



**NANYANG
TECHNOLOGICAL
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Dynamic Loading of Carrara Marble in a Heated State

presented by:

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Outline

- Introduction
- Methodology
- Results
- Discussion

Introduction

- Dynamic compression while rock is still heated
- Split Hopkinson Pressure Bar – powered by nitrogen gas gun and fitted with customised oven



Introduction

- Scenarios:
 - fire in unlined mining tunnel
 - traffic accident in service tunnel
 - any case where there is **dynamic loading during a fire**
- Mont Blanc tunnel fire (1999)
 - Damaged shotcrete lining leading to rock damage



Introduction

- Stress shadowing



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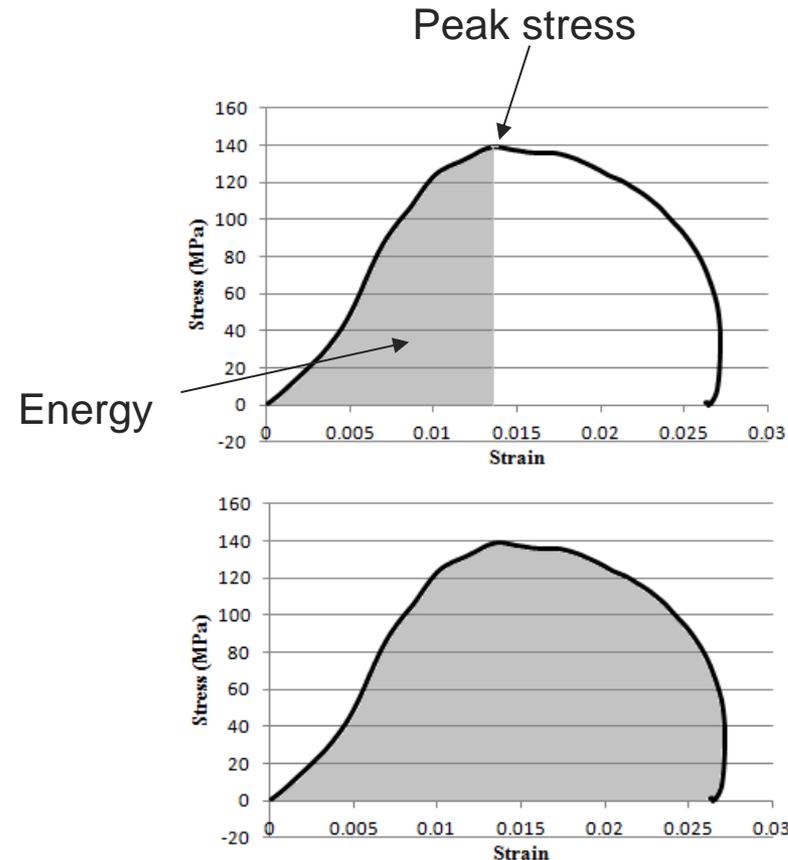
Methodology

- Carrara marble discs were cut from a slab using a water jet abrasive machine
- Heated at a rate of 2 °C per minute to temperatures of 250 °C, 500 °C and 750 °C
- Tested at pressures of 4 bars, 6.5 bars and 9 bars
- 3 wave analysis



Methodology

- Energy at **peak stress** and **total energy** absorbed is calculated using area under the stress-strain curve
- Particle size distribution of fragments done via **dry sieving**

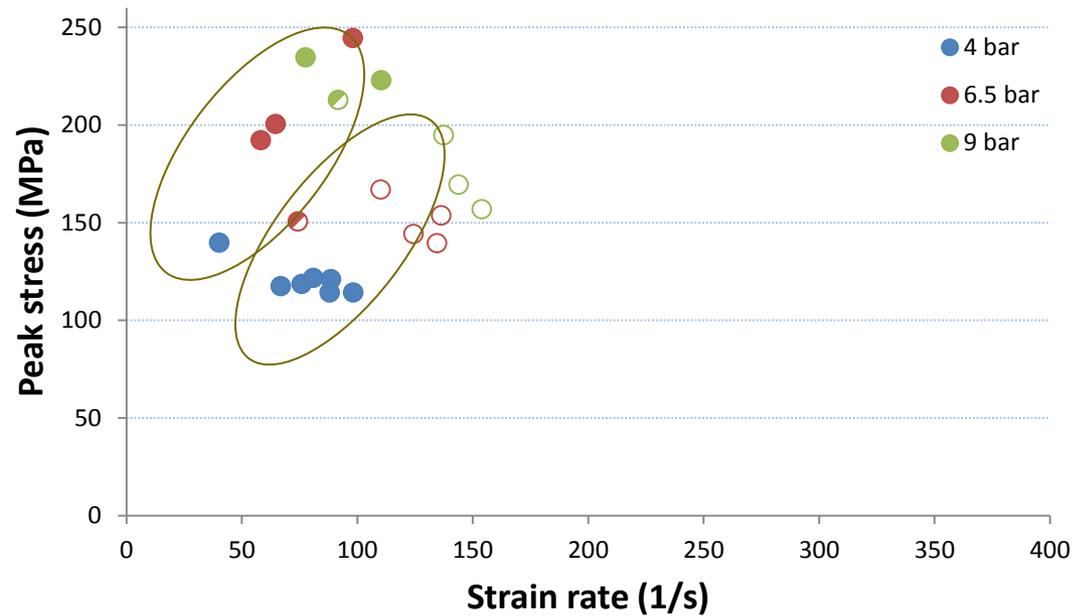


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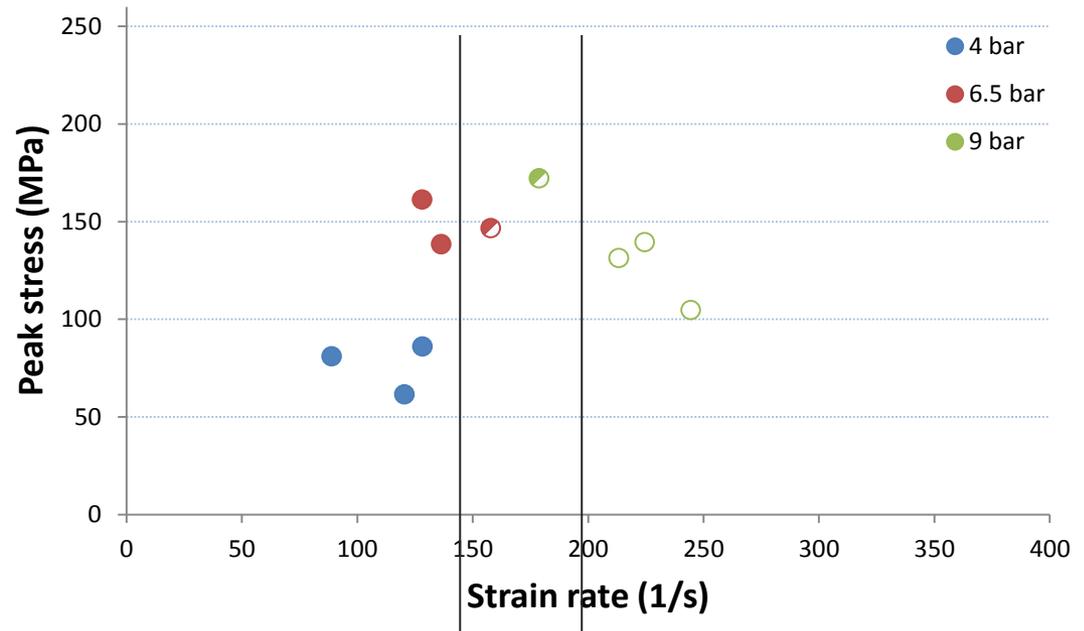
Results

- Different types of failure mode preferred at different temperature and pressures
- Axial splitting and pulverization observed at low temperatures



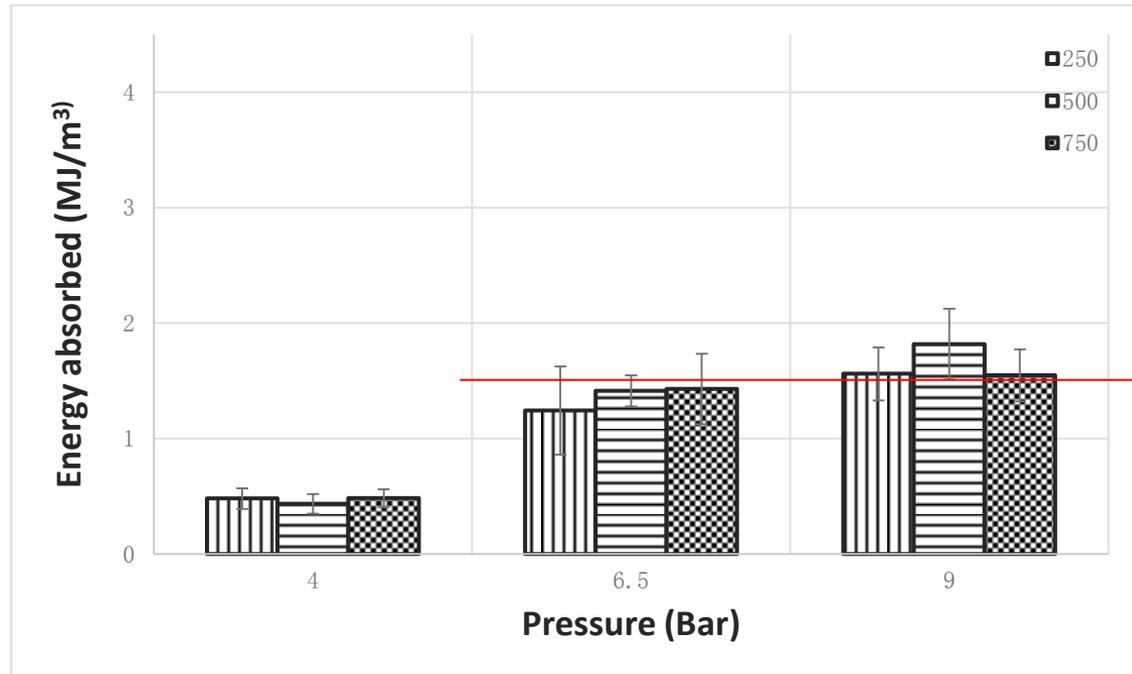
Results

- Failure mode also changes with respect to **strain rate**
- **Transition zone** of axial splitting observed
- Similar to observation by Doan and Billi (2011)



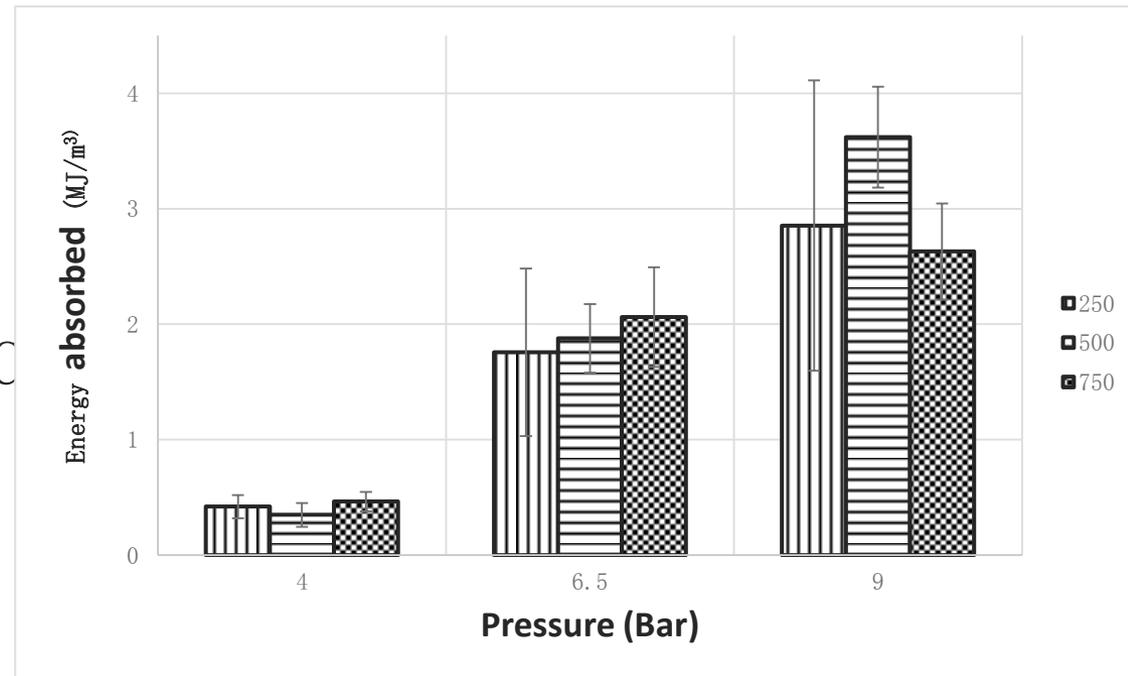
Results

- Minor increase in energy absorbed at peak stress from 6.5 bars to 9 bars
- Lower strength
- Higher strain



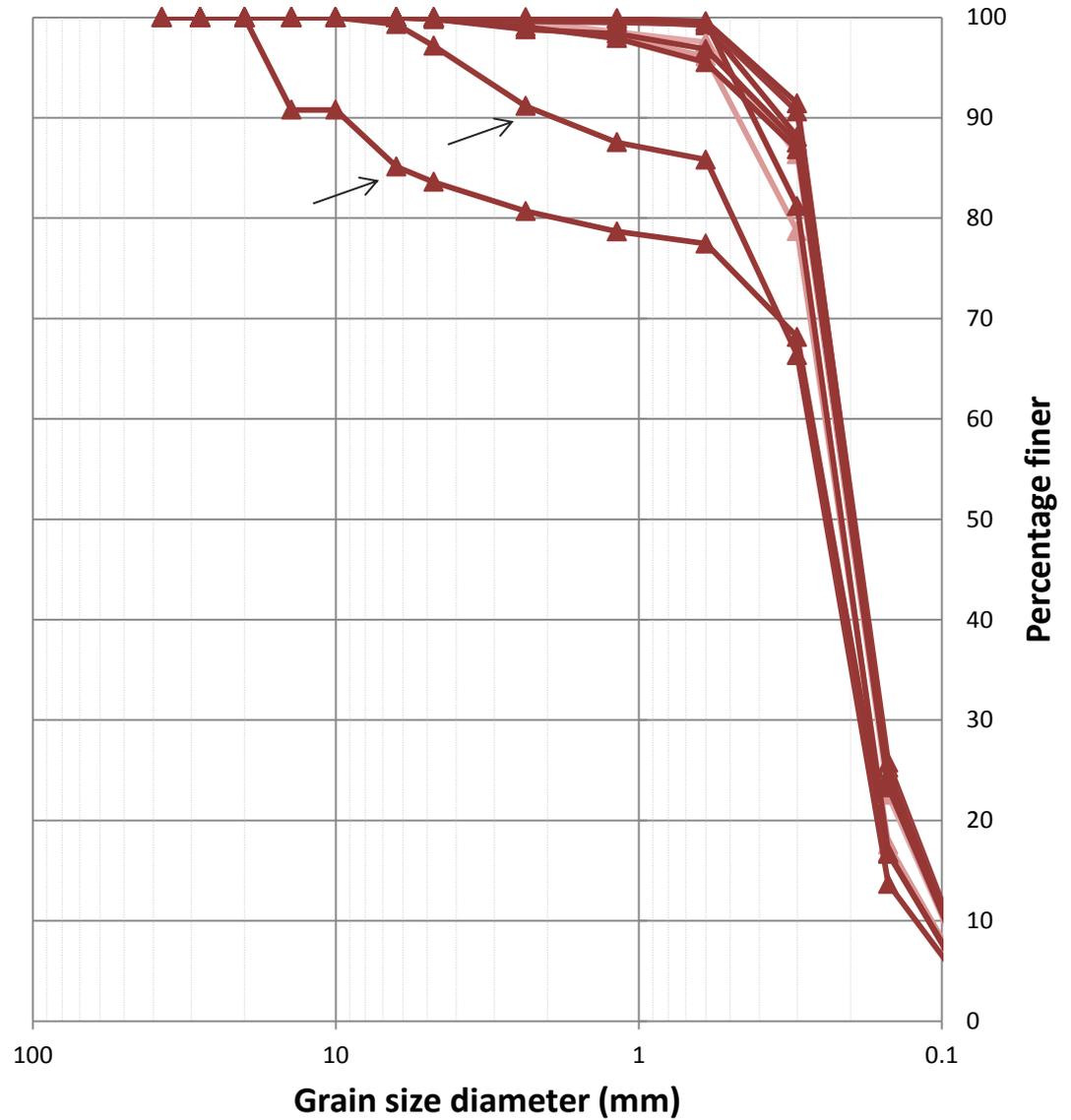
Results

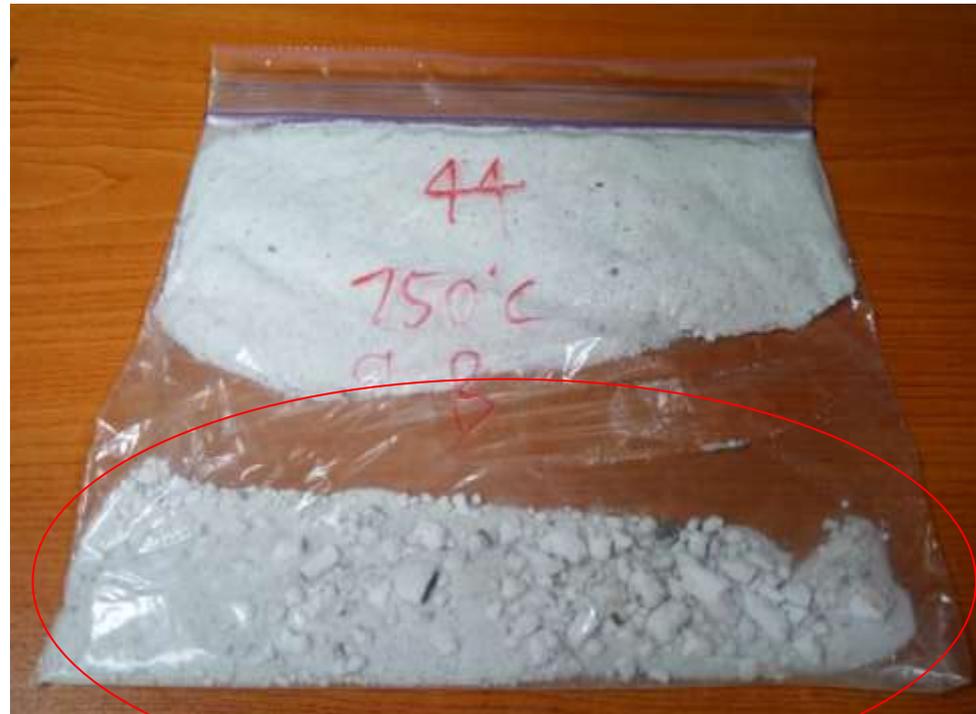
- Major increase in total energy absorbed from 6.5 bars to 9 bars
- Large standard deviation for 250 °C specimens
- Different amount of energy consumed for different failure mode
- Possible stress shadowing



Results

- Particle size distribution of fragments found via dry sieving





From Liu and Xu
(2013)



25 °C



100 °C



200 °C



400 °C



600 °C



800 °C



1000 °C

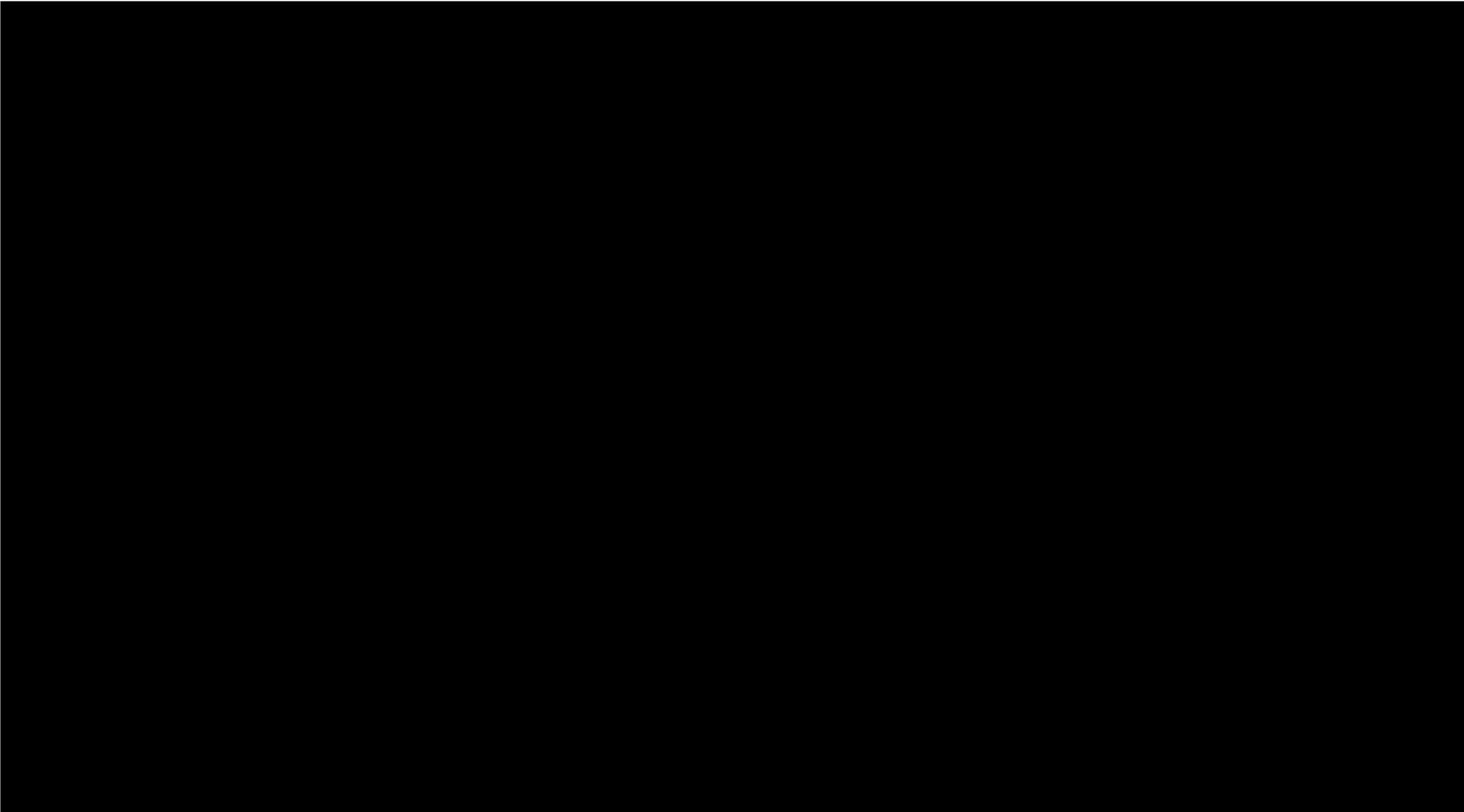
Failure modes of marble under different temperatures. (a) T=25 °C, (b) T=100 °C, (c) T=200 °C, (d) T=400 °C, (e) T=600 °C, (f) T=800 °C and (g) T=1000 °C.

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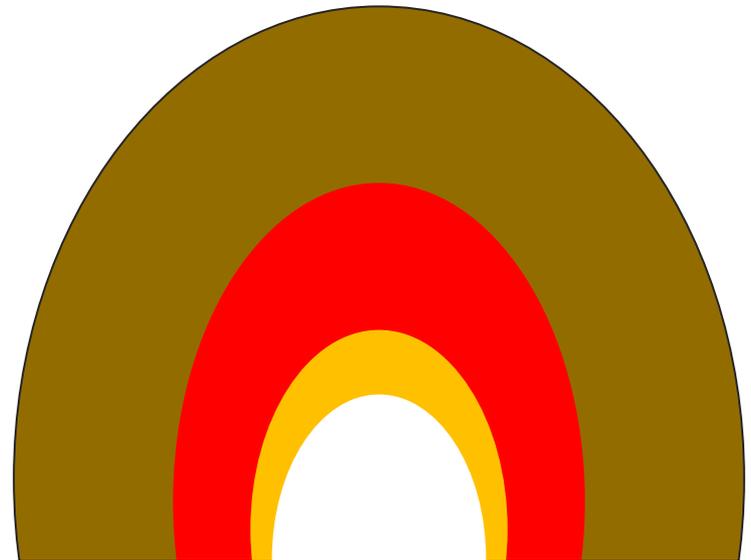
Discussion

- Similar amount of energy needed for specimens to fail
- Difference in total energy absorbed is due to difference in average fragment size
- Strength of specimens inversely correlated to heating temperature
- Strain rate effect decreases as temperature increases



Discussion

- Heated rocks **absorbs more energy**
- Assumes no stress shadowing
- Compromised rock acts as **'crumple zones'**
- May **reduce area of damaged rock** due to dynamic loading



Thank you