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The Equi-Biaxial Fatigue Characteristics of EPDM under True (Cauchy) Stress Control Conditions

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The Equi-Biaxial Fatigue Characteristics of EPDM under True (Cauchy) Stress Control Conditions

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Introduction

- Load amplitude control, analogous to engineering stress control, is often employed when carrying out dynamic uniaxial and biaxial testing of rubber components

- Engineering stress does not fully describe the behaviour of viscoelastic materials under load
  - Cross sectional area during deformation is assumed constant

- True Stress represents the actual stress acting on a material
  - Takes the reduction in cross sectional area into account

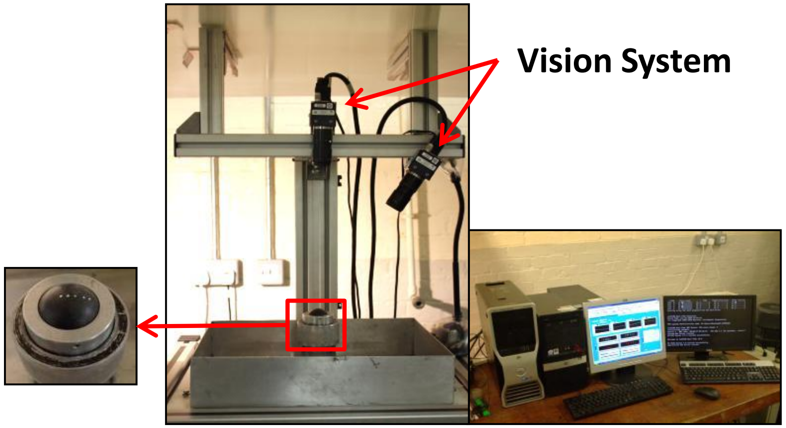
- Despite this, true stress control fatigue testing is little used
  - It is difficult to maintain constant true stress amplitudes, especially for equi-biaxial testing
  - Engineering stress is the norm in industry today

Research Objectives

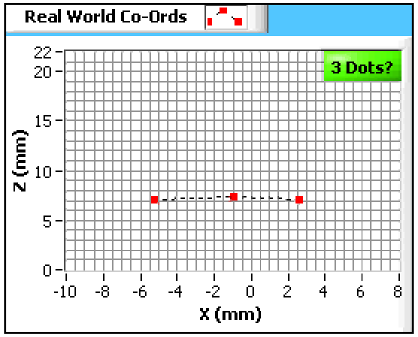
- To investigate if true stress amplitude is a feasible control parameter for equi-biaxial fatigue tests of rubber
- To carry out equi-biaxial fatigue tests under both engineering stress amplitude control and true stress amplitude control
- To compare and highlight the differences between both methods of control
- To evaluate the effect of the differing load histories experienced by samples under engineering stress and true stress control fatigue testing

DYNAMET

- DYNAMET is an equi-biaxial elastomer testing system using the bubble inflation method
  - Deformation is equi-biaxial in a specified region centred on the pole
    - $\Rightarrow$ stress is equi-biaxial
- Vision data is used to determine the coordinates of markings on a sample
  - Coordinates are then used to calculate the radius of curvature and stretch ratio within the pole region
- Stress is calculated using the formula shown
- Cycling can be controlled using eng stress, true stress, stretch ratio, volume or pressure limits



The DYNAMET System



Real World Coordinates

$$\sigma_{eng}=(P.r.\lambda)/2t_o$$

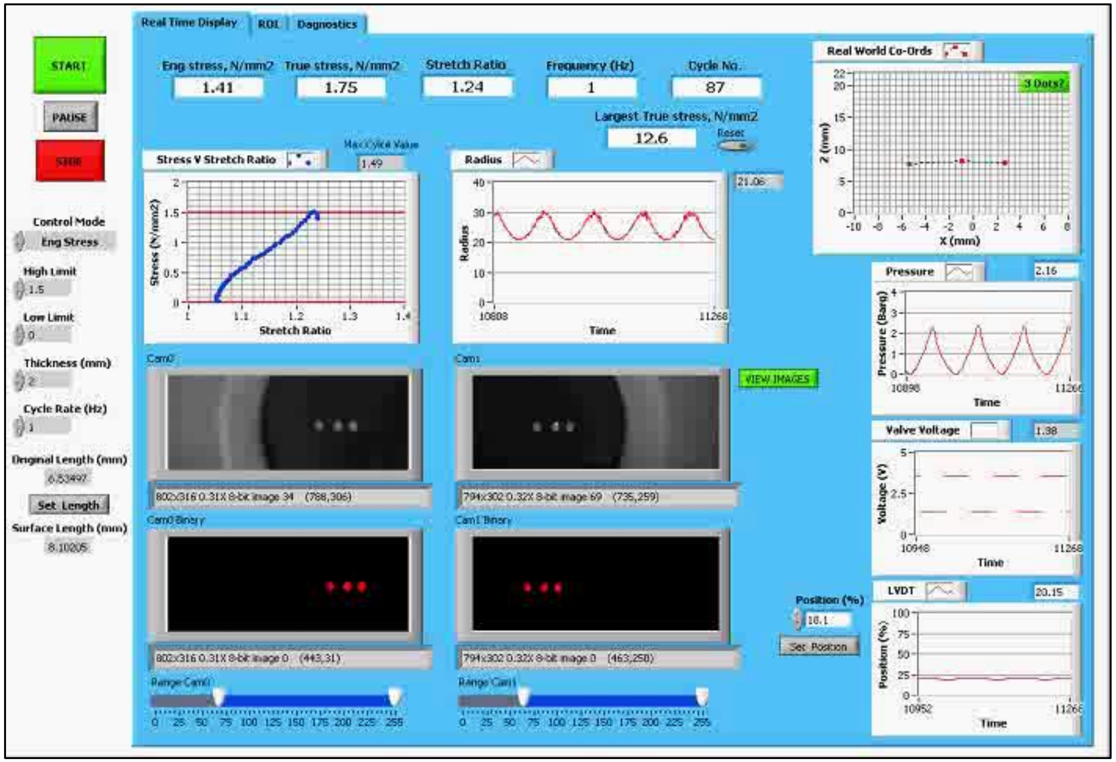
σ_{eng} = *engineering stress*
P = *pressure*
r = *radius of curvature*
λ = *stretch ratio*
t_o = *original thickness*

Murphy, N., Ph.D Thesis

DYNAMET

Recent Developments:

- True stress control is now possible
- Testing of transparent materials is now possible
- Data logging has been improved
- The control programme and user interface have been improved



Engineering Stress Control Test Demonstration

Development Still Required:

- Constant strain rate

Cycle Number	Lambda	Eng Stress (Mpa)	True Stress (Mpa)	Cycle Rate (Hz)	Pressure (Bar)	Radius (mm)	Orig. Length (mm)	Cur. Length (mm)	LVDT	Valve Voltage (V)	Cycle Time (mS)
1	1.01	0.005288	0.005341	1	0.001	20.420938	6.38	6.44	20.00	3.625	10
1	1.02	0.034236	0.034921	1	0.005	20.871433	6.38	6.51	20.10	3.625	10
1	1.03	0.248276	0.255724	1	0.036	21.280098	6.38	6.57	20.20	3.625	10

Example DYNAMET Data Output

True Stress Control

- True Stress Control (using bubble inflation)

  - Engineering Stress control using: $\sigma_{eng}=(P.r.\lambda)/2t_o$
  - True Stress control using: $\sigma_{true}=\sigma_{eng}.\lambda$

σ_{eng} = engineering stress
P = pressure
r = radius of curvature
λ =stretch ratio
t_o = original thickness

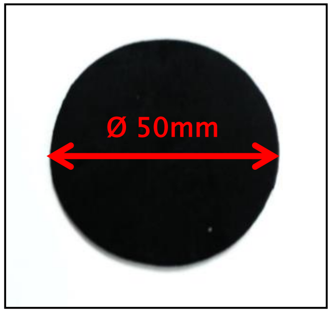
To achieve true stress control the maximum applied load must be continually adjusted to account for the changes in cross sectional area

- Implementing this control can ensure that the fatigue sample will fail at a pre-determined true stress amplitude

Murphy, N., Ph.D Thesis

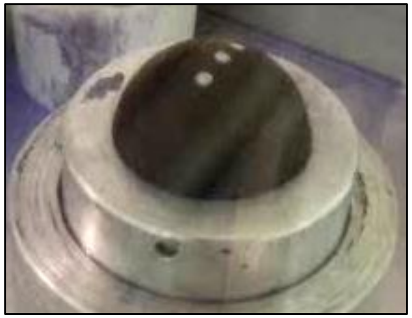
Test Method

- Test carried out using 1.6mm thick, 50mm diameter discs of EPDM (Shore 70 hardness)



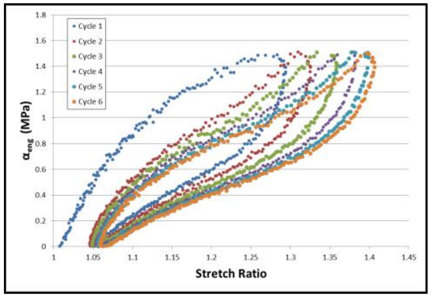
EPDM Circular Sample

- Samples clamped at their periphery and are cyclically inflated to a maximum upper stress amplitude at a cyclic rate of 1Hz until failure occurs



Sample Inflation

- Each sample was pre-conditioned by subjecting it to 6 cycles to the maximum stress control limit



Pre-conditioning cycles

Test Data Sets

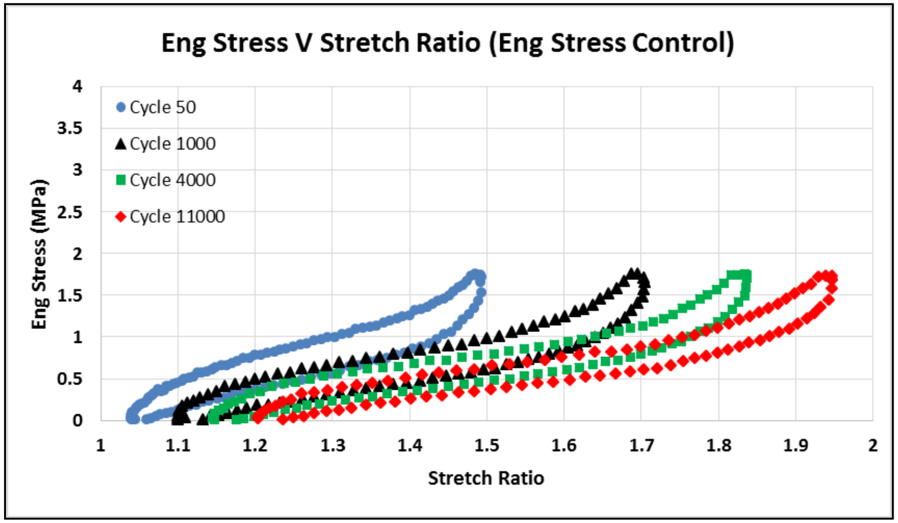
- Two studies carried out:
  1. First set of samples were cyclically loaded to a constant maximum engineering stress until failure occurred

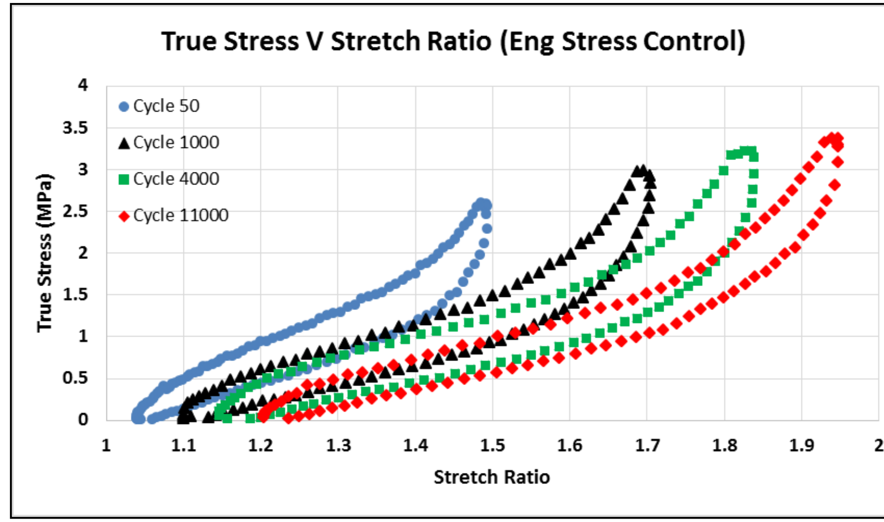
  2. Second set of samples were cyclically loaded to a constant maximum true stress until failure occurred

- Engineering stress, true stress and stretch ratio values were logged every 10ms throughout tests

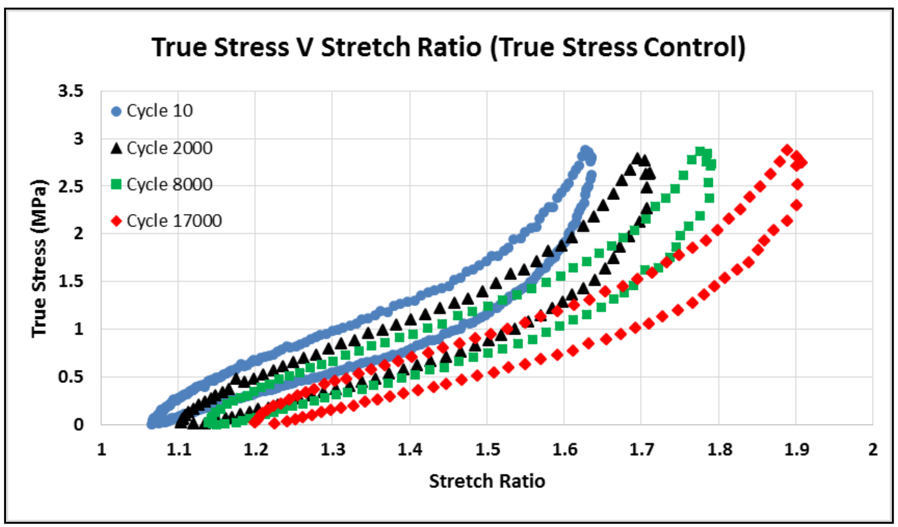
- Both sets of data were graphed as stress/stretch ratio plots for comparison

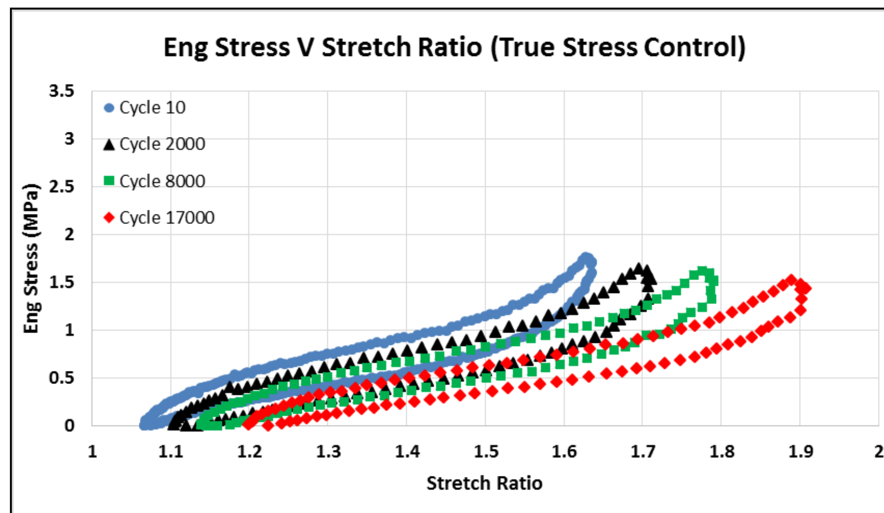
Results





- Engineering Stress Control: True stress increases throughout tests

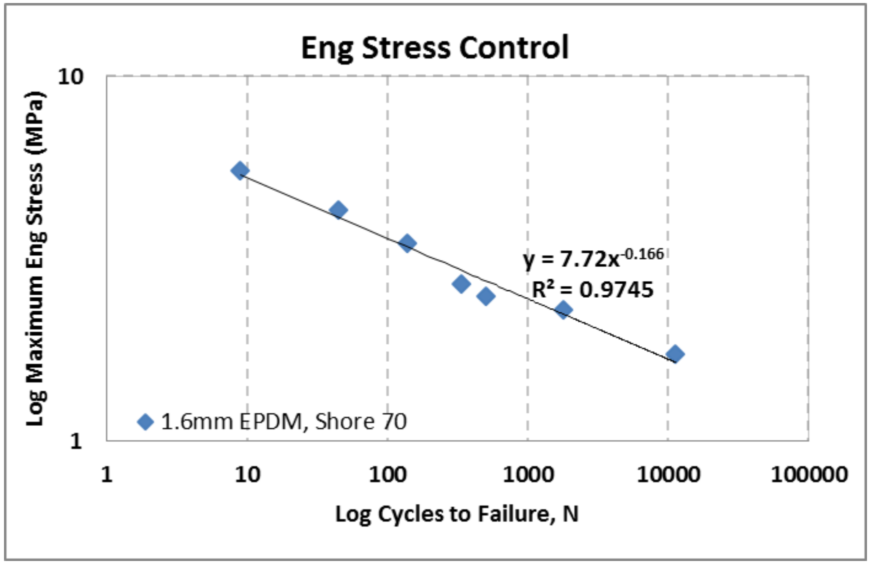




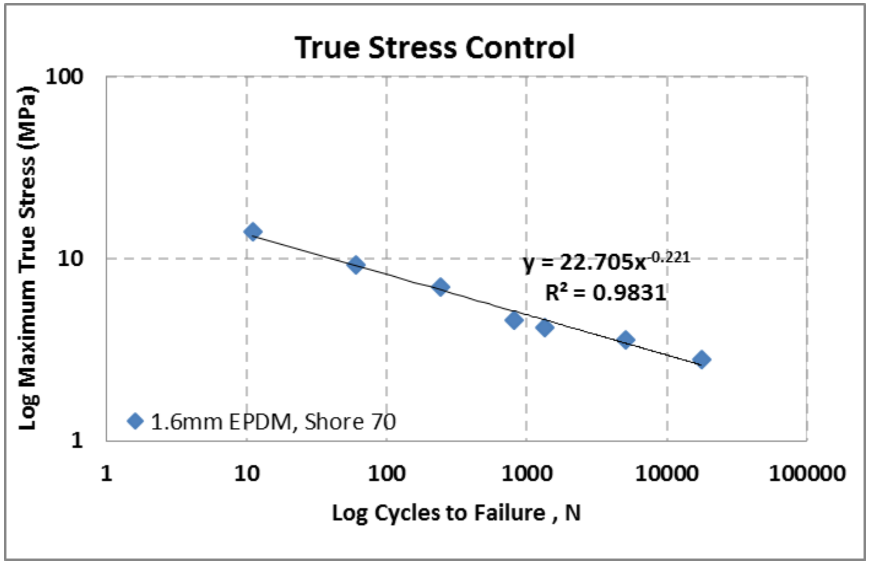
- True Stress Control: Engineering stress decreases throughout tests

Results

- Wöhler curves produced for each data set



Engineering Stress Control Wöhler Curve

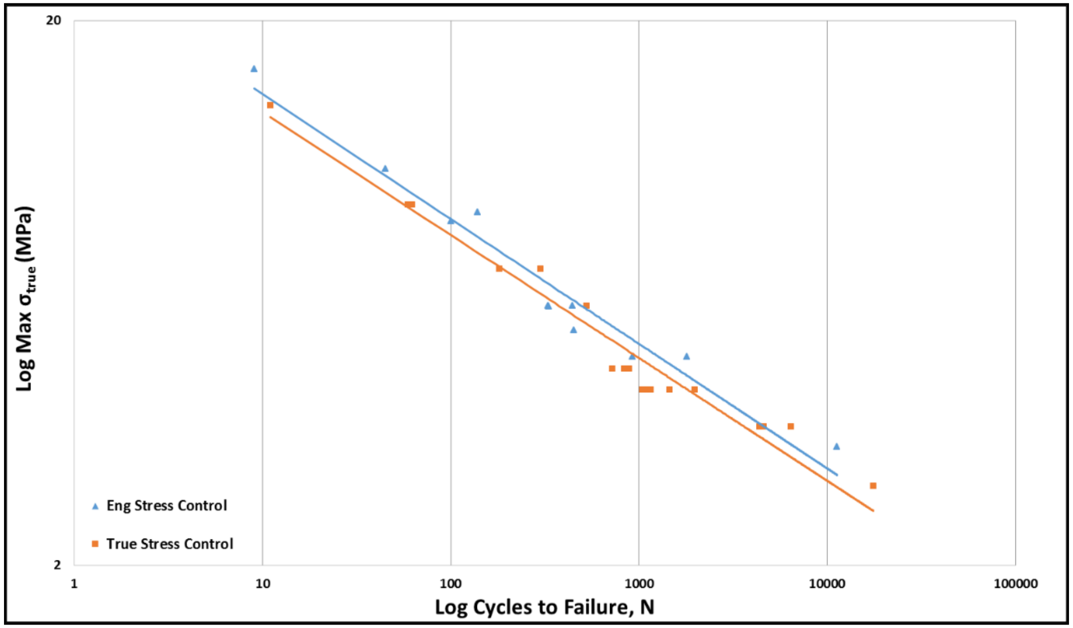


True Stress Control Wöhler Curve

- Not directly comparable due to the very different loading histories which occur during engineering and true stress control fatigue tests

Results

- Maximum true stress applied against no. of cycles to failure, for both engineering and true stress control data sets



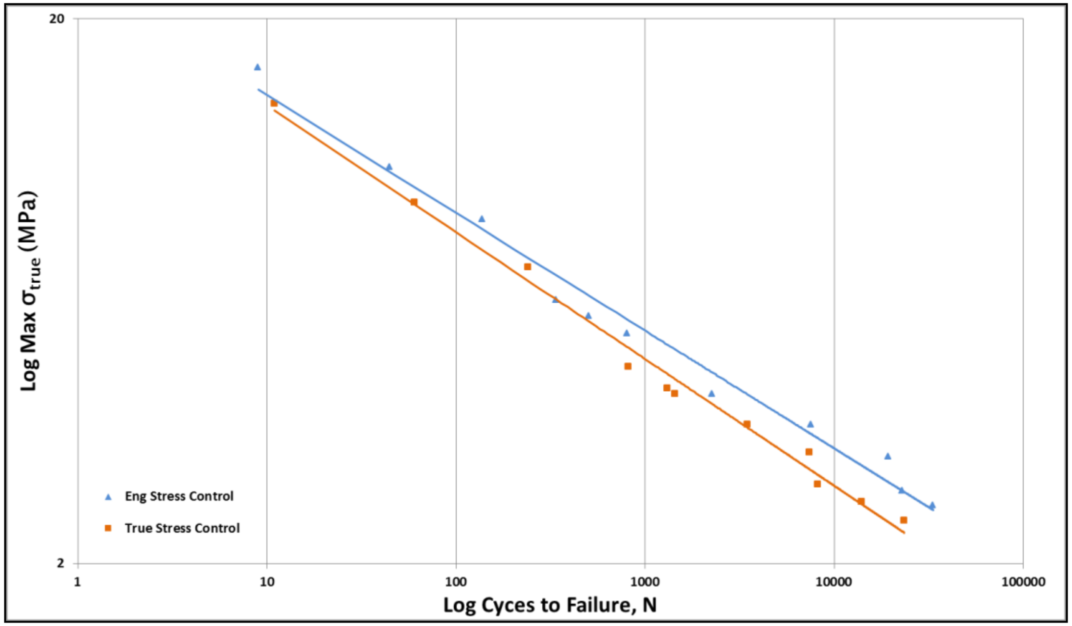
True Stress V Engineering Stress Control

- Appears to show, that an engineering stress control fatigue test will give a good representation of fatigue behaviour during constant true stress control

However……

Further Testing

- Testing extended to include fatigue tests of longer duration

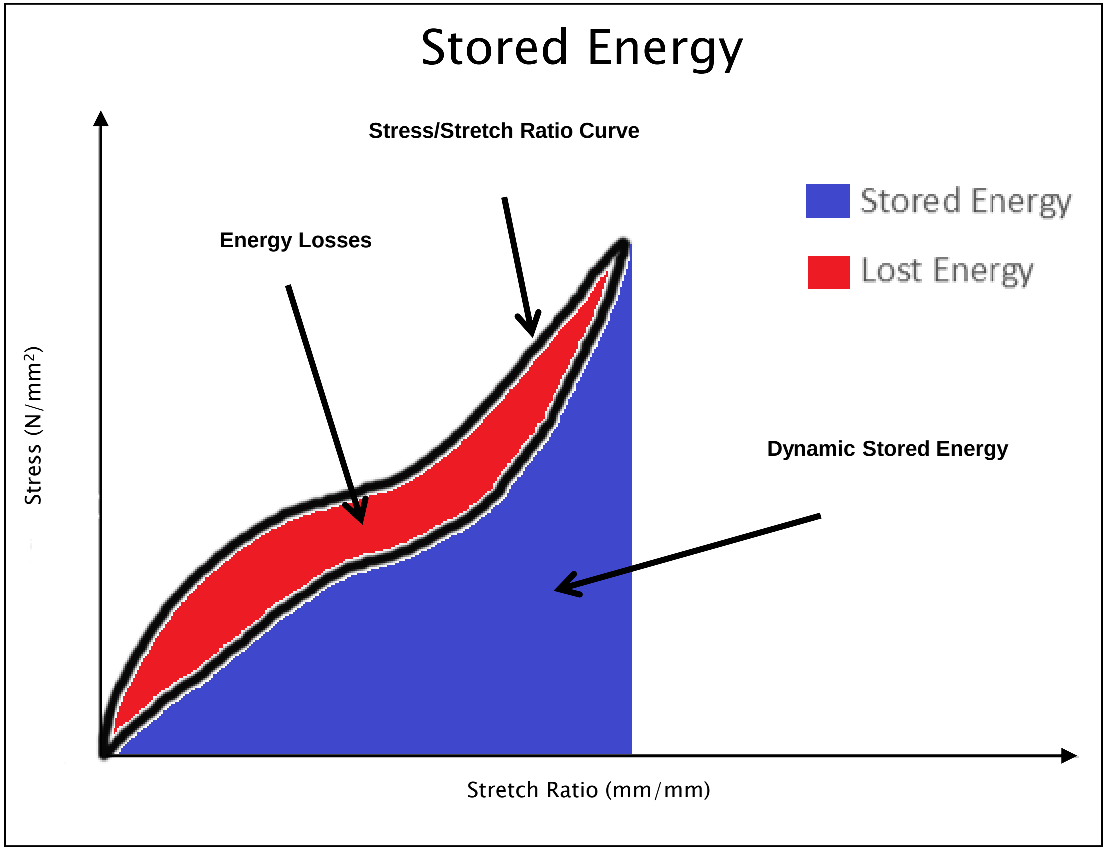


True Stress V Engineering Stress Control Revised

- Revised results show that engineering stress control and true stress control do not give comparable fatigue lives
- Therefore engineering stress is not a good approximation of true stress control fatigue life
- Lower stresses with higher cycles accumulated are more representative of actual service conditions

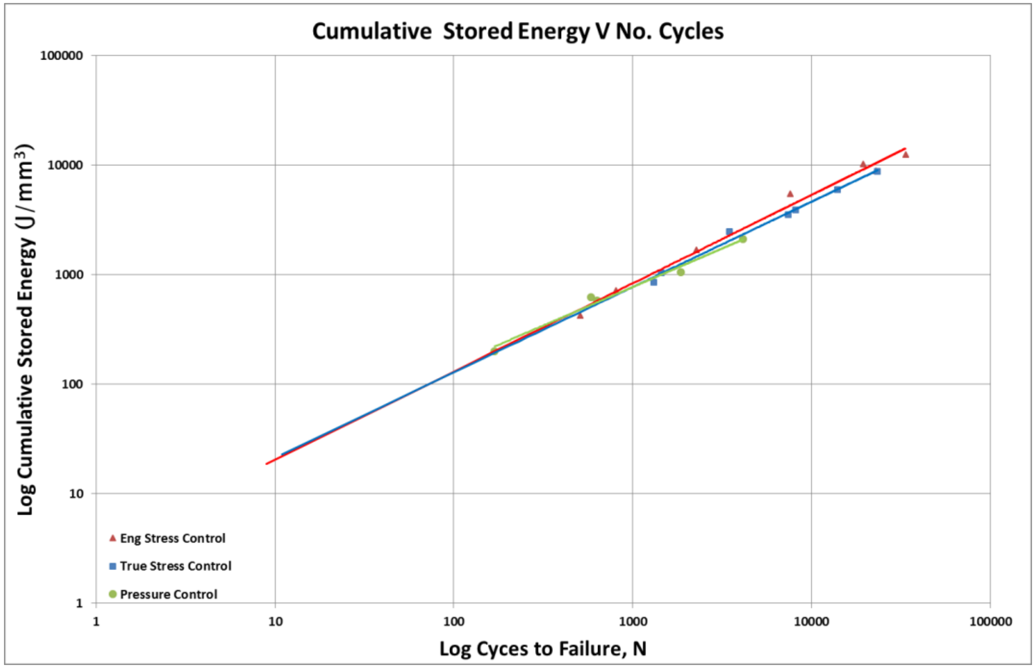
Stored Energy

- What is Stored Energy?
  - Stored energy is the energy that is stored during the deformation of the material



Further Testing

- Cumulative stored energy Vs. Number of cycles to failure



- Gives similar results using either control method
- Accounts for the different loading histories
- Appears to be a credible fatigue predictor which is independent of load control method
- Constant pressure control is not dependent on the relation between engineering and true stress giving an independent control method

Conclusion

- It is possible to carry out an equi-biaxial fatigue test using true stress amplitude as a control parameter

- True stress and engineering stress loading control methods appear to be comparable as failure predicators in high stress cycles

- However true stress load control results in shorter fatigue lives for lower stress cycles which are more indicative of actual service behaviour

- True stress control is necessary if a specific true stress value is desired at sample failure and throughout a test

- Cumulative stored energy possibly a fatigue life predictor, reflects loading history and is independent of the load control method

Future Work

- Increase range of tests to include lower load amplitudes
- Test a range of different elastomers
- Further investigation into stored energy as a fatigue life predictor
- Develop strain rate control

Thank You for Your Attention!

Any Questions?