CORROSION PROTECTION OF AEROSPACE GRADE MAGNESIUM ALLOY ELEKTRON™ 43 FOR USE IN AIRCRAFT CABIN INTERIORS

7th Triennial International Fire & Cabin Safety Research Conference

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Magnesium Properties

- Lightest structural metal: avg. 1.8 g/cm^3
- Current materials:
  - Aluminum: 2.7 g/cm^3
  - Steel: 7.8 g/cm^3
- High specific strength
- Excellent machinability
- Capacity to absorb vibration and impact
- Traditional alloys have low strength at elevated temperatures
- Traditional alloys have low resistance to creep: elevated temperatures and constant loading lead to additional deformation over time

What's stopping us?

- FAA regulations require high levels of flammability resistance and/or self-extinguishing behavior for all cabin interior materials
- Perception of increased corrosion
- Cost
- High strength requirements

- SAE AS8049: Performance Standards for Seats in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft
- Section 3.3.3 prohibits the use of magnesium and its alloys in the cabin interior
- TSO certification requires compliance to SAE AS8049

Flammability

DOT-FAA-AR-11-3: EVALUATING THE FLAMMABILITY OF VARIOUS MAGNESIUM ALLOYS

Current flammability testing is being supported strongly by the FAA Technical Center. Large, machined primary components of the seats (legs, spreaders, cross tubes) will be excellent candidates for magnesium usage.

Mechanical Properties

Strength of primary components is crucial

Dynamic test requirements include 16G longitudinal, 14G download structural, and 16G front row head and knee path evaluations

For each test, blunt force trauma, seatback deformation, and sharp edges will be evaluated. The lumbar and femur loads will also be assessed.

For an aircraft seat, design, processes, and materials all play a part in the integrity of the structure. Crucial material properties include ultimate and yield strength, percent elongation under load, and impact resistance.

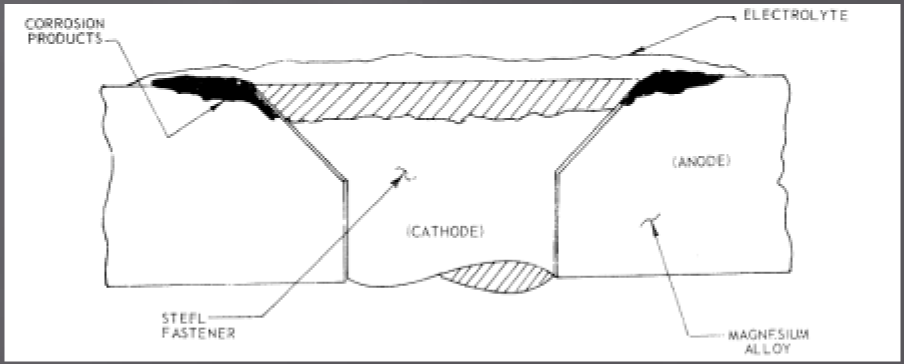
Corrosion

- Magnesium is one of the most electropositive metals on the galvanic scale
- When coupled in an electrolyte with a more cathodic element, magnesium will serve as a sacrificial anode. Impurities in the magnesium alloy can also result in corrosion by creating an internal cathode.
- Under normal environmental conditions (no sustained moisture or exposure to electrolytes), magnesium alloys exhibit corrosion resistance comparable to or better than mild steels.
- Corrosion mechanism results in the formation of a protective oxide film.

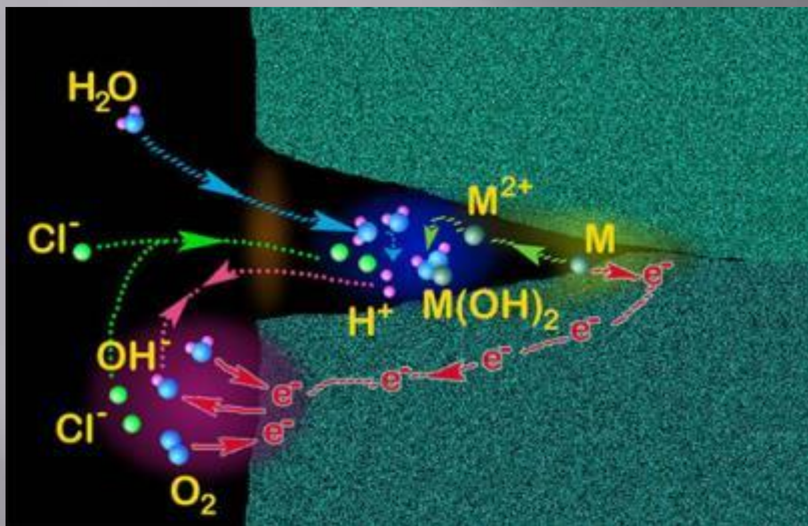
Types of Corrosion

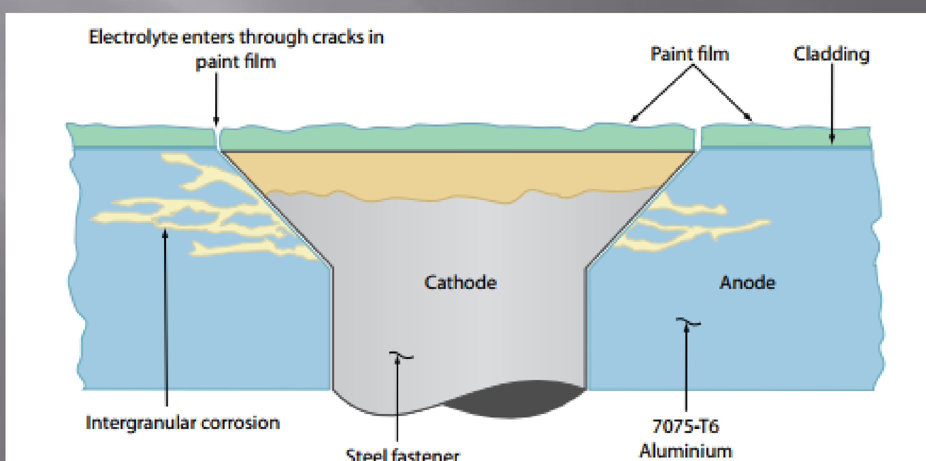
- General corrosion
  - In aqueous solutions, an electrochemical reaction results in the dissociation of magnesium with water to produce a crystalline film of magnesium hydroxide and hydrogen gas.
  - General corrosion can be reduced by utilizing high-purity alloys without introducing flux inclusions.

- Galvanic corrosion
  - Dissimilar metal-to-metal contact bridged by an electrolyte results in corrosion of the less noble metal.
  - Stringent design and assembly practices can reduce the risk of galvanic corrosion.



Types of Corrosion





- Localized Attack
  - Pitting
    - Atmospheric attack leads to surface roughening
  - Crevice Corrosion
    - Trapped moisture leads to increased corrosion of the metal due to the development of an anodic region within the crevice because of the exclusion of oxygen.
  - Intergranular Corrosion
    - Occurs at grain boundaries and is due to the precipitation of a secondary phase
  - Filiform Corrosion
    - Water and oxygen migrate through protective coatings and create active microgalvanic cells

Elektron^{TM} 43

- The driving factors for magnesium alloys in aerospace – increased creep resistance at elevated temperatures, improved corrosion resistance, and improved mechanical properties - led to the development of WE43, trademarked as Elektron 43
- Elektron 43 is well suited for age hardening due to the yttrium and rare earth content
- Binary compounds of Mg-Nd and Mg-Y are able to form in equilibrium with the magnesium solid solution. Maximum strength is achieved through age-hardening treatments.

Corrosion Testing: Salt Spray

- A 5 +/- 1% by weight sodium chloride solution in a pH range of 6.5 - 7.2 was atomized as a fog into a heated cabinet maintained at 35° C The samples were placed into the chamber at an angle 15 - 30° from the vertical and tested for 96 hours per ASTM B117 [70]. Following the test, the samples were rinsed in deionized water not warmer than 38° C and allowed to air dry. The panels were then visually examined for signs of corrosion and assessed according to the criteria specified.

- Pass / Fail Criteria

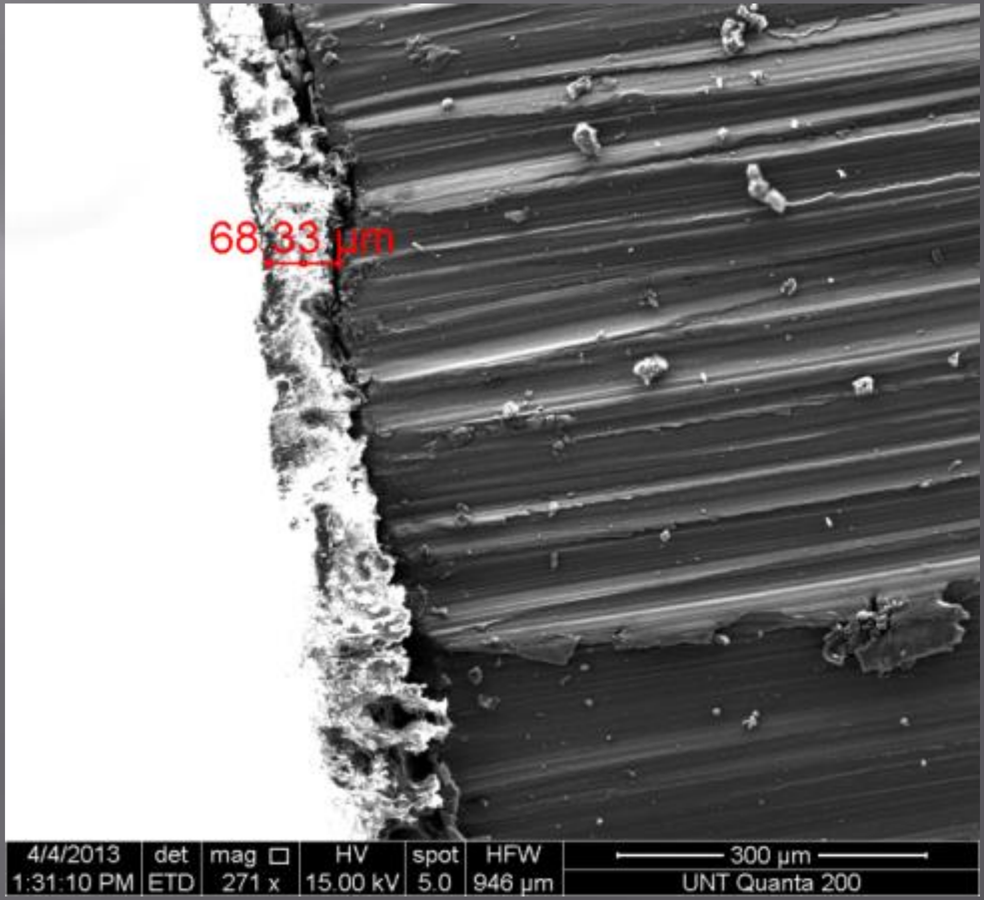
- No more than five isolated spots or pits per test specimen OR no more than fifteen isolated spots or pits on combined surface of all five specimens
- Spots or pits must not exceed 0.031″ in diameter

Corrosion Testing: Salt Spray

- Elektron 43 tested with Aluminum 7075-T651 as a baseline
- Three surface conditions
  - Bare
  - Trivalent chromate coating
  - Trivalent chromate coating + TGIC powder coat
- Metals performed equivalently in all surface conditions

Coating Thickness

Sample ID	Measured thickness (inches)
Magnesium, M11	0.0023
Magnesium, M12	0.0027
Magnesium, M13	0.0022
Aluminum, A11	0.0020
Aluminum, A12	0.0022
Aluminum, A13	0.0026



Sample M12, after salt spray = 0.00269" (2.69 mils)

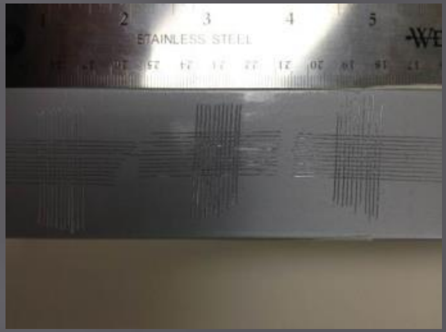
Coating Adhesion

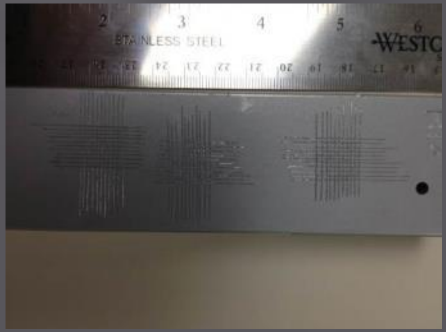
- Destructive testing to verify adhesion of the coating per Method B of ASTM D3359.
- Three lattice patterns are scribed into the surface of the coating, each with eleven cuts one millimeter apart.
- 3M 250 tape is applied over the scribe marks and smoothed in place to ensure good contact
- The tape is removed in one smooth motion at an angle of 180° from the face of the sample.
- The sample as well as the tape is visually examined for intercoat separation
- any adhesion loss is rated per the ASTM standard.
- Pass / Fail criteria
  - Small flakes of the coating allowed to detach at lattice intersections; however, less than ten percent of the surface area allowed to be affected.

Coating Adhesion

- Adhesion loss is rated on a scale of 1B to 5B, with 1B representing complete separation and 5B representing no separation.
- All tested samples were scored with a 5B.

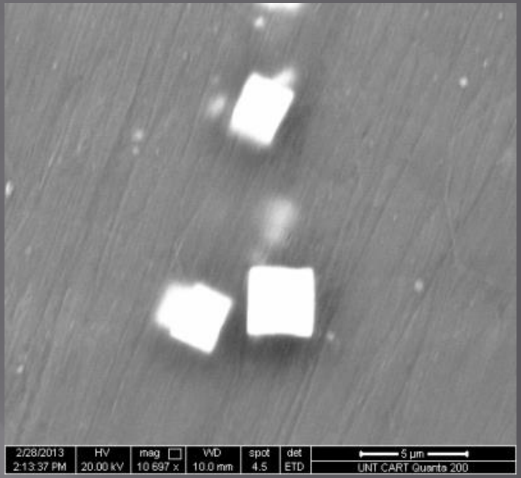




Environmental Scanning Electron Microscopy

- Accelerating voltage for analysis was primarily 15 kV, with limited use of higher voltage when necessary to penetrate deeper into the sample.
- Analysis began with the goal of verifying the reported chemistry of the Elektron 43 alloy. Unique microstructures were located using SEM, then the surface was mapped using EDAX.



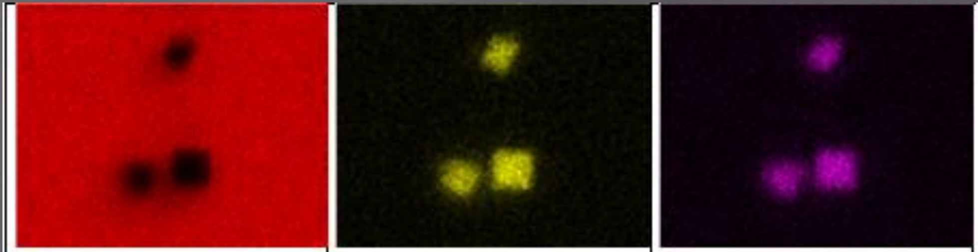
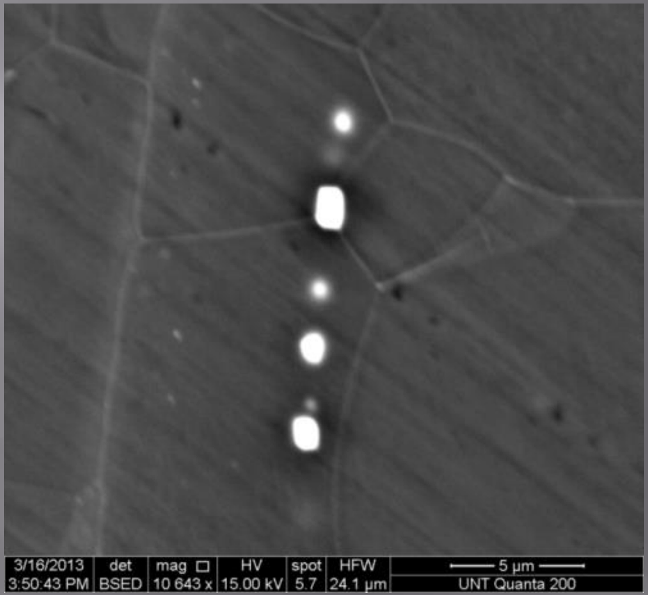


Figure 3-43
Magnesium matrix

Figure 3-44
Yttrium precipitates

Figure 3-45
Zirconium precipitates

Precipitate Identification



- Spheroidal precipitates

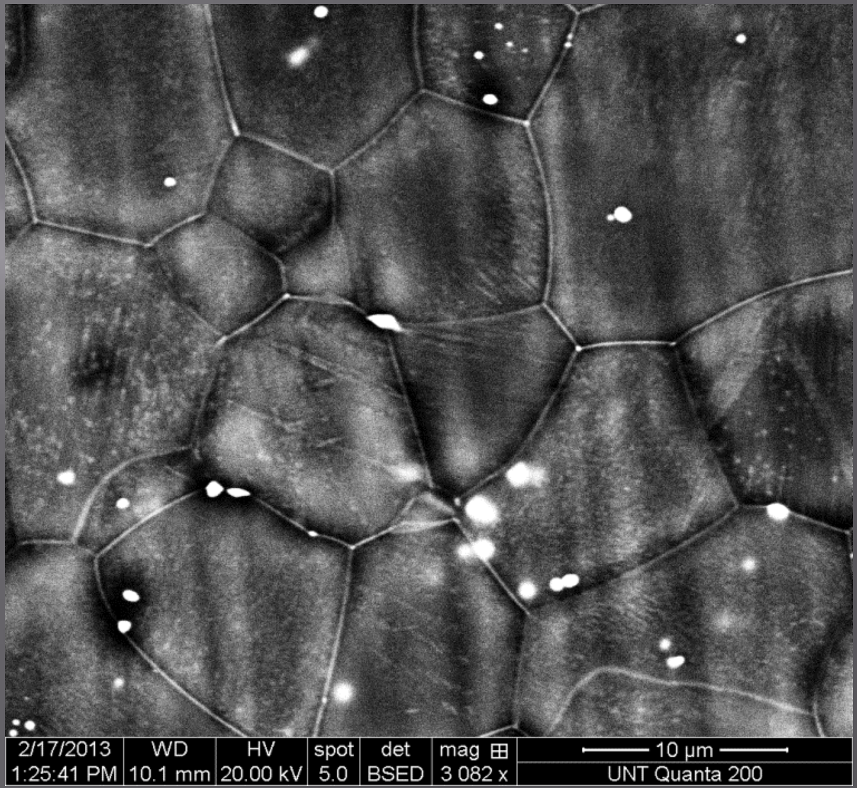
Element	% weight
Mg	84.63
Y	11.44
Zr	0.68
Nd	3.25

- Cubic precipitates

Element	% weight
Mg	38.79
Y	55.34
Zr	0.80
Nd	5.07

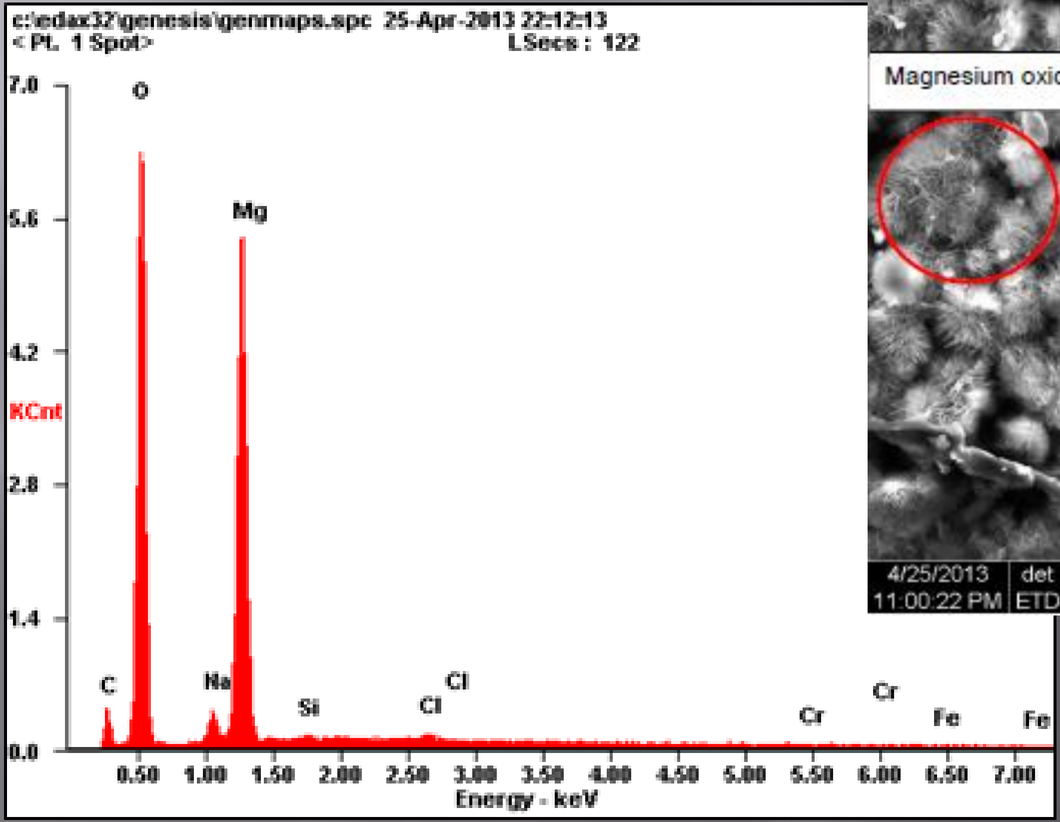
Characteristics

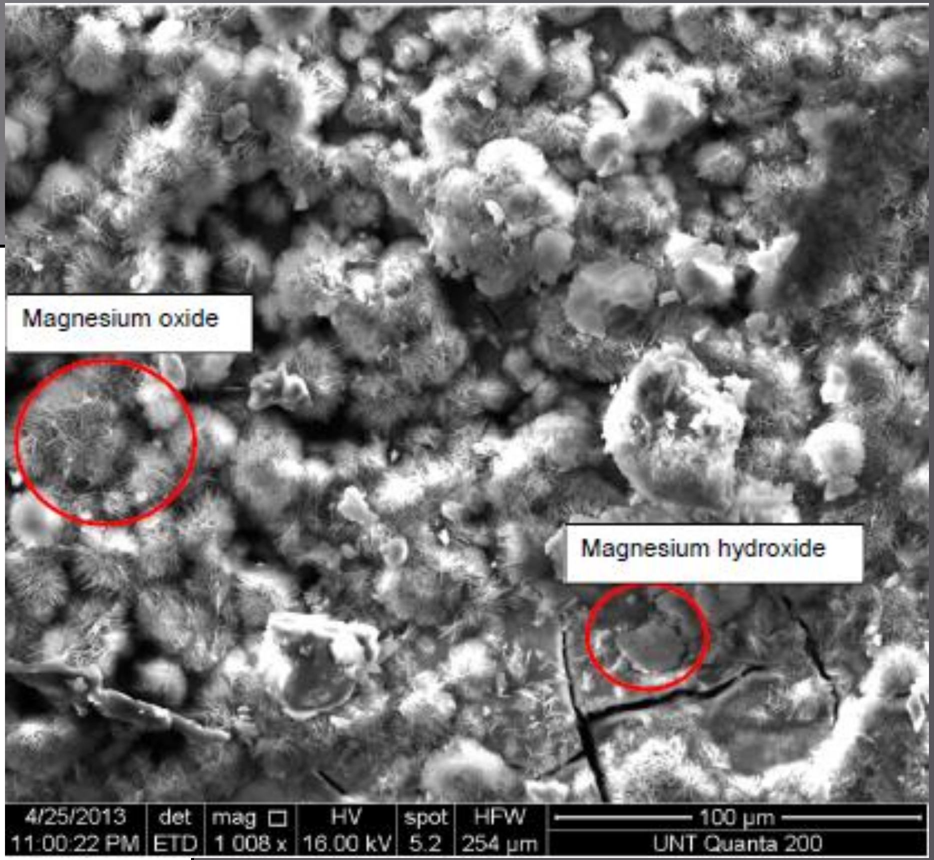
- BSED illustrates precipitate emergence at grain boundaries
- Areas of recrystallization showing increased grain size
- In general, the grains can be seen to be very uniform throughout the metal with a dispersion of precipitates within the matrix.



ESEM Analysis following salt spray testing: Bare samples

- Following salt spray testing, the samples with the most evidence of corrosion products were selected for additional analysis.

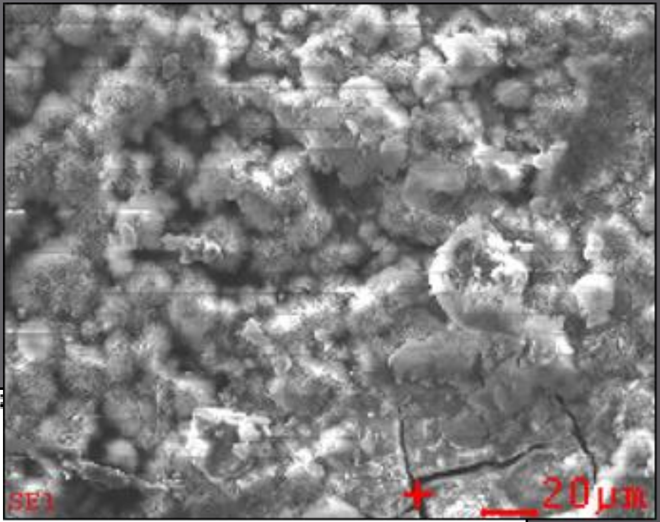


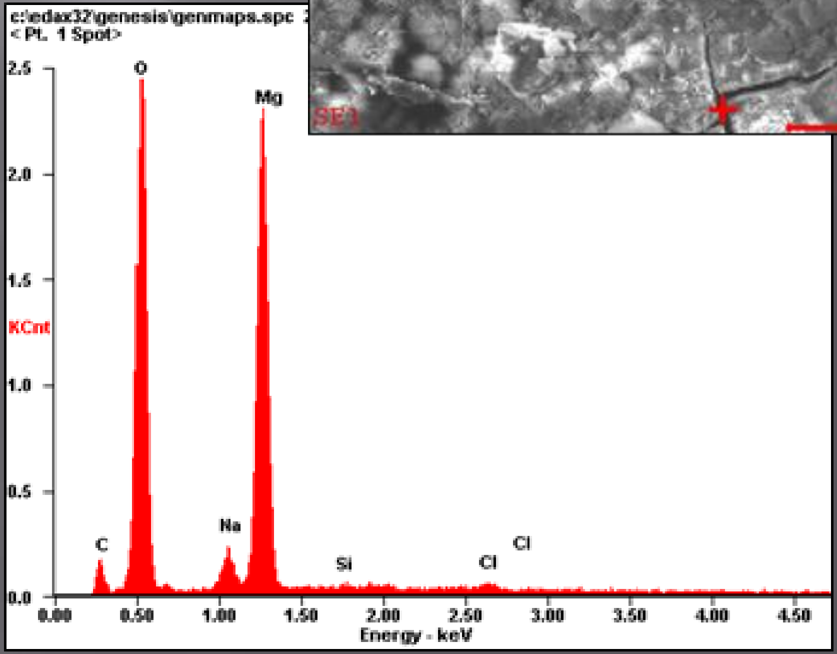


ESEM Analysis following salt spray testing: Bare samples

- Within the crack, the percentages of sodium and chlorine were found to be very slightly higher than on the overall sample. The amount of magnesium within the crack was slightly less than the average. Other elements remained proportionally equivalent.

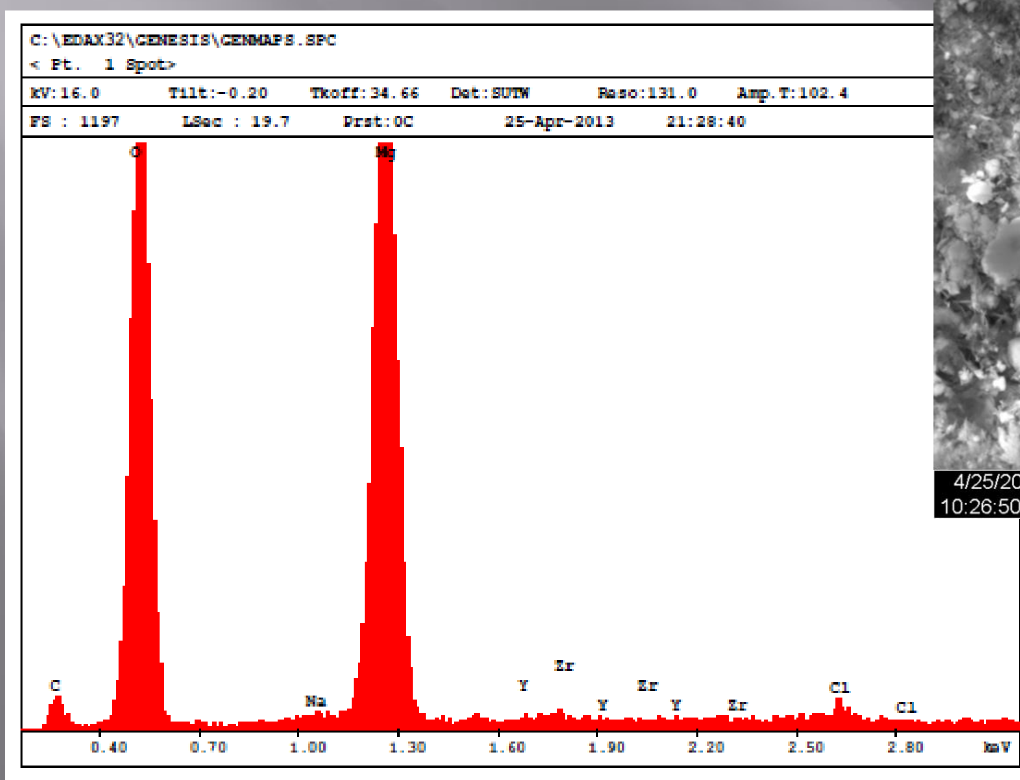
- This finding indicates that the sodium chloride solution was able to penetrate the magnesium matrix, initially via a pitting mechanism.

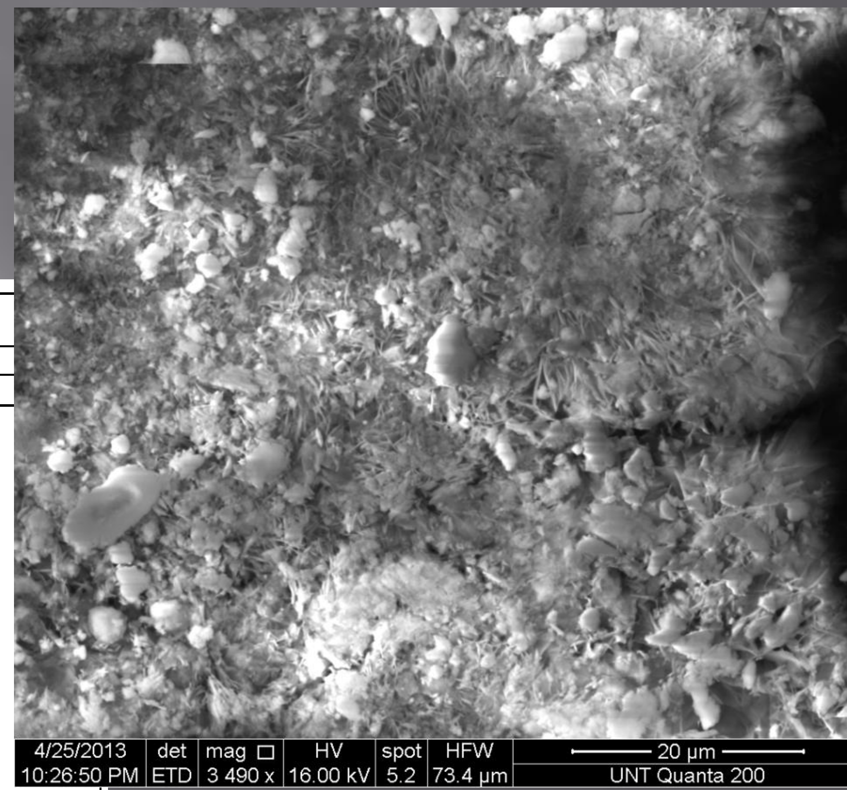




ESEM Analysis following salt spray testing: Trivalent chromate coated samples

- The characteristic petals of magnesium oxide and plates of magnesium hydroxide are still clearly visible





ESEM Analysis following salt spray testing: Trivalent chromate coated samples

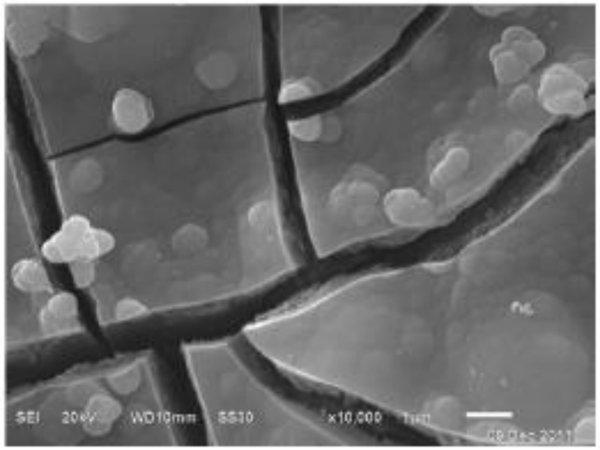


Figure 3-58
Trivalent chromate coating on magnesium, no salt spray testing
Image credit: Dr. Bruce Davis, MEL

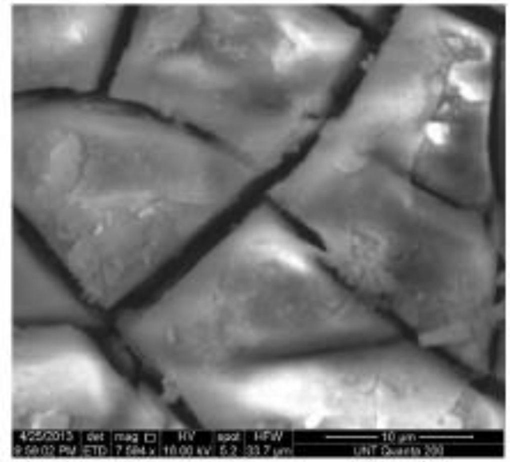
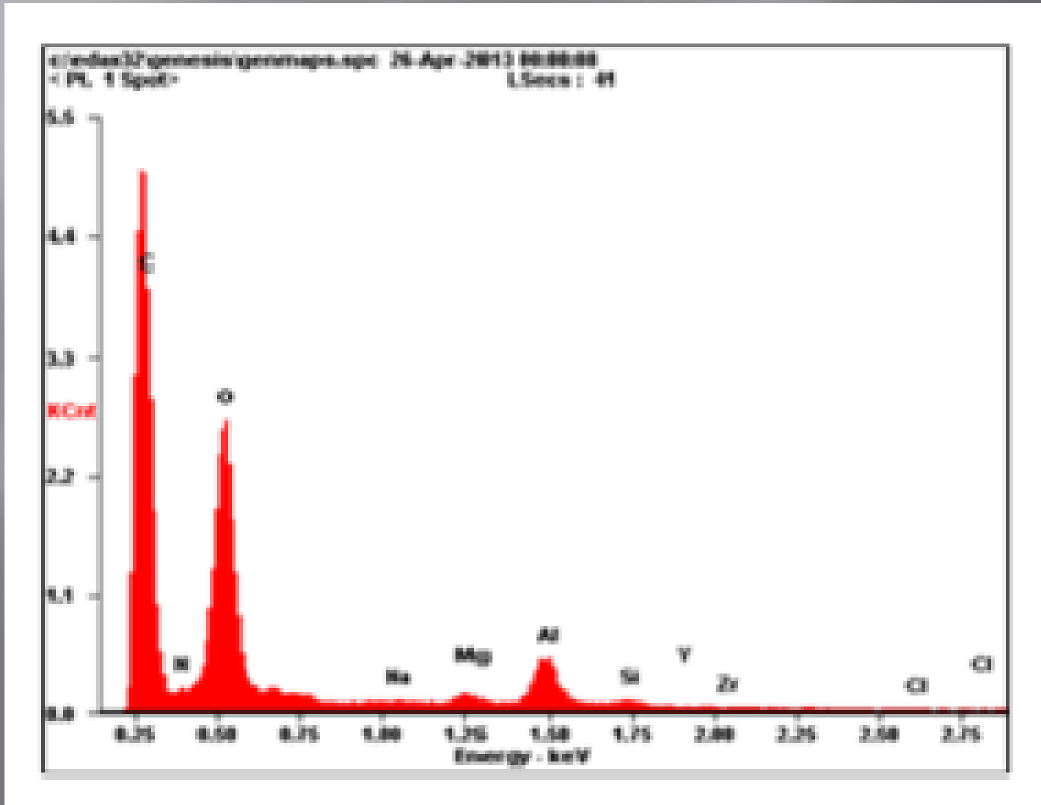


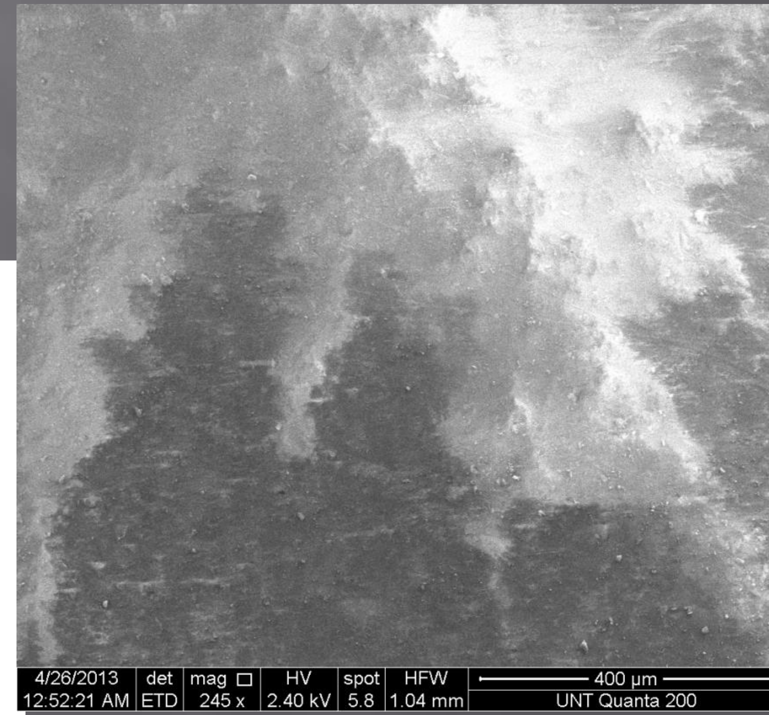
Figure 3-59
Trivalent chromate coating on magnesium, after salt spray testing

- EDAX measurements of the surface reveal the chromium and fluorine components of the chemical film. The presence of these elements verifies that the film is still present on the sample following salt spray testing.

ESEM Analysis following salt spray testing: Trivalent chromate coating + powder coating samples

- Analyzing the powder coated samples proved to be a challenge as standard voltage accelerations destroyed the coating.





Carbon, oxygen, nitrogen, aluminum, and silicon are all components of the TGIC powder coat chemistry. At 0.60 weight percentage, the magnesium value detected is negligible.

Conclusions

- It was shown that the magnesium alloy Elektron 43 performed at the same level of corrosion resistance of aluminum alloy 7075-T651 for all three surface conditions: bare, trivalent chromate coated, and trivalent chromate coated plus powder coated.

- Adhesion testing showed that the trivalent chromate coating formed an excellent substrate for the powder coat. All samples were rated at the highest level; no loss of protective coating was observed.

- It was determined that the artificial aging process resulted in a multi-phase material containing α-magnesium matrix, yttrium/zirconium cuboids and yttrium/neodymium precipitates. The grains were recrystallized and evenly distributed. Cubic particles mostly located along grain boundaries were determined to be primarily composed of yttrium. A smaller number of spheroid precipitates were observed and determined to be composed of yttrium and neodymium.

Conclusions

- For bare samples, the corrosion products were composed of magnesium oxide and magnesium hydroxide. The lack of the protective films resulted in pitting.
- The samples which received a trivalent chromate coating exhibited the same corrosion products, but in thicker sections. EDAX revealed the presence of fluorine and chromium from the damaged coating.
- The samples which received a trivalent chromate coating as well as powder coat performed very well. No pitting, cracks, or other corrosion was evident. Corrosion products were limited to areas that had not been protected, such as tooling holes. The surface of the powder coated sample exhibited no build-up of corrosion products.

Recommendations

- The results of the analysis on both the bare and trivalent chromate coated samples indicates that it is absolutely necessary for magnesium alloys to have a more robust and protective coating than trivalent chromate alone.

- These results show conclusively that, in terms of corrosion, Elektron 43 can easily be treated with industry standard coatings (trivalent chromate and TGIC powder coating) and will meet the requirements for usage in aircraft cabin interiors.

- It is cautioned that, even with excellent protective coatings, dissimilar metal contact and liquid entrapment should be eliminated during the design phase.