Realize Your Product Promise™

Shape Memory Alloy – Superelastic vs. Shape Memory Effect Models

Sheldon Imaoka

ANSYS Technical Support Group

Revision 4

Shape Memory Alloy

The Shape Memory Alloy material model (TB,SMA) has been available in ANSYS for nearly a decade.

In ANSYS 14.0, a new option for SMA is introduced.

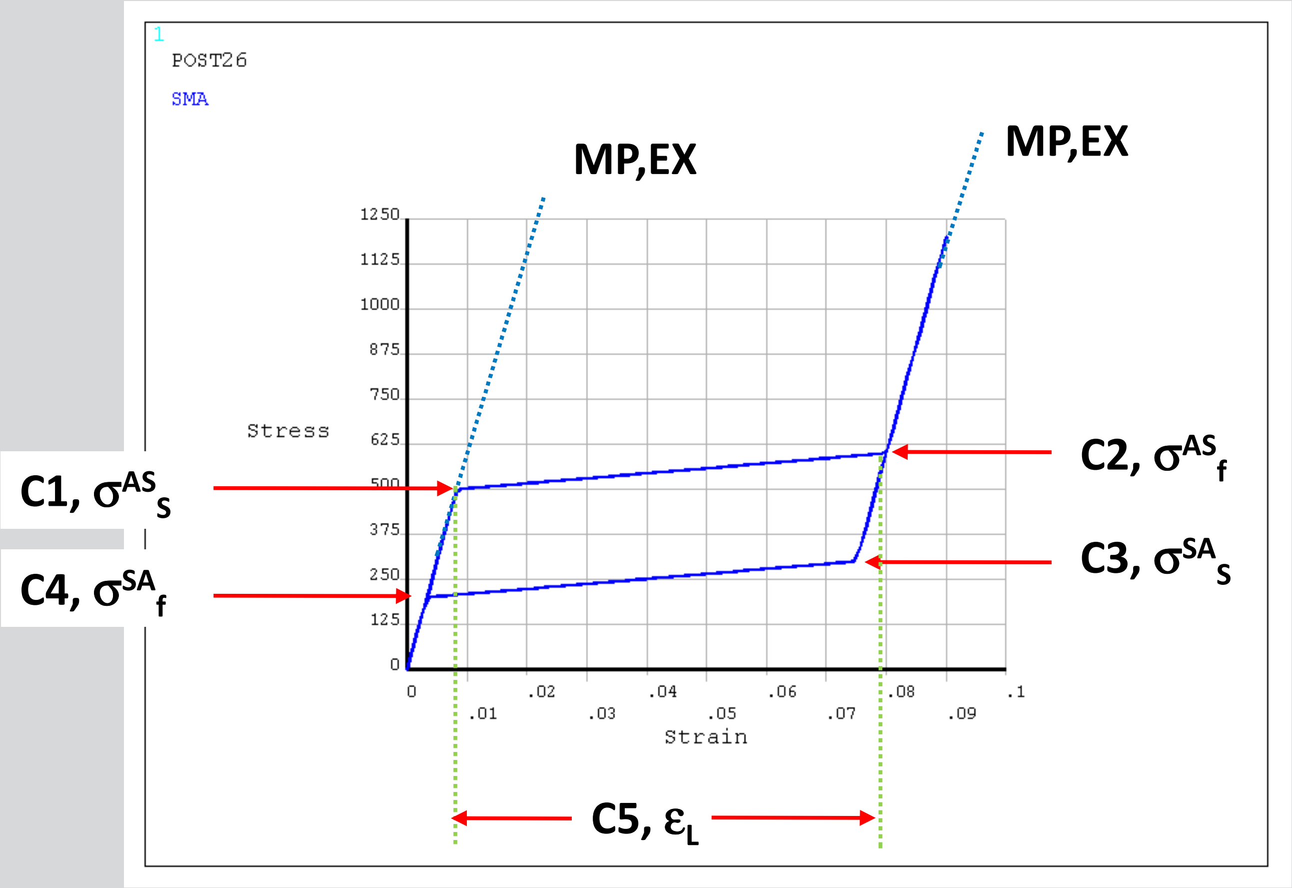
- The pre-14.0 formulation is now renamed *SMA for Superelasticity* and is accessed with TBOPT=SUPE
- The new 14.0 formulation is referred to as *SMA with Shape Memory Effects* and is activated with TBOPT=MEFF

Please refer to the *Material Reference* in the ANSYS 14.0 Help for details on both options (TB,SMA,matid,,,TBOPT)

This short presentation will help users understand the differences in material inputs

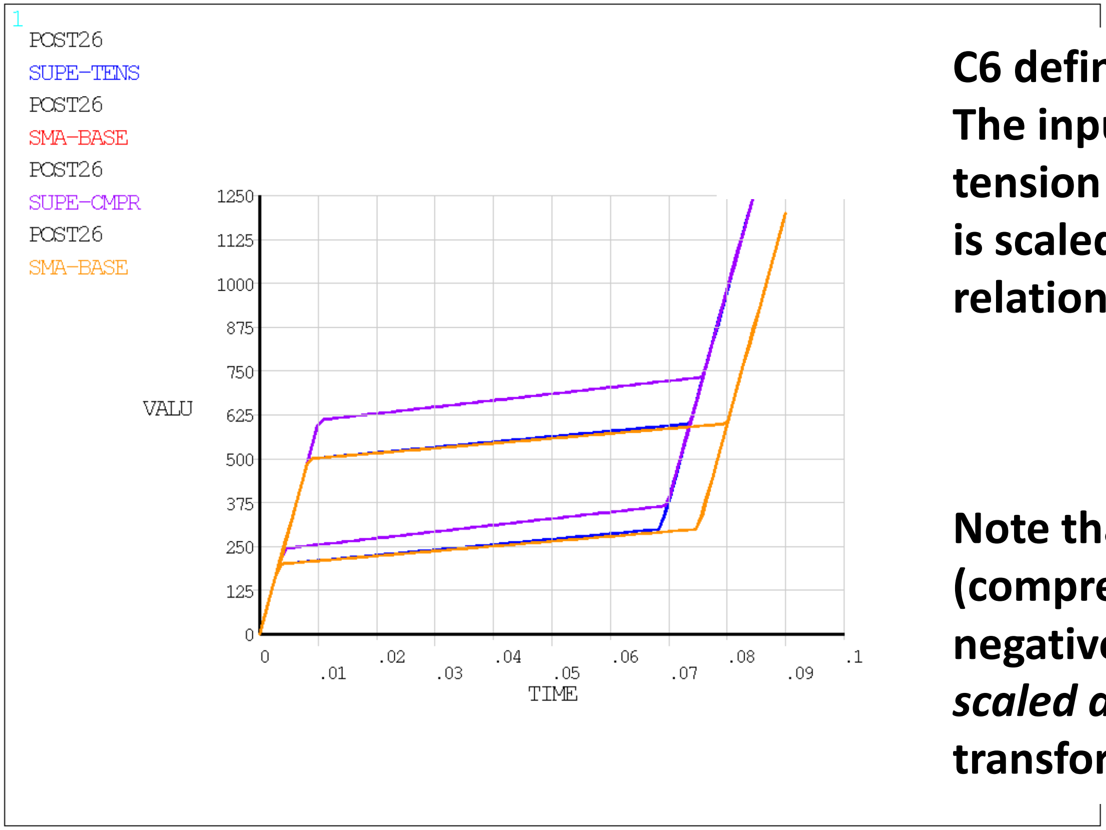
Superelastic Option

TB,SMA,matid,,,SUPE constants shown below:



Superelastic Option

The 6th constant, α, changes the response in compression. Example of α=0.1 below:



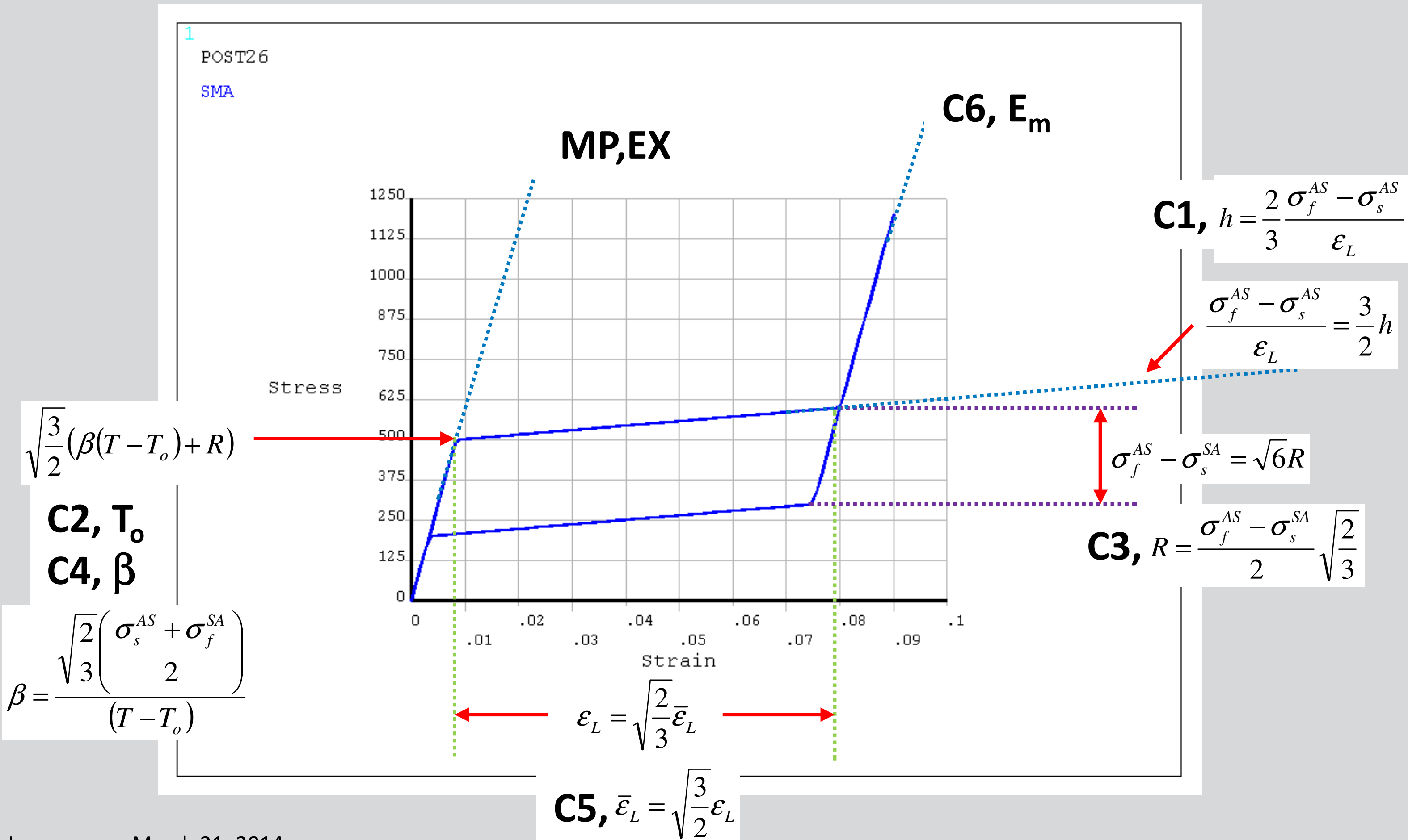
C6 defines the difference in compression. The input C1-C4 coefficients describe tension behavior. Compression response is scaled accordingly via the following relationship:

$$\alpha = \frac{\sigma_c^{AS} - \sigma_t^{AS}}{\sigma_c^{AS} + \sigma_t^{AS}}$$

Note that all constants are positive (compression stress not input as negative). Also note that *ε_L needs to be scaled as a result*, and slopes in transformation region will change.

Shape Memory Effect Option

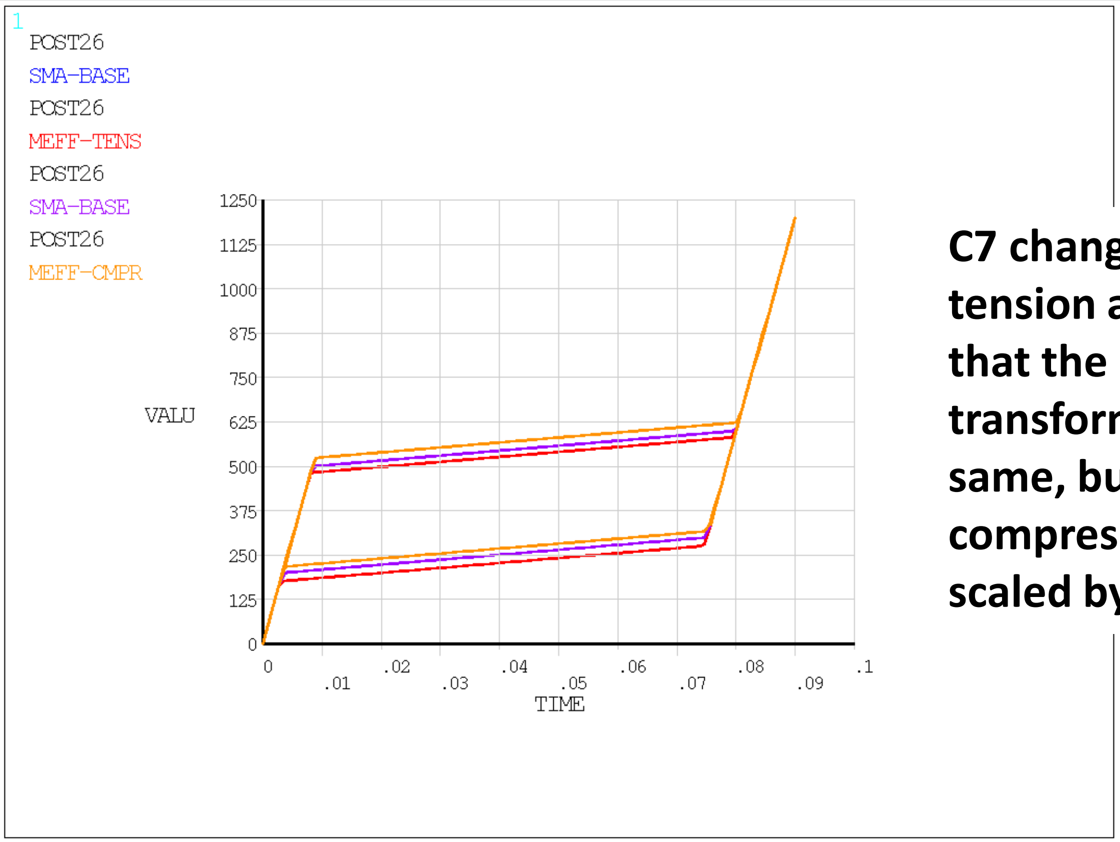
TB,SMA,matid,,,MEFF options shown below:



  March 21, 2014

Shape Memory Effect Option

The 7th constant, *m*, is the Lode dependency parameter, changing tension vs. compression:



C7 changes the response in tension and compression. Note that the maximum transformation strain is the same, but *both* the tension and compression responses are scaled by stress only.

Shape Memory Effect Option

To calculate *m* and *R*, take the uniaxial tension σ_t and compression σ_c strengths at $T=T_o$ and use the relation below:

$$m = \sqrt{\frac{27}{2}} \frac{\sigma_c - \sigma_t}{\sigma_c + \sigma_t} \qquad R = 2\sqrt{\frac{2}{3}} \frac{\sigma_c \sigma_t}{\sigma_c + \sigma_t}$$

Comparison of both models

- **TBOPT=SUPE assumes martensite elastic modulus is same as austenite. TBOPT=MEFF supports different martensite modulus.**
- **TBOPT=SUPE allows for different stress-strain slopes depending on transformation. TBOPT=MEFF assumes same slope for both transformations.**
- **Because of formulation of TBOPT=MEFF, there is a factor of sqrt(3/2) (or sqrt(2/3)) that arises compared with true stress/strain values. Please be careful of this.**
- **The stress at which transformation starts for TBOPT=MEFF is based on both *R* and $\beta(T-T_o)$.**
- **TBOPT=MEFF includes temperature term, allowing for modeling of shape memory effect. TBOPT=SUPE is just superelastic phenomenon, although input of temperature-dependent coefficients is possible.**

Comparison of both models

- Both TBOPT=SUPE and TBOPT=MEFF can model ‘stiffer’ response in compression, but they do it in a very different manner, so while relationships between all other constants for some situations can be established, this effect is not as straightforward to correlate between both models.
  - Because of equations used, the TBOPT=MEFF model may not be able to model drastically different tension vs. compression responses (usually not an issue for Nitinol).
  - TBOPT=SUPE accepts negative input for tension > compression. This is not physically valid for Nitinol, but it is worth noting that it is *possible* to model such a material with TBOPT=SUPE.

Selection of the Material Model

- If shape memory effect (i.e., temperature-induced transformation) is required, use TBOPT=MEFF.
- If only superelastic effect (e.g., isothermal conditions) is required, either model can be used, although TBOPT=SUPE may be more straightforward to implement.
  - TBOPT=SUPE allows different slopes for transformation region
  - TBOPT=MEFF allows different martensite elastic modulus
- For TBOPT=MEFF, unsymmetric matrices result, so use NROPT,UNSYM if convergence difficulties are encountered.

