Best Practices for the Prevention of Corrosion on Vehicles and Equipment Used By Transportation Agencies for Snow and Ice Control

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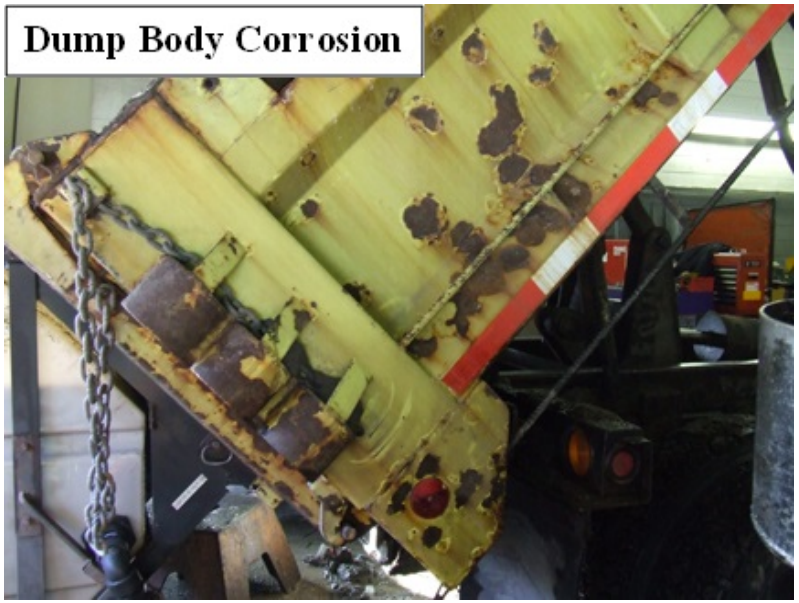
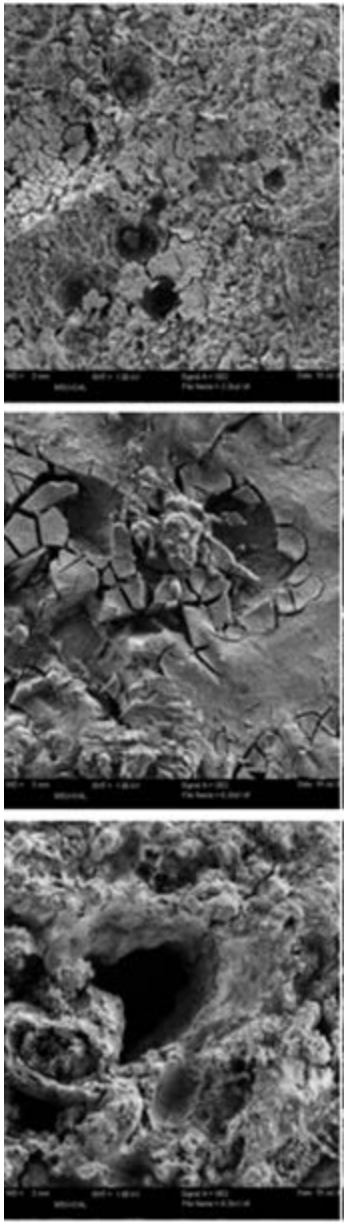
Introduction

- Large amounts of deicers are applied onto winter roadways
- Mainly chloride-based salts to depress freezing point
- These corrosive salts are a major risk to DOT vehicles

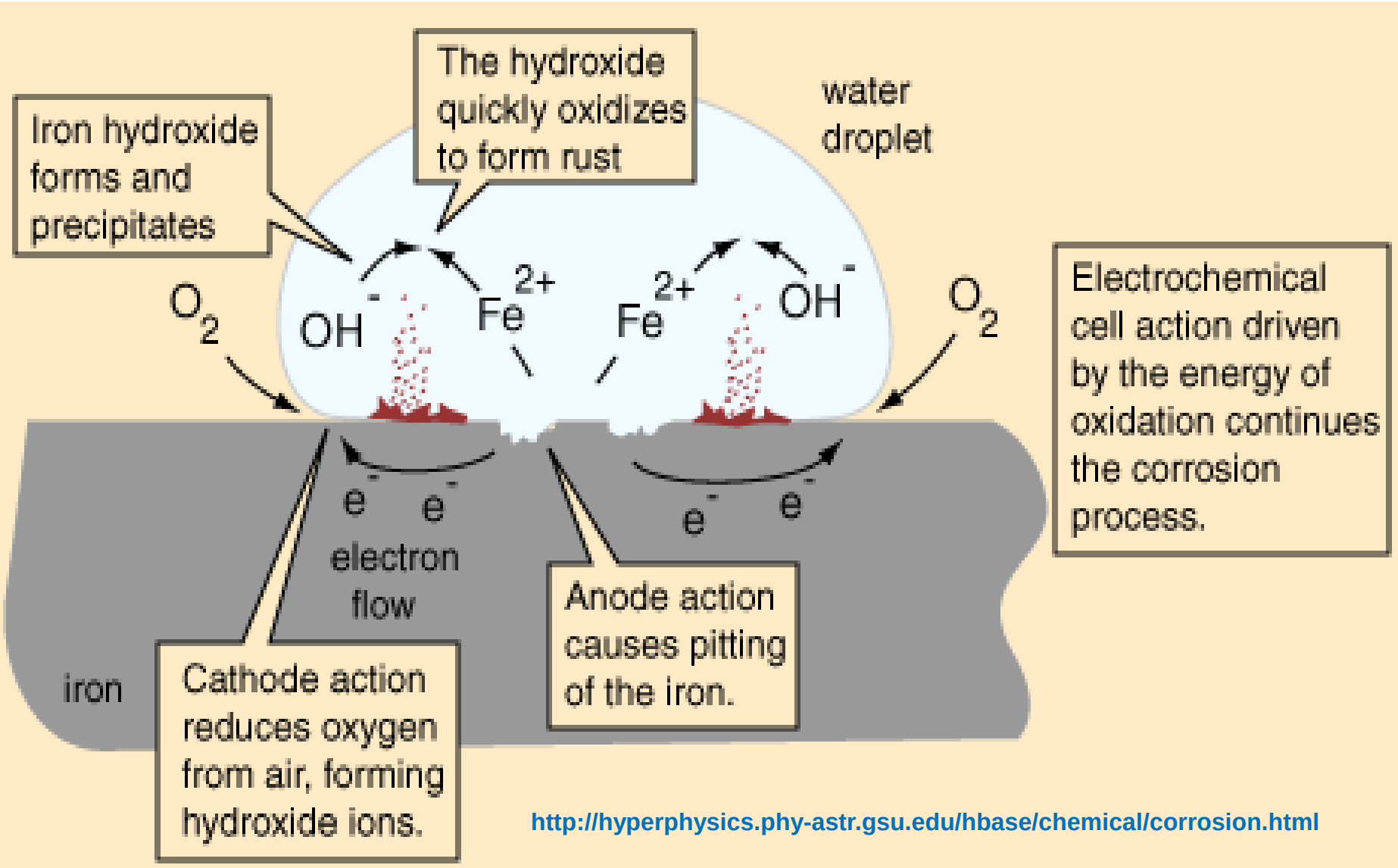


Corrosion Definition

- **Corrosion is deterioration of material due to the reaction with its environment**
- **Carbon steel, cast iron, aluminum alloys, magnesium alloys, copper and copper alloys: used in different components of winter maintenance vehicles and can be corroded by deicers**
- **A variety of corrosion forms can take place in a vehicle.**

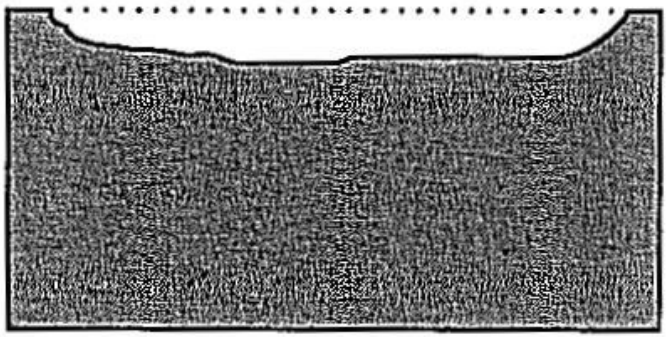


Corrosion as an Electrochemical Process



http://hyperphysics.phy-astr.gsu.edu/hbase/chemical/corrosion.html

General Corrosion

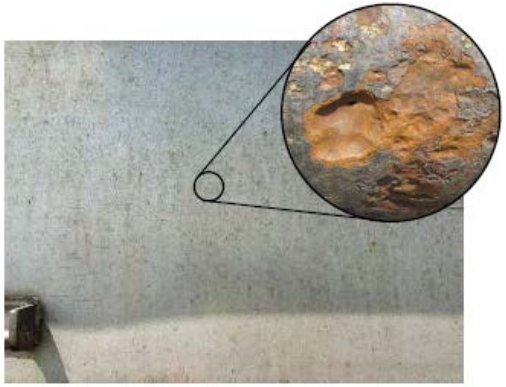


- **Surface area deteriorates at the same rate: Due to poor material selection**
- **Can be included in design calculations, such as increasing wall thickness**
- **Easy to prevent by:**
  - **Good material selection**
  - **Coatings**
  - **Corrosion inhibitors**

Localized Corrosion

- **Occurs *locally on confined areas* of a surface**
- **Cause *unexpected failures***
- ***Localized corrosion* categories:**
  - **Pitting**
  - **Filform**
  - **Intergranular**
  - **Galvanic**
  - **Stress corrosion cracking (SCC)**
  - **Fatigue**
  - **Fretting**
  - **Crevice**
  - **Microbially Influenced Corrosion (MIC)**

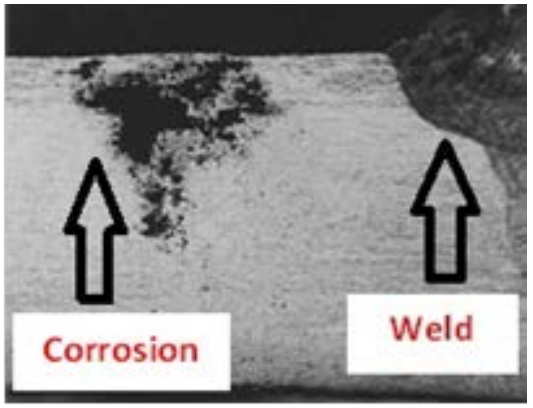
Pitting **is a severe form of localized corrosion in which damage in the shape of deep holes occurs.**



Crevice corrosion **occurs at the interface of a metal and another surface, often where a small volume of stagnant solution is contained.**

Filform corrosion **is a special form of crevice corrosion which happens beneath some types of coatings.**

Intergranular attack **occurs at grain boundaries. (Specifically for stainless steel this occurs in heat affected zones at a short distance from the weld.)**

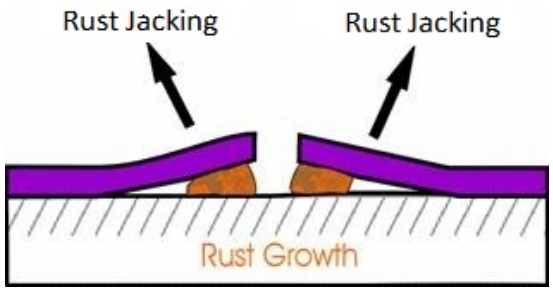


Galvanic corrosion **occurs when two dissimilar metals are in contact. The less resistant metal corrodes much more than the more resistant metal.**

SCC **is the growth of crack formation in a corrosive environment. It can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress, especially at elevated temperature.**

Corrosion fatigue **is caused by the combined effects of cyclic stress and corrosion.**

- **Rust jacking (a kind of corrosion fatigue) is the displacement of building elements due to the expansion of corrosion products.**



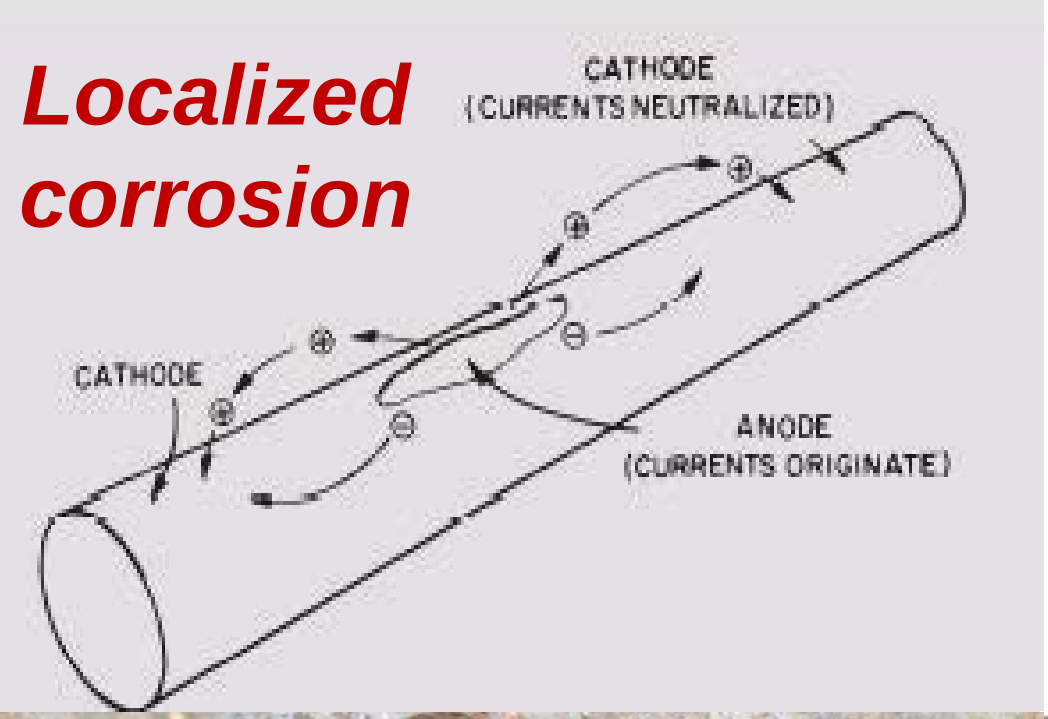
Fretting corrosion **happens at the interface between contacting, loaded metallic surfaces in the presence of slight vibratory motions.**

Microbially influenced corrosion (MIC):

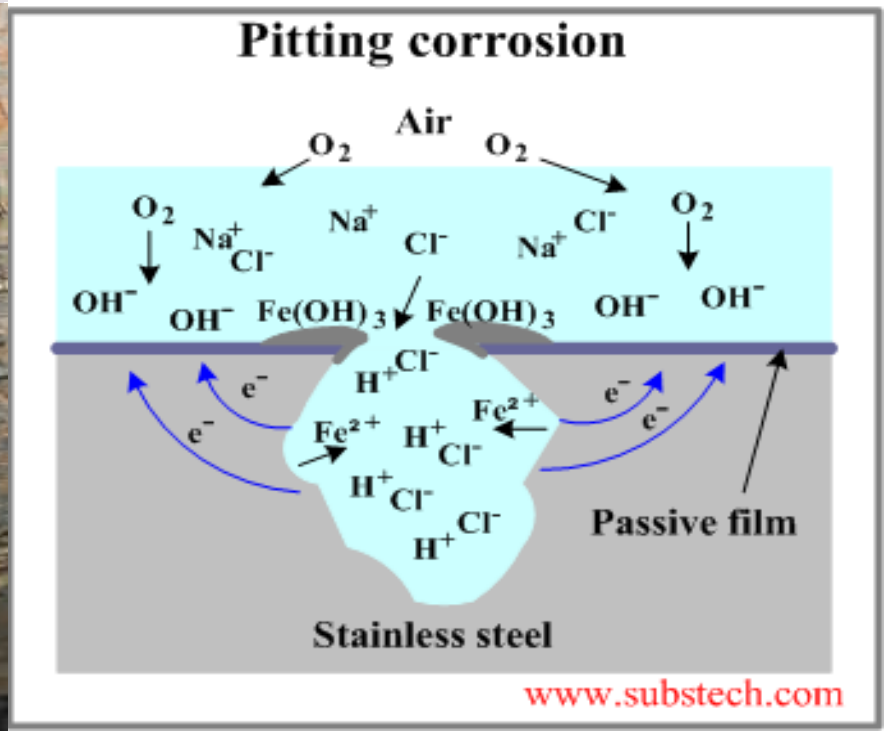
A special form of biological corrosion which is directly caused by microorganisms or because of their products

Microbially influenced corrosion can be a concern for snow and ice control equipment when agencies use bio-based products.

Localized corrosion



- Small anode area: **faster corrosion rate** *(vs. general corr.)*
- "Unpredictable": difficult to prevent



Causes and Effects of Corrosion

- Chloride deicers are easily available, relatively inexpensive, and easier to use for winter maintenance, but…
- The average estimated annual costs per northern transportation agency for corrosion management:
  - ✓ Training programs ($190,938)
  - ✓ **Materials selection** ($320,667)
  - ✓ Design improvements ($45,000)
  - ✓ Corrosion monitoring & testing ($10,000)
  - ✓ Proactive maintenance ($171,424)
  - ✓ **Reactive maintenance** ($325,000)

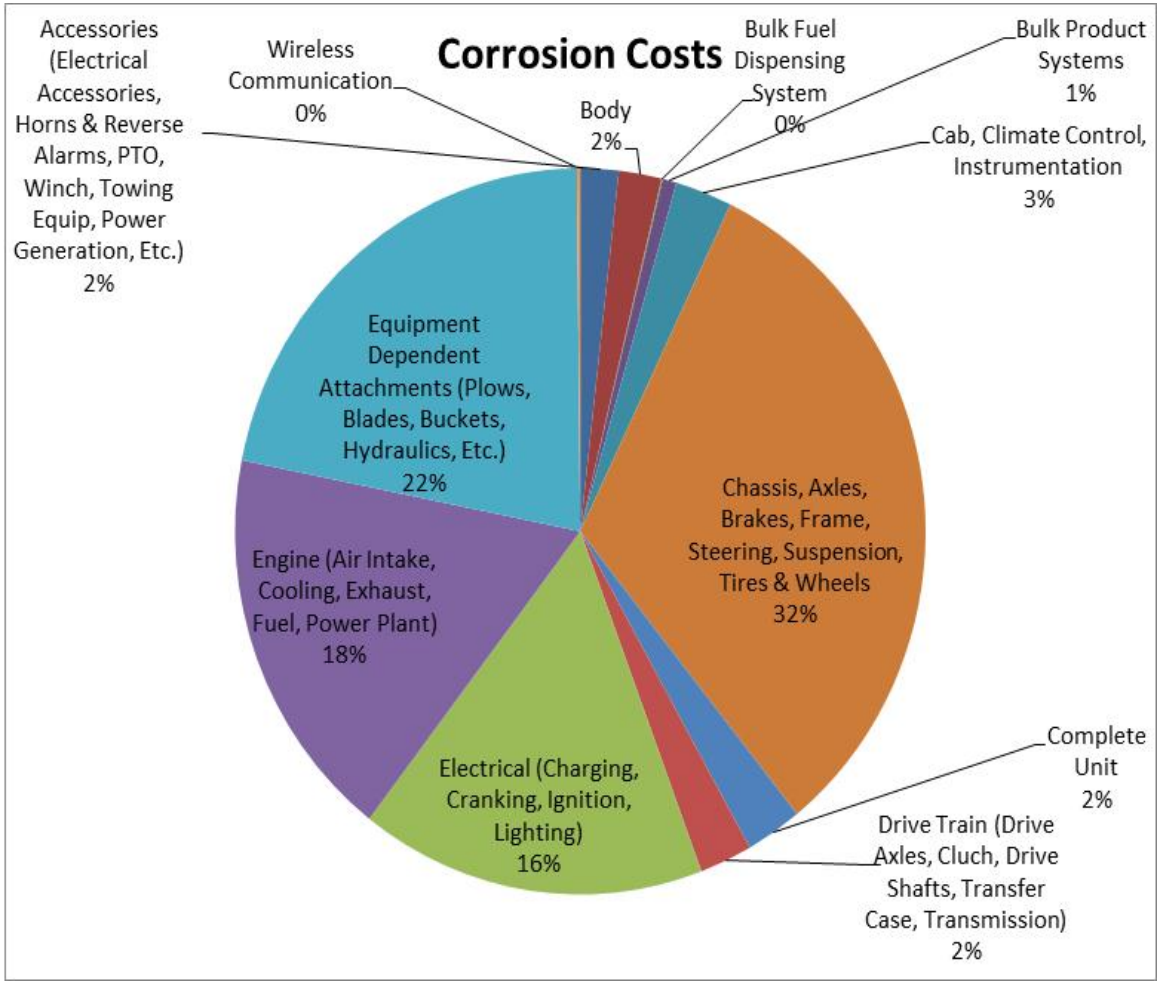
Corrosion-prone parts

Most Severe

- **electrical wiring**
- **frames**
- **brackets and supports**
- brake air cans
- spreader chute

High Repair Costs

- **chassis**
- **axles**
- **brakes**
- frame
- suspension
- tires & wheels
- electrical components



Materials Selection: Survey Results

Materials	Uniform corrosion	Localized corrosion	Response count (*)
Cast irons	81.3% (26)	21.9% (7)	**32**
Aluminum alloys	55.9% (19)	50.0% (17)	**34**
Magnesium alloys	68.2% (15)	36.4% (8)	**22**
Copper and copper alloys	67.9% (19)	35.7% (10)	**28**
Carbon steels	73.5% (25)	32.4% (11)	**34**
Stainless steels	50.0% (12)	50.0% (12)	**24**
Metallic coatings	64.0% (16)	40.0% (10)	**25**
Metallic glass	56.3% (9)	43.8% (7)	**16**
Composites	68.8% (11)	31.3% (5)	**16**

Cost-Benefit Analysis of Mitigating Deicer Corrosion to DOT Equipment

- For an average agency, it is assumed that the empirical 20/80 rule may apply to the 25% of corrosion costs which can be avoided by best practices, in the absence of actual data being available.
- In other words, you can reduce the current cost of corrosion risk related to deicer exposure by 80% × 25%, if the agency can increase its current investment in corrosion control by 20%. ***This is possible by conducting risk analysis to identify the critical 20% of corrosion-related failures and focusing more on training and risk-based maintenance.***
- Based on the data from the survey responses, the benefit/cost ratio of further improving corrosion from deicers to DOT fleet equipment can be estimated as follows: **(80% × 25% × $14,050,368) / (20% × $1,063,029) = 13.2**

Materials Used for Snow and Ice Control

- ***Inert materials*** have no de-icing properties; they simply provide temporary traction on icy pavement (e.g. sand).
- ***Chemically active*** de-icing materials are:
  - Sodium chloride
  - Calcium Chloride
  - Magnesium Chloride
  - Potassium Acetate
  - CMA
  - Sodium Acetate
  - Potassium Formate
  - Blends…

New Equipment Specification; Build to Last

Is It Worth The Cost? YES

Many of these design and construction recommendations may add to the overall cost of purchasing a new vehicle in the range of 10-20% over an agency's current specs. However, this is justified by the long-term reduction in maintenance (repair, replacement, and reconditioning) due to corrosion.

1. *Metal Materials Selection*
2. *Design Improvements*
3. *Considerations for welded joints*
4. *Coatings for Corrosion Protection*

Metal Materials Selection

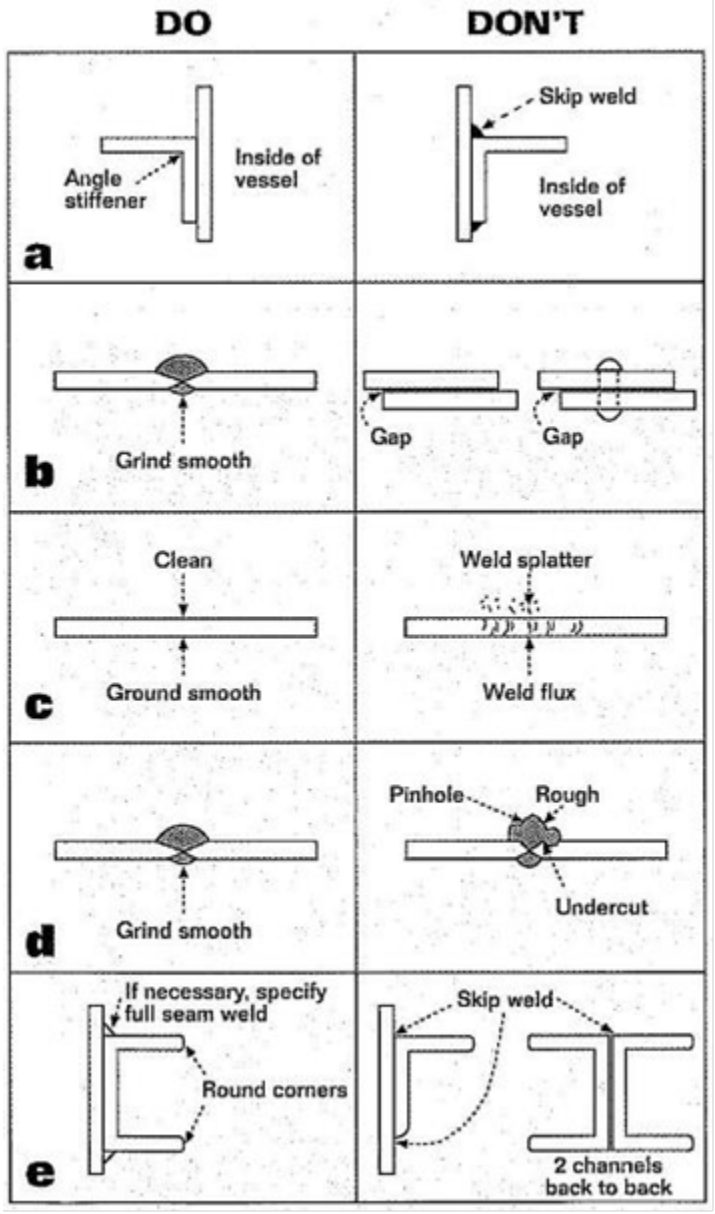
- Magnesium alloys and mill product forms of aluminum alloys 2020, 7079, and 7178 should not be used for structural applications.
- The use of 7xxx-T6 Al alloys should be limited to a thickness of no more than 0.080 inches. Where stress corrosion cracking is the main problem, 7075-T6 can be replaced by 7050-T7451.
- Higher carbon content and hardness in steel would make it susceptible to SCC or embrittlement. In SCC of austenitic stainless steel (300 series SS) by chlorides, substitution of duplex stainless steels will often eliminate the problem.
- Using steels containing molybdenum such as 316 SS can reduce pitting corrosion. Intergranular corrosion can be reduced by using the stabilized (321 or 347) or low-carbon (304L or 3I6L) stainless steels.

Design Improvements

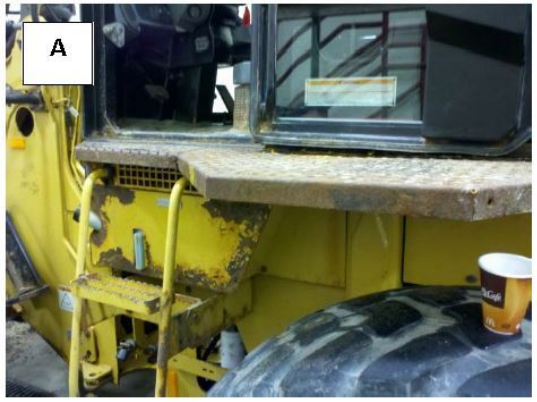
- Where water may accumulate, include holes for **drainage**. Minimum diameter for all drains should be 0.375”. The drainage holes should be shielded or oriented to avoid direct road splash.
- Avoid **sharp corners** that make it difficult for protective coatings to function.
- Remove notches and other **stress-concentrating features**. Rounded filets and angles also reduce stress concentrations.
- Crevice corrosion can be minimized by **proper design of welded joints and gaskets** that minimize crevices, sealing the crevices and periodic cleaning.
- **Contact between dissimilar metals** should be avoided. Where it is not possible, both metals should be coated.
- Use a coating with low water vapor transmission characteristics and excellent adhesion. **Zinc-rich coatings** can be considered for carbon steel because of their cathodic protection ability.

Considerations for welded joints

- Eliminate the weld splatter using blasting or chipping
- Rough welding should be ground smooth
- If feasible, welds should be double coated
- Where corrosion is possible, **use continuous welds** instead of discontinuous welds (tack or skip welds)
- Remove brackets and extra metal followed by ground smoothing areas of previous contact
- Remove weld flux after finishing welding



Protect Your Asset by a Professional Coating!



Coatings for Corrosion Protection

- ❑ Coatings must meet many requirements: **long-lasting, easy to apply, environmentally friendly, cost-effective, high performance**.
- ❑ An ordinary coating that is applied to a well prepared surface may perform better than a high-quality coating which is installed over a substrate with inappropriate or poor **surface preparation**.
- Use of a suitable **salt remover (rust remover)** effectively increases coating performance.
- In situations where grit blasting is prohibited or unusable for safety and environmental reasons; rust removers should be used for surface preparation prior to coating.
- When time is critical, time can be saved by using a rust converter.
- Rust converters could be applied to the metal surface as a primer coat supplemented with oil based or epoxy paint.
- Rust converters are not suitable for damaged coatings.

Repair, Rehabilitation & Retrofitting of Existing Equipment

- ❑ Evaluation Process for Fleet

- A thorough inspection and operational check of each unit;
- An initial itemized list of repair/maintenance work for each vehicle;
- A general assessment rating using a standardized grading (alpha-numerical or defined term);
- A priority ranking for each item, for example: Critical, Urgent, Needed, Recommended;
- A detailed cost estimate for each vehicle;
- A determination of expected service life if repairs/rehab is done;
- A decision for the course of action for each unit of equipment; and
- Final cost estimate based on evaluation

- ❑ Repair and Restoration

- Restoration means replacing a component.

- ❑ Modifications

- Such as replacing strobe warning lights mounted on the cab roof with ones mounted on a cross-bar.

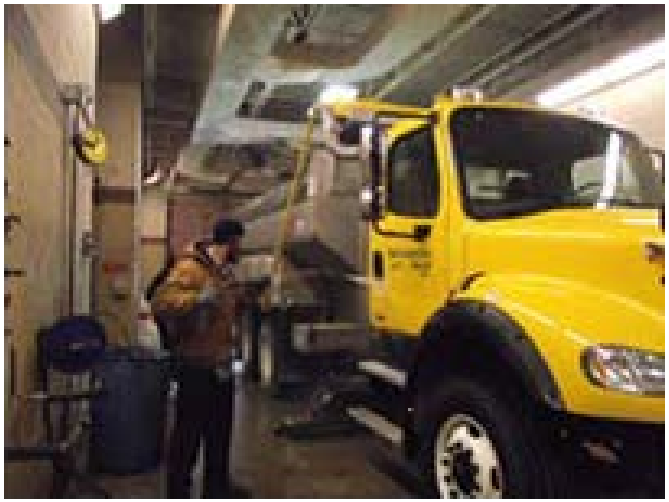
Protect Equipment Assets by Preventive Maintenance!

Preventive Maintenance Practices for Equipment

- ***Reactive methods*** are used to deal with existing corrosion by cleaning corroded parts with a rust remover, replacing the ones that are too far gone for rehabilitation, ...
- A reactive treatment may in some cases be the most cost effective means of dealing with corrosion if the parts are easy to clean, or easily replaced and fairly inexpensive.

- ***Preventive methods*** are the proactive strategies which may involve the use of corrosion inhibited products, the use of corrosion resistant materials for equipment components, dielectric grease, **enclosed wiring connections**, the use of sacrificial anodes, **the use of coatings**, and **frequent and regular washing of equipment**.

Wash Vehicle Daily!



Washing

- Washing should **focus on trouble spots** like frame rails, brake components, underneath of the chassis and other areas that tend to collect materials.
- Perform routine washing preferably with hot water and then fast drying.
- Preferably do not use a pressure washer, because water can be forced into areas and cannot escape which leads to corrosion. Use low pressure wash and high volume (flow rate) of about 300 psi/300 gpm.
- Use physical action together with washing to remove the road salt.
- Use salt removers to remove the salt captured in crevices. But the effectiveness of salt neutralizers is alloy specific.
- More cleaning liquid is not necessarily better, a high concentration of washing compound may attack some of the plastic components.
- Once active corrosion of metals has started, washing should be coupled with other means, e.g., applying spray-on corrosion inhibitor.

Findings from Lab Study

- The use of the salt remover HighTight can significantly enhance the anti-corrosion performance of carbon steel (C1010) and stainless steel (SS304L) in 30% $MgCl_2$ solution compared to washing with water or soap water, but not that of the aluminum alloy (Al1100).

- Sugar beet by-product could form an organic protective layer on the surface of both coated and bare carbon steel (C1010) samples, with much more anti-corrosion benefit for bare coupons. But this organic layer can be removed by power wash.

Electrical issues

- Eliminate the junction boxes wherever possible, and relocate them to inside the cab off the floor.
- Install modified protective cover for battery.
- Use high-quality weather-proof terminations (e.g., buss-style connectors) and compression fittings in addition to shrink wrapping susceptible electrical wiring components.
- Do not probe the wires to test for continuity and avoid any damage of wiring insulation.
- Apply a non-conductive; non-sodium based **di-electric grease** on all electrical connections (plugs, sockets, battery terminals, etc.).
- Make clean the electrical connectors on a regular basis (at least every six month) with water (not soap) and a wire brush, and re-grease with dielectric grease.
- Minimize connectors to the extent possible by using continuous wiring.
- Use anti-corrosive spray for protecting the battery posts and terminals.
- Do not apply paint to the rubber seals around lights.

Brake components/chassis

- Inspect all brake components even by removing brake drums to checking the entire lining surface, the brake shoe web, rollers, cam, etc.
- Be careful about automatic slack adjusters (ASA). Make sure ASAs are thoroughly lubed and there is no evidence of internal rusting.
- Require throttle, brake, and clutch pedals to be suspended in specifications.
- Install corrosion sealed air brake chambers and spray on protective coatings on all brake valves.
- Pull brake drums on a regular basis.
- Use rubberized undercoating for aluminum brake valves.
- In the rebuilding process specify rust-proof painted and epoxy-coated brake shoes.
- Specify **self-healing undercoats**, full fenders and fender liners for chassis.
- Install a large full width, full height under chassis sand guard on all front discharge sanding bodies.

Frame/body/beds and other parts

- Carbon steel fuel, hydraulic and air tanks can be replaced with aluminum tanks.
- Replace standard E-coat steel painted wheels with powder coated versions. Use powder coating for fuel tank and frame rails.
- Use stainless steel truck boxes, pre-wetting tanks, and sanders.
- Use zinc anodes in solution tanks and zinc nickel alloy engine oil pan.
- Use stainless steel couplers, under tailgate spreaders and cooler lines.
- Use poly faced snow plows to reduce corrosion and also lessen weight. Use stainless steel.
- Use greaseable tailgate linkages and attach them to on board automatic lube system.
- Replace radiators every two years (based on Washington State DOT recommendations).
- Install grit guards on wheels.
- Wrap hydraulic fittings with anticorrosive wrap.
- Use glad hand seals with dust flaps for air system.

In-field success of some proactive maintenance methods (a) aluminum fuel tank, (b) stainless steel hydraulic pipes, (c) poly tandem fender guards, (d) E-coated frame rail.

Training and Facility Management

- ***Operators,*** including contractors, need to know the basic characteristics of each product being used, including inert abrasives.
- ***Mechanics*** who repair and maintain the fleet need basic information on the materials used and the associated characteristics, especially an understanding of the corrosiveness of each chemical.
- ***Supervisors and managers*** are responsible for making sure that operators and mechanics and others involved in transporting, handling, and storing materials have the proper training.
- ***Good housekeeping*** should be an every-day standard at any agency facility where materials are stored and handled.

Concluding Remarks

- Agencies should **track the data** relevant to analyzing the direct costs of deicer corrosion to their equipment assets and the direct benefits of countermeasures, to enable reliable, quantitative cost-benefit analysis.
- Agencies should implement **an extensive preventive maintenance program** that may involve use of salt removers together with routine washing; protecting of electrical components by sealing or moving them to inside the cab; reapplication of post-assembly coatings; spray-on corrosion inhibitors and many other operational changes which can be supplemented by corrective maintenance practices to minimize the negative impact of deicer corrosion to equipment asset.
- Supervisors are responsible for ensuring compliance with procedures and practices regarding vehicle inspection and operation, and also **staff and contractors training**.

Acknowledgements

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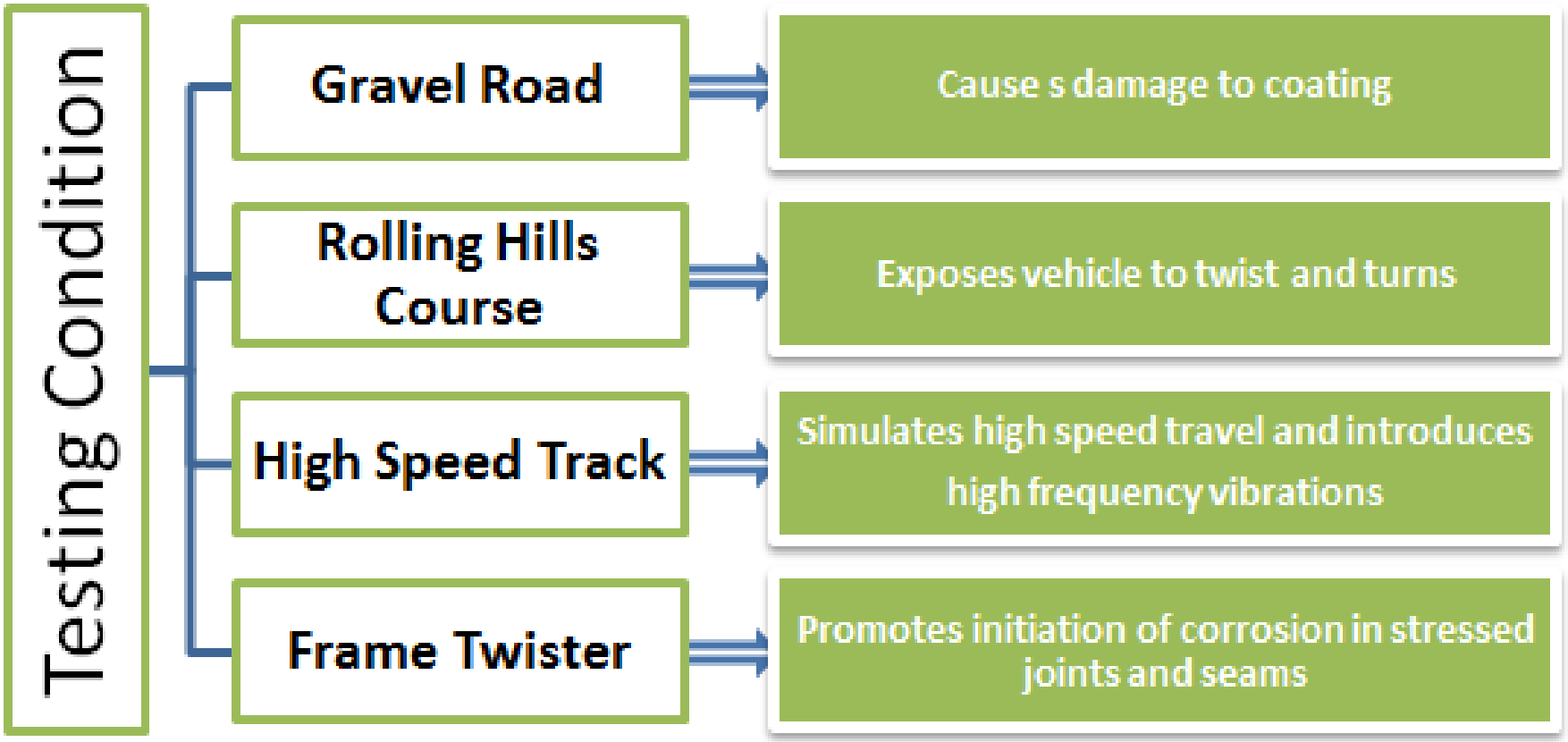
WASHINGTON STATE UNIVERSITY

Center for Environmentally Sustainable Transportation in Cold Climates
CESTiCC

Q&A

Accelerated durability test by US Army



Based on GM tests that accurately simulate 10 years of cosmetic corrosion and 3 years of crevice corrosion