Rubber Fibre Composite Modelling and its Influence on Fatigue Damage Assessment

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Abstract

A novel multi-axial energy-based approach is presented and used to demonstrate the influence of different finite element (FE) modelling techniques on the prediction of the fatigue life of a rubber composite with long oriented fibres. It is shown that the simplest modelling methods using 2D elements with rebar layers, layered 2D elements or layered 3D elements do not allow for a precise determination of the critical location and damage value. In contrast, modelling methods with 3D matrix and discrete reinforcement provide much better results. The predicted critical location corresponds to the measured one, although the predicted fatigue life still differs from the measured results. The most complex microscopic modelling method shows the best agreement between the predicted and measured fatigue life. Since microscopic modelling is not suitable for modelling larger products made of rubber fibre composite, it is also noted that modelling techniques with 3D matrix and discrete reinforcing elements can be used with the same accuracy if the fatigue life curve is obtained from measurements on the specimens made of composite material rather than the specimens made of the critical base material (rubber).

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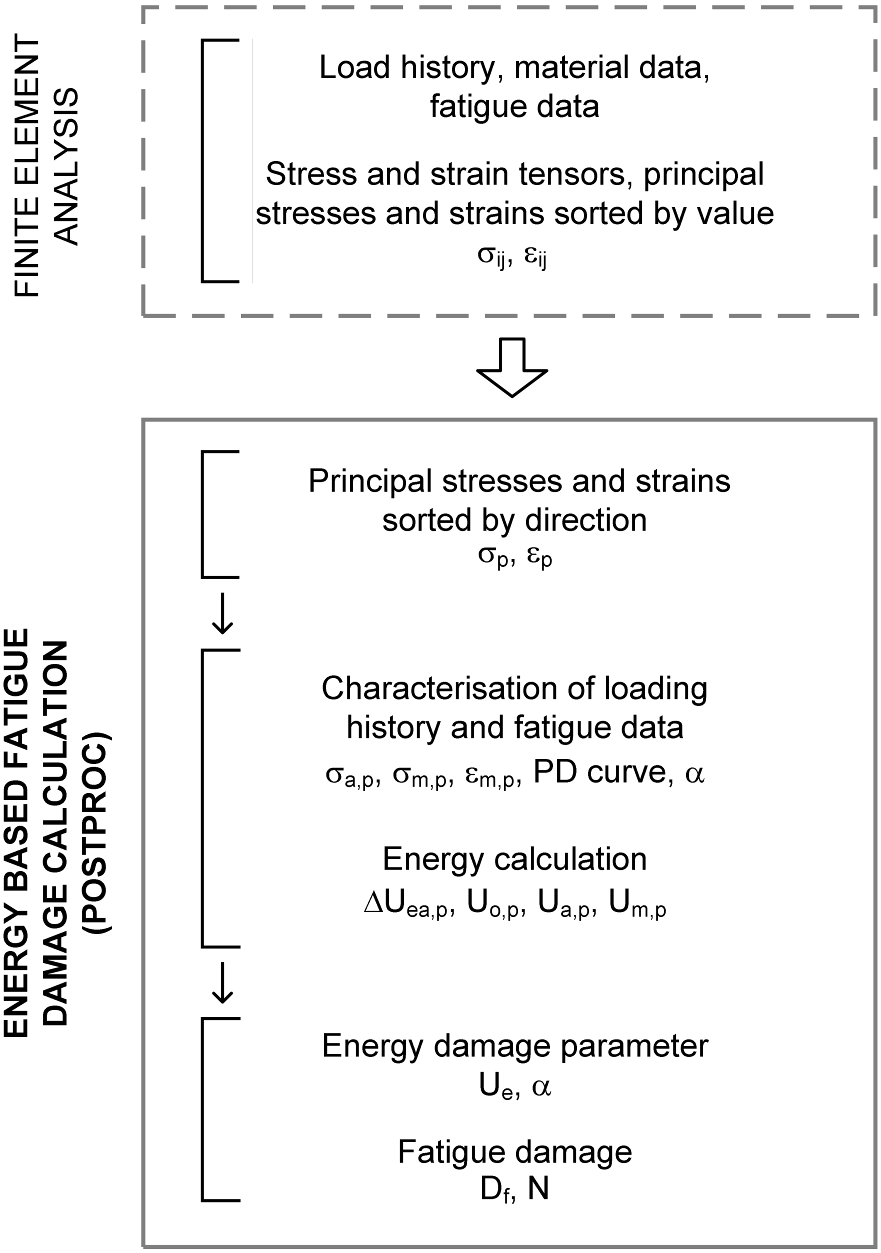
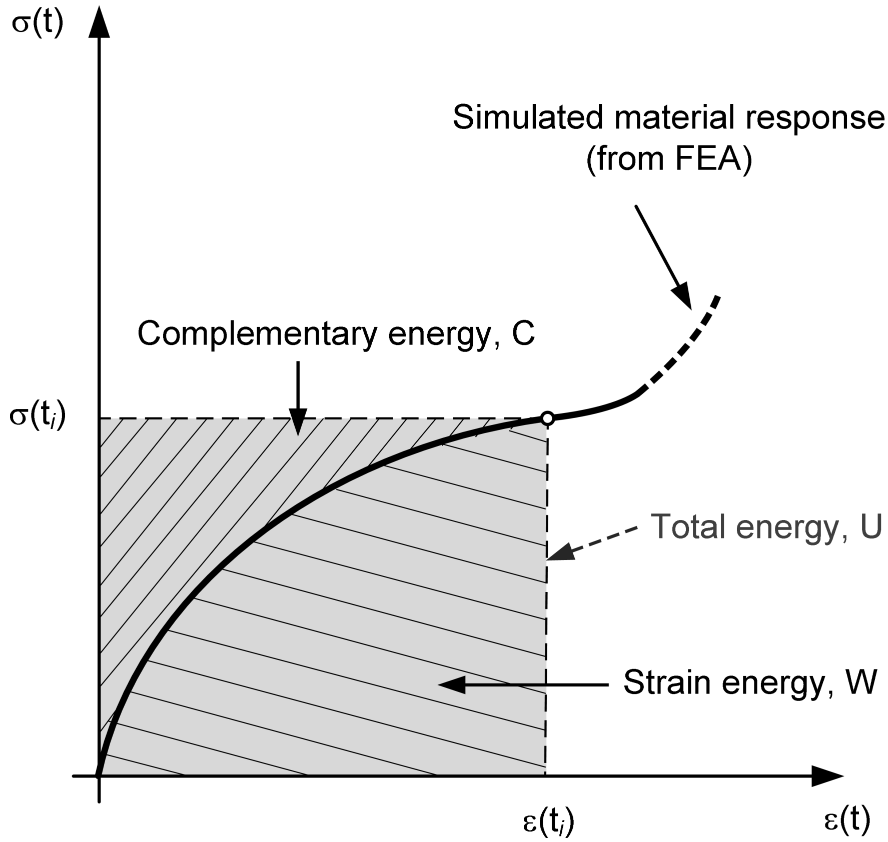
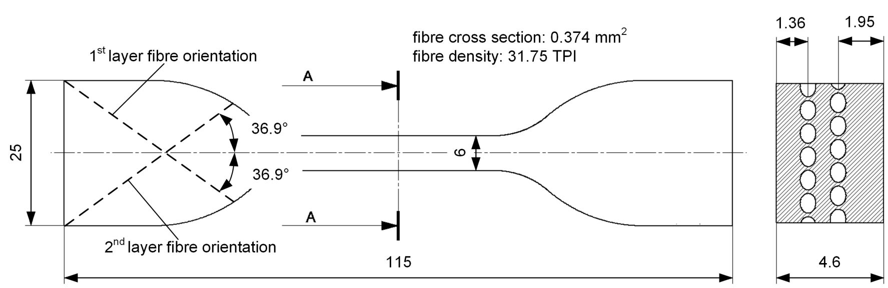
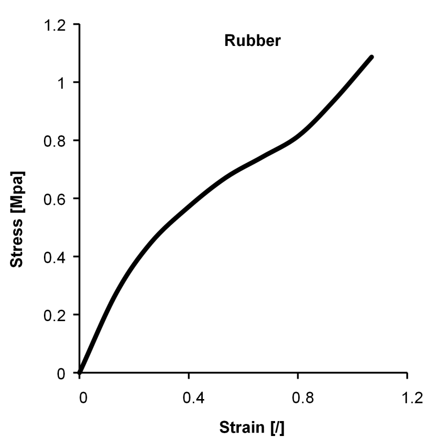
Material Model	Hyperelastic Marlow (defined by uniaxial test)		Elastic	Transversely isotropic elastic	Orthotropic elastic
Section	Rubber matrix		Rebar layers + truss elements	Sections of reinforced material - micro model	Reinforcement plies - mixed modelling
Parameters	Nom. Stress [MPa]	Strain [/]	E=2300MPa	E_1=20MPa	E_1=1800MPa
	0	0	v=0.45	E_2=20MPa	E_2=1MPa
	0.2738	0.1346		E_3=2300MPa	E_3=1MPa
	0.4467	0.2607		v_{12}=0.45	v_{12}=0.002
	0.5717	0.4004		v_{13}=0.004	v_{13}=0.002
	0.6721	0.5365		v_{23}=0.004	v_{23}=0.45
	0.7427	0.6699		G_{12}=6.896MPa	G_{12}=0.33MPa
	0.8150	0.8017		G_{13}=50MPa	G_{13}=0.33MPa
	0.9336	0.9288		G_{23}=50MPa	G_{23}=0.345MPa
	1.0867	1.0696			

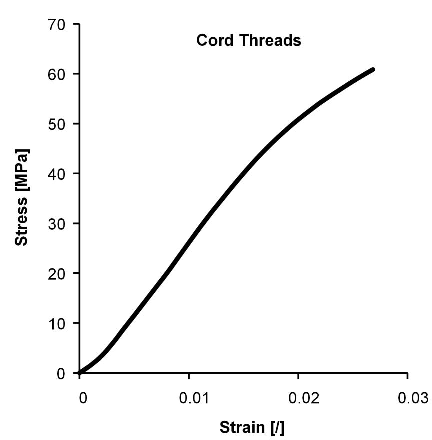
Modelling technique	U_{ae}^{cycle} [J/mm^3]	Fatigue life N [cycles]
2D structural matrix with rebar layers	0.224	$2.5\text{x}10^8$
3D matrix + embedded 2D surface elements with rebar layer	0.294	$5.4\text{x}10^7$
3D matrix + 2D surface elements with rebar layer	0.334	$2.63\text{x}10^7$
3D matrix + embedded 1D truss elements	0.250	$1.35\text{x}10^8$
2D mixed modelling	0.058	$5.11\text{x}10^{11}$
3D mixed modelling	0.054	$7.64\text{x}10^{11}$
Complete 3D micro modelling	0.540	$1.75\text{x}10^6$
Measured results (average)	/	$1.92\ \text{x}10^6$

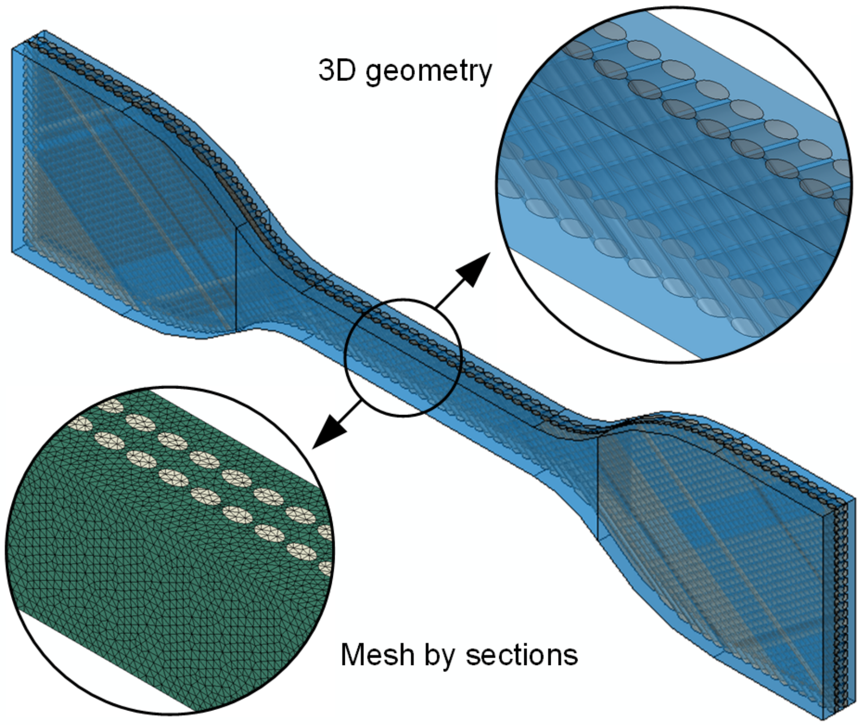

FINITE ELEMENT ANALYSIS
Load history, material data, fatigue data
Stress and strain tensors, principal stresses and strains sorted by value
σ_{ij}, ε_{ij}
ENERGY BASED FATIGUE DAMAGE CALCULATION (POSTPROC)
Principal stresses and strains sorted by direction
σ_p, ε_p
Characterisation of loading history and fatigue data
$\sigma_{a,p}$, $\sigma_{m,p}$, $\varepsilon_{m,p}$, PD curve, α
Energy calculation
$\Delta U_{ea,p}$, $U_{o,p}$, $U_{a,p}$, $U_{m,p}$
Energy damage parameter
U_e, α
Fatigue damage
D_f, N

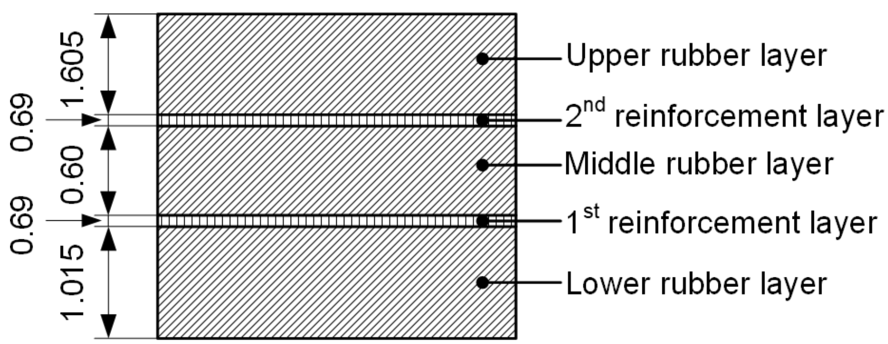

σ(t)
Simulated material response
(from FEA)
Complementary energy, C
σ(t$_i$)
Total energy, U
Strain energy, W
ε(t$_i$)
ε(t)

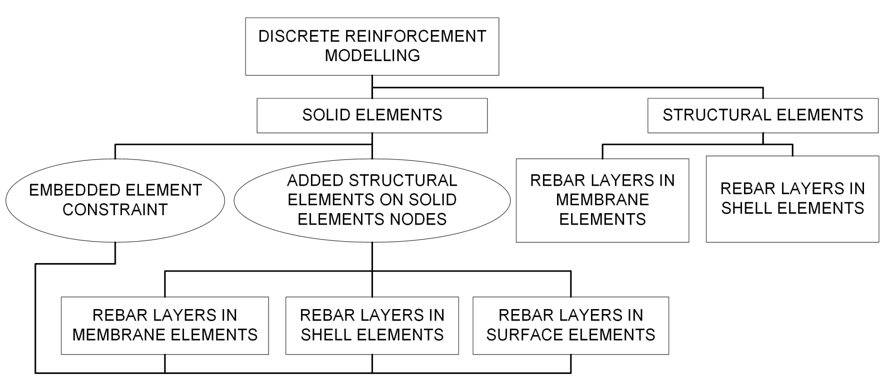

1st layer fibre orientation
2nd layer fibre orientation
fibre cross section: 0.374 mm²
fibre density: 31.75 TPI
36.9°
36.9°
A
A
25
6
115
1.36
1.95
4.6

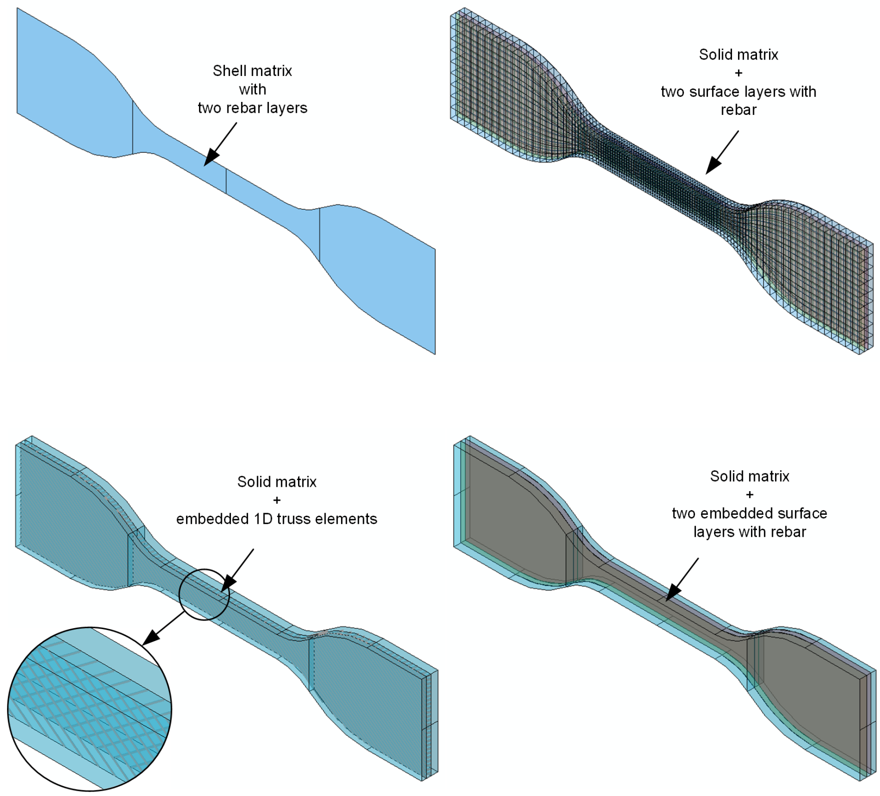

Rubber
Stress [Mpa]
Strain [/]
0
0.2
0.4
0.6
0.8
1
1.2
0
0.4
0.8
1.2

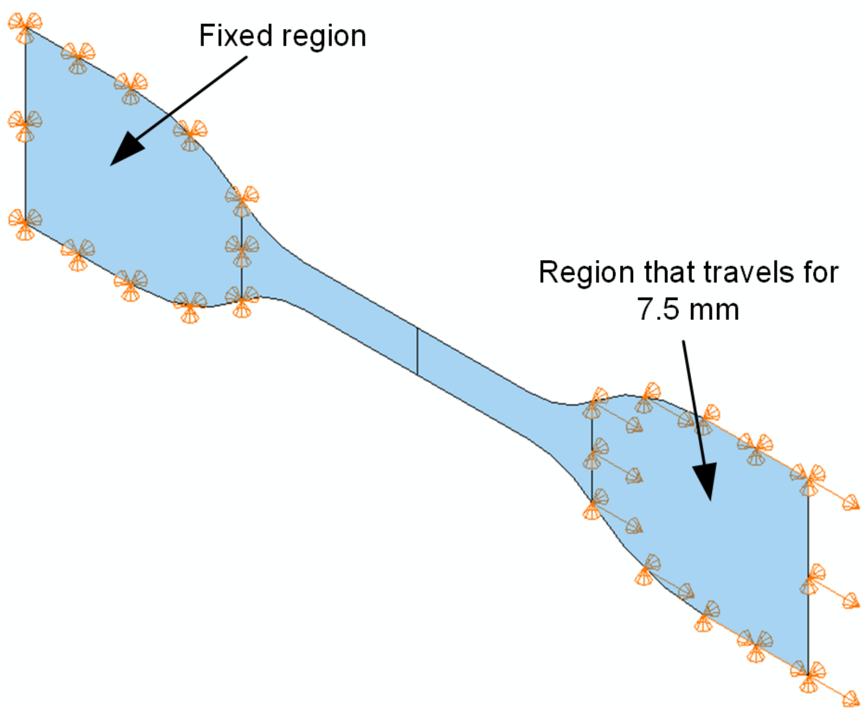

Cord Threads
Stress [MPa]
Strain [/]
0
10
20
30
40
50
60
70
0
0.01
0.02
0.03

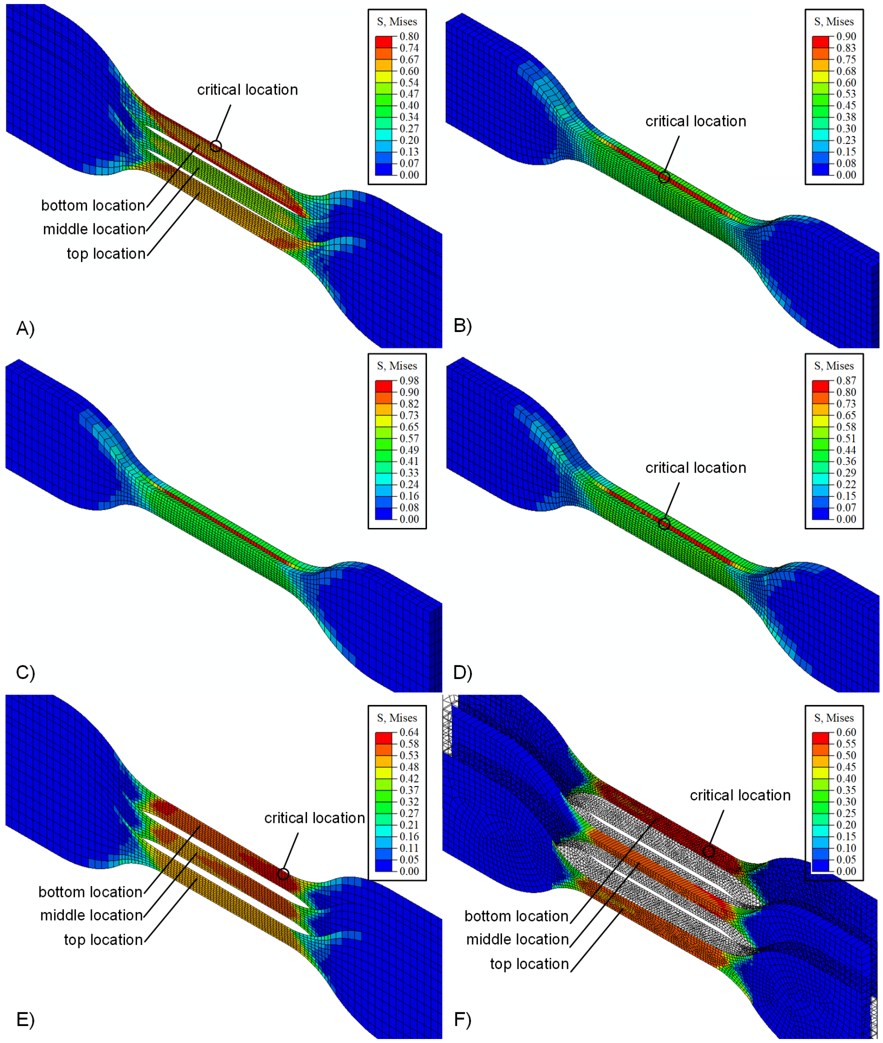

3D geometry
Mesh by sections


1.605
0.69
0.60
0.69
1.015
Upper rubber layer
2nd reinforcement layer
Middle rubber layer
1st reinforcement layer
Lower rubber layer

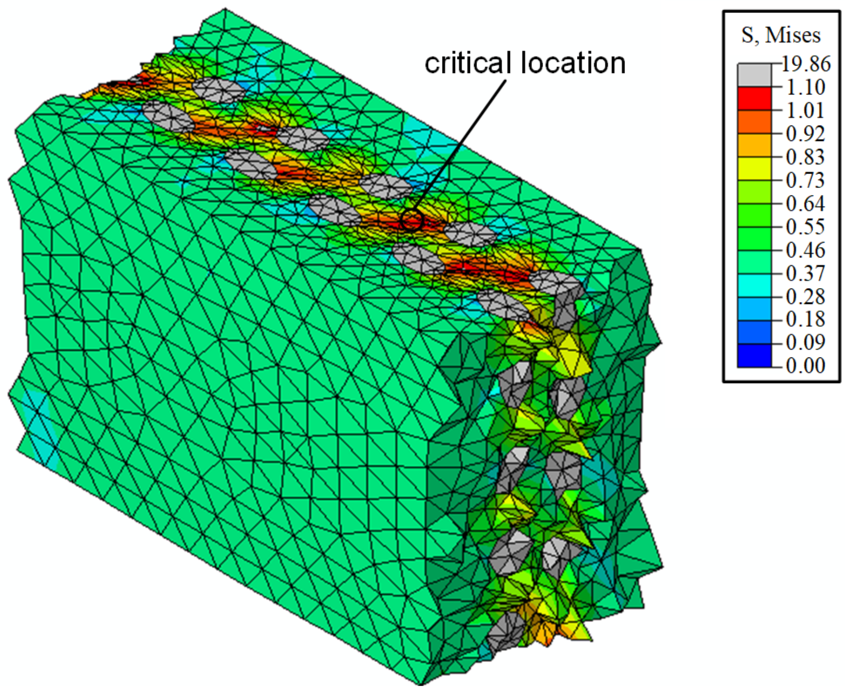

DISCRETE REINFORCEMENT MODELLING
SOLID ELEMENTS
STRUCTURAL ELEMENTS
EMBEDDED ELEMENT CONSTRAINT
ADDED STRUCTURAL ELEMENTS ON SOLID ELEMENTS NODES
REBAR LAYERS IN MEMBRANE ELEMENTS
REBAR LAYERS IN SHELL ELEMENTS
REBAR LAYERS IN MEMBRANE ELEMENTS
REBAR LAYERS IN SHELL ELEMENTS
REBAR LAYERS IN SURFACE ELEMENTS

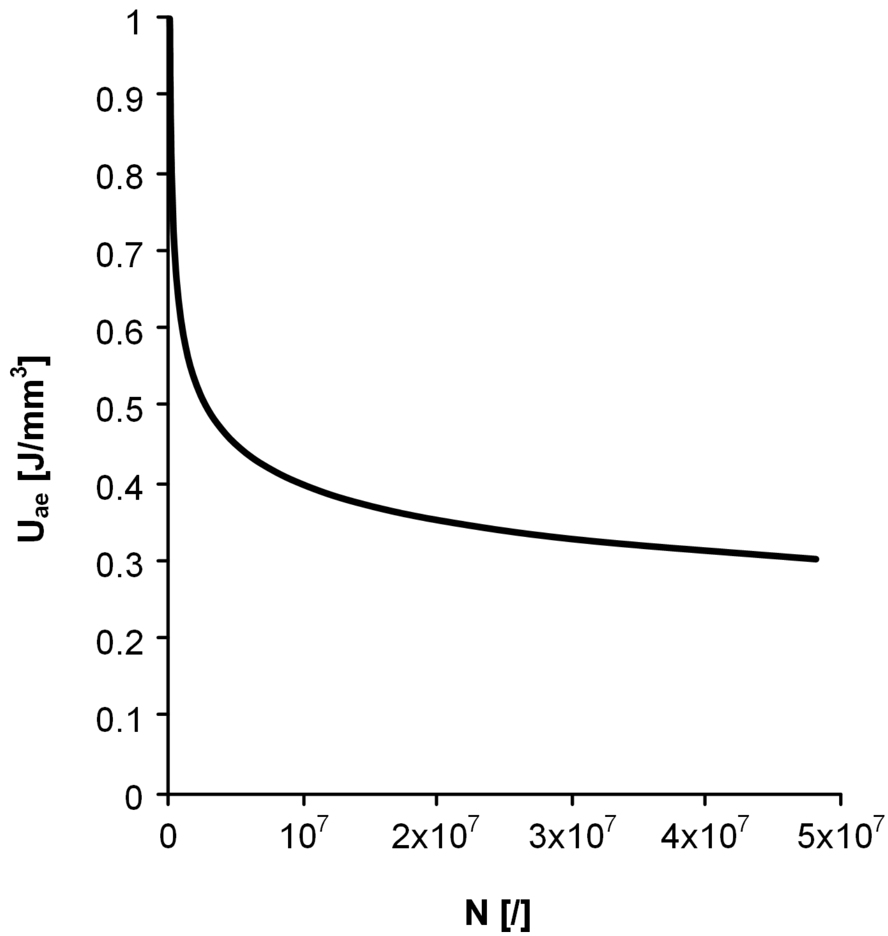

Shell matrix
with
two rebar layers
Solid matrix
+
two surface layers with
rebar
Solid matrix
+
embedded 1D truss elements
Solid matrix
+
two embedded surface
layers with rebar


Fixed region
Region that travels for
7.5 mm



A)
critical location
bottom location
middle location
top location
B)
critical location
C)
D)
critical location
E)
critical location
bottom location
middle location
top location
F)
critical location
bottom location
middle location
top location
S, Mises


critical location
S, Mises
19.86
1.10
1.01
0.92
0.83
0.73
0.64
0.55
0.46
0.37
0.28
0.18
0.09
0.00


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
U_{ae} [J/mm^3]
0
10^7
$2x10^7$
$3x10^7$
$4x10^7$
$5x10^7$
N [/]