EXPLORING THE PROPERTIES OF FREE STANDING COLUMN BUILT OUT OF DESIGNED GRANULAR PARTICLES USING LEVEL SET-DISCRETE ELEMENT METHOD

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ROADMAP

- Introduction, Motivation and possible future applications.
- Choosing initial shape of particles for experiments and simulations.
- LS-DEM(Level Set-Discrete Element Method).
- Experiments and simulation results.
- Optimizing shape of particles for maximizing both compressive and tensile strength.
- Ongoing and future work.

Introduction & Motivation

Dierichs, K. and Menges, A., 2016

- Aggregate architectures are full-scale spatial formations made from loose granular matter
- The idea is to design a grain shape that governs the behaviour of the structure
- Reduce the material cost
- Easy to dismantle and reuse

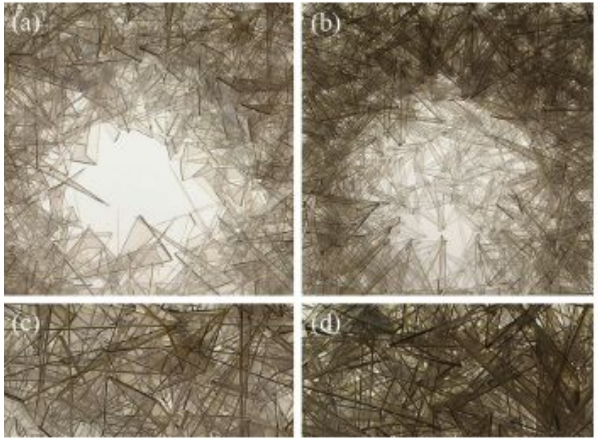
Additional Possible Applications

- Green Construction
- Variable structures because of voids

Range of Cooling Effect:

https://www.holidify.com/places/jaipur/hawa-mahal-sightseeing-2131.html

Optical Properties:



Dierichs, K. and Menges, A., 2016. Towards an aggregate architecture: designed granular systems as programmable matter in architecture. *Granular Matter*, *18*(2), p.25.fig.9

Choosing the initial shape

Dierichs, K. and Menges, A., 2016

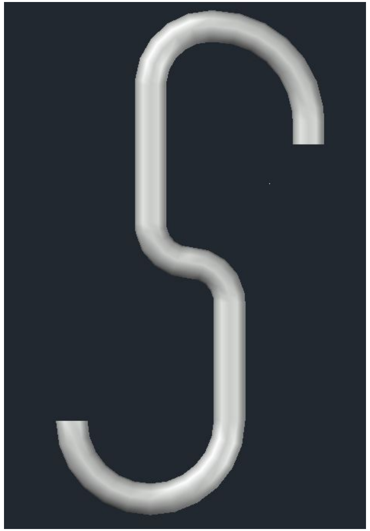
To begin with the simulations, we chose S-shaped particles

Why “S” shaped particles?

- These particles are capable of entangling among themselves

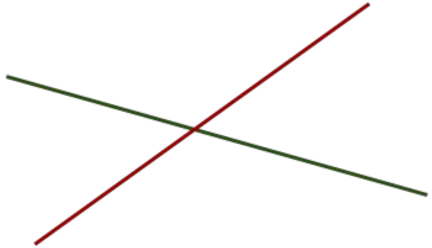
- This shape (due to entanglement) will help the column to resist tension

Choosing the shape of “S”

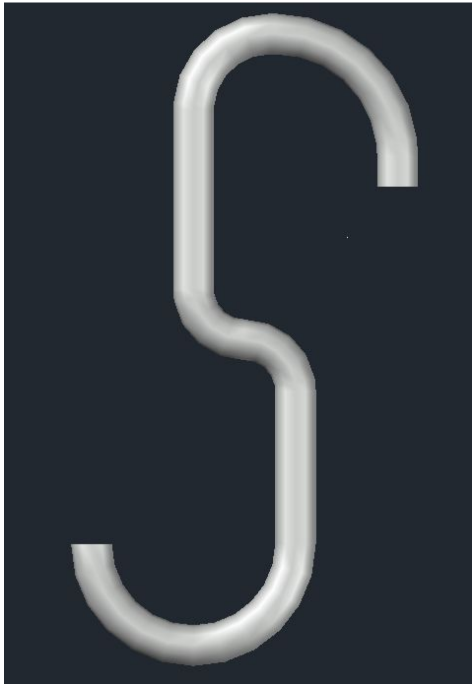


Choosing the shape of “S”

Straight portions of “S”



Curvy “S”

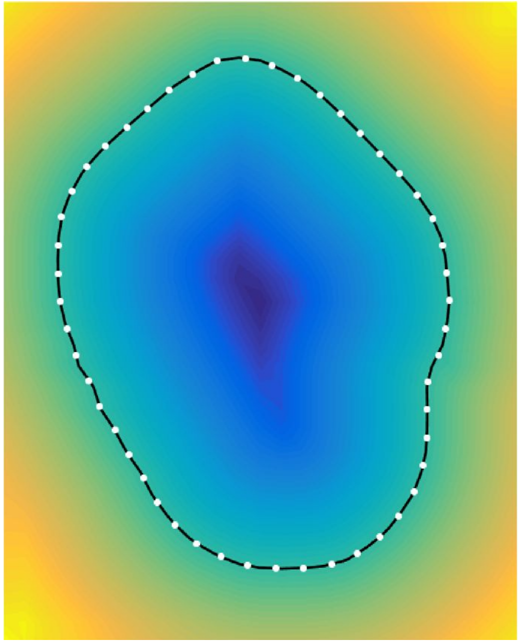


Choosing the shape of "S"

- If S shaped particle falls with straight portion then it won't be able to interlock.

- Increasing the curvature of "S" shaped particle increases the probability of interlocking

LS-DEM (Level Set-Discrete Element Method)

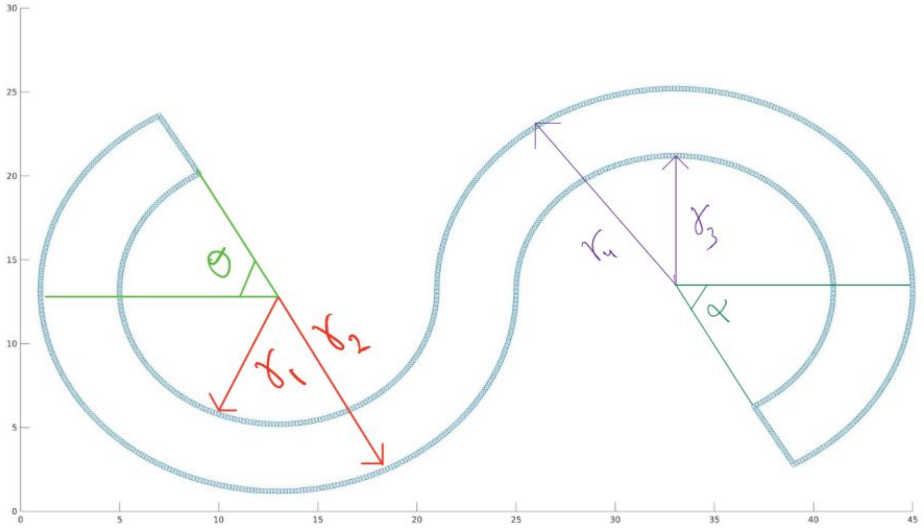


https://www.semanticscholar.org/paper/Level-set-discrete-element-method-for-computations-Kawamoto-And%C3%B2/4165b5d76d1de3a5151938bacd12335a10e4d022

- LSDEM is used to represent the shape of the constituent particles
- A level set function is an implicit function whose value, at a given point, is the signed distance from that point to the surface of the particle
- The values of a level set function are stored at discrete points on a grid, and interpolation is used to compute values between grid points.
- Normal force-linear contact or Hertzian contact model
- Tangential force- Coulomb friction model

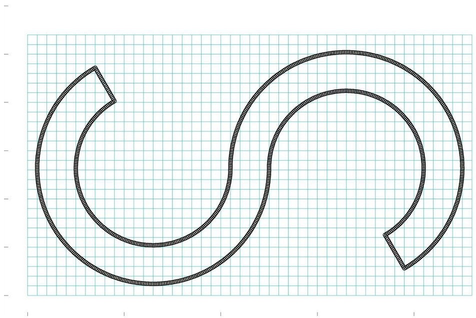
Input file for 2D S-shaped particles

Shape Parameters

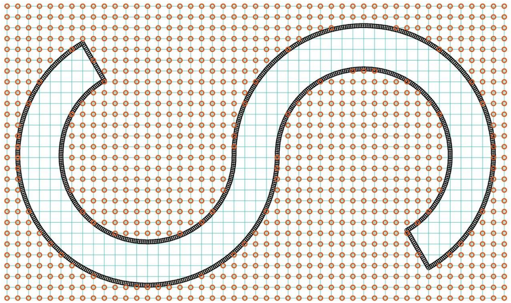


- Two cases - symmetric and unsymmetric
- Currently - Symmetric case

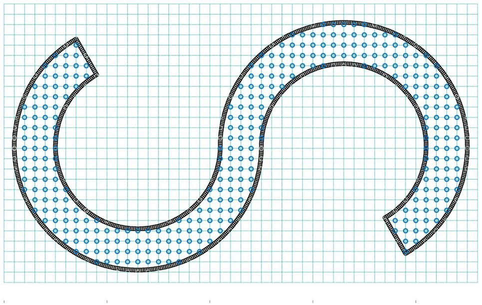
Input file for 2D S-shaped particles



- Referred concept of 3D objects.
- Total 6 equations.
- Position of each grid point with respect to particle.
- Surface is divided uniformly

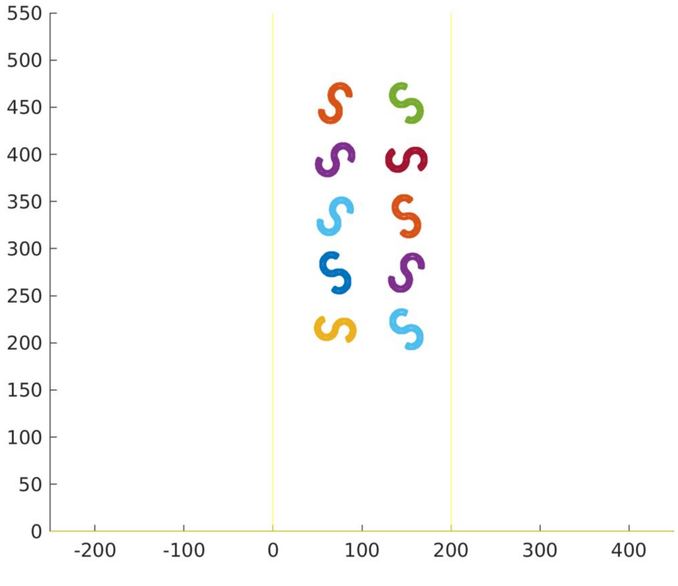


Nodes outside the particle

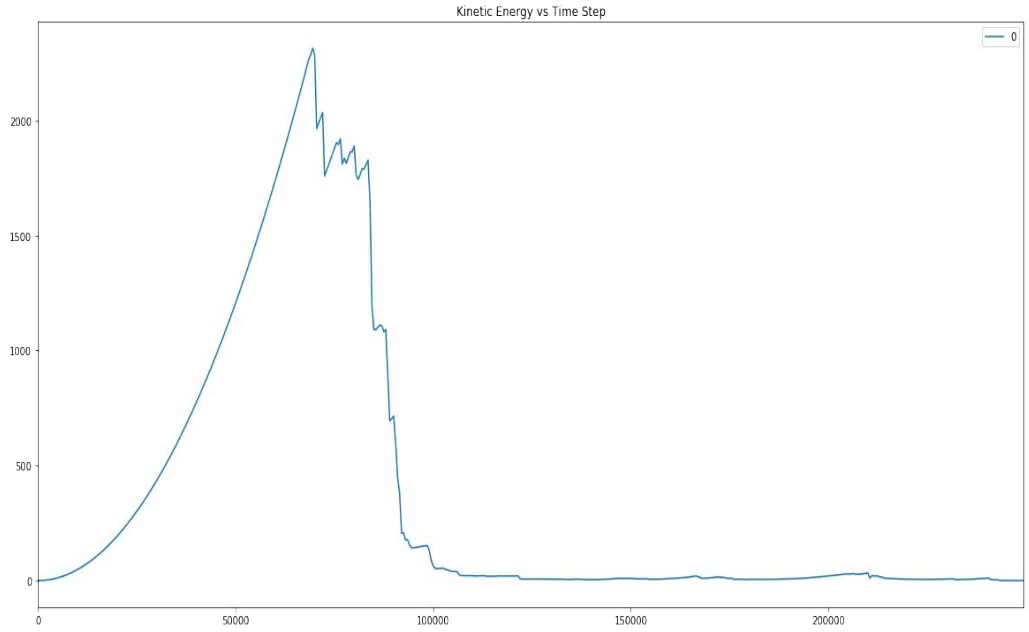


Nodes inside the particle

Pluviation of 2D S-shaped particles



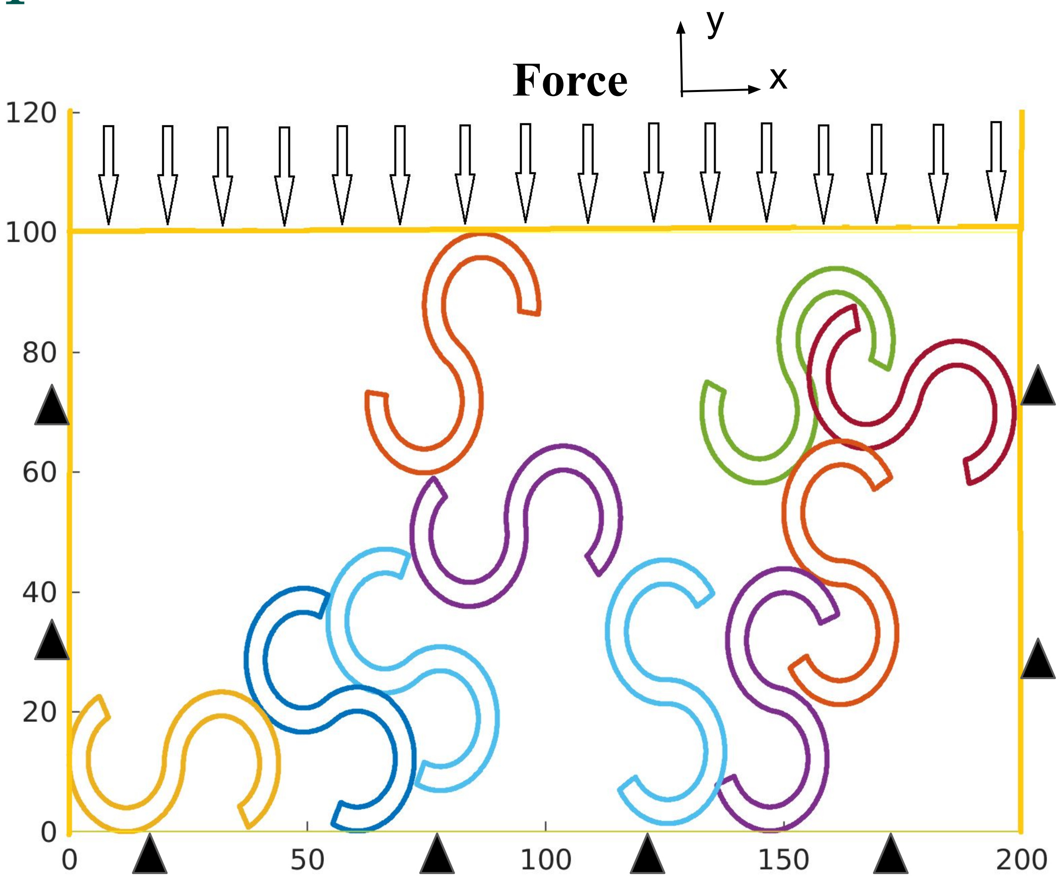
Kinetic Energy



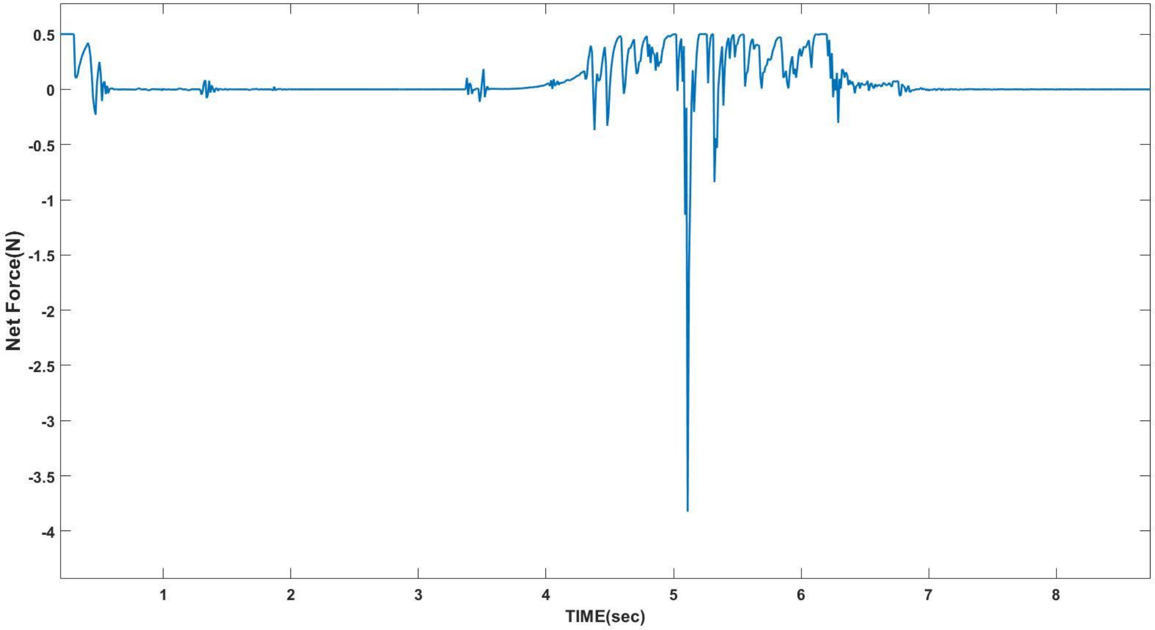
Time Step

Stress-Controlled Compression

- Uniformly distributed compressive force is applied on the top wall.
- Stress Tensor = $\begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{-Force}{width} \end{bmatrix}$
  - The top wall moves down and compresses the particles until the stress produced by the particles is equal to the stress on the top wall.
  - The strain produced in the system is calculated from the displacement of the top wall.
  - Strain= $\frac{Initialposition - FinalPosition}{InitialPosition}$
  - Compressive strength.

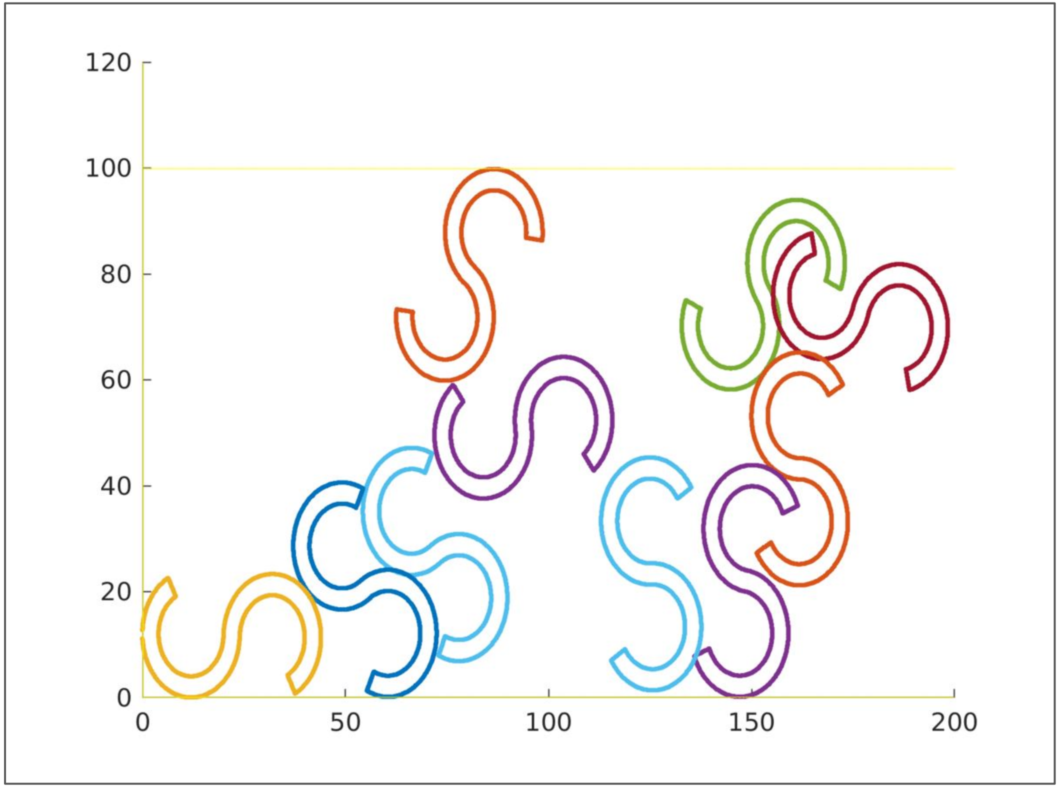


Net Force on Top Wall

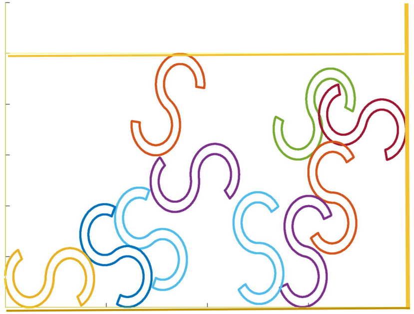


- Verified the code for different forces applied on the top wall.
- Finally, the net force on the wall always converged to 0.

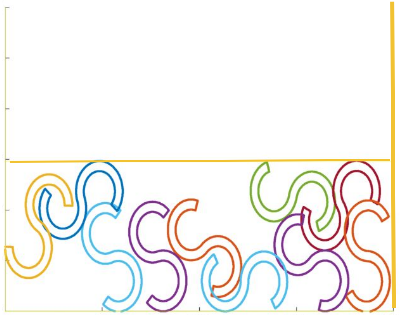
Stress-Controlled Compression on 10 Particles



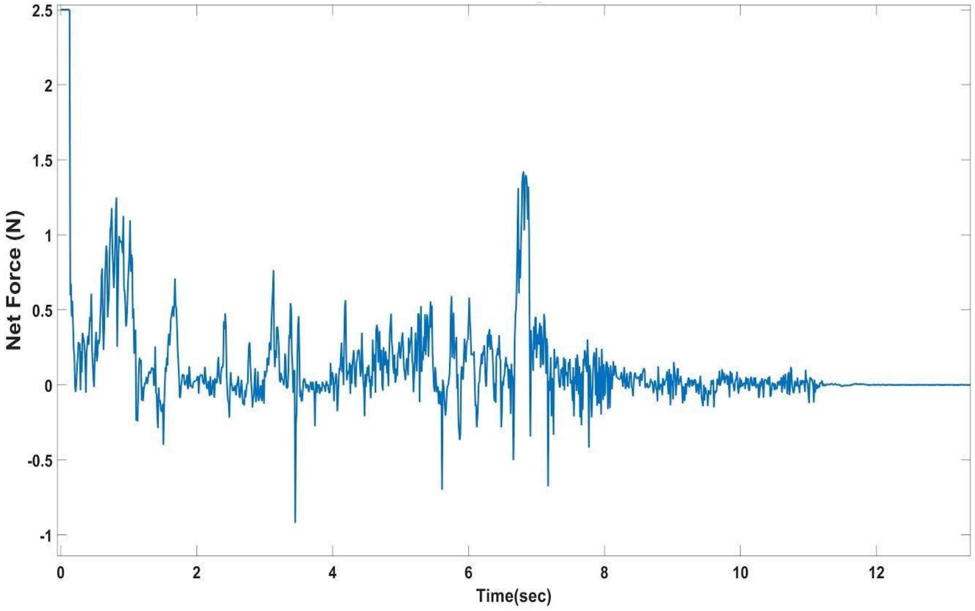
Initial Position

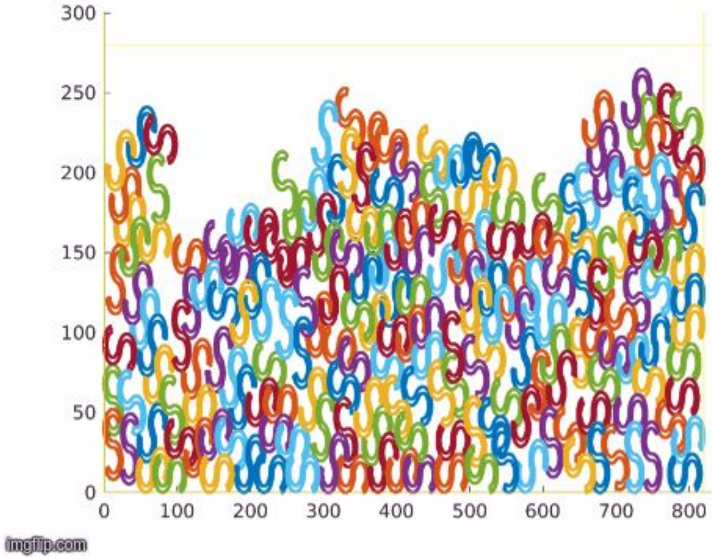


Final Position

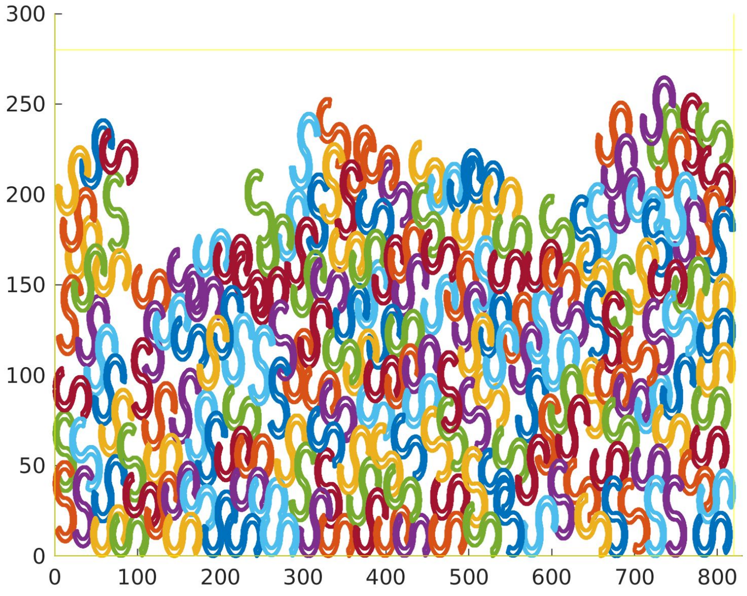


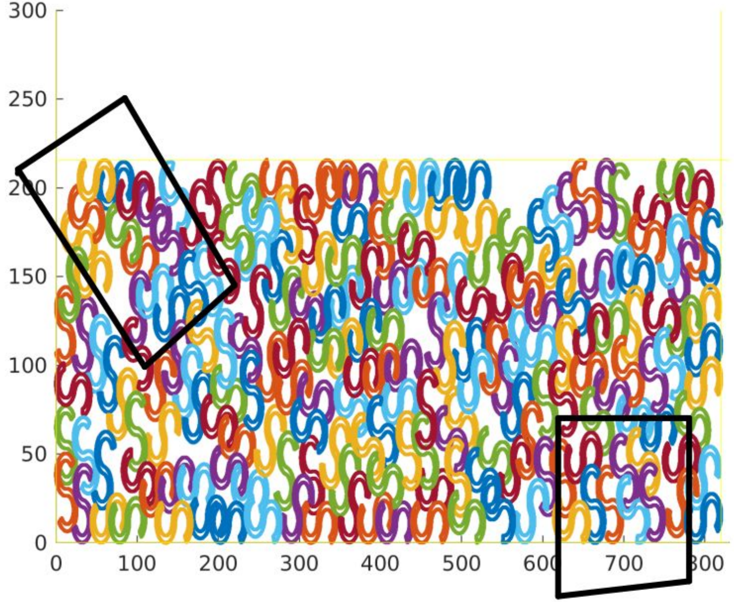
Stress-Controlled Compression on 200 Particles



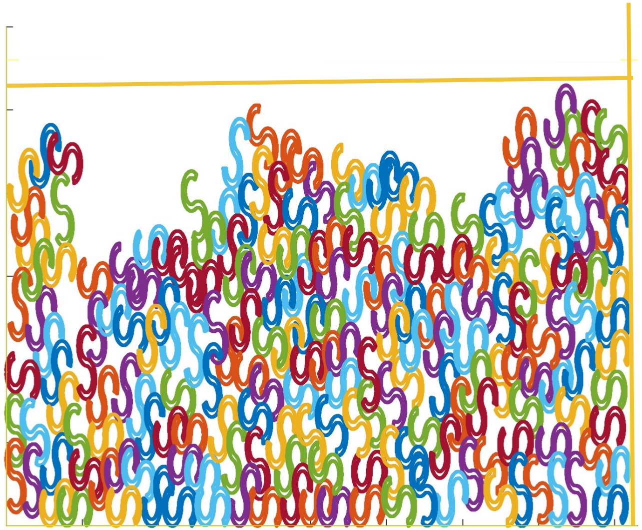


Extra Interlocking Due to compression





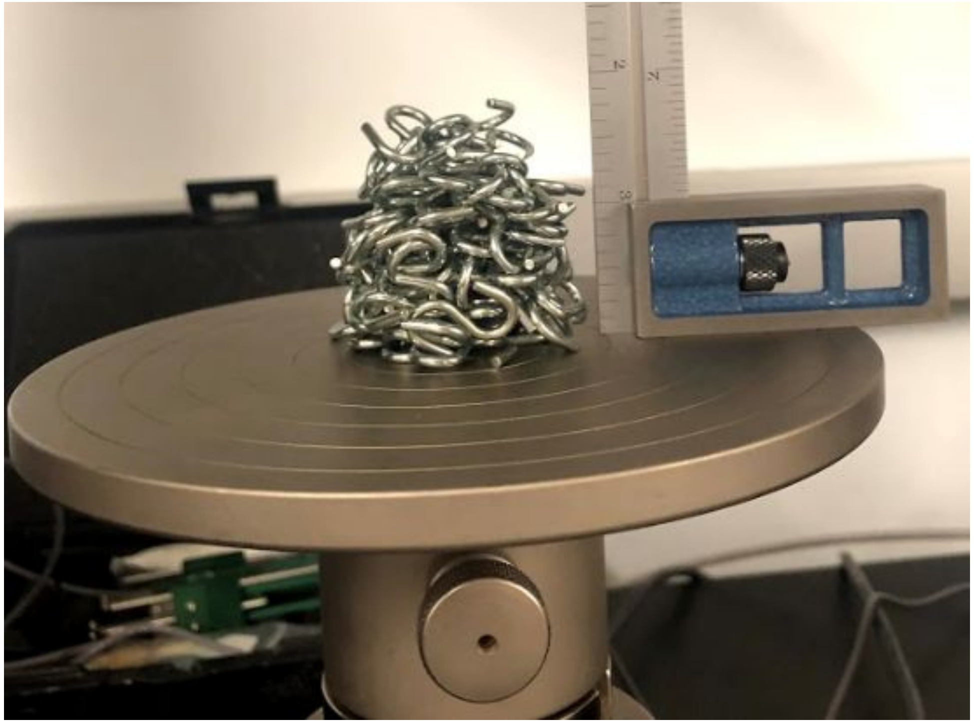
Stress-Controlled Compression on 200 Particles



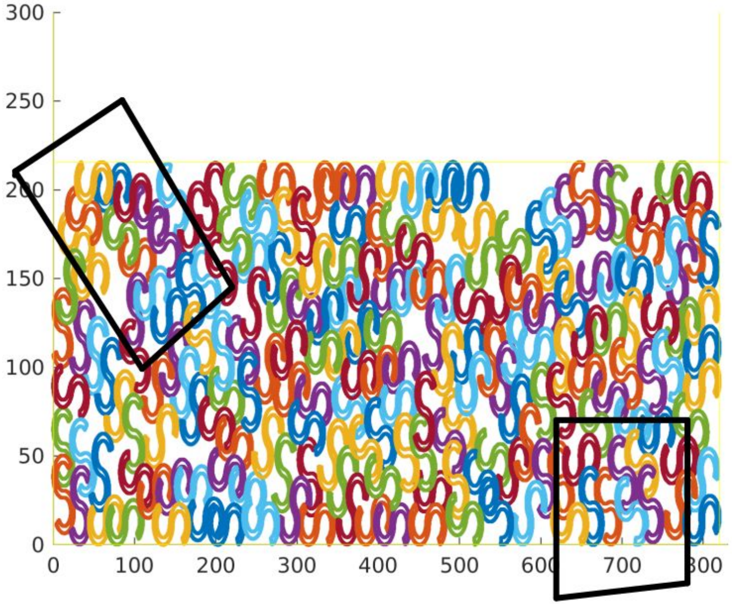
Initial Position

Final Position

Experiments

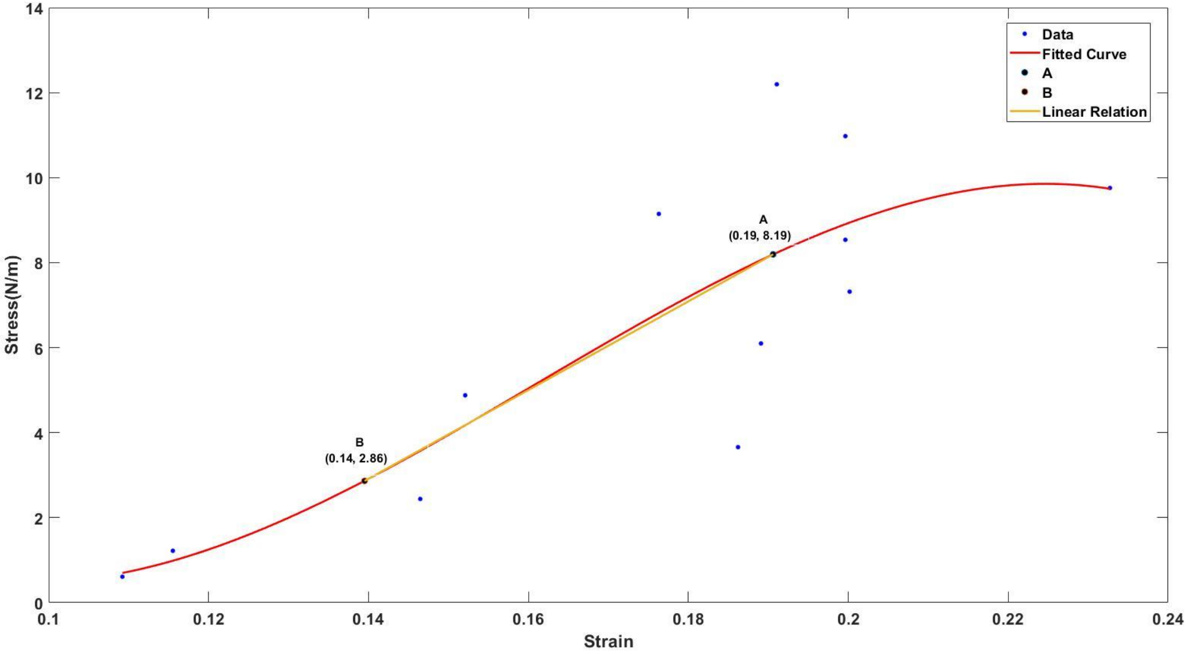


Stress-Controlled Compression on 200 Particles



- Compression increased interlocking.
- Chain of particles.
- Increase in tensile strength.

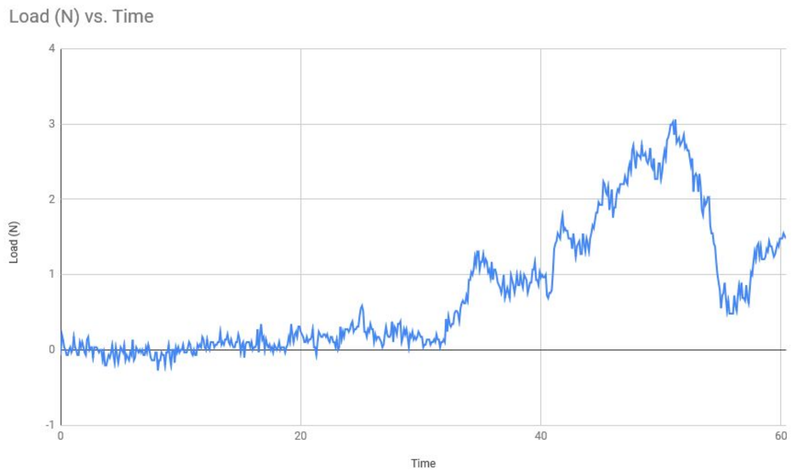
Stress-Strain Plot for 200 Particles



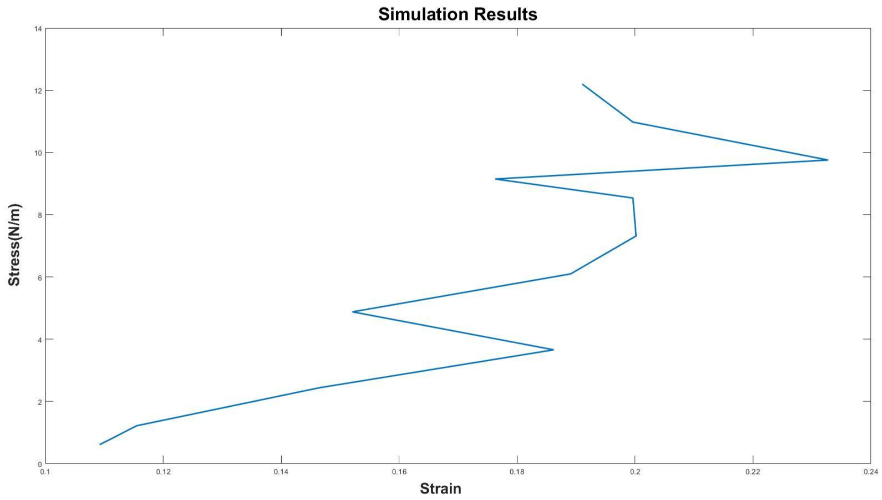
Compressive strength=104.30 N/m

- Compressive strength is small because of voids and particles are capable of displacing themselves into these voids.

Comparing Results of Simulation and Experiment



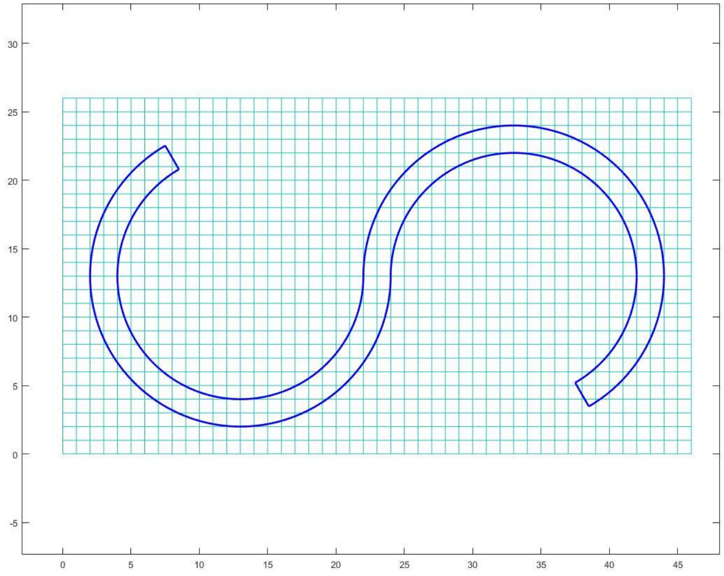
Strain-Controlled

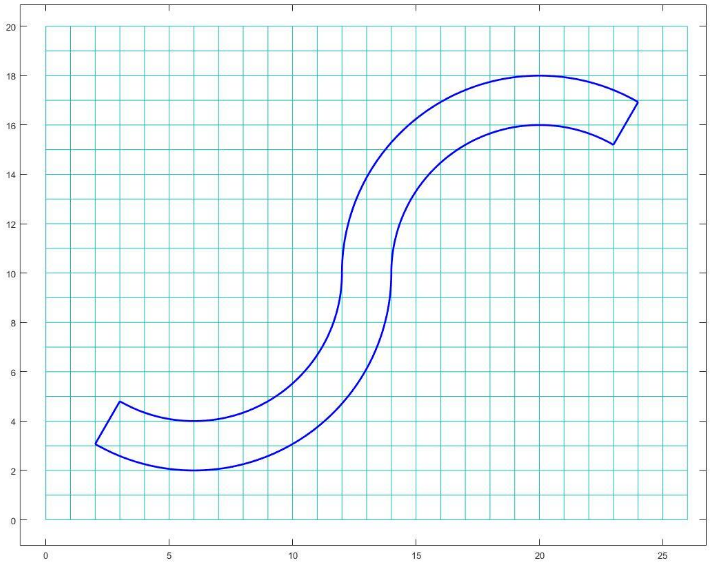


Stress-Controlled

Optimization of Computation

- Wrote a robust code for 2D case to get Level-set.
  - Shape and size will vary in the search of optimization
  - The grid dimensions are set according to the particle shape and size to optimize the computation

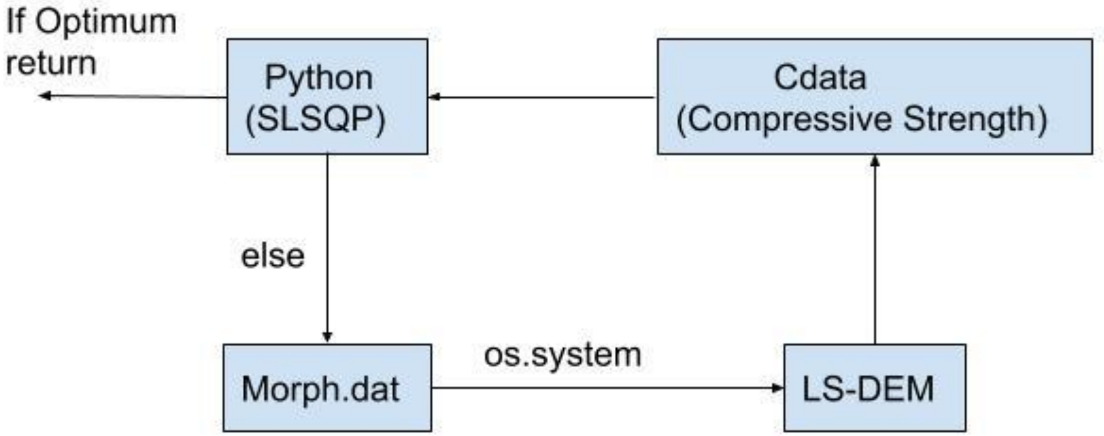




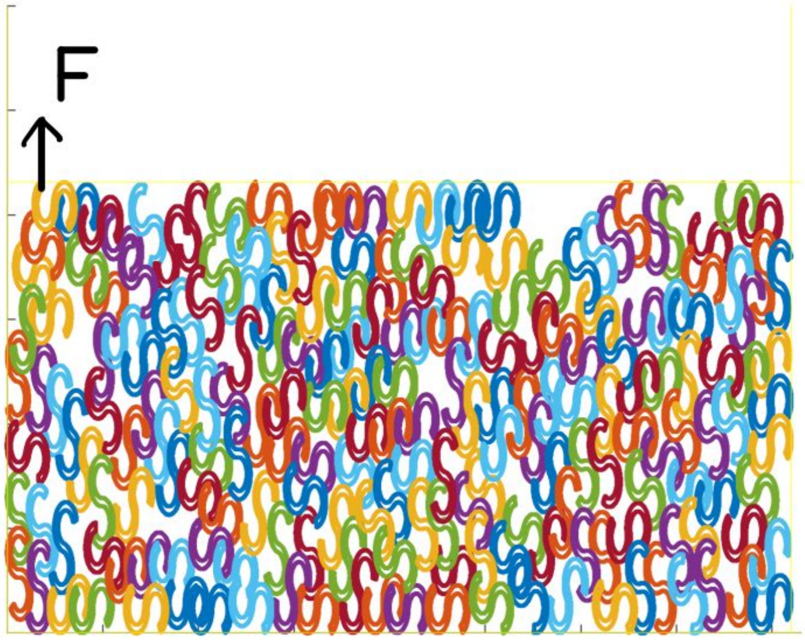
Optimizing shape for compressive strength

Framework

- Constraints
- The framework is ready and can be used for both 3D and unsymmetric case



Tensile Force on Particles



- Expecting the chains of particles
- This will increase tensile strength

Ongoing and future work

- Understanding how to analyse the 2D structure under tensile force using LS-DEM
- Optimizing 2D shape in both compression and tension
- Repeating the same with 3D particle
- Validating the results obtained by simulations through experiments

Thank you!