Advanced Aluminum Alloys Enabling Performance Improvements

Joint Armaments Conference – Seattle, WA

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LIGHTER, FASTER, STRONGER

Travis Schmidt
Les Yocum · Dustin Bush · Jeff Caratelli

Overview

- Aluminum Alloy Development Timeline
- Range of Aluminum Alloys depending on design drivers
  - High Fatigue Forging Alloys
  - High Strength Extrusion Alloys
  - Elevated Temperature Alloys
- Corrosion Resistance
- Coatings

Alcoa Advanced Alloys / Products Extrusions & Forgings Map

Upper Wing Stringers

Old Baseline: 7150-T6511
Current Baseline: 7055-T77511,7055-T79511
New Products: Al-Li 2099-T83, Al-Li-E-1, AlLi-E-2, 7xxx-E-2, 7xxx-E-3

Fuselage Frames

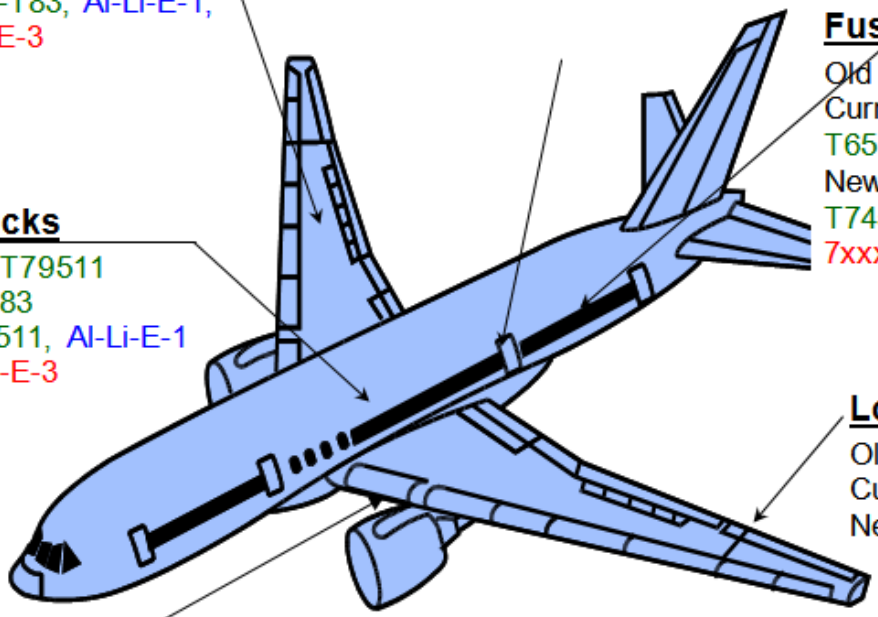
Old Baseline: 2024-T42/7075-T62 sht
Current Baseline: 2024-T4312 extr./7175-T73
New Products: Al-Li 2099-T83,2099-T8E67,7055-T76511,7055-T74511

Fuselage Stringers

Old Baseline: 2024-T3511, 7075-T73511
Current Baseline: 7055-T76511HF, 6110-T6511
New Products: Al-Li 2099-T83, 7055-T74511, Al-Li-E-1, Al-Li-E-2, 7xxx-E-2, 7xxx-E-3.

Floor Beams/Seat Tracks

Old Baseline: 7075/7175-T79511
Current Baseline: 2099-T83
New Products: 7055-T76511, Al-Li-E-1 Al-LI-E-2, 7xxx-E-2, 7xxx-E-3



Lower Wing Stringers

Old Baseline: 2024-T3511
Current : 2026-T3511
New Product: Al-Li 2099-T8E67

Forgings for Wing/ Fuselage

Old Baseline:
7175-T7351, 7050-T7452
New Product:
7085-T7452, Al-Li-FG-1, Al-Li-FG-2, New HS Alloy

Products for Elevated Temps (Wheels/Pylon Area)

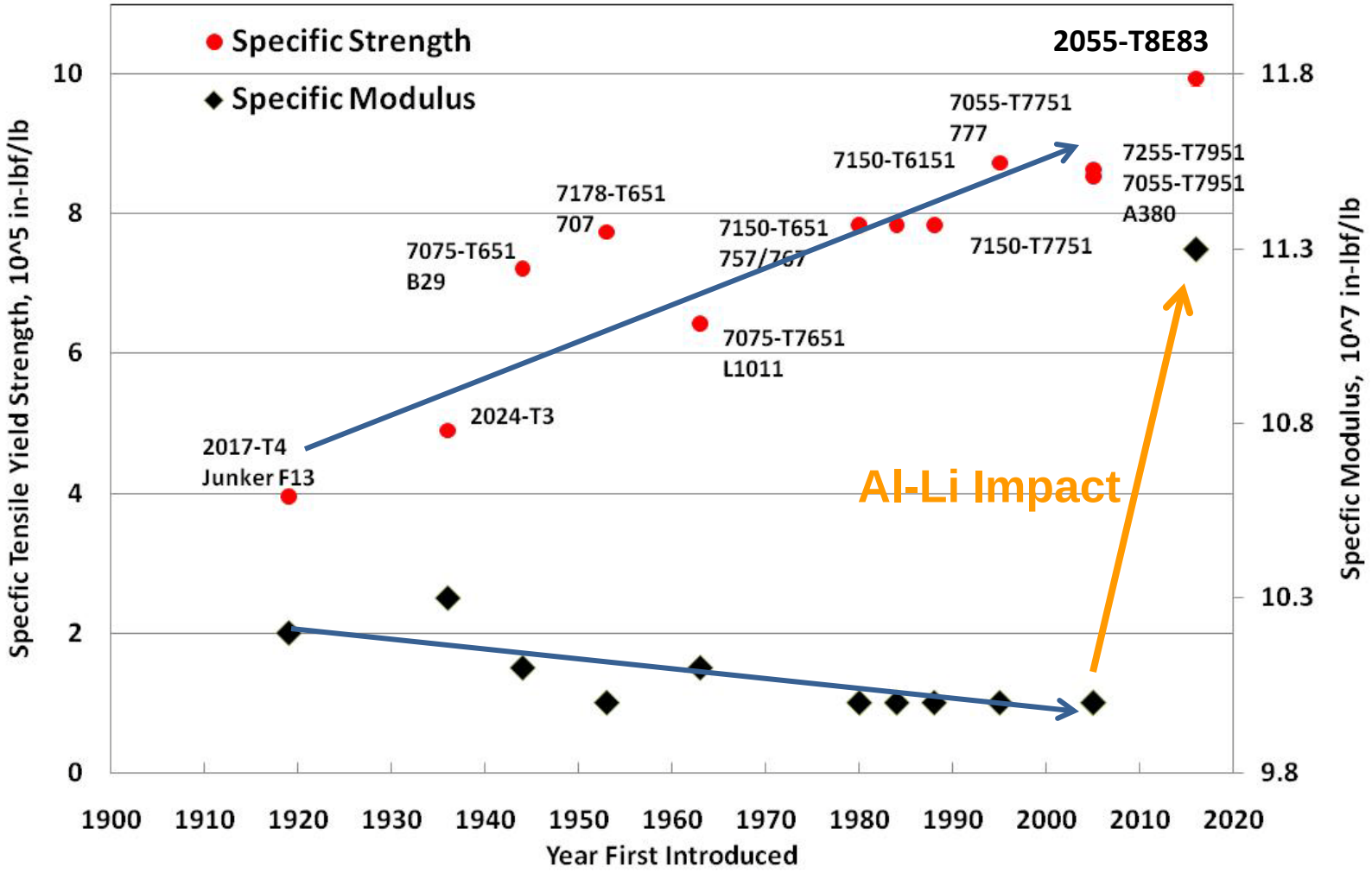
Old Baseline: 2014A-T652 forging, 2618A-T651 plate
New Product: 2040-T62 forging, 2099-T83 extrusions

Green = Commercial

Blue = Under Development

Red = Theoretical

Al-Li Alloys Design Shift



High Strength Advanced Forging Alloys 7255-T74, 7085-T76, & 2040-T6 Property Comparison

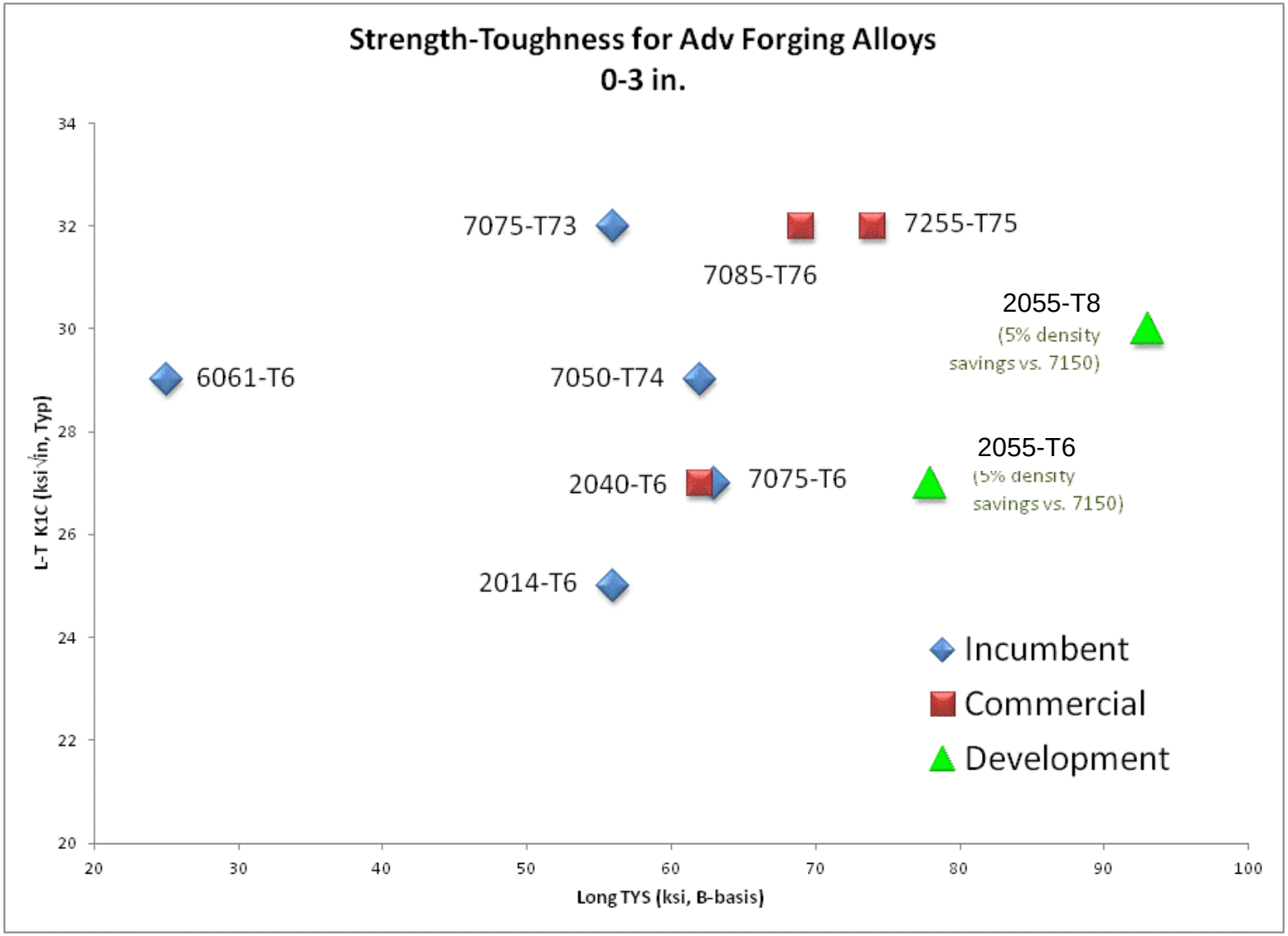
7255-T74, 7085-T76, and 2040-T6 0-3" Die Forging Alloy Property Comparison										
Property Attribute	**2055-T6(TYP)**	**2055-T852(TYP)**	**7255-T75**	**7085-T76**	**2040-T6**	**7075-T6**	**7050-T74**	**7075-T73**	**2014-T6**	**6061-T6**
S-N Fatigue (Smax at 10^7 Cycles)	**na**	**50**	**45**	**45**	**50**	38	35	34	35	28
Longitudinal Ultimate Strength Min, ksi	**83**	**98**	**80**	**74**	**70**	74	72	66	65	38
Transverse (LT) Ultimate Strength Min, ksi	**78**	**93**	**78**	**73**	**67**	71	68	62	64	38
Longitudinal Yield Strength Min, ksi	**78**	**93**	**74**	**69**	**62**	63	62	56	56	25
Transverse (LT) Yield Strength Min, ksi	**73**	**88**	**72**	**66**	**62**	61	56	53	55	25
Longitudinal Percent Elongation Min, in/in	**8**	**7**	**7**	**7**	**6**	7	7	7	6	7
Transverse (LT) Percent Elongation Min, in/in			**6**	**5**	**6**	3	5	3	2	5
Typical L-T Fracture Toughness, KIc, ksi*rt-in	**27**	**30**	**32**	**32**	**27**	27	29	32	25	29
Stress Corrosion Cracking Threshold (ksi)	**in process**	**35**	**35**	**35**	**25**	15	35	42	15	35

High Strength Advanced Forging Alloys 7255-T74, 7085-T76, & 2040-T6 Property Comparison

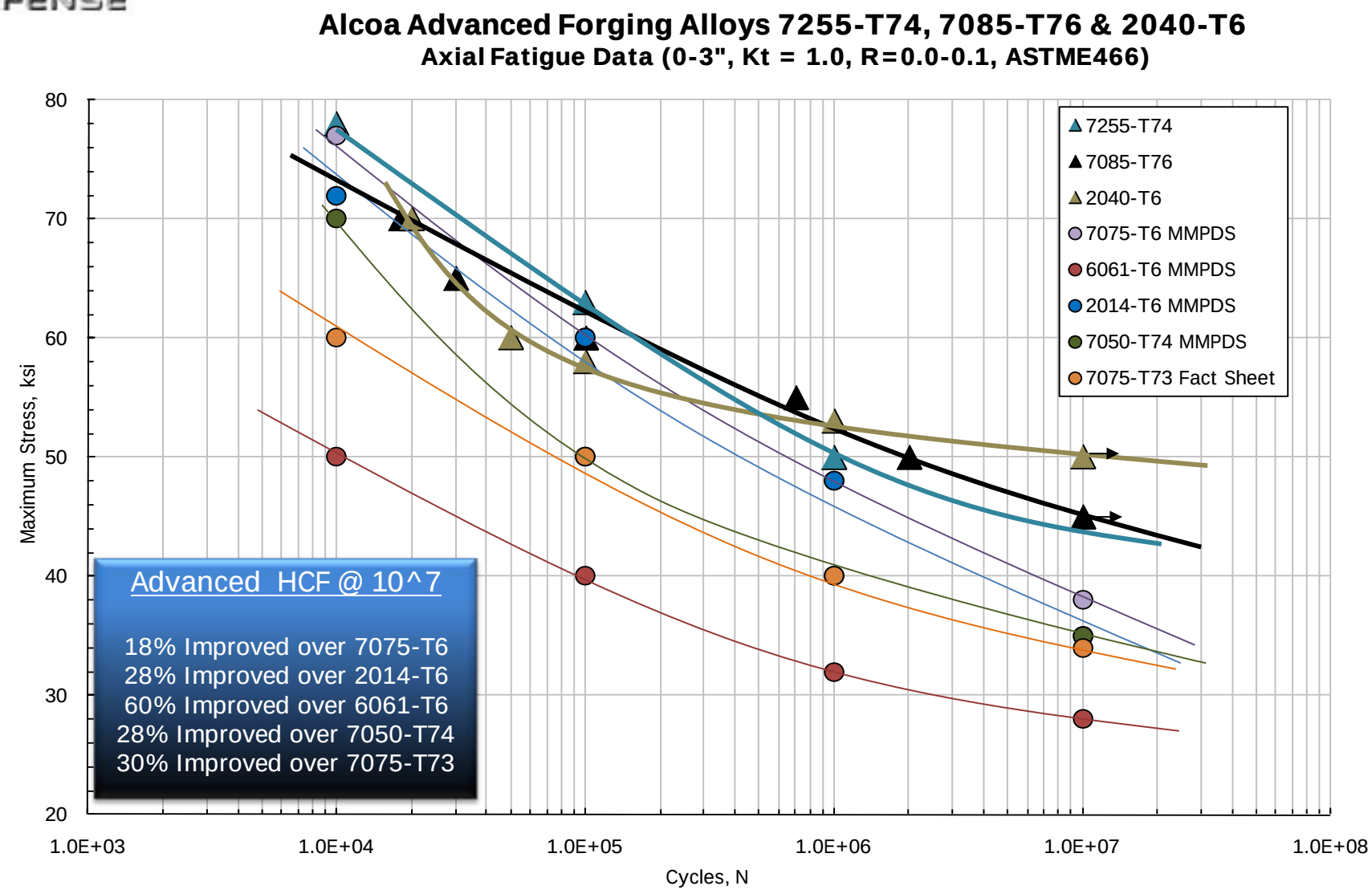
7255-T74, 7085-T76, and 2040-T6 0-3" Die Forging Alloy Property Comparison										
Property Attribute	2055-T6(TYP)	2055-T852(TYP)	7255-T75	7085-T76	2040-T6	7075-T6	7050-T74	7075-T73	2014-T6	6061-T6
S-N Fatigue (Smax at 10^7 Cycles)		32%	18%	18%	32%	--	-8%	-11%	-8%	-26%
Longitudinal Ultimate Strength Min, ksi	12%	32%	8%	0%	-5%	--	-3%	-11%	-12%	-49%
Transverse (LT) Ultimate Strength Min, ksi	10%	31%	10%	3%	-6%	--	-4%	-13%	-10%	-46%
Longitudinal Yield Strength Min, ksi	24%	48%	17%	10%	-2%	--	-2%	-11%	-11%	-60%
Transverse (LT) Yield Strength Min, ksi	20%	44%	18%	8%	2%	--	-8%	-13%	-10%	-59%
Longitudinal Percent Elongation Min, in/in	14%	0%	0%	0%	-14%	--	0%	0%	-14%	0%
Transverse (LT) Percent Elongation Min, in/in			100%	67%	100%	--	67%	0%	-33%	67%
Typical L-T Fracture Toughness, Klc, ksi*rt-in	0%	11%	19%	19%	0%	--	7%	19%	-7%	7%
Stress Corrosion Cracking Threshold (ksi)		133%	133%	133%	67%	--	133%	180%	0%	133%

- **strength**
- **weight/density**
- **modulus**
- **corrosion**

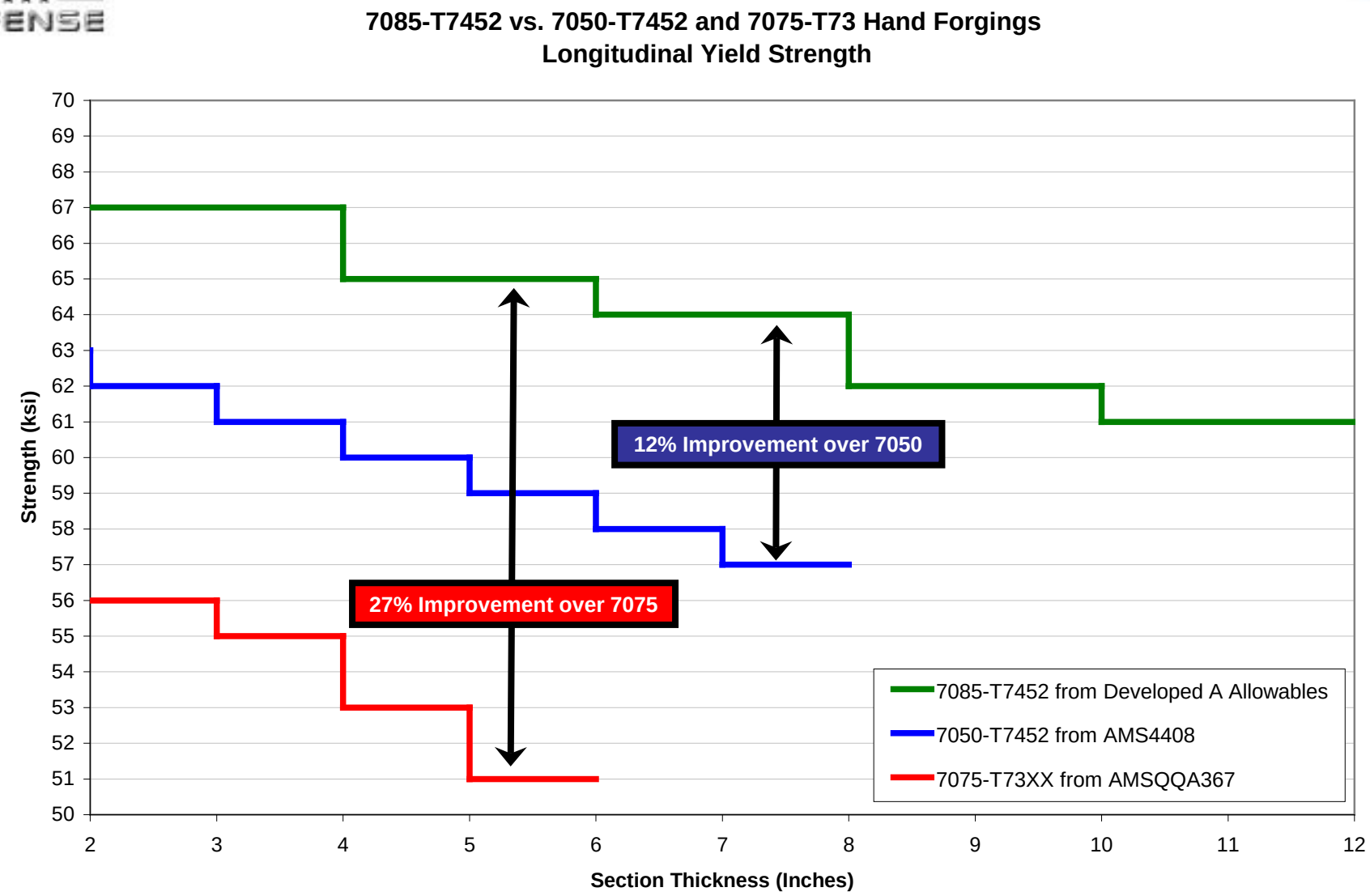
Strength-Toughness for Forging Alloys



High Strength Advanced Forging Alloys 7255-T74, 7085-T76, & 2040-T6 Fatigue Performance



7085-T74511 vs. 7050-T7452 & 7075-T73 Hand forgings



7085 Thick Section Forgings

JSF Bulkhead Forgings

All Highlighted Parts From Alcoa 7085-T7452 Forgings

Army Mortar Base Plates

Armor Wheels

World's Largest Die Forging - 7085

Airbus A380 Inner Front Spar

Airbus A380 Inner Rear Spar

High Strength Extrusion Alloys

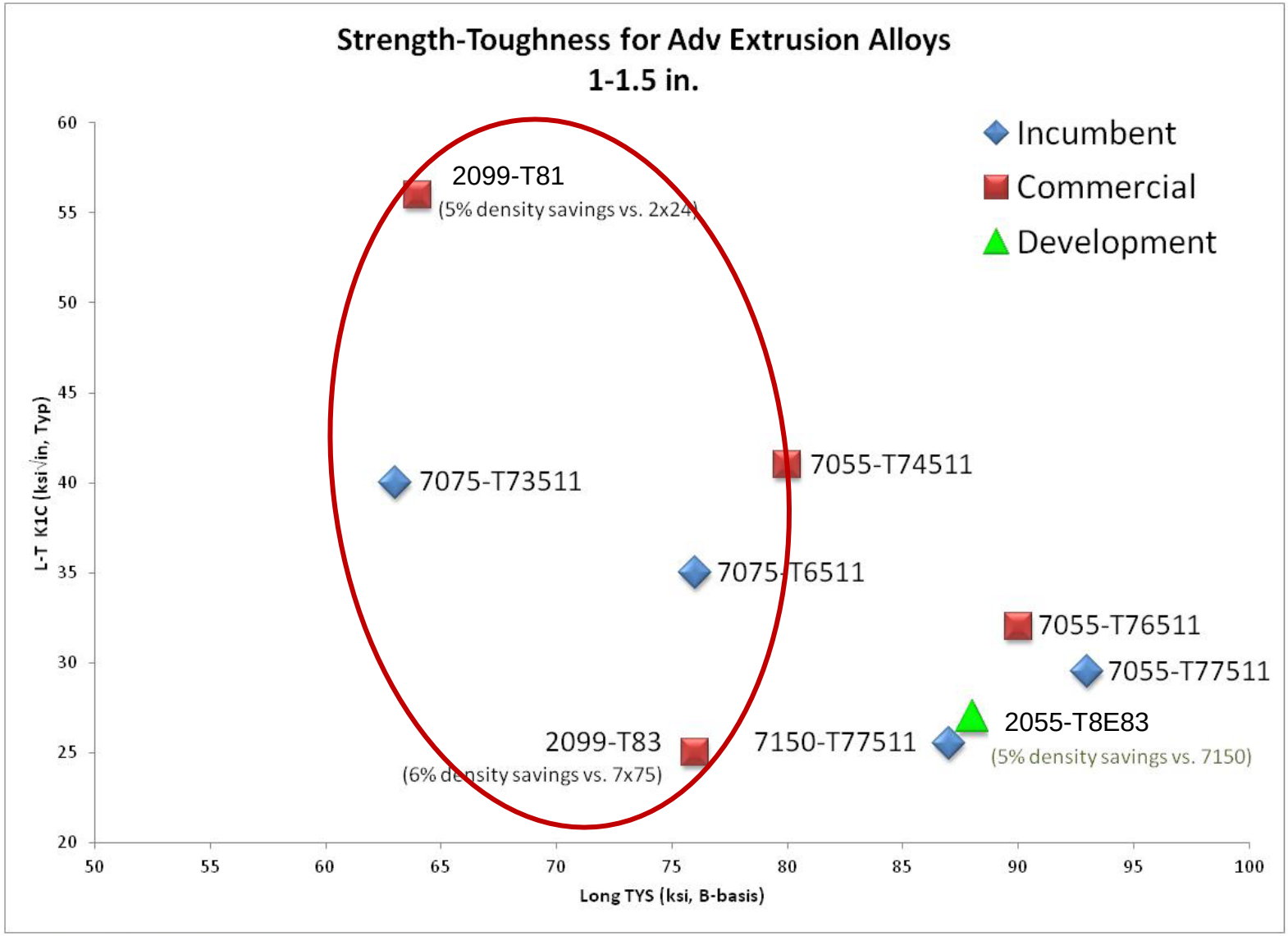
PROPERTY	7075-T6511 Baseline Extrusion	2099-T83 Extrusion	2055-T8E83 Extrusion	7055-T74511 Extrusion	7055-T76511 Extrusion	7055-T77511 Extrusion	C555-T6511 Extrusion	7150-T77511 Extrusion
thickness	0.750-1.499	0.500 - 1.000		0.500 - 3.000	0.500 - 3.000	0.5 - 1.500		0.750 - 2.000
Product Form Available	All Extrusions	All Extrusions	All Extrusions	All Extrusions	All Extrusions	All Extrusions	All	All Extrusions
DENSITY, lbs/in^3	0.101	0.095	0.097	0.103	0.103	0.103	0.103	0.102
Longitudinal Yield Strength Min, ksi	72	71	85	78	86	90	100 (Typ)	84
Longitudinal ULT Strength Min, ksi	81	79	89	85	91	94	98 (Typ)	89
Longitudinal % Elong Min	7	7	7	8	9	9	8 (Typ)	8
Specific Strength, UTS (ksi)/Density (lbs/in^3)	802	832	876	825	883	913	971	873
Longitudinal Transverse Yield Strength (LT) Min, ksi	65	65	70	74	80	84	N/A	78
Longitudinal Transverse Ultimate Strength (LT) Min, ksi	75	73	74	80	85	88	N/A	83
Compression Yield Strength (CYS) Min, ksi	72	69	85	78	88	92	N/A	84
Shear Strength Min, ksi	43	40	N/A	45	47	48	N/A	46
Bearing Ultimate Strength, e/D=1.5 , ksi	113	103	N/A	117	125	128	N/A	123
Bearing Yield Strength, e/D=1.5 , ksi	93	84	N/A	99	106	109	N/A	108
L-T Fracture Toughness , Kic (typical)	27	27	30	35	25	28	N/A	27
Fatigue Life, 10^7, R= 0.1, kt =1.0 , ksi	N/A	53	N/A	45	43	N/A	N/A	N/A
Fatigue Life, 10^5, R= 0.1, kt =1.0 , ksi	N/A	62	N/A	60	65	N/A	N/A	N/A
Elastic Modulus (TENSILE) 1,000 ksi (typical value)	10.4	11.4	11.2	10.3	10.4	10.4	N/A	10.3
Elastic Modulus (COMPRESSION), 1,000 ksi (typical value)	10.7	11.9	11.7	10.7	10.8	11	N/A	10.7
Exfoliation Corrosion (ASTM G34 Worst Case Visual Rating)	ED	EA (Note 1)	EA	EB	EB	EB		EB
Short Transverse SCC, ASTM G47 Threshold, ksi	8	35	35	35	25	15	N/A	25
Specification	AMS-QQ-A-200/11	AMS 4287		AMS 4324	AMS 4336A	AMS 4337		AMS 4345

High Strength Extrusion Alloys

- strength
- weight/density
- modulus
- corrosion

PROPERTY	7075-T6511 Baseline Extrusion	% IMPROVEMENT OVER 7075-T6511						
		2099-T83 Extrusion	2055-T8E83 Extrusion	7055-T74511 Extrusion	7055-T76511 Extrusion	7055-T77511 Extrusion	C555-T6511 Extrusion	7150-T77511 Extrusion
thickness	0.750-1.499							
Product Form Available	All Extrusions							
DENSITY, lbs/in^3	0.101	-5.9%	-4.0%	2.0%	2.0%	2.0%	2.0%	1.0%
Longitudinal Yield Strength Min, ksi	72	-1.4%	18.1%	8.3%	19.4%	25.0%	38.9%	16.7%
Longitudinal ULT Strength Min, ksi	81	-2.5%	9.9%	4.9%	12.3%	16.0%	21.0%	9.9%
Longitudinal % Elong Min	7	0.0%	0.0%	14.3%	28.6%	28.6%	14.3%	14.3%
Specific Strength, UTS (ksi)/Density (lbs/in^3)	802	3.7%	9.3%	2.9%	10.2%	13.8%	21.1%	8.8%
Longitudinal Transverse Yield Strength (LT) Min, ksi	65	0.0%	7.7%	13.8%	23.1%	29.2%	N/A	20.0%
Longitudinal Transverse Ultimate Strength (LT) Min, ksi	75	-2.7%	-1.3%	6.7%	13.3%	17.3%	N/A	10.7%
Compression Yield Strength (CYS) Min, ksi	72	-4.2%	18.1%	8.3%	22.2%	27.8%	N/A	16.7%
Shear Strength Min, ksi	43	-7.0%	N/A	4.7%	9.3%	11.6%	N/A	7.0%
Bearing Ultimate Strength, e/D=1.5 , ksi	113	-8.8%	N/A	3.5%	10.6%	13.3%	N/A	8.8%
Bearing Yield Strength, e/D=1.5 , ksi	93	-9.7%	N/A	6.5%	14.0%	17.2%	N/A	16.1%
L-T Fracture Toughness , Kic (typical)	27	0.0%	11.1%	29.6%	-7.4%	3.7%	N/A	0.0%
Fatigue Life, 10^7, R= 0.1, kt =1.0 , ksi	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fatigue Life, 10^5, R= 0.1, kt =1.0 , ksi	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Elastic Modulus (TENSILE) 1,000 ksi (typical value)	10.4	9.6%	7.7%	-1.0%	0.0%	0.0%	N/A	-1.0%
Elastic Modulus (COMPRESSION), 1,000 ksi (typical value)	10.7	11.2%	9.3%	0.0%	0.9%	2.8%	N/A	0.0%
Exfoliation Corrosion (ASTM G34 Worst Case Visual Rating)	ED							
Short Transverse SCC, ASTM G47 Threshold, ksi	8	337.5%	337.5%	337.5%	212.5%	87.5%	N/A	212.5%
Specification	AMS-QQ-A-200/11							

Strength-Toughness for Extrusion alloys (1 to 1.5 in.)

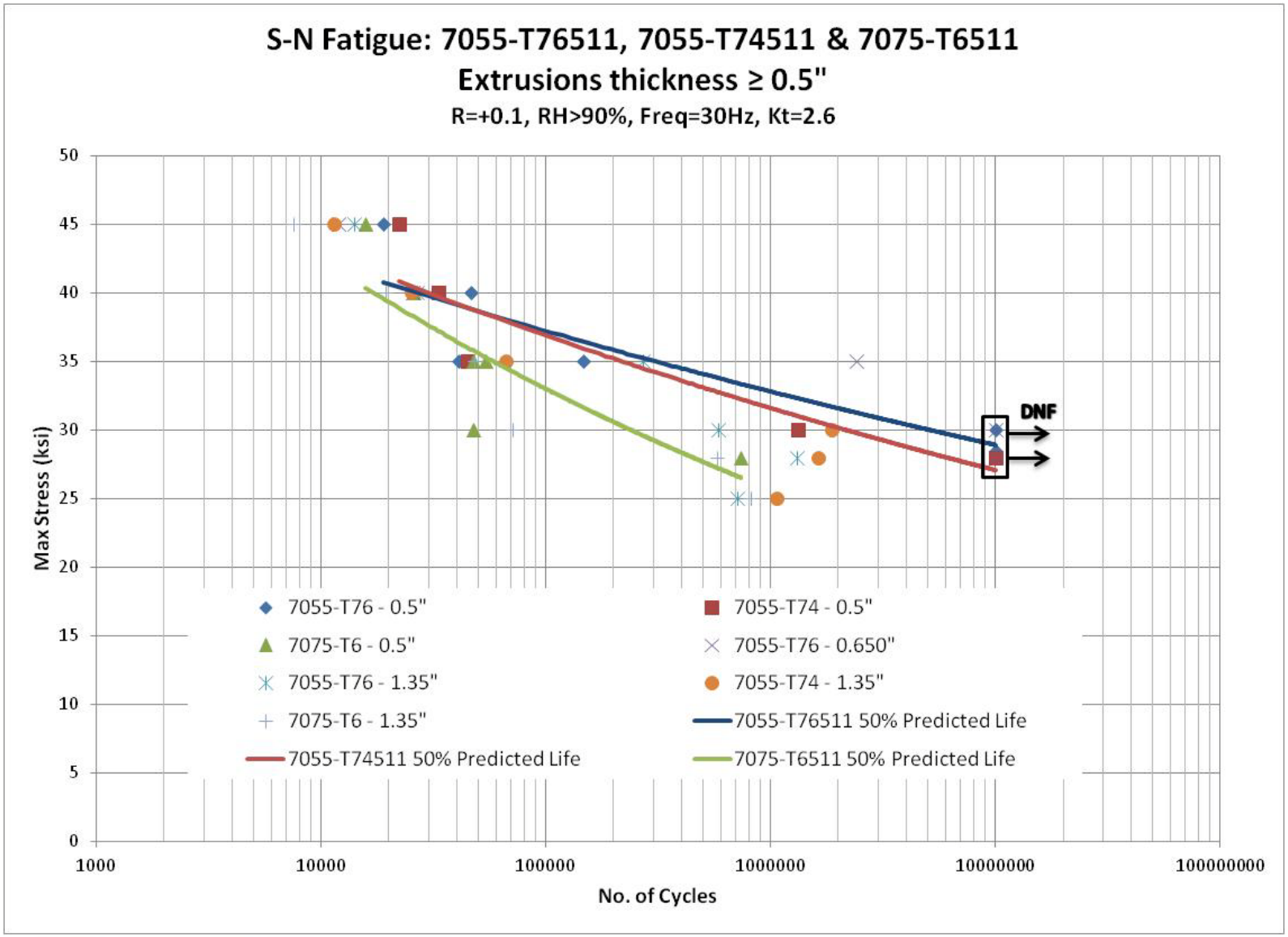


2055 (4th Generation Al-Li) Applications

High Strength Al-Li for 7XXX Replacement

- 2055-T8E83 provides higher compressive yield strength to 7075-T6511 with
  - 4% lower density
  - 25 to 30% improvement in Tensile and Compression Yield Strength
  - 8% improvement in Modulus
- 2055-T8E83 provides equivalent compressive yield strength to 7150-T77511 with
  - 5% lower density
  - 8% improvement in fracture toughness
  - 7% improvement in Modulus
- Improved S-N fatigue
- Superior Corrosion

7055 Extrusion Fatigue



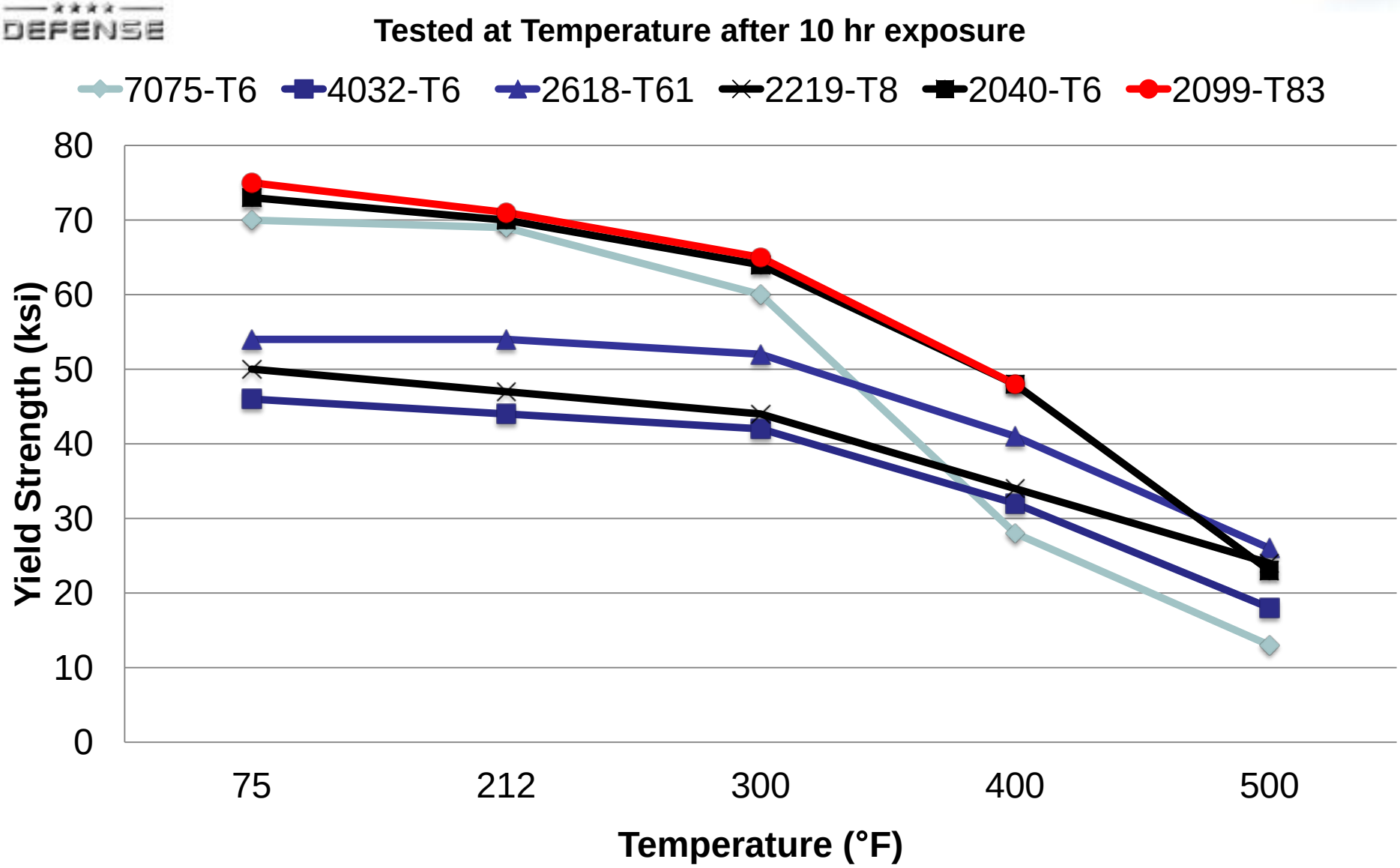
Elevated Temperature Alloys

PROPERTY	ALLOY/TEMPER/ EXTRUSION				
	2618-T61	2219-T8511	4032-T651	2040-T8511	2099-T83
DENSITY, lbs/in^3	0.100	0.103	0.097	0.101	0.095
Longitudinal Yield Strength Min, ksi	46	51	48	62 (est)	71
Longitudinal ULT Strength Min, ksi	57	71	52	70 (est)	79
Longitudinal % Elong Min	7	9	4	5 (est)	7
Specific Strength, UTS (ksi)/Density (lbs/in^3)	570	689	536	693	832
Compression Yield Strength (CYS) Typical ksi	46 (est)				69
Shear Strength (Typical) ksi	38				40
Elastic Modulus (TENSILE) 1,000 ksi (typical value)	10.8	10.7	10.7	10.5	11.9
Exfoliation Corrosion (ASTM G34 Worst Case Visual Rating)					EA (Note 1)
Long Transverse SCC, ASTM G47 Threshold, ksi				25 (est)	35
Specification	AMS-QQ-A-367	ASTM B221	AS&D/ANSI 35.2	N/A	AMS 4287

Elevated Temperature Alloys

PROPERTY	2040-T8511 % IMPROVEMENT OVER BELOW:			2099-T83 % IMPROVEMENT OVER BELOW:		
	2618-T61	2219-T8511	4032-T6	2618-T61	2219-T8511	4032-T6
DENSITY, lbs/in^3	-1.0%	1.9%	-4.1%	-5.0%	-7.8%	-2.1%
Longitudinal Yield Strength Min, ksi	34.8%	21.6%	29.2%	54.3%	39.2%	47.9%
Longitudinal ULT Strength Min, ksi	52.2%	37.3%	45.8%	38.6%	11.3%	51.9%
Longitudinal % Elong Min	-28.6%	-44.4%	25.0%	0.0%	-22.2%	75.0%
Specific Strength, UTS (ksi)/Density (lbs/in^3)	21.6%	0.5%	29.3%	45.9%	20.6%	55.1%
Compression Yield Strength (CYS) Typical ksi	NA			50.0%		
Shear Strength (Typical) ksi	NA			5.3%		
Elastic Modulus (TENSILE) 1,000 ksi (typical value)	-2.8%	-1.9%	-1.9%	10.2%	11.2%	11.2%
Exfoliation Corrosion (ASTM G34 Worst Case Visual Rating)						
Long Transverse SCC, ASTM G47 Threshold, ksi						
Specification						

Elevated Temperature Performance

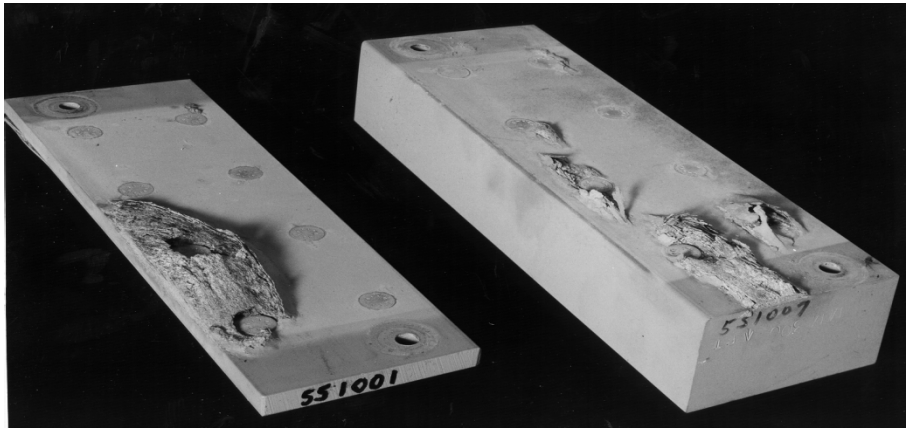


7055 -T74 & -T76 Tempers Guarantee EXCO Rating EB or Better

7055-T74 (EB) 7075-T6 (ED)

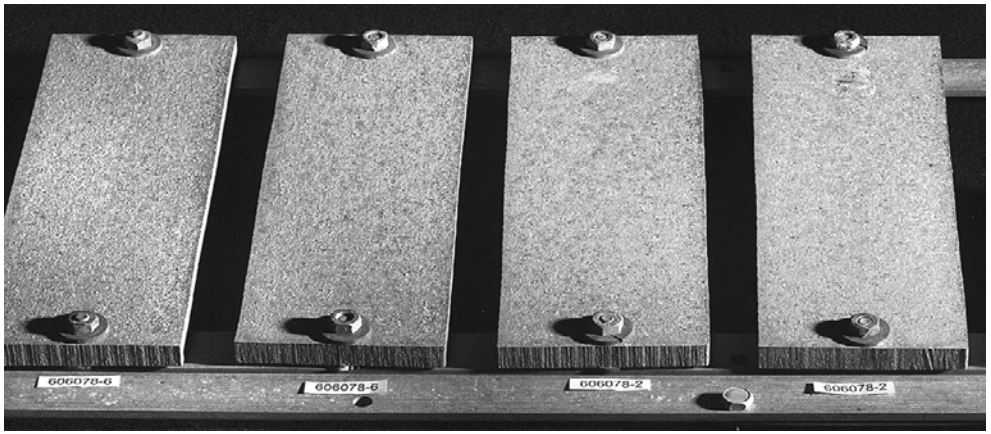
Exposure panels of 7055-T74 (A) and 7075-T6 (B) taken from mid-thickness (t/2 plane) in 0.5-inch extrusions after 1 year of exposure at Sea Coast (Pt. Judith, RI).

2099 Corrosion Resistance



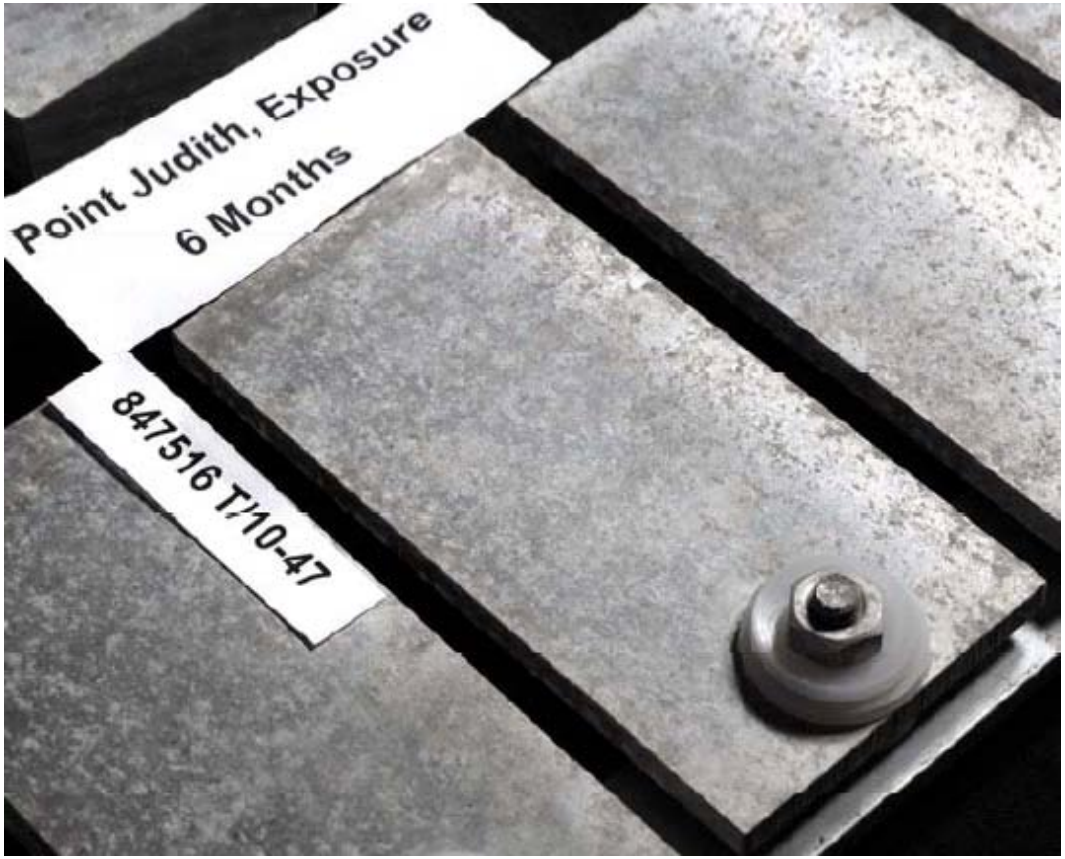
7150-T6511 specimens coated and fastened and exposed at seacoast for 4 years. Severe exfoliation propagated from coating defects.

Al-Li 2099-type plate with no coating exposed at seacoast for 20 years. No exfoliation occurred.



Corrosion resistance is a key property and is considered “up front” in recent alloy development.

2055-T8E83 Corrosion Resistance



Al-Li High Strength extrusions show no corrosion in seacoast exposure for over 6 months.

SCC testing up to 35 ksi has no failures in 90 days.
Long term testing at Point Judith site greater than 425 days with no failures.

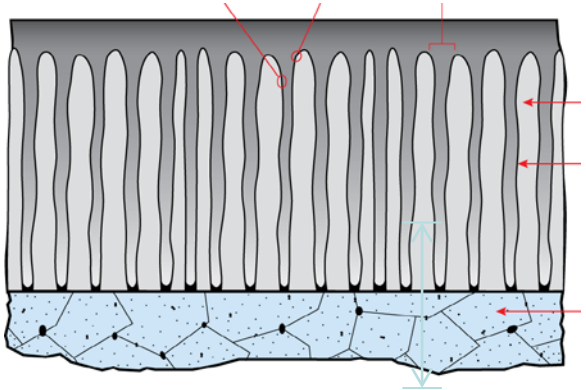
NanoOxide™ - AFE Technology

Background:

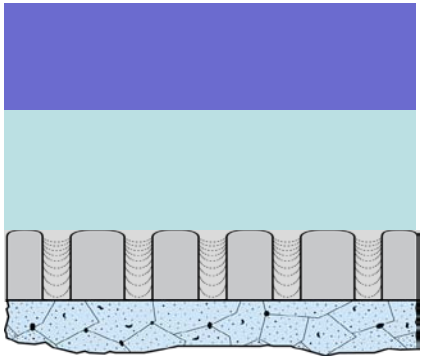
- Airline wheel maintenance an issue
  - Labor intensive
  - Paint stripping
  - Rework cost
- Wheel finishing operations involve chemicals and solvents that require special handling

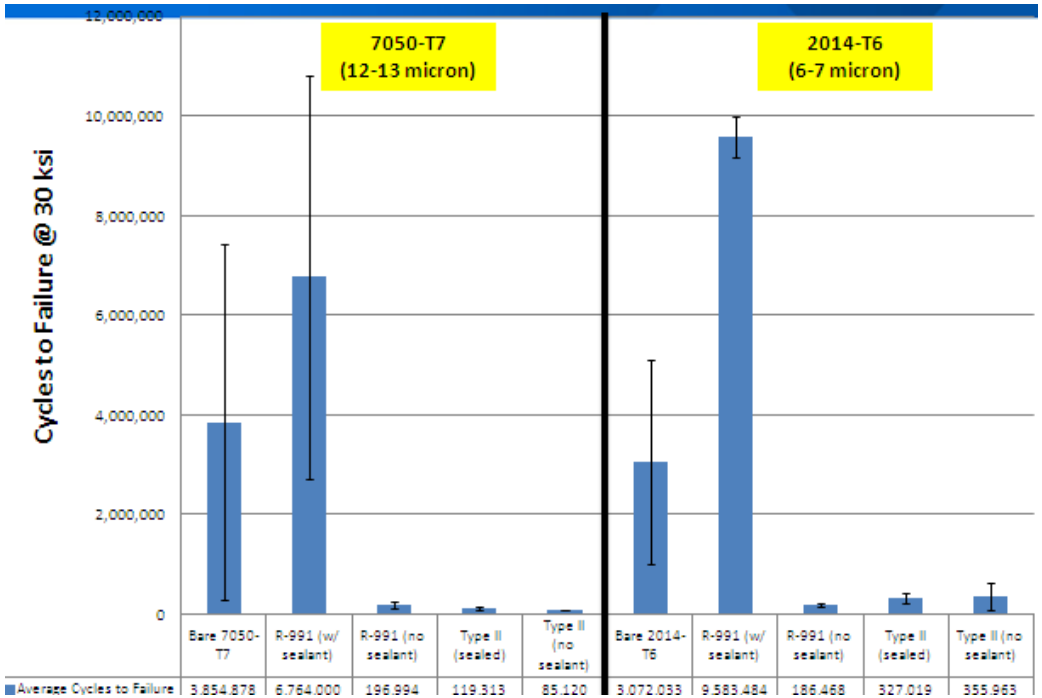
Objective:

- Develop surface treatment to address performance, maintenance, and environmental issues with current process
- Ability to implement utilizing current manufacturing flow path



VS.





NanoOxide™ Corrosion Testing
B117 Salt Spray Testing-1000 hrs

NanoOxide™

NanoOxide™ treated wheel

Conventional Anodizing

Type II Anodize Control Wheel (not painted)

Other Coatings

- Synergistic Coatings
  - Harder-than-steel, permenantly dry-lubricated aluminum surfaces
  - Resists corrosion, abrasion, and galling
  - Outwear and outperform case-hardened steel, stainless steel and chrome plated parts

- Plasma Electrolytic Oxidation (PEO)
  - Electrical current passed through bath of proprietary electrolyte solution, converting surface into a hard yet flexible ceramic
  - Extremely fine scale surface connected porosity enables absorption and retention of liquid lubricants
  - Ideally suited for lubricated wear applications while still providing high corrosion resistance

- Hollow Cathode Plasma Immersion Ion Processing (HCPIIP)
  - Extremely hard, smooth coating for applications requiring corrosion, wear and erosion resistance, longer service life, improved flow performance, reduced operating costs and more…

Summary

- Alloy Development Timeline
- Range of Aluminum Alloys depending on design drivers
  - High Fatigue Forging Alloys
  - High Strength Extrusion Alloys
  - Elevated Temperature Alloys
- Corrosion Resistance
- Coatings

Travis Schmidt

Application Engineer

Lafayette Operations
Lafayette, IN

Cell: (765)237-2619
Office: (765)771-3073
Travis.Schmidt@alcoa.com