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Monotonic and Cyclic Behavior of Trabecular Bone Under Uniaxial and Multiaxial Loading

By

Ardiyansyah Syahrom

Mohd Al - Fatihhi Mohd Szali Januddi

Rabiatul Adibah Abdul Rahim

Director
Sports Innovation and Technology Centre
Institute of Human Centred Engineering
Universiti Teknologi Malaysia
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OUTLINE

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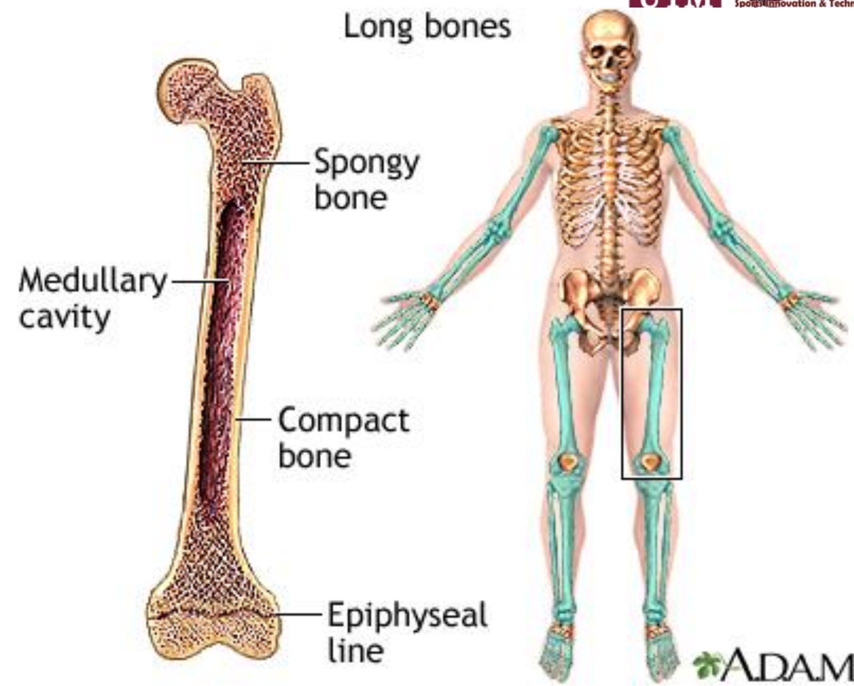
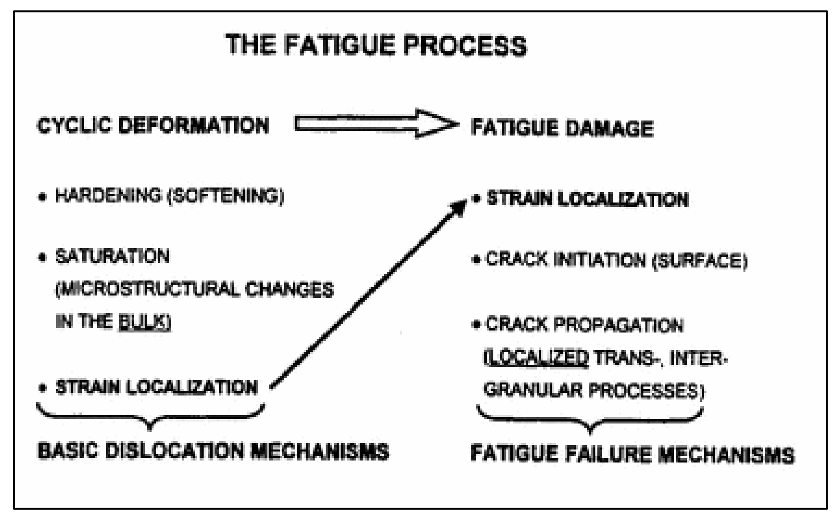
  - Fatigue Behaviour of Bovine Trabecular Bone
  - Computational Analyses
- **Conclusion**

INTRODUCTION

BACKGROUND

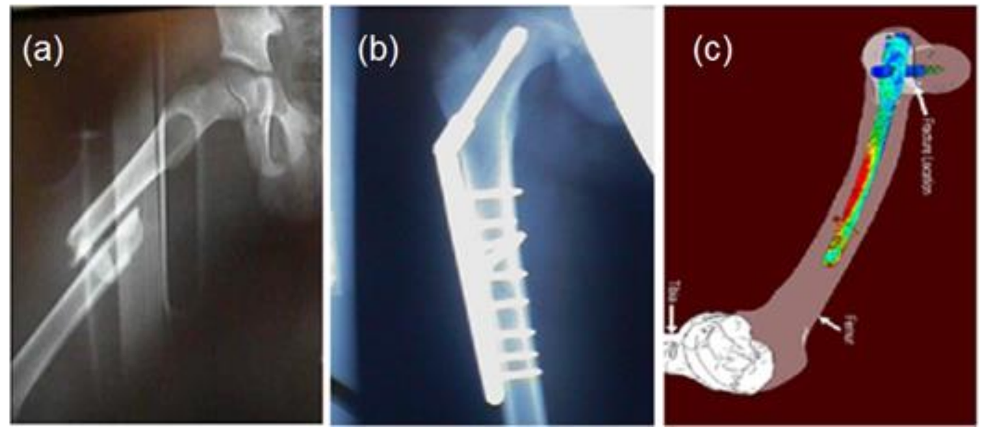
- Bone: The skeletal system
  - Cortical bone
  - **Trabecular bone**
- Bone mechanics
  - Mechanical properties
  - Fatigue properties
  - Multiaxial Behaviour of Trabecular Bone
  - Failure criterion





PROBLEM STATEMENT

- Bone fatigue fracture
- Multiaxial stresses and strains in vivo
- Osteoporosis
- Research questions
  - How do the **orientation** affect the trabecular behaviour under multiaxial fatigue loading?
  - What is the **influence of torsional loading** on the behavior of trabecular bone under compressive fatigue and monotonic loading?

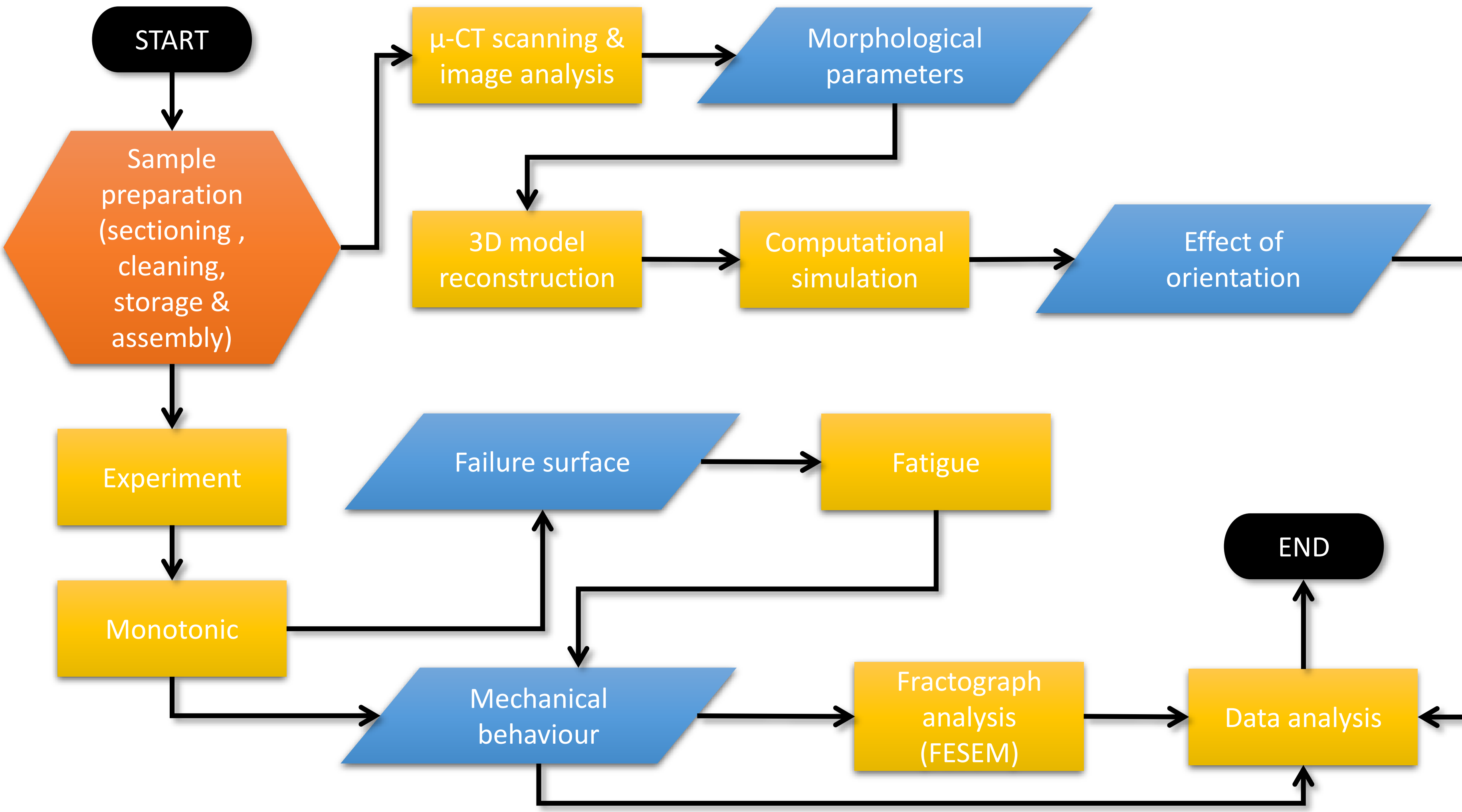


OBJECTIVES

- To simulate compressive fatigue life and investigate the effect of sample orientation.
- To evaluate the torsional loading effects onto the fatigue compressive behavior of bovine trabecular bone

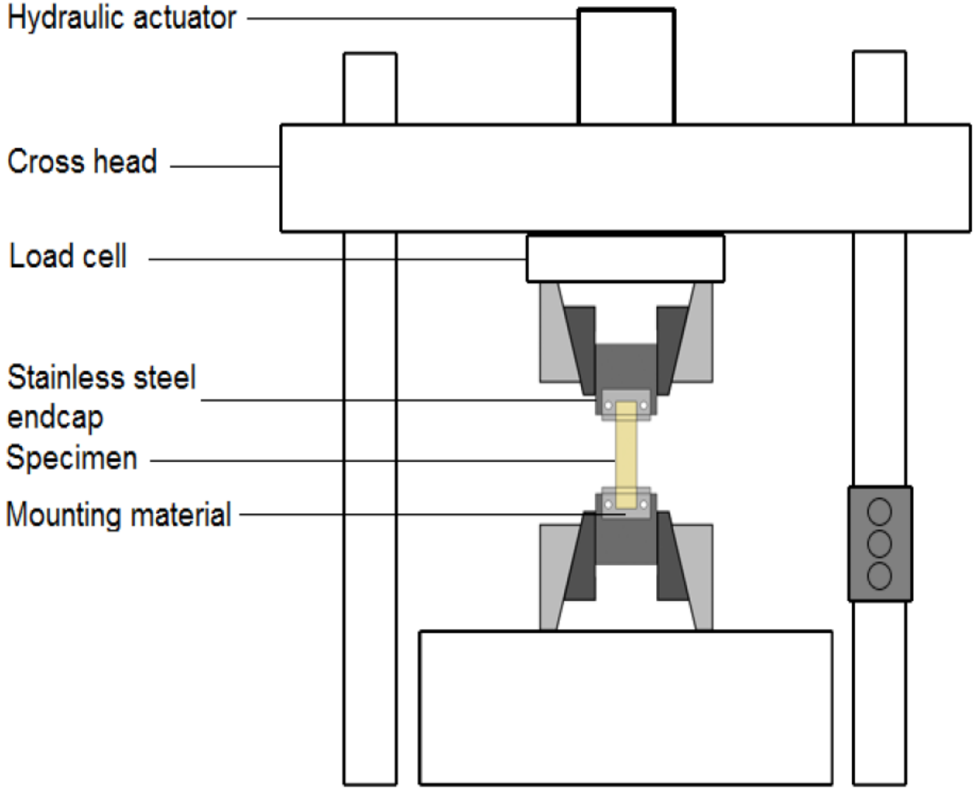
METHODOLOGY

RESEARCH DESIGN

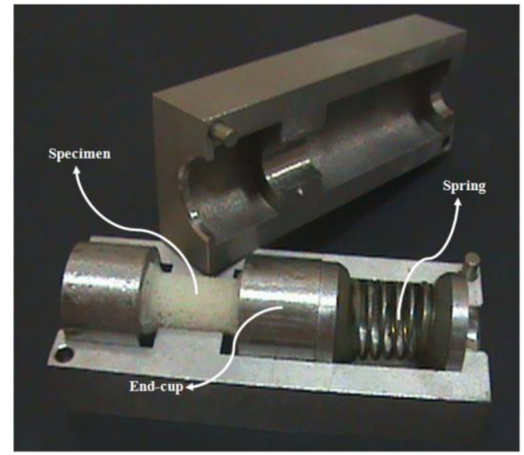


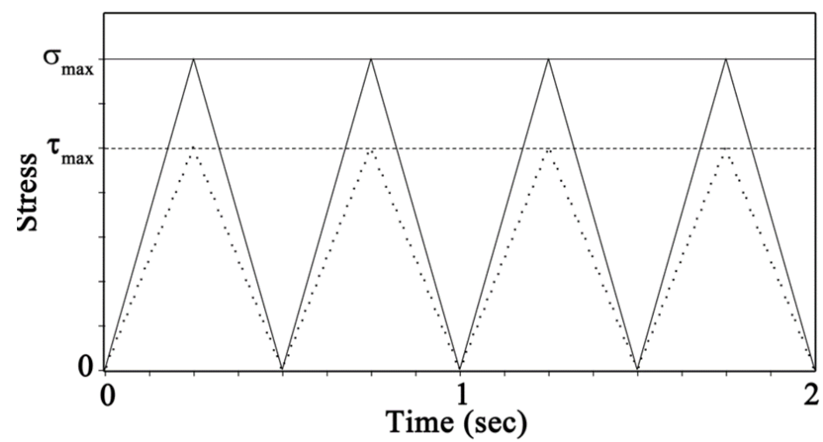
SAMPLE PREPARATION

EXPERIMENTAL SETUP

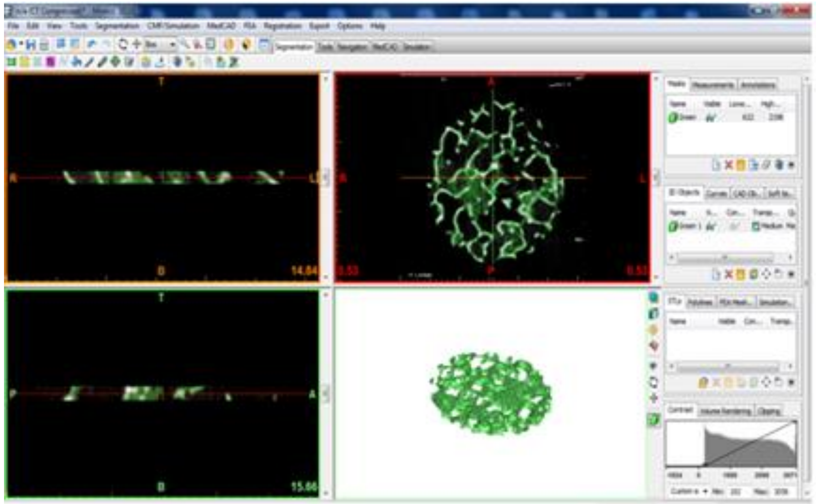


Instron 8874 universal testing machine



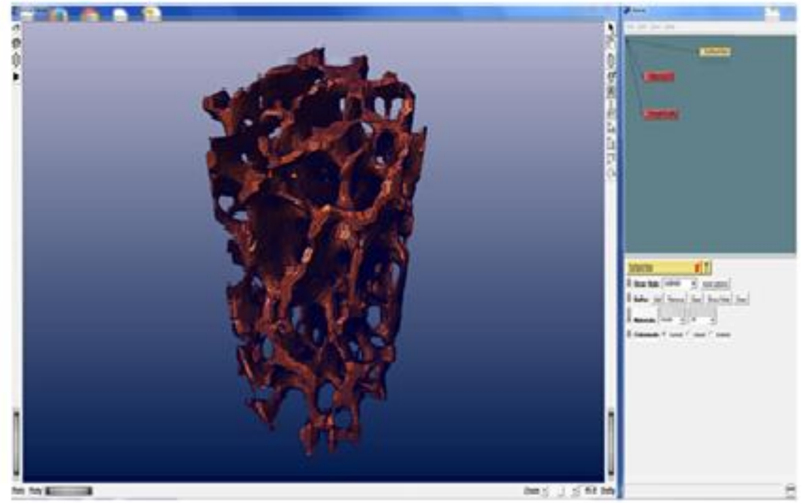


COMPUTER SIMULATION



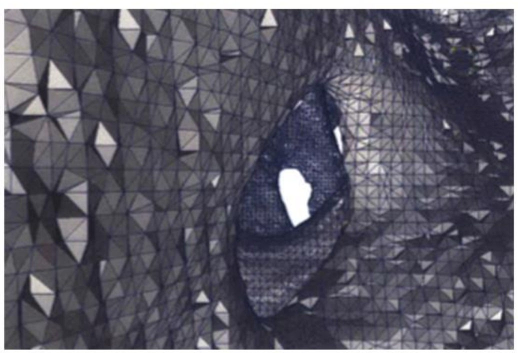
(a)

MIMICS software

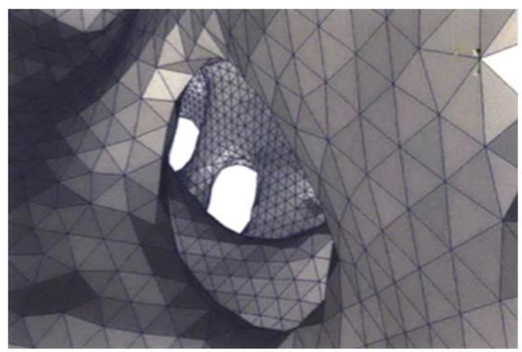


(b)

AMIRA software



(a)



(b)

COMPUTER SIMULATION

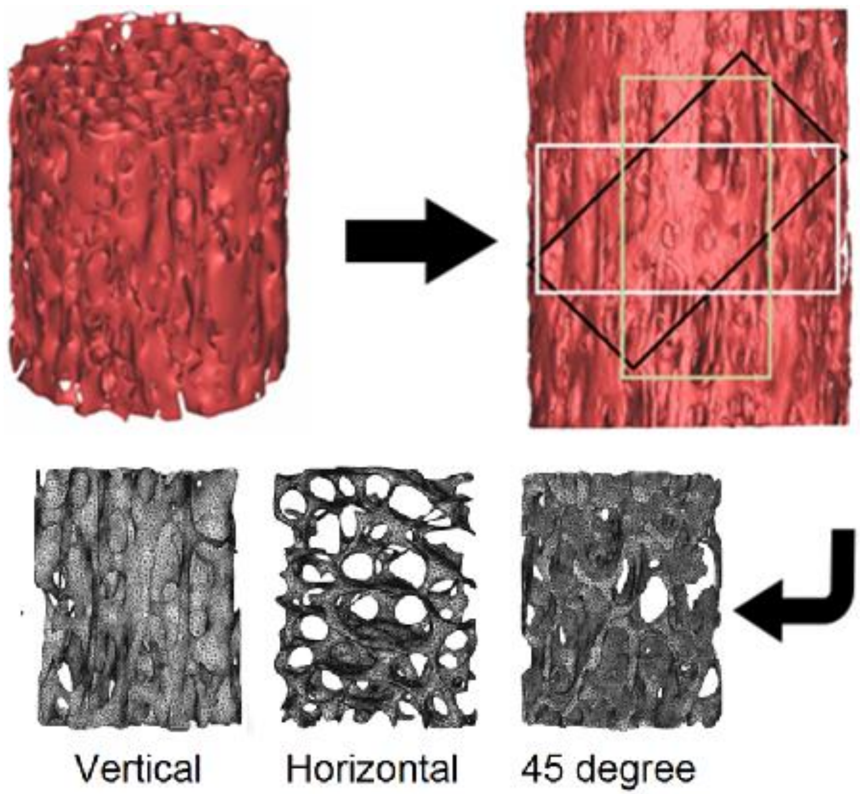


Figure: Models preparation and orientation

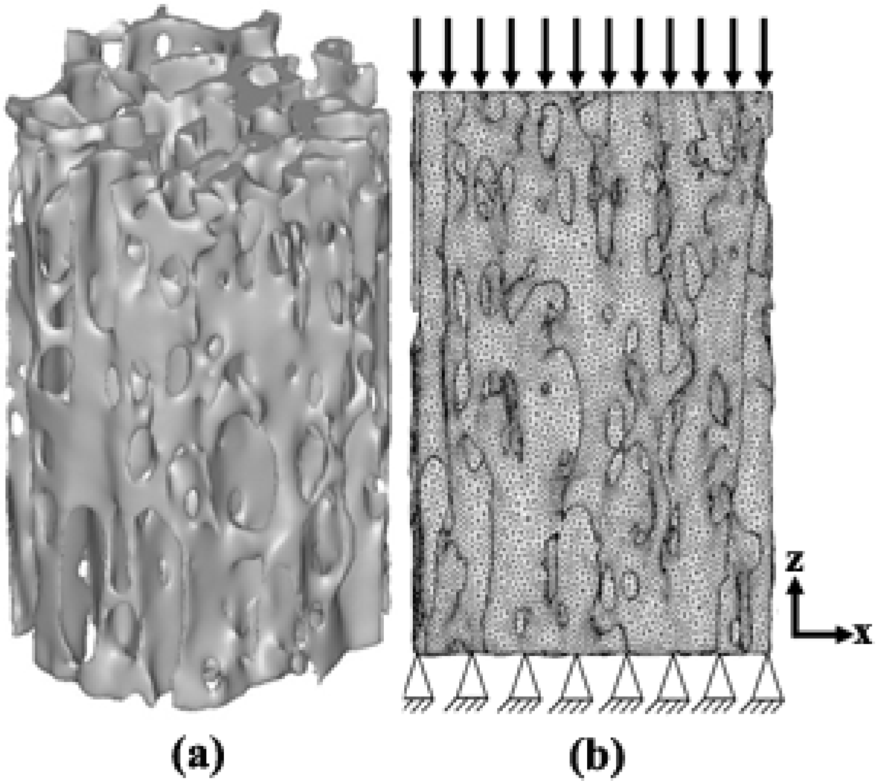
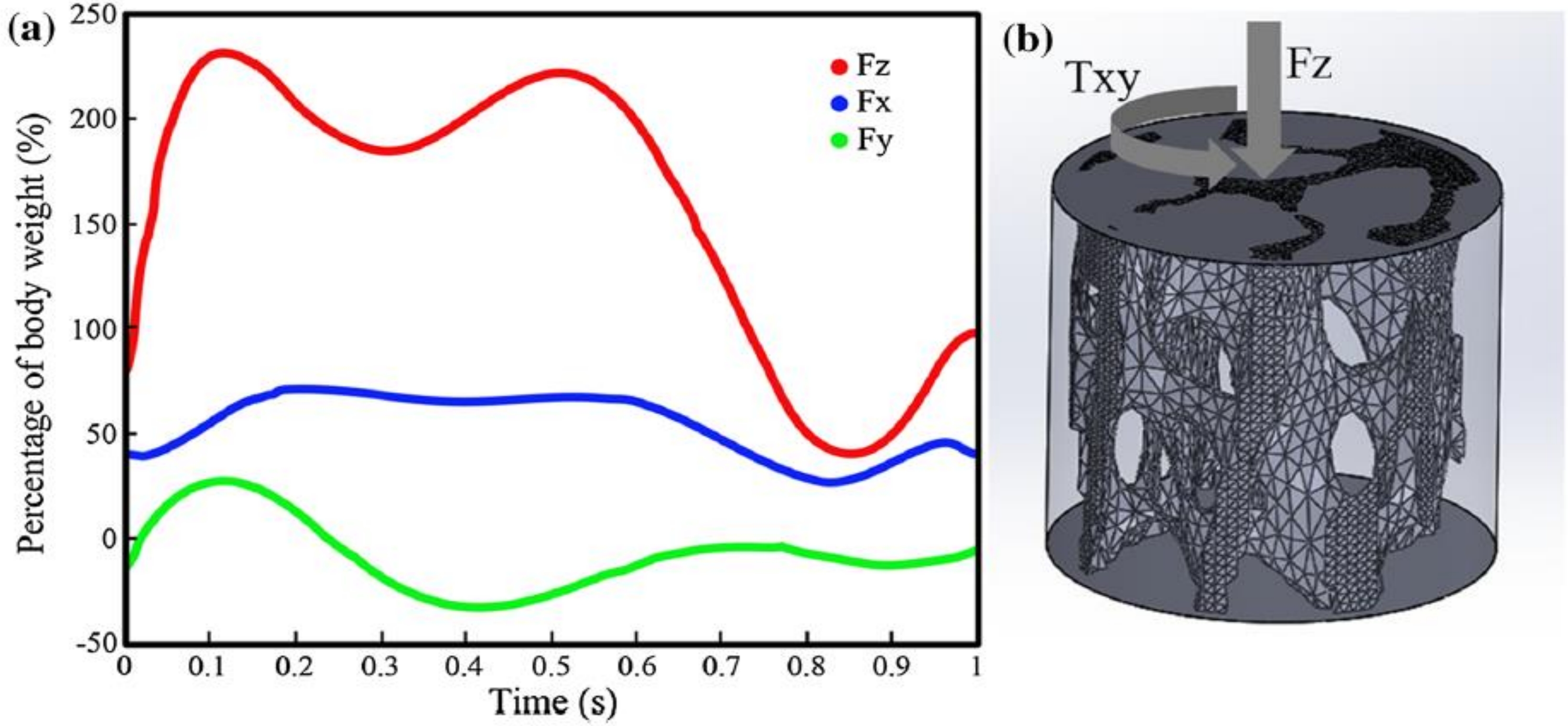


Figure: Boundary condition

BOUNDARY CONDITIONS



- F_x = - 1E6 (- $0.3434t^7 + 1.1756t^6 - 1.5667t^5 + 1.0239t^4 - 0.3369t^3 + 0.0490t^2 - 0.0013t + 0.0002$)
- F_y = - 1E5 (- $1.1068t^7 + 3.8818t^6 - 4.8999t^5 + 2.4244t^4 - 0.0797t^3 - 0.2734t^2 + 0.0542t - 0.0010$)
- F_z = -1E5 (- $2.9006t^7 + 7.0557t^6 - 3.5732t^5 - 3.5934t^4 + 4.4087t^3 - 1.6199t^2 + 0.2244t + 0.0048$)

COMPUTER SIMULATION

Table: Parameters used in fatigue modelling of trabecular bone

Property	Parameter	Value	Property group
Fatigue strength coefficient	$\sigma_{f'}$	26.4MPa	Basquin
Fatigue strength exponent	B	-0.155	Basquin
Fatigue ductility coefficient	εf ′	0.0134	Coffin-Manson
Fatigue ductility exponent	C	-0.097	Coffin-Manson
Q	critical plane evaluation	3	NA
Initial yield stress	σ_{ys0}	50.4 [MPa]	NA
Kinematic tangent modulus	E_{Tkin}	$0.05E_0$	NA

RESULTS AND DISCUSSIONS

1) FATIGUE BEHAVIOUR OF BOVINE TRABECULAR BONE
2) COMPUTATIONAL ANALYSES

FATIGUE BEHAVIOUR OF BOVINE TRABECULAR BONE

Table: Summary of the lifetime curve obtain in different stress states.

Stress state	Lifetime curve	R^2
C	$\sigma_{norm} = 1.1602 - 0.067 \log(N_f)$	0.86
CD	$\sigma_{norm} = 1.1386 - 0.074 \log(N_f)$	0.75
CT	$\sigma_{norm} = 1.1033 - 0.086 \log(N_f)$	0.68
TD	$\sigma_{norm} = 1.1070 - 0.090 \log(N_f)$	0.72
T	$\sigma_{norm} = 1.0579 - 0.072 \log(N_f)$	0.82

$$(\sigma/\sigma_y)^2 + (\tau/\tau_y)^2 = 1$$

where

σ_y = apparent compressive yield stress
τ_y = apparent shear yield stress

$$\left(\frac{\sigma_a}{E_0(N_f)}\right)^2 + \left(\frac{\tau_a}{G_0(N_f)}\right)^2 = 1$$

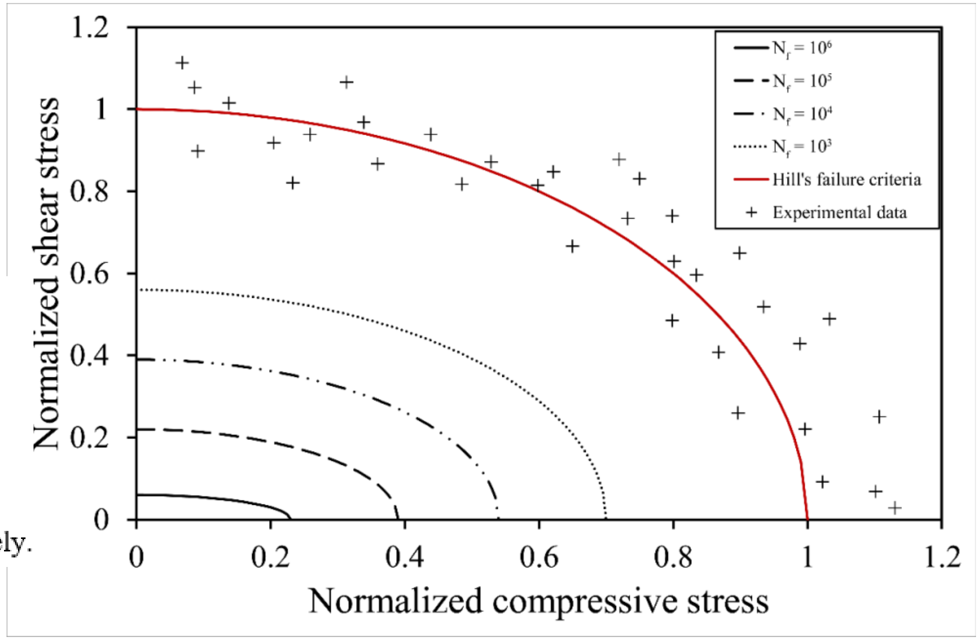
Where,

σ_a = maximum cyclic compressive stress

τ_a = maximum cyclic shear stress

E_0 & G_0 are initial modulus and modulus of rigidity respectively.

Figure: Monotonic compressive and combined fatigue compressive-shear strength.



FATIGUE BEHAVIOUR OF BOVINE TRABECULAR BONE

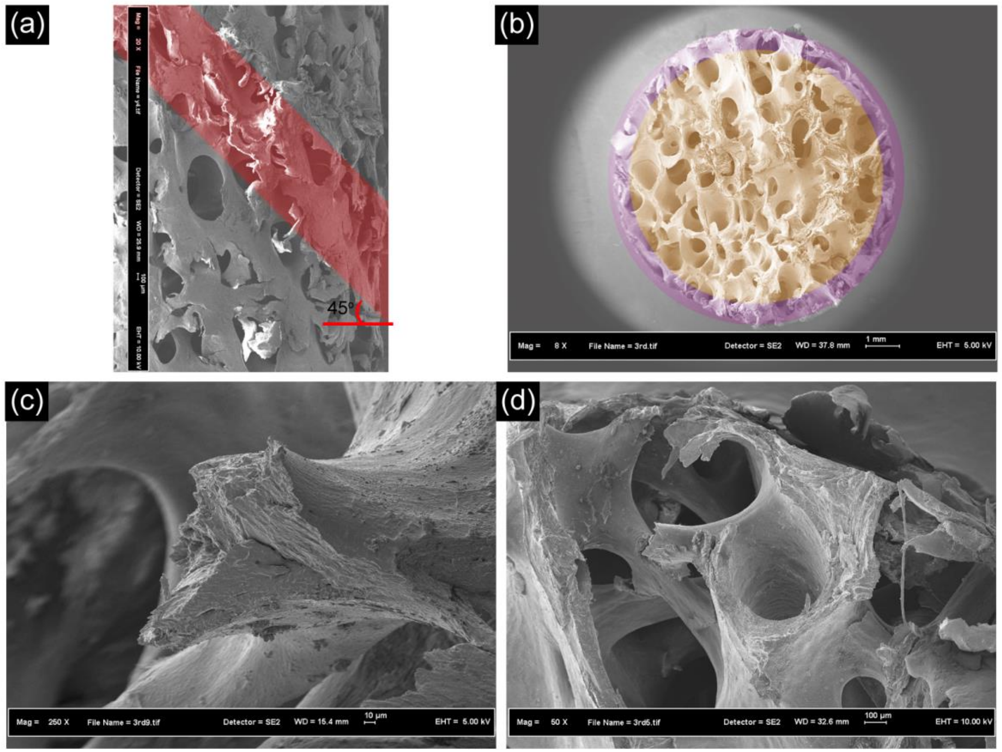


Figure: SEM micrograph of trabecular sample subjected to combined compression-torsion loading. (a) Fracture line of the sample (at 100µm), (b) fracture surface of the sample (at 1mm), (c) icicle-like fracture of a trabeculae with stump structure left (at 10µm), and (d) delaminating effect on sample surface (at 100µm).

COMPUTATIONAL ANALYSES

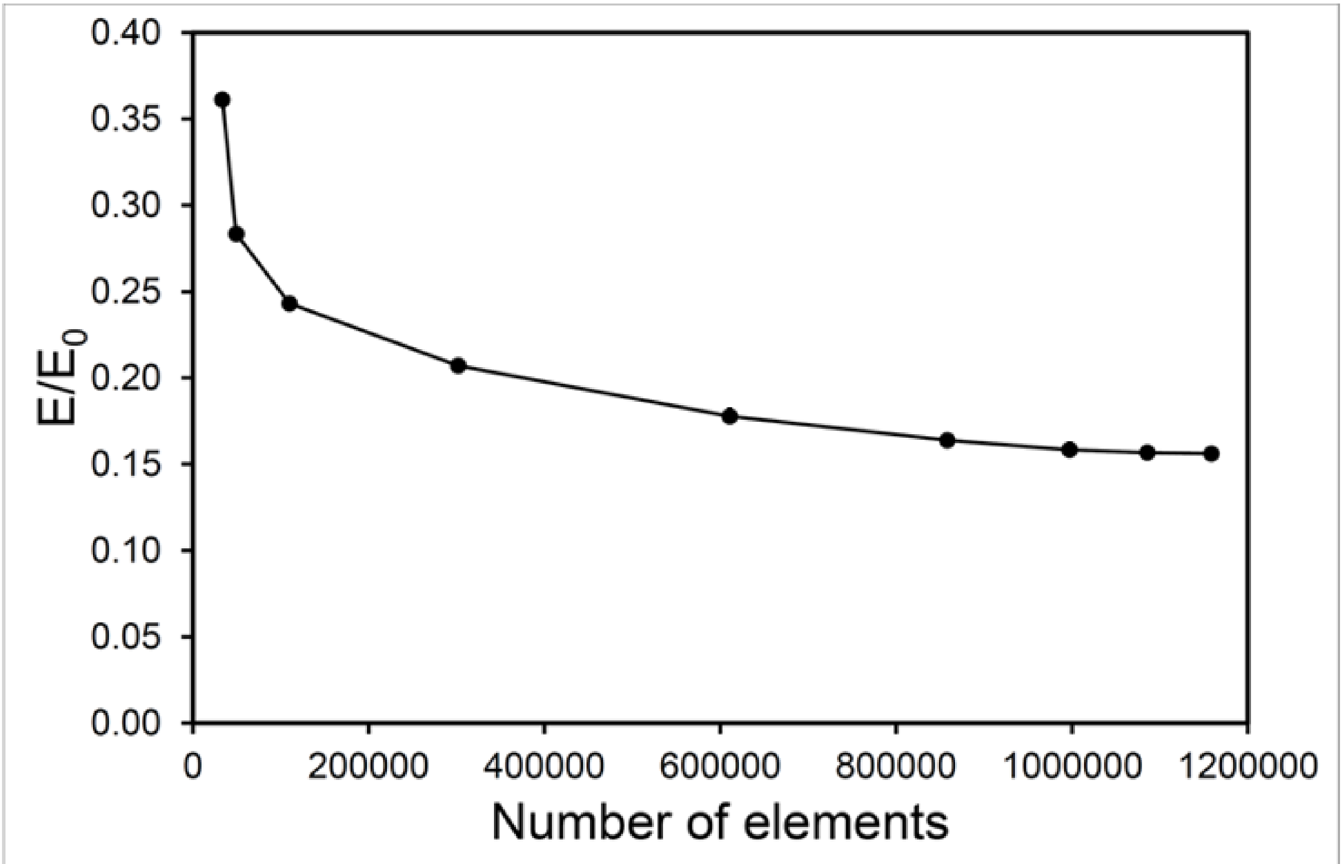


Figure: Convergence study for the finite element analysis

COMPUTATIONAL ANALYSES

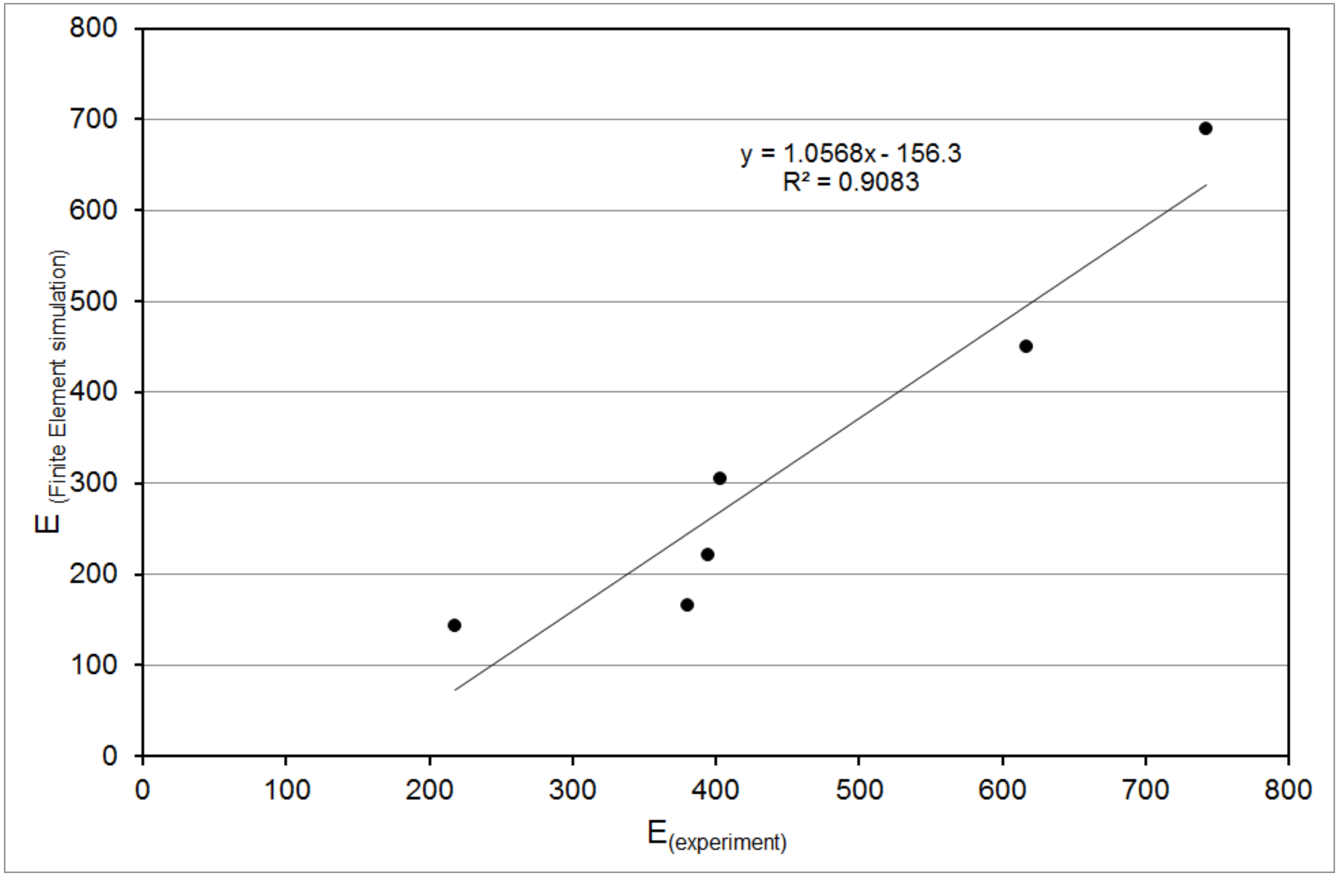


Figure: Comparison between FE simulation and experimental modulus with periodic boundary condition.

COMPUTATIONAL ANALYSES

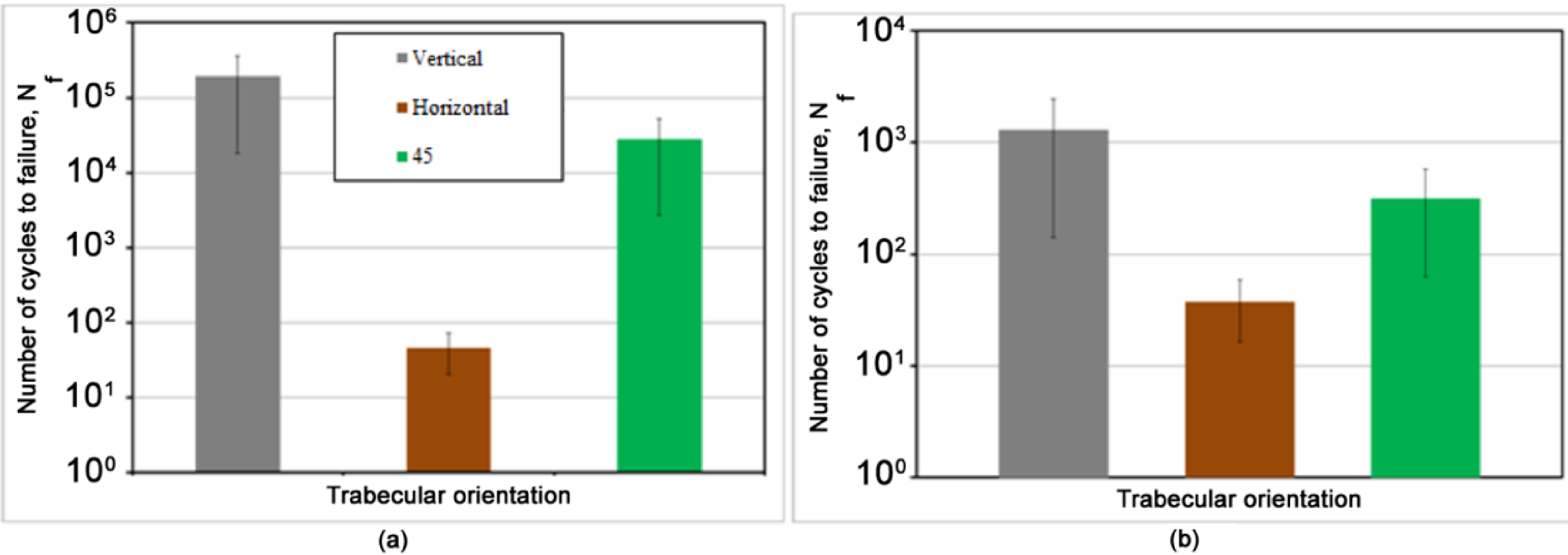


Figure: Comparison of (a) uniaxial and (b) multiaxial life prediction of the models at different trabecular orientation.

COMPUTATIONAL ANALYSES

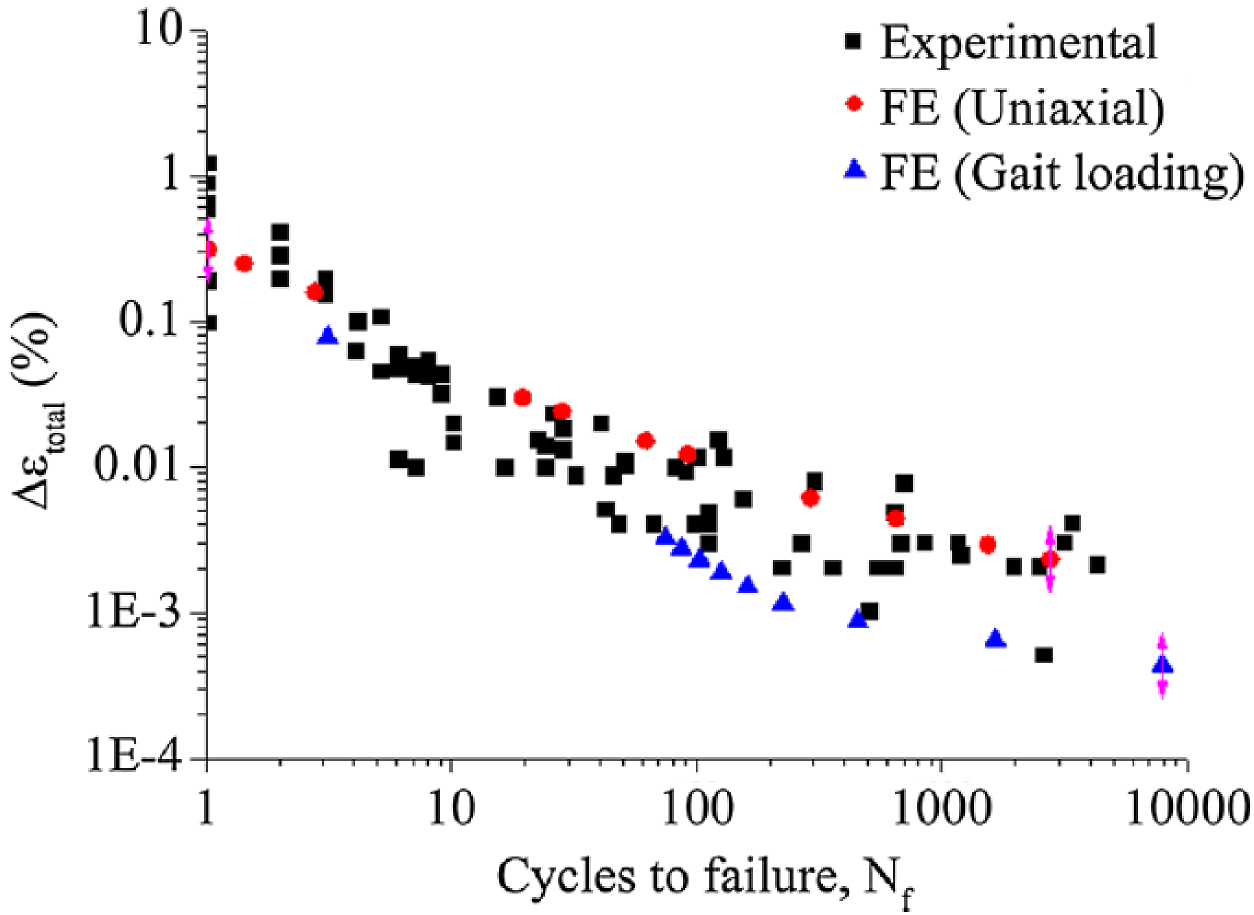


Figure: Comparison of finite element prediction with experimental data from literature showing the relationship of applied strain on the cycles to failure.

COMPUTATIONAL ANALYSES

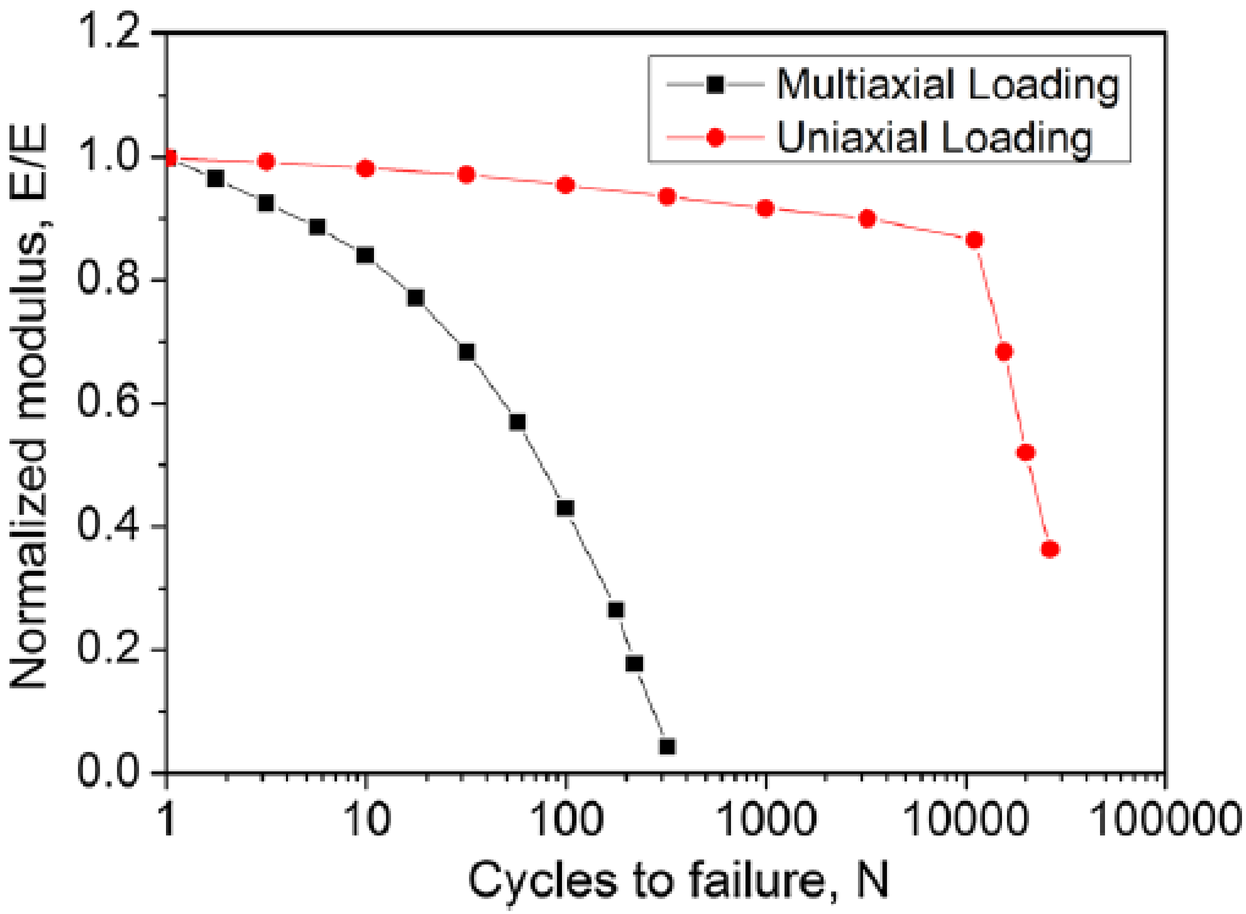


Figure: Predicted normalized modulus with increment of applied stress corresponding to the number of cycles to failure.

COMPUTATIONAL ANALYSES

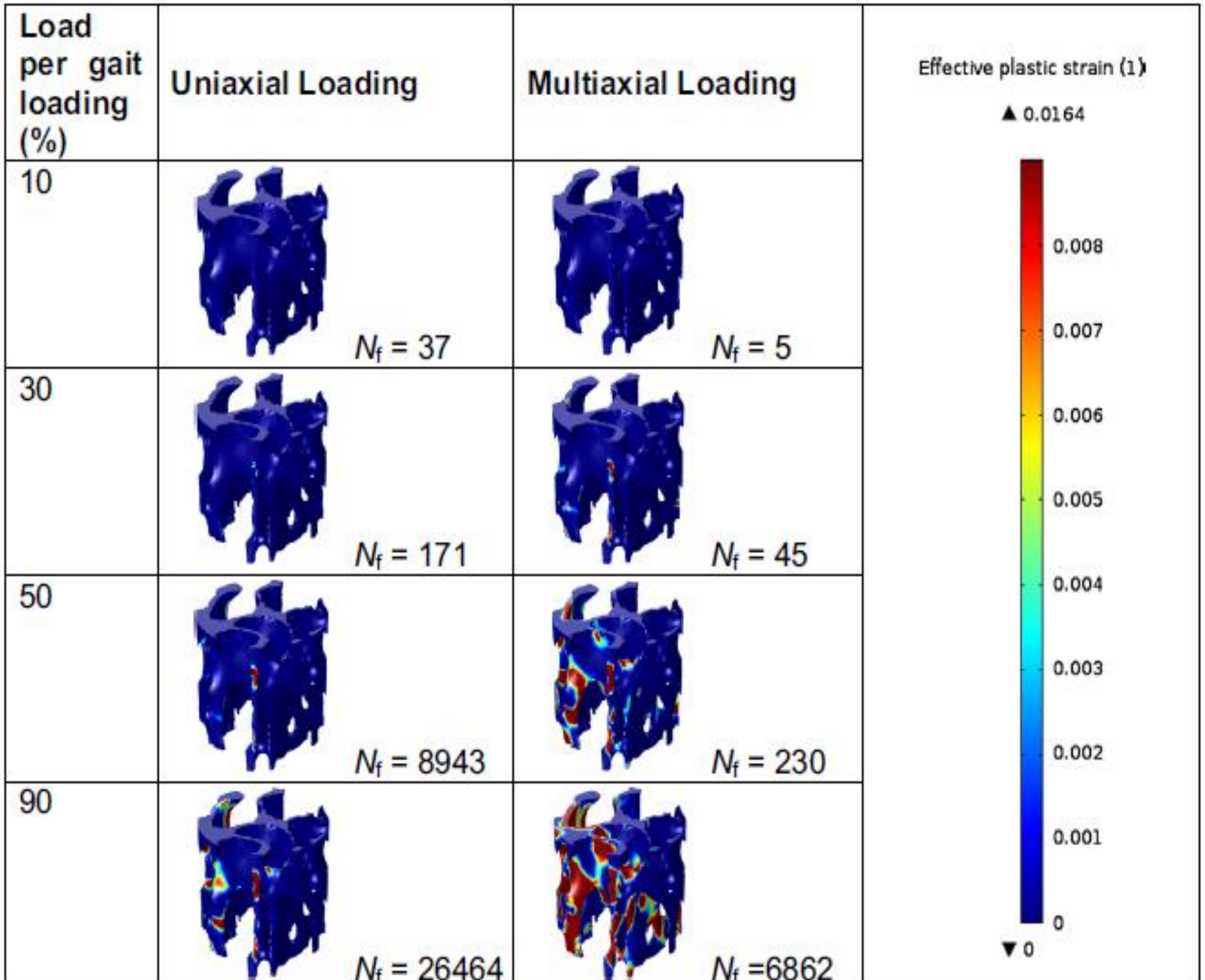


Figure: Contour of effective plastic strain predicted by FE simulations under uniaxial and multiaxial loading (final fatigue loading cycles taken from gait loading).

CONCLUSION

CONCLUSION

- The mechanical properties of bovine trabecular bone were observed to be deteriorated by the **superpositioned torsional loading**. In monotonic test, **multiaxial compressive-torsional loading has been found to induce brittle fracture and reduce the strength of the sample by 27%**.
- **Fatigue life reduction was significant when the shear stress is about 24% greater than maximum compression stress**. In other words, even at compression-torsion stress ratio of 4:1, the shear stress manifest itself to dominantly affect the fatigue life of the trabecular bone.

THANK YOU