The Role of Loading Rate in Creep Properties of Ti-834

PURDUE UNIVERSITY
School of Materials Engineering

Hannah Doyle, Hugh Grennan, Dane Moebius, Tyler Muller, Madeline Schroeder
Faculty Advisors: Kevin Trumble and Michael Titus
Industrial Sponsors: Andrew Hinshaw, Kim Blastic, Haydn Schroader

Howmet Aerospace certifies the mechanical properties of superalloy components for jet engines through creep and hot tensile testing. In performing 100-hour creep tests on Ti-834 using newly installed creep frames from ATS, Howmet observed elevated creep in these samples compared to historic results. Our group investigated possible material and testing factors could contribute to the observed behavior, including; load rate, stress, temperature, and processing. Load-and-hold and creep testing was conducted to test hypothesis for various contributors allow for elimination of load rate, stress, and temperature as possible factors. The group also provided recommendations of additional areas that would be possible contributors to the observed creep behavior.

This work is sponsored by Howmet Aerospace, Whitehall, MI

HOWMET AEROSPACE

Project Background

- Standard creep testing, defined by ASTM E139, measures strain with time “at and following the instant” of application of the full stress.
- Prior to the onset of the test, some amount of creep strain develops in the sample during loading.
- Many older, SATEC-brand machines used by Howmet apply load manually via weights over about 1-2 minutes. (Fig. 1)
- ATS-brand machines use an automated hot-step loading sequence to reach full load in 8-10 minutes. (Fig. 1)

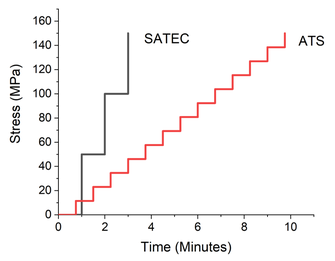

Figure 1: *Schematic loading schedules for each machine.*

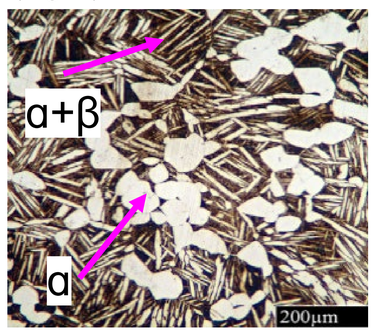

Figure 2: *The microstructure of Ti-834 is composed of lamellar α+ β, and primary α’ [1].*

- Ti-6Al-4Sn-42r-1Nb or Ti-834 is a near α alloy designed for creep resistance
  - 15% equiaxed α in α+β, matrix (Fig. 2)
- Typically solution treated (1293K, 2 hr) and aged (973K, 2hr)
- Formed by hot ring rolling, used for compressor rings
- Certification testing samples came from same ingots
- Ti-834 typically has a 100-hour creep strain of 0.082% at 600°C and 150 MPa
- Primary creep appears to be occurring during loading in tandem with elastic deformation, which is not measured in standard creep tests and causes discrepancies in results.
- We hypothesize that slower loading rates give more time for primary creep to occur, leading to an increase in primary creep strain overall.
- Our goal is to recommend best creep testing practices to Howmet which resolve the discrepancies between their machines.

Observational Data

- For Ti-834 certification at Howmet, samples must not exceed 0.2% strain within 100-hour creep test (Fig. 3)
- Two out of the three new test were performed or the same machine and thermocouple

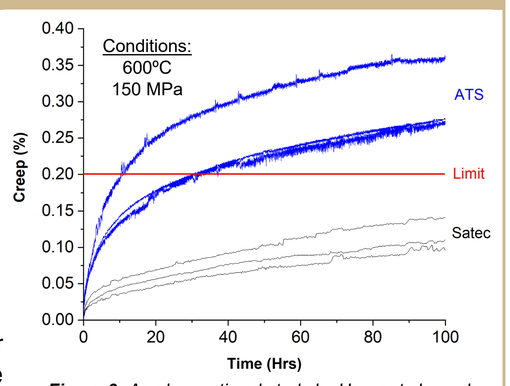

Figure 3: *An observational study by Howmet showed that creep tests performed on Ti-834 on their new ATS machines had a tendency to not conform to requirements compared to on their existing SATEC machines*

- Ti-834 creep samples tended to exceed 0.2% strain and fail on ATS machines, while tests performed on older SATEC machines passed

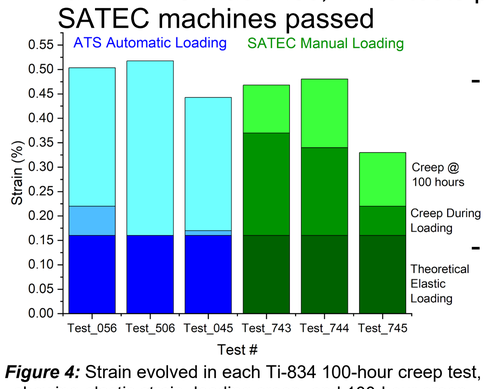

Figure 4: Strain evolved in each Ti-834 100-hour creep test, showing elastic strain, loading creep, and 100-hour creep.

- Based on theoretical elastic strain, manually loaded tests appear to creep more while loading
- The total strain during loading and holding appear to be equal (Fig. 4)
- Based on these initial results, we sought to create an experimental setup that isolated loading rate to observe its effect on creep behavior

Experimental Design

Load-and-hold Testing: controlled load rate to identify any corresponding changes in creep response

- Performed on UHMWPE as a model at room temperature, where conditions are shown below:

Condition #	Total Load	Load Rate	Hold Time
1	1.6 ksi ~11 MPa	100 lb/min	15 minutes
2	1.6 ksi ~11 MPa	20 lb/min	15 minutes

- Similarly, load-and-hold tests performed on Ti-834 under conditions shown below:

Trial #	Temperature	Total Load	Time to Load	Hold Time
1-2	1112 ºF (600 ºC)	22 ksi ~150 MPa	30 seconds	30 minutes
3-4	1112 ºF (600 ºC)	22 ksi ~150 MPa	5 minutes (300 s)	30 minutes
5-6	1112 ºF (600 ºC)	22 ksi ~150 MPa	10 minutes (600 s)	30 minutes

100-hour Creep Testing: eliminating variables affecting creep

- Set of tests were run on Purdue’s ATS creep frame to replicate the load profiles seen on Howmet’s ATS frame
- Set of tests were run at increased load (166 MPa and 188 MPa) to test the extent to which stress impacts primary creep response

Results and Discussion

UHMWPE Load-and-Hold

- Fig. 5, the “bands” represent the ranges of creep curves for each loading rate
- UHMWPE samples loaded faster exhibited greater creep response, contradicting our hypothesis, but validating the load-and-hold procedure

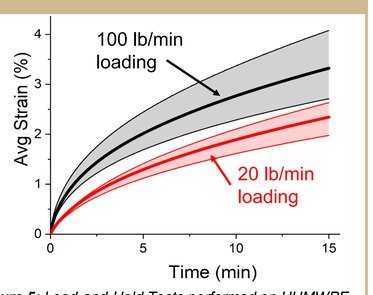

Figure 5: *Load-and-Hold Tests performed on UHMWPE, showing the strain response during holding once full load is reached.*

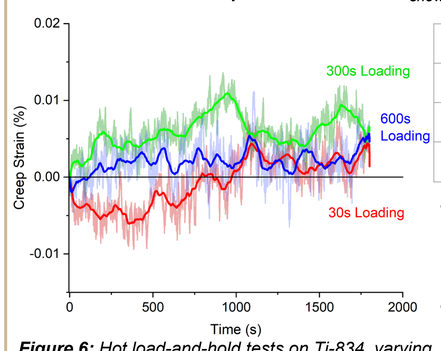

Figure 6: *Hot load-and-hold tests on Ti-834, varying force application rate.*

Test Method	% creep in 0.5h
Load-and-Hold	0.005
ATS Creep	0.038
SATEC Creep	0.015

- Load-and-hold results showed minimal creep in 30 minutes (Fig. 6)
- May be attributed to using a strain gauge with insufficient sensitivity

Creep Test Loading Profiles

- No evident change in creep response due to load rate
- Creep may be affected by loading profile on creep frame
- Loading profiles (Fig. 7) determined by extracting load values while ramping stress
- Each loading “step” is a combination of 2-3 smaller increments
- Samples sometimes are held at penultimate load before the test

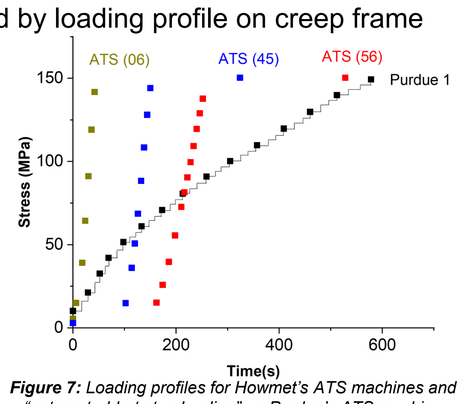

Figure 7: *Loading profiles for Howmet’s ATS machines and “automated-hot step loading” on Purdue’s ATS machine*

- Creep response may be affected by these anomalies identified in Fig. 7

Purdue Creep Curves

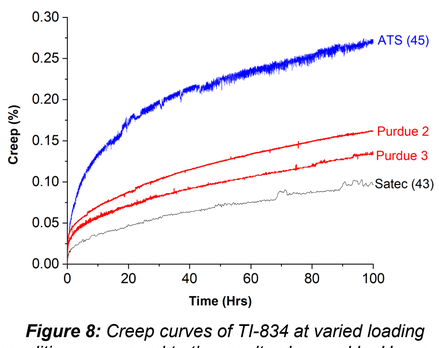

Figure 8: *Creep curves of TI-834 at varied loading conditions compared to the results observed by Howmet.*

- Fig. 8, Purdue tests had ~40-50% reduction in total creep compared to the Howmet ATS machine
- Varying load application method did not influence creep response

Discussion and Analysis

- The power law creep rate is given by,

$$\dot{\varepsilon} = A\sigma^n \exp\left(-\frac{E}{RT}\right)$$

where n is the power-law exponent, and E is activation energy

- Application of higher stress than intended by the ATS test machine could result in the higher observed creep
- Two literature values for n were found giving 188 MPa and 166 MPa to achieve a sufficiently high creep rate [3]
- 188 MPa (25% stress increase from standard testing) still did not replicate the phenomenon (Fig. 9)

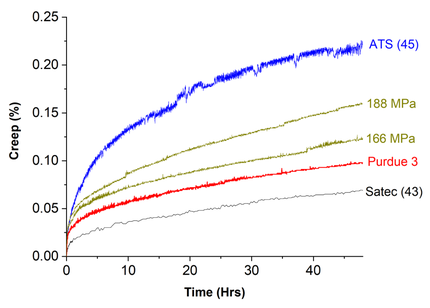

Figure 9: *Creep curves of Ti-834 at varied held stresses*

- A stress error of 25% was determined to be highly unlikely given calibration procedures.

Table 1: *Elemental Composition Percentages Ti-834 [4]*

Ti-834 Composition Chart		
Element	Weight %	
	Min	Max
Aluminum	5.5	6.1
Tin	3	5
Zirconium	3	5
Niobium	0.5	1
Molybdenum	0.25	0.75
Silicon	0.2	0.6
Carbon	0.04	0.08
Iron	-	0.05
Oxygen	0.075	0.15
Nitrogen	-	0.03
Hydrogen	-	0.006
Residual Elements, each	-	0.05
Residual Elements, total	-	0.2
Titanium	Remainder	

- Trace impurities of iron in Ti-834 affect transient creep strain [3]
- Increased concentrations of iron allows for quicker attainment of steady state due to formation of a high number of interstitial vacancy pairs [3]
- Variation of iron composition (0-.05%) between samples could be a contributor to creep variation
- Recommend Howmet compare creep results to iron content

Conclusions & Recommendations

- We eliminated several factors that may have caused the discrepancy in Howmet’s data:
  - Not loading rate/load application dependent
    - UHMWPE load-and-hold response is contradictory to Howmet’s initial ATS data
    - Load-and-hold tests on Ti-834 did not exhibit significant differences dependent on load rate
    - Creep tests performed in ATS frame at Purdue showed similar behavior to original SATEC machines
  - Not stress dependent
    - Creep tests at notably higher stresses still had lower creep response compared to original ATS results
  - Likely not temperature dependent
- Recommend investigation of possible equipment or software control contributor
- Recommend over-check of other possible material contributors such as heat treatment, composition etc.

Acknowledgements

- Andrew Hinshaw, Kim Blastic, and Haydn Schroader from Howmet Aerospace for support, samples, and guidance
- Tom Mann for running and supporting creep tests at Purdue
- Jenni Fifer for additional training and help with equipment

References

1. Abdallah, Z., Perkins, K., & Williams, S., Advances in the Wilshire extrapolation technique—full creep curve representation for the aerospace alloy titanium 834., 2012
2. Meyers, M. A., & Chawla, K. K., *Mechanical behavior of materials*. Cambridge University Press, 2009
3. Gollapudi, S., Satyanarayana, D. V. V., Phaniraj, C., & Nandy, T. K., *Transient creep in titanium alloys: Effect of stress, temperature and trace element concentration.*, 2012
4. *High strength, high temperature, creep resistant alloy - timet*. TIMETAL 834. (n.d.)