Contaminant Leaching from Recycled Particulate Materials under Load

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by

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Outline

- Introduction
- Scenarios of Leaching under Load
- Leaching under coupled processes
- Leaching Surface Evolution under Stress
- Experimentation
- Some Results
- Conclusions

INTRODUCTION

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Rationales

- Increase in demand for high volume construction materials
- Reusability of materials as aggregates
- Evaluation of long-term durability of reuse aggregates
- Development of realistic scenarios
- Need for inputs in LCA models

INTRODUCTION

Goals

- Factors affecting leaching under more realistic scenarios
- Establish measurable parameters for estimation of phenomenological leaching coefficients
- In particular, investigate effects of uni-axial loading on leaching coefficients of some metals

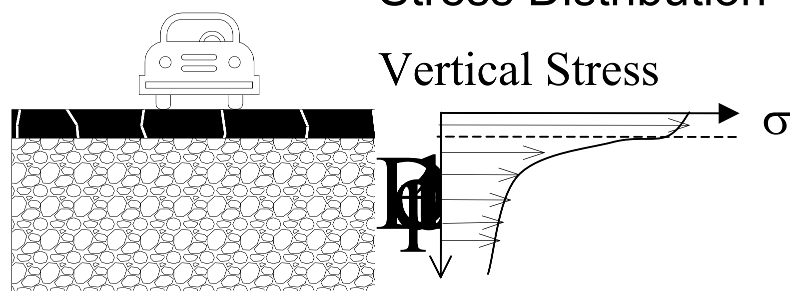
SCENARIOS OF LEACHING UNDER LOAD

SCENARIOS OF LEACHING UNDER LOAD

a: Underneath a slab

Stress Distribution

Vertical Stress



Leachant Infiltration:

Intergranular flow after entry through cracks in the slab

Significant of Load inclusion on Leaching phenomena:

Porosity decrease from:

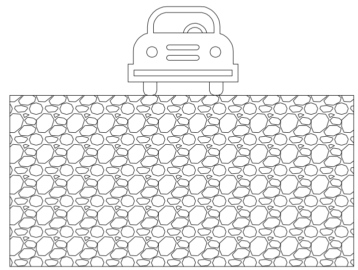
- Compaction
- Grain contact enlargement
- Pressure dissolution
- Grain breakage induced increase in specific surface area

Applications:

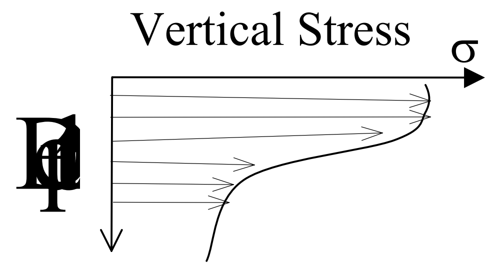
- Highway and airport pavement
- Parking loads
- Building foundations

SCENARIOS OF LEACHING UNDER LOAD

b: <u>Without a cover</u>



Stress Distribution



Leachant Infiltration:

Intergranular flow through direct infiltration

Significant of Load inclusion on Leaching phenomena:

Porosity decrease from:

- Compaction
- Grain contact enlargement
- Pressure dissolution
- Grain breakage induced increase in specific surface area

Applications:

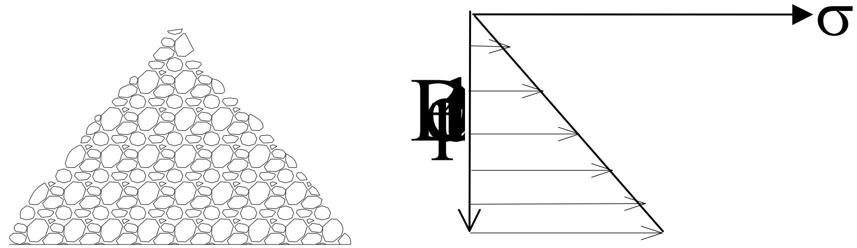
- Unsurfaced roads
- Load embankments and fills

SCENARIOS OF LEACHING UNDER LOAD

c: **<u>Under self weight</u>**

Stress Distribution

Vertical Stress



Leachant Infiltration:

Intergranular flow after entry through cracks in the slab

Significant of Load inclusion on Leaching phenomena:

Porosity decrease from:

- Compaction
- Grain contact enlargement in basal particles
- Pressure dissolution

Applications:

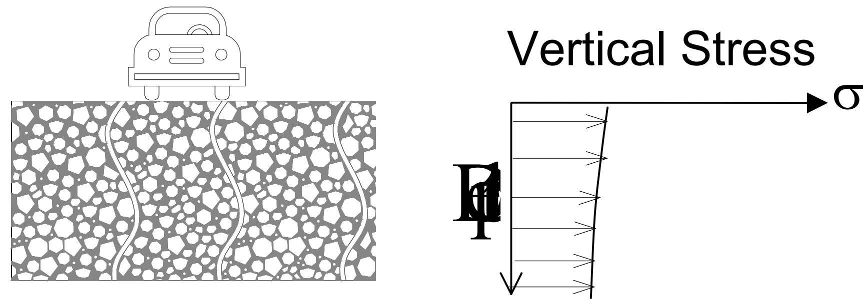
- Waste piles
- Aggregate piles

SCENARIOS OF LEACHING UNDER LOAD

d: <u>In monolithic form</u>

Stress Distribution

Vertical Stress



Leachant Infiltration:

Flow through fracture with flow negligible through cemented matrix

Significant of Load inclusion on Leaching phenomena:

- Shear fragmentation generated of grains in fracture opening

Applications:

- Concrete highway and airport pavement

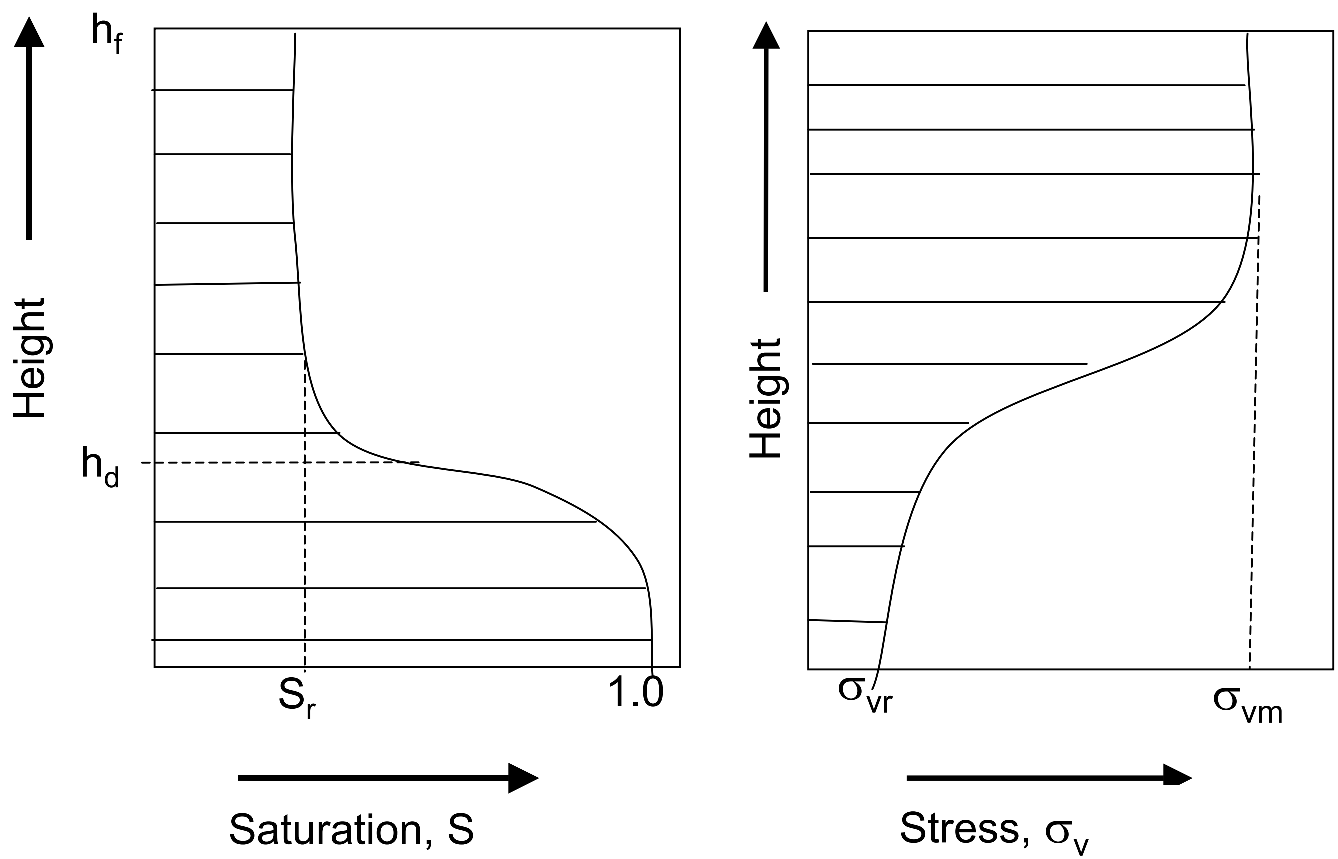
SCENARIOS OF LEACHING UNDER LOAD

Possible Impacts of Load-induced Phenomena on Leaching Parameters

Phenomena	Impact Leaching Parameter
1. Porosity decrease due to compaction	• Greater constraint to intergranular diffusion of substances • Decrease in leachant flow rate • Increase in the tortuosity of transport channels for contaminants release from grains
2. Grain Contact enlargement	• Decrease in the specific surface area of grains exposed to the leachant • Grain dilation with increase in sizes and connecting of intergranular transport channels for diffusing species
3. Pressure dissolution	• Increase in the availability of leached contaminants for transport from the media • Changes in shape factors of partially dissolved particles
4. Grain breakage induced increase in specific surface area	• Increase in specific surface area available for contaminant leaching from the grains of the particulate matter • Increase in the tortuosity of transport channels for contaminants release from grains

SCENARIOS OF LEACHING UNDER LOAD

Saturation and stress conditions in a loaded, uncemented particulate medium between infiltration events.



LEACHING UNDER COUPLED PROCESSES

LEACHING UNDER COUPLED PROCESSES

Predicting Leaching Potential of Contaminants from a System on Coupled Effects of Various Effects

Fluxes in coupled processes (Hines and Maddox 1985)

$$F_i = D_{i1}N_1 + D_{i2}N_2 + \cdots\cdots\cdots + D_{in}N_n = \sum_{j=1}^{n} D_{ij}N_j$$

The term $D_{ij}N_j$ may be the contribution of the chemical, mechanical, hydraulic, pressure, thermal, or other related gradients to the leaching of substance (i) from the system.

One of critical parameters : Volumetric Specific Surface Area

LEACHING UNDER COUPLED PROCESSES

If only the concentration gradient is present in the system = **Fick's law**

A special relationship of Fick's Law:

$$\frac{M_t}{M_{so}} = 2\left(\frac{D_L}{\pi}\right)^{0.5} \frac{S_S}{1-n_m} t^{0.5}$$

- Contaminant released from a medium is influenced by the surface area of the particles that interact with the leachant.
- Volumetric specific surface area is the significant parameter of the medium in leaching potential of contaminants.

LEACHING SURFACE EVOLUTION UNDER STRESS

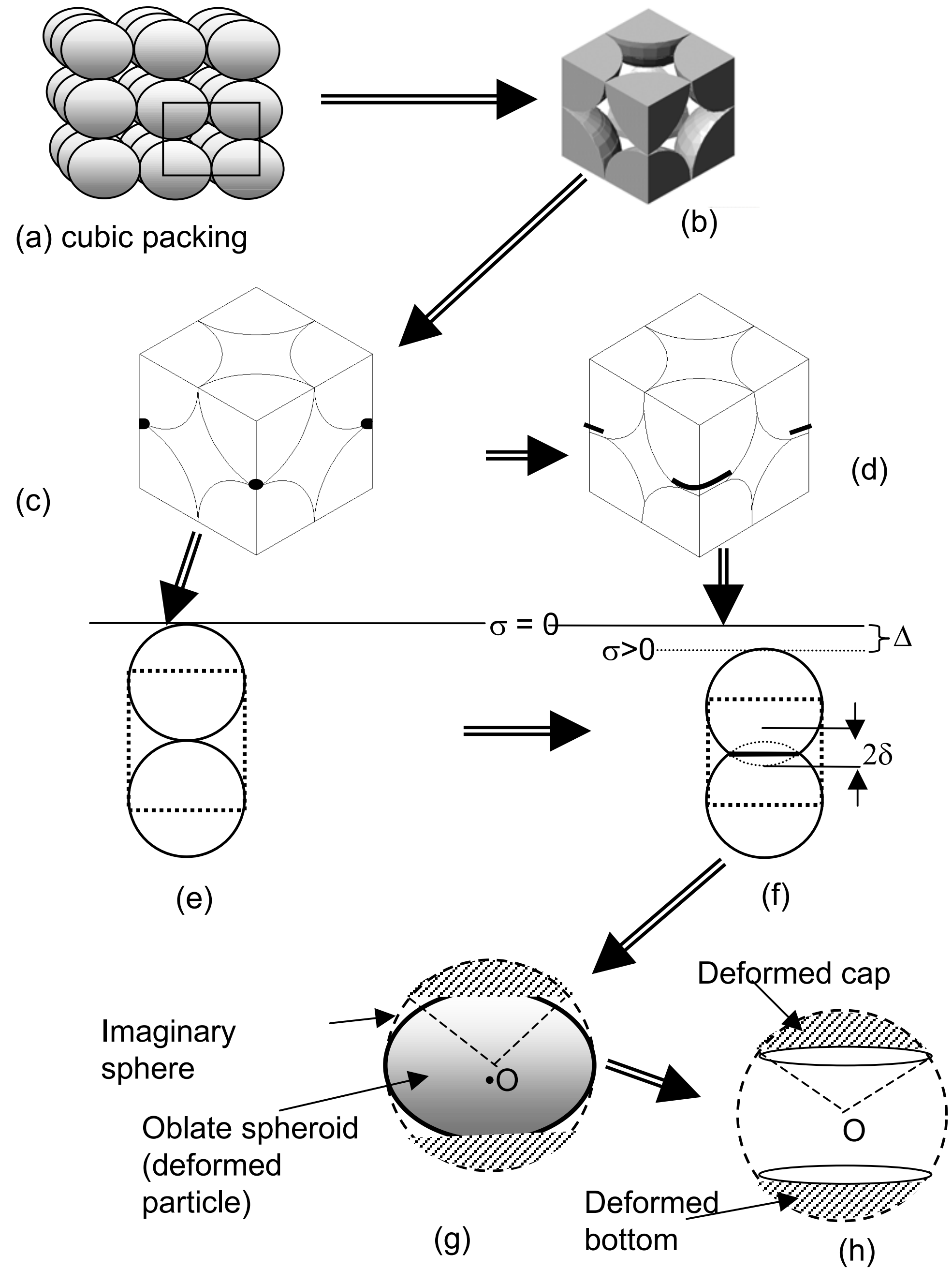
LEACHING SURFACE EVOLUTION UNDER STRESS

For this study:

uniaxial steady load regime.

change in leachability can be attributable to the following factors:

- decreasing in particulate leaching surface with increase in load
- decrease in porosity and thus permeability with increase in load and increase in intra particle dilation with increase in load.



LEACHING SURFACE EVOLUTION UNDER STRESS

Relating Particle Strain (e) to Bulk Porosity (n_σ) under Load

$$\varepsilon = 0.6057 - 0.5095 n_\sigma - 1.6015 n_\sigma^2$$

Estimation of the Mass Specific Surface Area (S_σ) of Strained Particles under Uniaxial Load

$$S_\sigma = \frac{6(0.7714 - 0.5948 n_\sigma - 0.9397 n_\sigma^2 + 1.0920 n_\sigma^3 - 0.3289 n_\sigma^4)}{G_s \rho_w d}$$

Converting mass specific surface area, S_σ, of a bulk material of a known porosity, n, to its equivalent volumetric specific surface area, S_s,

$$S_S = S_\sigma \rho_w G_s (1 - n)$$

Relating Leaching Potential and Volumetric Specific Surface Area

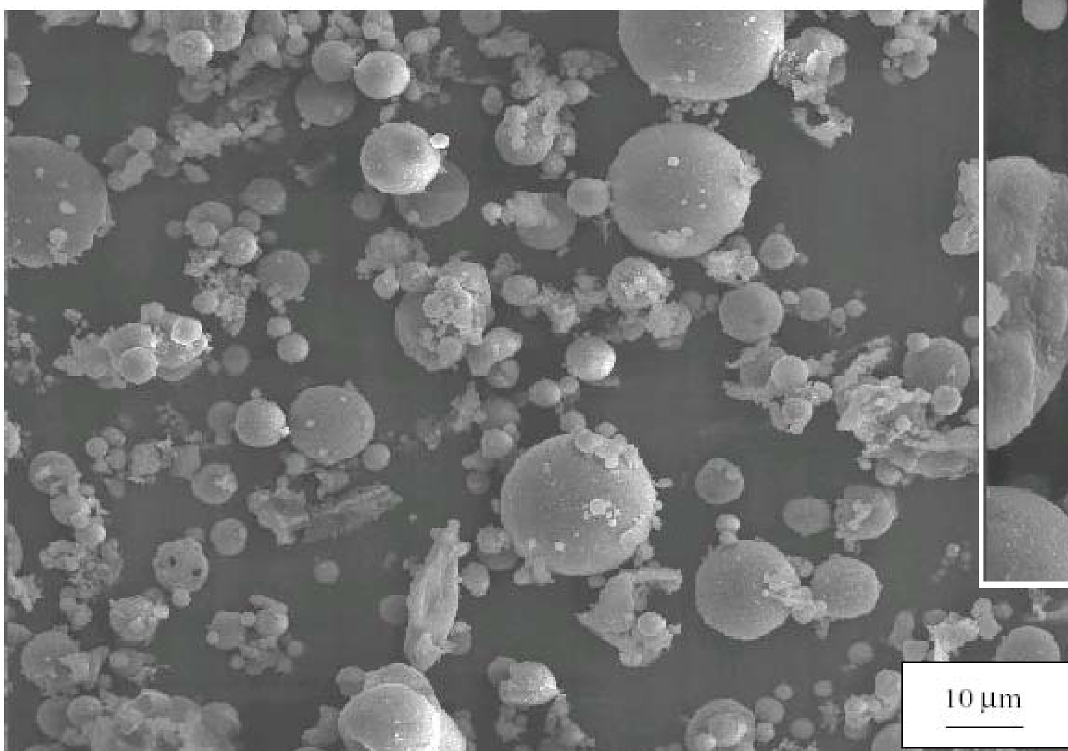
$$\frac{M_t}{M_{s0}} = 12\left(\frac{D_L}{\pi}\right)^{0.5} \frac{(0.7714 - 0.5948 n_\sigma - 0.9397 n_\sigma^2 + 1.0920 n_\sigma^3 - 0.3289 n_\sigma^4)}{d}$$

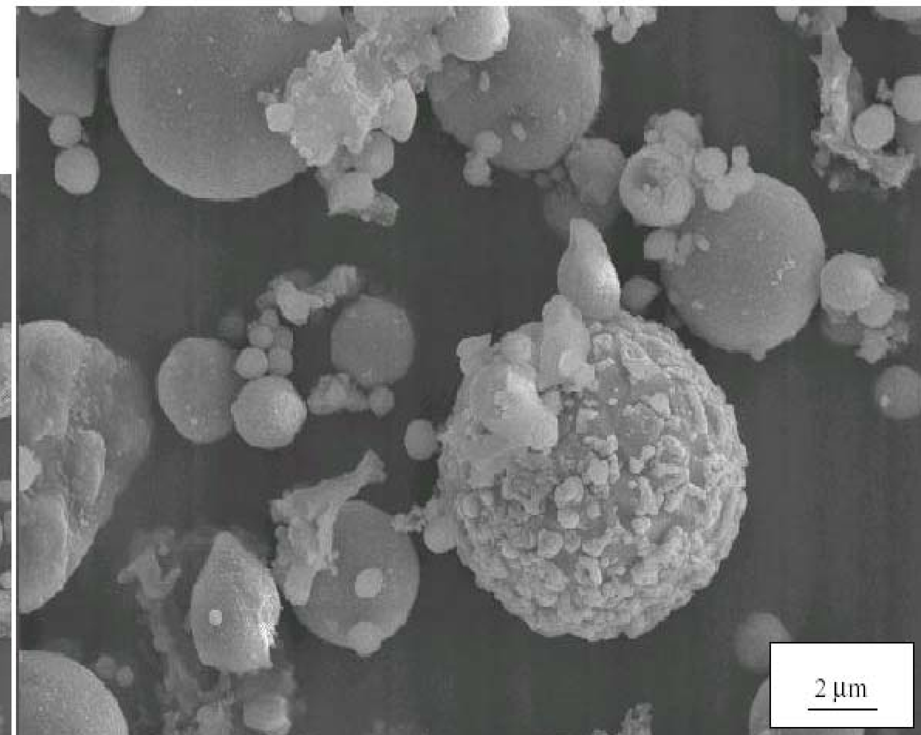
EXPERIMENTATION

EXPERIMENTATION

Flyash used falls within the size distribution range typical of silty

SEM images of the Flyash Tested

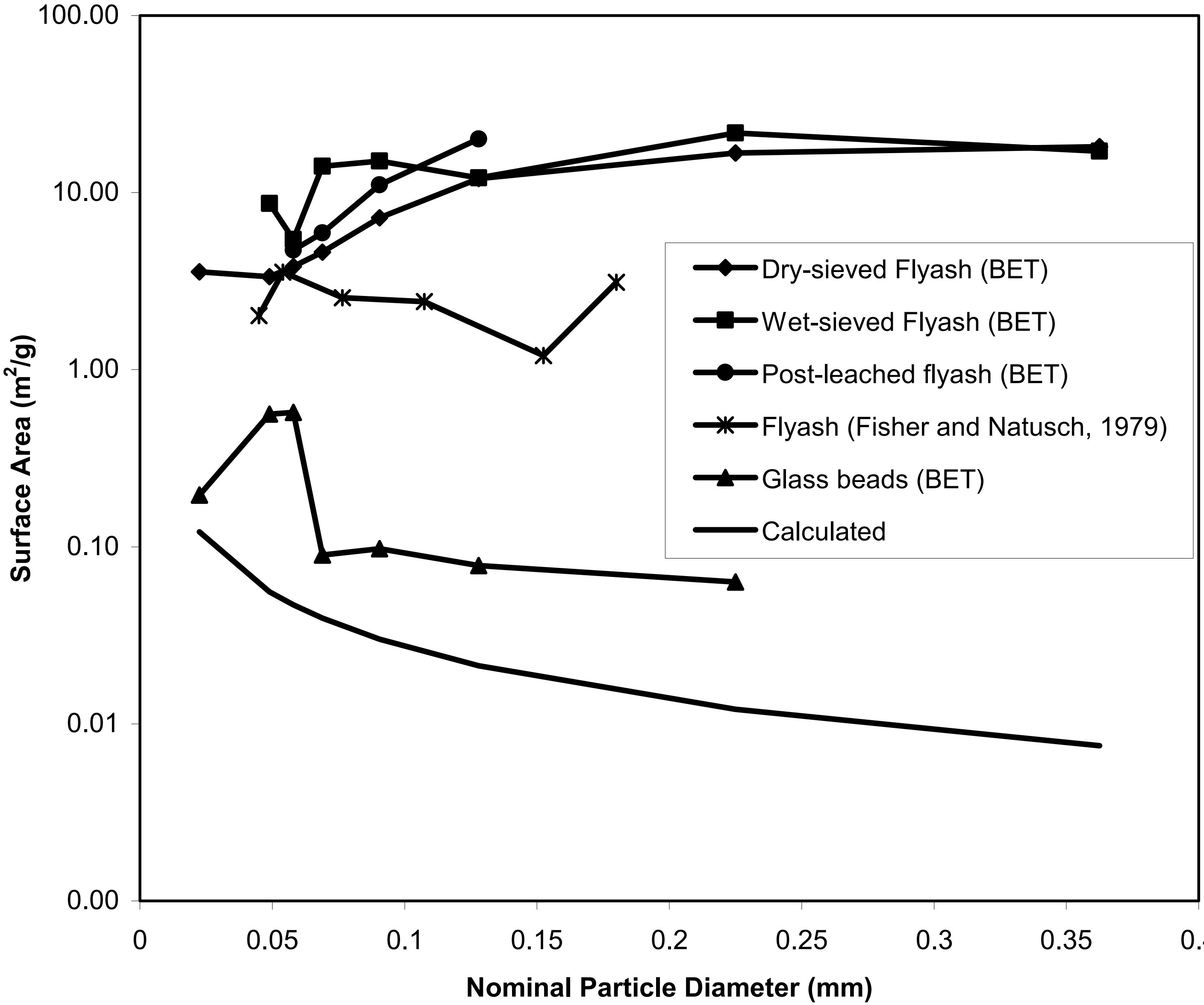




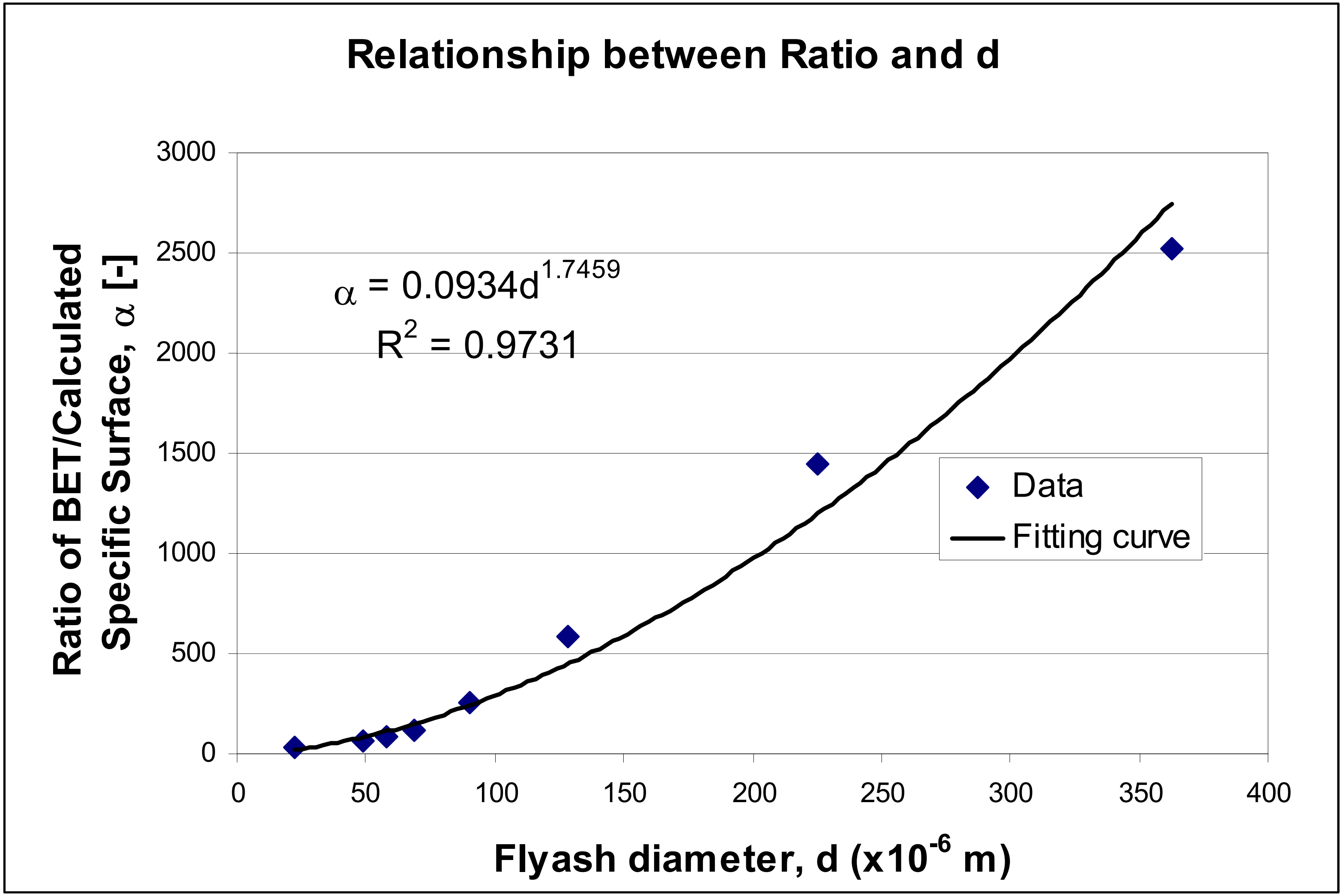
Specific Surface Area Results:
(BET-measured and Theoretically Calculated Values - TCV)

Particle Size (μm)	Specific Surface Area (m^2/g)			
	Fly Ash (Pre-leached)	Fly Ash (Leached)	Glass Beads	TCV
45 - 53	3.345	ND	0.561	0.0557
53 - 63	3.828	4.746	0.575	0.0470
63 - 75	4.612	5.927	0.09	0.0395
75 - 106	7.207	11.069	0.098	0.301
106 - 150	12.019	20.115	0.078	0.0213
150 - 300	16.773	ND	0.063	0.0121
300 - 425	18.144	ND	ND	0.0075
Notes: ND – No data				

Brunauer, Emmett and Teller (BET) surface area measurements of the flyash and glass beads, and theoretically calculated values (TCV) in the same size ranges.



Ratio of the BET-measured specific surface area to calculated values as a function of flyash particle diameter

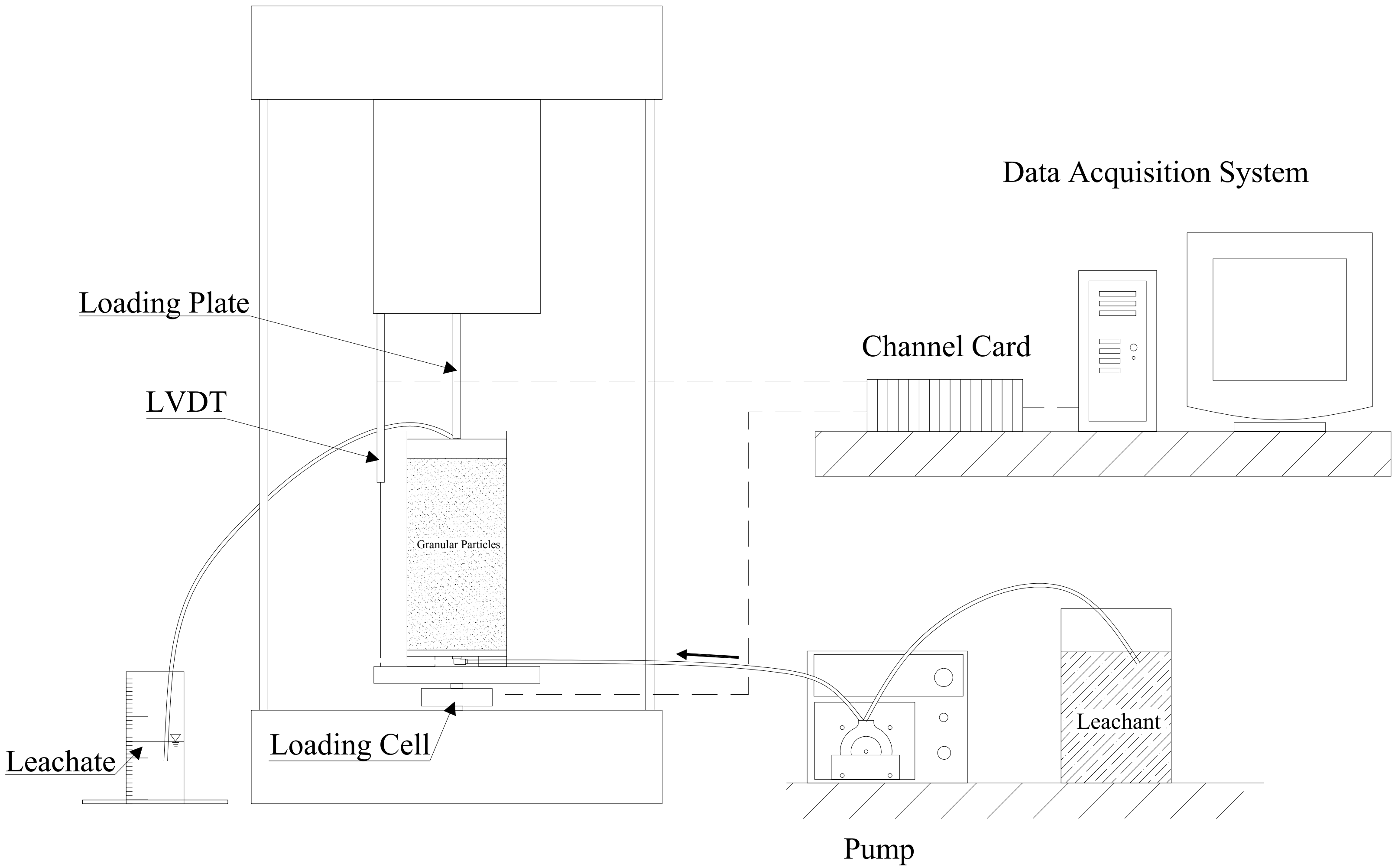


XRF results of the flyash used

Elements	Concentration (ppm)
Si	485,387.3
Al	287,779.0
Fe	94,007.8
K	50,264.5
Ca	25,708.3
Ti	20,911.9
S	10,417.6
Mg	9,784.5
Na	5,371.9
Sr	2,628.4
Cr	1,534.8
P	1,496.5
V	825.0
Zr	792.4

Elements	Concentration (ppm)
Cu	748.2
Zn	422.1
Mn	422.1
Y	364.5
Rb	307.0
Co	268.6
Ga	189.9
Cd	44.1
Se	62.5
As	90.2
Pb	17.02
Mo	ND
Hg	ND
Note: Targeted contaminants in this study are in bold	

Experimental set-up (leaching under uniaxial loading)



Uniaxial Loading Leaching Setup (Picture)

SOME RESULTS

Comparison of estimation methods (traditional and model): Effects on variation of S_s with measured $n\sigma$.

Applied Stress (kPa)	Porosity, n_σ	Estimated Volumetric Specific Surface Area (cm^{-1})	
		Traditional Method	Model
1425	0.4610	621.92	602.97
2850	0.3812	714.00	586.37
2850	0.3917	701.88	589.29
2850	0.3708	726.00	583.28

Comparison of the effect of estimation method (traditional and proposed model) on variation of S_s with measured n_σ

Applied Stress (kPa)	Porosity, n_σ	Volumetric Specific Surface Area (cm^{-1})			
		Calculated		Measured (BET)	
		Traditional Method	Model	Traditional Method	Model
1425	0.4610	621.92	602.97	105250.38	102043.60
2850	0.3812	714.00	586.37	120832.90	99232.92
2850	0.3917	701.88	589.29	118782.57	99728.36
2850	0.3708	726.00	583.28	122863.71	98710.80

Leaching coefficients, D_L (cm^2/s), of Copper at pH = 6

a: Calculated specific surface area (S_s(TCV))

Test Condition		Leaching coefficient, D_L, (cm^2/s)			
		L/S=1	L/S=2	L/S=5	L/S=10
Column		8.46×10^{-16}	1.09×10^{-15}	1.24×10^{-15}	1.43×10^{-15}
Leaching under load, σ (kPa)	570	2.00×10^{-16}	2.00×10^{-16}	NT	NT
	1,425	3.50×10^{-16}	NT	NT	NT
	5,710	4.00×10^{-15}	3.00×10^{-15}	5.00×10^{-16}	5.00×10^{-16}

NT = Not Tested

b: BET-measured specific surface area (S_s(BET))

Test Condition		Leaching coefficient, D_L, (cm^2/s)			
		L/S=1	L/S=2	L/S=5	L/S=10
Column		2.95×10^{-20}	3.81×10^{-20}	4.33×10^{-20}	4.99×10^{-20}
Leaching under load, σ (kPa)	570	6.98×10^{-21}	6.98×10^{-21}	NT	NT
	1,425	1.22×10^{-20}	NT	NT	NT
	5,710	1.40×10^{-19}	1.05×10^{-19}	1.75×10^{-20}	1.75×10^{-20}

NT = Not Tested

Leaching coefficients, D_L (cm^2/s), of Arsenic at pH = 6

a: Calculated specific surface area (S_s(TCV))

Test Condition		Leaching coefficient, D_L, (cm^2/s)			
		L/S=1	L/S=2	L/S=5	L/S=10
Column		3.33×10^{-07}	6.67×10^{-07}	1.00×10^{-06}	2.00×10^{-06}
Leaching under load, σ (kPa)	570	1.50×10^{-17}	5.00×10^{-18}	NT	NT
	1,425	NT	NT	NT	NT
	5,710	5.00×10^{-15}	1.00×10^{-14}	2.50×10^{-14}	3.00×10^{-14}
NT = Not Tested					

b: BET-measured specific surface area (S_s(BET))

Test Condition		Leaching coefficient, D_L, (cm^2/s)			
		L/S=1	L/S=2	L/S=5	L/S=10
Column		1.16×10^{-11}	2.33×10^{-11}	6.98×10^{-11}	3.49×10^{-11}
Leaching under load, σ (kPa)	570	5.24×10^{-22}	1.75×10^{-22}	NT	NT
	1,425	NT	NT	NT	NT
	5,710	1.75×10^{-19}	3.49×10^{-19}	8.73×10^{-19}	1.05×10^{-18}
NT = Not Tested					

CONCLUSIONS

Conclusions

Ratios of specific surface area measured by BET to that computed range from 65 to 2827 as particle grain size increases from 49 μm to 364 μm.

For column leaching tests performed in a bulk material with porosity of about 0.55, the computed leaching coefficients of Cu, As and Se from flyash based on TCV specific surface area are found to be of 3 orders of logarithmic magnitude higher than those based on BET measurement.

Cu seems to leach more at stress levels of 570 and 5,710 kPa than column leaching tests at the same L/S ratios. While Se and As seem to leach more at stress level of 570 and 5,710 kPa, respectively, than column leaching.

Conclusions

Batch, column, and stress-induced leaching environments resulted in different leaching relationships and intensity.

Method of estimation of specific surface area affect the determination of leaching parameters.

For a stressed medium, the specific surface area decreases with load when particle deformation is accounted for

These results confirm the presence of internal porosity in flyash particles and also show that the value of the internal porosity increases with increasing grain size.