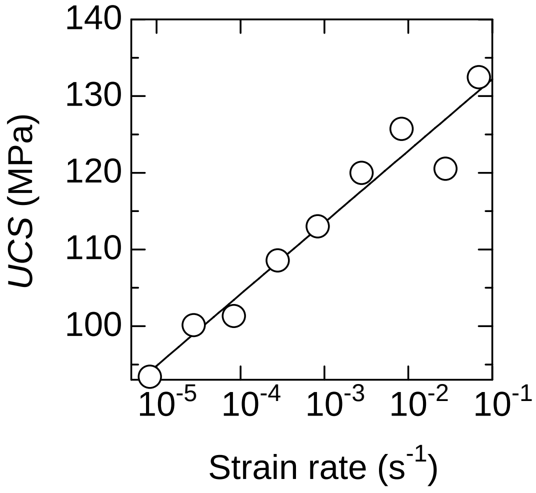
7. Effects of various conditions on deformation and failure of rock

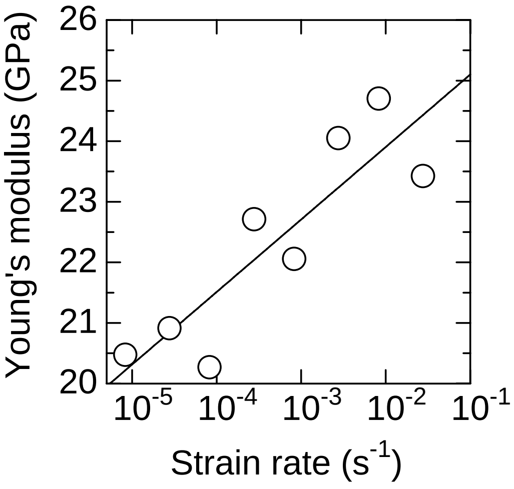
7.1 Loading rate

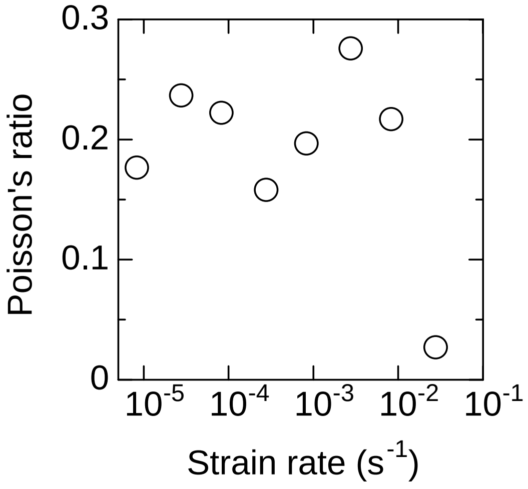
Strain rate of rock mass

- Very slow strain rate by tectonic movements (10^{-16} s^{-1}～10^{-14} s^{-1}) to very fast (around 10^{3} s^{-1}) by blasting
- Strain rate affects deformability and strength significantly
- Stability analysis should be based on deformability and strength at a strain rate which is likely to occur.

Under compressive stress





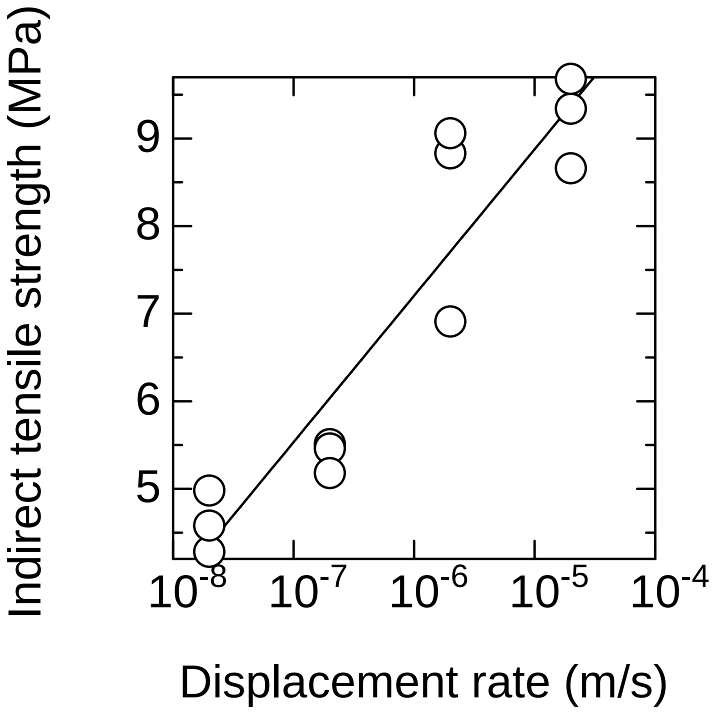


UCS Young's modulus Poisson's ratio

Results of uniaxial compression tests for Pombetsu sandstone

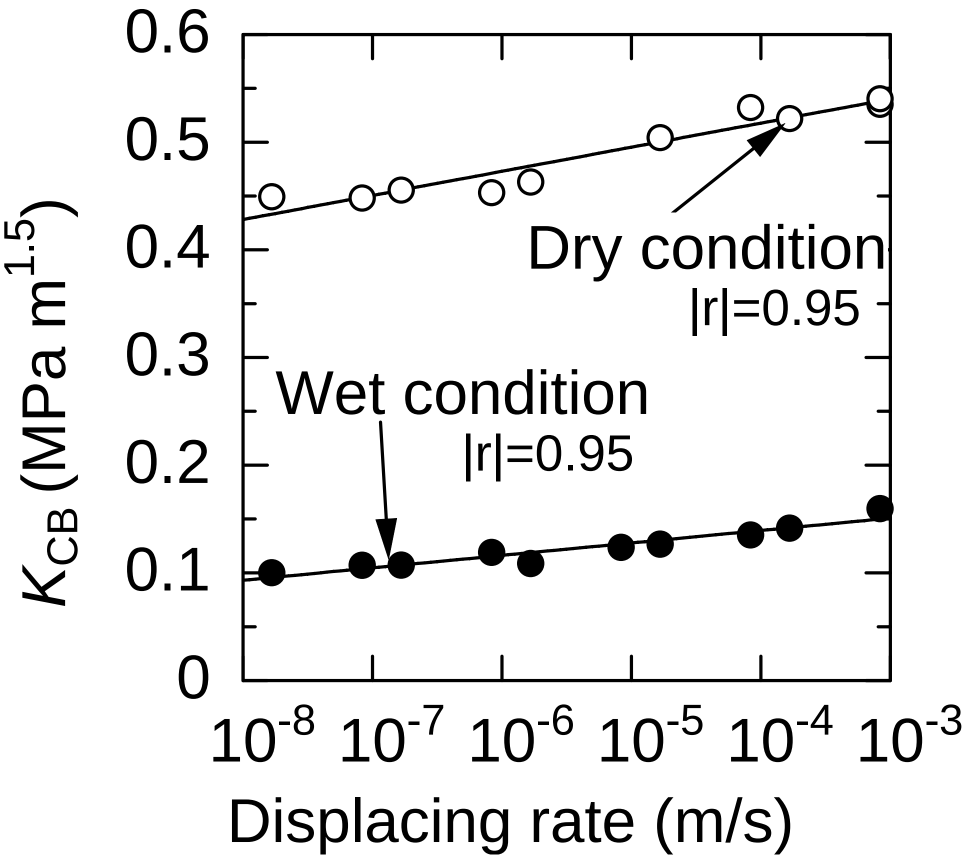
Brazilian test

- Inada granite



Fracture toughness

- Effect of loading rate on fracture toughness of Shirahama sandstone



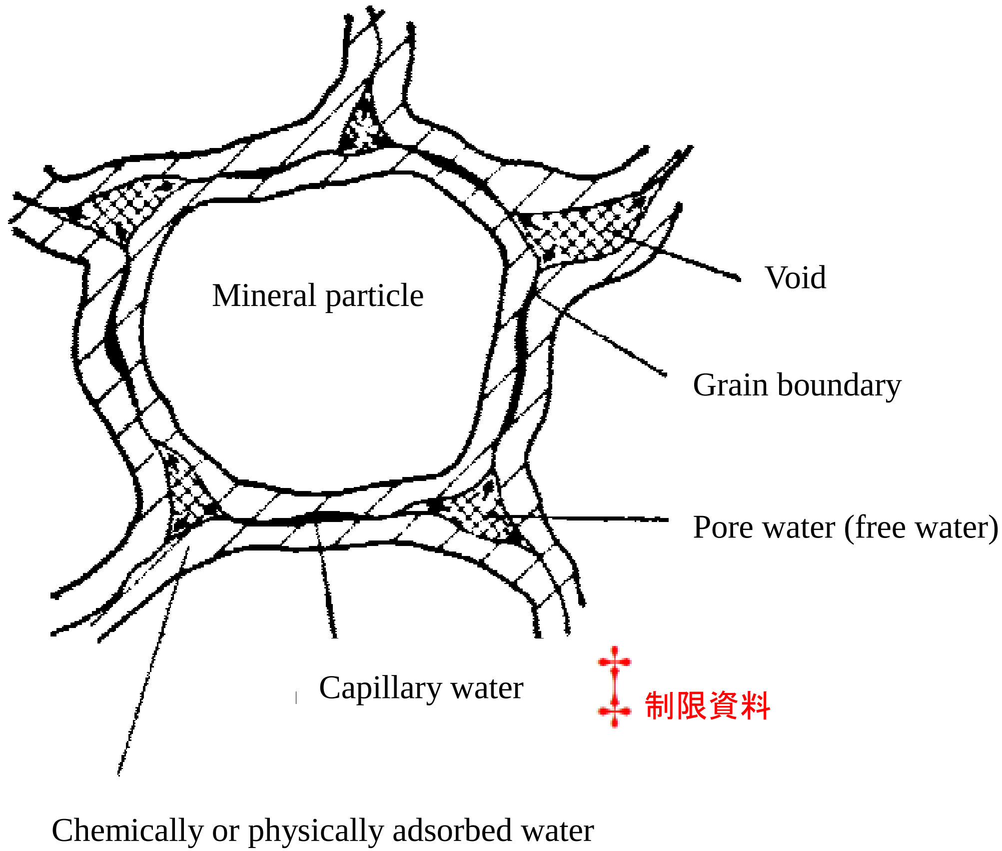
Cause of loading rate-dependency of strength etc.

- Rock whose strength is mainly due to such covalent bond as Si-O etc. (granite etc.)
  - Stress corrosion at crack tips.

- Sandstone etc.
  - Stress corrosion at crack tips.
  - Loading rate-dependency of cementing clay material
  - Suction (negative pore pressure) due to dilatancy

7.2 Effects of water

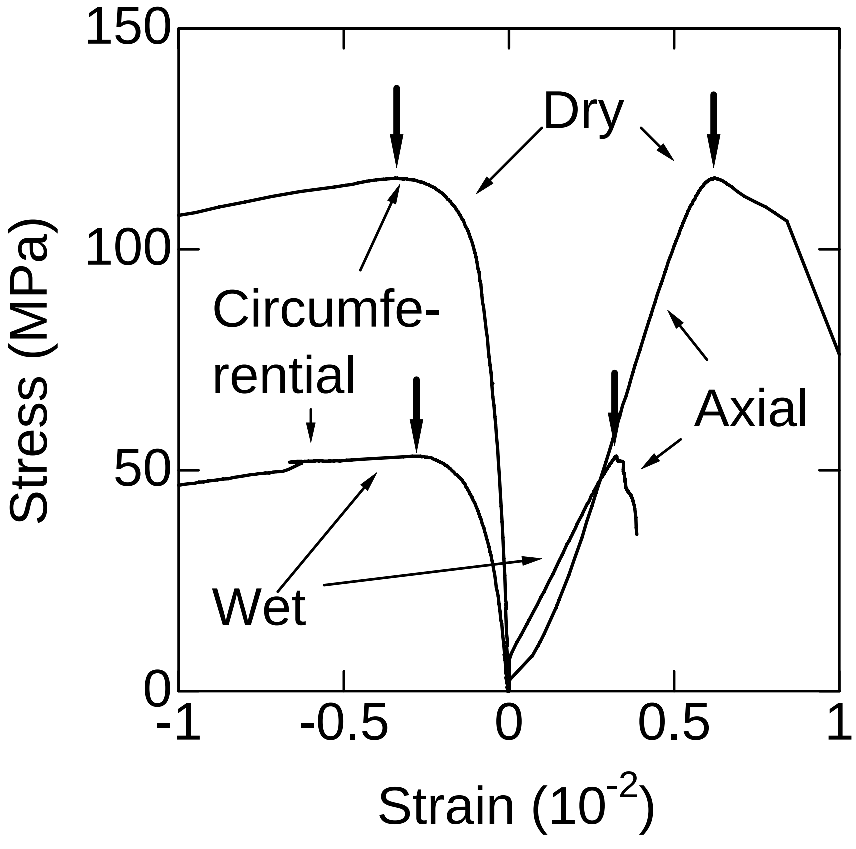
- Water in rock



制限資料

日本機械学会（1989）、岩石破壊力学とその応用、コロナ社、p. 25図2-18を修正

- Stress-strain curves in uniaxial compression tests for dry and wet Kamisunagawa sandstone.



Mechanism of weakening by water

- Decrease in friction between n
- Increase in stress corrosion rat

$$V = V_0 a(\mathrm{H_2O}) \exp\left(\frac{-E_{\mathrm{act}} + \alpha K_{\mathrm{I}}}{RT}\right)$$

- Decrease in fracture toughness
  - Example: surface energy of quartz (J/m^2)
    - Fresh surface in vacuum: > 2
    - Bonded with hydroxyls: 0.48～0.69
    - Saturated by water:0.41～0.46
    - In water: 0.34～0.39（Parks, 1986）
- Cement
  - Decrease in clay strength
  - Elusion of calcite

pH

- There is a possibility that rock mass is subjected to water of various pH
  - Acid water: organic acid water due to imperfect resolution of plant, inorganic acid water around hot springs or due to such sulfide as pyrite etc.
  - Alkali water: Getting mixed alkali hot spring or concrete.
- Weakening of quartz under large pH (Atkinson,1984)
- ζ potential, NaCl etc.

7.3 Effects of temperature

Temperature

- Rock mass can be subjected to various temperature
  - High temperature
    - Plate earthquake
    - Geothermal energy extraction
    - High level nuclear waste disposal (80～100^{o}C)
  - Low temperature
    - Underground storage of LNG (0～–50^{o}C))
    - Steep cliffs in cold regions

Effects of high temperature

- Differential stress-strain curves of a basalt under confining pressure of 500 MPa (Griggs *et al.*, 1960)

著作権処理の都合で、
この場所に挿入されていた

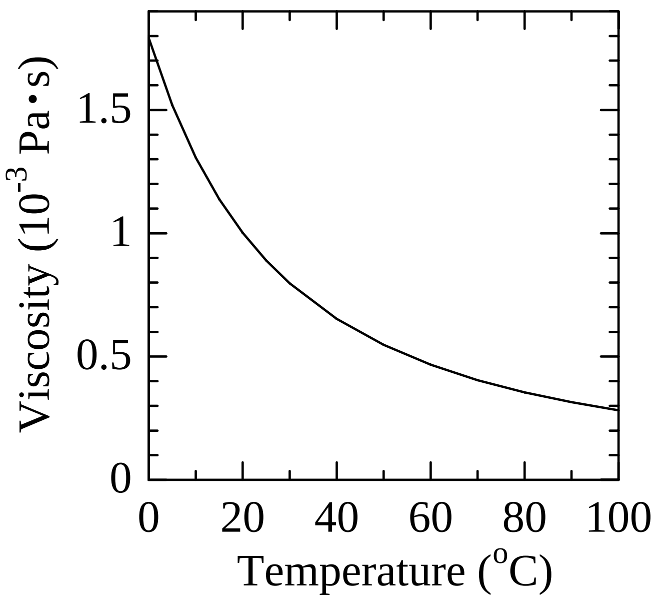
『山口梅太郎・西松裕一（1991）、岩石力学入門第3版、東京大学出版会、p. 202図6.17a』

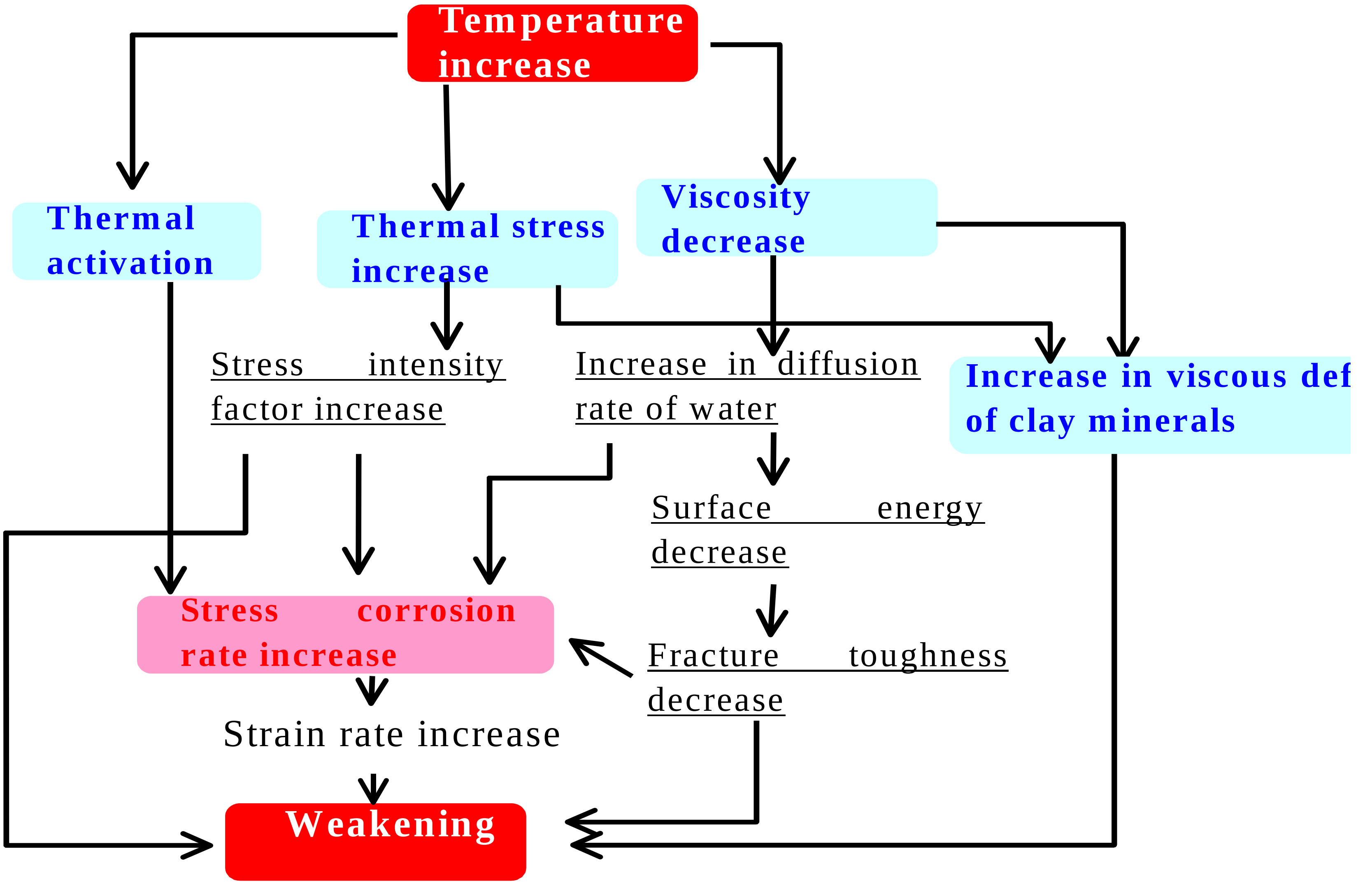
を省略させて頂きます。

Weakening mechanisms under high temperature

- Thermal stress
  - Thermal cracks
  - Increase in stress intensity factor
- Increase in stress corrosion rate
- Decrease in viscosity of water

$$V = V_0 a(H_2O)\exp\left(\frac{-E_{act} + \alpha K_I}{RT}\right)$$




Temperature increase
Thermal activation
Thermal stress increase
Viscosity decrease
Stress intensity factor increase
Increase in diffusion rate of water
Increase in viscous def
of clay minerals
Surface energy decrease
Stress corrosion rate increase
Fracture toughness decrease
Strain rate increase
Weakening

Effects of low temperature

- UCS vs. temperature for some rocks (Denchuken, 1987)

著作権処理の都合で、
この場所に挿入されていた

『電力中央研究所(1987)、低温化、
高温化での岩石・岩盤の特性調査、
電力中央研究所報告、U87010, p.2, Fig. 1.1』

を省略させて頂きます。

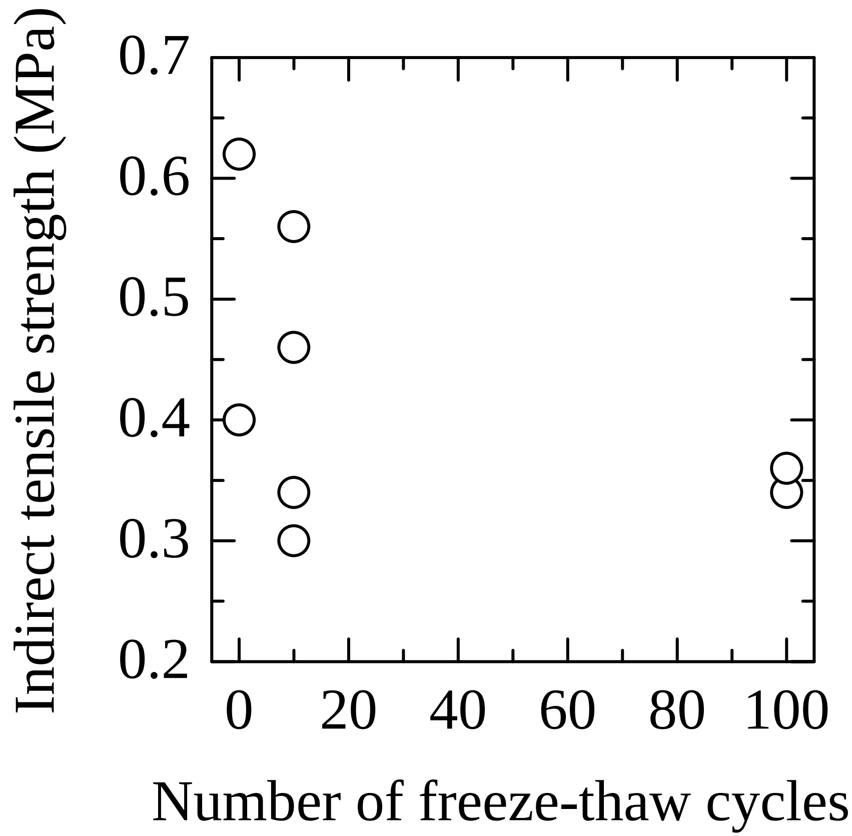
Strengthen mechanism under low temperature

- Adherence of cracks, voids etc. by freezing
- Activity of water decreases
- Thermal activation is inhibited

$$V = V_0 a(\mathrm{H_2O}) \exp\left(\frac{-E_{\mathrm{act}} + \alpha K_{\mathrm{I}}}{RT} \right)$$

Freeze-thaw cycle

- Near surface of rock slope in cold regions etc.
  - Fractures grow by freezing pressure
  - Rock mass is not weakened by freezing
  - Rock fall may occur when rock mass thaws
  - Repeated rock fall
    - Formation of overhang
      - Giant rock slope collapse

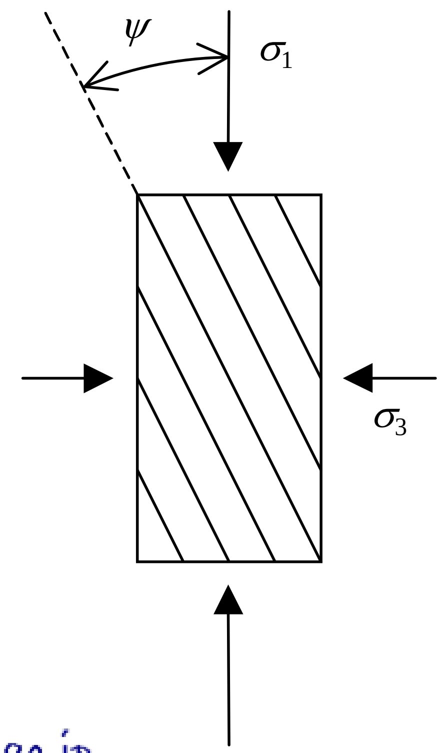


Indirect tensile strength of Takinosawa hyaloclastite in freeze-thaw cycles (Fujii et al., 2002)

7.4 Anisotropy

Anisotropy

- Anisotropy of triaxial strength for a slate (Goodman, 1980)



著作権処理の都合で、
この場所に挿入されていた

『Goodman (1980), Introduction to Rock Mechancs, John Wiley and Sons, p. 89, Fig. 3.23a』

を省略させて頂きます。

Cause of anisotropy in strength

- Mineral particles are anisotropic
- Rock is a composition of mineral particles
- Texture and structure of rock (foliation, sedimentary plane, flat particles, oriented microcracks, etc.) is more important in an engineering point of view than anisotropy of mineral particles

7.5 Scale effects

著作権処理の都合で、この場所に挿入されていた

『Goodman (1980), Introduction to Rock Mechancs, John Wiley and Sons, p. 86, Fig. 3.21』

を省略させて頂きます。

- UCS vs. specimen length (Goodman, 1980)

- Large scale uniaxial compression test (Goodman, 1980)

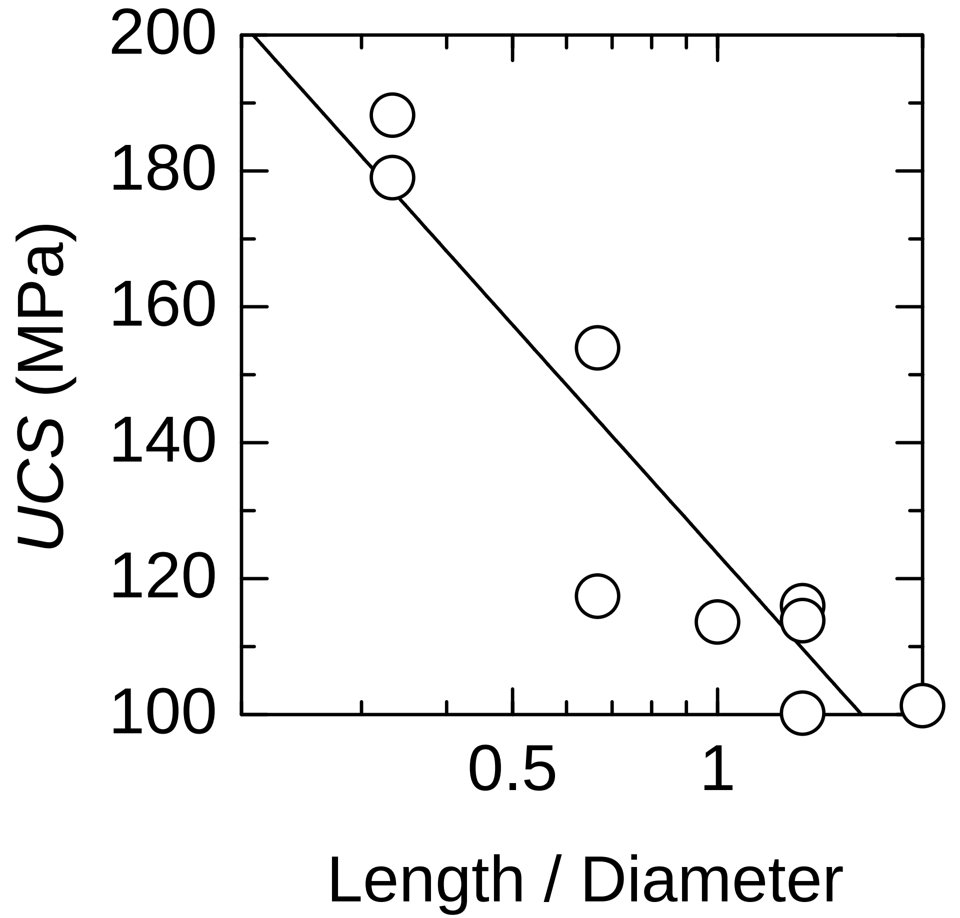
著作権処理の都合で、この場所に挿入されていた

『Goodman (1980), Introduction to Rock Mechancs, John Wiley and Sons, p. 87, Fig. 3.22』

を省略させて頂きます。

7.6 Shape effects

- UCS of Pombetsu sandstone



7.7 Weathering

- Physical weathering
  - Freeze-thaw cycle
  - Cyclic thermal stress
  - Repeated drying and moistening
- Chemical weathering
  - Water-mineral reaction
    - Ex. Pyrite in a rock is oxidized and sulfate is generated. Calcite is dissolved by the sulfuric acid and gypsum is created or illite is decomposed by the sulfuric acid and jarosite is created (Okada et al., 2003)
      - $4FeS_2 + 15O_2 + 10H^2O \rightarrow 4FeOOH$ (limonite) $+ 8H_2SO_4$
      - $CaCO_3 + H_2SO_4 + 2H_2O \rightarrow CaSO_4 2H_2O + H_2O + CO_2$
      - $4(KAl_2Si_3O_8(OH)_2) + 12FeSO_4 + 48H_2O \rightarrow 4(KFe_3(OH)_6(SO_4)_2 + 8Al(OH)_3 + 12Si(OH)_4 + 4H_2SO_4$