ENGINEERING PROPERTIES OF FOAMED RECYCLED GLASS AS A LIGHTWEIGHT FILL

NESMEA 2016, Newark, DE

Robert H. Swan, Jr. – Drexel University
Seungcheol Yeom* – Drexel University
Kurt J. Sjoblom – Drexel University
Timothy D. Stark – University of Illinois at UC
Archie Filshill – Aero Aggregates, LLC

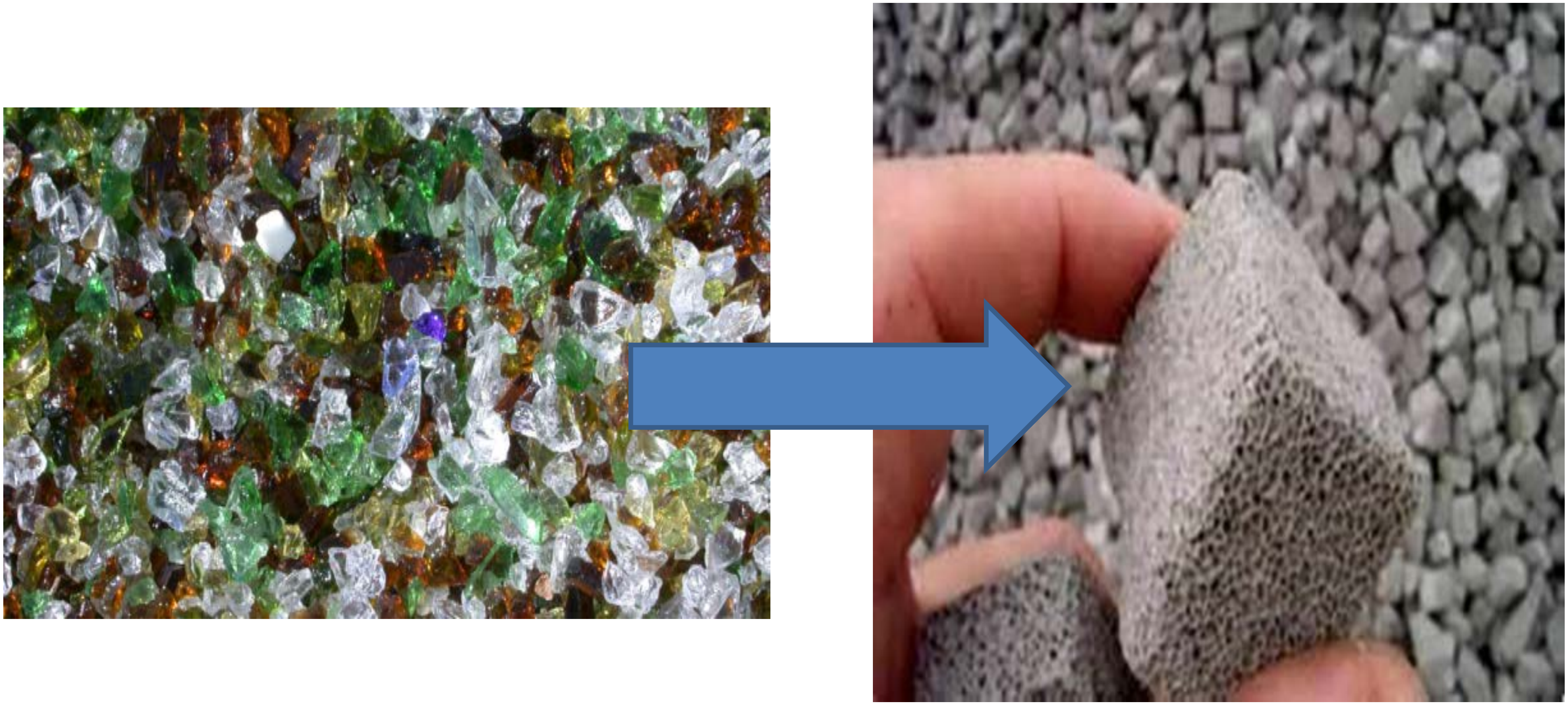
DREXEL UNIVERSITY
Civil, Architectural, and Environmental Engineering
College of Engineering

NESMEA
North Eastern States' Materials Engineers Association

OUTLINE OF PRESENTATION

- Background
- Testing Program
  - Materials
  - Testing Methodology
- Discussion and Results
  - Effect of Compaction Energy
  - Effect of Static Compression
  - Effect of Direct Shear Testing
- Conclusions

Process transforms glass cullet into a new material – Foamed Glass



Glass Processing

- Cleaning of glass cullet
- Uses all colors and any size

- Milled into powder
- Mixed with foaming agent

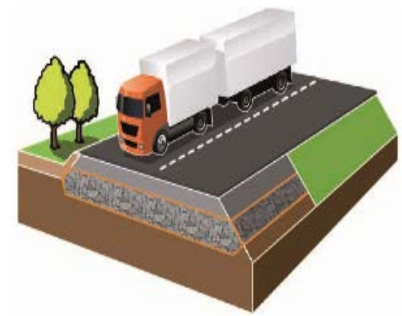
Foamed Glass Kiln

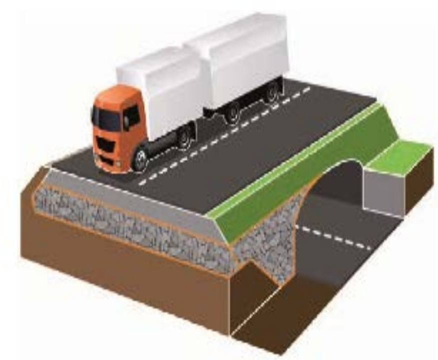
History of Lightweight-Foamed Glass Aggregates (LWA-FG)

- Developed in Germany in early 1980’s
- Technology taken to Norway in 1990’s
- Thermal barrier for roadways
- Led to lightweight applications
- Growth throughout Scandinavia
  - Geotechnical Applications
- Germany and Switzerland
  - Thermal insulation
  - Additive for lightweight concrete

Foamed Glass Aggregates Applications

- Many uses for lightweight aggregates
  - Embankment fill over soft soils
  - Retaining walls
  - Bridge abutments
  - Reduced lateral load of backfill
  - Under foundation slab insulation
  - Insulation layer
  - Greenroofs and Plaza decks



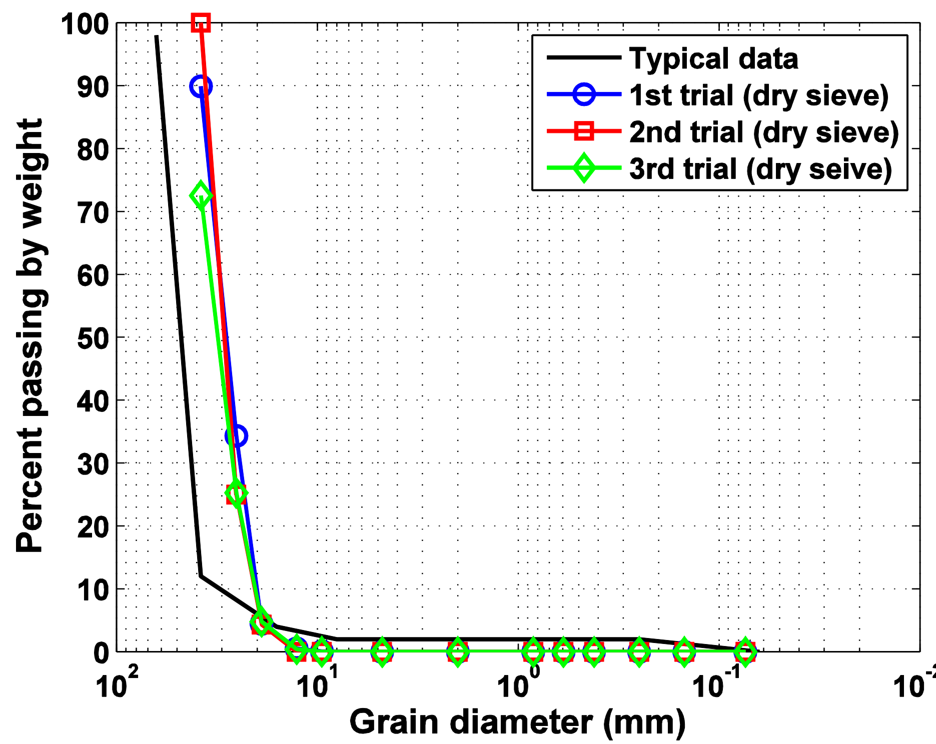


LWA-FG MATERIALS

- LWA-FG material provided by Aero Aggregates, LLC
- LWA-FG made from 100% recycled glass

Typical properties

Property	Manufacturer	Actual
Particle size range (mm)	10 to 60	10 to 30
D_{10} (mm)	38	20
D_{30} (mm)	42	27
D_{60} (mm)	50	30
C_u/C_c	1.32/0.93	1.5/1.22
Bulk Density (kg/m^3)	210	227



TESTING METHODOLOGY

- Testing program
  - evaluate the change in grain size distribution (GSD) of the LWA-FG material as a function of:

i. Compaction energy (impact and vibratory)
ii. 1-D compression (consolidation and creep)
iii. Direct shear behavior

  - Dry and wet grain-size analyses were performed after each of the engineering property tests
  - Goal was to assess the amount of particle breakage due to crushing effect of:

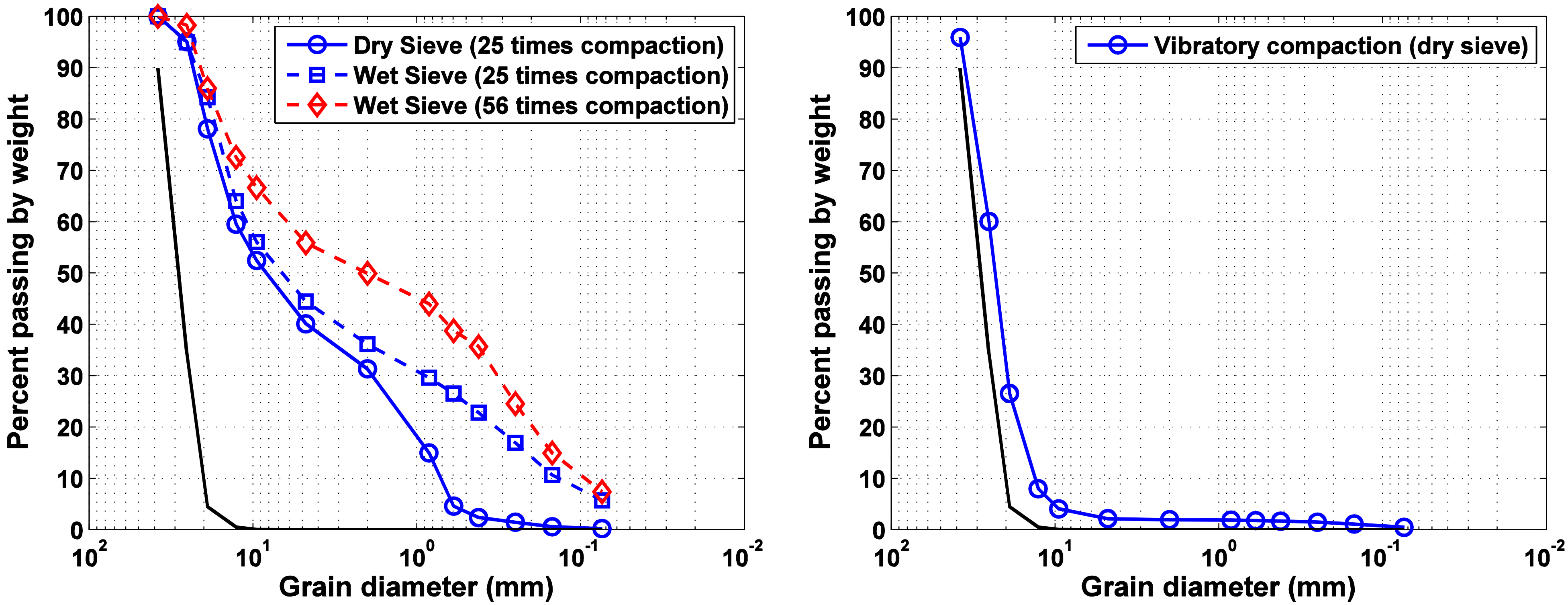
i. Compaction
ii. Compression
iii. Shearing

  - Each post grain-size analysis was compared to the average as-received particle-size analysis on the LWA-FG material (trial #1 previous slide)

DISCUSSION/RESULTS – EFFECT OF COMPACTION ENERGY

- Two sets of impact compaction tests on the LWA-FG material
  - Test #1 used ASTM D 1557 Method C (compactive energy 2,700 kN-m/m^3)
    - Compacted Density – 612 kg/m^3
  - Test #2 used modified ASTM D 1557 Method C (compactive energy 1,200 kN-m/m^3) which is twice the energy of ASTM D 698
    - Compacted Density – 536 kg/m^3
- One vibratory compaction test on the LWA-FG material
  - Maximum index density using ASTM D 4253
    - Maximum density – 325 kg/m^3
  - Minimum index density using ASTM D 4254
    - Minimum density – 227 kg/m^3

EFFECT OF COMPACTION ENERGY



GSD by Impact Compaction

GSD by Vibratory Compaction

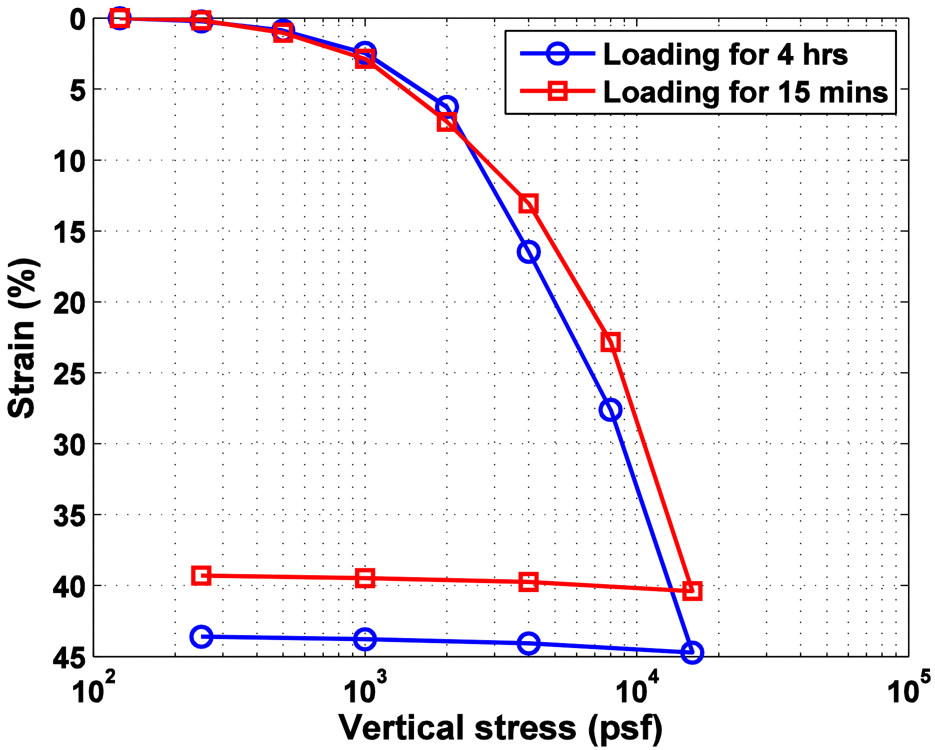
EFFECT OF STATIC COMPRESSION

- Two sets of one-dimensional (1-D) sustained static compaction tests on the LWA-FG material using ASTM D 2435

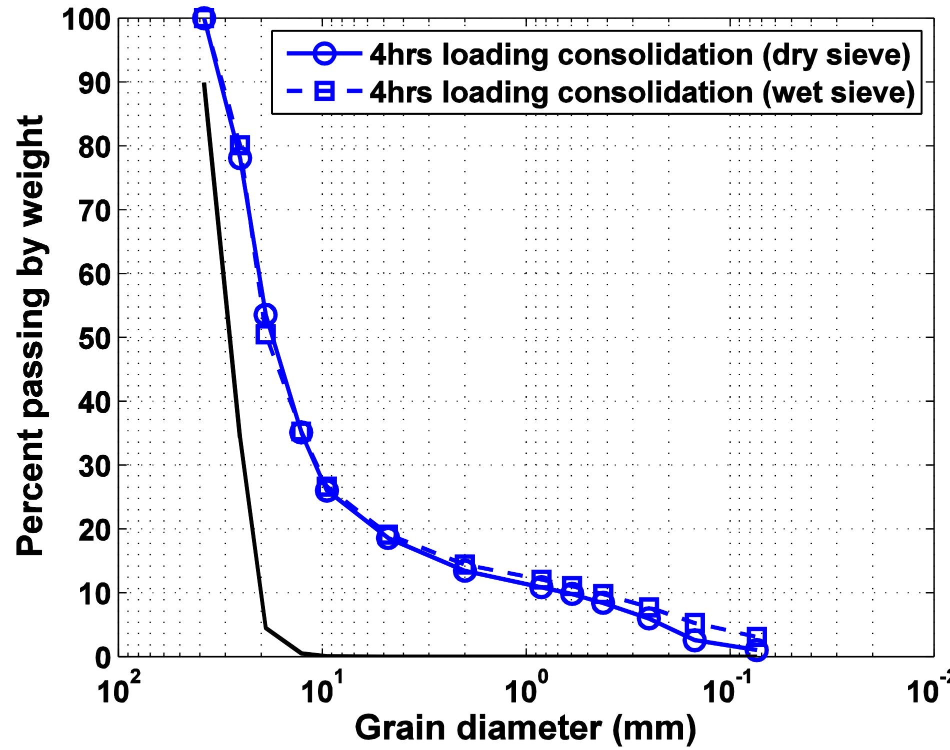
Test Set #1	Test Set #2
8 Loading from 6 to 766 KPa (in double load increments)	8 Loading from 6 to 766 KPa (in double load increments)
3 Unloading from 192, 48 and 12 KPa	3 Unloading from 192, 48 and 12 KPa
Loading for 15 minutes during test	Loading for 4 hours during test

- A single 1-D sustained load (creep) test on the LWA-FG material was conducted using ASTM D 2435
  - Test conducted under a constant load of 24 KPa
  - Load was maintained for 10,025 minutes (7 days)
  - Vertical deformations taken every 5 minutes

EFFECT OF STATIC COMPRESSION

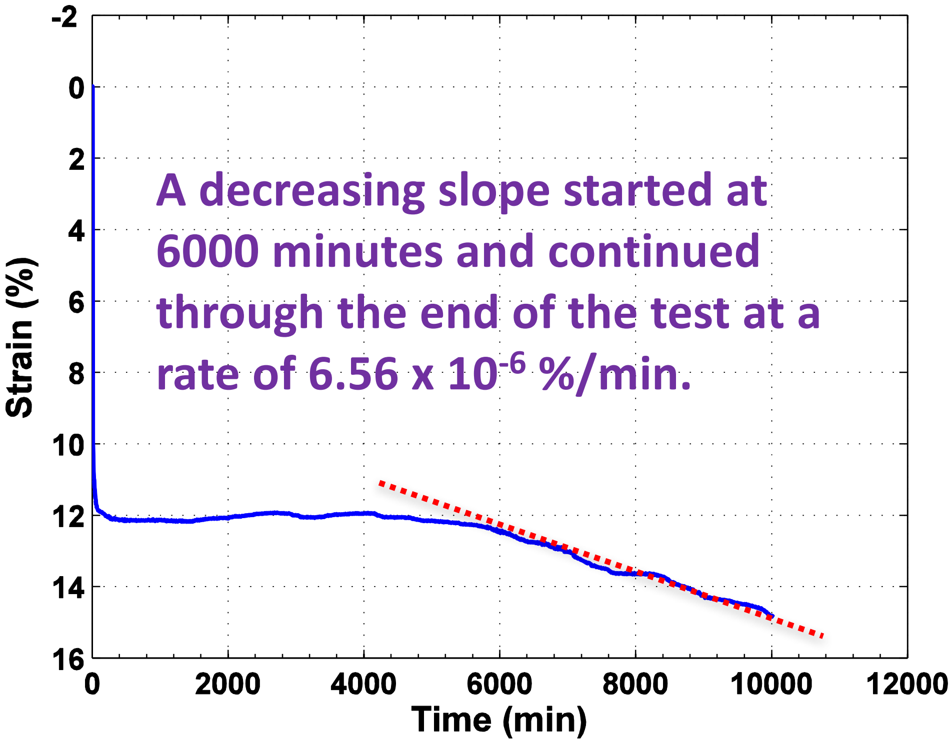


Vertical Stress vs. Strain

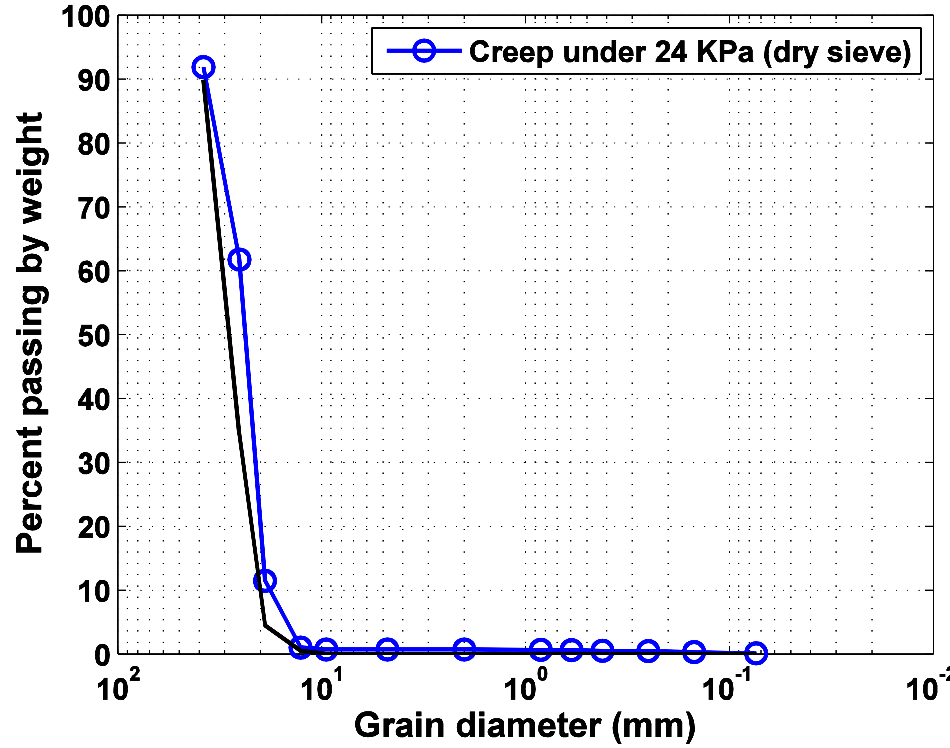


GSD by 4 Hour Loading

EFFECT OF STATIC COMPRESSION



Vertical Stress vs. Time (Creep) Under Vertical Stress of 24 kPa

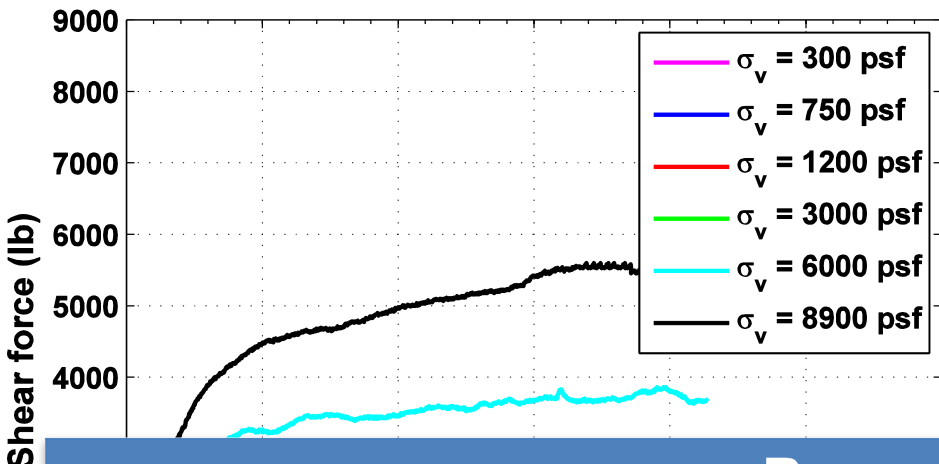


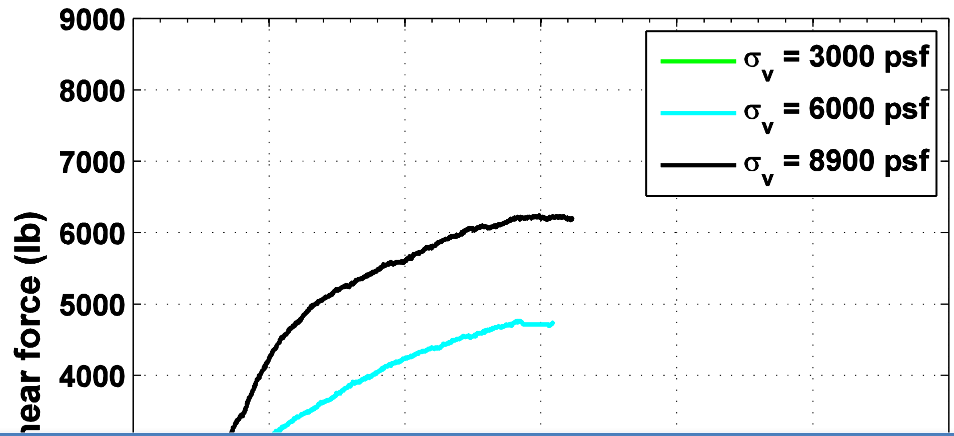
Creep Loading Under 24 kPa

EFFECT OF DIRECT SHEAR TESTING

- Two sets of direct shear test series were conducted on the LWA-FG material following ASTM D 3080M using a large scale shear box having plane dimensions of 305 mm by 305 mm and a total depth of 153 mm
  - Test Series #1 – conducted on as-received LWA-FG material
    - placed dry lightly tamped
    - normal stresses of 14.4, 35.9, 57.5, 144, 287, and 426 kPa
    - each normal load was maintained for 15 minutes
    - shear displacement rate of 1 mm/min
  - Test Series #2 – conducted on modified LWA-FG material
    - material was modified with ASTM D 1557 compactive energy
    - placed dry lightly tamped
    - normal stresses of 144, 287, and 426 kPa
    - each normal load was maintained for 15 minutes prior to shearing
    - shear displacement rate of 1 mm/min

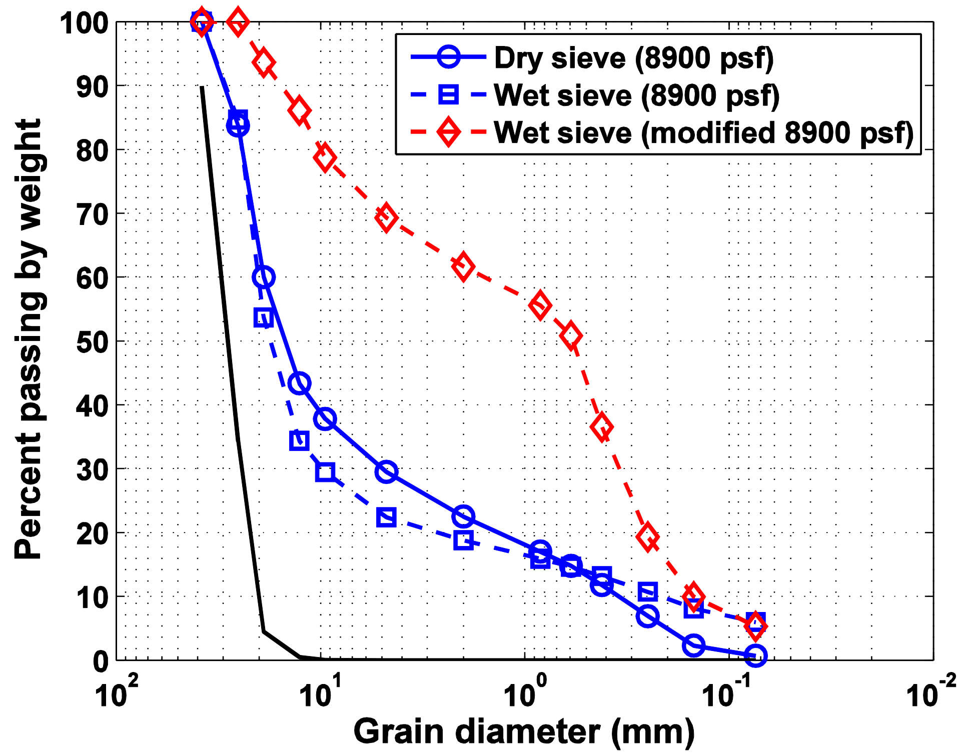
EFFECT OF DIRECT SHEAR TESTING





Tested Material	Range of Normal Stress (kPa)	Peak Friction Angle (º)	Peak Cohesion (kPa)
As-received LWA-FG	14.4 to 57.5	56	2.1
As-received LWA-FG	35.9 to 144	29	45.8
As-received LWA-FG	144 to 426	27	46.0
Modified LWA-FG	144 to 426	31	51.5
Arulrajah et al. (2015)	10 to 40	55.7	23.4

EFFECT OF DIRECT SHEAR TESTING



Creep Loading Under 24 kPa

CONCLUSIONS

- Useful laboratory data showing effect of particle breakage on the engineering property testing of LWA-FG material.
- LWA-FG material is a very brittle material that improves its mechanical properties as a function of particle breakage.
- LWA-FG material transforms from a uniformly graded material to a very well graded material as a function of impact compactive energy or direct shear.
- Static loading under vertical stresses greater than 192 KPa have a moderate effect on particle distribution approaching a well graded distribution.