#1106: HyperElastic Material Models - Applications and Usage

Product: OptiStruct
Product Version: HW 13.0 and above
Computer Operating System: Windows 7, Vista_x64
Linux 64 (RHEL 5.9,RHEL 6.2, SUSE 11 SP2)
Categories: Solver
Subcategories: Material Models

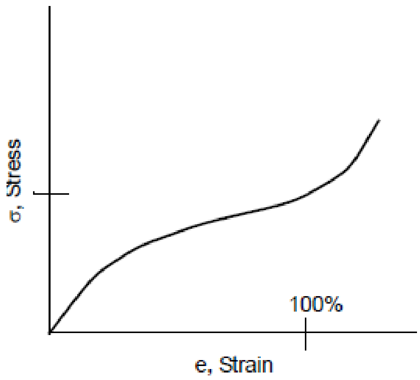
Topic Objective:

To define the material properties for non-linear hyper-elastic (Elastomeric) materials

Topic Details

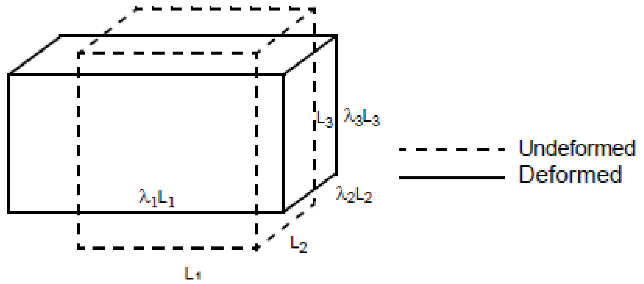
An elastomer is a polymer which shows non-linear elastic stress-strain behaviour. The term elastomer is often used to refer to materials which show a rubber-like behaviour.

Elastomeric materials are elastic in the classical sense. Upon unloading, the stress-strain curve is retraced and there is no permanent deformation. Elastomeric materials are initially isotropic. Figure below shows a typical stress-strain curve for an elastomeric material.



Calculations of stresses in an elastomeric material requires an existence of a strain energy function which is usually defined in terms of invariants or stretch ratios

In the rectangular block in the below figure λ_1, λ_2 and λ_3 are the principal stretch ratios along the edges of the block



In practice, the material behaviour is (approximately) incompressible, leading to the constraint equation:

$\Lambda_1 \lambda_2 \lambda_3 = 1$

The strain invariants are defined as

$$I_1 = \lambda_1^2 + \lambda_2^2 + \lambda_3^2$$
$$I_2 = \lambda_1^2\lambda_2^2 + \lambda_2^2\lambda_3^2 + \lambda_3^2\lambda_1^2$$
$$I_3 = \lambda_1^2\lambda_2^2\lambda_3^2$$

The hyperelastic material model:

1. is isotropic and non-linear;
2. is valid for materials that exhibit instantaneous elastic response up to large strains (such as rubber, solid propellant, or other elastomeric materials); and
3. Requires that geometric no linearity be accounted for during the analysis step, since it is intended for finite-strain applications.

Most elastomers (solid, rubber like materials) have very little compressibility compared to their shear flexibility. In cases where the material is highly confined (such as an O-ring used as a seal), the compressibility must be modelled correctly to obtain accurate results. In applications where the material is not highly confined, the degree of compressibility is typically not crucial; for example, it would be quite satisfactory in OptiStruct to assume that the material is fully incompressible: the volume of the material cannot change except for thermal expansion.

In OptiStruct, the use of PLSOLID bulk data entry is recommended in both compressible and nearly compressible cases.

Hyperelastic materials are described in terms of a “strain energy potential,” which defines the strain energy stored in the material per unit of reference volume (volume in the initial configuration) as a function of the strain at that point in the material.

OptiStruct provides a generalized Mooney-Rivlin (Polynomial model) to model approximately incompressible isotropic elastomers.

MATHE Bulk data entry is used to define the material properties for nonlinear hyperelastic materials based on generalized Mooney-Rivlin (Polynomial) model.

Format

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
MATHE	MID	Model							
	C10	C01	D1	TAB1	TAB2		TAB4		
	C20	C11	C02	D2	NA	ND			
	C30	C21	C12	C03	D3				
	C40	C31	C22	C13	C04	D4			
	C50	C41	C32	C23	C14	C05	D5		

Field	**Contents**
MID	Unique material identification number. No default (Integer > 0)
Model	Specifies the type of hyperelastic material model MOONEY – Selects the generalized Mooney-Rivlin hyperelastic model Default = MOONEY (Character, <MOONEY, blank>)
NA	Order of the distortional strain energy polynomial function Default = 2 (0 < Integer ≤ 5)
ND	Order of the volumetric strain energy polynomial function (see comment 2). Default = 1 (Integer)
Cpq	Material constants related to distortional deformation (Model = MOONEY). Default = 0.0 (Real)
Dp	Material constants related to volumetric deformation (Model = MOONEY). Default = 0.0 (Real ≥ 0.0)

TAB1	Table identification number of a TABLES1 entry that contains simple tension-compression data to be used in the estimation of the material constants, Cpq, related to distortional deformation. The x-values in the TABLES1 entry should be the stretch ratios and y-values should be values of the engineering stress. (Integer > 0 or blank)
TAB2	Table identification number of a TABLES1 entry that contains equi-biaxial tension data to be used in the estimation of the material constants, Cpq, related to distortional deformation. The x-values in the TABLES1 entry should be the stretch ratios and y-values should be values of the engineering stress. (Integer > 0 or blank)
TAB4	Table identification number of a TABLES1 entry that contains pure shear data to be used in the estimation of the material constants, Cpq, related to distortional deformation. The x-values in the TABLES1 entry should be the stretch ratios and y-values should be values of the nominal stress. (Integer > 0 or blank)

User can directly define the co-efficients for examples: If you choose Mooney as the HyperElastic material model C10 and C01 co-efficients need to be defined in the MATHE card.

In addition to this, the user can define the stress-strain curve using TABLES1 entry and evaluate the material co-efficients using experimental curve fit method.

The Generalized Mooney-Rivlin polynomial form of the Hyperelastic material model is written as a combination of the deviatoric and volumetric strain energy of the material. The potential (*U*) is written in polynomial form, as follows

$$U = \sum_{p+q=1}^{N_1} C_{pq} \left(\bar{I}_1 - 3\right)^p \left(\bar{I}_2 - 3\right)^q + \sum_{p=1}^{N_2} \frac{1}{D_p} \left(J_{elas} - 1\right)^{2p}$$

Where,

N_1 is the order of the distortional strain energy polynomial function (NA)

N_2 is the order of the volumetric strain energy polynomial function (ND). Currently only first order volumetric strain energy functions are supported (ND=1).

C_{pq} are the material constants related to distortional deformation (Cpq)

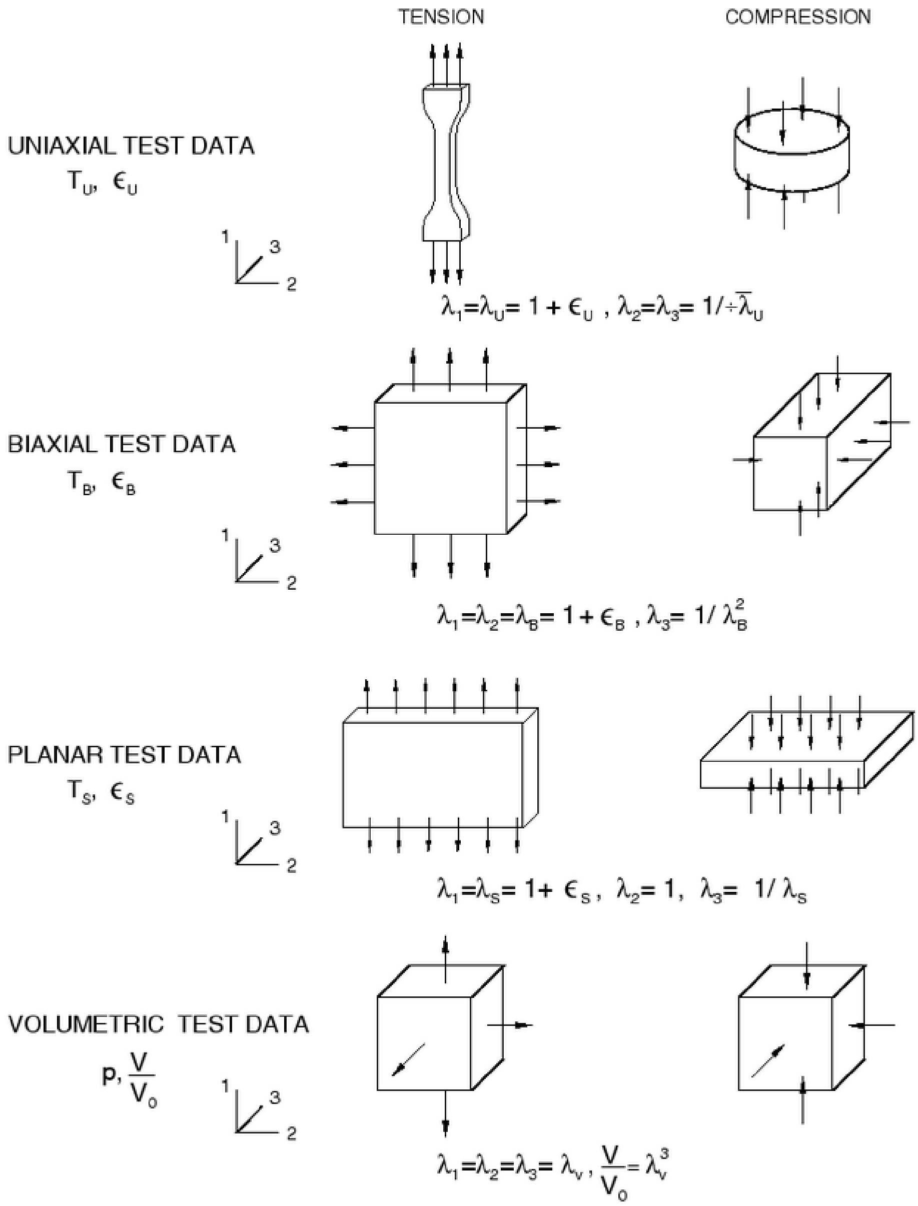
$\bar{I}_1$, $\bar{I}_2$ are invariants internally calculated by OptiStruct

D_p are material constants related to volumetric deformation (Dp). These values define the compressibility of the material.

J_{elas} is the elastic volume strain calculated internally by OptiStruct

For a homogeneous material, homogeneous deformation modes suffice to characterize the material constants. OptiStruct accepts test data from the following deformation modes:

- Uniaxial tension and compression
- Equibiaxial tension and compression
- Planar tension and compression (also known as pure shear)



The material MATHE can be used in conjunction with PARAM, LGDISP, 1 to activate large displacement analysis with hyperelastic materials.