A simplified approach to the simulation of rubber-like materials under dynamic loading

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abstract

The simulation of rubber materials is becoming increasingly important in automotive crashworthiness simulations. Although highly sophisticated material laws are available in LS-DYNA to model rubber parts, the determination of material properties can be non-trivial and time consuming. In many applications, the rubber component is mainly loaded uniaxially at rather high strain rates. In this paper a simplified material model for rubber is presented allowing for a fast generation of input data based on uniaxial static and dynamic test data.

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Implementation
of MAT_181 in LS-DYNA

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Mechanical behaviour of rubber

- Nearly incompressible
- hyperelastic under quasistatic loading
- highly rate-dependent under dynamic loading

Numerical simulation

- Quasistatic hyperelastic response : best fit for the Ogden functional based on uniaxial tension, simple shear and biaxial testing
- Dynamic viscoelastic response : best fit for a generalized Maxwell model
- Example of implementation : MAT_77 (Ogden or general hyperelastic) in LS-DYNA

Practical problems :

- Very often, only uniaxial tensile and/or compressive test results are available
- Parameter fitting can be difficult and time consuming
- Sometimes dynamic response cannot be fitted by a generalized Maxwell model

MAT_SIMPLIFIED_RUBBER

- A pragmatic and simplified alternative is proposed
- Ogden functional is computed from uniaxial tensile and compressive data only (fit is exact)
- Viscoelastic approach is replaced by rate-dependent hyperelasticity
- Incompressibility is assumed

MAT_SIMPLIFIED_RUBBER

- Implemented in LS-DYNA v970 as MAT_181 in December 2002
- Tested extensively in a number of industrial simulation projects since

MAT_181 : user input for quasistatic response

SGL	Specimen gauge length
SW	Specimen width
ST	Specimen thickness
LC/TBID	Load curve or table ID, defining force versus actual change in gauge length

If SGL=1 and SG=ST=1 then engineering stress/strain curves are input

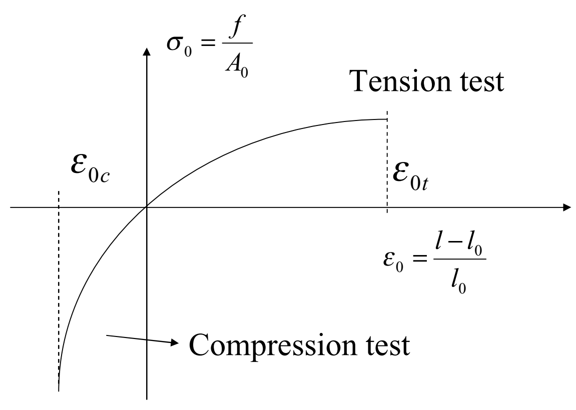
MAT_181 : user input

User must provide full range of data taking incompressibility into account :

$$\varepsilon_{0\min} = \min\left(\varepsilon_{0c}, \frac{1}{\sqrt{\varepsilon_{ot}+1}} - 1 \right)$$

$$\varepsilon_{0\max} = \max\left(\varepsilon_{0t}, \frac{1}{\sqrt{\varepsilon_{oc}+1}} - 1 \right)$$

Typical strain range from -0.8 to 1.2



MAT_181 : user input

To avoid localisation, negative slopes in the true stress versus true strain curve should be avoided, thus :

compression :

$$\frac{\partial \sigma}{\partial \varepsilon_0} = \frac{\partial \sigma_0 (1+\varepsilon_0)}{\partial \varepsilon_0} = \frac{\partial \sigma_0}{\partial \varepsilon_0}(1+\varepsilon_0) + \sigma_0 > 0$$

tension :

$$\frac{\partial \sigma_0}{\partial \varepsilon_0} > 0$$

Some theory :

- MAT_SIMPLIFIED_RUBBER will reproduce the quasistatic uniaxial tension and compression tests exactly, no fit is done
- Under quasistatic arbitrary 3D loading the response of MAT_SIMPLIFIED_RUBBER is identical to MAT_OGDEN based on parameters that would allow an exact fit of the uniaxial test results

Some theory : Ogden model

$$W = \sum_{i=1}^{3} \sum_{j=1}^{n} \frac{\mu_j}{\alpha_j} \left(\lambda_i^{*\alpha_j} - 1 \right) + K \left(J - 1 - \ln J \right)$$

$$\lambda_i^* = \lambda_i J^{-1/3} = \frac{\lambda_i}{J^{1/3}} \qquad J = \lambda_1 \lambda_2 \lambda_3 = \frac{V}{V_0}$$

Ogden functional depends on principal stretch ratios

$$\sigma_i = \sum_{j=1}^{n} \frac{\mu_j}{J} \left[\lambda_i^{*\alpha_j} - \sum_{k=1}^{3} \frac{\lambda_k^{*\alpha_j}}{3} \right] + K \frac{J-1}{J}$$

true stress

Expression for true stress :

$$\sigma_i = \sum_{j=1}^{n} \frac{\mu_j}{J} \left[\lambda_i^{*\alpha_j} - \sum_{k=1}^{3} \frac{\lambda_k^{*\alpha_j}}{3} \right] + K \frac{J-1}{J}$$

Generalisation : f need not be polynomial

$$f(\lambda) = \sum_{j=1}^{n} \mu_j \lambda^{*\alpha_j}$$

Polynomial function

$$\sigma_i = \frac{1}{J} \left(f(\lambda_i) - \frac{1}{3} \sum_{j=1}^{3} f(\lambda_j) \right) + K \frac{J-1}{J}$$

Some theory : simplified model

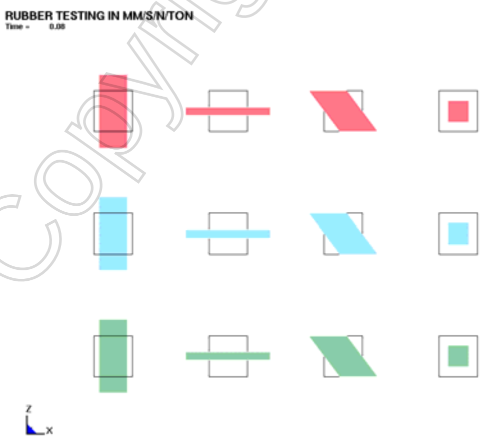
$$\varepsilon_{oi} = \lambda_i - 1$$

$$f(\lambda_i) = \lambda_i \sigma_0(\varepsilon_{0i}) + \sum_{n=1}^{\infty} \lambda_i^{(-1/2)^n} \sigma_0\left(\lambda_i^{(-1/2)^n} - 1\right)$$

$$for\_:\_\left|\lambda_i^{(-1/2)^n} - 1\right| \leq 0.01$$

Principal strain follows from principal stretch ratio
f is evaluated from the tabulated uniaxial engineering stress/strain data

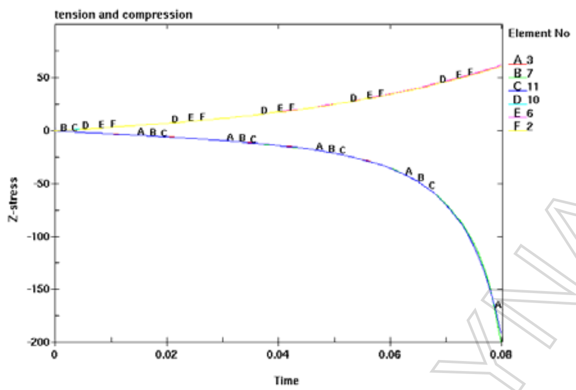
Comparison of material laws for rubber in LS-DYNA :



Single element tests for 4 basic loadcases

compare MAT_77, MAT_77 with fit and MAT_181

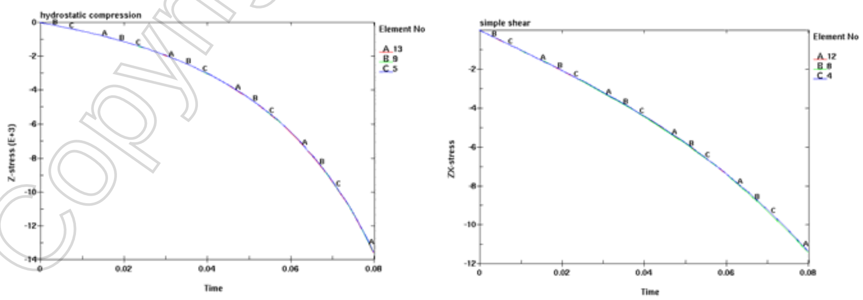
Comparison of material laws for rubber in LS-DYNA :



Uniaxial response is identical for all 3 models

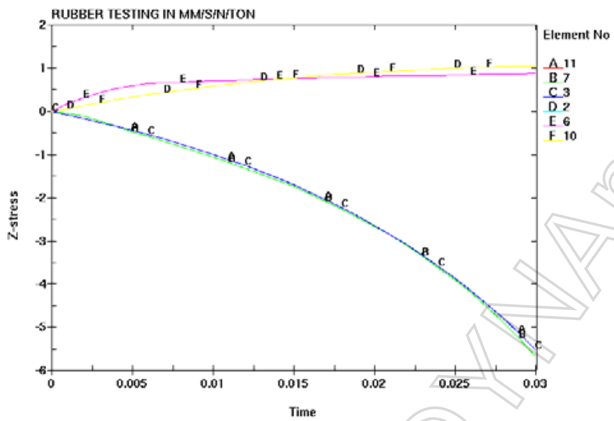
least squares fit is also very close

Comparison of material laws for rubber in LS-DYNA :



Hydrostatic and shear response of MAT_181 are equivalent to the Ogden model

MAT_181 follows test curve :

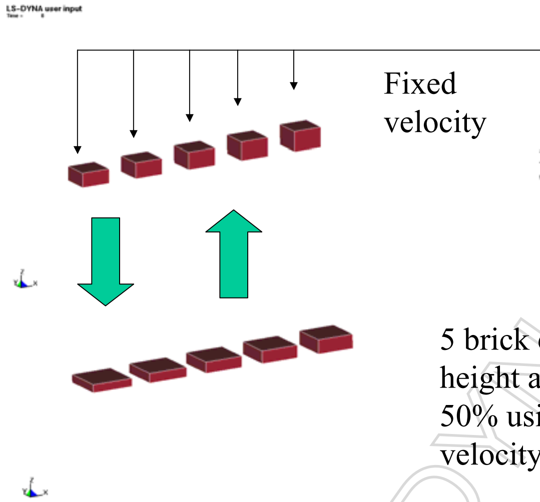


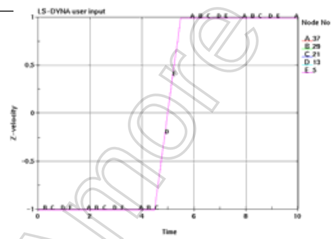
Some test curves may be hard to fit with an Ogden-type functional

MAT_181 : user input for dynamic response

TENSION	0=rate effects only in loading 1= rate effects in loading and unloading
RTYPE	0=true strain rate 1=engineering strain rate
AVGOPT	0=simple average 1=running average

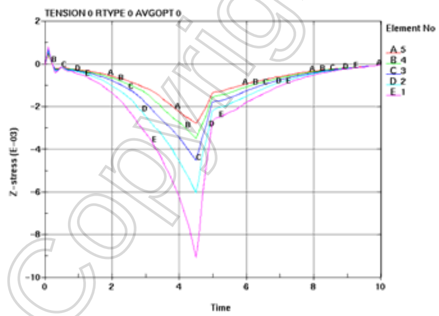
Treatment of rate effects :

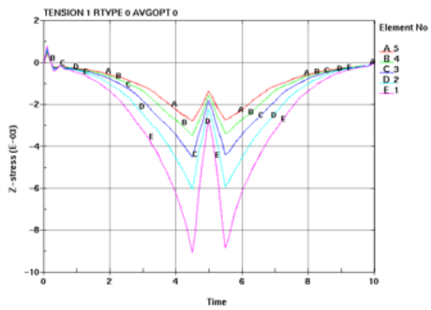




5 brick elements of different height are compressed about 50% using the same loading velocity

Effect of TENSION :



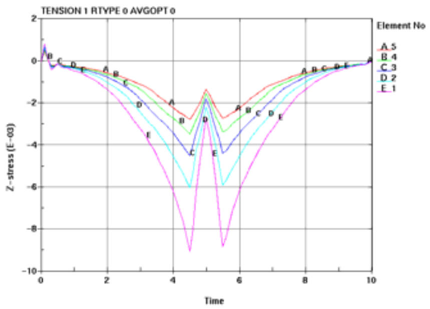


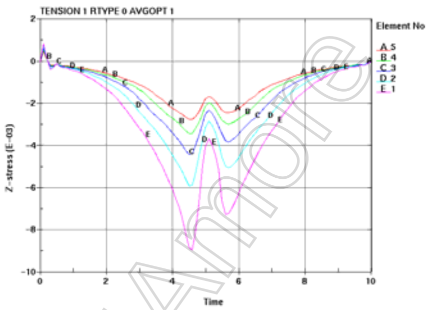
TENSION=0
rate effect only in loading

TENSION=1
rate effect also in unloading

rate dependent hyperelasticity shows no exponential stress relaxation

Effect of AVGOPT :

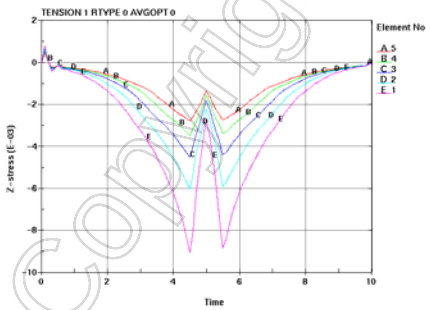


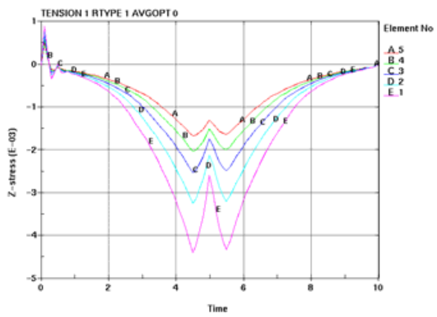


AVGOPT=0
simple 12 point average
of strain rate

AVGOPT=1
running average of strain rate

Effect of RTYPE :





RTYPE=0
true strain rate
test results hard to obtain

RTYPE=1
engineering strain rate
test results at constant speed

Practical choices :

- Rate dependent hyperelasticity is not as physical as viscoelasticity
- some formulation choices must be made by the user
- in our applications, we have used TENSION=0, RTYPE=1 and AVGOPT=1

Applications :

- Application examples include :
  - assembly adhesives (rubber-based)
  - MVSS-201 head impactor skin
  - pedestrian head impactor skin

Future developments :

- Implementation of MAT_181 for shell elements
- Application on a PVB windshield interlayer, previous simulation work regarding this material has been presented in the 11th international workshop of computer aided mechanics of materials, September 2002

Conclusions :

- With MAT_181 no parameter identification is necessary if uniaxial test results are available
- Highly nonlinear rate effects can be considered in the model
- Elastic oscillations sometimes cause instabilities, viscous hourglass control is recommended

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