Reducing the Corrosion of a Potential Vehicular Structural Alloy

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The Purpose

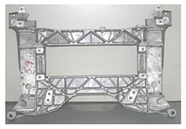
Automotive Industry:

- Corrosion of structural steel on vehicles
  - Caused by salt treated roads
- Focused on increasing gas mileage
- Two ways to increase gas mileage using current technology
  - Improve efficiency of the engine
  - Reduce the overall weight of the vehicle
    - Engine cradles, control arms, bracing
- Change the structural material
  - Needs to be lighter than steel
  - Needs to be as stiff as steel
  - Needs to be easy to shape
- Possible Replacement Metals
  - Aluminum, Magnesium
    - Metals prone to corrosion

Why Use Magnesium?

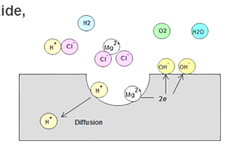
Magnesium Alloys:

- Feasible option for reducing the weight of vehicles
- High Stiffness to Weight Ratio
  - Steel: 25.7 GPa*cm^3/g
  - Aluminum: 25.6 GPa*cm^3/g
  - Magnesium: 25.9 GPa*cm^3/g
- High Strength to Weight Ratio
  - Steel: 107.1 MPa*cm^3/g
  - Aluminum: 114.8 MPa*cm^3/g
  - Magnesium: 164.0 MPa*cm^3/g
- Excellent Castability and Easy Machinability
- Low corrosion resistance



Corrosion of Magnesium

- Three Oxidation – Reduction Reactions
  - Magnesium, water, and oxygen
- Forms magnesium hydroxide precipitate
  - Magnesium and water
- Forms magnesium hydroxide precipitate and hydrogen gas
  - Magnesium, sodium chloride, and water
- Magnesium chloride, sodium hydroxide, and hydrogen gas
- Corrosion Locations
  - Surface Effects
- General corrosion
- Pitting Corrosion
  - Bulk Effect



Reducing the Corrosion of Magnesium

Magnesium Alloys:

- Addition of other elements to the magnesium
  - Changes the surface of the magnesium
  - Reduces corrosion
  - More expensive
- Magnesium Alloy AE44
  - 4% Aluminum
  - 4% Rare Earth Elements
  - 92% Magnesium

Other Problems With Magnesium

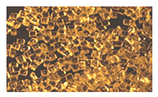
Galvanic Corrosion:

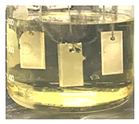
- Two metals in contact
  - One metal can corrode preferentially to another metal
- Magnesium corrosion can be accelerated if in contact with other metals on vehicle

Coatings to Reduce Corrosion of Magnesium

Polyetherimide (PEI):

- Amber colored and Amorphous
  - No distinct crystalline structure
- Glass transition temperature – 217°C
- Density – 1.27 g/cm^3
- Hydrophobic and solvent resistant
  - Repels water
  - Not easily dissolvable by salt and other chemicals on the road
- Prevents direct contact with other metals
- Two Methods Tested
  - Polymer Solution Casting
  - 3D printing a polymer coating (JuggerBot)

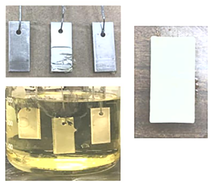




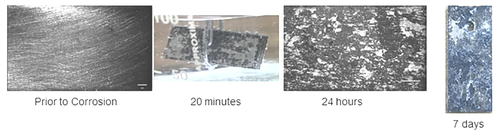
Procedure

Solution Casting:

- Preparing magnesium samples
  - Sanded with 600, 800, and 1200 grit sandpaper.
  - Wash with Acetone, Acetone Semiconductor, and Ethyl Alcohol.
- Preparing polymer solution
  - Dissolve 5.985 g of PEI in 145.5 mL of Dichloromethane (DCM).
- Dip samples in solution
  - Samples were hung via paper clips from a glass stir rod sat atop the solution's beaker.
  - After 24 hrs, the solution solidifies and samples are left with a polymer coating.
- Samples were coated through 3D printing
  - Six samples were taken to JuggerBot (YBI)
  - Samples were then coated by 3D printing.

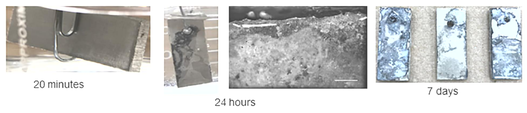


Results: Uncoated Magnesium



- Corrosion is visible within 10 seconds
  - Indicated by dark grey area forming
- Large amounts of corrosion visible after 24 hours
  - Indicated by a large portion of the surface covered by dark grey area with minimal light areas of the original magnesium surface
- Complete removal of the magnesium surface after 7 days
  - Indicated by the complete disappearance of the light colored areas that would indicated a magnesium oxide film

Results: Solution Cast Magnesium

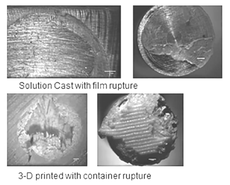


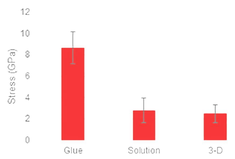
- No corrosion seen after initial exposure
  - No dark grey area formation, smooth around edges
- Some corrosion visible after 24 hours
  - Indicated by a the presence of the dark grey area
  - Aqueous solution penetrated coating at edges
- Distinct corrosion after 7 days
  - Indicated by the formation of large areas of grey
  - Coating did offer some protection and was less than no coating

Results: 3-D Printed PEI and Magnesium

- No corrosion seen after 24 hours
  - No dark grey area formation, smooth around edges
- Some corrosion visible after 3 days
  - Indicated by a the presence of the dark grey area
  - Aqueous solution penetrated likely through the connecting groove
  - As seen with adhesion testing, failure occurred at the connecting groove
- Distinct corrosion after 7 days, although less than solution cast samples
  - Indicated by the formation of medium grey across the surface
  - Likely not enough aqueous solution inside the cavity to cause large amounts of pitting
  - Coating offered more protection than solution casting, likely because of thickness

Results: Adhesion Testing





- Stress results indicate the polymer did not actually bond to the Magnesium surface
  - If bonded, break would have occurred at glue – coating interface
  - Occurred at metal – coating interface
- Glue – metal interface is stronger than the coating – metal interface
  - No distinct difference between solution casting and 3-D printing adhesion strength

Conclusions and Future Work

- Polymer Solution Casting
  - Significantly reduces corrosion
  - Not a perfect process
    - Imperfections in coating leads to corrosion
- 3D Printed Coating
  - Better corrosion reduction
  - Particular polymer was not transparent
    - Can't see if corrosion has begun without destroying coating
  - Difficult to implement on actual vehicle parts
- Improving Polymer Solution Casting process
  - More reliable corrosion prevention
- Further testing with transparent 3D printed coating
- Developing a chemical bond between alloy and polymer
  - Stronger adhesion