Master thesis

PACKING STRUCTURE OF POWDER COMPACTS

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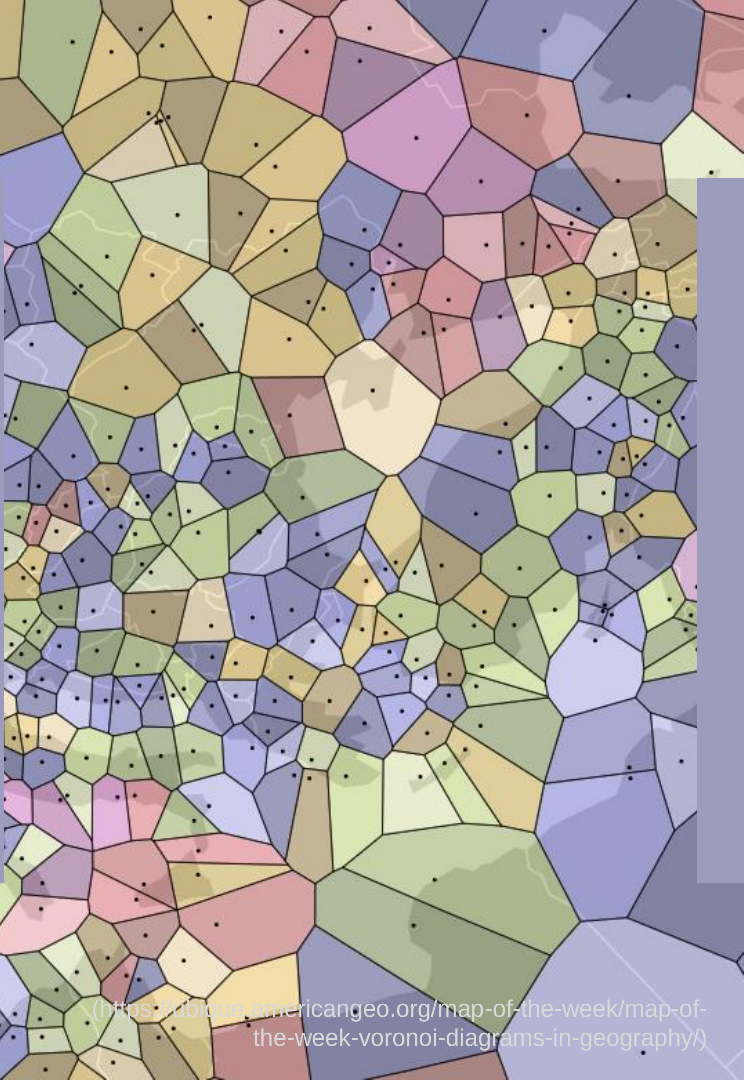

(https://ubique.americangeo.org/map-of-the-week/map-of-the-week-voronoi-diagrams-in-geography/)

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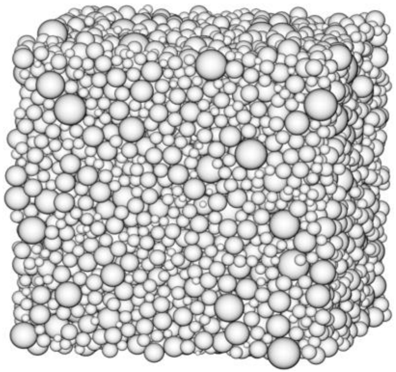
Why Packing Powder Compacts?

(http://greenconnectionsradio.com/taking-electric-cars-mainstream/)

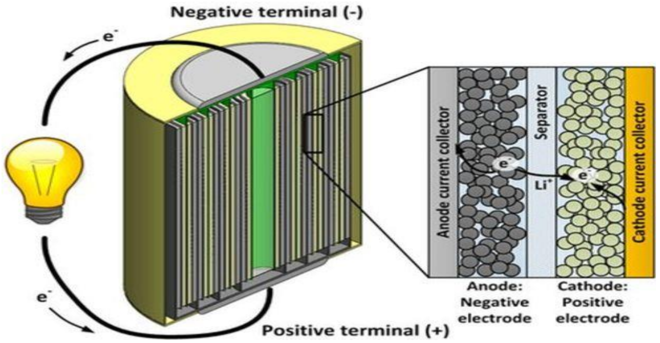
Be eco-friendly → Electro cars

My research project



(https://pubs.rsc.org/en/content/articlehtml/2014/sm/c3sm52959b).

Powder compact



(https://www.bbc.com/news/magazine-26993915).

Powerful battery

01 PACKING PARTICLES IMPORTANCE

- a wide range of applications: granular materials, composite materials, ceramics, construction materials, etc.
- minimization of the concrete pollution through modification of concrete mixture via particle packing method [1]
- microstructural arrangement of particles packing would better infer the chemical and physical properties of Portland Cement [2]

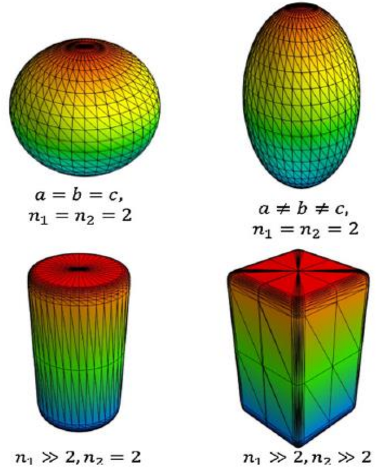


Figure 2: Superquadrics [6]

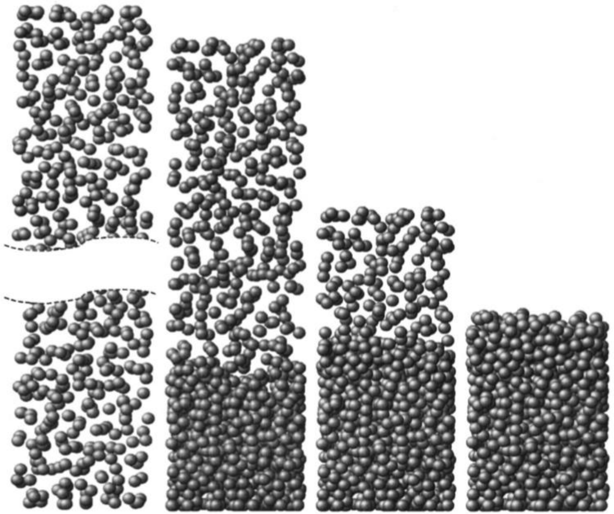


Figure 1: Simulation of packing spherical particles using DEM [5]

PARTICLE PARAMETERS EFFECT

- particle size distribution which influence on either volumetric or contact properties in a packing structure [3]
- the effect of non-spherical particles packing can significantly impact to the mechanical characteristics of material [4]
- limited research on packing of non-spherical particles

The AIM of the thesis research

!!!

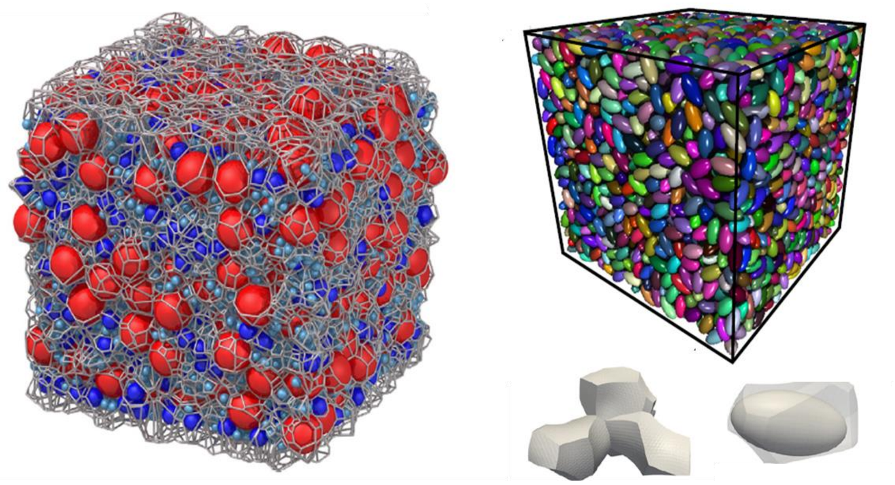
the recent works are limited to particles of spherical shape

is to ANALYZE packing structure and morphology of powder compacts made of particles of different shapes and binary mixture of spheres with fibers.

Objectives:

(1) generation of powder compact with particles of various shapes using Discrete Element Method,

(2) analysis of void spaces morphology using Voronoi Tessellation and void size distribution methodologies.



(a) (b)

Figure 3: Application of Voronoi tessellation for spherical (a) and non-spherical (b) mixtures compact [7, 8]

STUDY 1

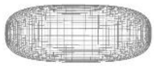
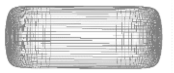
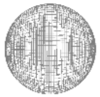
Effect of particle shapes on powder compact microstructure

- Generation forms of superquadrics and regarding compacts using DEM [9]

$$f(x,y,z) = \left(\left|\frac{x}{a}\right|^{n_2} + \left|\frac{y}{b}\right|^{n_2} \right)^{\frac{n_1}{n_2}} + \left|\frac{z}{c}\right|^{n_1} - 1 = 0$$

Mechanical properties	Young’s modulus, [Pa]	$5*10^6$
	Poisson ratio	0.4
	Restitution coefficient	0.6
	Friction coefficient	0.4
DEM parameters	Time-step, Δt [s]	$1*10^{-5}$
	Gravity, g [m/s^2]	9.81
Particles physical properties	Density, kg/cm^3	2500

Preparation for analysis:
- Image analysis of cross-sections (Void size distribution)
- Voronoi diagram analysis

	PILLS	*CYLINDERS*	*SPHERES*
a, m	0.004	0.004	0.0061
b, m	0.004	0.004	0.0061
c, m	0.01	0.0095	0.0061
n_1	3	10	2
n_2	3	2	2

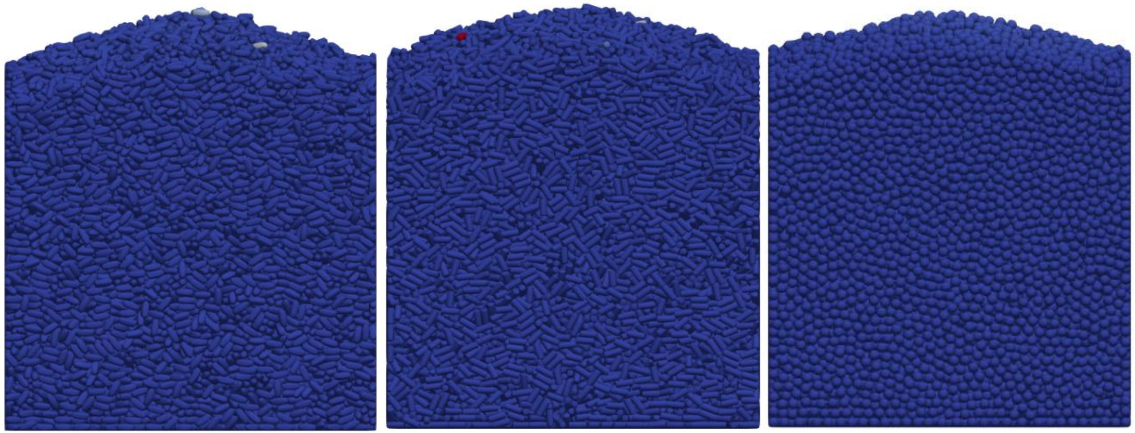


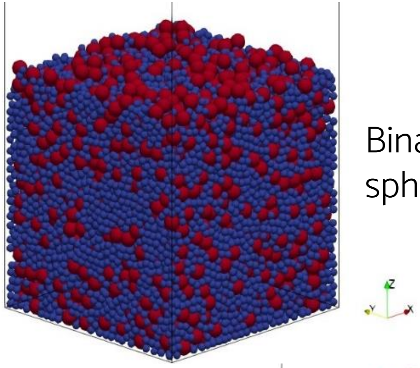
Figure 4: Visualization of packed compacts

STUDY 2

Effect of non-spherical particles inclusion into spherical powder compact mixture

Preparation for analysis:
- Image analysis of cross-sections (Void size distribution)

- Generation forms of superquadrics and their compacts using DEM



Binary mixture of spherical particles

Binary mixture with fibers

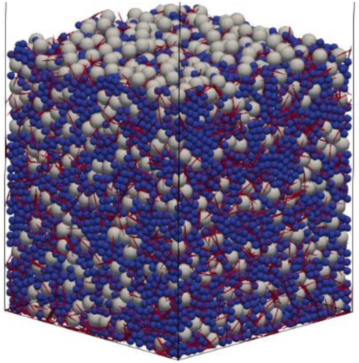
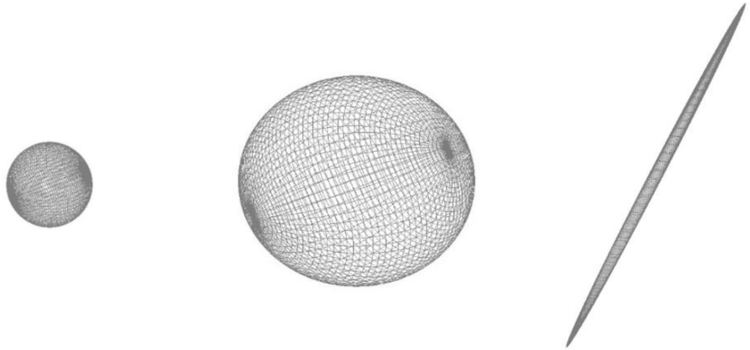


Figure 5: The images of packing structure



	Fine spherical	Coarse spherical	Fibers
a, m	0.002	0.004	0.0002875
b, m	0.002	0.004	0.0002875
c, m	0.002	0.004	0.006
n_1	2	2	2
n_2	2	2	2

Simulation	Fine	Coarse	Fiber
1	63	37	0
2	62	37	1
3	40	60	0
4	40	59	1

STUDY 1
Effect of particle shapes on compact morphology

- Void size distribution analysis based on the cross-sectional images analysis

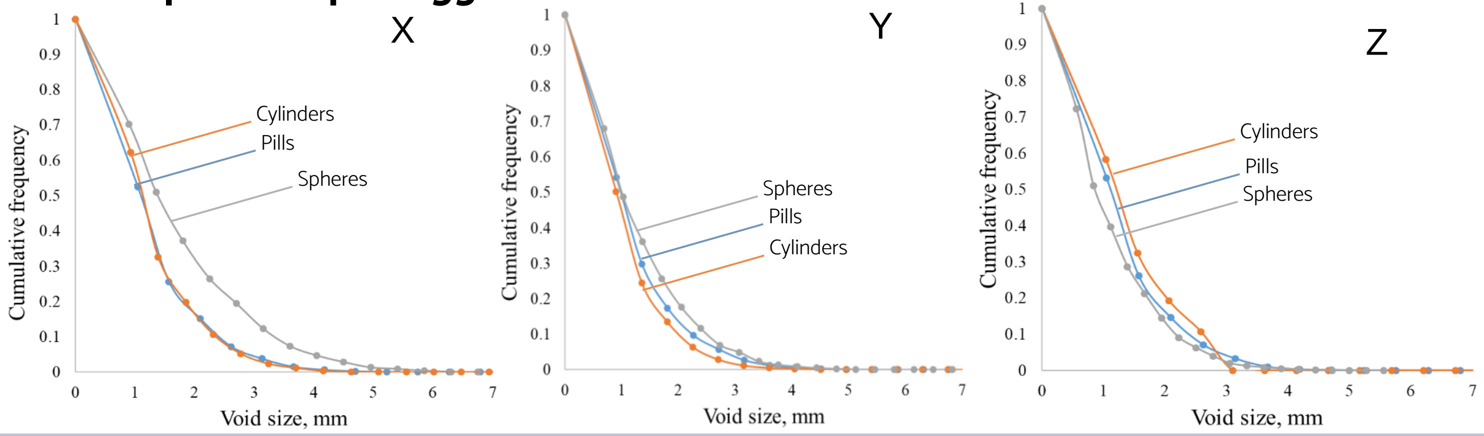


Figure 6: Normalized VSDs of three samples

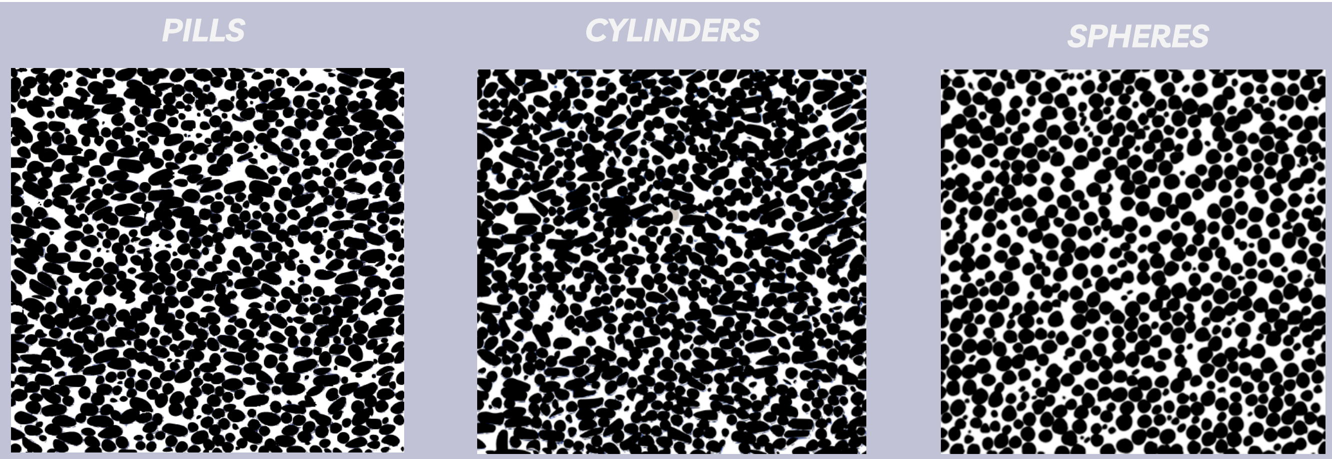


Figure 7: Colored cross-sectional images of three samples normal to X

STUDY 1
Effect of particle shapes on compact morphology

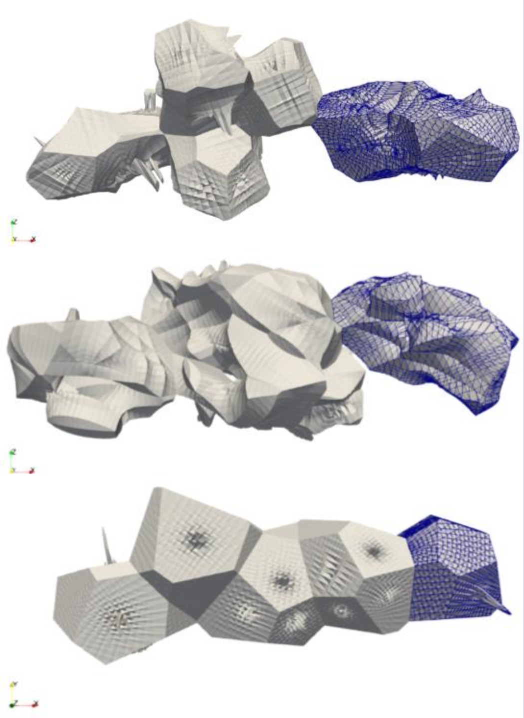


Figure 8: Visualization of five selected voronoi cells for each sample

- Voronoi tessellation analysis

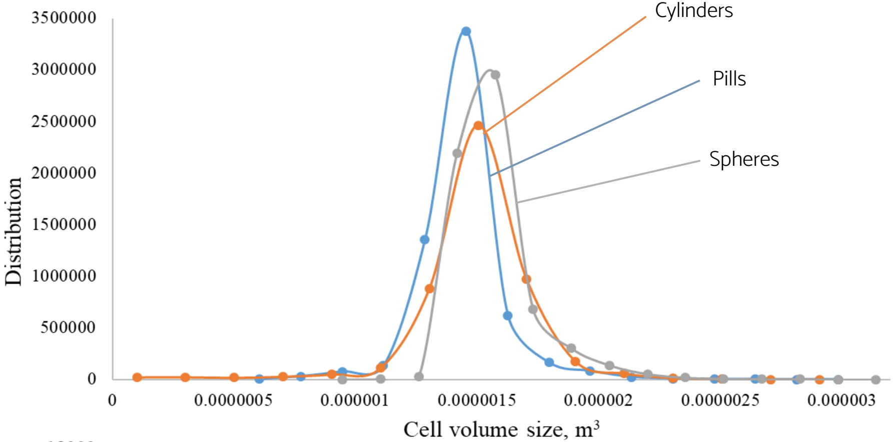


Figure 9: Normalized Voronoi cells volume correlation

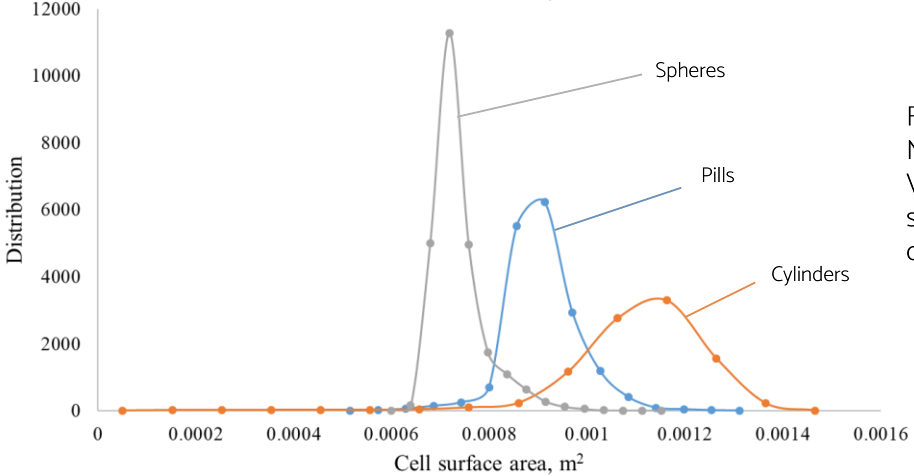


Figure 10: Normalized Voronoi cells surface area correlation

STUDY 2

Effect of non-spherical particles inclusion into spherical powder compact mixture

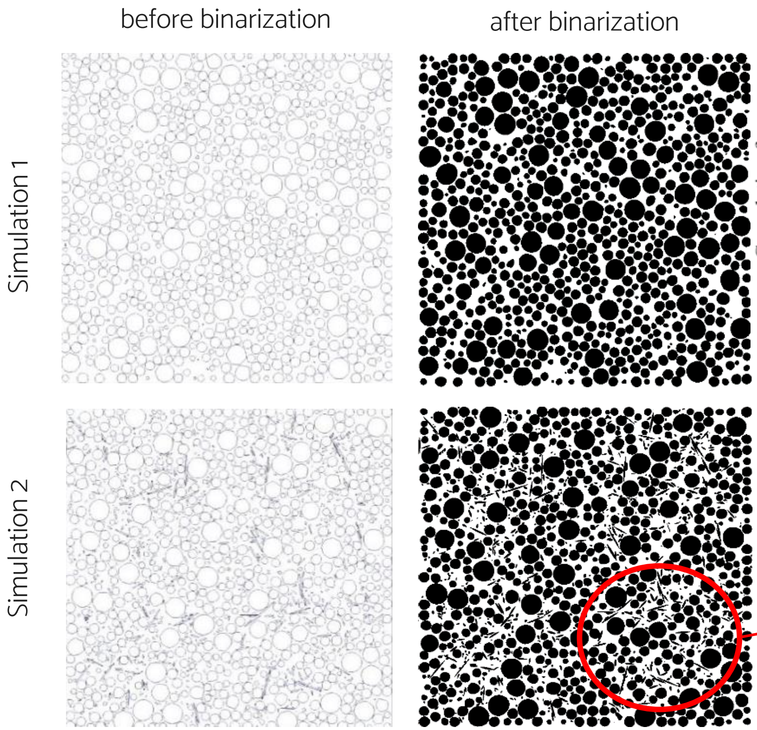
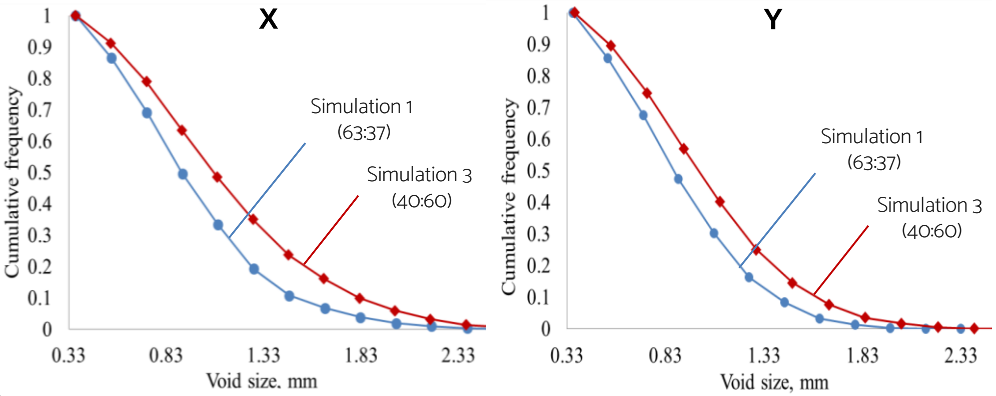
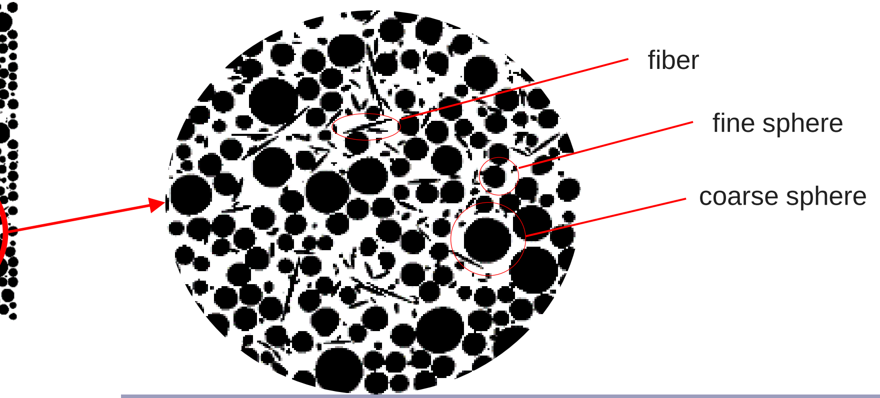


Figure 11: Images of compact cuts from DEM normal to Z direction

Figure 12:
VSD for simulations of binary mixtures of spherical particles





04 RESULTS & DISCUSSION

STUDY 2

Effect of non-spherical particles inclusion into spherical powder compact mixture

Parameters of void size distribution

Parameters		d_{50}	d_{90}	d_{10}	d_{90}/d_{10}
Simulation 1 (63:37)	x	0.914	0.500	1.475	2.950
	y	0.864	0.490	1.390	2.837
	z	0.930	0.485	1.626	3.353
Simulation 2 (62:37:1)	x	0.940	0.528	1.530	3.211
	y	0.900	0.500	1.457	2.944
	z	0.795	0.437	1.268	3.109
Simulation 3 (40:60)	x	1.068	0.570	1.830	2.898
	y	0.998	0.540	1.590	2.914
	z	0.984	0.533	1.657	2.949
Simulation 4 (40:59:1)	x	0.960	0.540	1.550	2.870
	y	0.965	0.540	1.515	2.806
	z	0.870	0.475	1.380	2.905

*the densest packed compact was obtained for ternary mixture with f_{fine}:f_{coarse}:f_{fiber} 63:37:1, the smallest voids median size d_{50}= 0.795 mm and the most uniform voids distribution

- Void size distribution analysis based on the cross-sectional images analysis

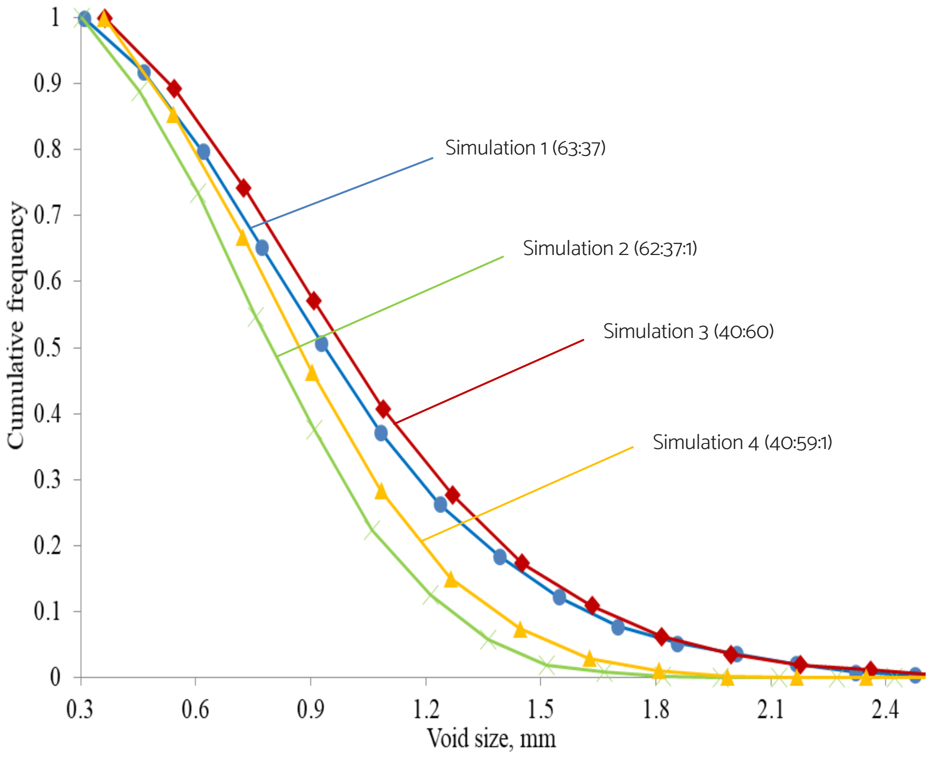


Figure 11:
VSD for all simulations in z direction

Study 1 on the effect of differently shaped particles compacts

Non-spherical form

the non-spherical form influences on the packing structure

Void size distribution

more uniform voids size distribution with small voids for pills and cylinders

Voronoi Tessellation

- more smooth voronoi cells for pills and cylinders
- sharpness of cylinder shape represented => wider range of voronoi cell volumes and surface area
- spheres => wider range of voronoi volume cells and less range of voronoi cell surface area

Study 2 on the effect of fiber inclusion into spherical particles mixture

Addition of non-spherical particles

addition of fibers into spherical particles mixture positively affected to the increase of packing

Void size distribution

the most packed compact f_{fine}:f_{coarse}:f_{fiber} 62:37:1

- the smallest voids with median size d_{50}= 0.795 mm
- the most uniform voids distribution

Recommendations

- further research on the evaluation of other superquadric forms
- extension of VT to analyze packing microstructure of complex bodies of superquadric compacts and mixtures of non-spherical particles
- Implementation of superquadrics with different aspect ratios and sharpness to analyze in two-dimensional and three-dimensional analyses

04 CONCLUSIONS & RECOMMENDATIONS

Publications and conference proceeding of author *based on the research*

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Packing Structure of Binary Particle Compacts with Fibers

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Analysis of Tortuosity in Compacts of Ternary Mixtures of Spherical Particles

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Microstructural Features of Ternary Powder Compacts

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