The Vacuum Heat Treatment of Titanium Alloys for Commercial Airframes

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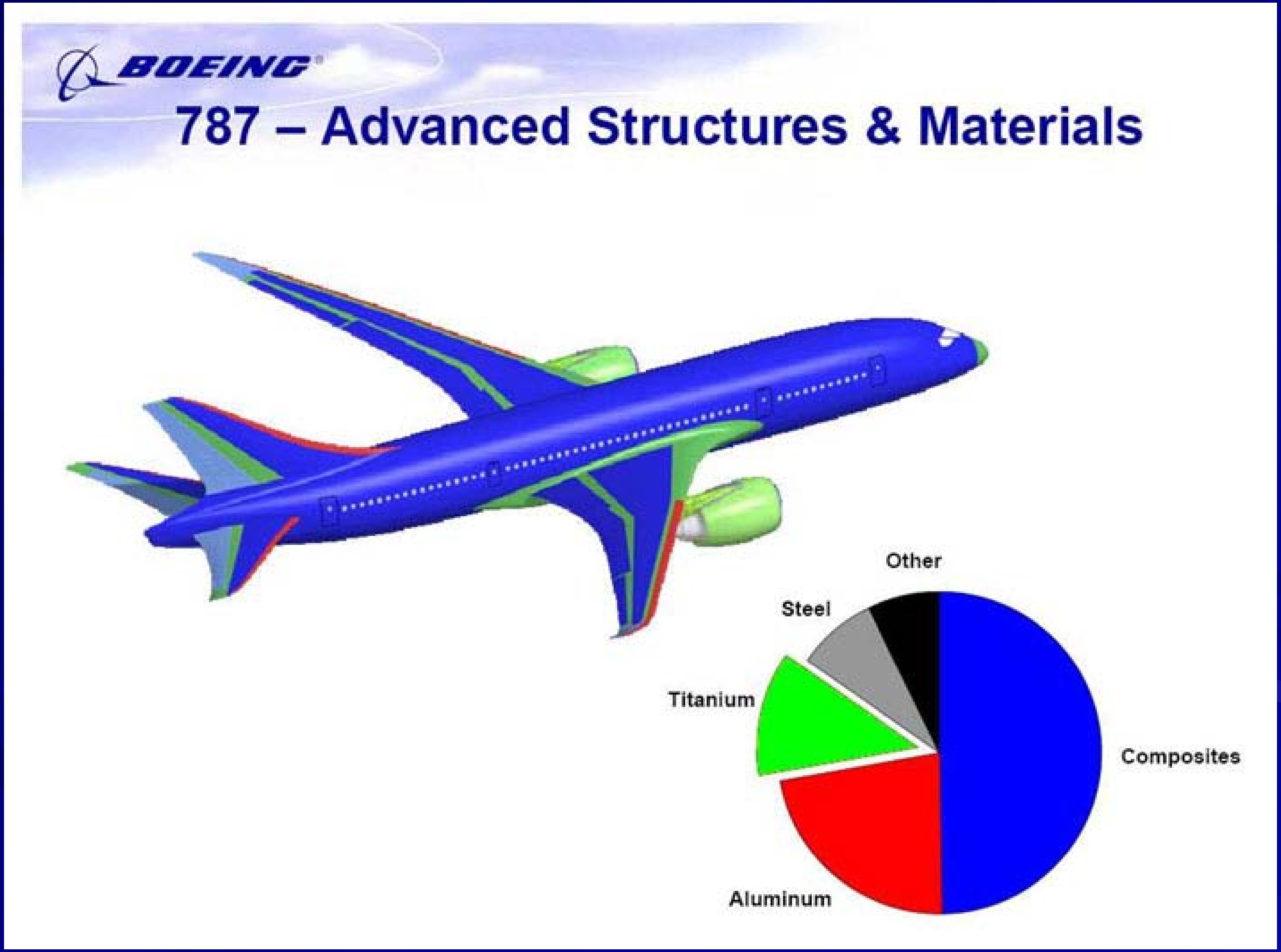
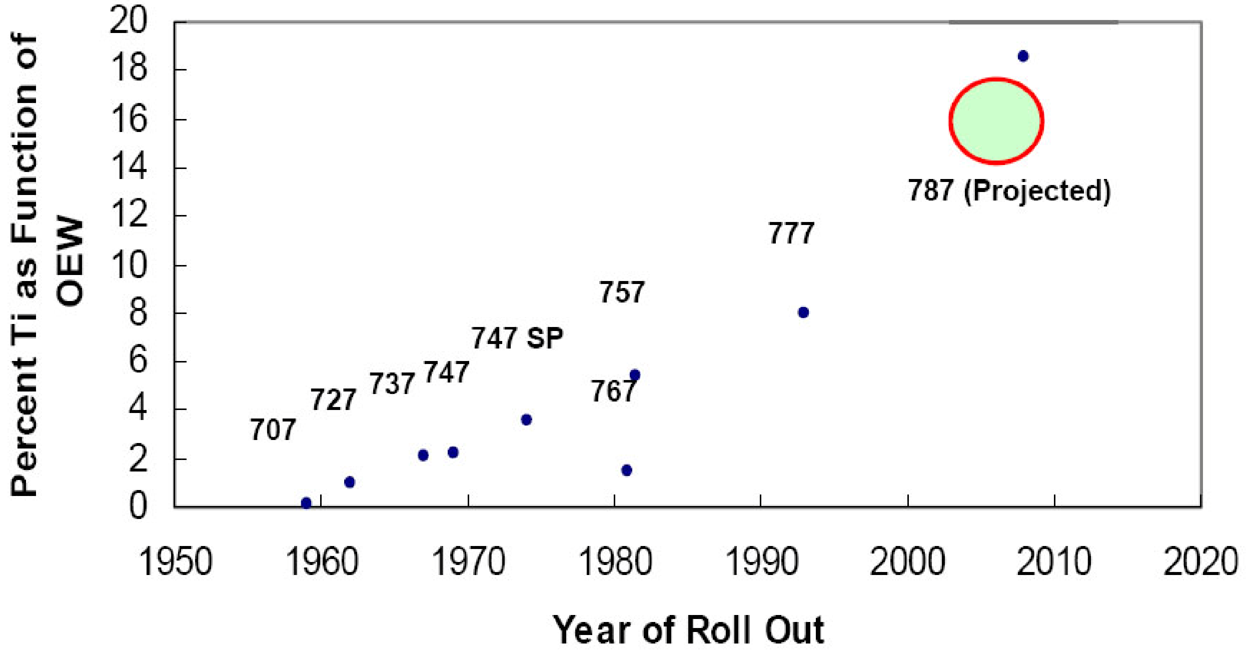
Titanium Growth In Airframes



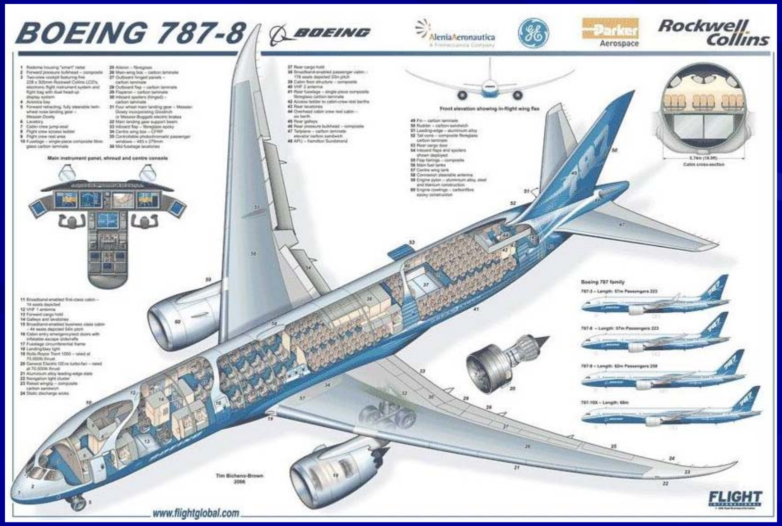
Titanium Growth In Airframes

Ti Usage in Aircraft Has Been Increasing



- Military Aircraft 9% (F-4) to 35% on Current Aircraft

Without Proper Heat Treating, Specific Metallurgical & Particular Dimensions Cannot be Attained



Specifications For Heat Treating Titanium

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ORIGINAL ISSUE: 11-SEP-1959	REV: (R) 04-OCT-1999 (T) 30-MAR-2007	
Authorizing Signatures on File	**HEAT TREATMENT OF TITANIUM AND TITANIUM ALLOYS**	**BAC5613**
	BOEING PROCESS SPECIFICATION	PAGE 1 of 27

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PROBLEM: Specifications often fail to recognize that titanium is an exotic material requiring exotic heat treating techniques!

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SAE Aerospace An SAE International Group	**AEROSPACE MATERIAL SPECIFICATION**	**SAE AMS-H-81200**	**REV. C**
		Issued 2001-04 Revised 2010-02 Superseding AMS-H-81200B	
Heat Treatment of Titanium and Titanium Alloys			

Titanium Specification Shortfall #1

PROBLEM: We need thermal processing of titanium which enhances near net shapes

TABLE 2 - Solution Heat Treatments

Alloy	Set Temperature °F	Set Temperature °C	Minimum Soaking Time Minutes (3)(5)	Quench (2)(8)
6Al-4V sheet	1725 (6)	941 (6)	15	water or polymer
6Al-4V ELI	1725 (6)	941 (6)	15	water or polymer
6Al-4V other	1750 (6)(7)	954 (6)	15	water or polymer
6Al-6V-2Sn	1625	885	20	water or polymer
13V-11Cr-3Al	1400	760	60	(1)
3Al-8V-6Cr-4Mo-4Zr	1500	816	30	(1)
10V-2Fe-3A1 (4)	Beta-50	Beta-28	60	(1)
15V-3Cr-3Al-3Sn	1450	788	30	(1)
6Al-2Sn-4Zr-2Mo	1770	966	60	(1)
8Al-1Mo-1V	1825	996	60	(1)
6Al-2Sn-4Zr-6Mo	1600	871	60	(1)

(1) a. For thicknesses under 0.5 inch (12.7 mm) - Air cool or faster.
b. For thicknesses from 0.5 to 2 inches (12.7 to 51 mm) - Air, oil, polymer, or water except (1) air shall not be used for 8Al-1Mo-1V or 6Al-2Sn-4Zr-2Mo and (2) air shall not be used for forgings of 13V-11Cr-3Al, 3Al-8V-6Cr-4Mo-4Zr, or 15V-3Cr-3Al-3Sn.
c. For thicknesses over 2 inches (51 mm) - Water.

(2) Inert gas back-fill may be substituted for air cool in vacuum and inert atmosphere furnaces.

(3) Soaking times (See 8.2.10) shown are for parts up to 0.10 inch (2.5 mm) thick. For thicknesses up to 1 inch (25 mm), add 1 minute to

- What are the exact rates of cooling needed for air, oil, polymer, or water quenching methods

We Need Cooling Rates…

Inert Gas Pressure Quench (Continued)

(4) The time for the center of the thermocoupled bar to cool from the austenitizing temperature to 400 F shall be in accordance with Table XIII.

TABLE XIII INERT GAS PRESSURE QUENCH PRODUCTION REQUIREMENT

---	---	MAXIMUM EQUIVALENT ROUND SECTION THICKNESS AT TIME OF HEAT TREATMENT, DIA. (INCH)		
		0.75	1.50	4.00
Minimum Quench Pressure (bar)	4340M	0.8	1.8	6.0
	4330M	1.8	N/A	N/A
	9Ni–4Co–0.30C	0.8	1.8	N/A
Time for surface of parts to cool from austenitizing temperature to 400 F (minutes) **FL 1 FL 7**	4340M	< 10	< 9	**FL 2**
	4330M	< 9	N/A	N/A
	9Ni–4Co–0.30C	< 10	< 9	N/A

BAC 5617

Properties obtained with Minimal Distortion

Titanium Specification Shortfall #2

PROBLEM: Assumes alpha case is a given & lacks uniform methods to help minimize or eliminate the oxygen rich layer

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6.3 THERMAL TREATING ATMOSPHERES ALLOWED

6.3.1 AIR

Air atmospheres shall be ambient air which is heated to the thermal treating temperature. When steel heat treating furnaces are used for titanium, the residual steel heat treating atmosphere shall be thoroughly purged from the furnace and a positive means of preventing leakage of gas from the steel heat treat atmosphere generator to the working zone of the furnace shall be provided. Also, before these furnaces are used, Quality Assurance shall certify that the purge cycle is adequate so that hydrogen pick-up is not excessive. Hydrogen pick-up test procedures are found in Section 12.1.

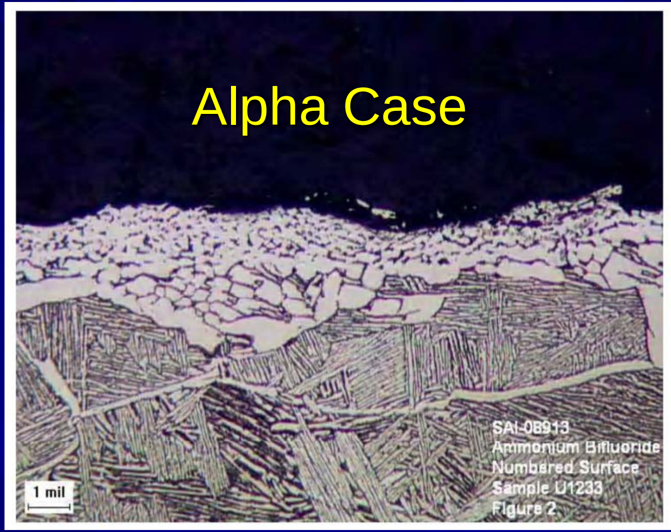
6.3.2 INERT GAS

Use an inert gas atmosphere for parts which can not be descaled after thermal treating above 1000 F, and for parts which are required to have a bright finish after thermal treating. Inert gasses conforming to the requirements of Section 5b.. or Section 5c.. shall be used for all parts of the thermal cycle including heating and cooling.

6.3.3 VACUUM

Vacuum furnaces or retorts may be used as a substitute for an inert gas atmosphere. The maximum pressure in the retort or furnace shall be 1 X 10-4 torr.

To Minimize Alpha Case…

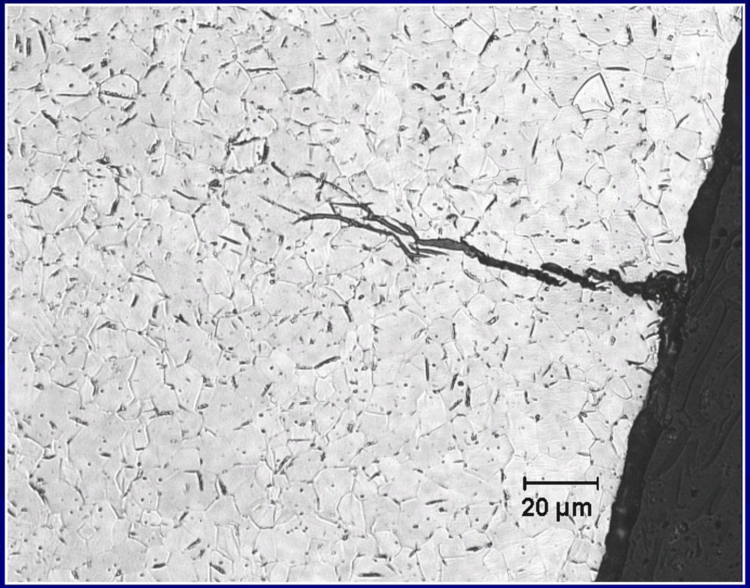


- Must process in vacuum atmospheres only
- More precise pre-cleaning methods
- Define bake out frequencies or requirements (furnace and / or fixturing)
- Employ the use of pre-holds for vacuum levels with slower heating rates. All of the specifications refer to minimum vacuum levels at temperature
- Acknowledge that multiple argon sweeps during pump down and prior to heating helps eliminate alpha case

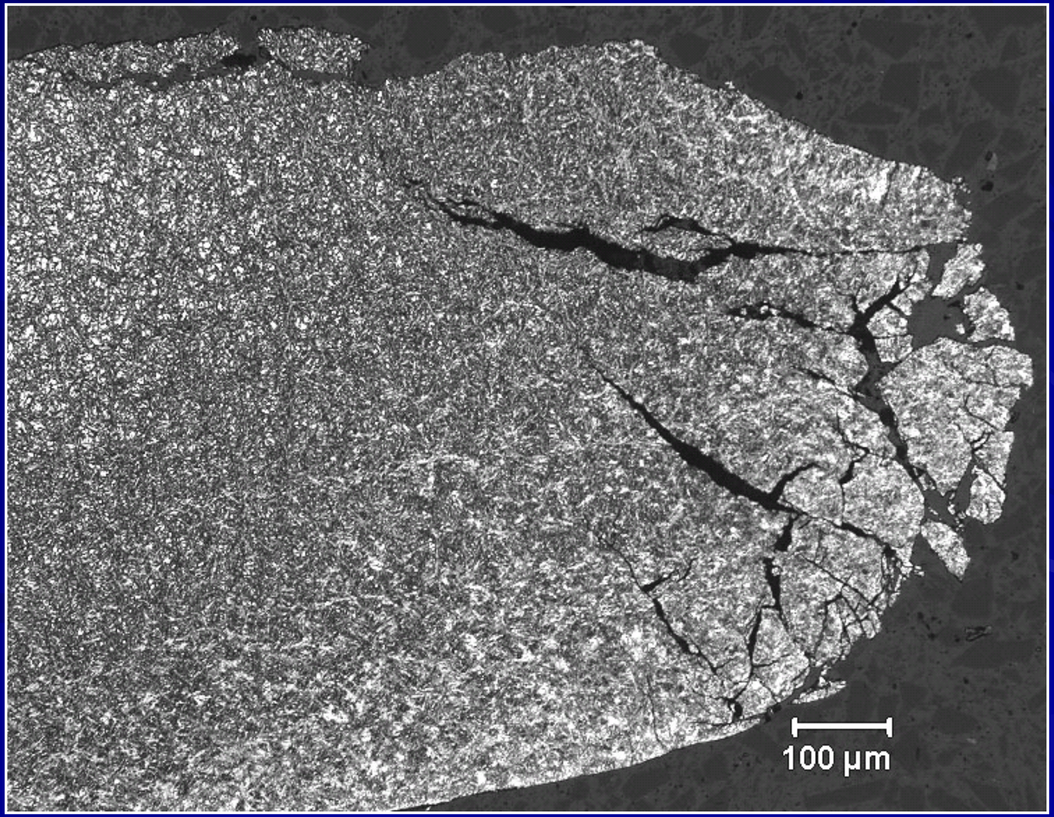
Titanium Specification Shortfall #3

PROBLEM: Hydrogen pick up verification for all thermal processes must be better defined

- A maximum level PPM of hydrogen must be specified



Images from TIMET



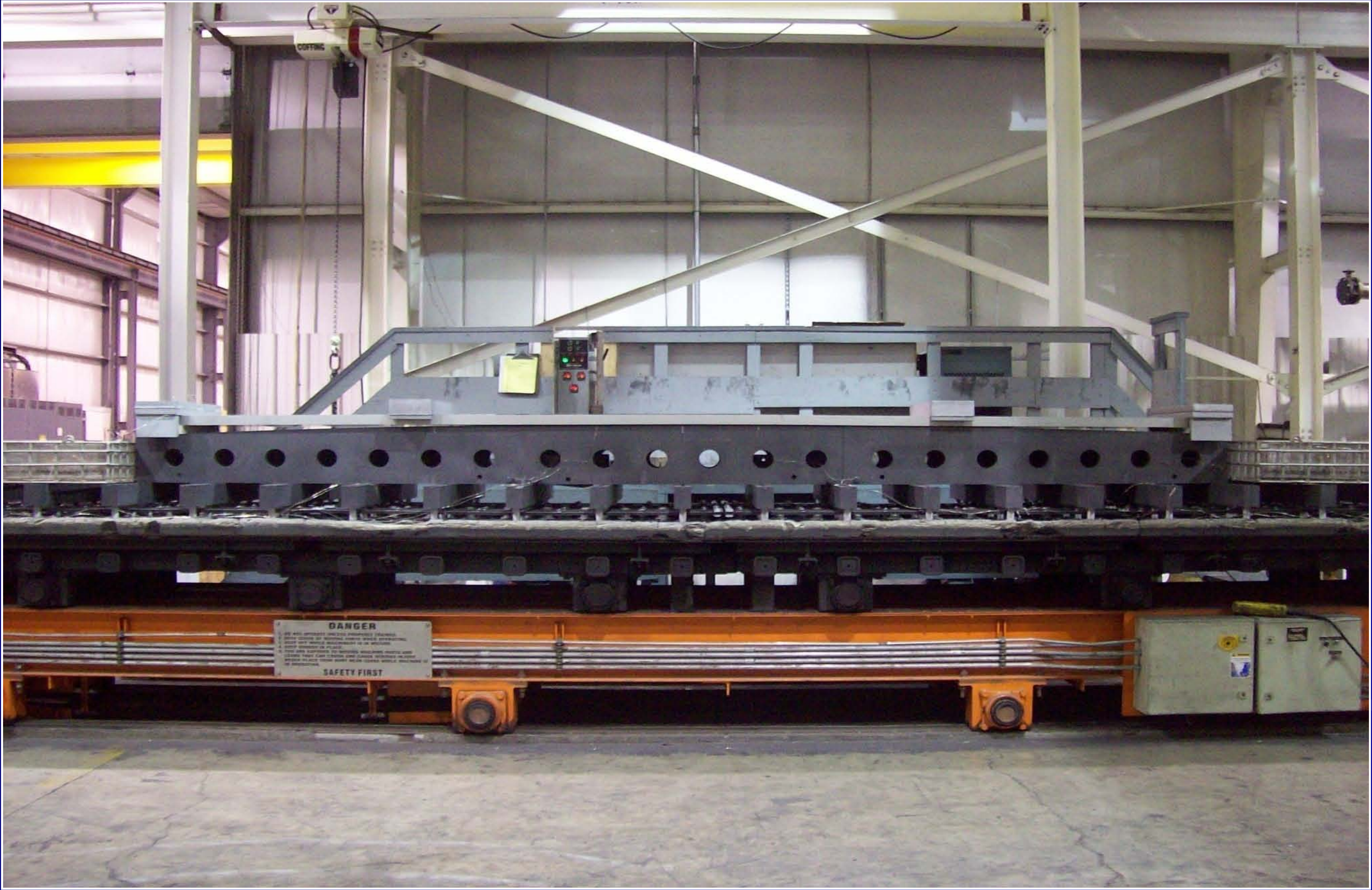
Titanium Specification Shortfall #4

PROBLEM: Specifications do not address how to minimize distortion, more specifically to utilize GRAPHITE

- Graphite has excellent heat transfer characteristics
- CTE of graphite is extremely close to the CTE of titanium
- Graphite remains dimensionally stable even after repeated cycling
- Graphite is easily machined to hold tight tolerances and hold intricate shapes

Dimensional Stability

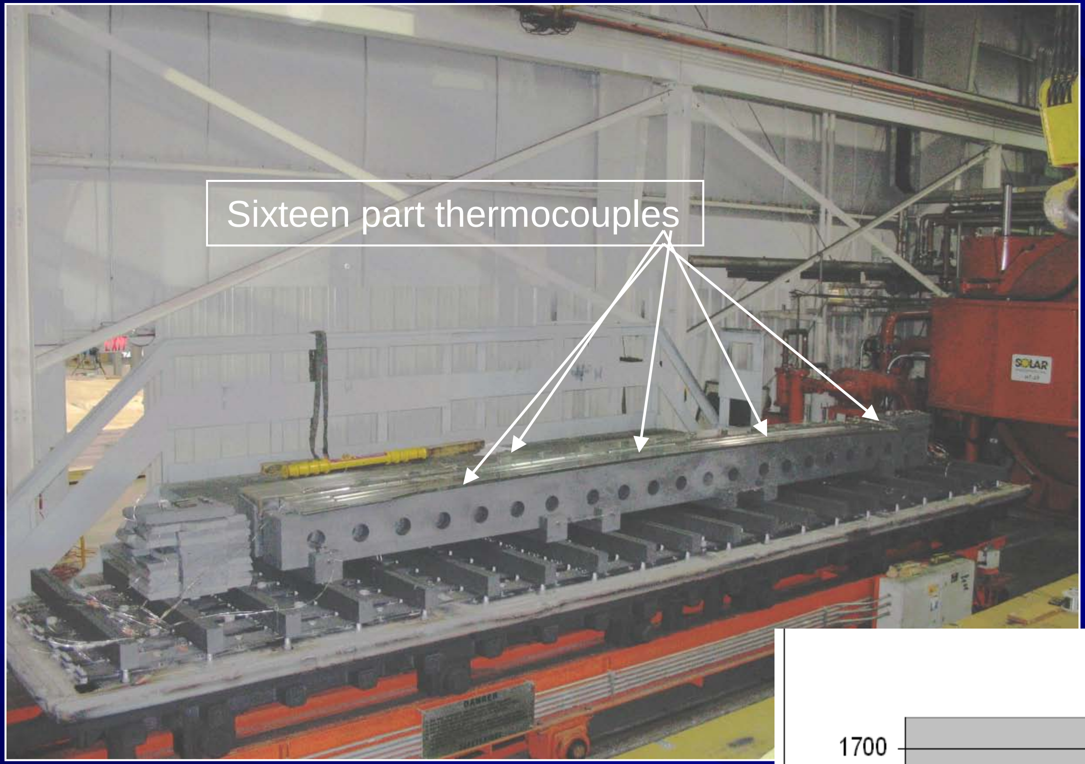
Vacuum Creep Forming

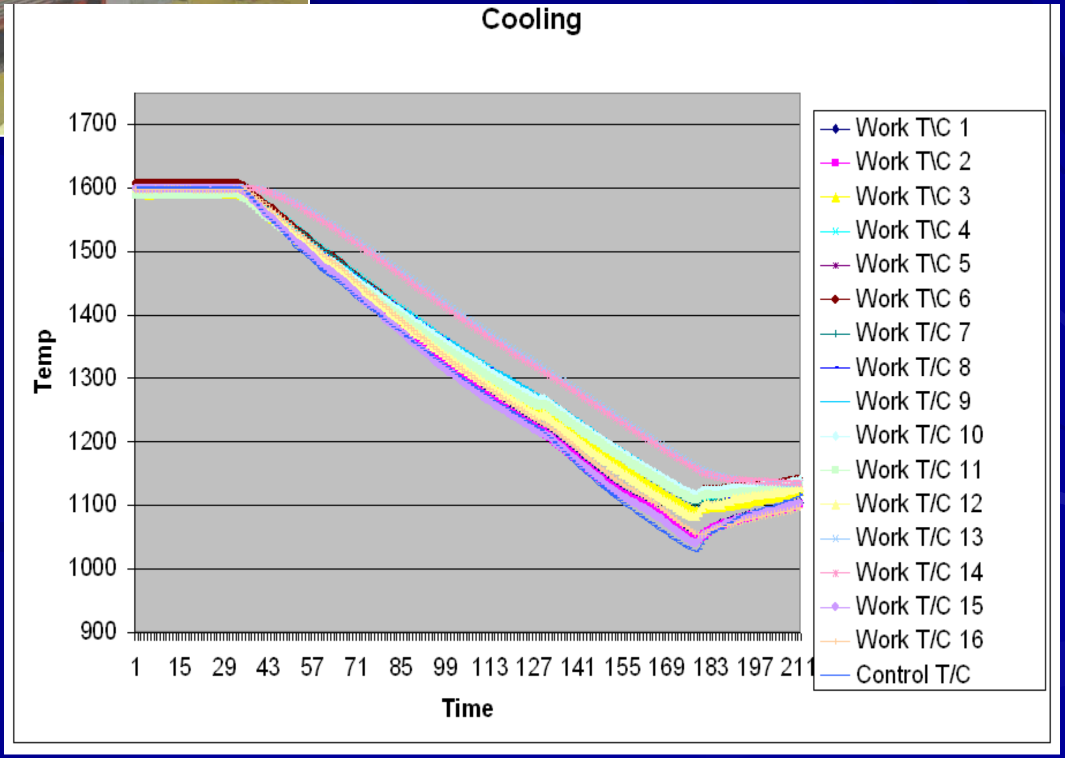


Titanium Specification Shortfall #5

PROBLEM: Specifications do not clearly define and differentiate between work and control thermocouples & their individual intricacies

- This is most imperative for innovative materials such as the near beta alloy Ti 5553 which are more hardenable with superior strength combined with high fracture toughness and excellent high cycle fatigue when compared to Ti 6Al4V
- BASCA thermal treatments ultimately allows for nearer net shapes therefore better buy: fly ratios


Sixteen part thermocouples


Cooling
Temp
1700
1600
1500
1400
1300
1200
1100
1000
900
1 15 29 43 57 71 85 99 113 127 141 155 169 183 197 211
Time
Work T\C 1
Work T\C 2
Work T\C 3
Work T\C 4
Work T\C 5
Work T\C 6
Work T/C 7
Work T/C 8
Work T/C 9
Work T/C 10
Work T/C 11
Work T/C 12
Work T/C 13
Work T/C 14
Work T/C 15
Work T/C 16
Control T/C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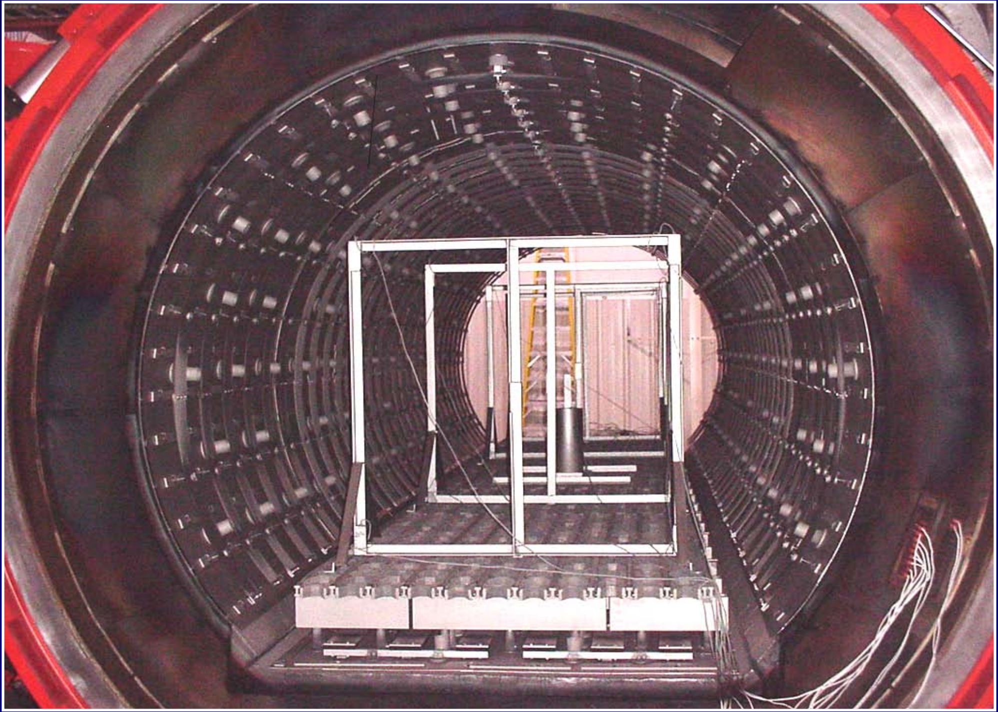
Temperature Uniformity Survey



700°F +3.13°F / -2.99°F
1000°F +5.37°F / -0°F
1200°F +3.02°F / -1.29°F
1500°F +3.58°F / -2.29°F
1800°F +4.75°F / -1.38°F
2000°F +4.82°F / -2.3°F

25 WORK THERMOCOUPLES

The Future of Vacuum Processing Titanium

- Titanium Metallurgists must interact with SAE / AMEC / Boeing committees to assist and update titanium heat treat specifications

Thank You