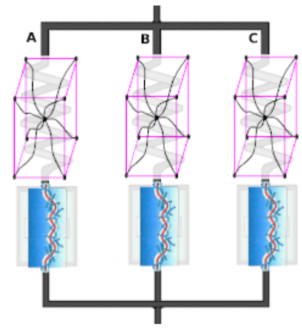
PolyUMod TNV Model

Introduction



The Three Network Viscoplastic (TNV) model is a general purpose viscoplastic material model capable of capturing the experimentally observed behaviors of many thermoplastics, including time-dependence, pressure-dependence of plastic flow, pressure-dependent bulk modulus, volumetric plastic flow, damage accumulation, and triaxiality dependent failure. The PolyUMod implementation of the TNV model uses 1, 2, or 3 parallel networks, and one optional failure model. The first three parameters of the material model specify the network type for each network, and the fourth parameter specifies the failure model type.

The model supports the following hyperelastic components: Yeoh, anisotropic HGOB hyperelastic HGOB (Holzapfel-Gasser-Ogden-Bergstrom), and the hyperfoam model. Each of these can be combined with optional Mullins damage. Each network can also have isotropic or anisotropic power-law viscoplasticity. The model can also use a strain or stress based failure model with a failure value that depends on the strain-rate and stress triaxiality.

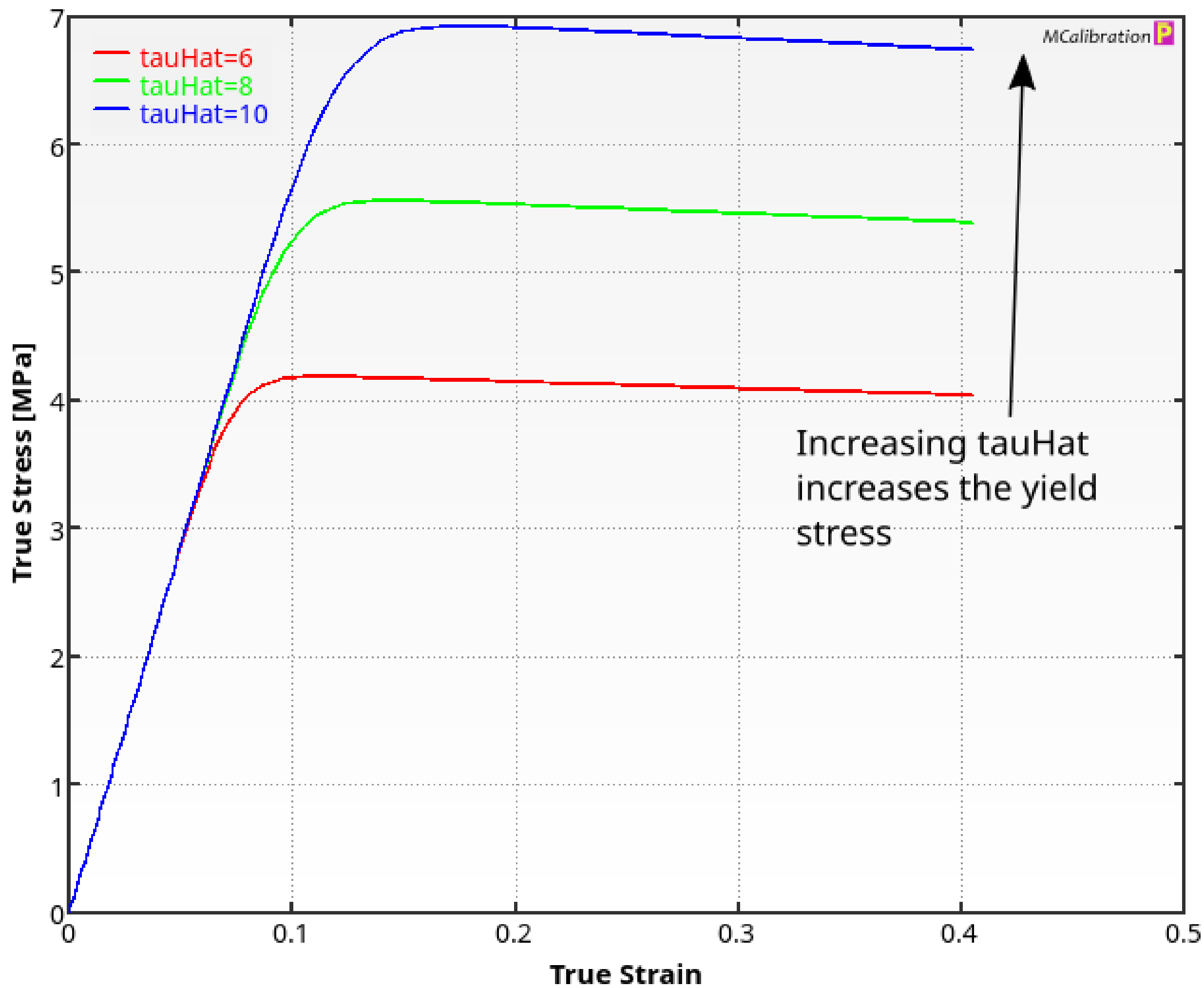
It is easy to explore all of these combinations using MCalibration! The details of each model component are listed in the PolyUMod User's Manual. The TNV model is an alternative to the PolyUMod Three Network (TN) model. The TNV model is more general and often slightly more accurate than the TN model. Also the TNV model can predict volumetric plastic flow. Temperature dependence is not part of the TNV model, but can be added using the multi-temperature framework.

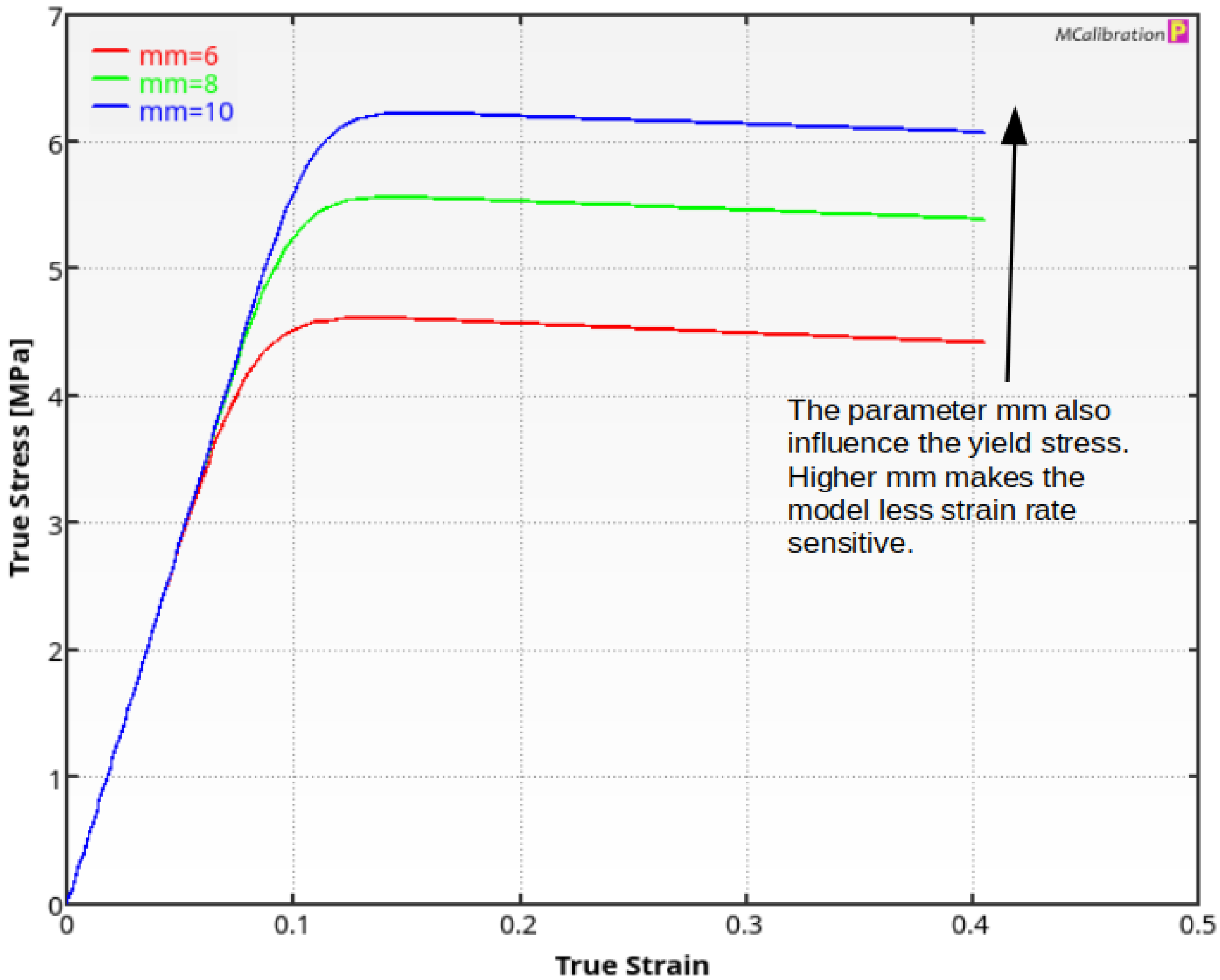
The following are the key state variables that are used by the TNV model.

Index	State Variable Name
39	Max principal stress/strain (depending on the failure model)
40	Stress triaxiality
41	max stress/strain divided by the failure stress/strain (depending on the failure model)
42	Failure damage factor D

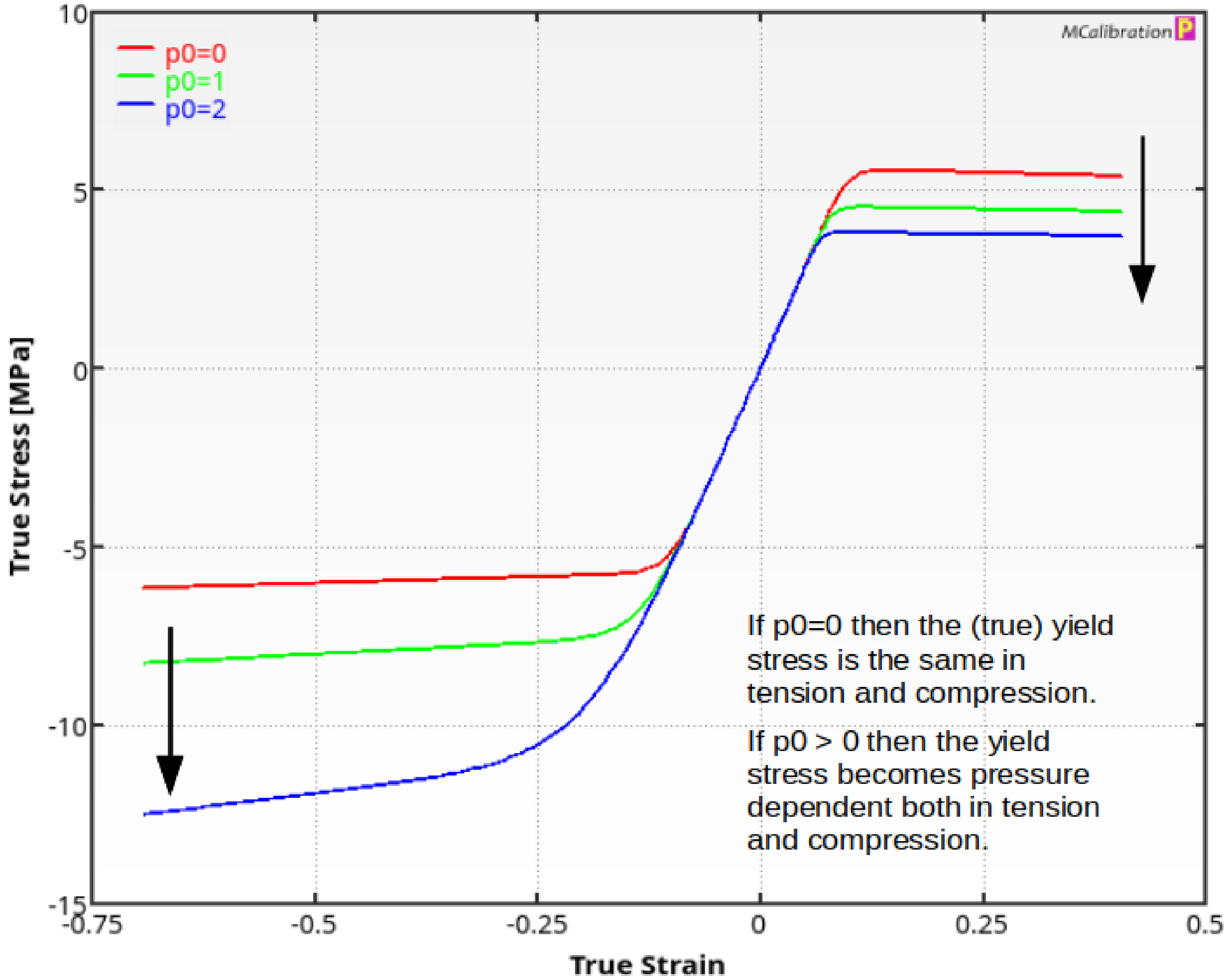
Parameters Controlling the Viscoplastic Flow

The TNV model uses the following material parameters to control the viscoplastic flow rate: [tauHat, mm, bb, p0, fff, epsF, ceps, fss]. The meaning of these parameters is explained graphically in the figures below.

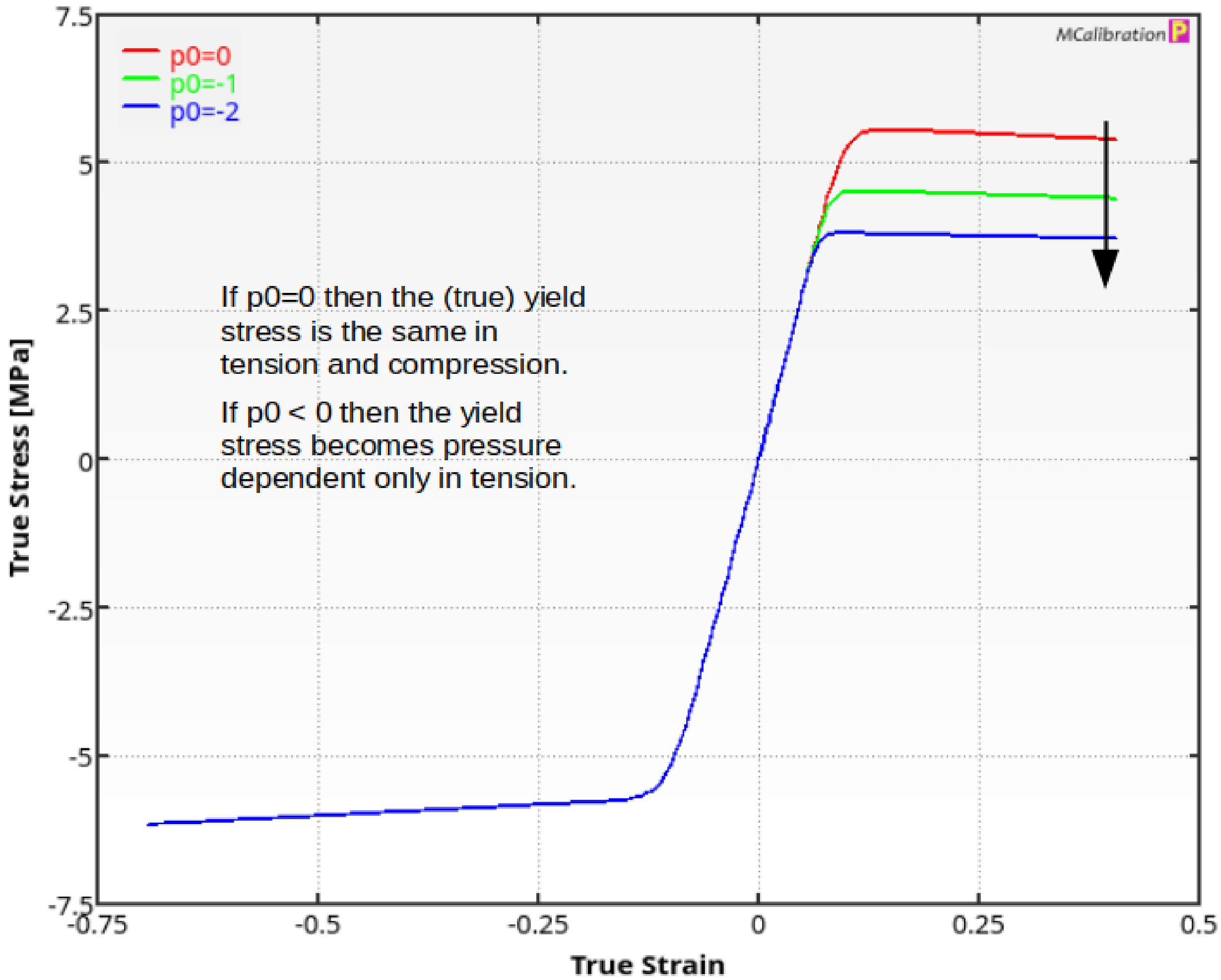




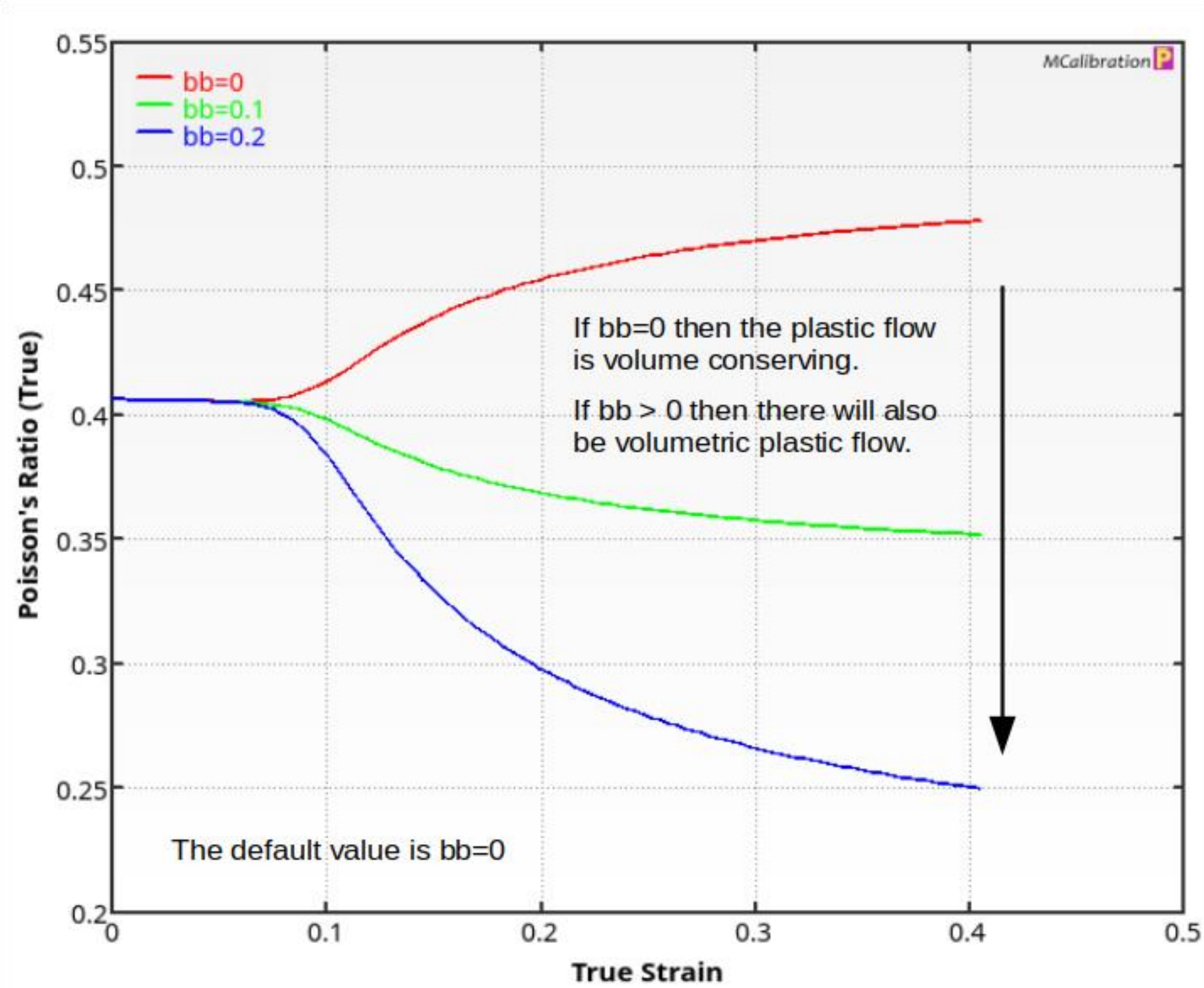
mm=6
mm=8
mm=10
MCalibration
The parameter mm also influence the yield stress. Higher mm makes the model less strain rate sensitive.
True Stress [MPa]
True Strain
0
1
2
3
4
5
6
7
0
0.1
0.2
0.3
0.4
0.5

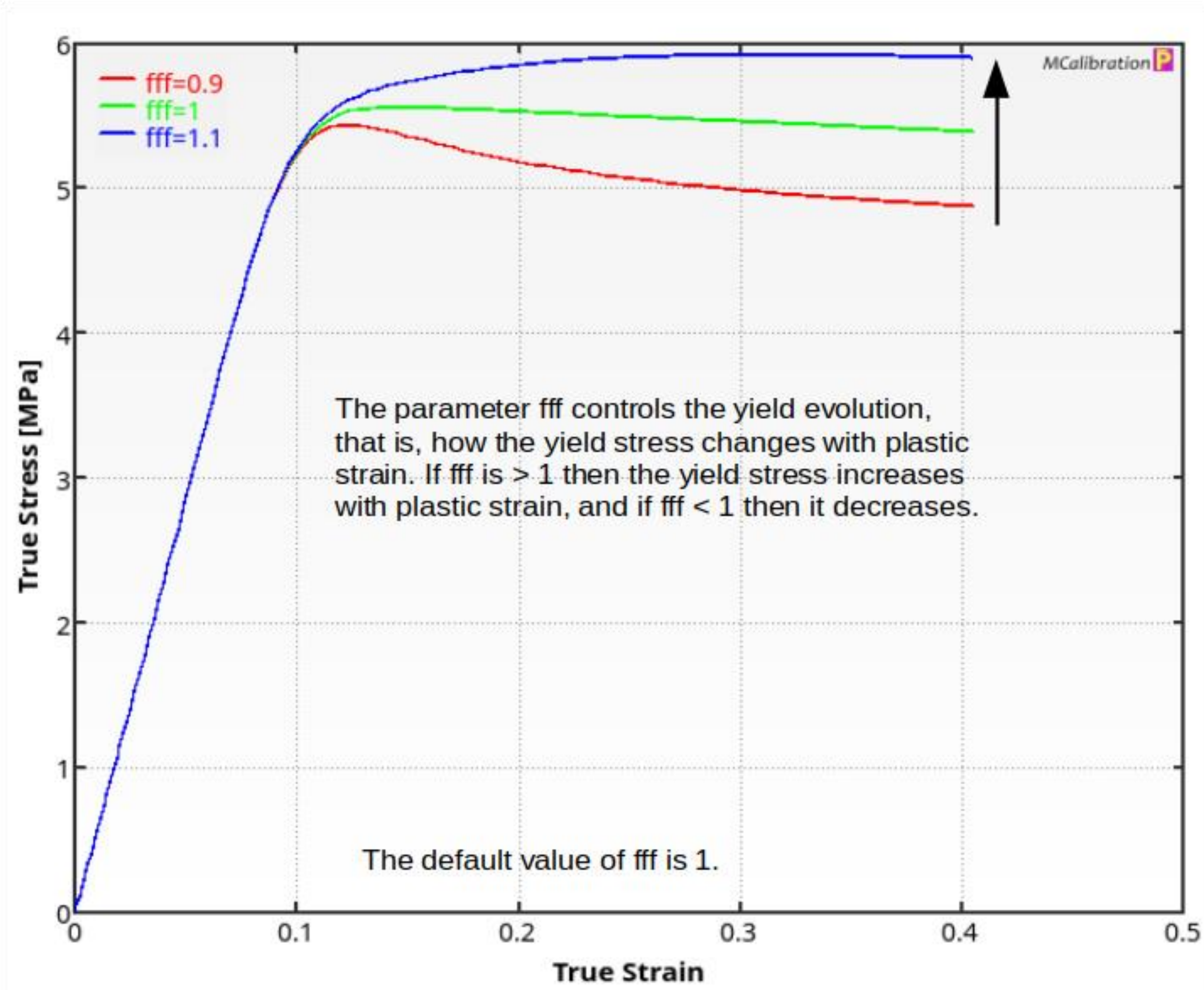


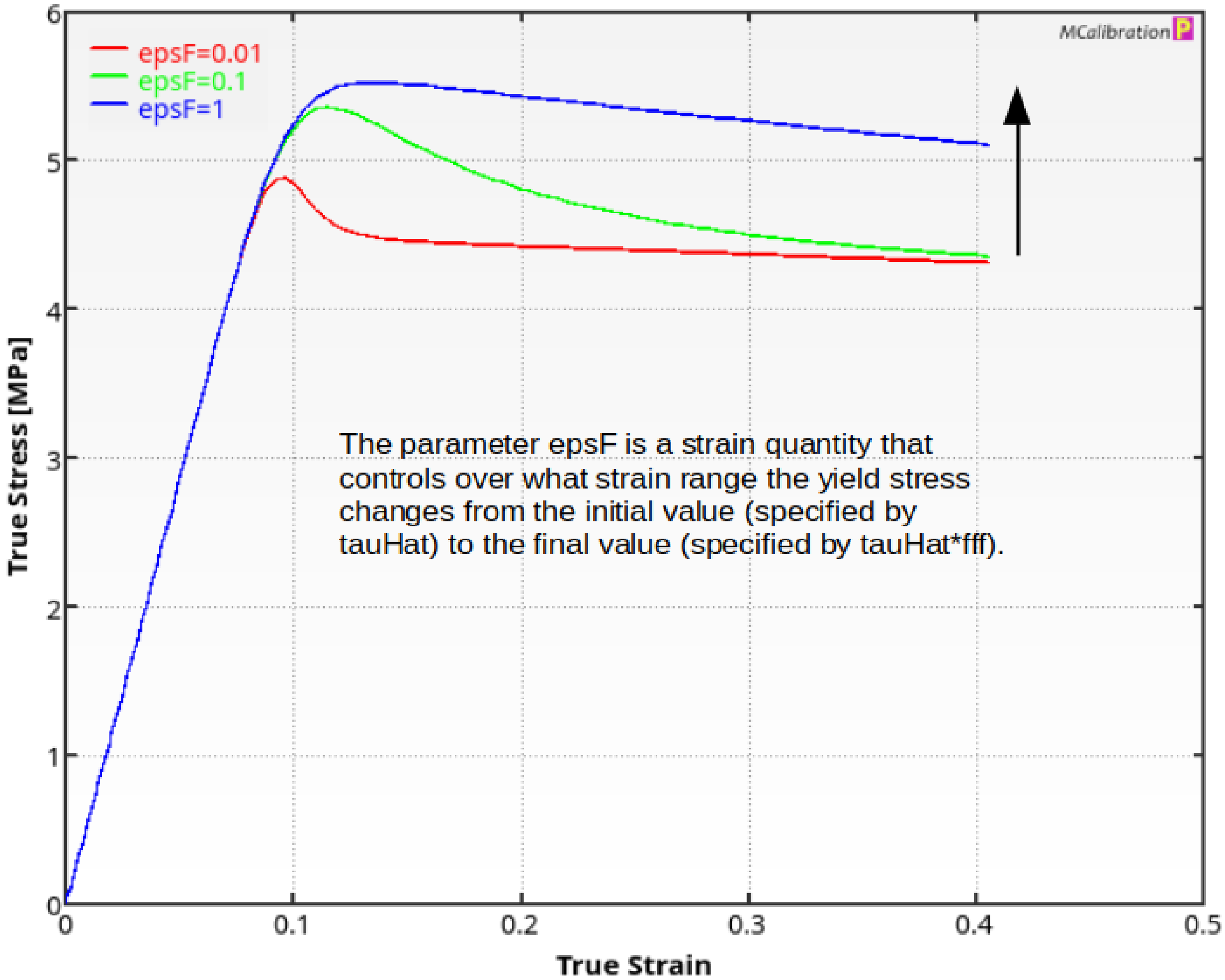
MCalibration
p0=0
p0=1
p0=2
If p0=0 then the (true) yield stress is the same in tension and compression.
If p0 > 0 then the yield stress becomes pressure dependent both in tension and compression.
True Stress [MPa]
True Strain
10
5
0
-5
-10
-15
-0.75
-0.5
-0.25
0
0.25
0.5



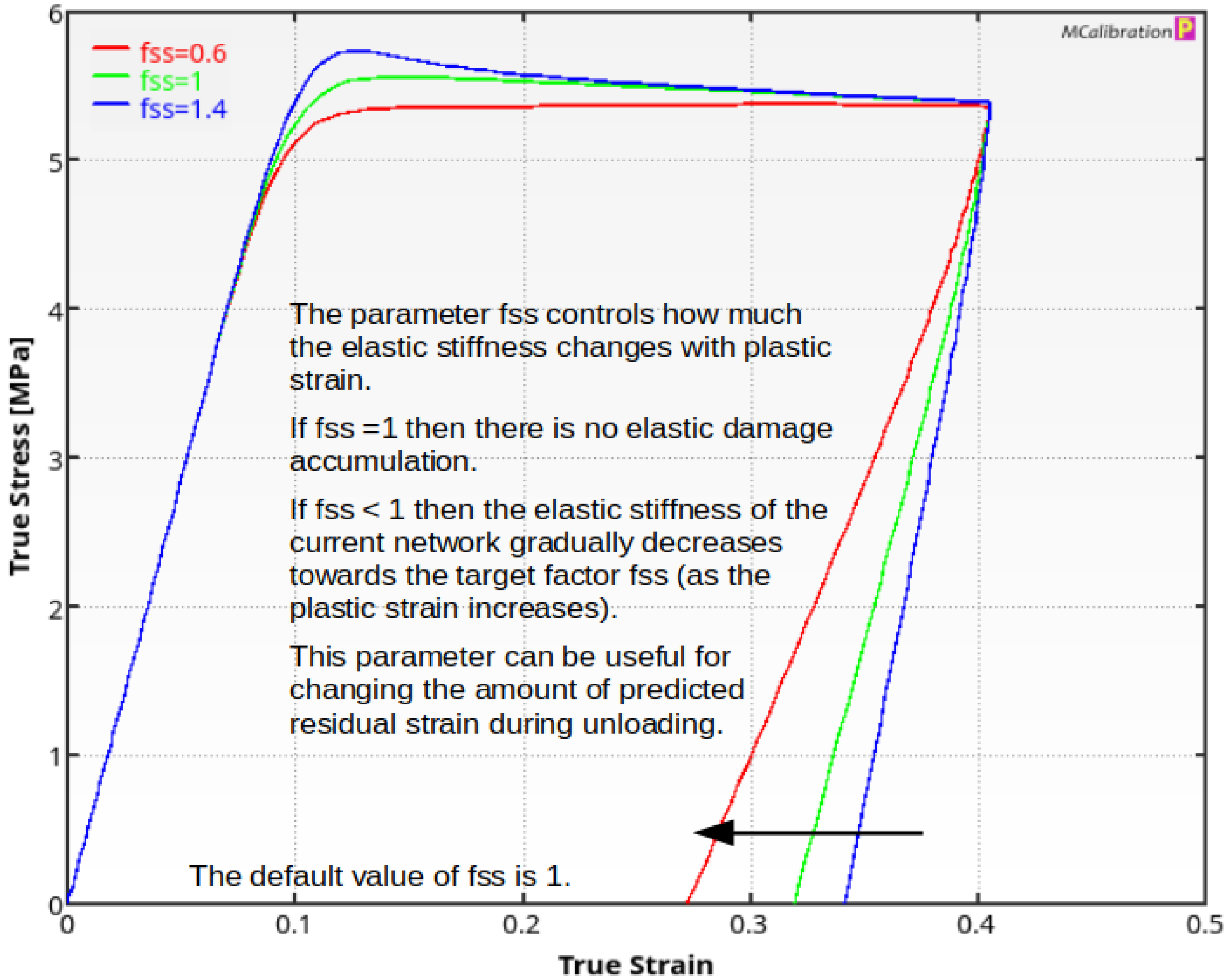
MCalibration
p0=0
p0=-1
p0=-2
If p0=0 then the (true) yield stress is the same in tension and compression.
If p0 < 0 then the yield stress becomes pressure dependent only in tension.
True Stress [MPa]
True Strain
7.5
5
2.5
0
-2.5
-5
-7.5
-0.75
-0.5
-0.25
0
0.25
0.5

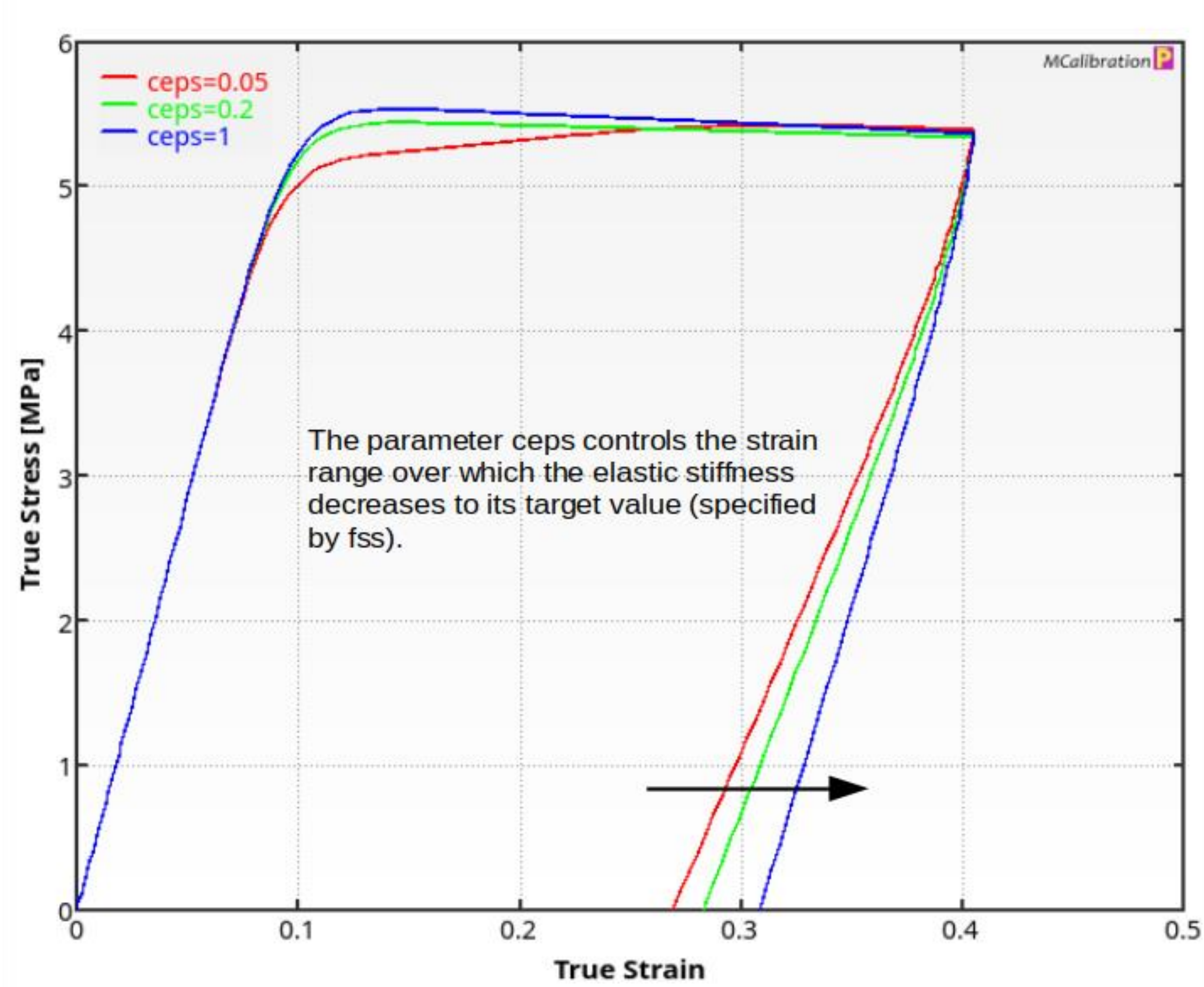

MCalibration
bb=0
bb=0.1
bb=0.2
If bb=0 then the plastic flow
is volume conserving.
If bb > 0 then there will also
be volumetric plastic flow.
The default value is bb=0
Poisson's Ratio (True)
True Strain
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0
0.1
0.2
0.3
0.4
0.5


fff=0.9
fff=1
fff=1.1
MCalibration
The parameter fff controls the yield evolution, that is, how the yield stress changes with plastic strain. If fff is > 1 then the yield stress increases with plastic strain, and if fff < 1 then it decreases.
The default value of fff is 1.
True Stress [MPa]
True Strain
0
1
2
3
4
5
6
0
0.1
0.2
0.3
0.4
0.5



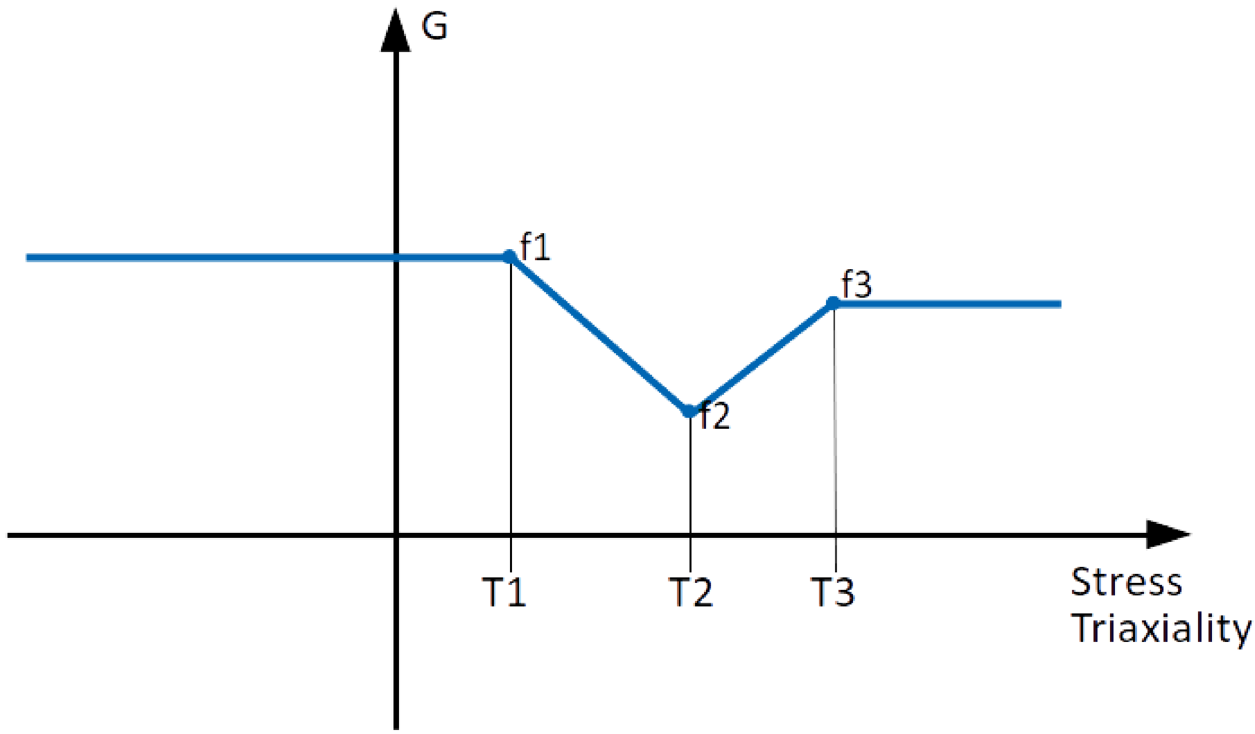
epsF=0.01
epsF=0.1
epsF=1
MCalibration
The parameter epsF is a strain quantity that controls over what strain range the yield stress changes from the initial value (specified by tauHat) to the final value (specified by tauHat*fff).
True Stress [MPa]
True Strain
0
1
2
3
4
5
6
0.1
0.2
0.3
0.4
0.5

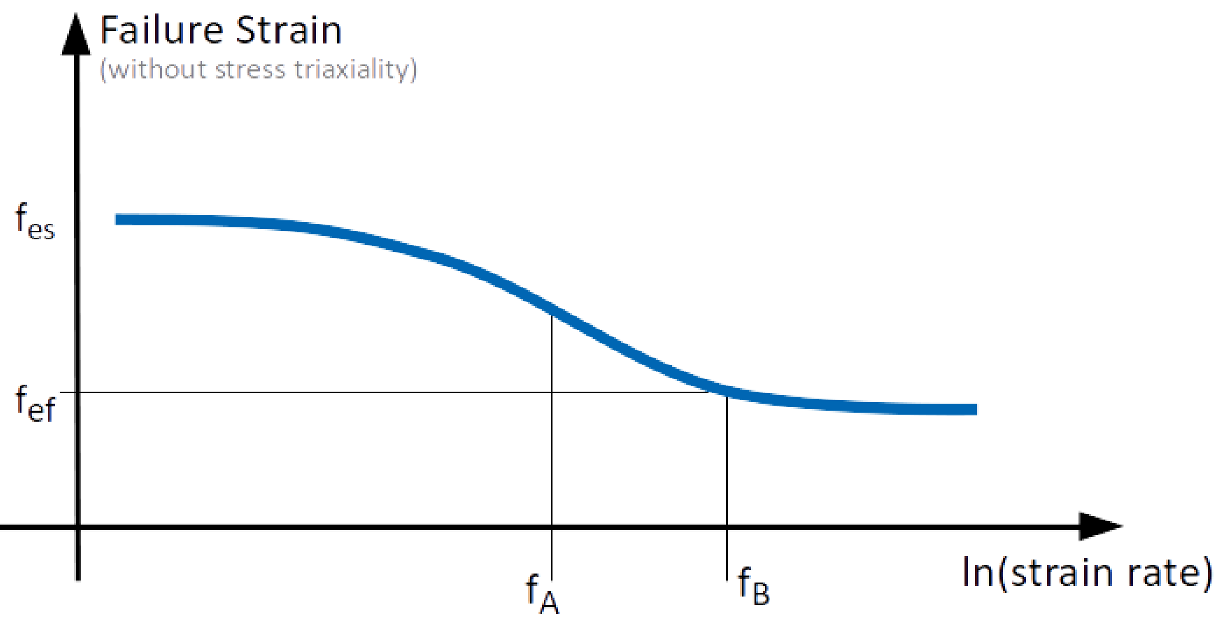

MCalibration
fss=0.6
fss=1
fss=1.4
True Stress [MPa]
True Strain
0
1
2
3
4
5
6
0
0.1
0.2
0.3
0.4
0.5
The parameter fss controls how much the elastic stiffness changes with plastic strain.
If fss =1 then there is no elastic damage accumulation.
If fss < 1 then the elastic stiffness of the current network gradually decreases towards the target factor fss (as the plastic strain increases).
This parameter can be useful for changing the amount of predicted residual strain during unloading.
The default value of fss is 1.



Failure Model Options

The TNV model supports either a strain-based or a stress-based failure model. The failure stress or strain is compared to either a Mises or Hill stress or strain value to determine if the material point should start to break down. The critical stress or strain can be modified to depend on the stress triaxiality ($\sigma_{triax}=tr[\sigma]/(3 \sigma_{mises})$) or the strain rate as indicated in the following figures.


G
f1
f2
f3
T1
T2
T3
Stress
Triaxiality


Failure Strain
(without stress triaxiality)
fes
fef
fA
fB
ln(strain rate)

Predefined Model Structures in MCalibration

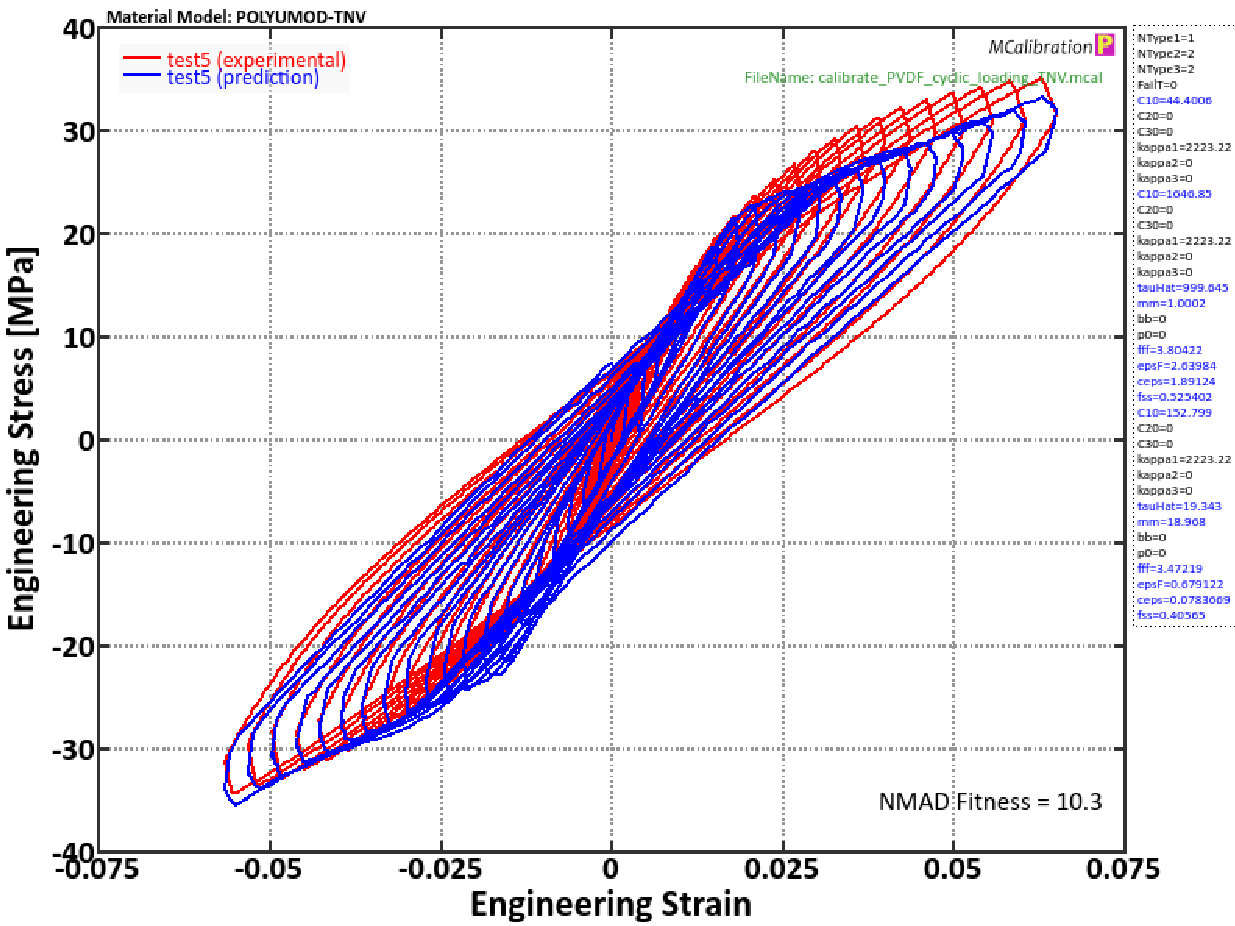
MCalibration introduces 4 predefined TNV model structures for the common polymer types:

- Elastomers:
    - Network 1: Yeoh hyperelasticity with Mullins damage
    - Network 2: Yeoh hyperelasticity with power-law flow
- Isothermal thermoplastics:
    - Network 1: Yeoh hyperelasticity
    - Network 2: Yeoh hyperelasticity with power-law flow
    - Network 3: Yeoh hyperelasticity with power-law flow
- Polyurethanes and Thermoplastic Elastomers (TPEs)
    - Network 1: Yeoh hyperelasticity with Mullins dmage
    - Network 2: Yeoh hyperelasticity with power-law flow
    - Network 3: Yeoh hyperelasticity with power-law flow
- Polymer Foams
    - Network 1: Hyperfoam
    - Network 2: Hyperfoam with power-law flow

These proposed model structures are starting points for reasonable models. You should always use actual experimental data when developing a material model.

Exemplar Predictions from the PolyUMod TNV Model

There is an example of the model predictions from the PolyUMod TNV model. The figure compares experimental data for a polyvinylidene fluoride (PVDF) material with predictions from the TNV model. The model accurately captures the experimentally observed behavior.



Recommended Experimental Test Plan

It is difficult to specify an optimal experimental test plan that is based on a small number of experimental tests because the optimal test plan is application specific. If you are interested in the non-linear viscoplastic response of a rubber, thermoplastic, or thermoset polymer at finite (>1%) strains, then I recommend the following "smart" test plan:

Cyclic Uniaxial Tension

- Applied strain history:
    - Load to 1% strain, hold the strain for 1 min, unload to a force that is close to 0;
    - then continue to load to 5% strain, hold the strain for 1 to 10 min, unload to a force that is close to 0;

    - then continue to load to 10% strain, hold the strain for 1 to 10 min, unload to a force that is close to 0;
    - then continue to load to 50% strain, hold the strain for 1 to 10 min, unload to a force that is close to 0;
    - finally, either load to failure in tension, or unload to zero.
- Repeat this experiment 2-3 times (using different specimens) in order to determine the experimental repeatability.
- Testing temperature: one temperature to be selected based on the application.
- The testing should be performed using ASTM D638 type IV (or similar) dogbone-shaped specimens.
- All loading and unloading should be performed at a constant engineering strain rate of about 0.01/s to 0.1/s.
- If you are interested in obtaining a temperature-dependent material model, then repeat these tests at 2 or more temperatures.

Uniaxial Compression

If you are interested in a thermoplastic material, then I also recommend that you run one uniaxial compression test in order to determine if the yield stress (also called the flow resistance) depends on the hydrostatic pressure.

- I recommend performing a monotonic compression test to an engineering strain of about -20%.
- Repeat the experiment 2-3 times (using different specimens) in order to determine the experimental repeatability.
- Repeat the test at 2 or more temperatures if you are interested in obtaining a temperature-dependent material model.
- Use a cylindrical specimen with a diameter that is equal to its height, both between 5 and 15 mm.

The results from this experimental test plan are sufficient to calibrate a non-linear viscoplastic material model like the TNV model.