Compressive Strengths of Various Mortar Mixes Containing Synthetic Lightweight Aggregate

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Presentation Outline

- Waste reuse ‘philosophy’
- Synthetic Lightweight Aggregates, SLA
  - Background
  - Quick Summary of Previous Work
- Results of Current Research on Mortar Concretes with SLA
- Conclusions of Work to Date
- Next Steps

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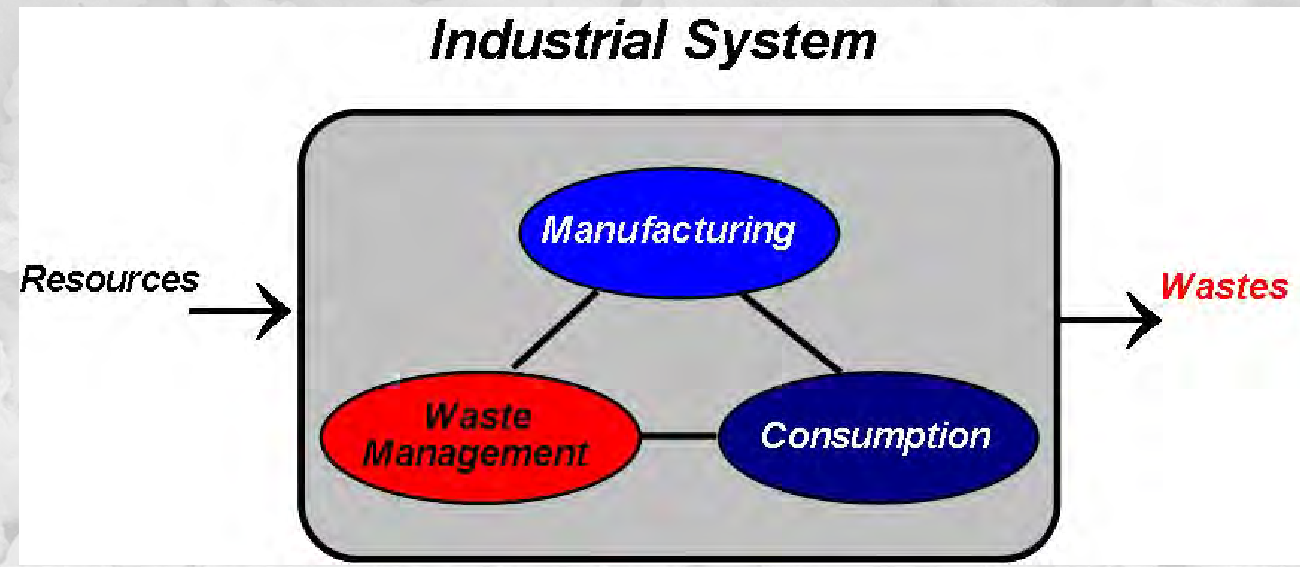
Waste Management

Through a Lens of Industrial Ecology (IE)

- The basic ideology of IE is to optimize the interaction of various system components to create a more efficient and sustainable system.
  - where both Resource use and Waste development are minimized



Waste Reuse Research

Overall Research Goals / Objectives

- Develop reuse strategies for high volume waste materials which are
  - Engineered solutions
  - Environmentally-sound
  - Economically-viable
- Following tenets of IE, a ‘complex systems’ research approach is needed to evaluate valid reuse strategies

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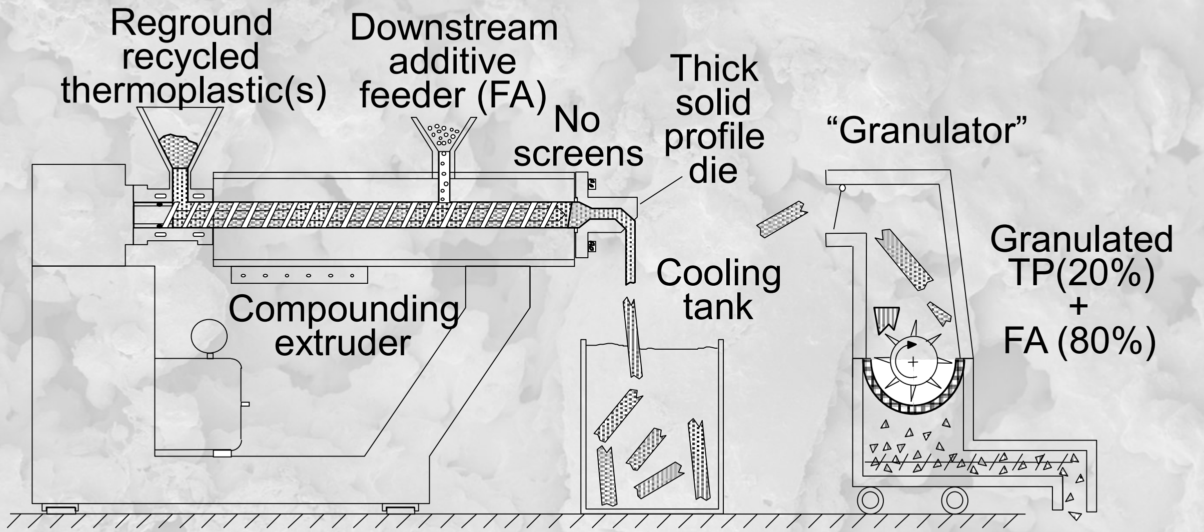
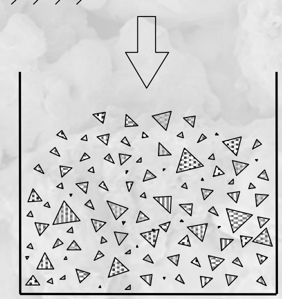
SLA Manufacturing



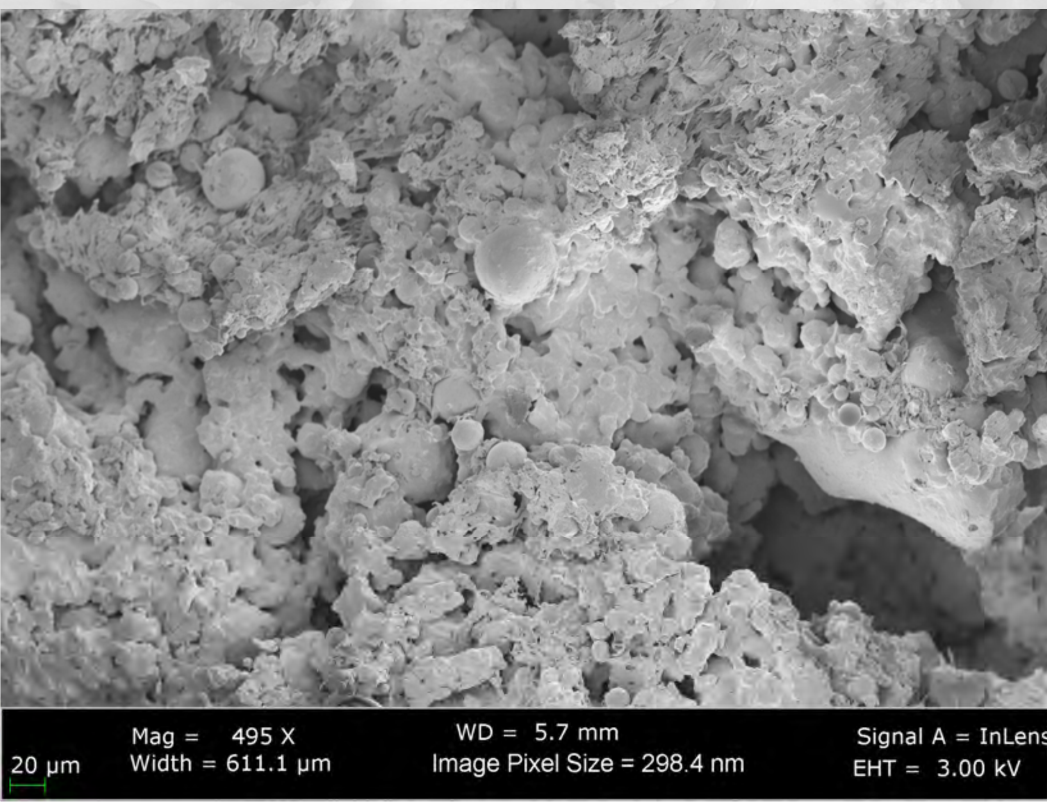
No special equipment, processes, or materials!

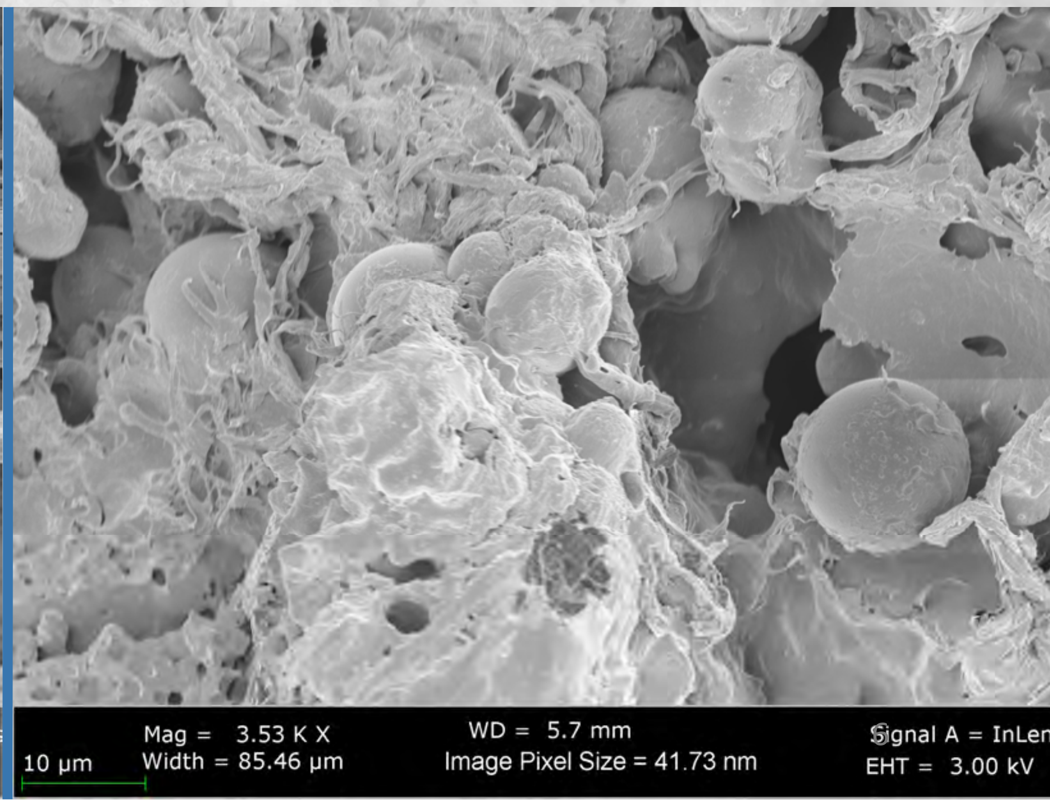


Scanning Electron Microscopy

80:20 MPHCFA SLA

80% High Carbon Fly ash and 20% Mixed Plastics





Previous Research

WOCA 2017 - Swan and Bonora on Mortar Concretes

- Created mortar concrete mixes with w/c ratio of 0.55
  - Aggregate satisfied ASTM's standard C33 gradation for fine aggregate for concrete (≤ U.S. No. 4 sieve)
  - Three SLA contents – 0%, 3.3%, 6.6% - created by replacing particles in the range of the No. 8 and No. 4 sieve
- Results indicated a reduction in concrete strength (f'_c) with a reduction in concrete unit weight (density) with inclusion of SLA
- Questions at that time…
  - What are impacts of higher SLA contents?
  - What about substitutions of other ranges in particle size

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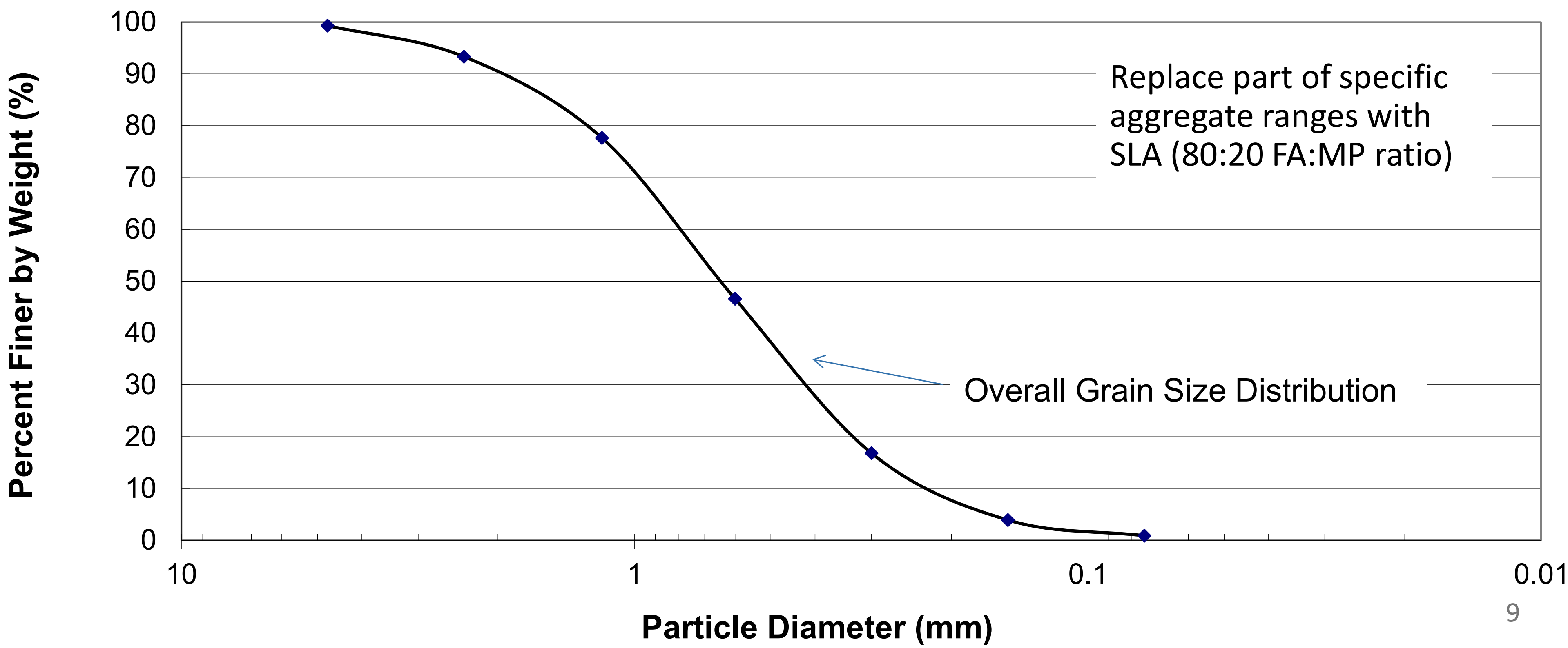
Current Research

Mortar Concretes with Various SLA Content

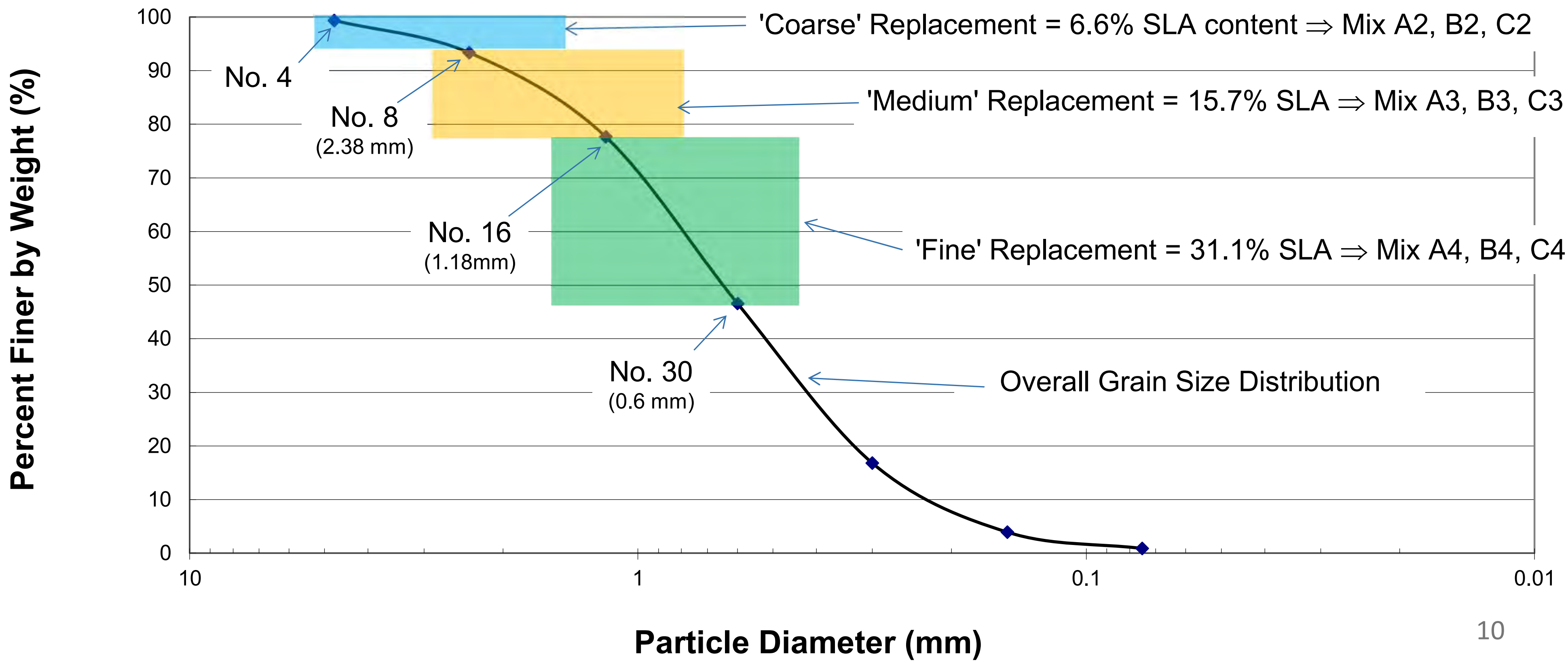
- Created and tested multiple mortar mixes
  - Formed by mixing only Portland Cement, water and aggregate and setting in cylindrical molds
  - Nominal specimen dimensions: 5cm diameter by 10 cm length
  - Aggregate satisfied ASTM's standard C33 gradation for fine aggregate for concrete
  - Three water-cement ratios used: 0.45 (Mix A's), 0.55 (Mix B's) and 0.65 (Mix C's)

Grain Size Distribution of Concrete Aggregate



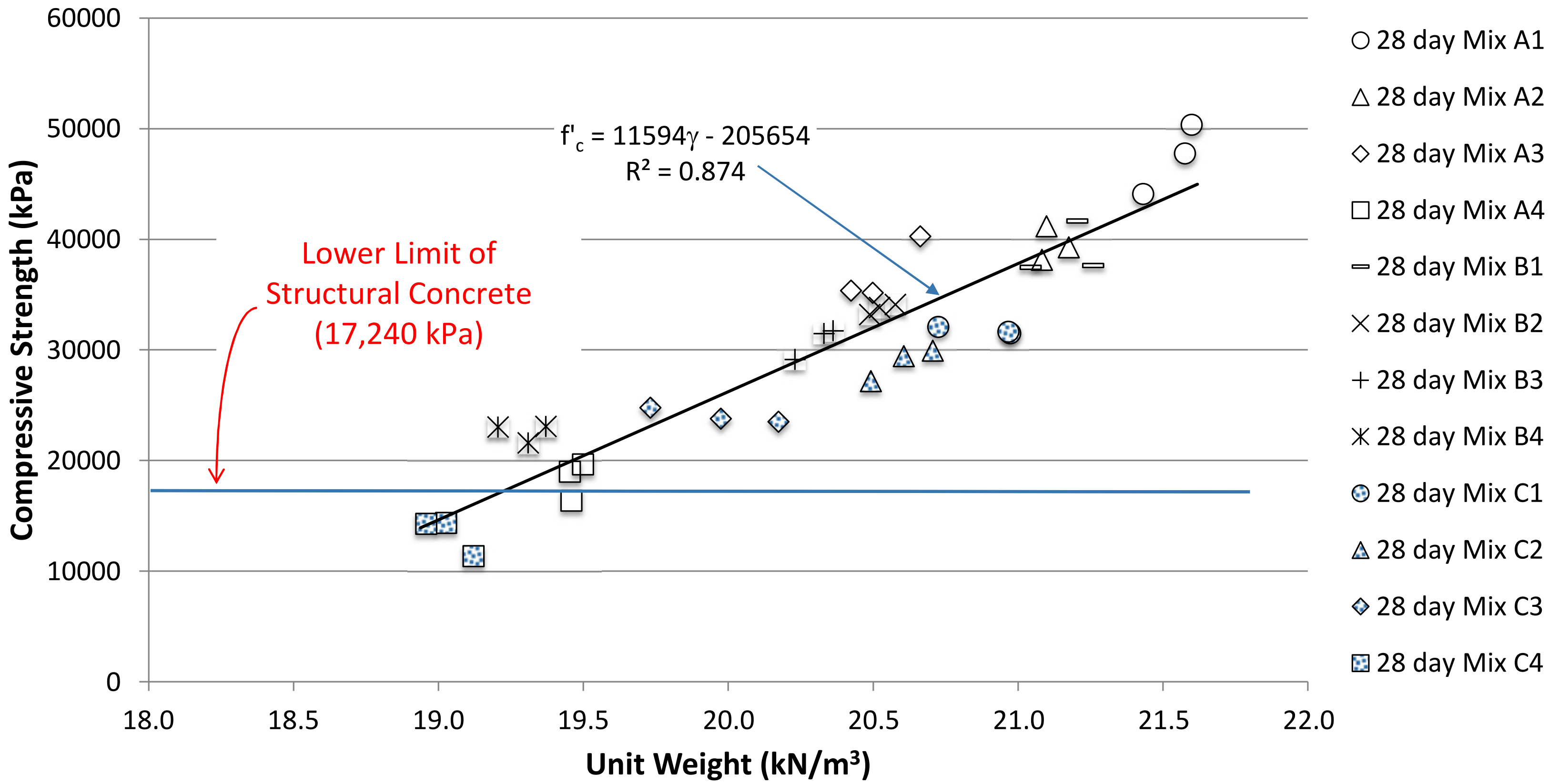
Grain Size Distribution of Concrete Aggregate

Replacement of natural particles with SLA



Concretes Compressive Strength, f'_c

[28-day; 3 specimens for each mix]



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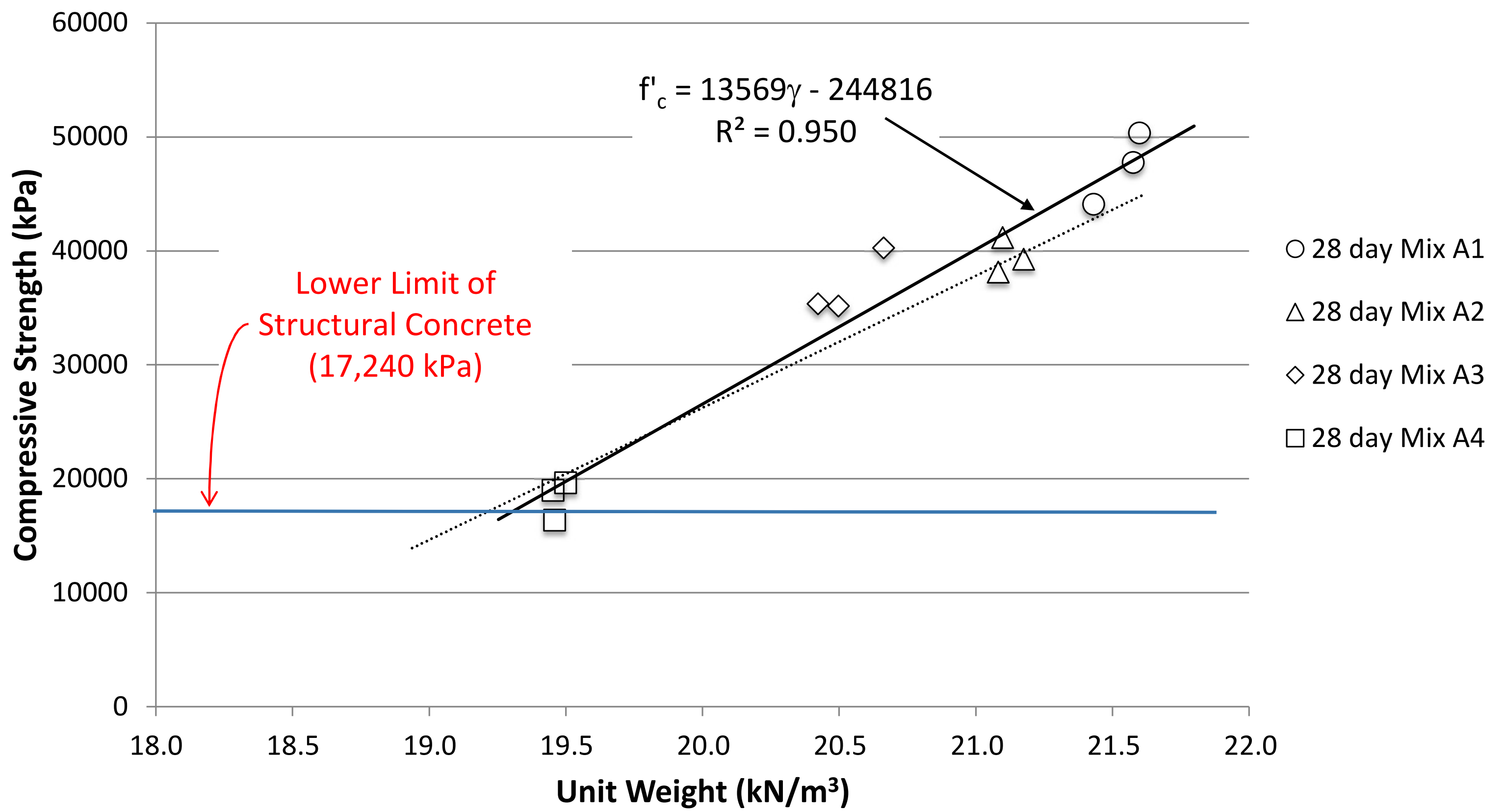
Compressive Strength, f'_c – Mix A's

[w/c=0.45; 28-day; 3 specimens for each mix]



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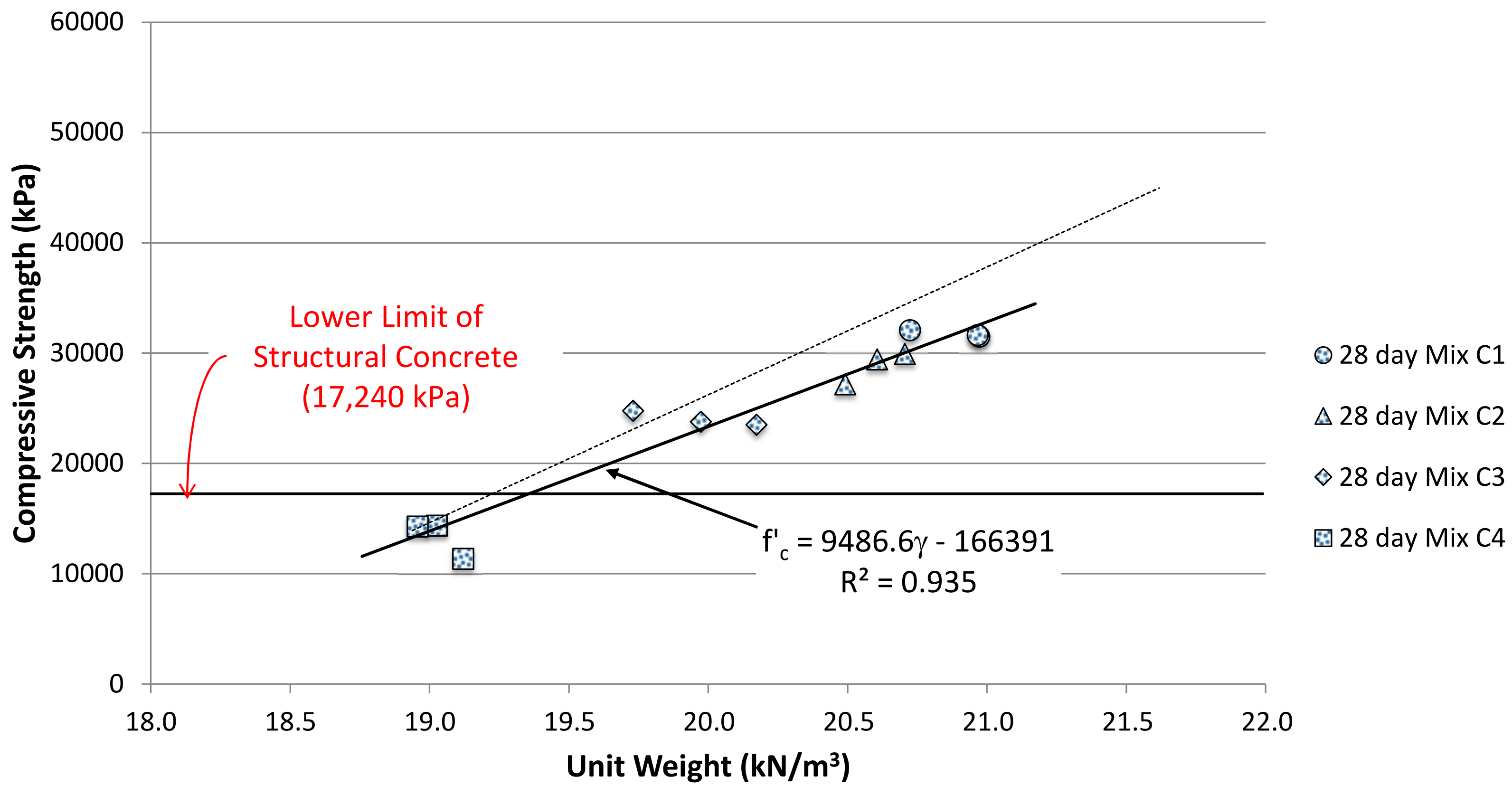
Compressive Strength, f'_c – Mix C's

[w/c=0.65; 28-day; 3 specimens for each mix]



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Conclusions from Strength Testing

- Test results confirms reductions in the unit weight and compressive strengths of mortar concretes with an increase in SLA content
  - Results show well known phenomenon that the strength of concretes reduce as its unit weight decreases ***<u>and</u>***
  - Results show well known phenomenon that the strength of concretes decrease as the w/c ratio decreases
- The strength of concrete depends significantly on the SLA content ***regardless of the w/c ratio***

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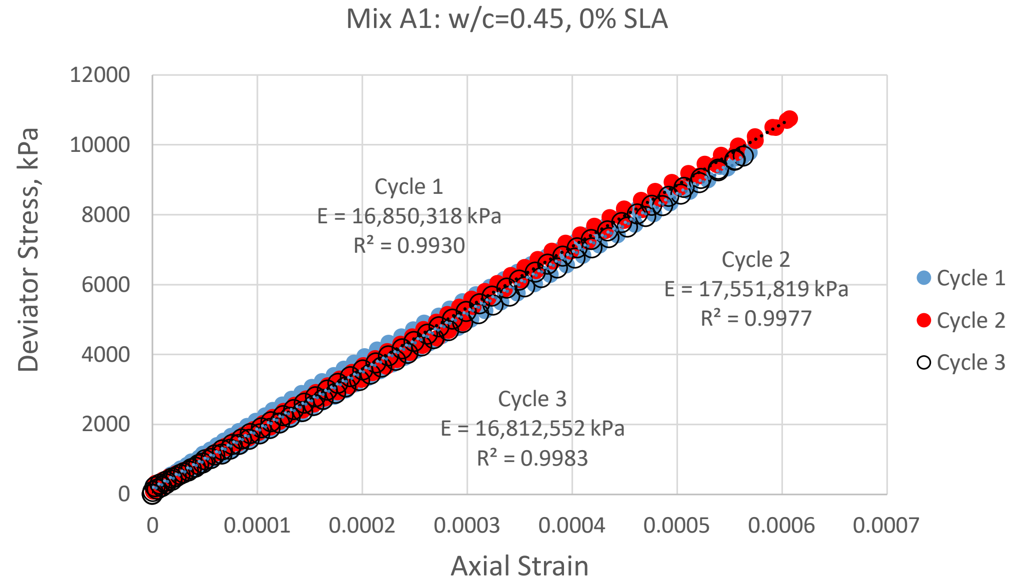
Measured Elastic Modulus

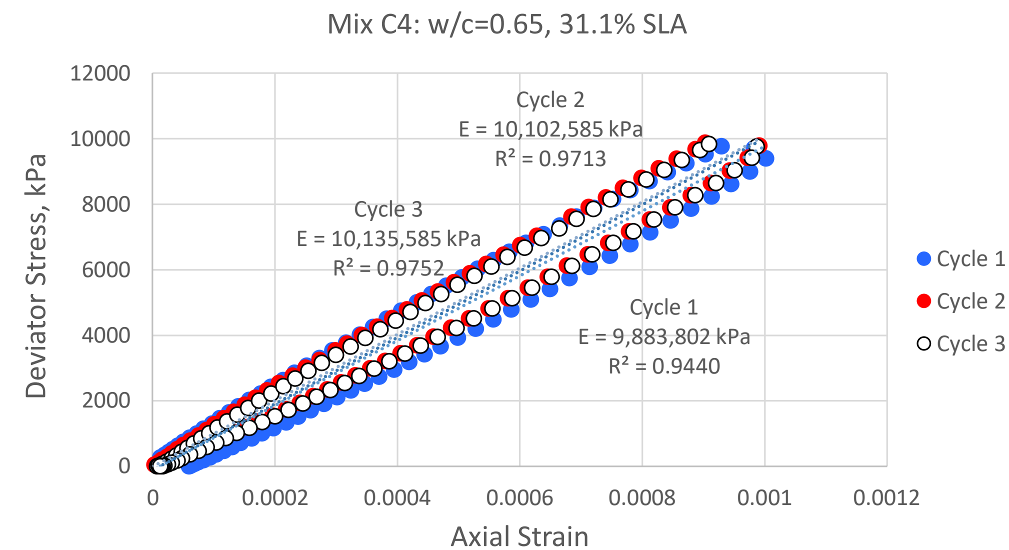
- Measurement of moduli done on separate tests than strength
  - New cylindrical specimens – 3.6cm diameter by 7.1cm length
- Specimens subjected to three cycles of loading reaching maximum stresses of approximately 10,000 kPa.
- Slopes of stress-strain responses used to calculate elastic modulus for each load cycle.
- As with compressive testing, the Mixes of A, B and C were the focus

Measured Elastic Modulus

Apparatus and Sample Measurement

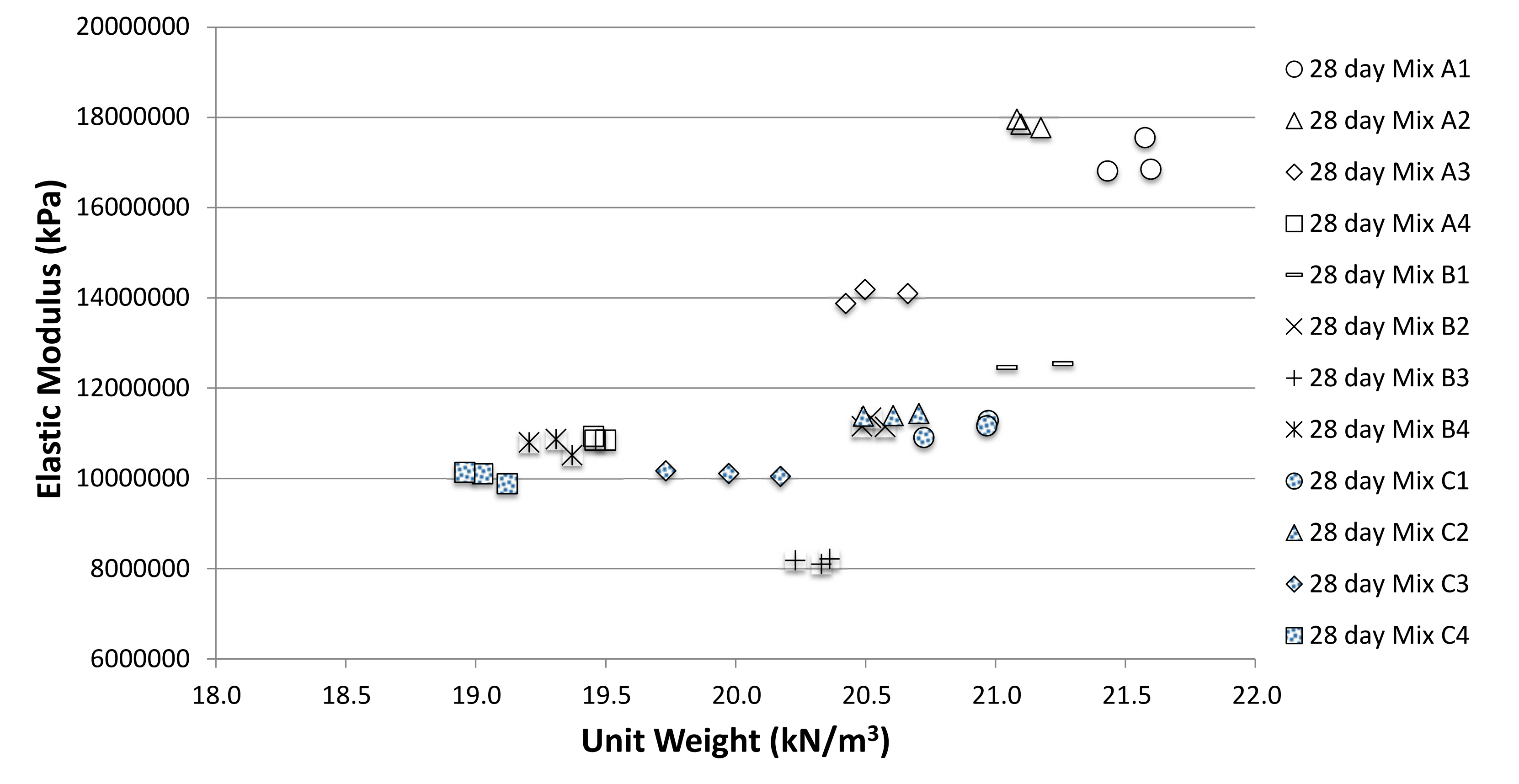
Apparatus Set-up





Measured Elastic Modulus

[All Tests at 28 days; 3 cycles of stress ⇒ 3 values per specimen]



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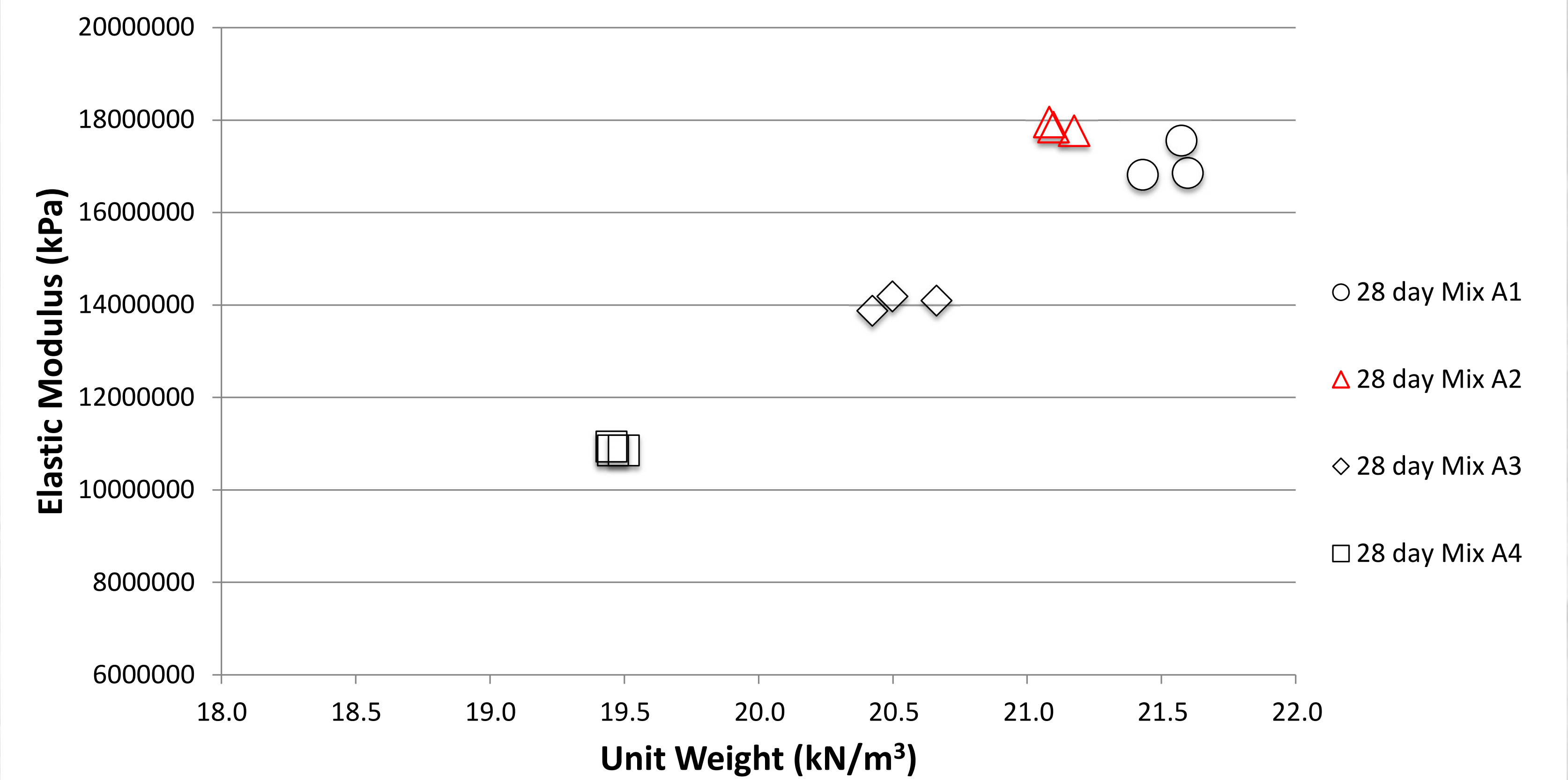
Measured Elastic Modulus

[Mix A's (w/c=0.45) at 28 days]



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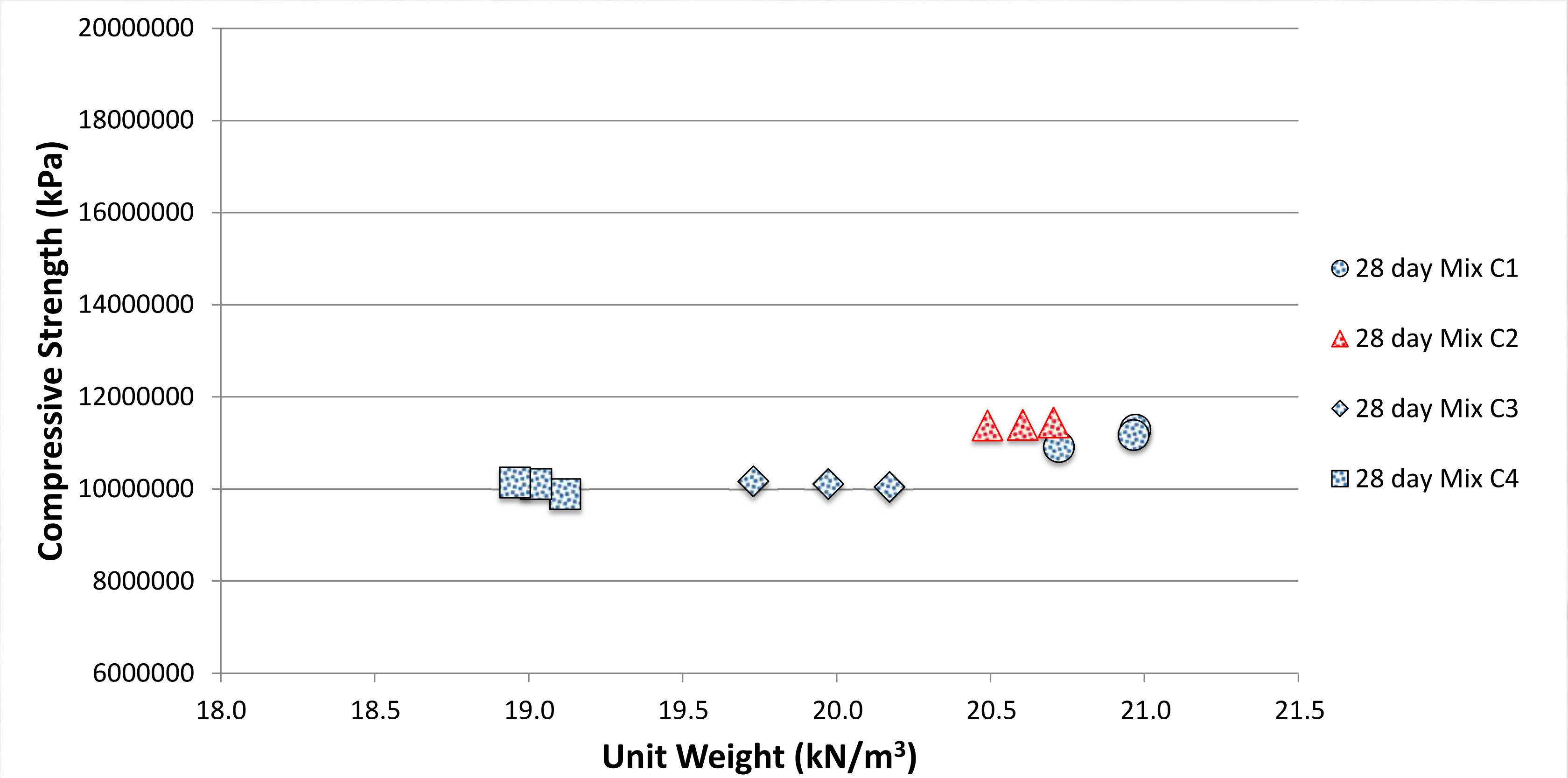
Measured Elastic Modulus

[Mix C's (w/c=0.65) at 28 days]



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Preliminary Conclusions

- Elastic response of concrete is evident
  - Even for the case for Mix C4 (w/c = 0.65 and 31.1% SLA) where the applied stress was approximately 50% of the f'_c of the concrete mix.
- Modulus results (should) follow similar trends as compressive strength; i.e., increase in modulus with increasing unit weight. However, this is not the case for all concretes created
  - Yes for w/c = 0.45 (Mix A's), but not for w/c = 0.65 (Mix C's)
- A unique phenomenon occurs where the moduli for concretes with 6.6% SLA content were similar to, or even higher than, concretes with 0% SLA.
  - This requires additional study

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Summary

- It should be recognized that inclusion of SLA in concretes can lead to significant impacts on its properties
  - Content should be limited to <7% as higher values could negatively impact concretes' compressive strength
  - Content around 6-8% may lead to improved elastic modulus values (though this needs further study)
- Overall, these results continue to show that SLAs are innovative materials
  - Potential impacts exist for infrastructure development and rehabilitation, waste management options, and environmental sustainability efforts

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Next Steps

- Explore impact of SLA at different replacement scenarios of natural aggregates
  - Cumulative replacement instead of one size range
  - Test for compressive strength and modulus
- Explore impact of aggregates sizes > No. 4 on concrete properties

Acknowledgements

- Bruce Ahirwe and Richard Haight
  - Two undergraduates who were instrumental in conducting the compression and modulus tests
  - Continuing the roll of students as collaborators in this research over the last couple of decades

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Thank You for
Your Attention!

Questions?

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References

- Swan, C.W. and Bonora, A.M.† (2017). Compressive, Flexural, and Tensile Strengths of Various Mortar Mixes Containing Synthetic Lightweight Aggregate", 2017 World of Coal Ash (WOCA) Conference in Lexington, KY - May 9-11, 2017, http://www.flyash.info/.
- Jin, N., and Swan, C. (2014). "Elastic Moduli Prediction of Synthetic Lightweight Aggregates", New Frontiers in Geotechnical Engineering, GSP 243, pp. 139-149.
- Neil, C. and Swan, C. (2011). "Arsenic Leachability from Coal Fly Ash Utilized in Synthetic Lightweight Aggregates", Proceedings in the 2011 Geo-Frontiers Conference, Dallas, TX. Geo-Frontiers 2011: pp. 1081-1090. DOI: 10.1061/41165(397)111
- Greenfield, A. (2010). "The Evaluation of Synthetic Lightweight Aggregate in Concrete Pavements." Final Report of Special Topics Course. Department of Civil and Environmental Engineering, Tufts University, 33pp.
- Elsayed, A. and Swan, C. (2007), "Compression Behavior of Synthetic Lightweight Aggregates", Proceedings of 2007 World of Coal Ash, Cincinatti, OH.
- Hooper, Fredick; Mallick, Rajib; O'Brien, Sean; and Kashi, Mohsen (2004). "Evaluation of Use of Synthetic Lightweight Aggregate (SLA) in Hot Mix Asphalt", 83rd Transportation Research Board Annual Meeting, Washington DC, January 11-15, 2004.
- Kashi, M.G., Malloy, R.A., Swan, C.W. (2003), "Pilot Scale Development and Use of Synthetic Lightweight Aggregate" final report for Chelsea Center For Recycling And Economic Development, 2003.
- Jansen, D.C., Kiggins, M.L., Swan, C., Malloy, R.A., Kashi, M.G., Chan, R.A., Javdekar, Siegal, C., and Weingram, J. (2001) "Lightweight Fly Ash/Plastic Aggregates in Concrete", Transportation Research Record, No. 1775 Concrete 2001, pp. 44-52.
- Kashi, M.G., Malloy, R.A., Swan, C.W. (2001), "Development Of Synthetic Aggregate For Construction Material" final report for Chelsea Center For Recycling And Economic Development, February 2001, 36pp.
- Malloy, R., Desai, N., Wilson, C., Swan, C., Jansen, D., & Kashi, M. (2001). High carbon fly ash / mixed thermoplastic aggregate for use in lightweight concrete. ANTEC 2001 Plastics: The Lone Star, Volume 3: Special Areas. (2001), Society of Plastics Engineers.

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