

VARIATIONS OF THE ELASTIC MODULUS OF AUTOMOTIVE STEELS AFTER YIELDING

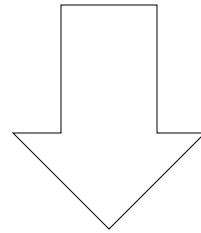
P. Matteis, G. Scavino, D. Firrao

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Overall aim

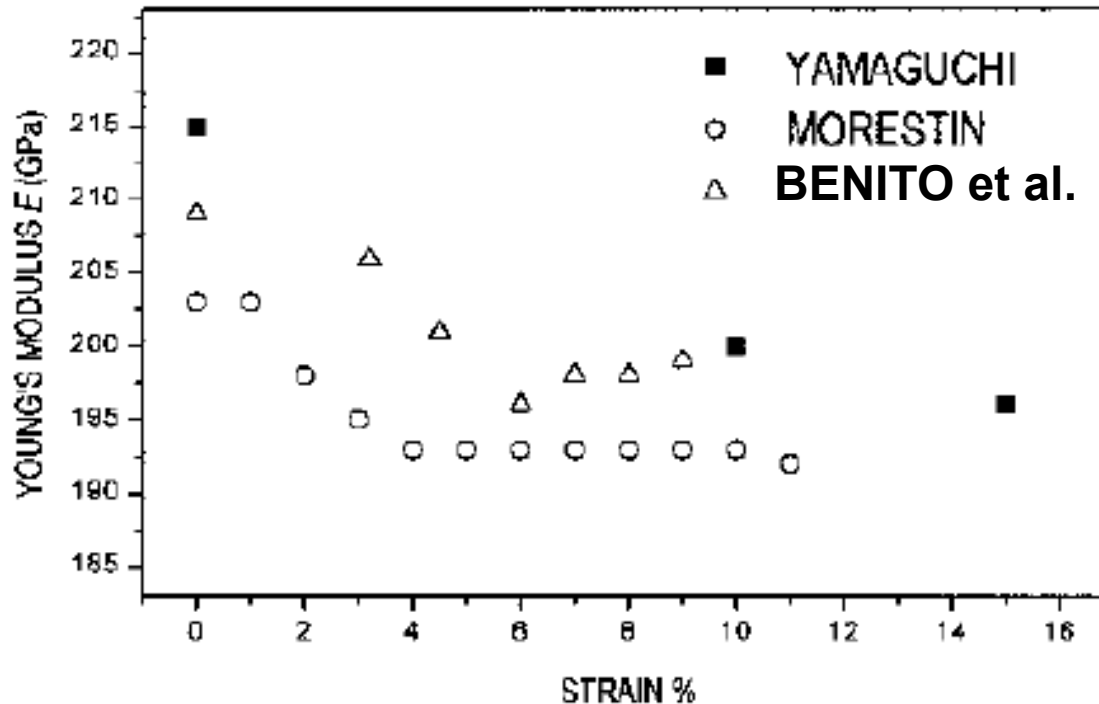
Accurate simulation of sheet cold forming processes for car body parts

FEM analyses sufficiently accurate to predict springback and to design *compensated* dies requires increasingly accurate material parameters



Accurate measurements of the elastic modulus on both virgin and already deformed steel

Previous works (1) – pure iron



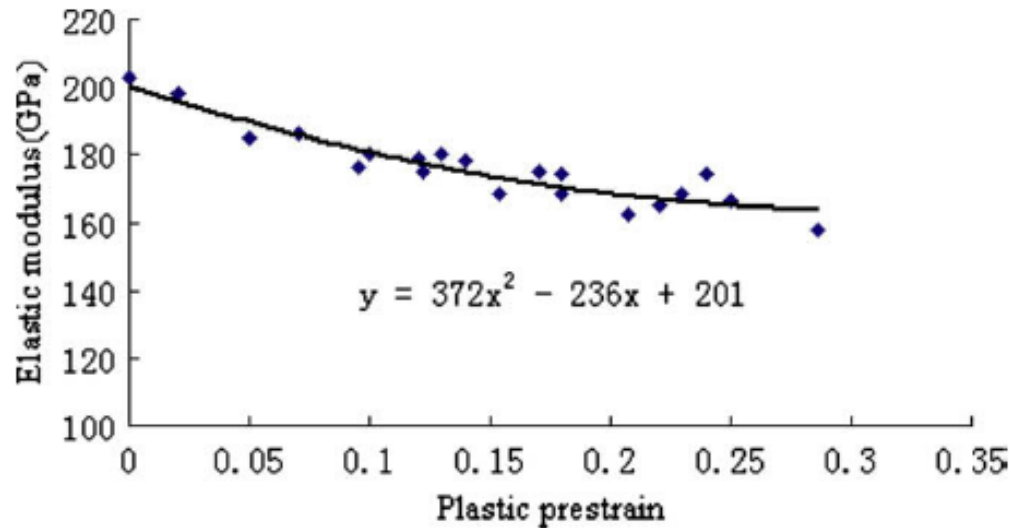
METALLURGICAL AND MATERIALS TRANSACTIONS A

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Change of Young's Modulus of Cold-Deformed Pure Iron in a Tensile Test

J.A. BENITO, J.M. MANERO, J. JORBA, and A. ROCA

Previous works (2) – TRIP steel, springback analyses



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ELSEVIER

Short Communication

Variation of elastic modulus during plastic deformation and its influence on springback

Hai Yan Yu*

Tested automotive steel sheets

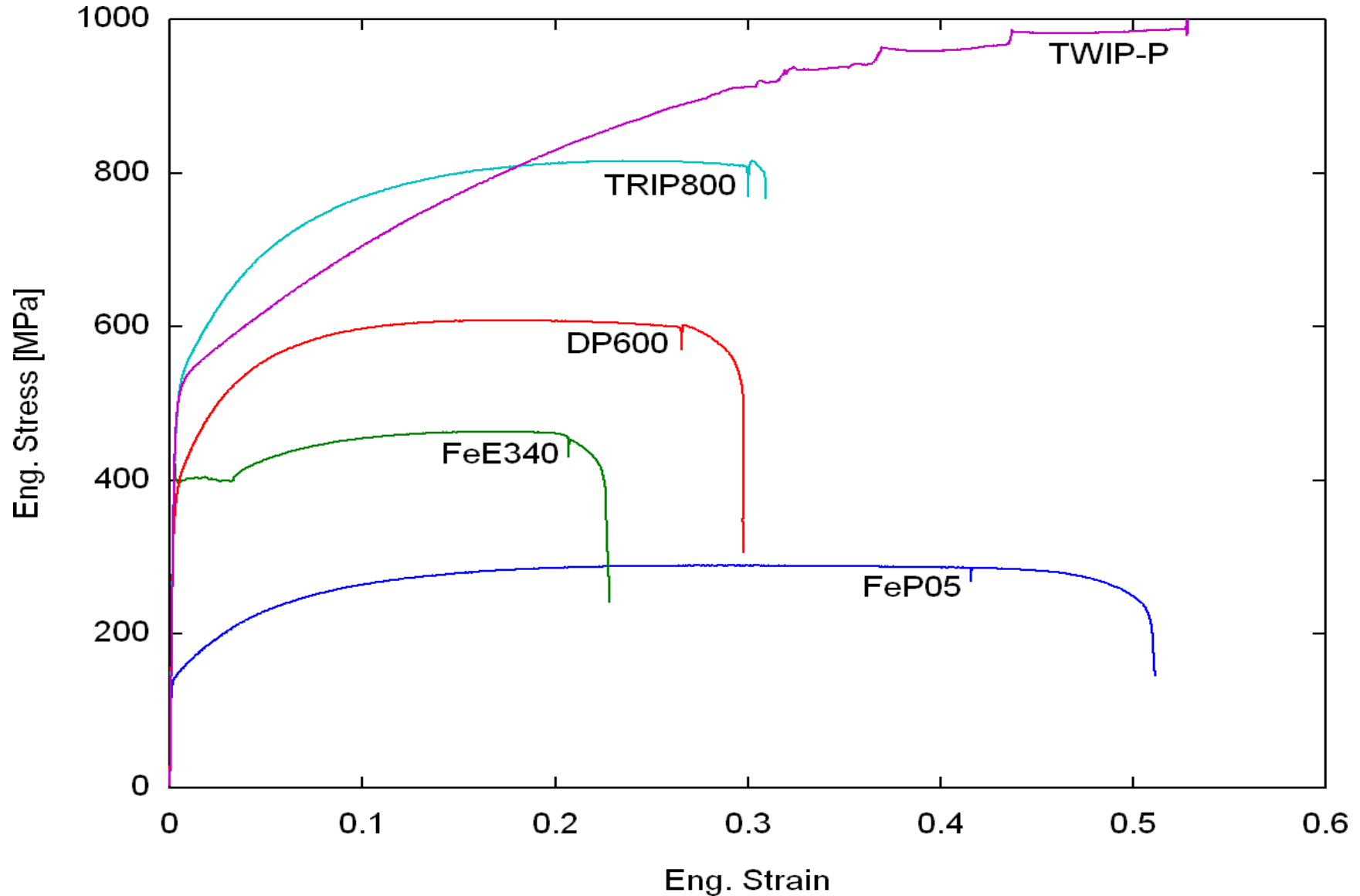
Grade	Thickn. [mm]	YS [MPa]			UTS [MPa]			e _t [%]		
		T	45	L	T	45	L	T	45	L
FeP05 (low carbon)	1	145	154	149	292	300	287	51	50	51
FeE340 (microalloyed)	1	433	394	384	476	455	469	23	36	37
DP600 (Dual Phase, ferrite & martensite)	1.55	388	387	388	615	610	614	30	21	25
TRIP800 (TRAsformation Induced Plasticity)	1	520	511	520	837	830	840	31	27	26
TWIP (18% Mn, 0.65% C, austenitic)	1.45	506	489	484	1010	997	993	53	63	47

As-received (i.e., cold rolled and heat treated) microstructure

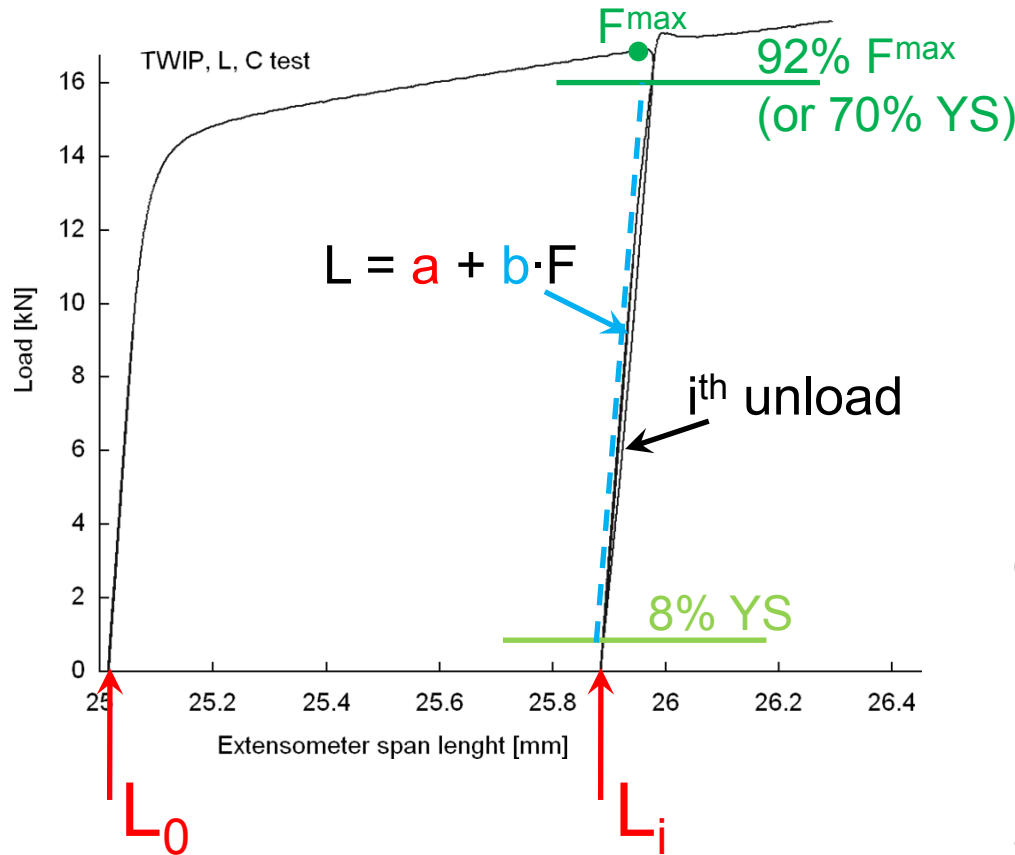
Protective Zn surface layers removed before testing

Tensile tests on 20 mm wide samples, with a 25 mm extensometer

Tested Materials – tensile curves (Orientation T)



Elastic modulus calculations



$$L = L_i \cdot (1 + \epsilon) = L_i + L_i \cdot (\sigma / E)$$

$$L = L_i + (L_i \cdot F) / (E \cdot S_i)$$

$$L = L_i + (L_i^2) / (L_0 \cdot S_0 \cdot E) \cdot F$$

(since $L_0 \cdot S_0 = L_i \cdot S_i$)

$$L = a + b \cdot F$$

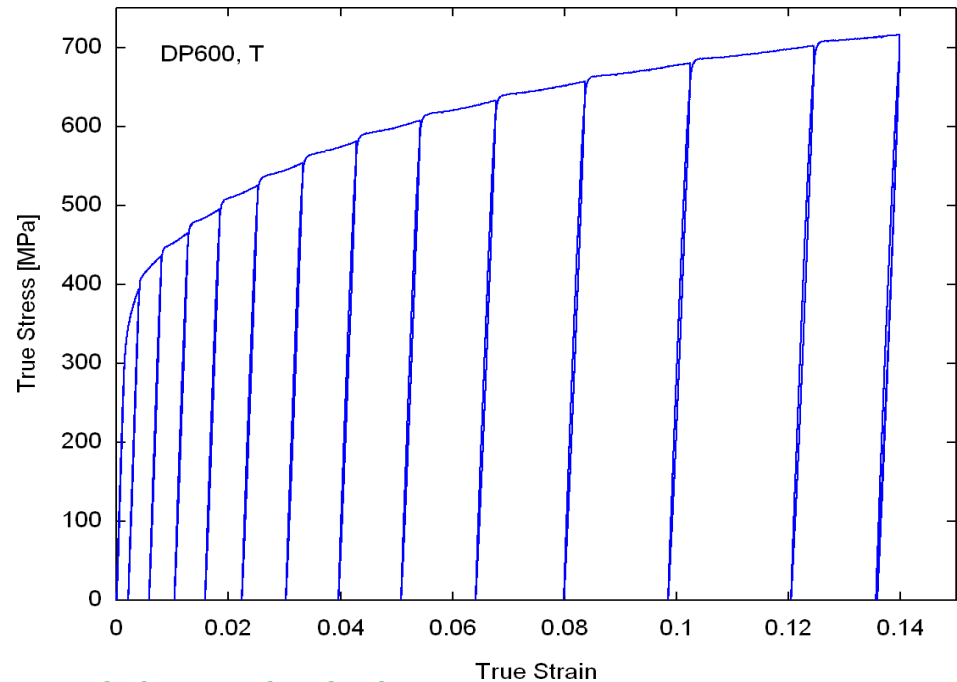
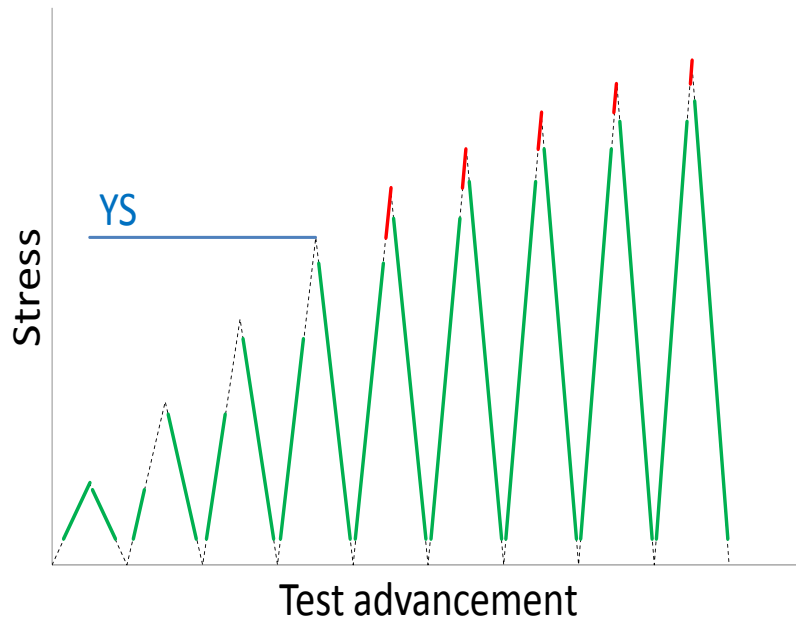
$$\rightarrow L_i = a$$

$$\rightarrow \text{Modulus} = E = a^2 / (L_0 \cdot S_0 \cdot b)$$

$$\rightarrow \text{Pre-strain} = \epsilon_i = \ln(L_i / L_0)$$

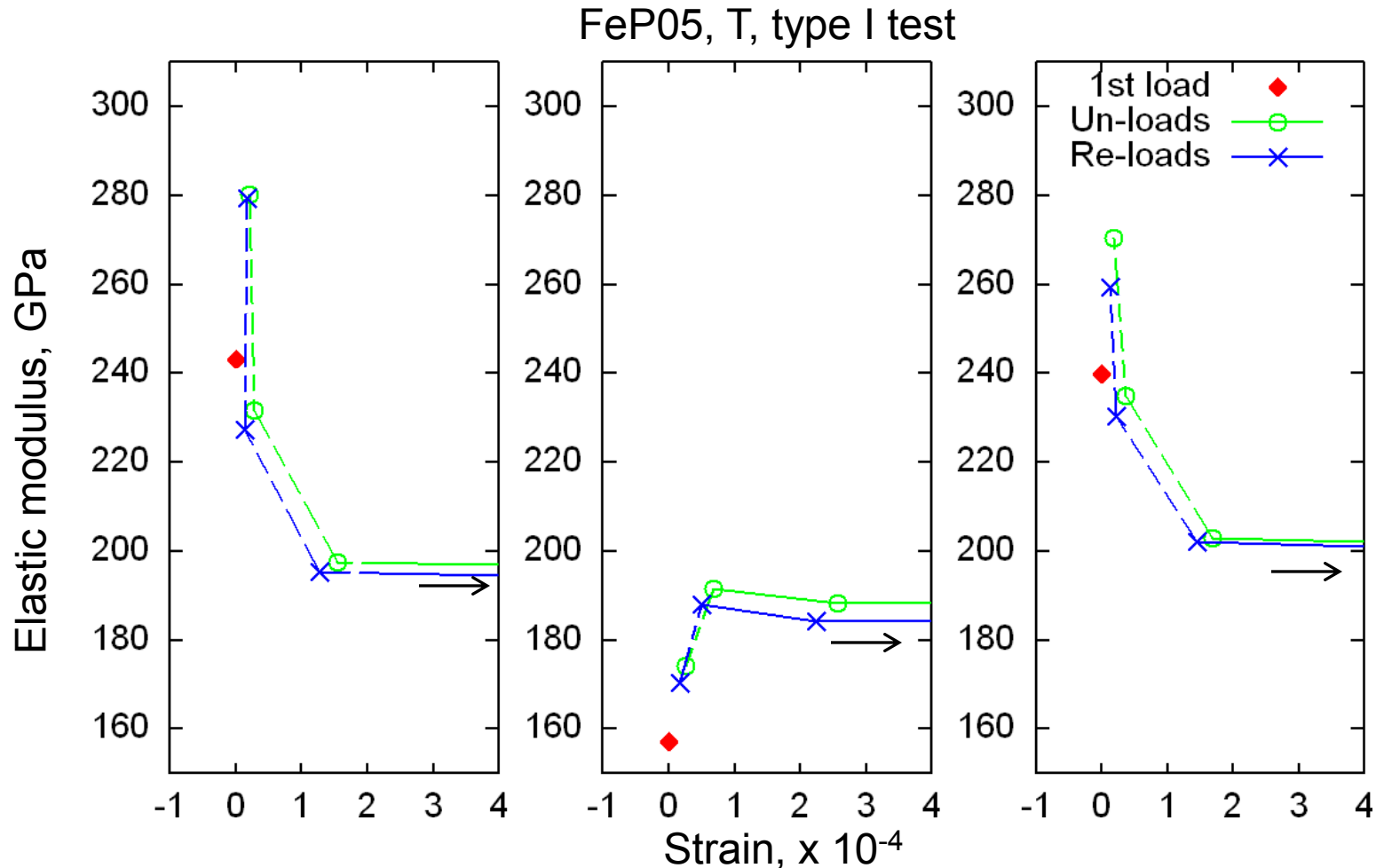
Type I tests

- unload – reload cycles up to $\approx 25, 50, 75$ and 100% of yield stress
- repeated **plastic strain steps**, starting from ≈ 0.004 true strain (each $\approx 20\%$ larger than the previous one)
- one elastic unload-reload cycle after each step (and one final unload)
- elastic strain rate $\approx 10^{-4} \text{ s}^{-1}$ in all cases



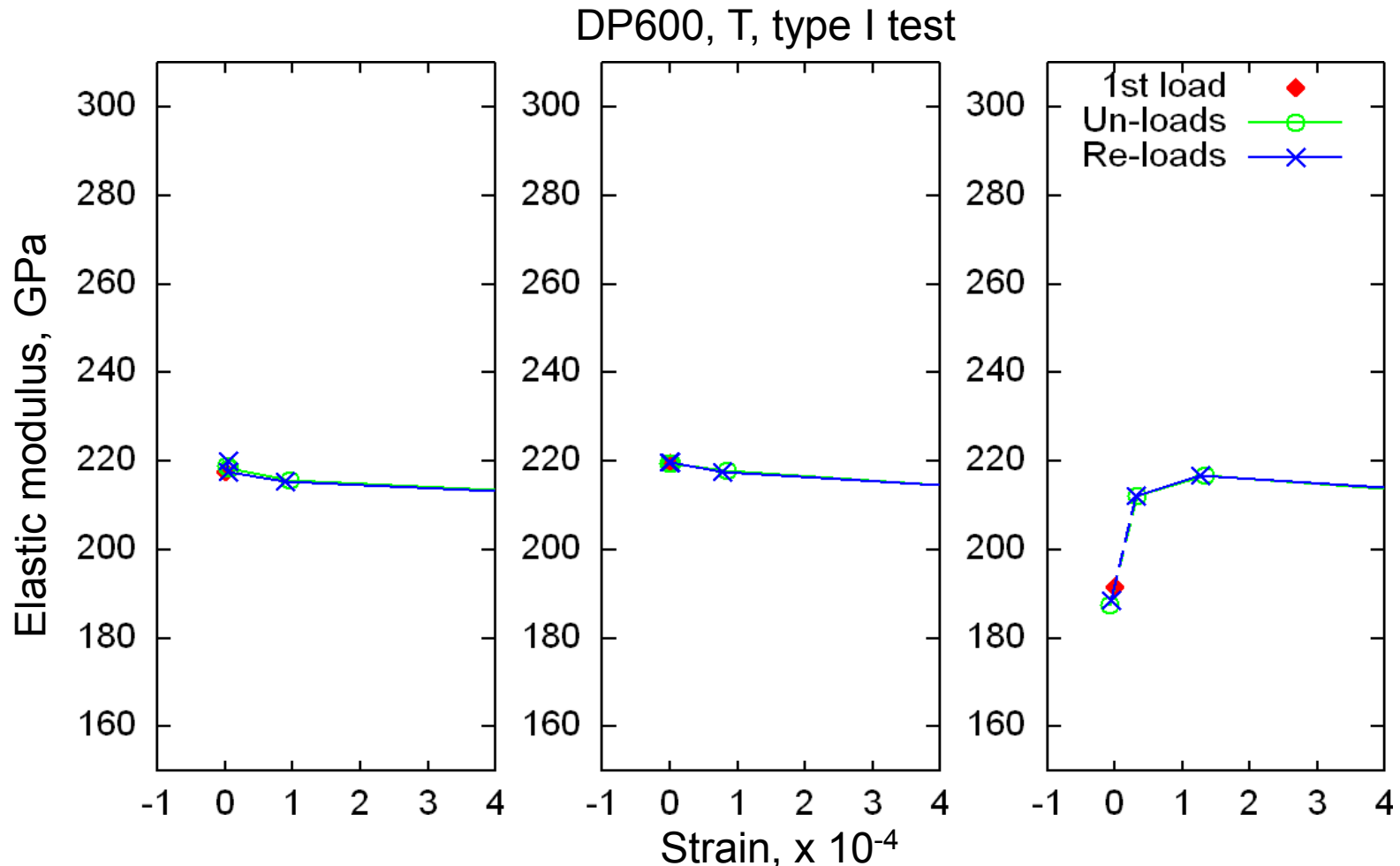
green lines: elastic modulus calculations

Results (1): elastic modulus from the 25, 50, 75 and 100% YS unload-reload cycles.



Large variations with increasing maximum stress, below YS, possibly due to **straightening**

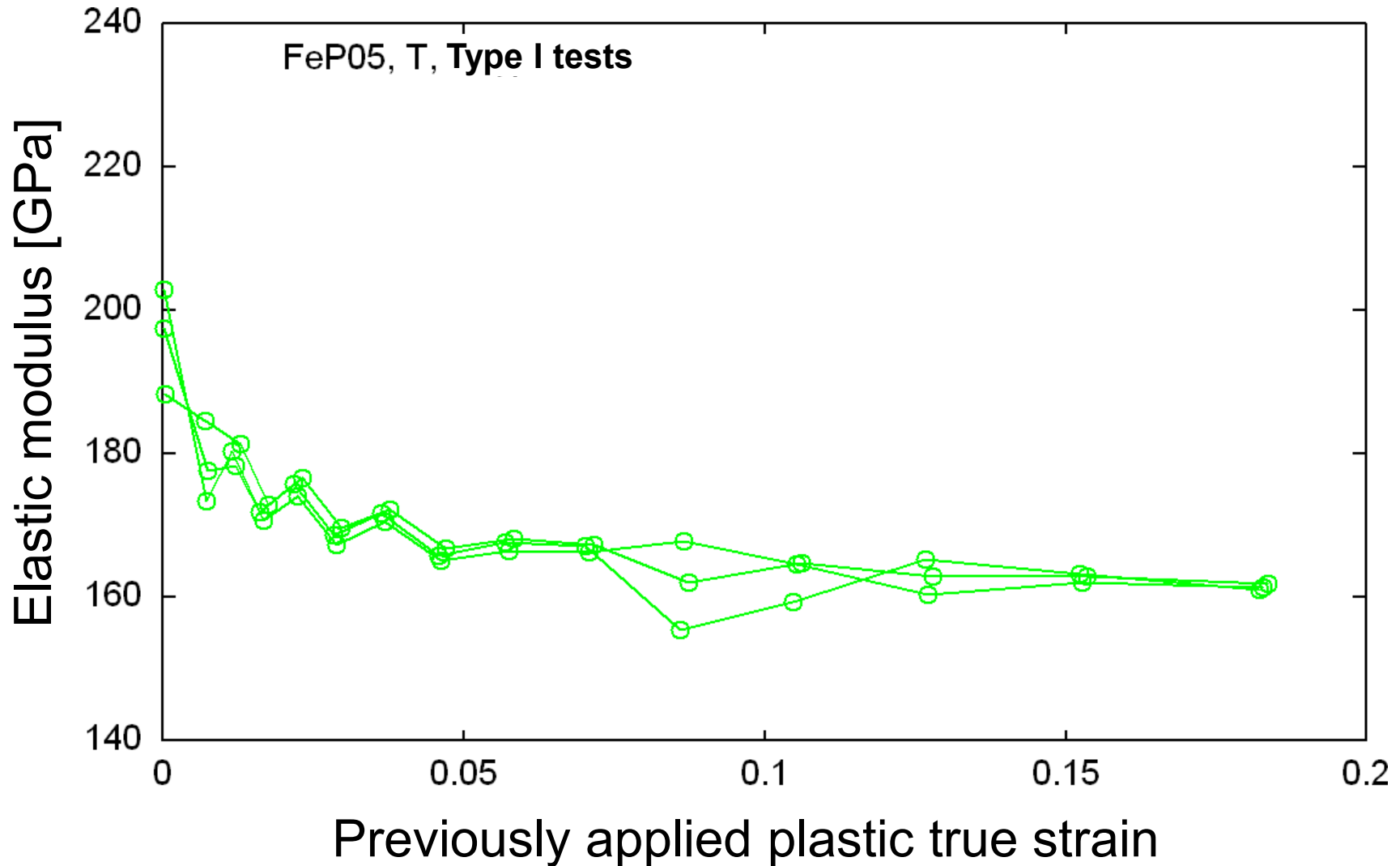
Results (1): elastic modulus from the 25, 50, 75 and 100% YS unload-reload cycles.



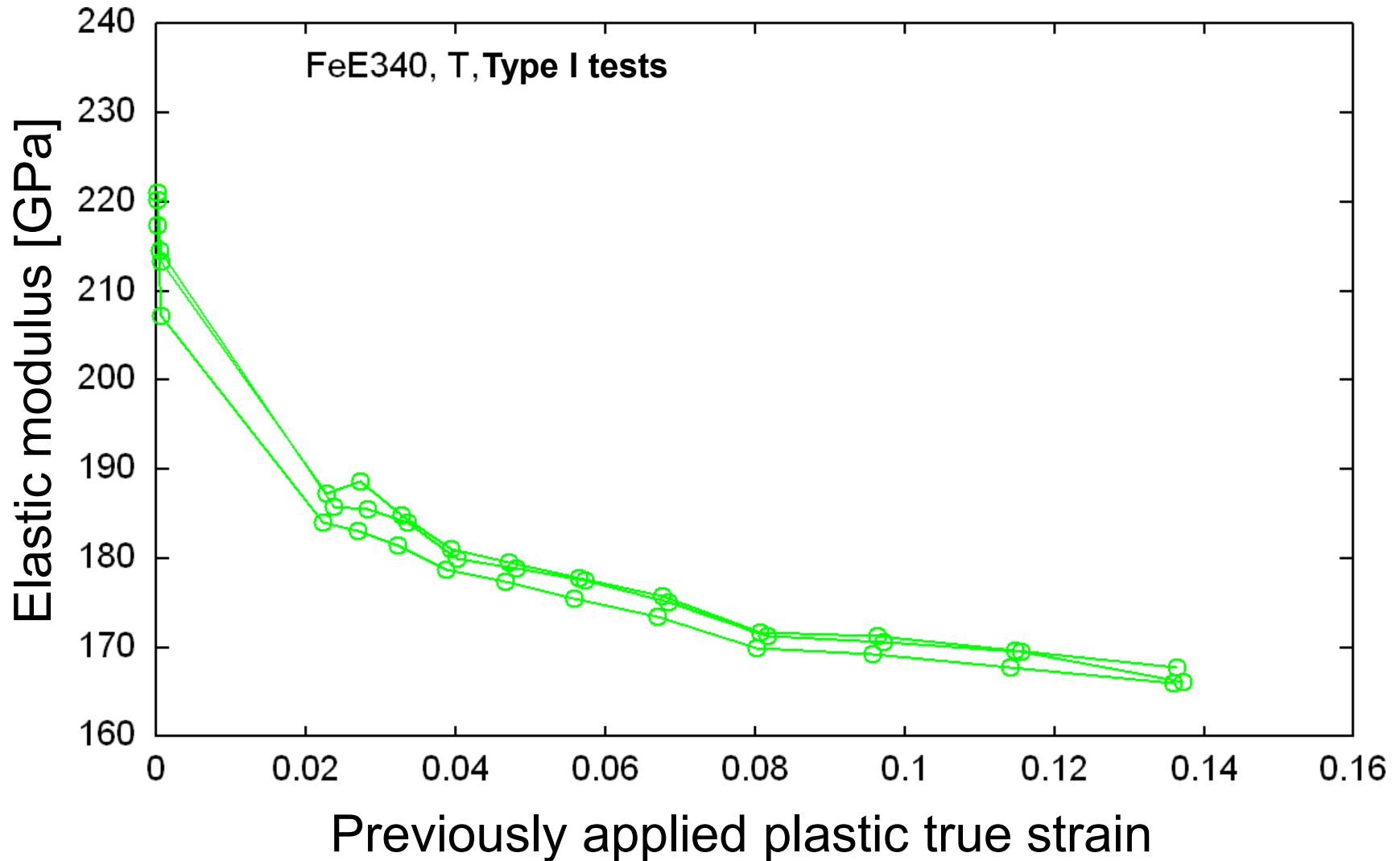
... but not in all cases.

The 0% strain modulus reported below will generally be for about 70% YS loading

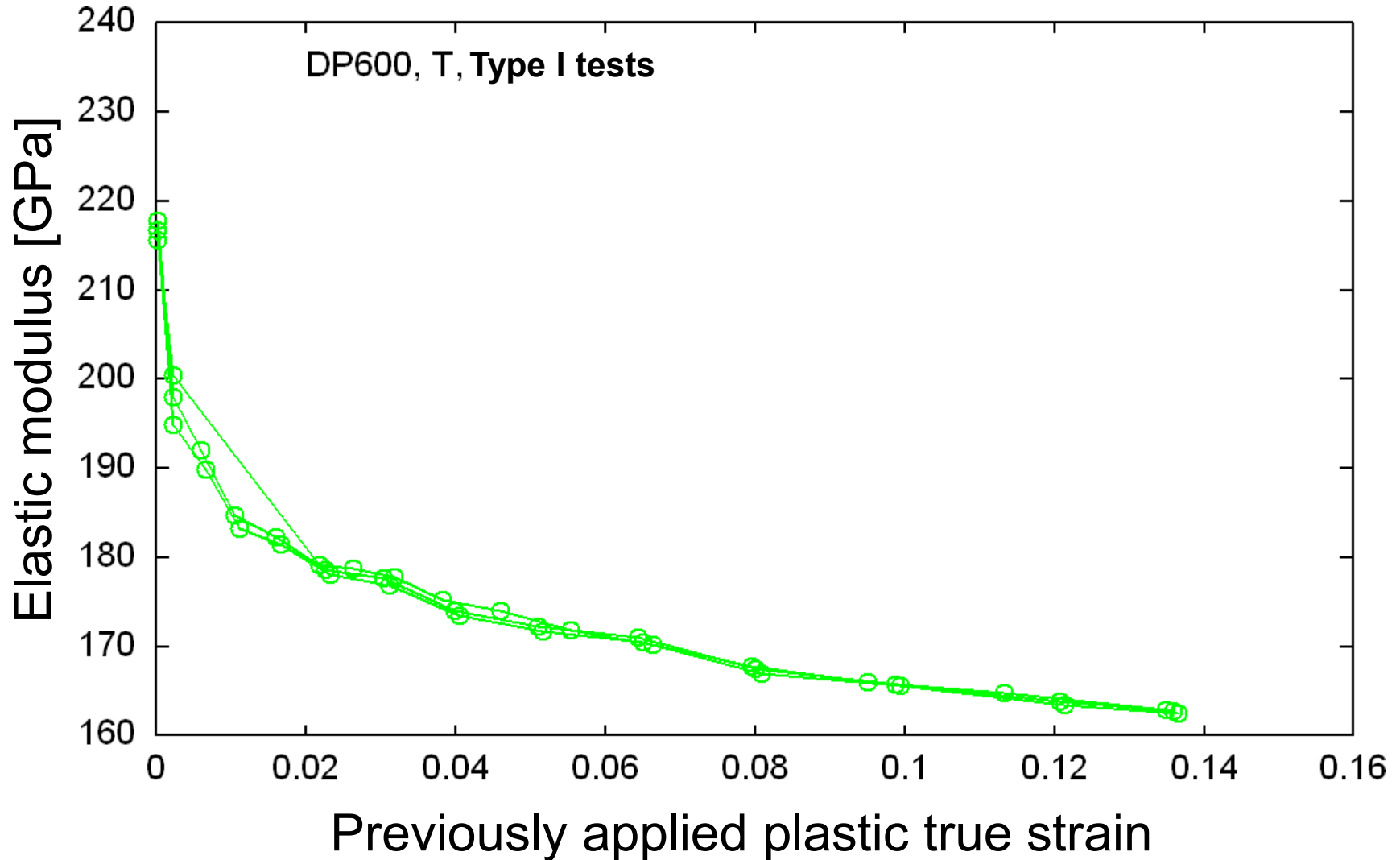
Results (2): elastic modulus of the 1st unload after the plastic prestrain (3 samples)



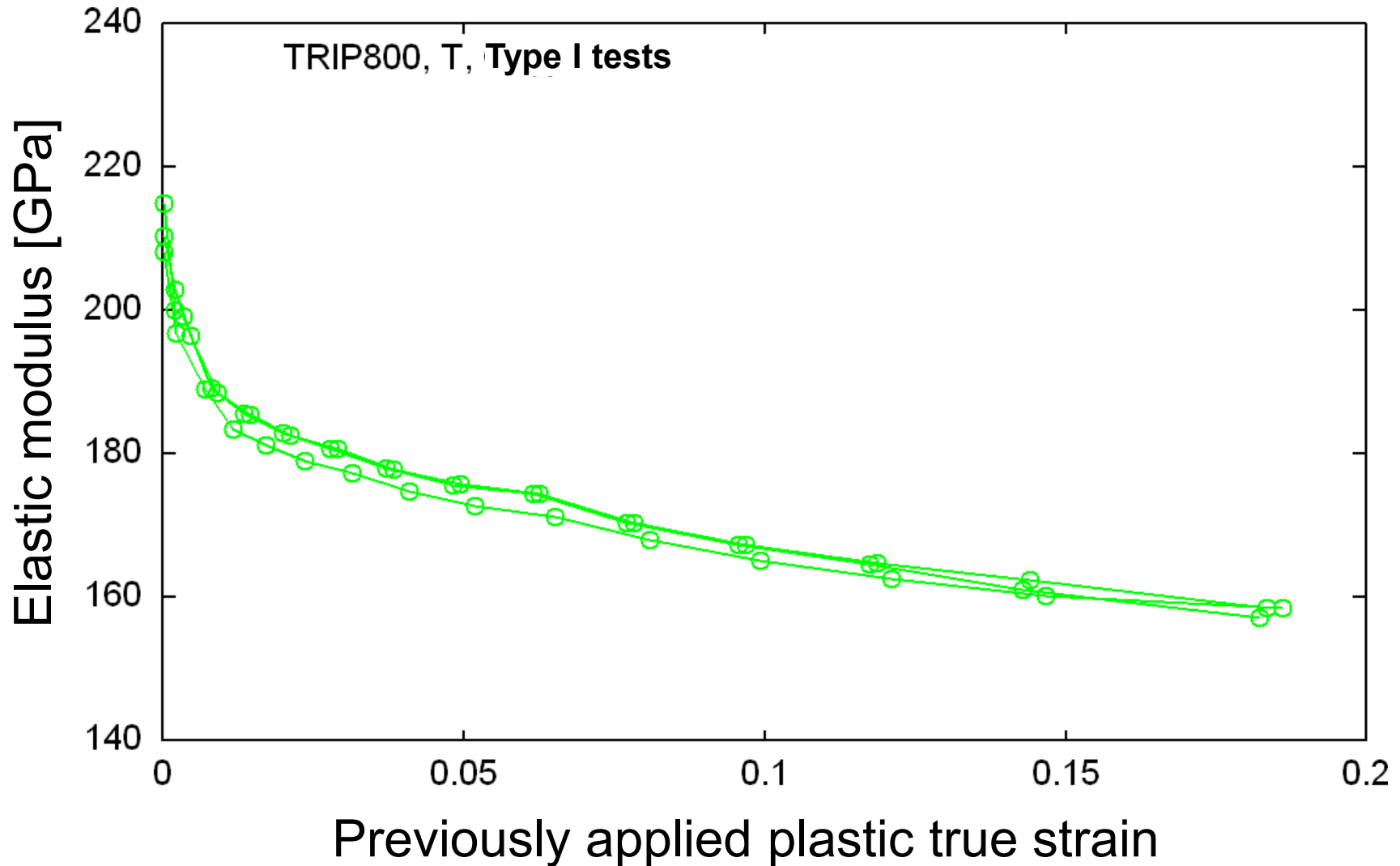
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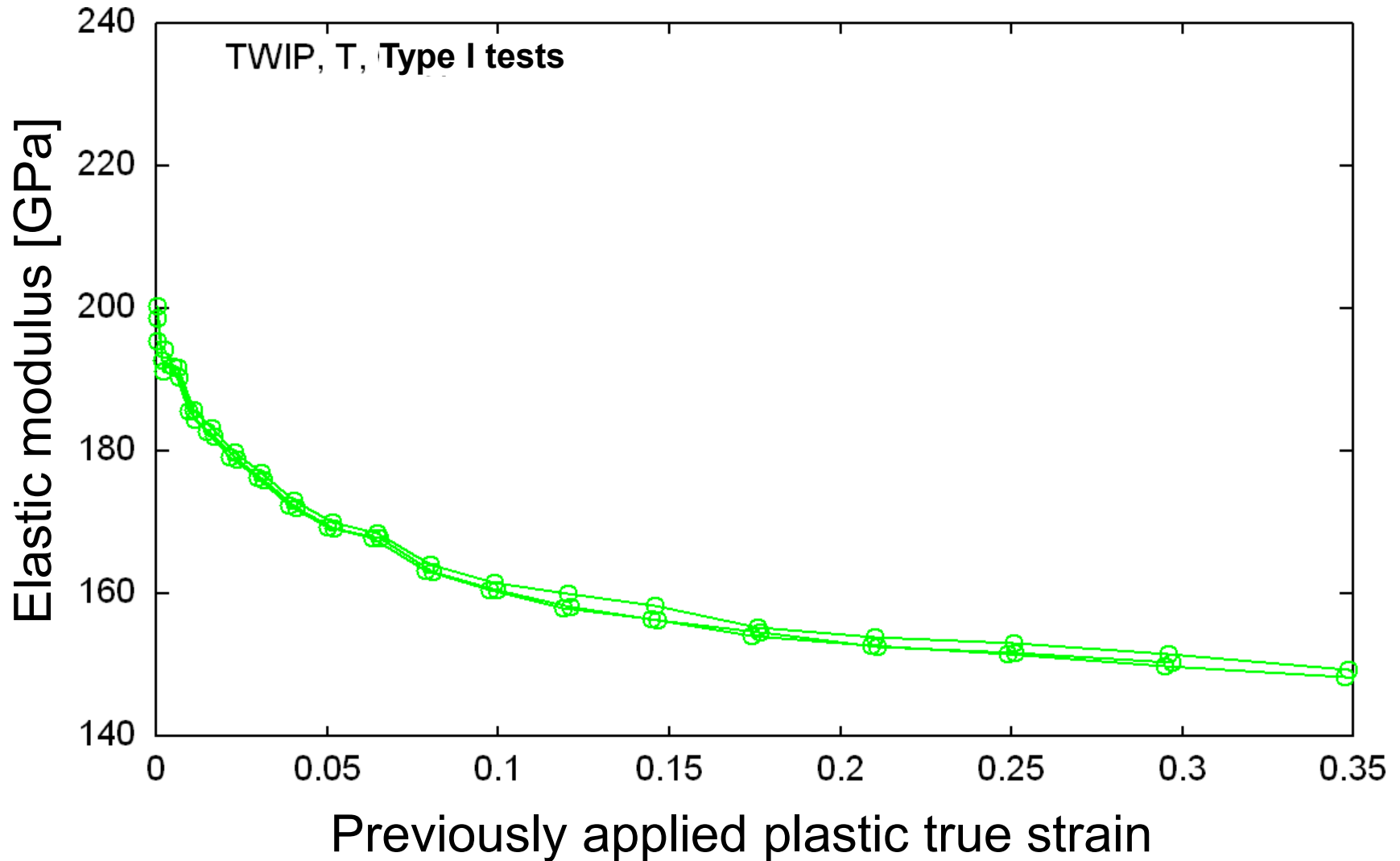
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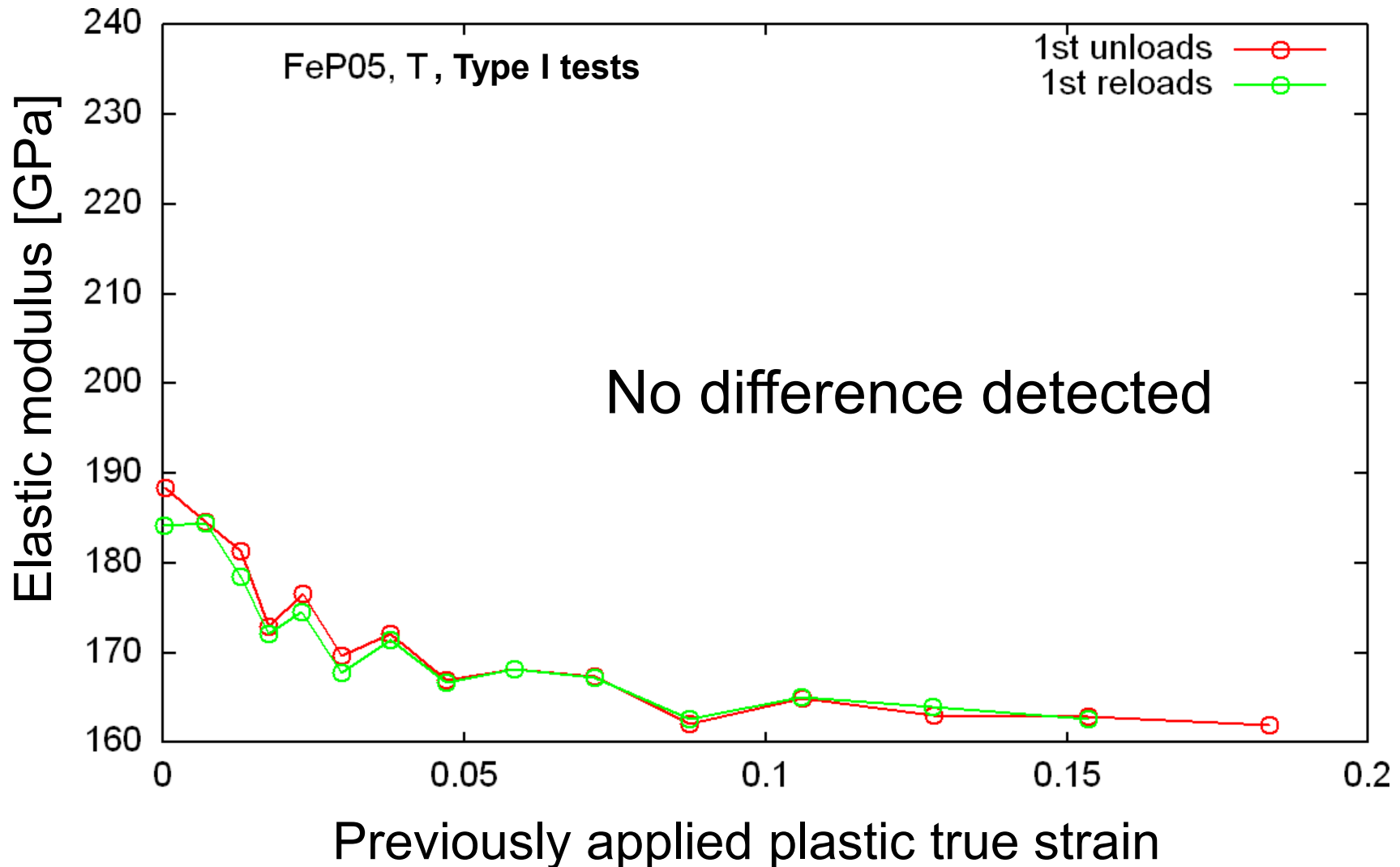
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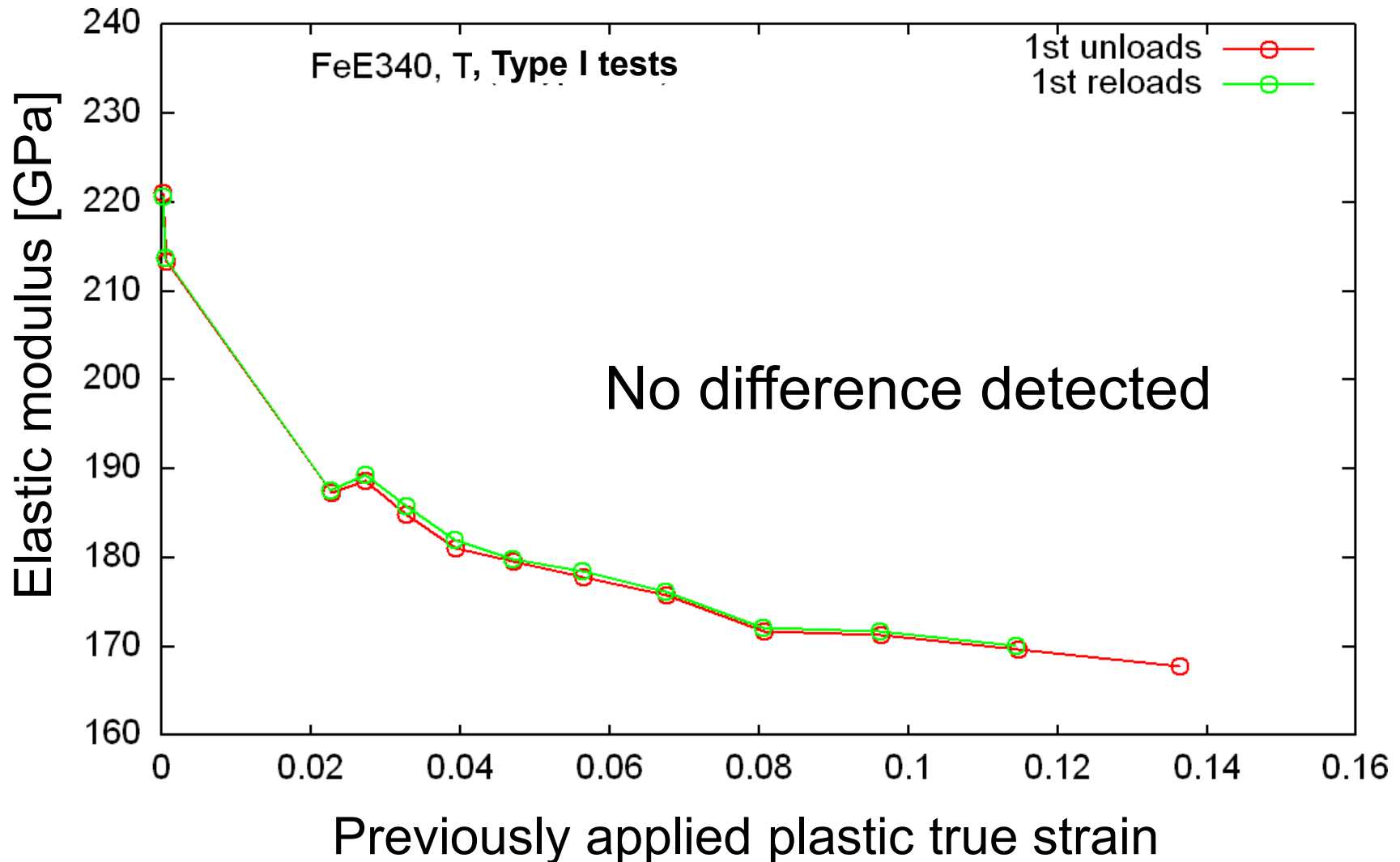
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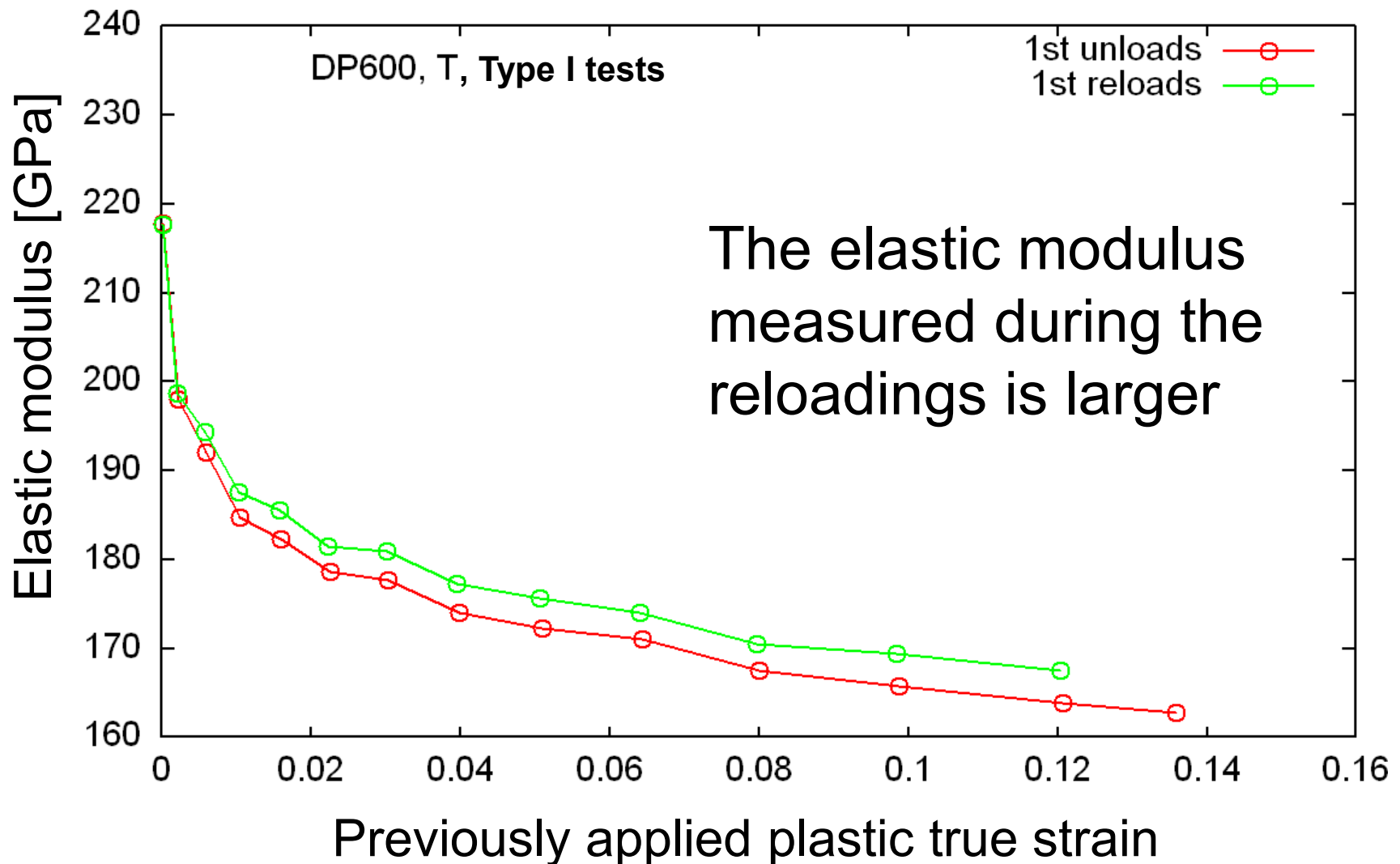
Results (3): elastic modulus obtained from the 1st unload after the plastic strain, or from the successive (1st) reload



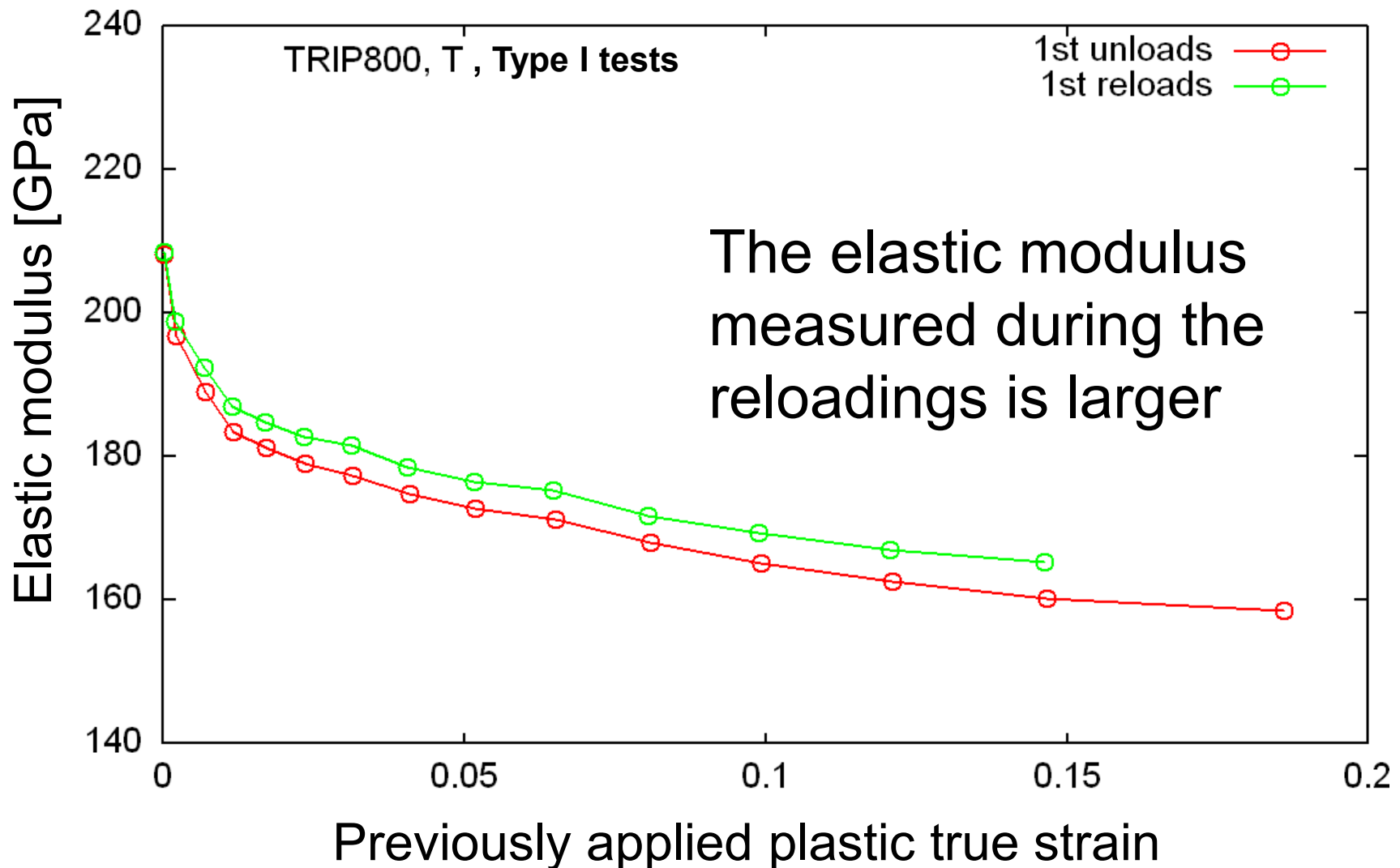
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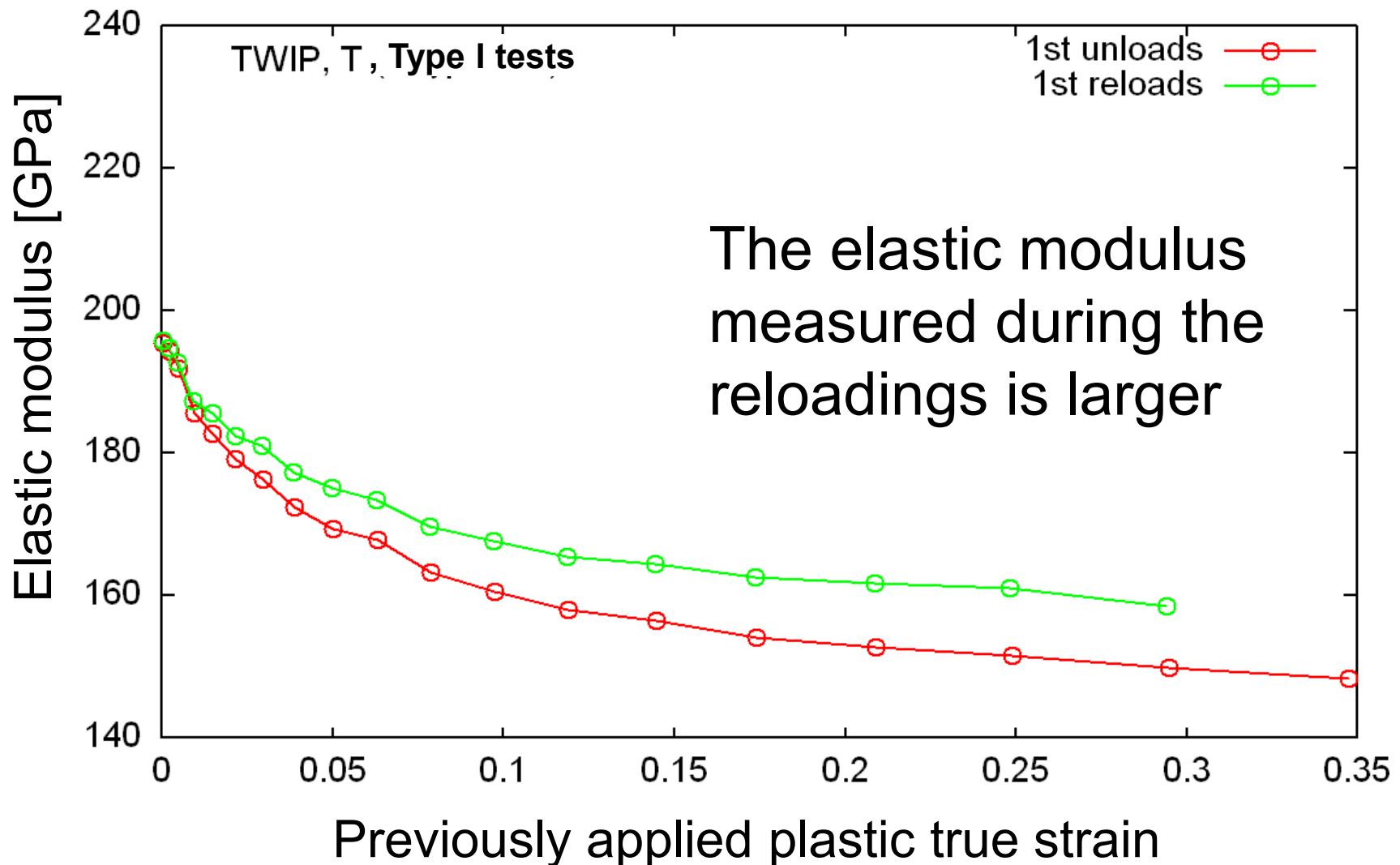
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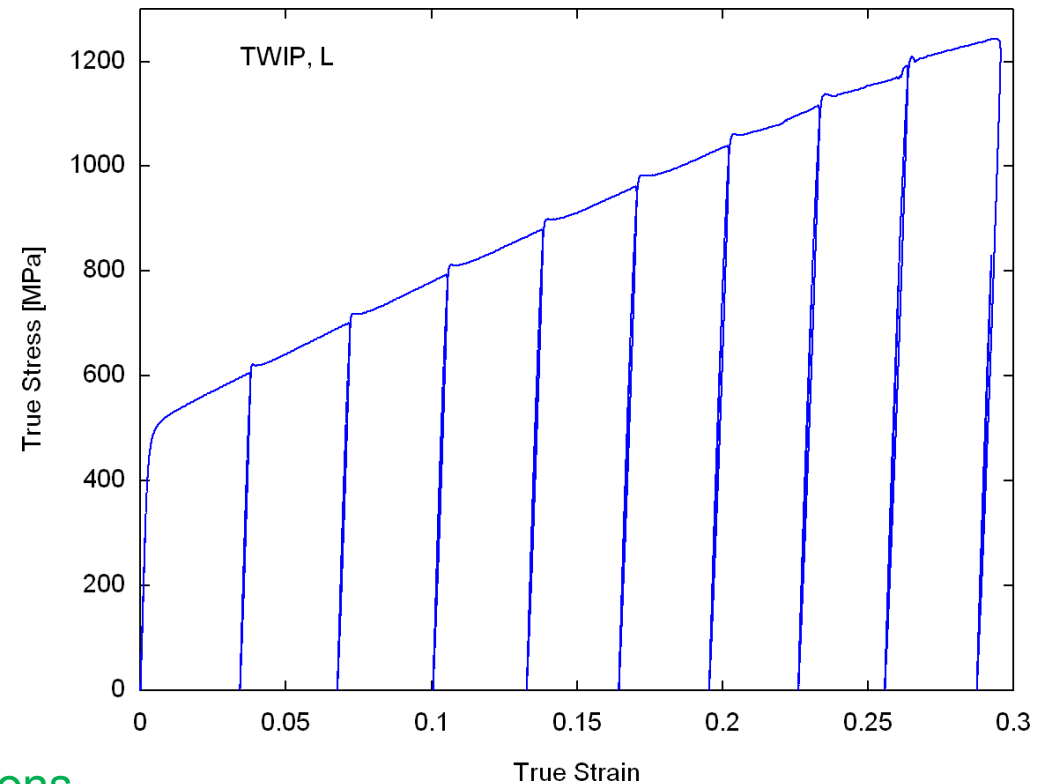
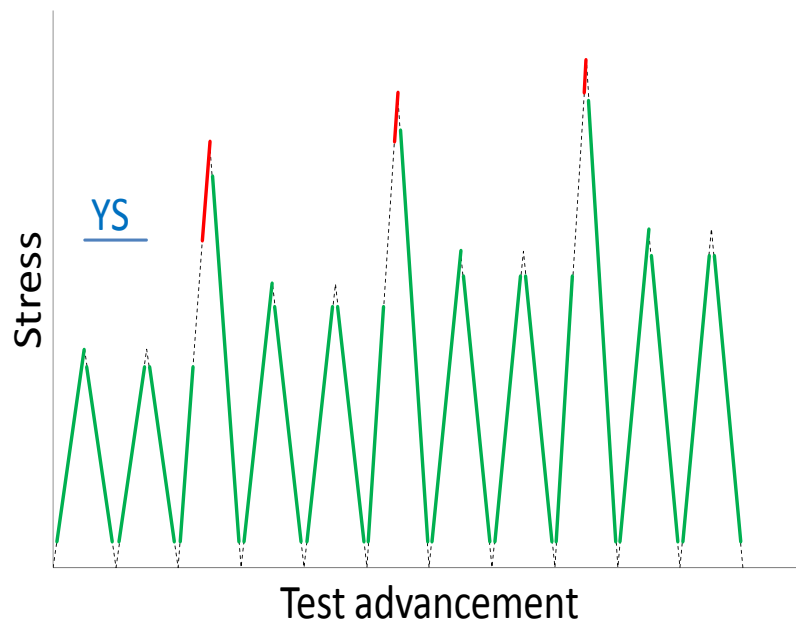


Results (3): elastic modulus obtained from the 1st unload after the plastic strain, or from the successive (1st) reload



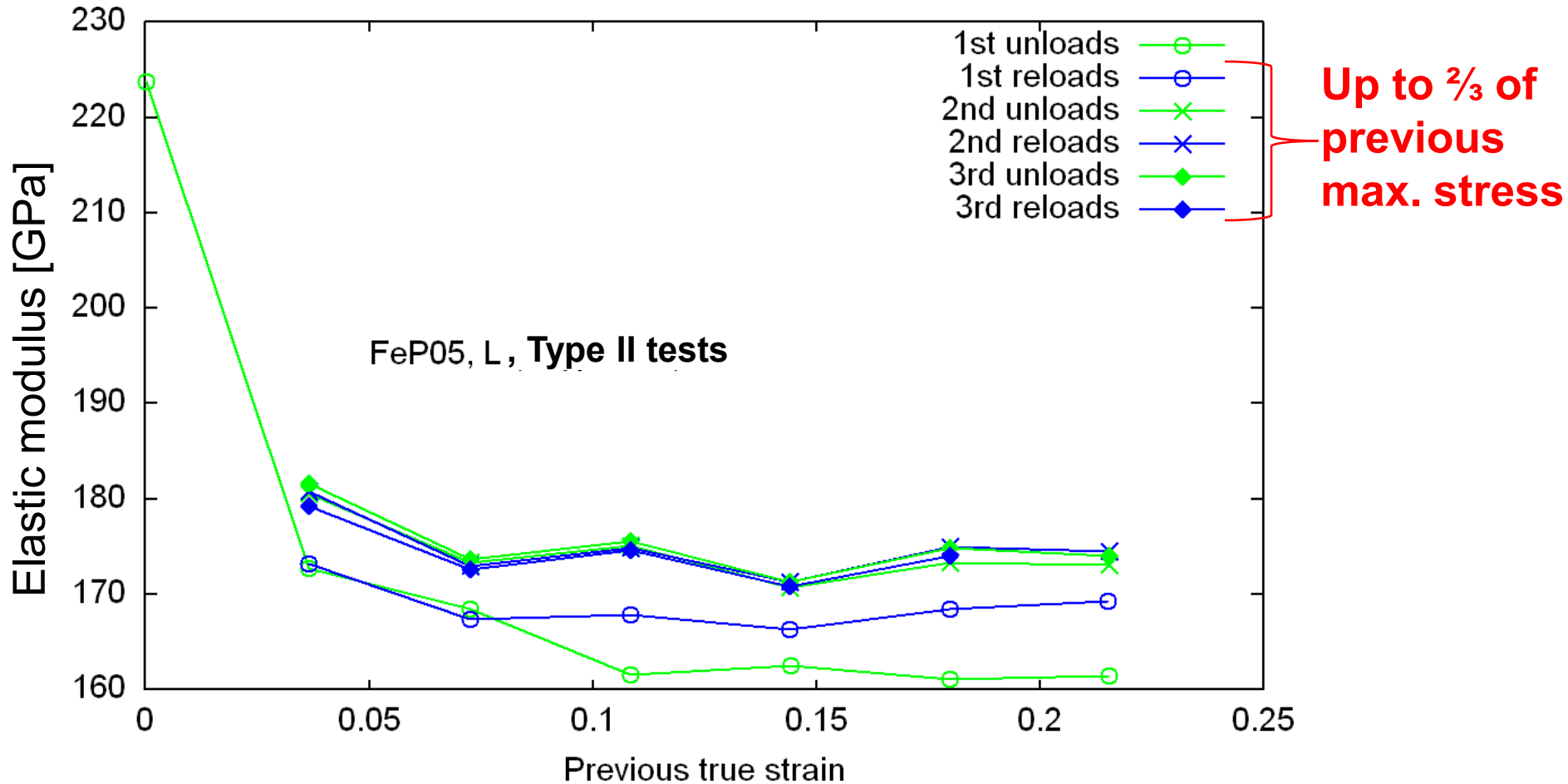
Type II tests

- repeated $\approx 3\%$ true **plastic strain steps**
(elastic strain rate: loading $\approx 10^{-3} \text{ s}^{-1}$, unloading $\approx 10^{-4} \text{ s}^{-1}$)
- 2 elastic unload-reload cycles at test start and after each plastic step, up to $\frac{2}{3}$ of YS or $\frac{2}{3}$ of previous maximum stress (strain rate $\approx 10^{-4} \text{ s}^{-1}$)



green lines: elastic modulus calculations

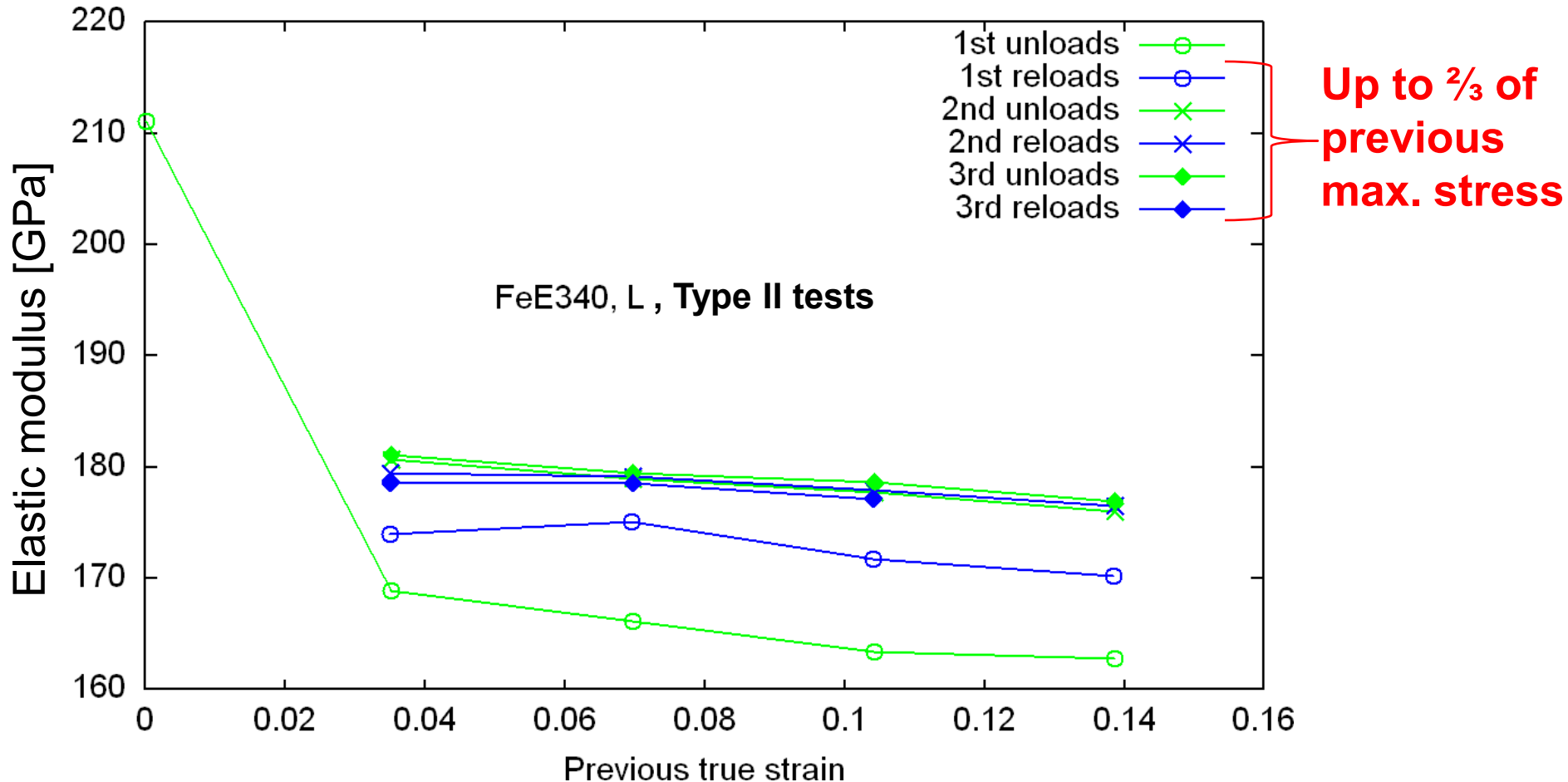
Results (4): elastic modulus measured upon successive unloads and reloads after the plastic strain



Differences are slightly broader than in type I tests, probably due to the lower reloading max. stress.

After the 2nd unload-reload cycle, an asymptote is reached

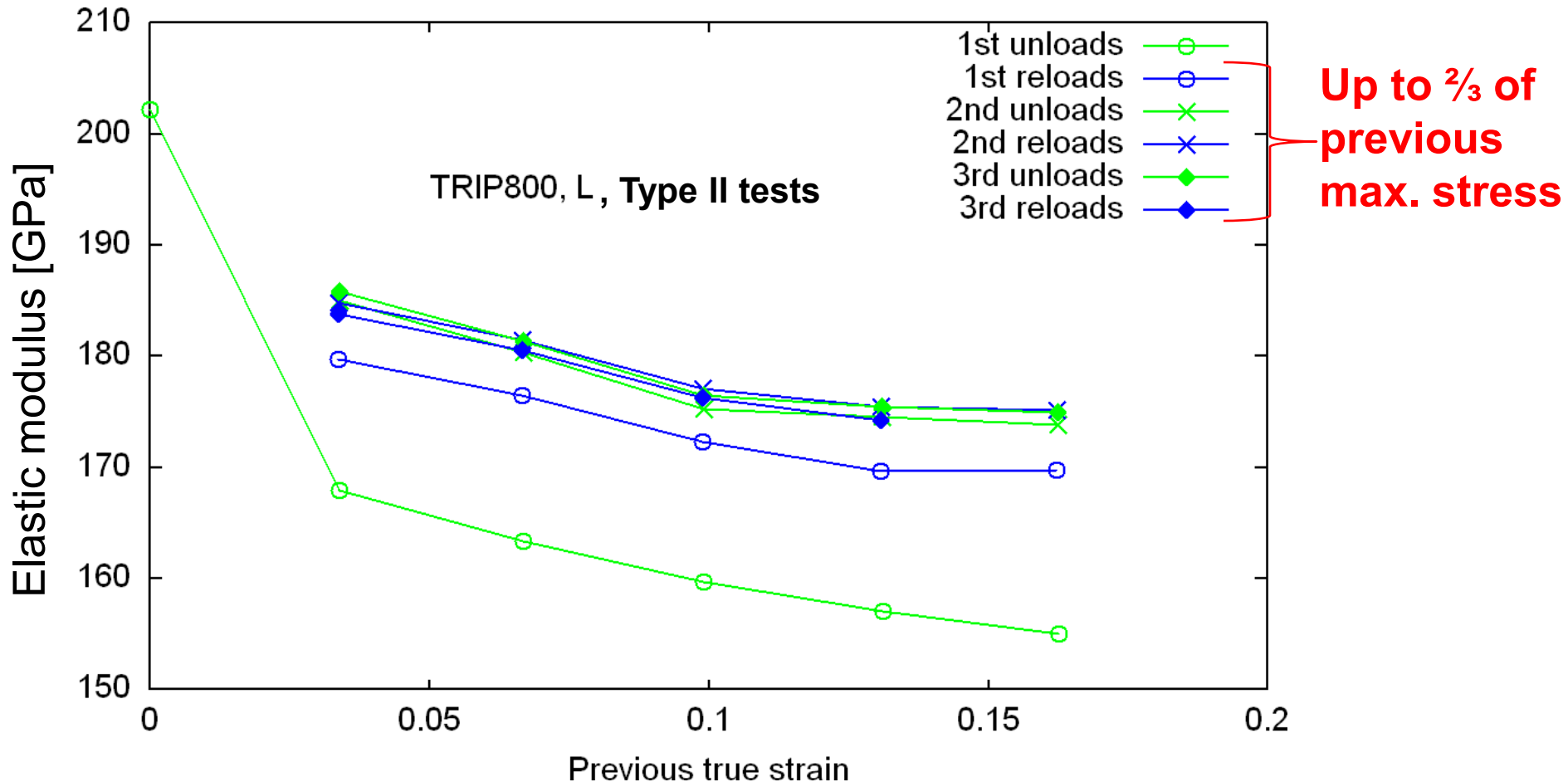
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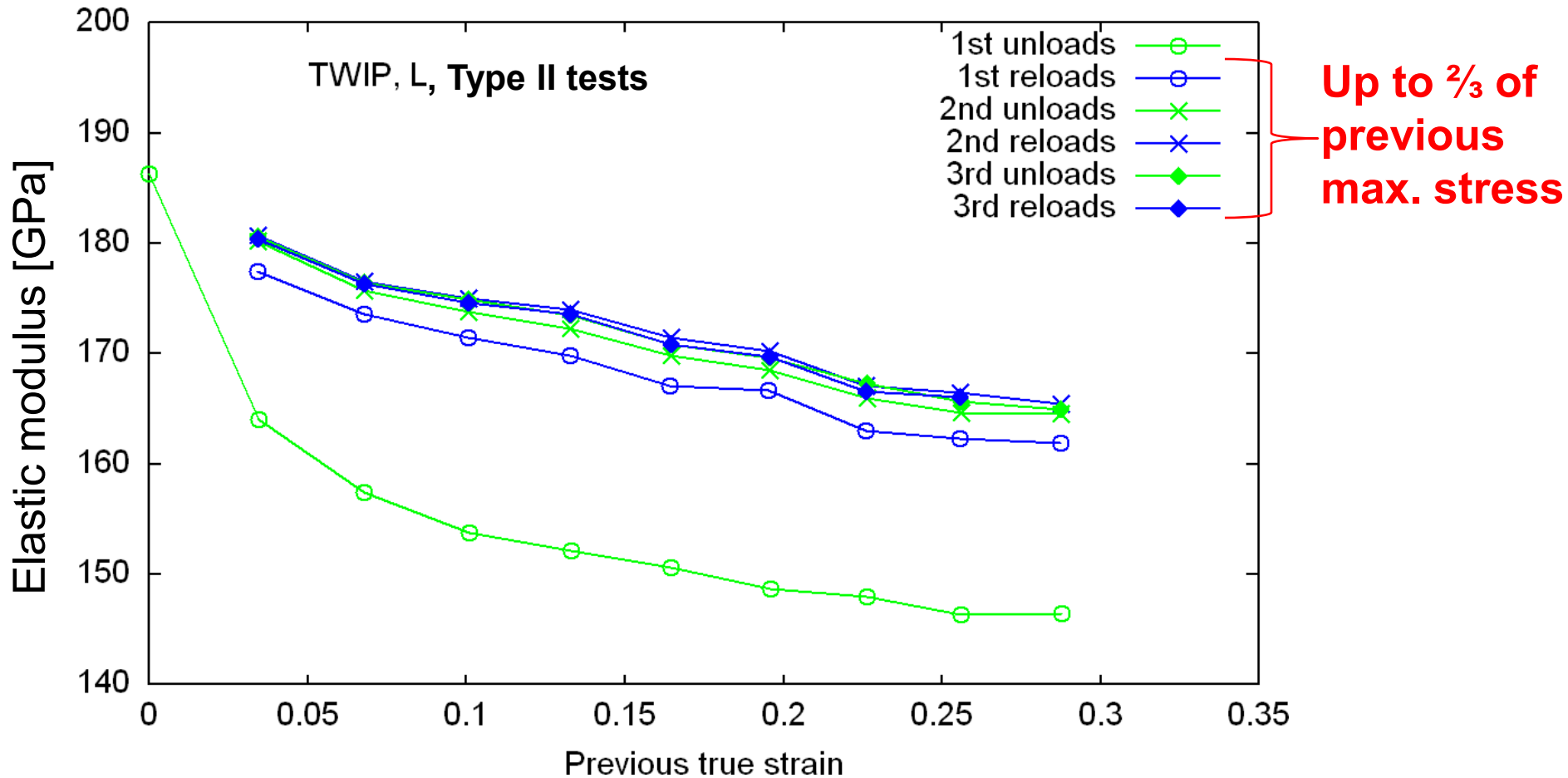
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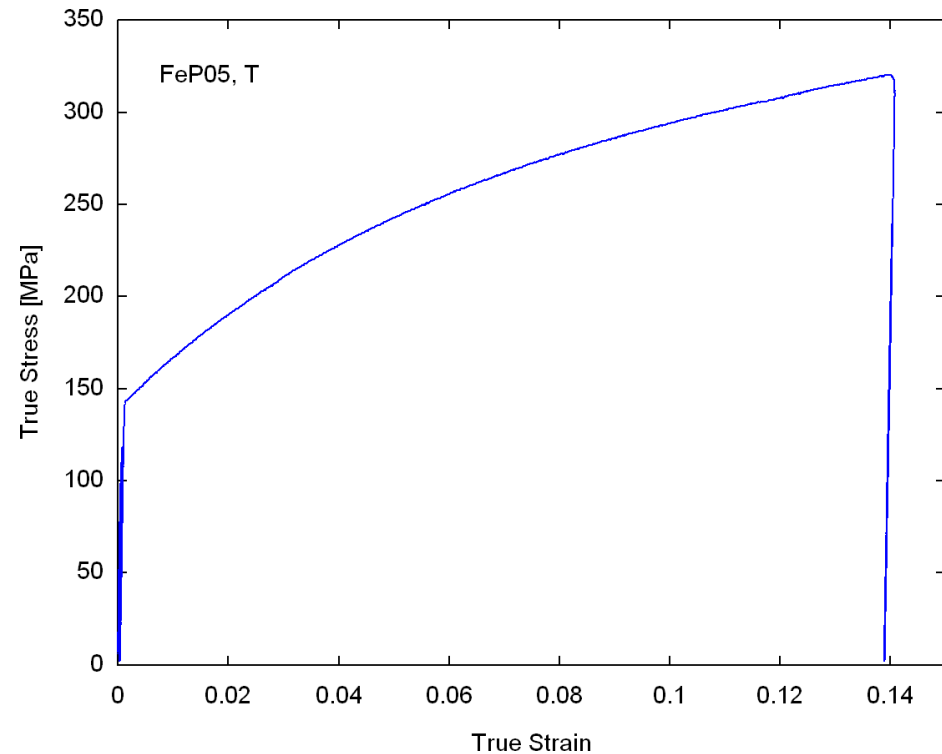
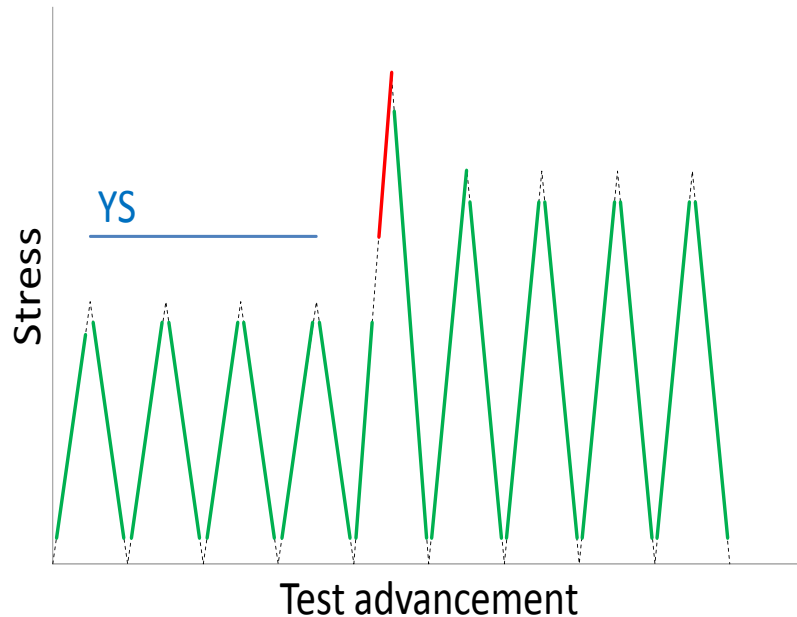


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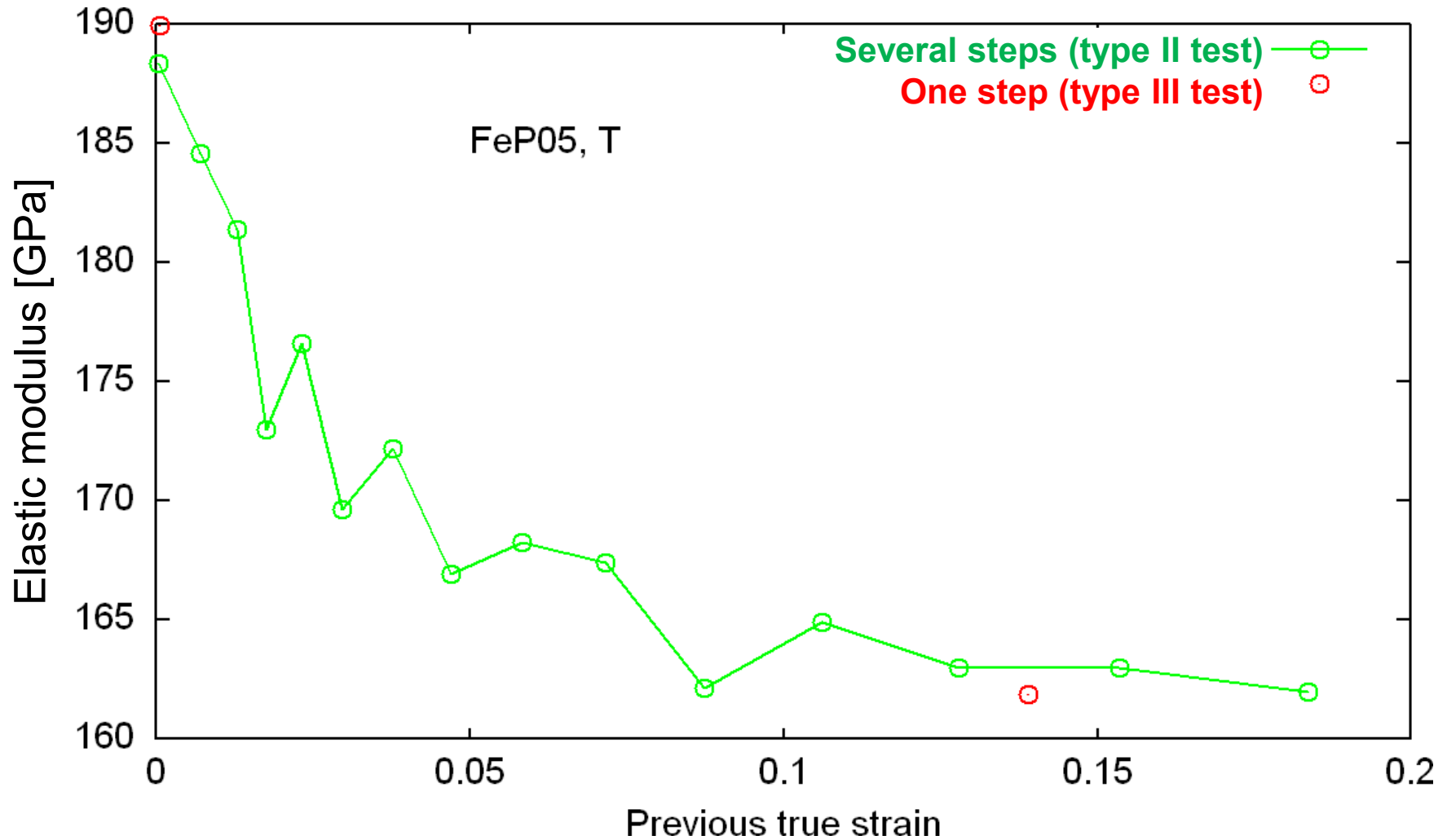
Type III tests

- one $\approx 14\%$ true **plastic strain step**
(elastic strain rate: loading $\approx 10^{-3} \text{ s}^{-1}$, unloading $\approx 10^{-4} \text{ s}^{-1}$)
- 4 elastic unload-reload cycles at test start, up to 80% YS, and after the plastic strain, up to 80% of maximum stress (strain rate $\approx 5 \cdot 10^{-5} \text{ s}^{-1}$)



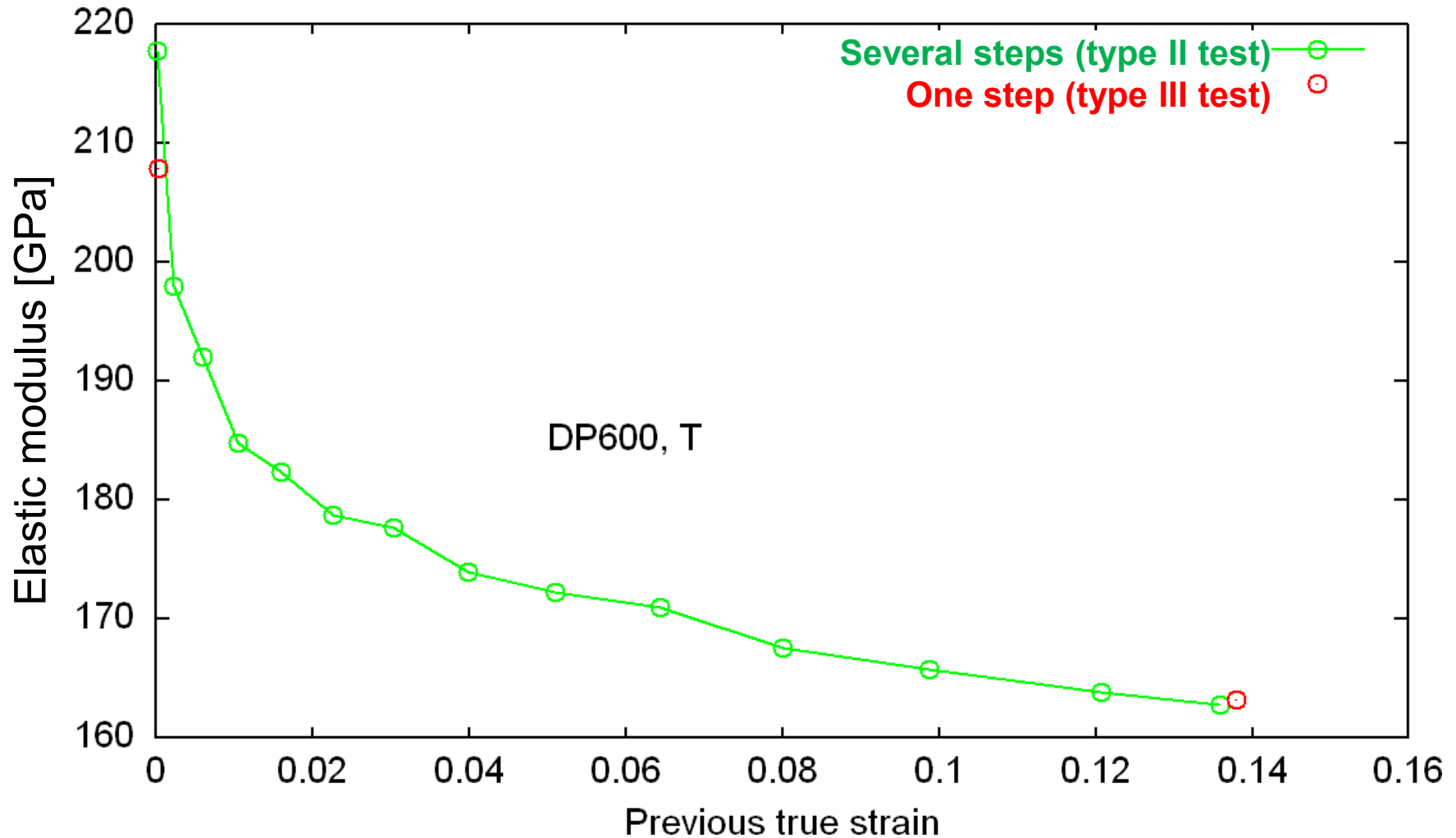
green lines: elastic modulus calculations

Results (5): elastic modulus measured after one or several prestrain steps (upon 1st unloading)



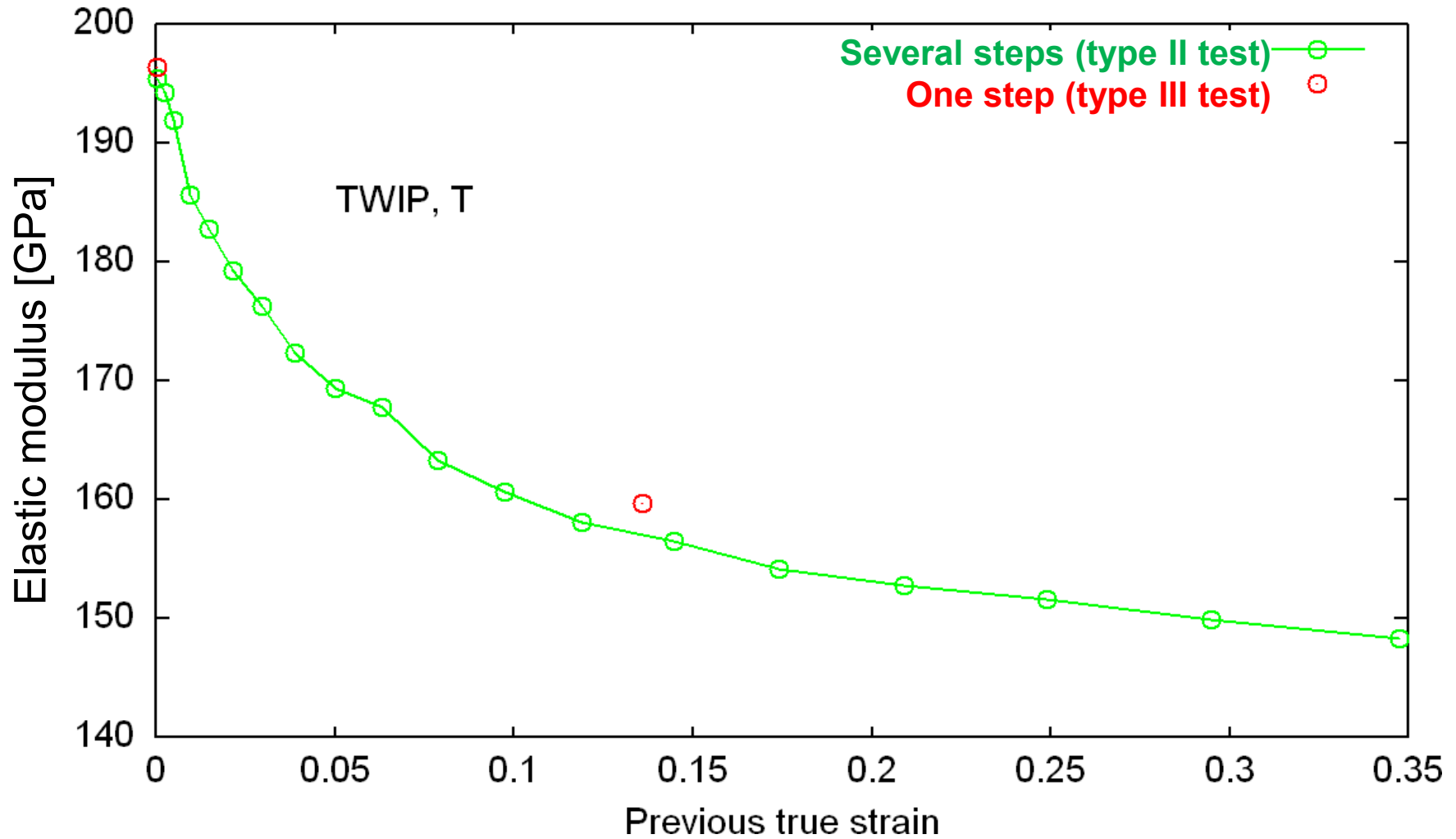
No relevant differences

Results (5): elastic modulus measured after one or several prestrain steps (upon 1st unloading)



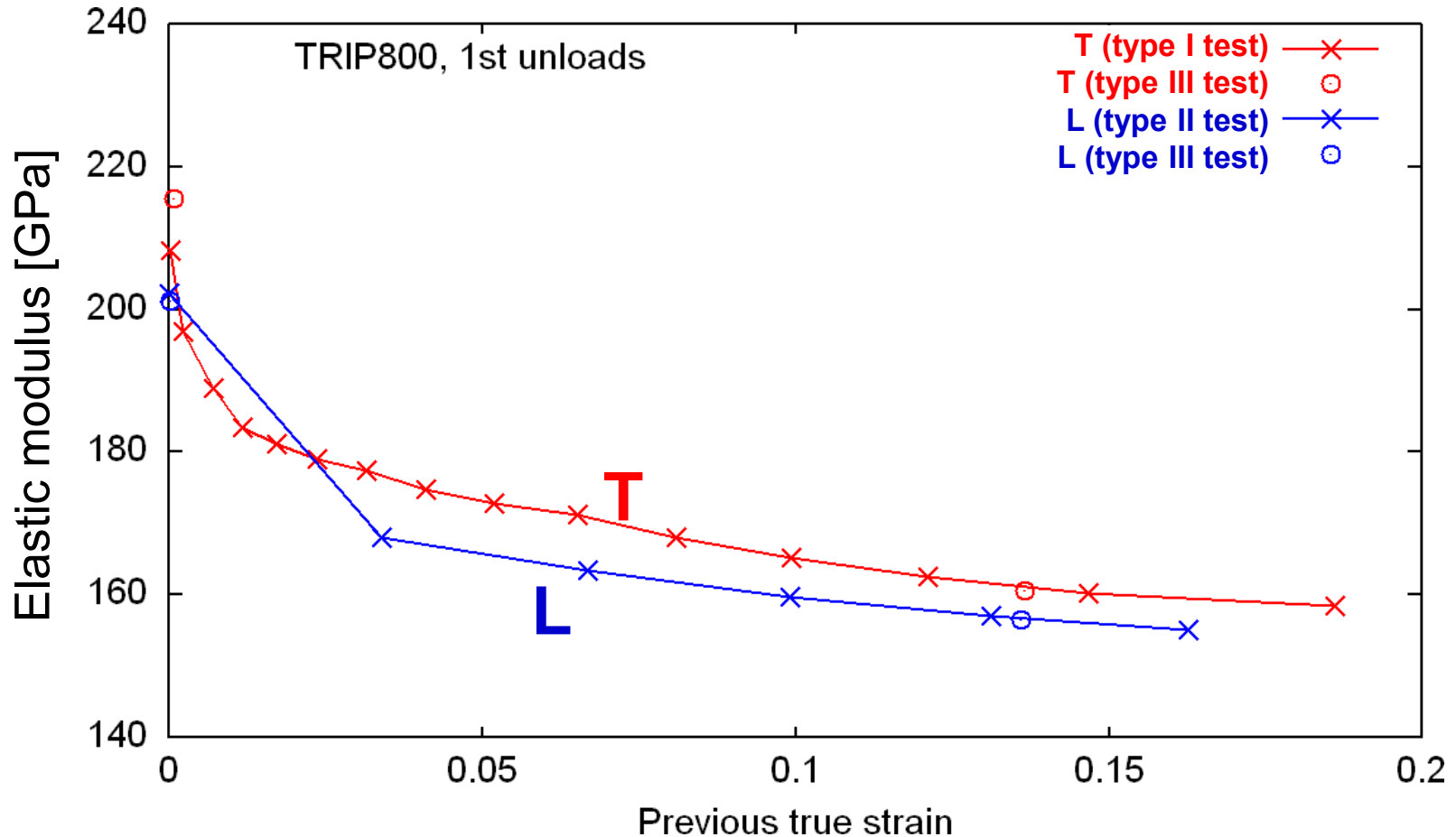
No relevant differences

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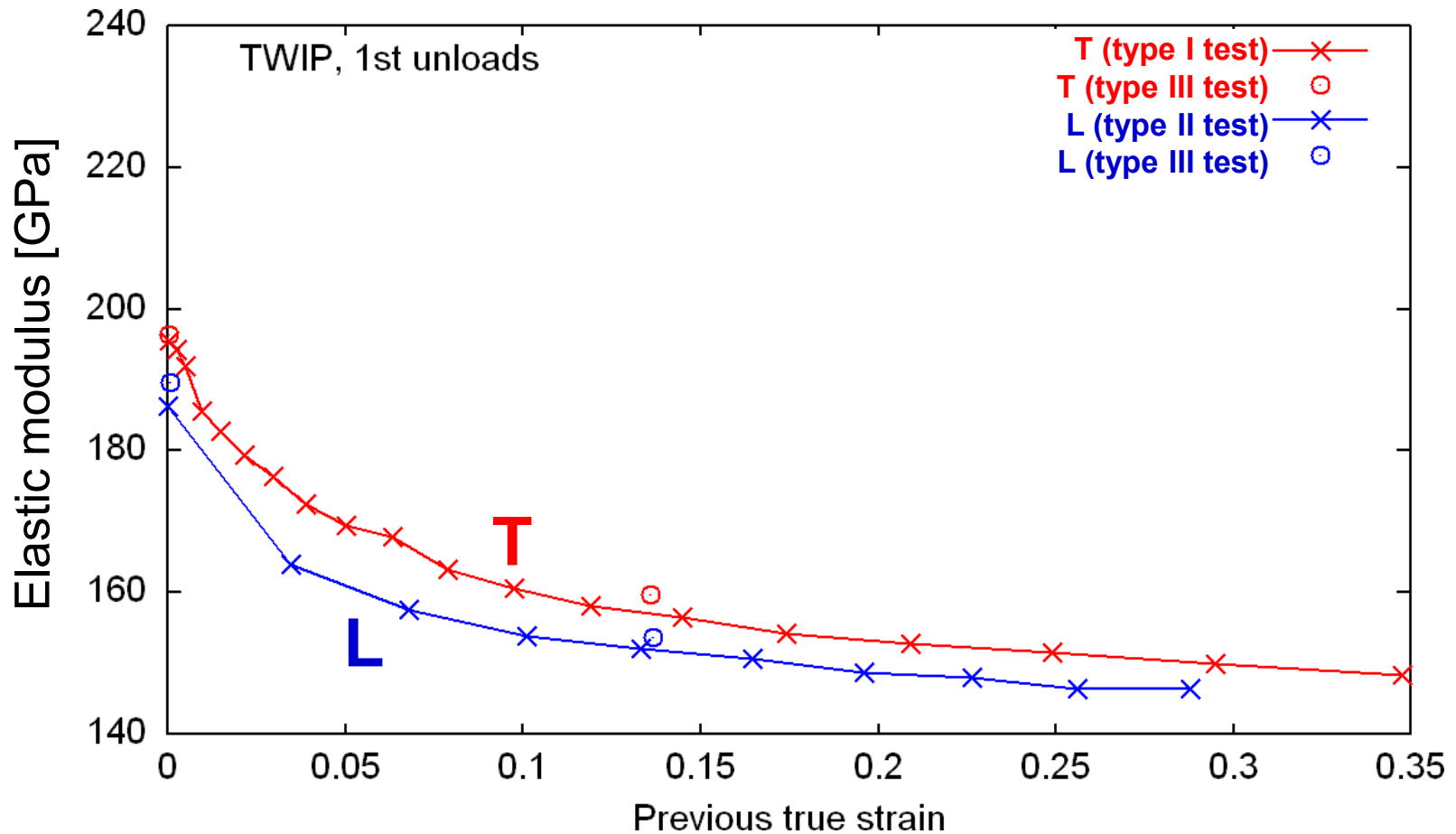
No relevant differences

Results (5): elastic modulus of specimens with T or L rolling orientations (measured upon 1st unloading)



A small difference due to the specimen orientation can be detected in most examined materials

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A small difference due to the specimen orientation can be detected in most examined materials

Conclusions

- The elastic modulus of the examined automotive steels decreases with increasing previous plastic deformation (done at room temperature)
- If one or more elastic unloading and reloading cycles are performed after a plastic deformation, increasing values of elastic modulus are detected, until an asymptote is reached (which, however, is still lower than the modulus of the undeformed steel)
- No significant differences are detected if the same previous plastic deformation is performed in one or several steps
- Smaller differences are due to the orientation relative to sheet rolling