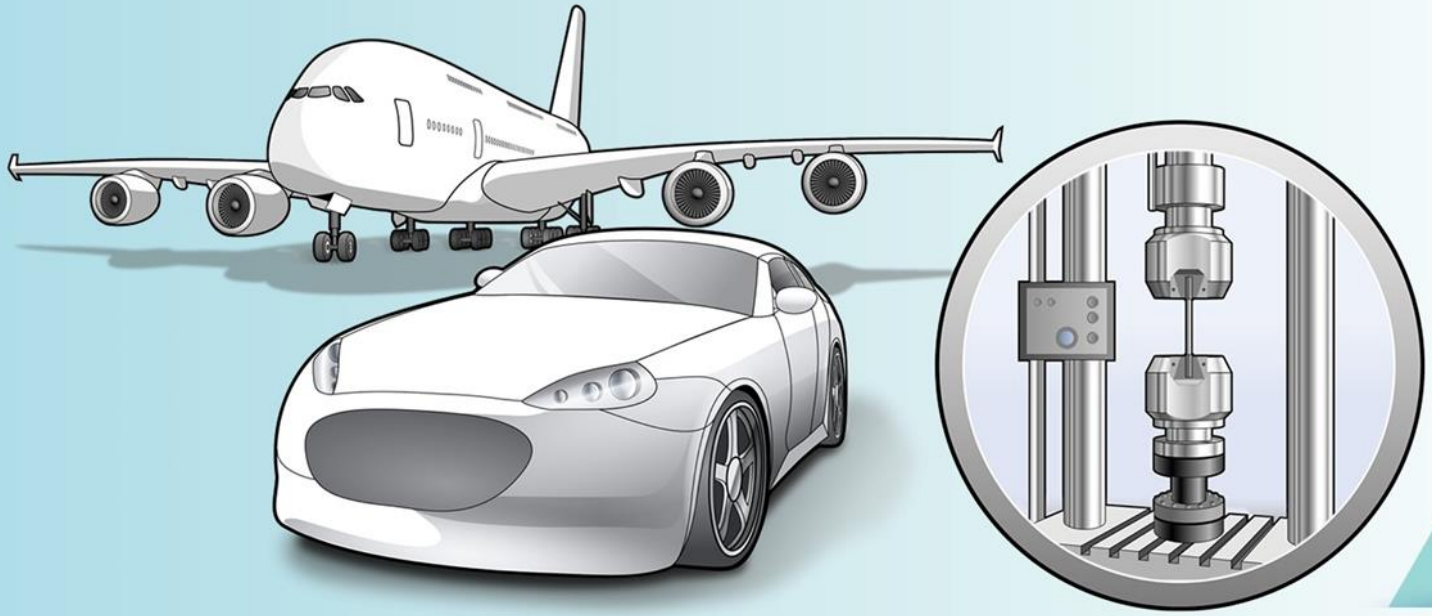

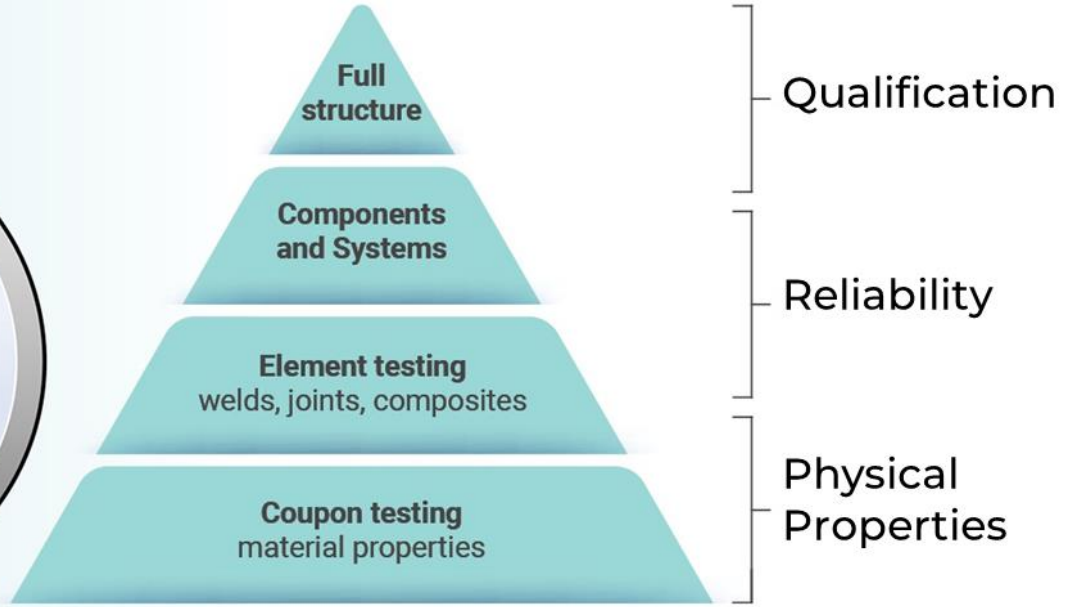

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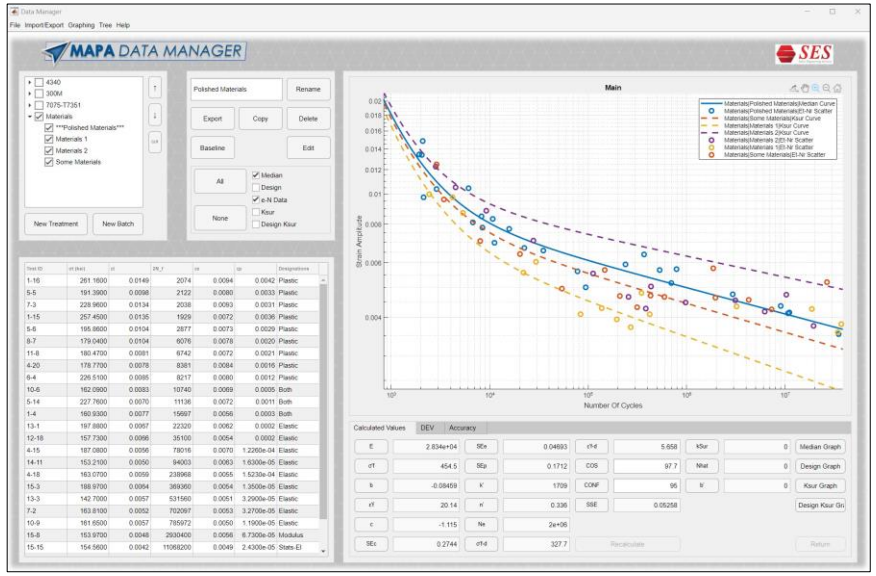

- **Application of the Material Assessment and Predictive Analysis (MAPA) Tool for Fatigue Data Management**

Mr. Ben Griffiths,
Chief Engineer, Select Engineering Services

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Application of the Material Assessment and Predictive Analysis (MAPA) Tool for Fatigue Data Management

Abstract

- SES is developing the MAPA tool to provide the United States Air Force with more precise predictive models for the fatigue characteristics of landing gear subject to surface treatments and coatings during design, maintenance, and overhaul. The MAPA tool manages raw fatigue test data and generates curve fits, strain-life parameters, and plots for rapid data mining. The MAPA tool also exports material property files formatted for direct input to nCode DesignLife for fatigue analysis.

- MAPA Data Management
  - To manage all raw fatigue test data, and resultant strain-life and K_{sur}, fatigue parameters.
  - To compare raw data and fitted curves.

- MAPA Curve Fit Editing
  - To curve fit raw fatigue test data into strain-life and K_{sur} , fatigue parameters.
  - To control the curve fitting process, to include/exclude data points, and to set design curve reliability and confidence levels.

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Application of the Material Assessment and Predictive Analysis (MAPA) Tool for Fatigue Data Management

- About the presenter, Mr. Ben Griffiths, Chief Engineer, Select Engineering Services

  - Ben Griffiths has a Master's degree in Mechanical Engineering from Utah State University and is a licensed Professional Engineer in the state of Utah. He has 10 years of experience conducting research and development with an emphasis on materials testing and analysis. Some of the research projects he has worked on include:
    - Fatigue testing/analysis of landing gear materials with various surface treatments
    - Full-scale crash testing of composite towers using surrogate aircraft wing sections
    - Electrically conductive coating qualification testing
    - Welding of thick section Grade 91 steel to study Type IV creep rupture

  - Mr. Griffiths is representing Select Engineering Services (SES) which is an employee-owned small business operating out of the state of Utah. SES primarily focuses on engineering and analytical services for the United States Air Force (USAF) and other DoD agencies.

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Materials and Surface Coatings and Processes

2023 HBK TECHNOLOGY DAYS

Presenters:

Dr Michelle Hill, Head of Materials testing, HBK

Mr Ben Griffiths, Chief Engineer, Select Engineering Services

Dr Andrew Halfpenny, Director of Technology – nCode products, HBK

Agenda

1. Materials and surface coatings and processes
   - Introduction
   - USAF Project Background and Significance

2. Fatigue methodology for combining surface treatment factors in strain-life fatigue
   - Strain-Life Testing
   - Theory and Calculations

3. **Application of the Material Assessment and Predictive Analysis (MAPA) Tool for Fatigue Data Management**
   - **Tested Results**
   - **MAPA Data Manager**
   - **Ongoing Efforts**

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TESTED RESULTS – ANODIZE ON 7075 ALUMINUM

- ***Anodizing Process for Aluminum***
  - Electrolytic process, forms oxidation on material surface (≈50% extends beneath surface)
  - Used on landing gears primarily for corrosion protection
- ***Anodize Type II***
  - Sulfuric acid bath process
  - Thickness typically 0.0001" (0.003mm) to 0.0005" (0.013mm)
- ***Anodize Type III***
  - Sulfuric acid bath process
  - Thickness typically 0.0005" (0.013mm) to 0.006" (0.152mm)
  - Forms harder deposit compared to Type II

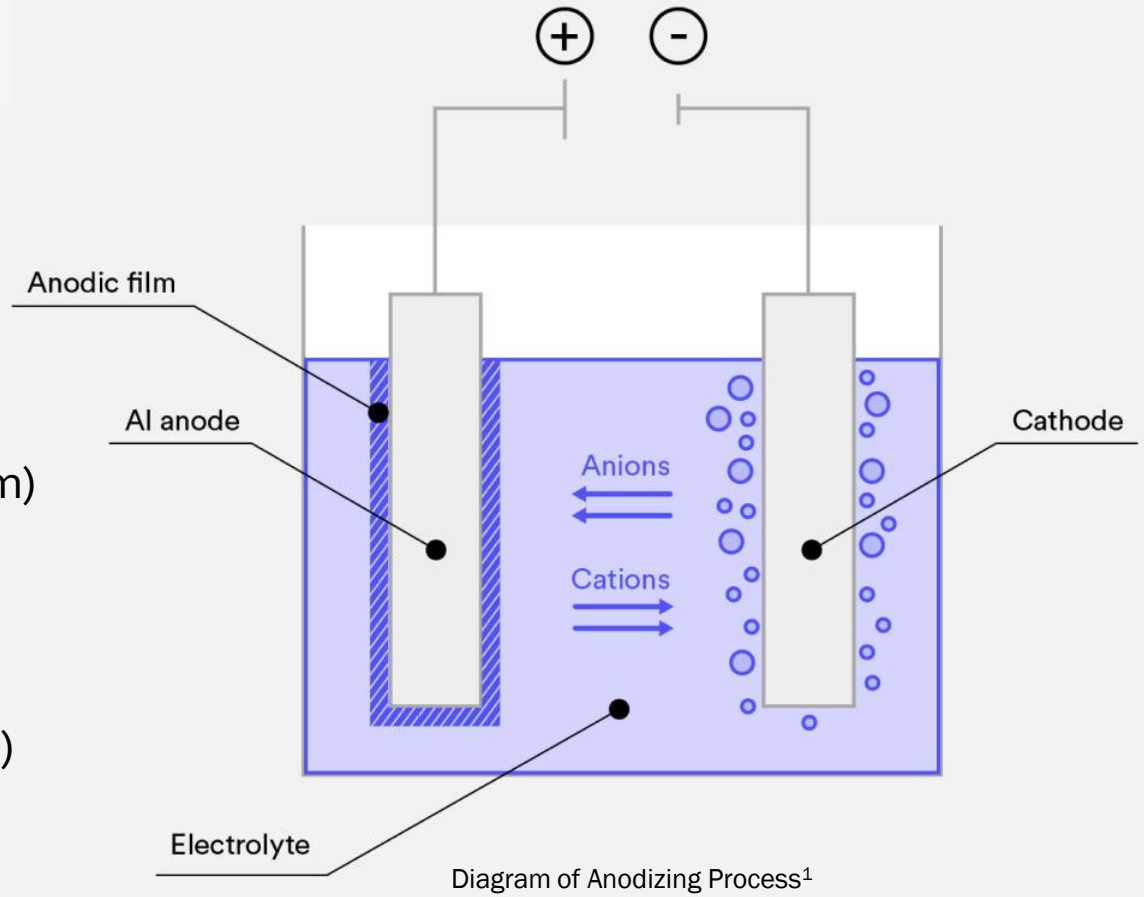

Diagram of Anodizing Process[1]

[1]https://www.hubs.com/surface-finishing-services/aluminum-anodizing-services/

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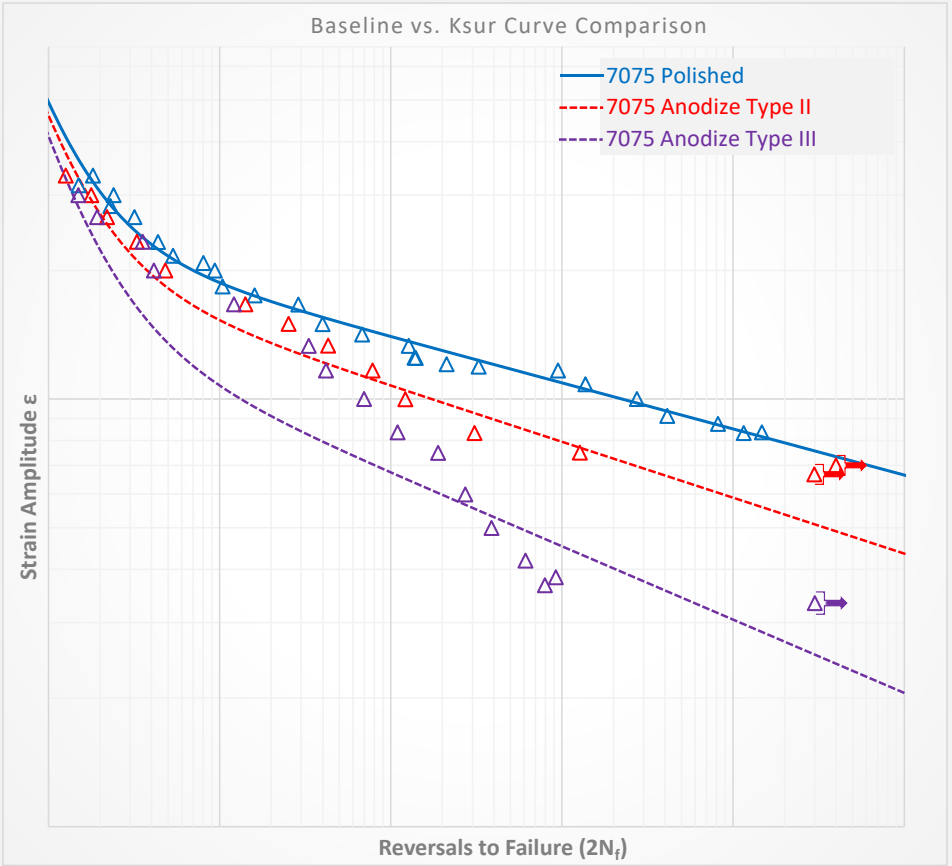
TESTED RESULTS – ANODIZE ON 7075 ALUMINUM

- ***Anodize Type II***
  - Significant fatigue life reduction
  - Shot peen effective in restoring fatigue performance (not shown in plot)
- ***Anodize Type III***
  - Very severe fatigue life reduction
  - Ksur model does not provide a good curve fit
  - Shot peen effective in restoring fatigue performance (not shown in plot)




Anodize Type II


Anodize Type III

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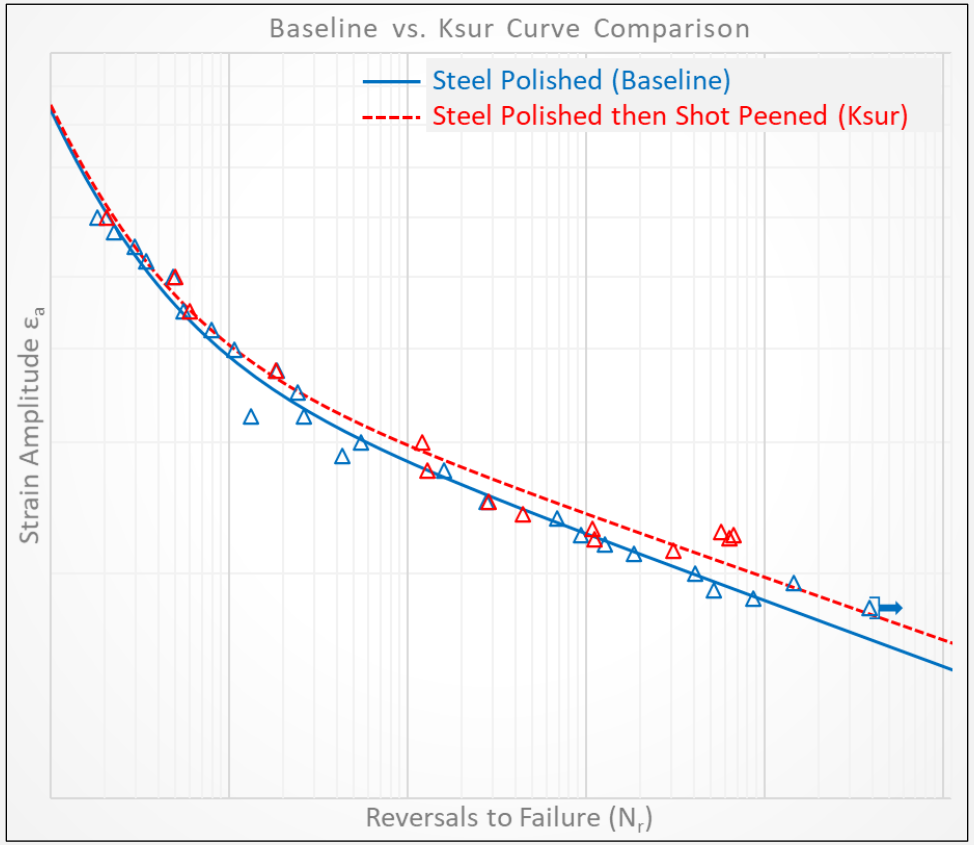
TESTED RESULTS - SHOT PEEN ON POLISHED 300M STEEL

- ***Polished then Shot Peened***
  - Slight increase in high-cycle fatigue life
  - Negligible benefit to the endurance behavior
  - Overall benefit to fatigue performance offset by increase in statistical scatter

Polished then Shot Peened

Shot Peening[1]



[1]https://www.wheelabratorgroup.com/aerospace

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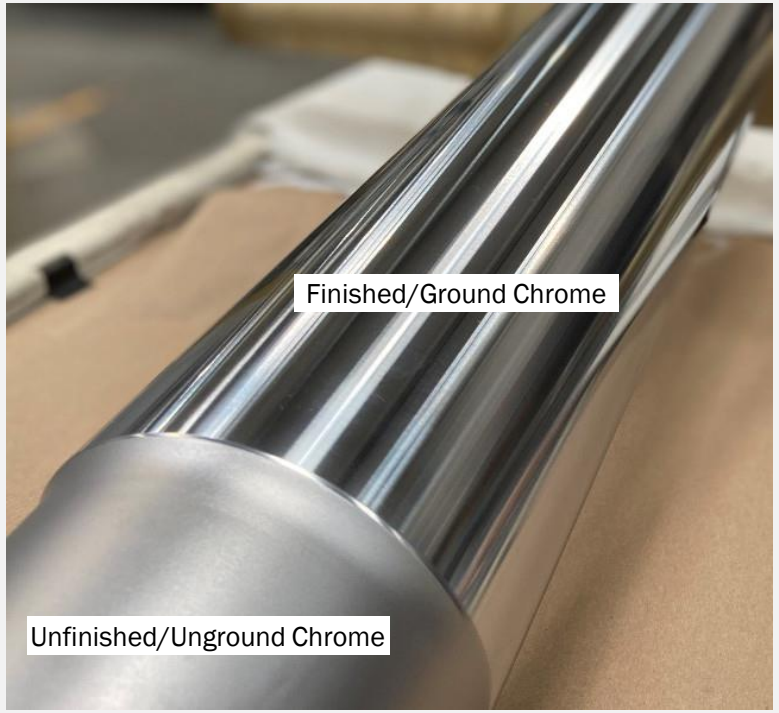
TESTED RESULTS - CHROME ON 300M STEEL

- ***Chrome Type I (plated to size)***
  - Thinner deposit: ≈0.002" (0.051mm)
  - Less microcracking than Type II
- ***Chrome Type II (ground to size)***
  - Plated to 0.002" (0.051mm) above final desired thickness, then ground to final dimensions
  - Final plating thickness ≈0.010" (0.254mm) or greater is possible
  - As coating thickness increases, microcracking increases to relieve tensile stress in chrome deposit
  - Microcracks can be beneficial in lubrication of sliding surfaces



Example Chrome Plated Part[1]

[1]https://apps.dtic.mil/sti/tr/pdf/ADA604889.pdf

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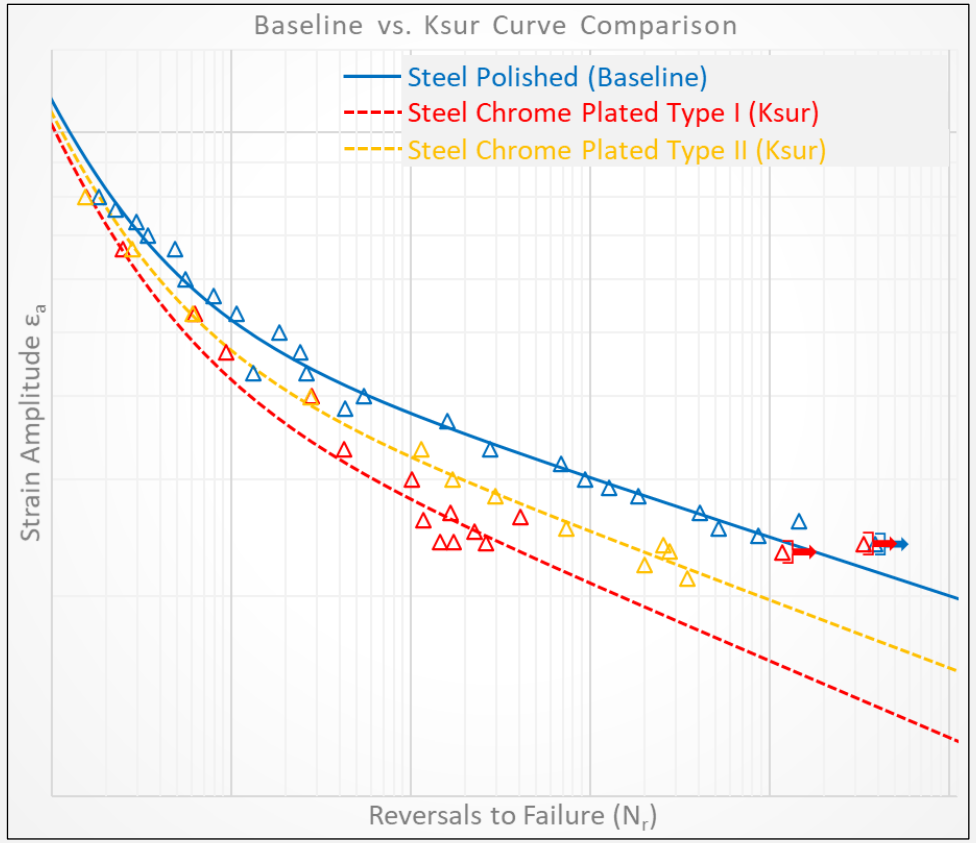
TESTED RESULTS - CHROME ON 300M STEEL

- ***Chrome Type I (plated to size)***
  - Substantial fatigue life reduction
  - Shot peen effective in restoring fatigue performance
- ***Chrome Type II (ground to size)***
  - Significant fatigue life reduction (less detrimental than Type I)
  - Shot peen effective in restoring fatigue performance
  - Same plating thickness as Electrolytic Nickel specimens
- ***Chrome Type II - Strip/Re-Plate at Half-Life***
  - Tested with shot peen only
  - No significant fatigue performance reduction

Chrome Type I

Chrome Type II



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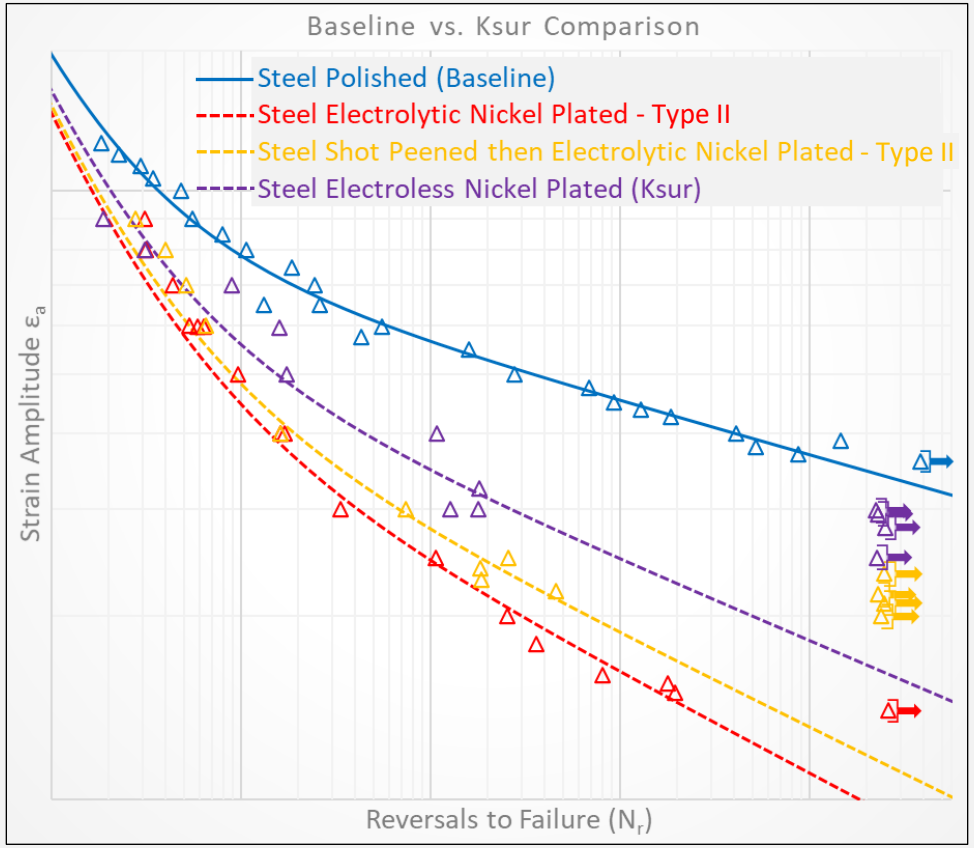
TESTED RESULTS - NICKEL ON 300M STEEL

- ***Electrolytic Nickel Type I (plated to size)***
  - Shot peen effective in restoring fatigue performance (not shown in plot)
- ***Electrolytic Nickel Type II (ground to size)***
  - Very severe fatigue life reduction
  - Shot peen not effective in restoring fatigue performance
- ***Electroless Nickel (plated to size)***
  - Substantial fatigue life reduction
  - Shot peen effective in restoring fatigue performance (not shown in plot)




Electrolytic Nickel Type I


Electrolytic Nickel Type II


Electroless Nickel

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TESTED RESULTS - WC-CO HVOF ON 300M STEEL

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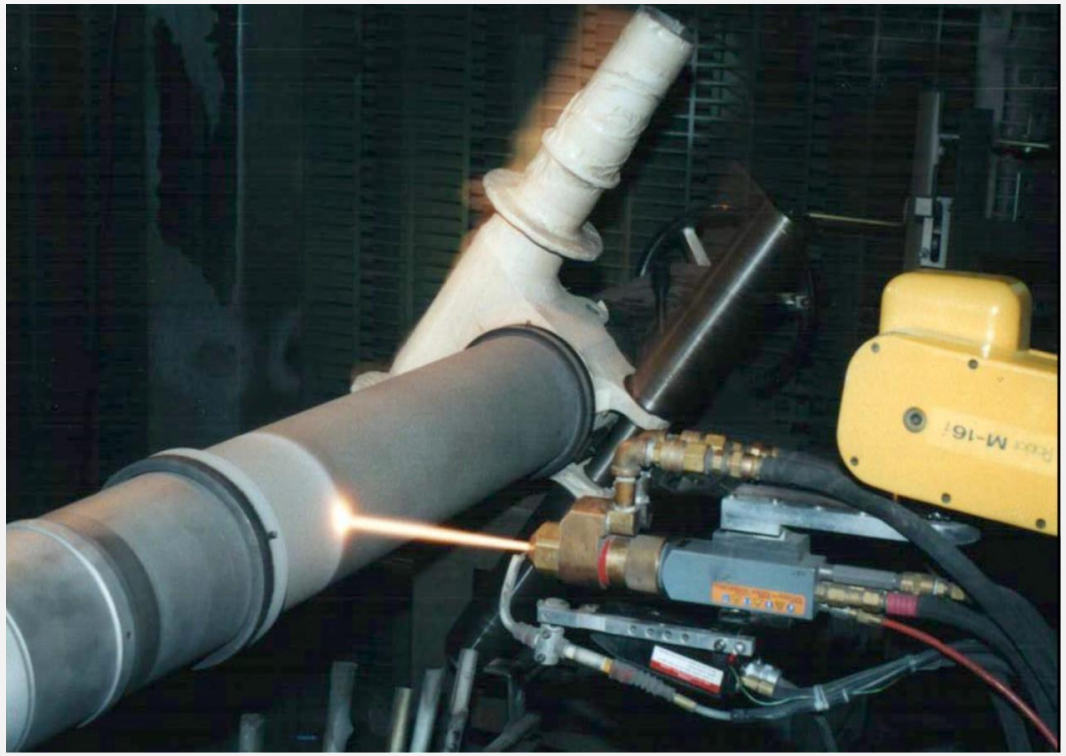
- ***Tungsten Carbide-Cobalt (WC-Co) High Velocity Oxygen Fuel (HVOF)***
  - Plated to 0.003" (0.076mm) above desired final thickness, then ground to final dimensions
  - Approved replacement for chrome targeted at reducing hazardous waste (hexavalent chromium)
  - Requires line of site for application
  - Wear surface lasts longer
  - More expensive to apply



Application of HVOF Coating to Landing Gear Component (Left); After grinding/finishing (Right)[1]

[1]https://apps.dtic.mil/sti/tr/pdf/ADA604889.pdf

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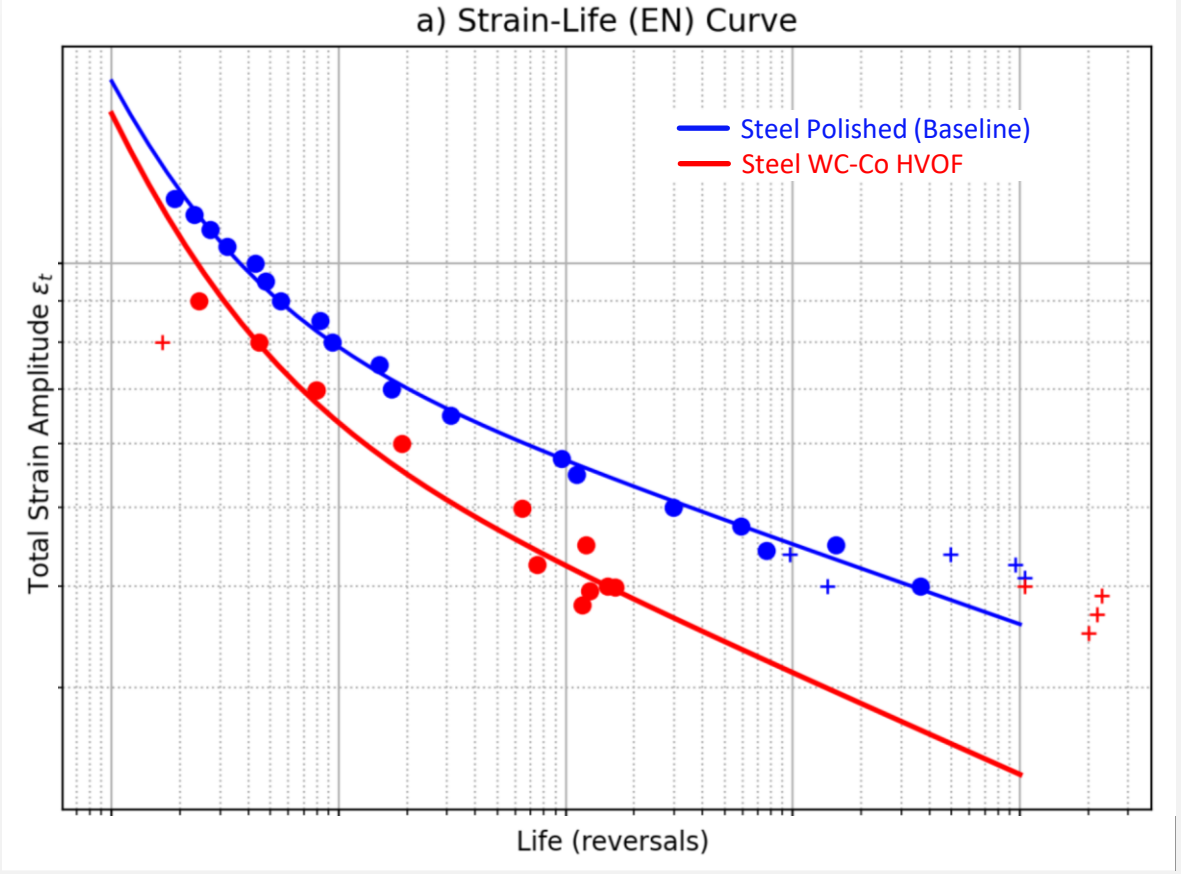
TESTED RESULTS - WC-CO HVOF ON 300M STEEL

- ***WC-Co HVOF***
  - Substantial fatigue life reduction
  - Shot peen effective in restoring fatigue performance (not shown in plot)

WC-Co HVOF



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TESTED RESULTS - CADMIUM ON 300M STEEL

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- ***Cadmium Plate***
  - Known carcinogen
  - Air Force has developed Zinc-Nickel plating process that is approved replacement for cadmium on landing gear
  - Used primarily for corrosion protection
  - Thickness typically 0.0002" (0.005mm) to 0.0005" (0.013mm)

Example Cadmium Plated Component[1]

[1]https://apps.dtic.mil/sti/tr/pdf/ADA604889.pdf

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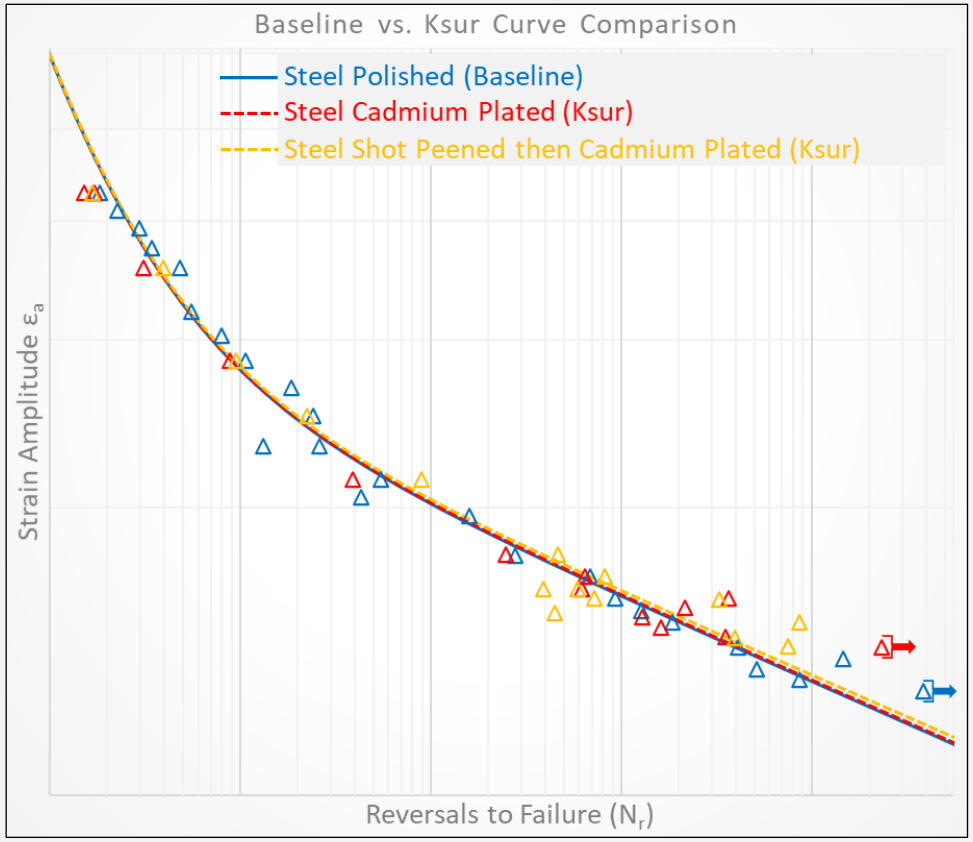
TESTED RESULTS - CADMIUM ON 300M STEEL

- ***Cadmium Plate***
  - No significant detrimental effect on fatigue performance
  - Shot peen offers no beneficial effect on fatigue performance
  - Fitted curves for Cadmium nearly identical to Baseline (ideal) curve



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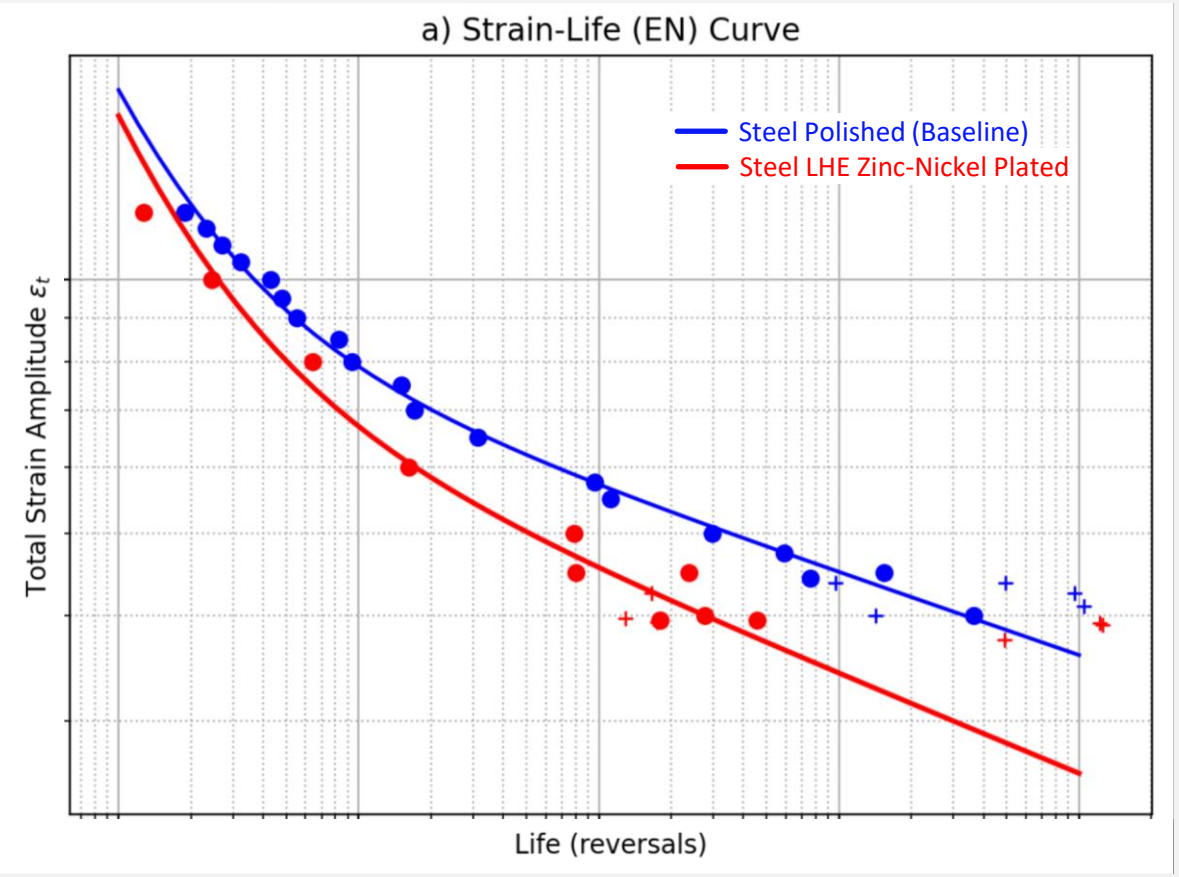
TESTED RESULTS – ZINC-NICKEL ON 300M STEEL

- ***Zinc-Nickel Plate***
  - Significant fatigue life reduction
  - Shot peen effective in restoring fatigue performance (not shown in plot)

Zinc-Nickel

Landing Gear Component Set Up for Zinc-Nickel Plating[1]



[1]https://www.airforcemedicine.af.mil/News/Photos/igphoto/2001764216/

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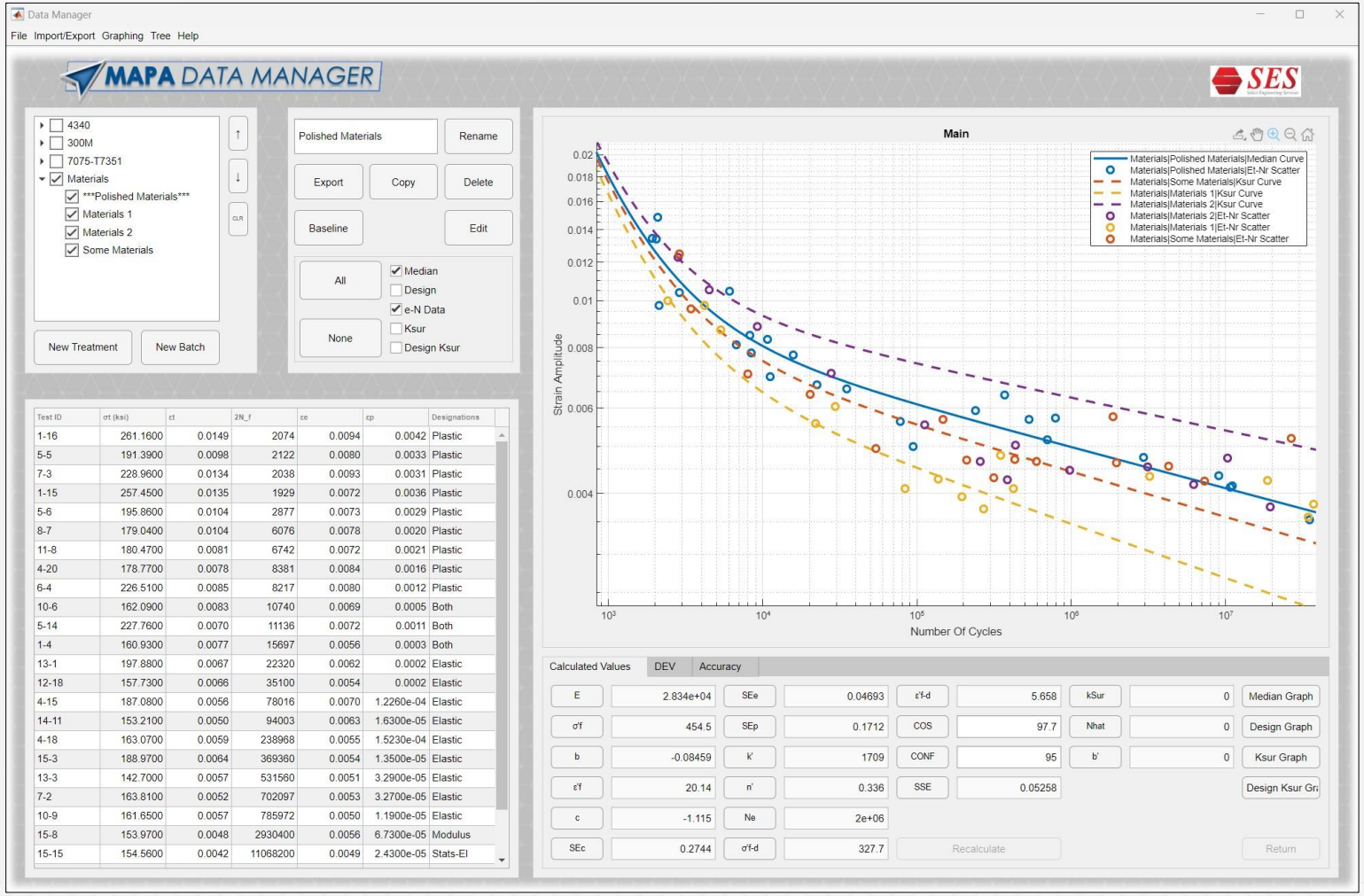
MAPA DATA MANAGER

- ***Capability Summary***
  - Application built in MATLAB
  - Rapid comparisons of raw data and fitted curves
  - Adjust curve fit designations and statistics
  - Generate parameters for input to nCode
  - Show/hide plots and print reports
  - Directed user inputs for raw fatigue data



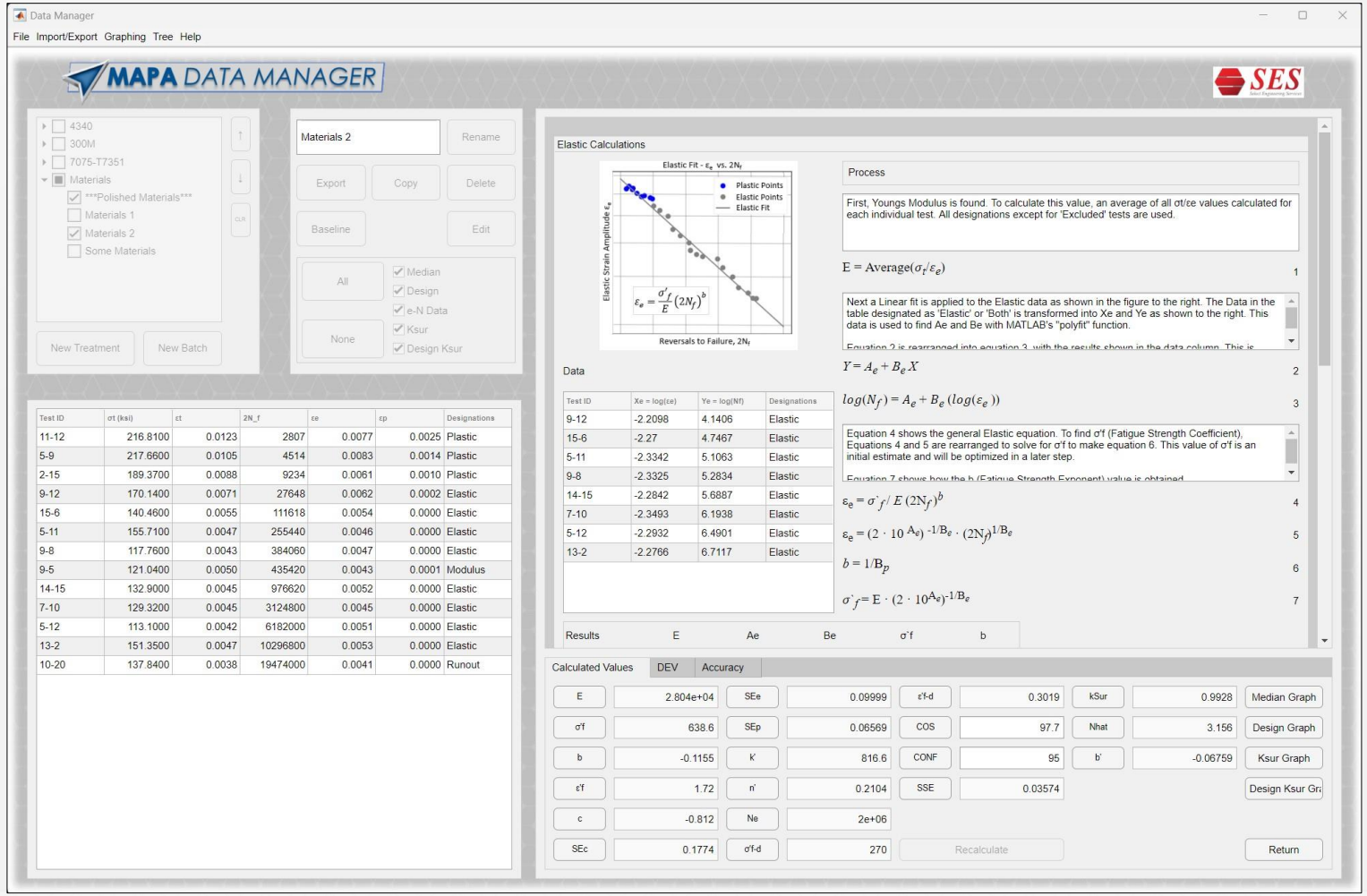
Test ID	σt (ksi)	εt	2N_f	εe	εp	Designations
1-16	261.1600	0.0149	2074	0.0094	0.0042	Plastic
5-5	191.3900	0.0098	2122	0.0080	0.0033	Plastic
7-3	228.9600	0.0134	2038	0.0093	0.0031	Plastic
1-15	257.4500	0.0135	1929	0.0072	0.0036	Plastic
5-6	195.8600	0.0104	2877	0.0073	0.0029	Plastic
8-7	179.0400	0.0104	6076	0.0078	0.0020	Plastic
11-8	180.4700	0.0081	6742	0.0072	0.0021	Plastic
4-20	178.7700	0.0078	8381	0.0084	0.0016	Plastic
6-4	226.5100	0.0085	8217	0.0080	0.0012	Plastic
10-6	162.0900	0.0083	10740	0.0069	0.0005	Both
5-14	227.7600	0.0070	11136	0.0072	0.0011	Both
1-4	160.9300	0.0077	15697	0.0056	0.0003	Both
13-1	197.8800	0.0067	22320	0.0062	0.0002	Elastic
12-18	157.7300	0.0066	35100	0.0054	0.0002	Elastic
4-15	187.0800	0.0056	78016	0.0070	1.2260e-04	Elastic
14-11	153.2100	0.0050	94003	0.0063	1.6300e-05	Elastic
4-18	163.0700	0.0059	238968	0.0055	1.5230e-04	Elastic
15-3	188.9700	0.0064	369360	0.0054	1.3500e-05	Elastic
13-3	142.7000	0.0057	531560	0.0051	3.2900e-05	Elastic
7-2	163.8100	0.0052	702097	0.0053	3.2700e-05	Elastic
10-9	161.6500	0.0057	785972	0.0050	1.1900e-05	Elastic
15-8	153.9700	0.0048	2930400	0.0056	6.7300e-05	Modulus
15-15	154.5600	0.0042	11068200	0.0049	2.4300e-05	Stats-El

E	2.834e+04	SEe	0.04693	ε'f-d	5.658	kSur	0
σ'f	454.5	SEp	0.1712	COS	97.7	Nhat	0
b	-0.08459	k'	1709	CONF	95	b'	0
ε'f	20.14	n'	0.336	SSE	0.05258		
c	-1.115	Ne	2e+06				
SEc	0.2744	σ'f-d	327.7				

MAPA DATA MANAGER

SES Select Engineering Services

- ***Capability Summary (cont'd)***
  - Calculation method tutorials and help menus
  - Visibility and traceability for data interpretation and classification of data points
  - Prevents human errors in data management
  - Automates tasks that would be time consuming



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ONGOING EFFORTS

- ***Integrate*** MAPA Material Assessment & Predictive Analysis Tool ***with*** DesignLife
- ***Expand surface treatment/material property database***
  - ≈500 fatigue tests completed - 26 surface treatments, 3 different materials

https://www.airforcetimes.com/news/your-air-force/2019/02/01/c-5-conducts-nose-gear-up-emergency-landing-at-travis/

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CLOSING

Questions/Comments

Ben Griffiths P.E.
Chief Engineer

ben.griffiths@sesut.com
801.528.5175

SES
Select Engineering Services
1544 Woodland Park Dr. Ste. 310
Layton, UT 84041

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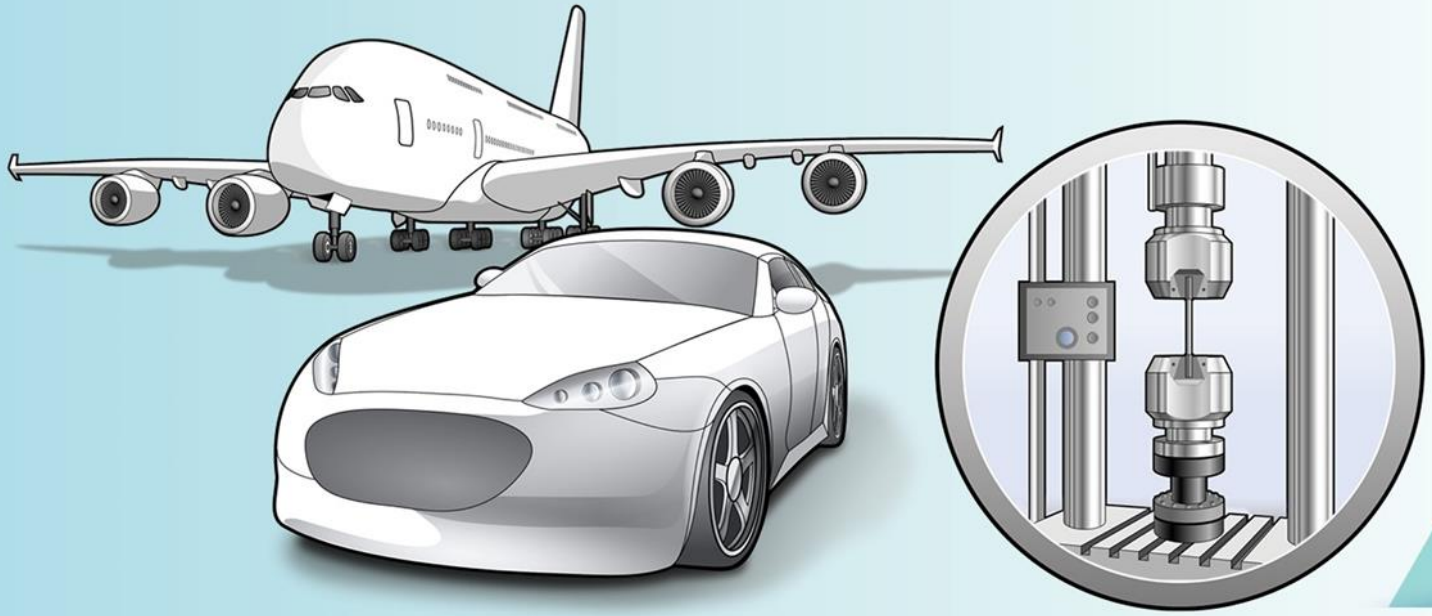

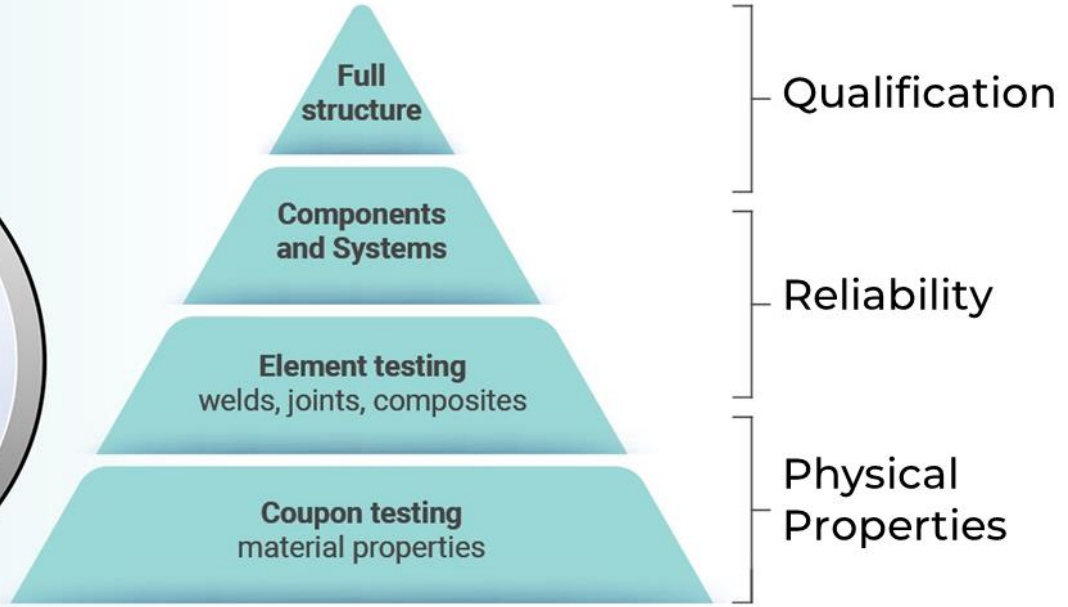

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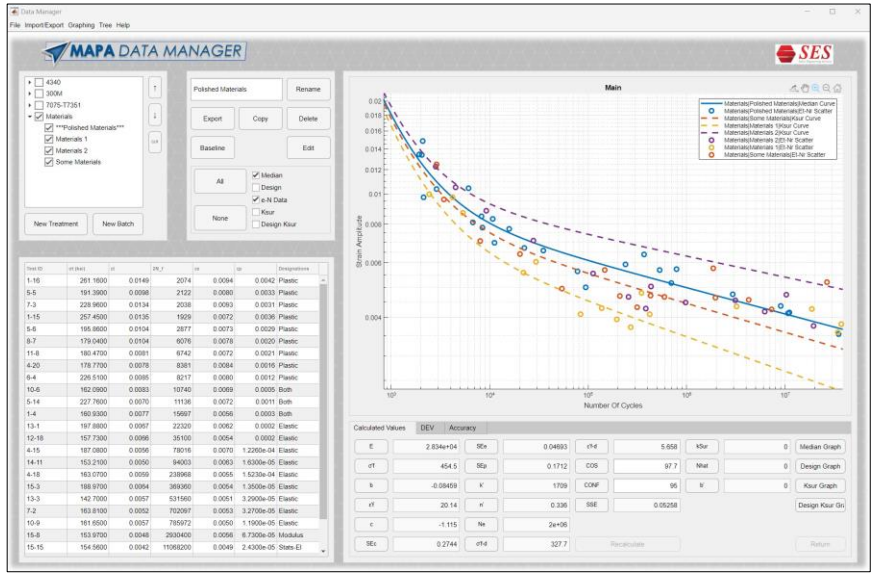

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