Summary of Ti64 MAT_224 V1.3 Logarithmic Input Decks

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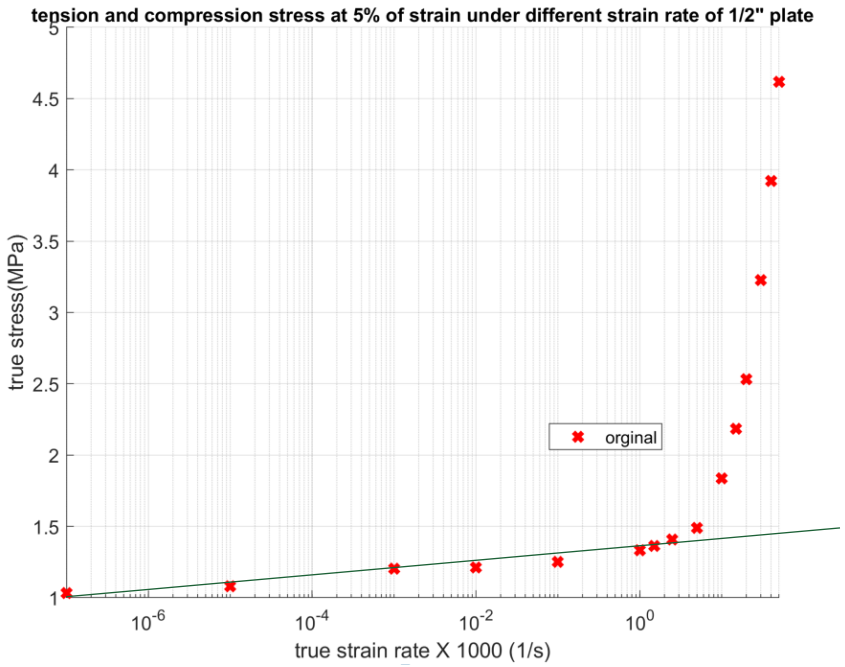
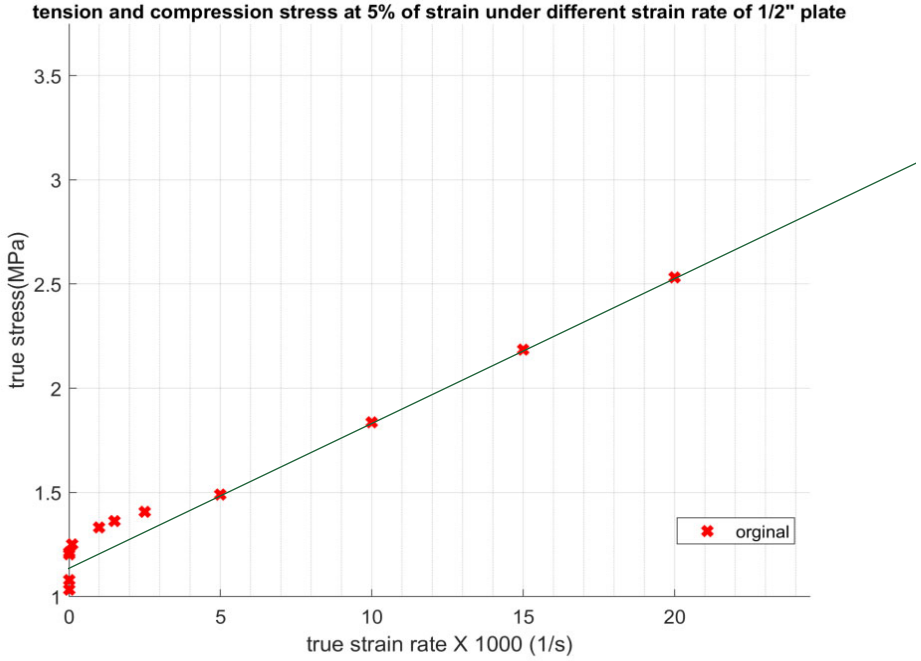
Ti64 MAT_224 with Logarithmic Input (V1.3)

Purpose:

- Standardize FAA model MAT224 input parameter format
  - Increase density of rate dependent hardening curves to reduce version dependency
- Utilize logarithmic input method
- Reduce LCINT from 1E6 to 1000 for fast simulation
- Achieve the same result as original 0.5” *MAT_224 with linear input (v1.2)

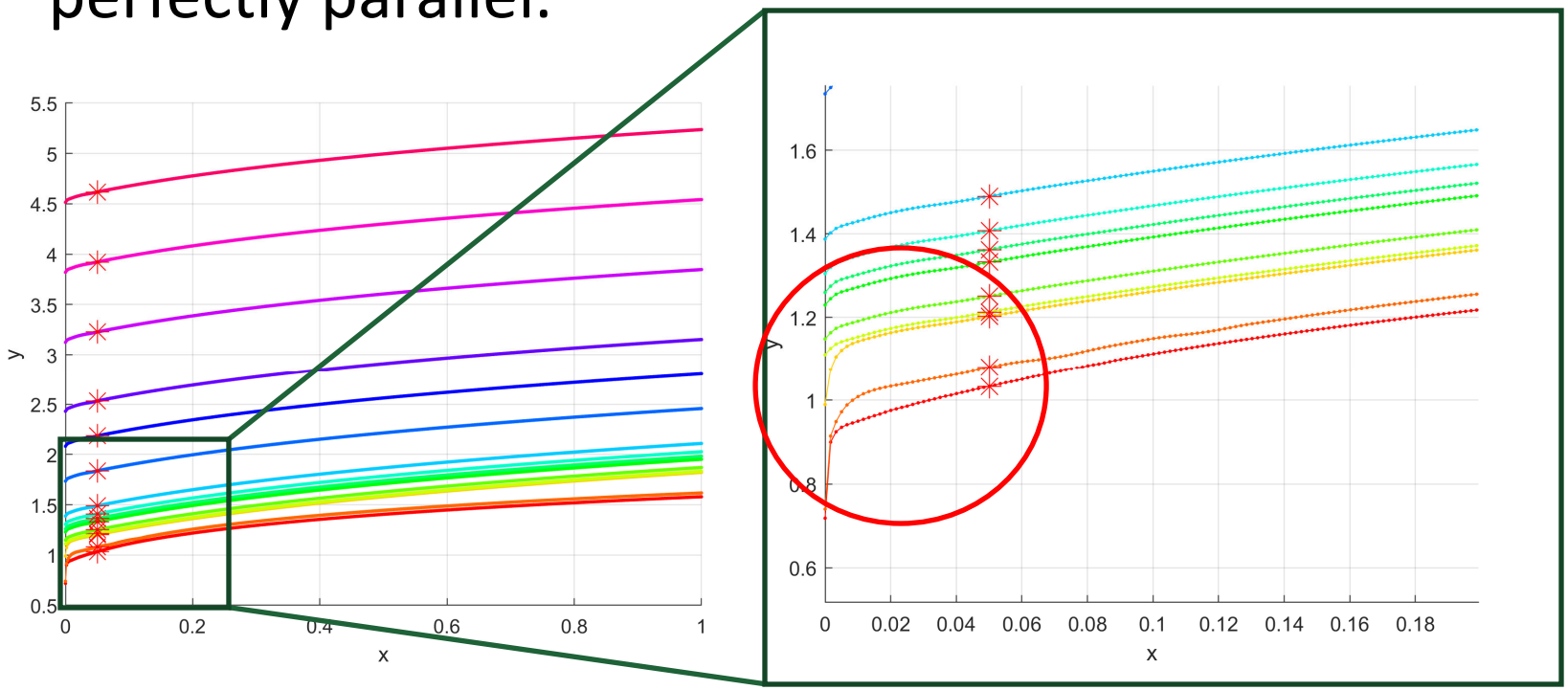
The stress at 5% strain for linear scale and natural logarithmic scale





Hardening Curve Augmentation Methodology

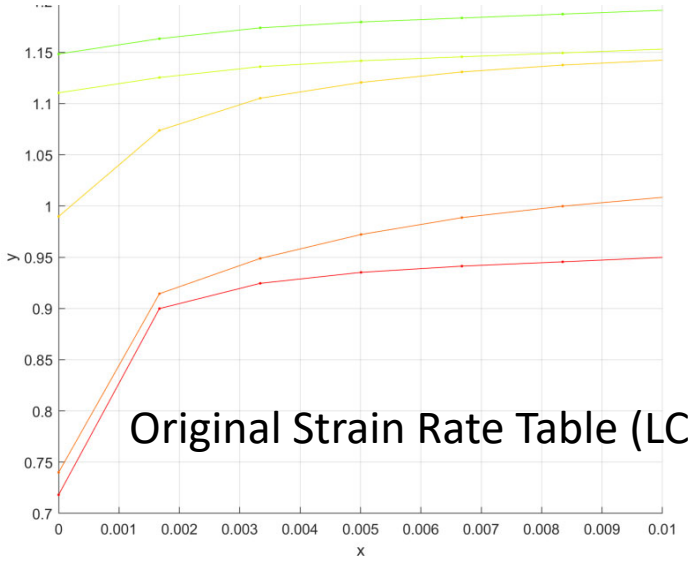
- Higher rate and lower rate hardening curves are NOT perfectly parallel.

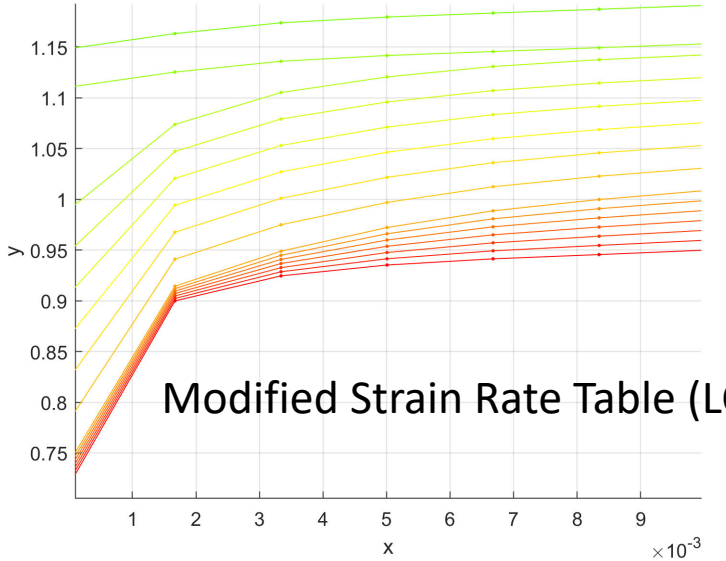


Strain Rate Table (LCK1)

Hardening Curve Augmentation Methodology

- Each data point of the additional curves is determined by interpolating between the two neighboring curves.
  - Interpolation between curves could linear or log





$$\dot{\varepsilon}_n = \dot{\varepsilon}_1 \frac{n}{N} + \frac{n}{N+1}\left(\dot{\varepsilon}_2 \frac{n}{N} - \dot{\varepsilon}_1 \frac{n}{N}\right)$$

$$\sigma_n^i = \sigma_1^i \frac{n}{N} + \frac{n}{N+1}\left(\sigma_2^i \frac{n}{N} - \sigma_1^i \frac{n}{N}\right)$$

(n=1,2,3…N)

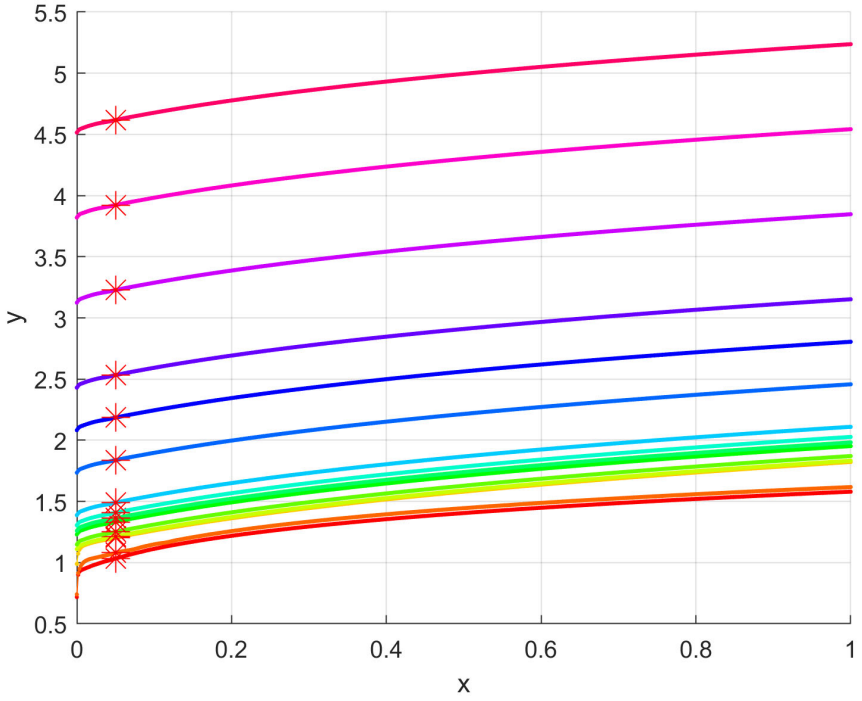
N: total number of additional curves between two adjacent curves

i: i=1,2,…600. Number of data point in a curve.

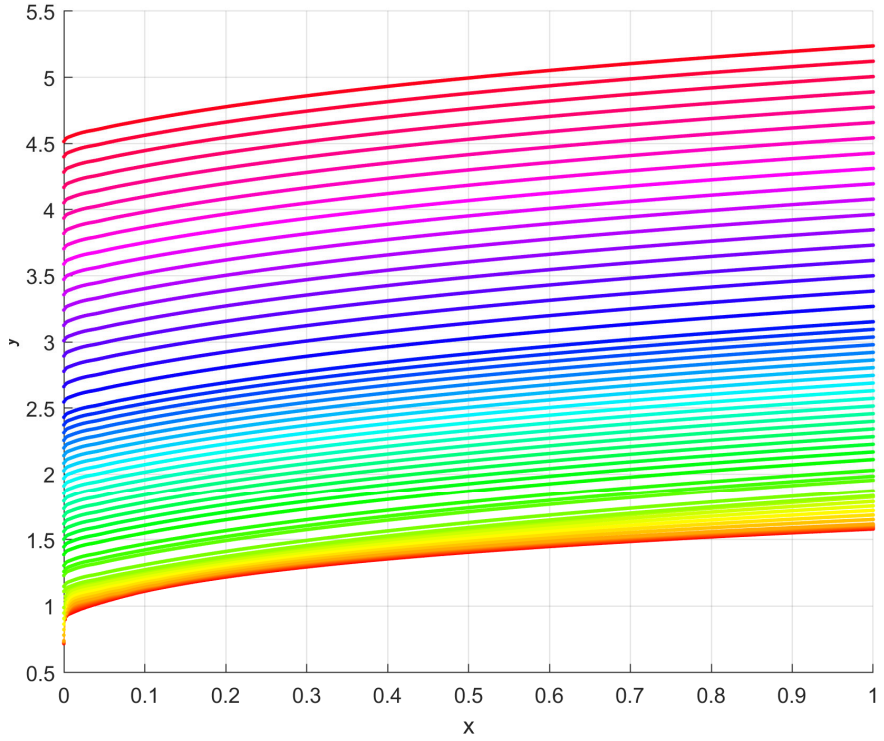
$\dot{\varepsilon}_1$ and $\dot{\varepsilon}_2$: strain rate of two adjacent curves.

σ_2^i *and* σ_1^i: stress of two adjacent curves.

Rate Dependent Hardening Table (LCK1) Comparison



Original Strain Rate Table (LCK1)



Modified Strain Rate Table (LCK1) - *Augmentation creates higher curve density*

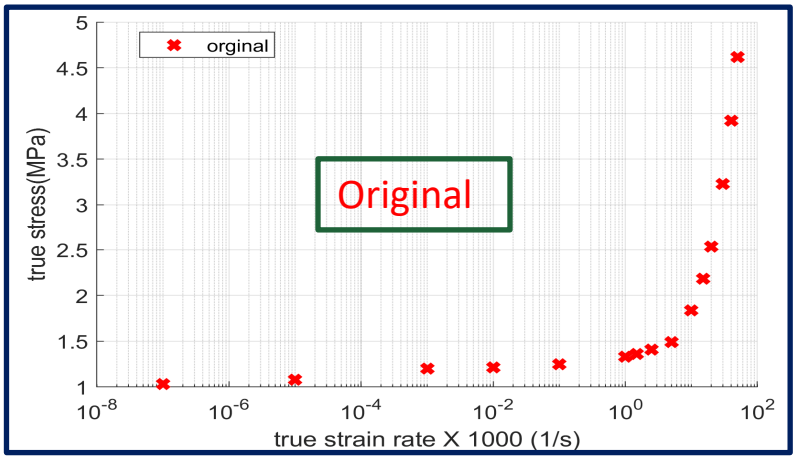
Trial Modification Variations

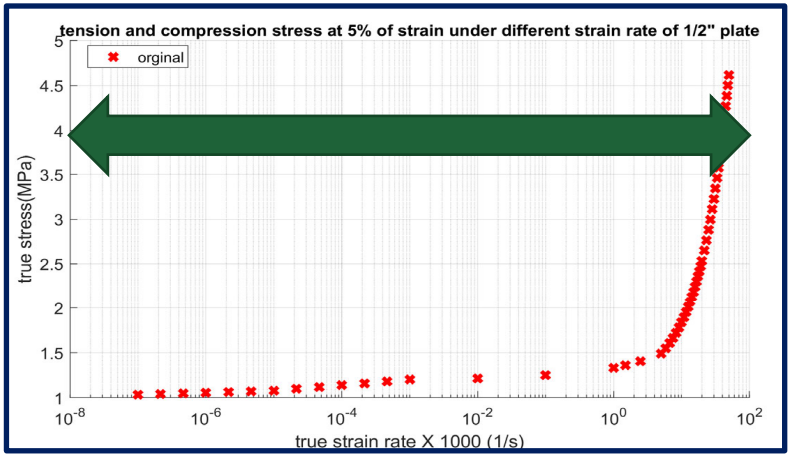
Model Name	Description	Result
Plateau	Ti64_MAT_224_V1.2	Baseline
Step 1	Add curves with **linear** interpolation for strain rates <=1 and strain rate >=5000	Same
Step 1_t2	Add curves with **linear** interpolation for all strain rates	Same
Step 2	Add Curves with **linear** interpolation for strain rates <=1 and strain rates >=5000, and change the table to logarithmic scale	Different Final answer
Step 2_t2	Add Curves with **linear** Interpolation for all strain rate, and change the table to logarithmic scale	Same
Step 2_t3	Add Curves with **log** interpolation for all, and change the table to logarithmic scale	Different

Conclusion: To convert linear table to logarithm table in *MAT_224:

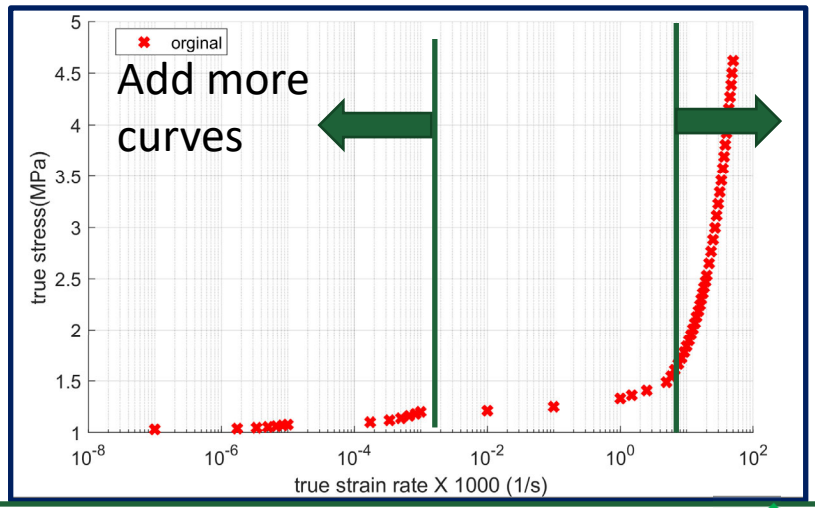
1. More curves are needed at all strain rate values.
2. The new curves will be **LINEARLY** interpolated from existing curves.

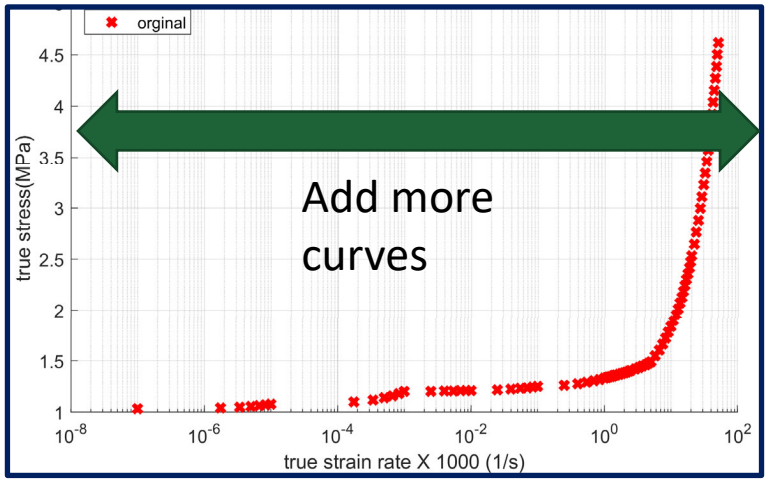
Differences Between Trial Modifications (presented on previous page)





Step_2_t3: Log Interpolation, Log Table ✗

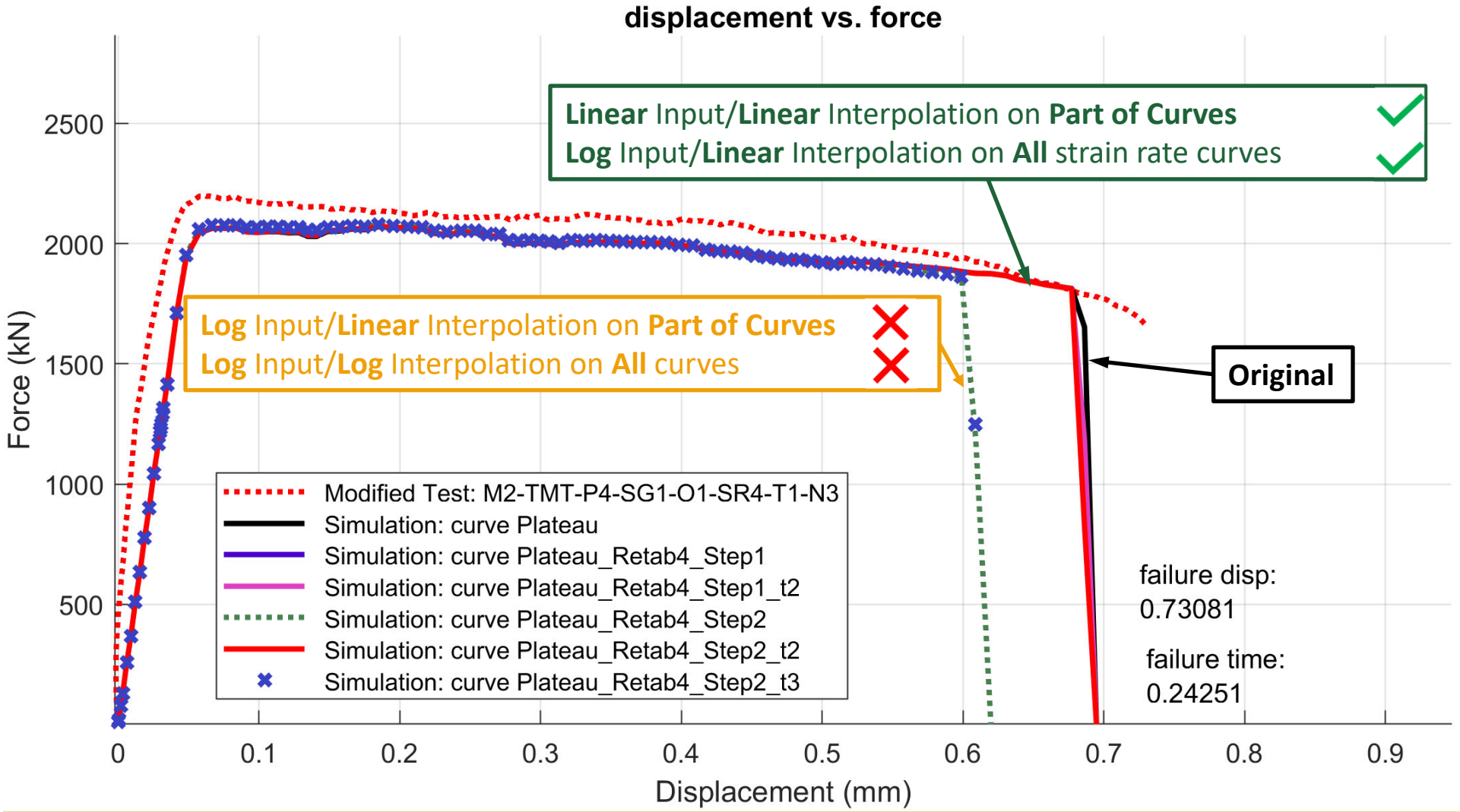




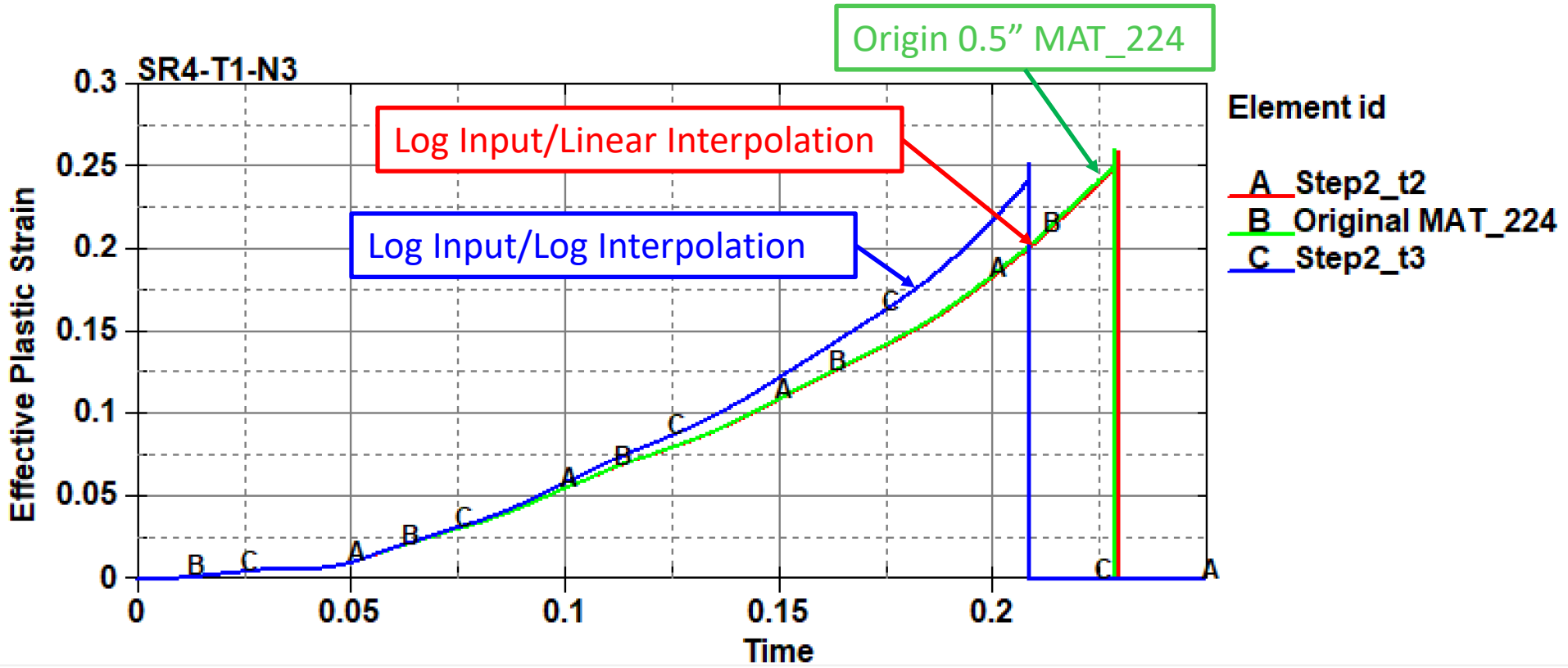
Step_1: Linear Interpolation, Linear table ✓
Step_2: Linear Interpolation, Log Table ✗

Step_1_t2: Linear Interpolation, Linear Table ✓
Step_2_t2: Linear Interpolation, Log Table ✓

Force Displacement Comparison

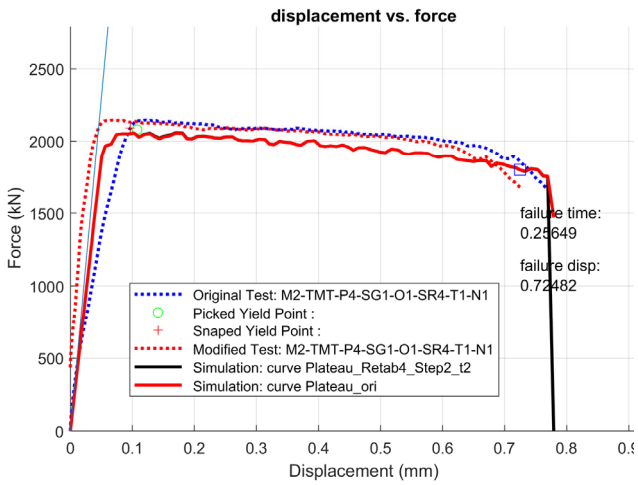


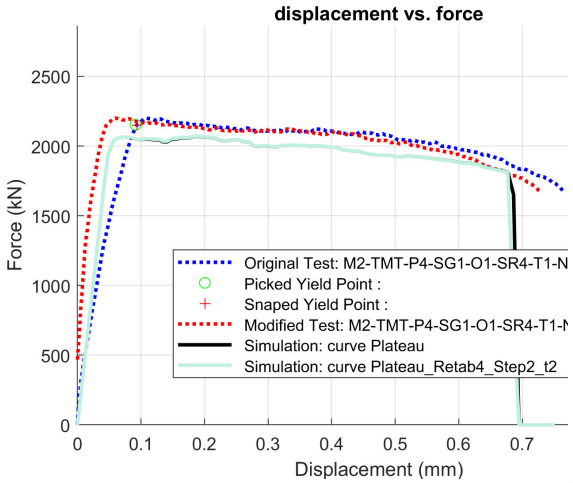
First Failed Element:
Linear Interpolation matches baseline results
Logarithmic interpolation does not

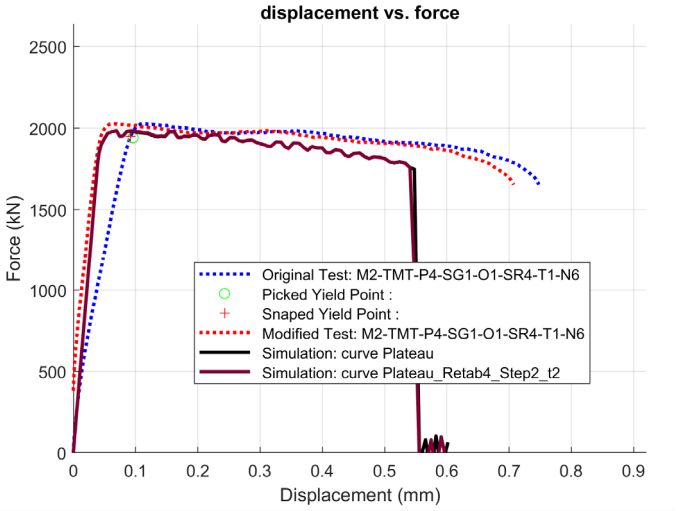


First Failed Element Comparison

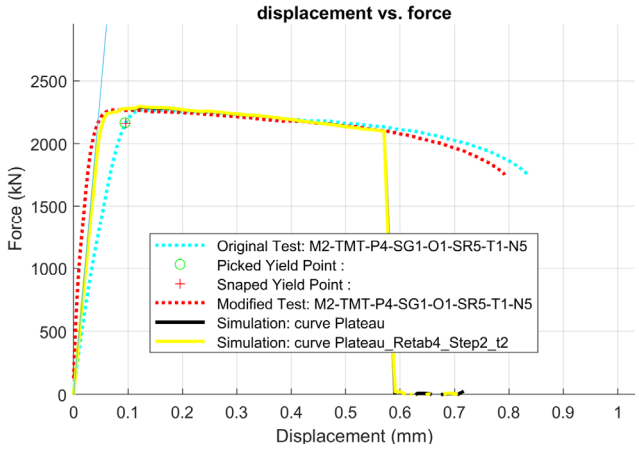
~650 1/sec Nominal Strain Rate Tests (SR4)







~1650 1/sec Nominal Strain Rate Test (SR5)



Ti64_MAT224_V1.3 Logarithmic Input Deck Updates

- Input format of strain rate table changed from linear scale to logarithmic scale.
- Add more hardening curves by linear interpolation.

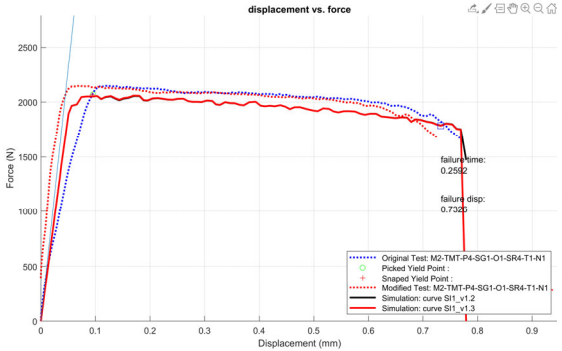
  (5 curves added between of all adjacent curves in LCK1)
- Defined LCINT=1000 on each DEFINE_CURVE card.
  - Remove global setting LCINT=1000000.
- Temperature Table, Failure Table, etc., were unchanged except where LCINT=1000 was added.
- The updated version were tested to give the same results to the Ti64_MAT224_V1-2 models.

Quality Assurance of All Three Different Unit Convention Versions

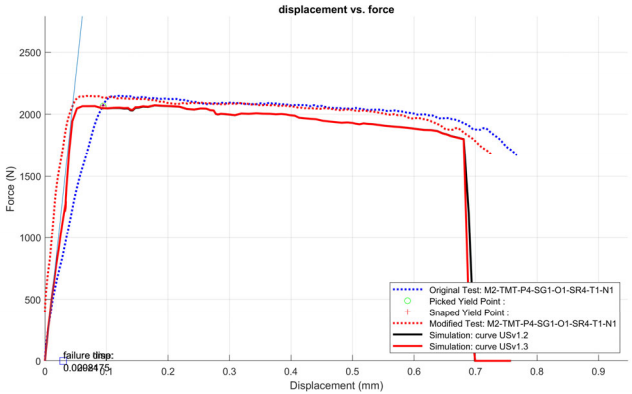
- Strategy: Simulate the high rate tension tests (SR4 and SR4) with V1.2 and V1.3 using all 3 units convention versions.
- Reason: Complete the validation.

~650 1/sec High Rate Test 1 M2-TMT-P4-SG1-O1-SR4-T1-N1_QA

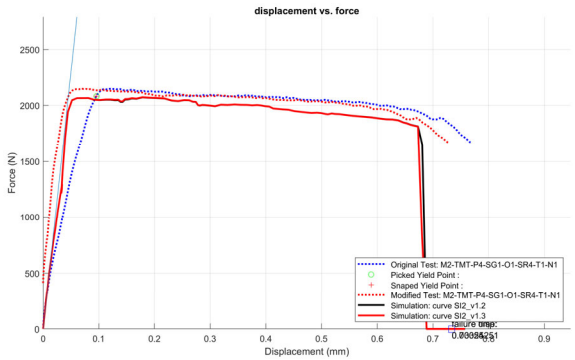
3 simulations are created following SI1, SI2 and US unit convention



V1.2/V1.3(SI1)



V1.2/V1.3 (SI2)



V1.2/V1.3 (US)

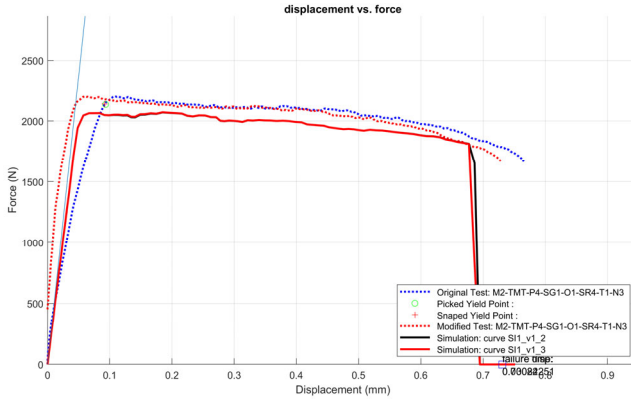
Units SI-1: mm, ms, kg, kN, Gpa, Kelvin

Units SI-2: mm, s, ton, N, MPa, Kelvin

Units US: in, s, lbf-s^2/in, lbf, psi, Rankine

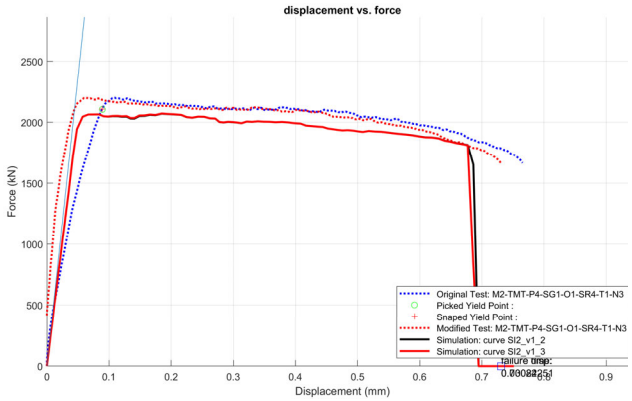
~650 1/sec High Rate Test 3 M2-TMT-P4-SG1-O1-SR4-T1-N3_QA

3 simulations are created following SI1, SI2 and US unit convention



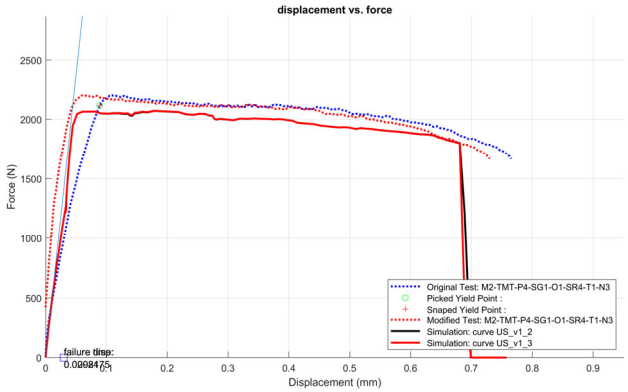
V1.2/V1.3(SI1)

Units SI-1: mm, ms, kg, kN, Gpa, Kelvin



V1.2/V1.3 (SI2)

Units SI-2: mm, s, ton, N, MPa, Kelvin

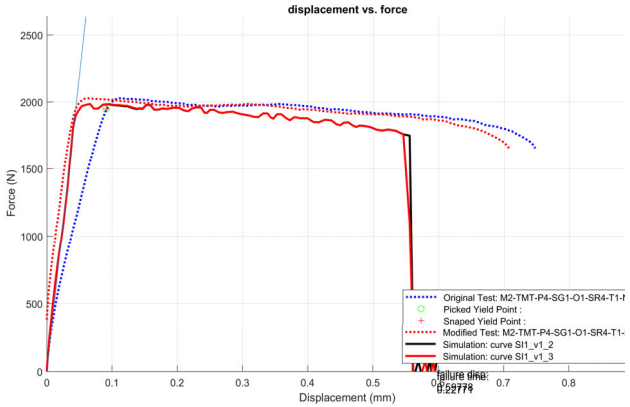


V1.2/V1.3 (US)

Units US: in, s, lbf-s^2/in, lbf, psi, Rankine

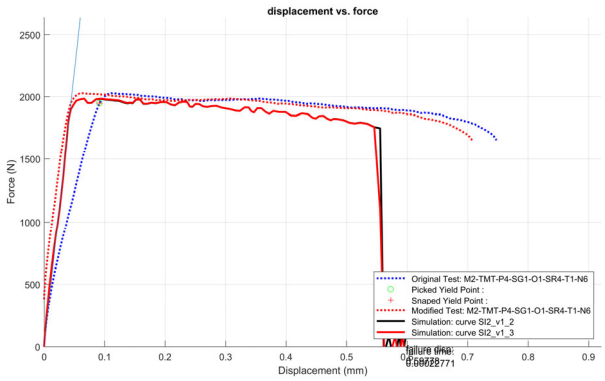
~650 1/sec High Rate Test 6 M2-TMT-P4-SG1-O1-SR4-T1-N6_QA

3 simulations are created following SI1, SI2 and US unit convention



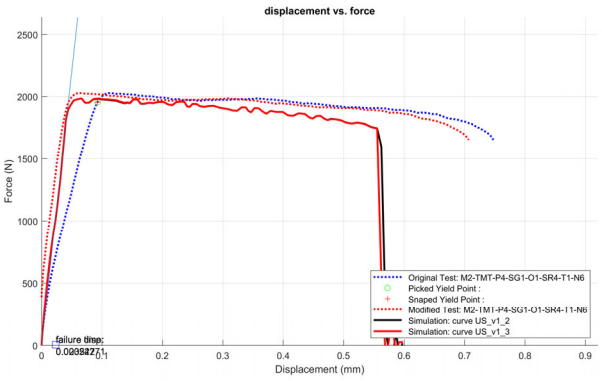
V1.2/V1.3(SI1)

Units SI-1: mm, ms, kg, kN, Gpa, Kelvin



V1.2/V1.3 (SI2)

Units SI-2: mm, s, ton, N, MPa, Kelvin

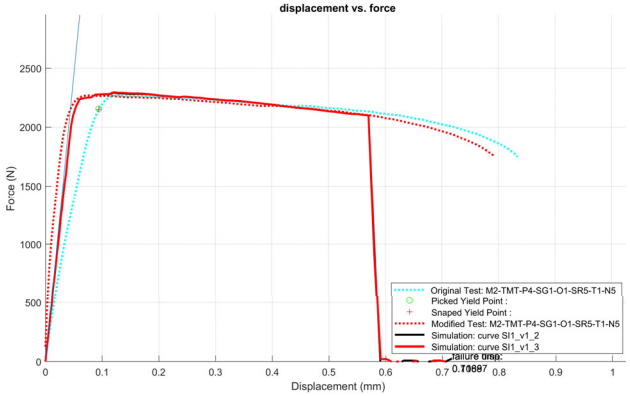


V1.2/V1.3 (US)

Units US: in, s, lbf-s^2/in, lbf, psi, Rankine

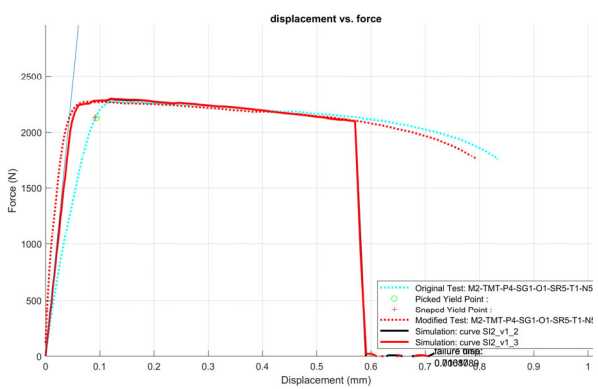
~1650 1/sec High Rate Test 5 M2-TMT-P4-SG1-O1-SR4-T1-N5_QA

3 simulations are created following SI1, SI2 and US unit convention



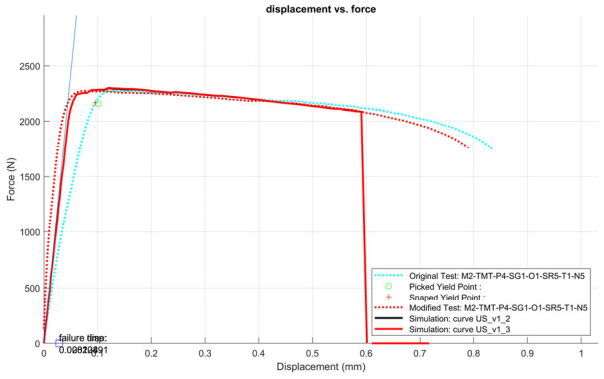
V1.2/V1.3(SI1)

Units SI-1: mm, ms, kg, kN, Gpa, Kelvin



V1.2/V1.3 (SI2)

Units SI-2: mm, s, ton, N, MPa, Kelvin



V1.2/V1.3 (US)

Units US: in, s, lbf-s^2/in, lbf, psi, Rankine

Conclusion

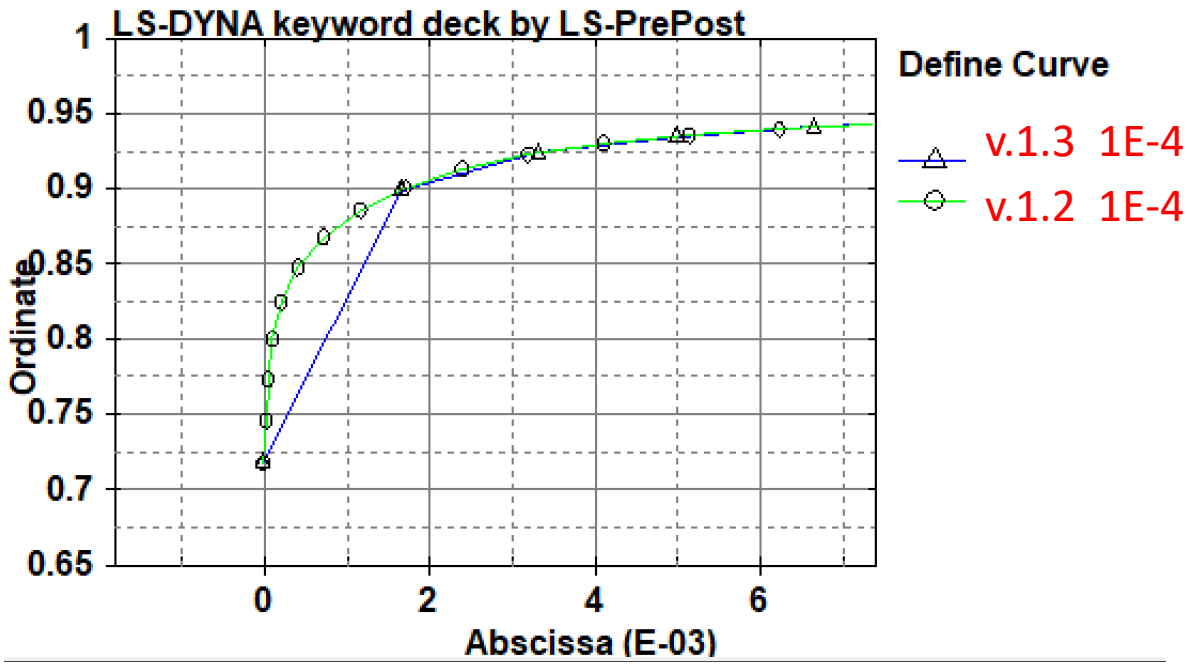
- Updated Ti64 MAT224 V1.3 produces the same results as V1.2
- Three V1.3 units system models (SI1, SI2, US) produce the same results as V 1.2
- The conclusion is validated against all tension higher rate test (SR4 and SR5)
- The V1.3 will be numerically more robust and produce more consistent results with potential version and modeling updates

Backup

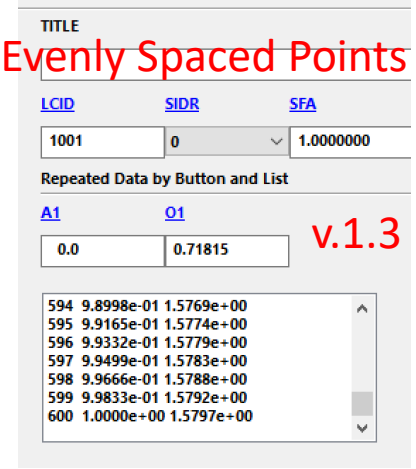
Q and A

- Q: Why are more curves needed for logarithmic input (v1.3) compared to the linear input (V1.2)
- A: V1.3 is based on V1.2 and is intended to produce the same results as V1.2. Since the original MAT224 (v1.2) interprets the curves linearly, more curves are needed to make the logarithmic input deck (V1.3) behave the same as the original. In another words, V1.3 needs to use a logarithmic interpolation to follow the result of a linear interpolation, therefore more curves are needed.
- Q: Why is the curve resolution of the original MAT224 higher at the very beginning
- A: The V1.3 intends to keep a 600 evenly spaced point between strain = 0 to strain =1 for all stress-strain curves. The beginning part of the curve lost some resolution, but does not create a significant difference in simulation results.

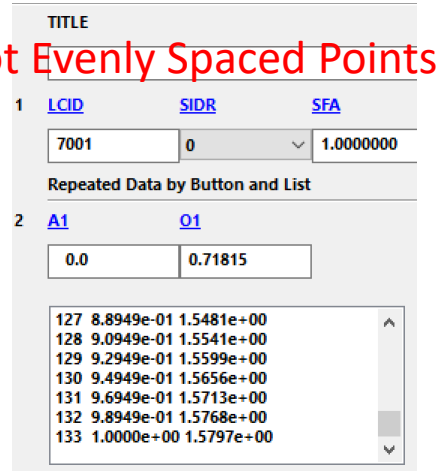
Ti64 V1.3 Low Strain Hardening Curve Resolution Reduction



600 Evenly Spaced Points



133 Not Evenly Spaced Points



V1.3 loses some resolution in low strains
due to requirement of evenly spaced points