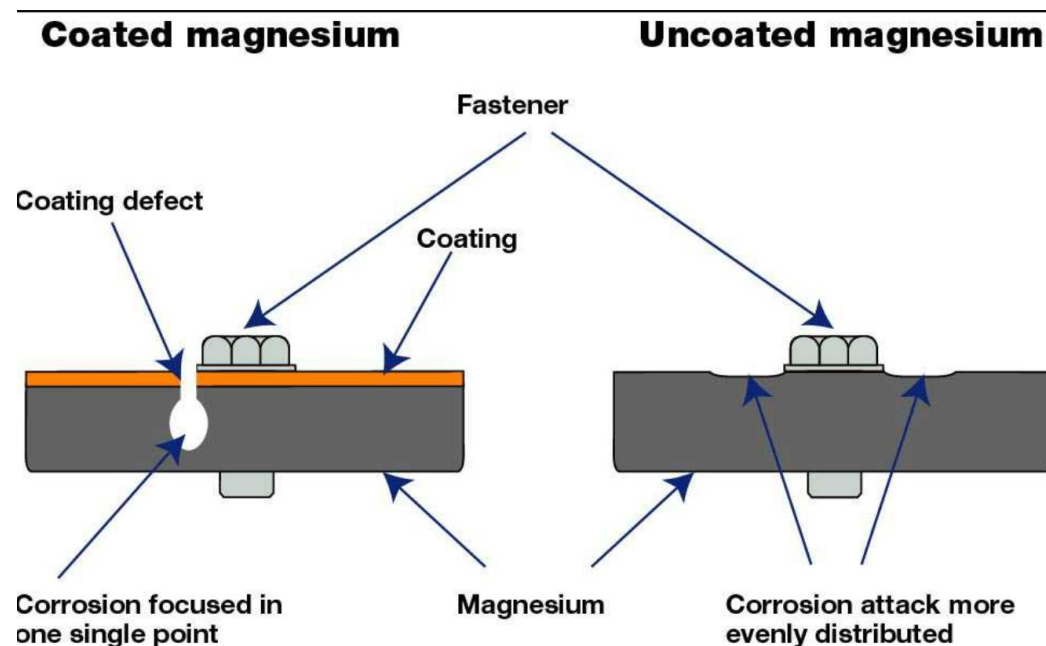
- Do not coat the Anode – If coating gets damaged (common) this concentrates all the current through a very small area, significantly increasing current density & corrosion rate



Coated w/o washer

Uncoated w/o washer

Uncoated with washer



Design and Coating Strategies to Control Mg Galvanic Corrosion

- **Coat the cathode side with compatible coating** (steel/Al bracket or fastener) to mitigate galvanic corrosion base metal attack of Magnesium (anode).

Bolt #	Description
1	1. Zinc plated (Dipsol NZ-200 Alkaline plating ~10um + ZT-444ABK clear chromate) + Nanomate NT-1810 topcoat.
2	2. Zinc plated (Dipsol NZ-200 Alkaline plating ~10um + ZT-444ABK clear chromate) + Nylok NY004-20C green coating underhead only.
3	3. Zinc plated (Dipsol NZ-200 Alkaline plating ~10um + ZT-444ABK clear chromate) + Nylok NY004-20C green coating on entire bolt head.

- Various coatings show the differences in mitigation levels based on the coating applied and **where** on the fastener.

At 161% End of Test (EOT) the parts were photographed. They are shown below in Figure #32 through Figure #40.



Figure #32 Bolt #1 @ 161% EOT

Figure #33 Bolt #2 @ 161% EOT

Figure #34 Bolt #3 @ 161% EOT

After sandblast, the assemblies were disassembled and are pictured below in Figure #50 through Figure #58.



Figure #50 Bolt #1 Disassembled @ EOT

Figure #51 Bolt #2 Disassembled @ EOT

Figure #52 Bolt #3 Disassembled @ EOT

Validation & Key Takeaways

- **Validation approach**
 - Use a combination of:
 - **Electrochemical / lab tests** (galvanic couples, polarization, impedance).
 - **Accelerated cyclic corrosion** (e.g., GMW14872 Option 6 and Mg-focused galvanic tests).
- **What to watch in results**
 - Pit depth and section loss around **fasteners and sleeves**.
 - Coating breakdown at **edges, bolt tips, and crevices**.
 - Impact on **joint stiffness, clamp load, and leak paths** (for structural or sealing joints)



Validation & Key Takeaways

- **Key messages**

- Magnesium enables **significant mass savings**, but its very anodic nature makes design discipline critical.
- High-risk combinations: **Mg with steel, Zn-Ni fasteners, stainless, and CFRP**, especially in wet/salt environments
- Robust solutions combine **material selection, geometry, isolation**, intermediate materials (stepped potential joints), **coatings, sealing, and appropriate validation**.
- Early engagement with **Corrosion Engineering** is essential whenever Mg is used in mixed-material structures.



Questions

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