Utilization of Cement Kiln Dusts for Clay Soil Stabilization

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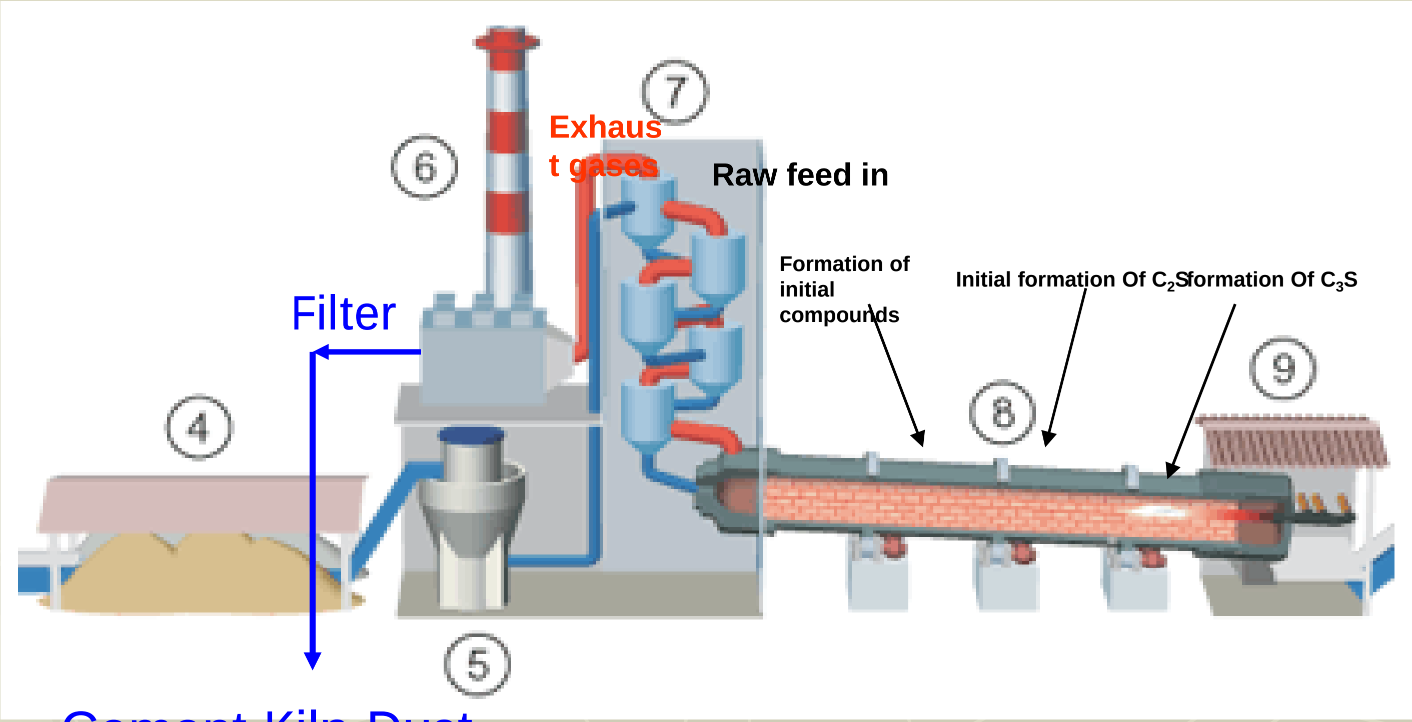
Sustainable Cement; Challenges, Opportunities and Applications

What are cement kiln dusts (CKDs)?



- calcined & unreacted raw feed
- clinker particles
- alkalis
- sulfates
- other volatiles

How much CKD is generated ?

Approximately 9 million tones of CKD for every 100 million tones of cement. 5 million tones of CKD are recycled as a raw material and the rest are considered as waste.

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CKDs and Waste Management

Pictures courtesy of M. Santagata, Purdue University

- *Airborne, air pollution*
- *Leaching of heavy metals*
- *Requires large space for disposal*

Sustainable Alternate Solution

- Beneficial utilization of CKDs-sustainability of cement production can be improved by utilizing some of the CKDs in other applications.

Objective

- To explore the potential of utilizing CKD as a soil stabilizing material

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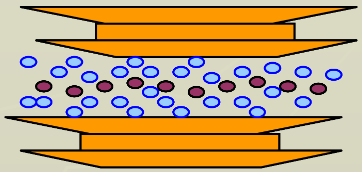
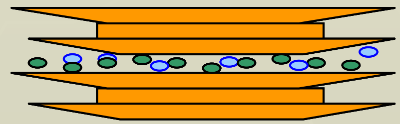
CKD as a soil stabilizer?

Why Soil Stabilization?



Clay particles before stabilization



Clay particles after stabilization

Can we substitute the traditional stabilizers with CKDs and would it be beneficial?

- Can we use all CKDs as effective soil stabilizers? Can they stabilize both expansive and non expansive soils?
- How effective are they compared to lime in stabilizing soils?
- What is the mechanism of stabilization? How durable are the CKD-stabilized soils?

Chemical composition of CKDs

Chemical composition by XRF	CKD-1	CKD-2	CKD-3	CKD-4	Type I Cement
	Weight (%)				
SiO_2	12.18	16.42	11.91	15.39	20.48
Al_2O_3	4.24	3.62	2.17	4.66	4.21
TiO_2	0.22	0.23	0.15	0.57	0.36
P_2O_5	0.08	0.09	0.09	0.09	0.09
Fe_2O_3	1.71	2.31	2.08	2.34	2.41
CaO	46.24	55.00	46.05	37.35	63.19
MgO	1.24	2.68	2.2	2.10	4.00
Na_2O	0.51	0.17	0.33	0.81	0.19
K_2O	4.89	2.89	1.43	7.0	0.28
Na_2O equiv.	3.72	2.05	1.27	5.36	0.373
Mn_2O_3	0.05	0.44	0.04	0.07	0.14
SrO	0.04	0.03	0.07	0.02	0.04
SO_3	14.62	12.69	4.21	5.80	2.76
Cl	0.59	0.74	0.35	3.26	-
LOI@ 750	14.22	3.92	29.63	27.65	1.76
free CaO **	13.85	29.14	5.32	3.26	1.58
Water-soluble Na_2O *	0.28	0.06	0.12	0.59	0.04
Water-soluble K_2O *	2.95	1.68	0.93	6.33	0.16

High free lime content CKDs

CKD-1

Free lime=13.85%

Sulfate = 14.62

Alkali = 3.72

CKD-2

Free lime=29.14%

Sulfate = 12.69

Alkali = 2.05

Low free lime content CKDs

CKD-3

Free lime=5.32%

Sulfate = 4.21

Alkali = 1.27

CKD-4

Free lime=3.26%

Sulfate = 5.80

Alkali = 5.36

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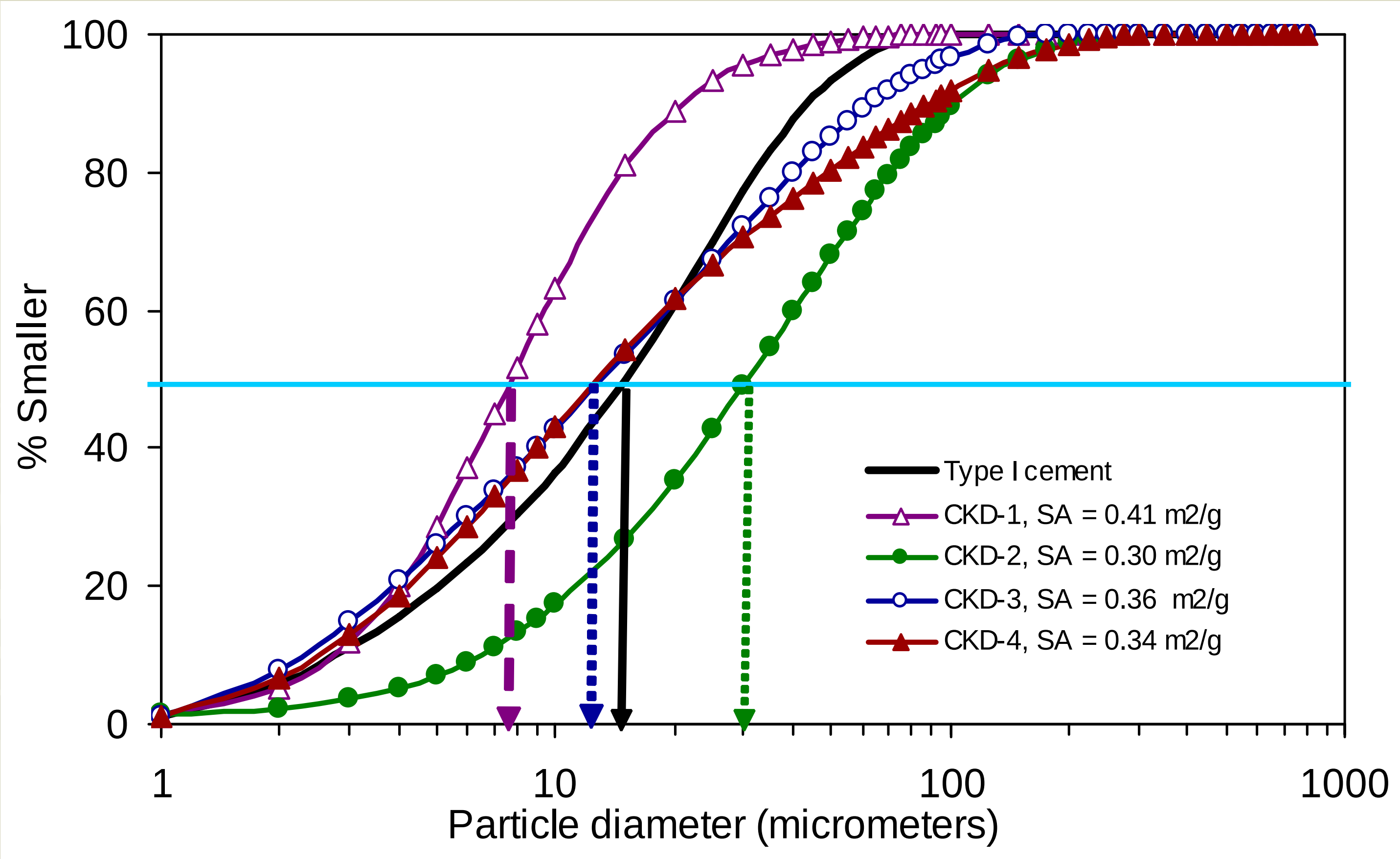
Particle size distribution and surface areas



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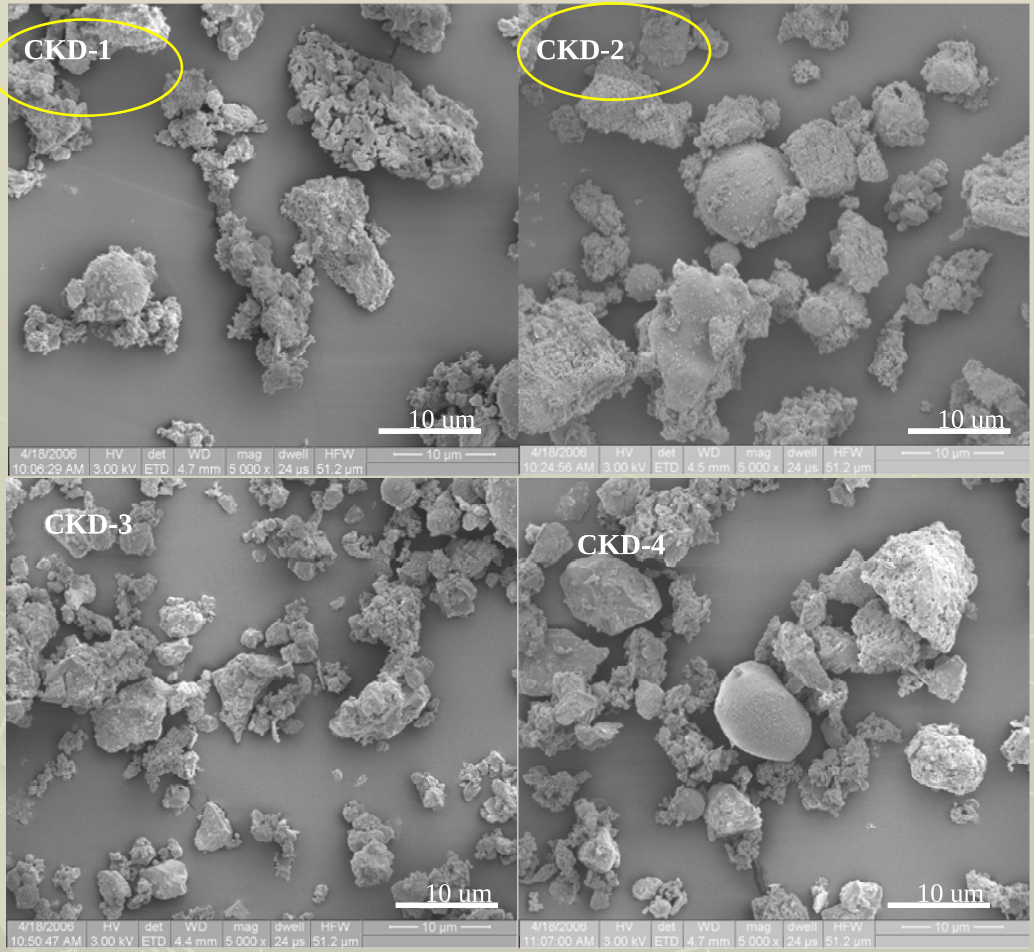
Morphology of CKD powders



SEM analysis

Agglomerated particles with poorly defined shapes

presence of some spherical particles (fly ash)

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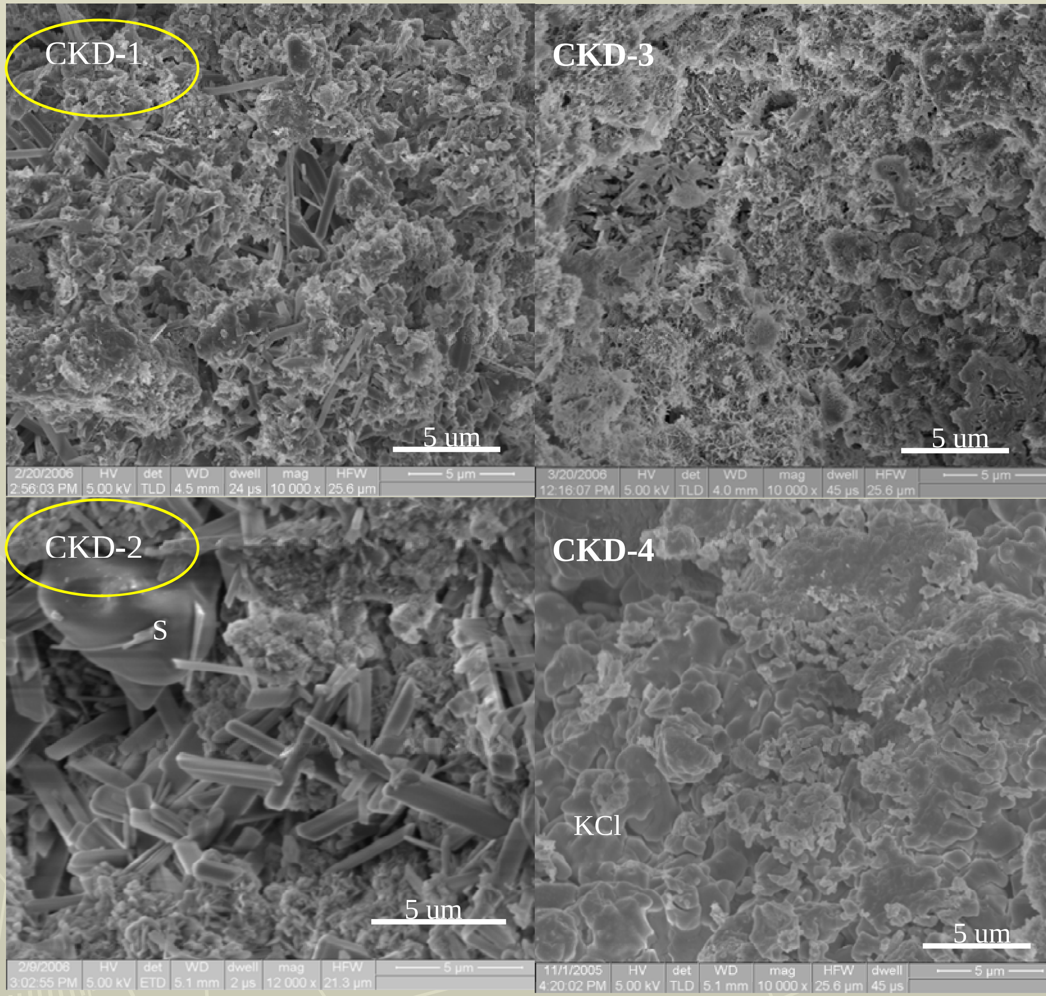
Morphology of hydrated CKD pastes (w/p=0.31)



Hydration changes the morphology of CKD powder. Hydration products in high free lime CKDs included needles of ettringite, occasional lath-shaped syngenite and sulfur-incorporating C-S-H-like phases

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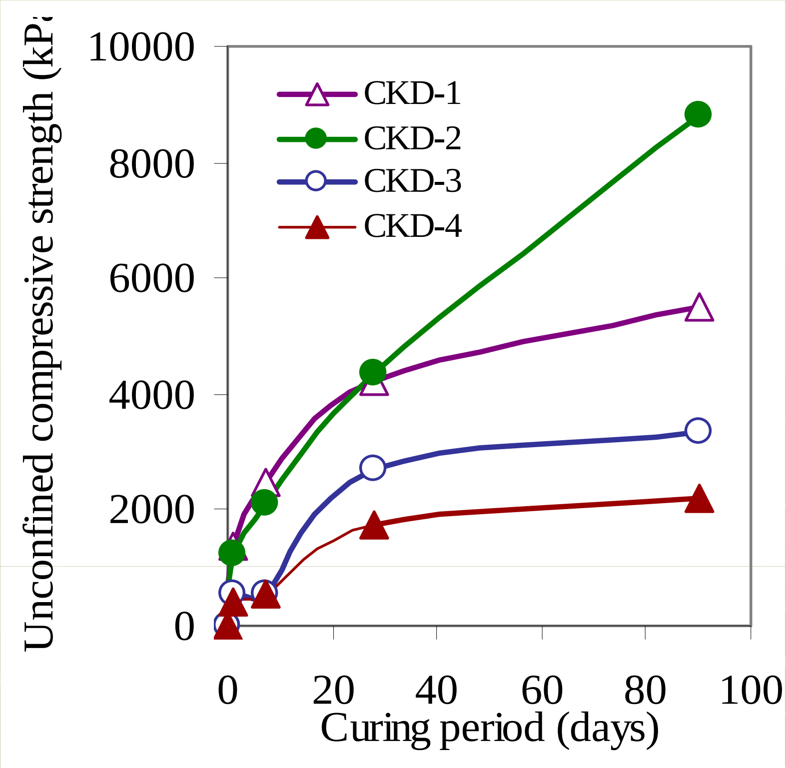
Strength of compacted and hydrated CKD pastes (w/p=0.31)



Compressive strength of CKDs compacted at constant moisture content

Engineering properties of CKD treated clays

3 “Model” Clays,

- Kaolinite
- Na-montmorillonite
- Ca-montmorillonite

Engineering properties evaluated included:

- Atterberg limits
- pH values
- Unconfined compressive strength (UCS)
- Stability and swelling

Physico-chemical effect of CKD addition were evaluated by:

- XRD, TGA, and SEM analyses

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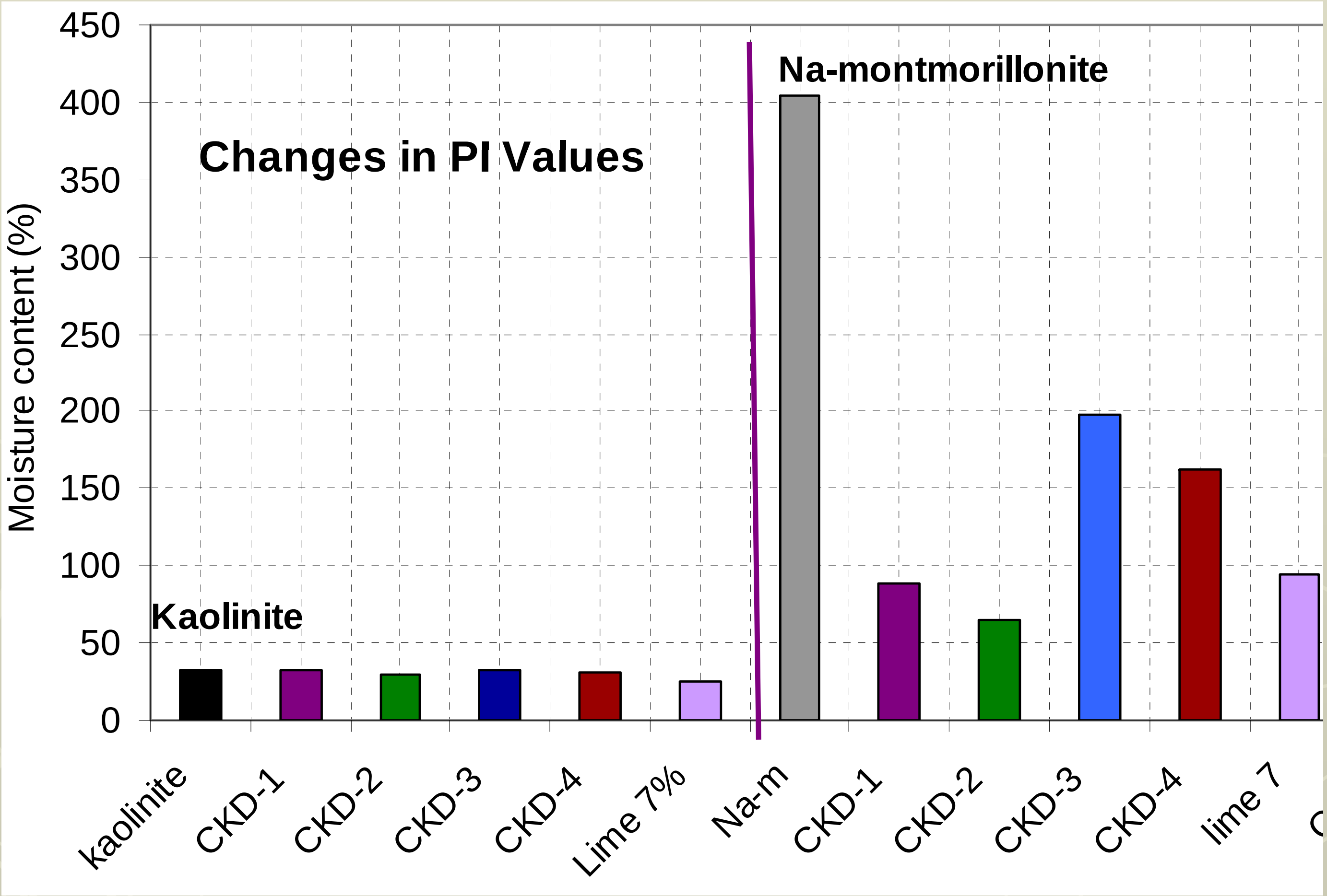
Effect of CKDs & lime on the Atterberg limit-PI



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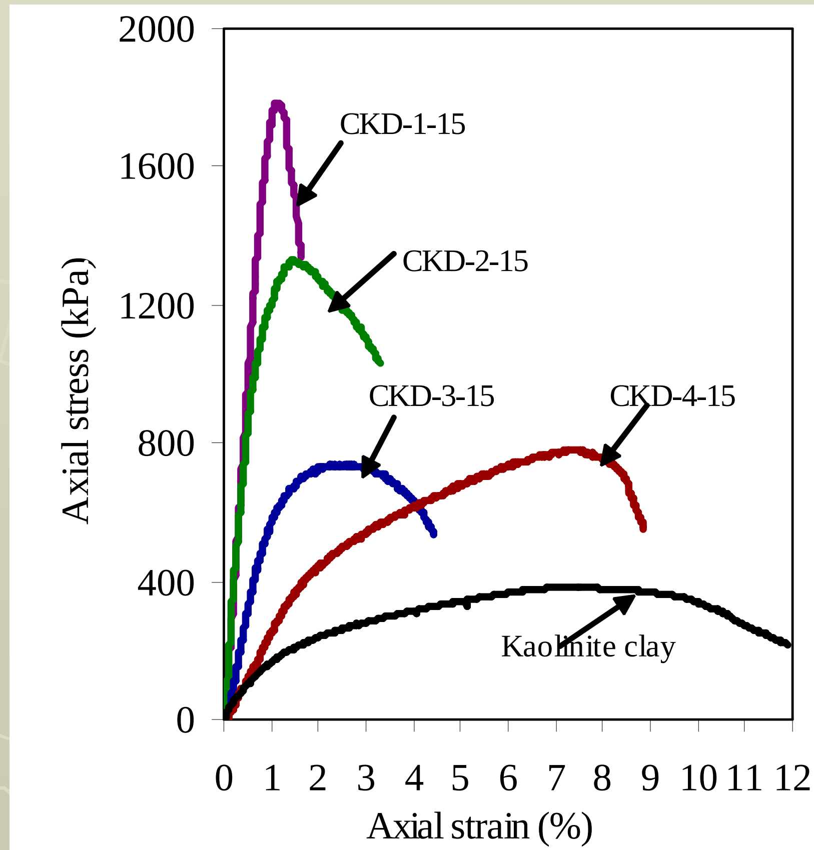
Effects of CKDs on the stress-strain behavior

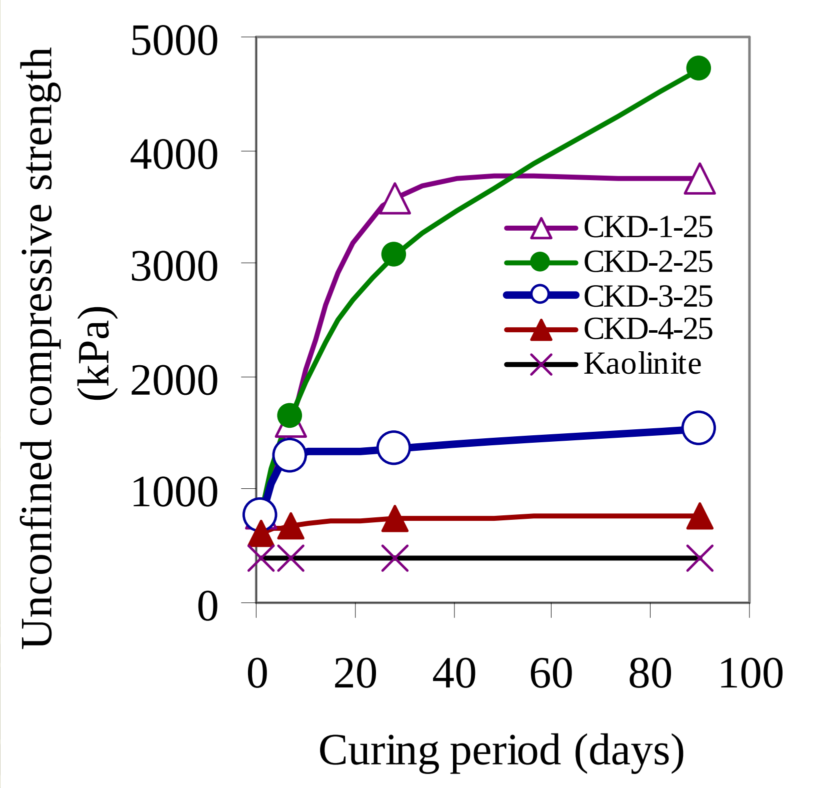
CKD-treated kaolinite clay



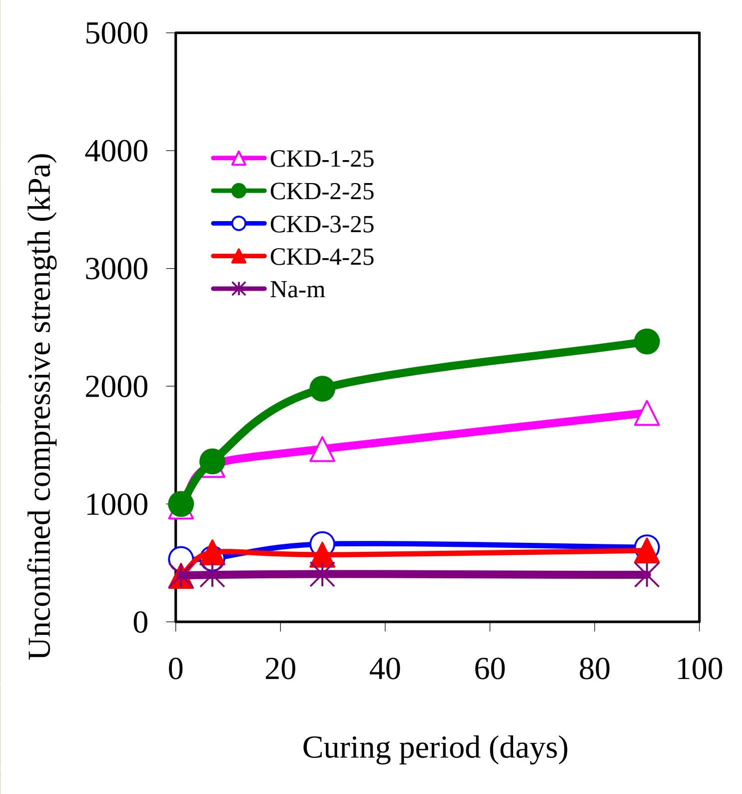
- Compacted CKDs treated kaolinite clay samples were prepared using Harvard miniature compaction equipment at a moisture content of 31%
- Strength and stiffness of CKDs-treated kaolinite clay increased significantly compared to untreated clay
- Strength and stiffness of CKD- treated Na-montmorillonite clay also showed the same trend.

UCS development in CKD-treated clays

kaolinite clay (non- expansive)



Na-montmorillonite clay (expansive)



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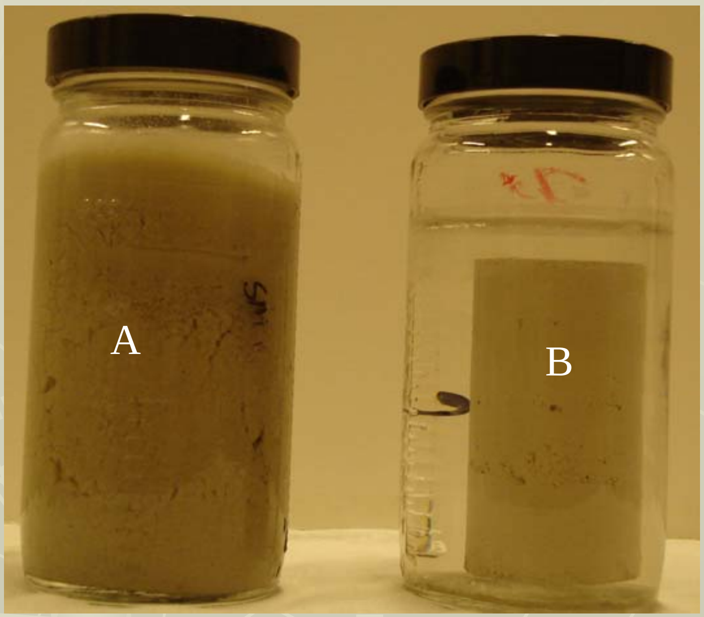
Visual swelling observation in CKD-treated Na-montmorillonite clay

High free lime content CKD treated Na-montmorillonite

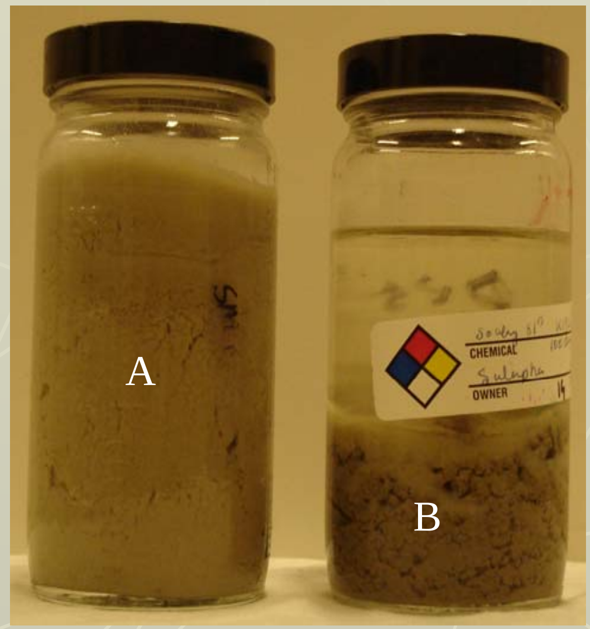


A-compacted clay alone

B -Comp.CKD-2 treated clay

No slaking or swelling was observed

Low free lime content CKD- treated Na-montmorillonite



A-compacted clay alone

B -Comp.CKD-4 treated clay

The compacted samples slaked but no swelling was observed

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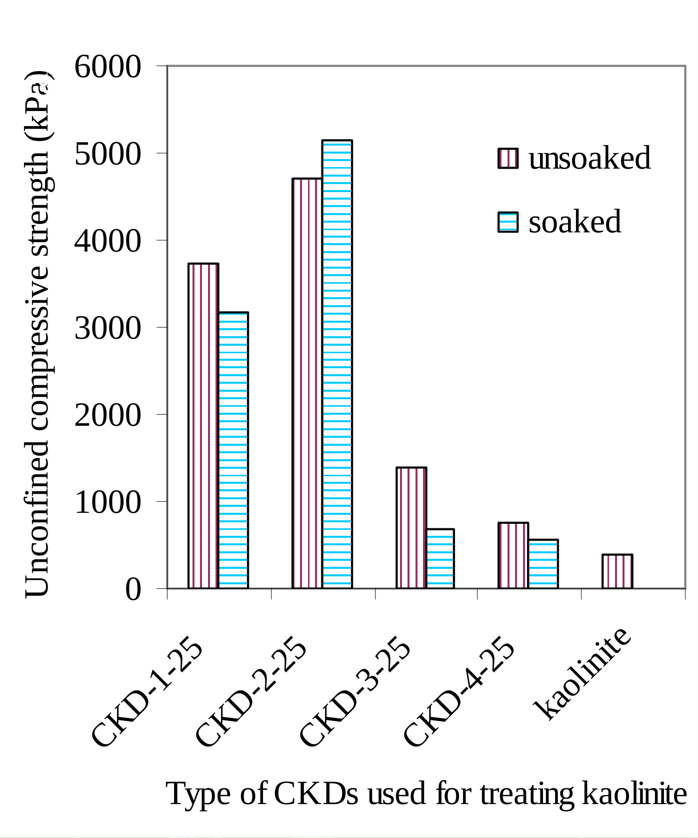
Stability of CKD-treated clays exposed to water

kaolinite



Stability-UCS of CKD-treated clay after soaking in water for 2 days. (after a curing period of 90 days)

- No loss of strength was observed for CKD-2 treated kaolinite and there was a small reduction in the strength in the case of the CKD-1 treated kaolinite
- CKD-3 and CKD-4 treated clay also retained more than 60% strength
- No loss of strength was observed in the case of lime-treated kaolinite
- Some loss of strength for Na-montmorillonite clay treated with CKD-1 and CKD-2 when soaked in water for 2 days. No loss of strength was observed in the case of the lime-treated Na-montmorillonite. CKD-3 and CKD-4 treated clays slaked upon soaking in water

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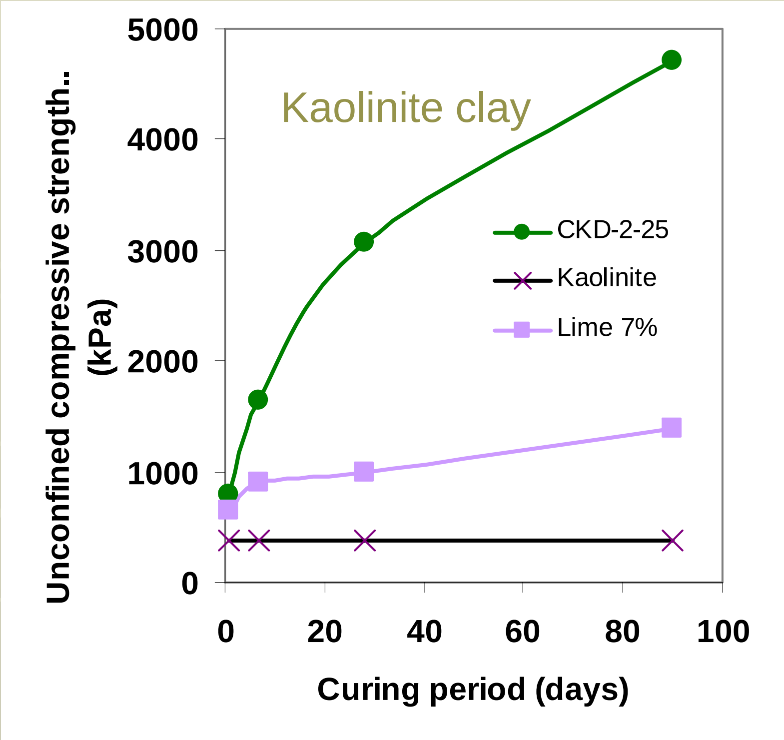
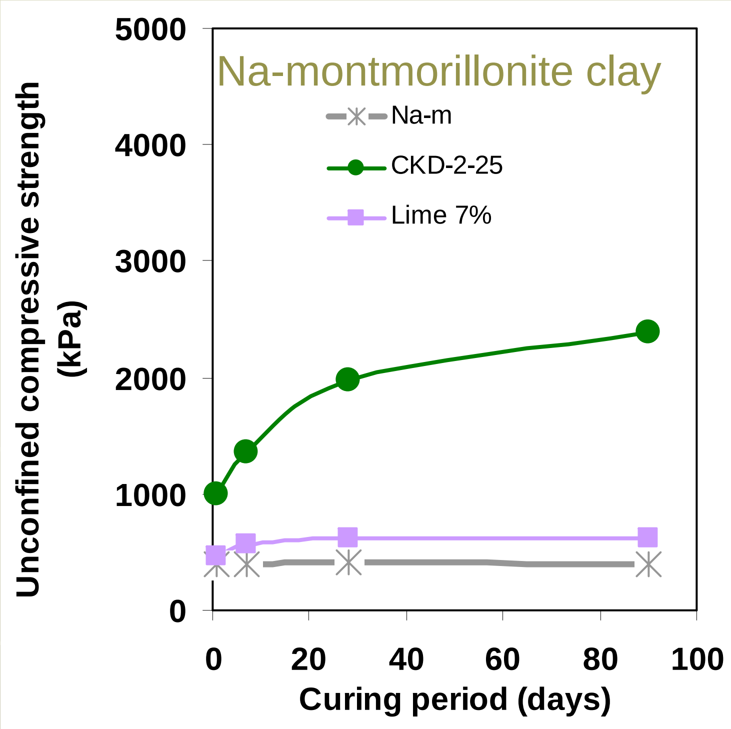
Comparison of UCS development in CKD-2 and lime treated clays





Irrespective of the type of the clay, UCS of CKD-2 treated clay was substantially higher than that of the lime-treated clays

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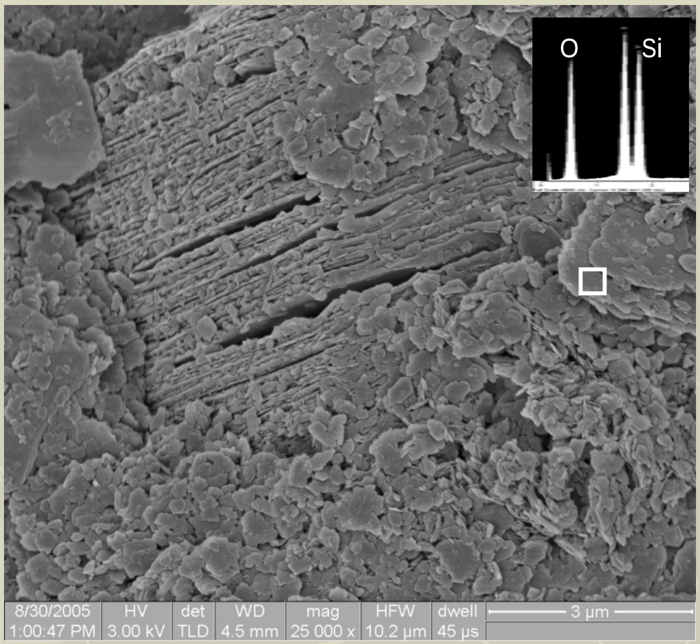
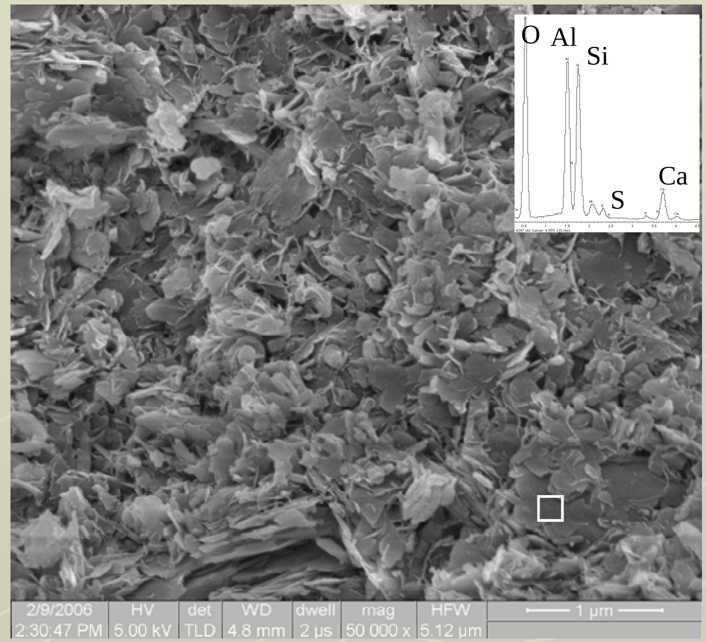
CKD-kaolinite clay interaction-SEM & EDS



Clay flakes appeared in “book-like” stacks and it appeared that each clay flake is a part of a stack



Compacted and cured kaolinite clay treated with 25% CKD-2. The clay flake stacks “disagglomerated” - no preferential orientation of the flakes in “random structure”

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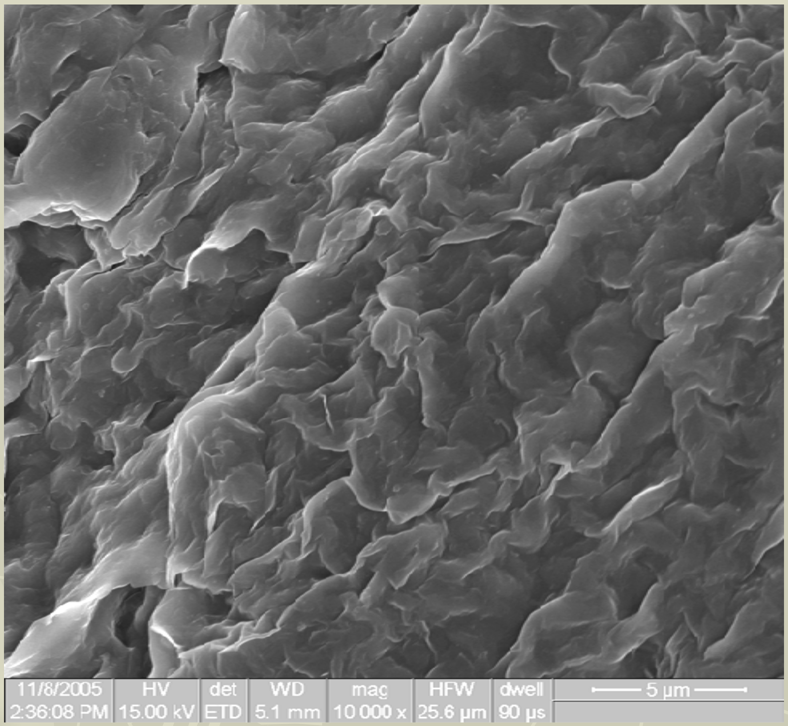
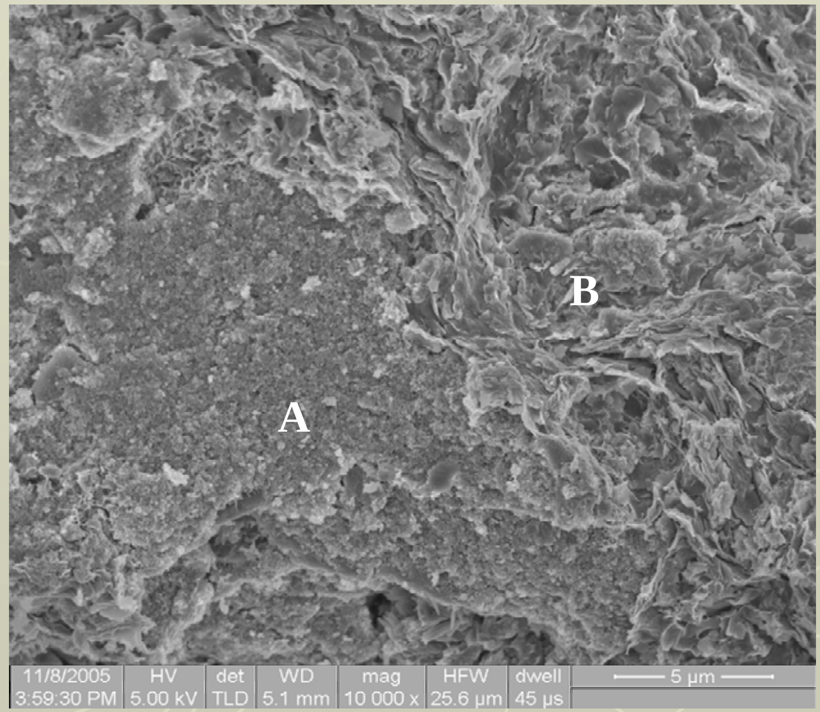
CKD-Na-montmorillonite clay interaction-SEM & EDS

90 day old compacted untreated Na-montmorillonite Clay



Undulating fluffy film-like structure



EDX pattern collected from the clay

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Summary

- All the CKDs enhanced the Atterberg limits, strength and stiffness of both the expansive and non expansive kaolinite
- Strength of the CKD-treated clays were substantially higher compared to the lime-treated clays
- All the CKD-treated kaolinite clay samples retained at least 50% strength upon soaking in water. High free lime content CKDs retained more strength compared to low free lime content CKDs
- The pozzolanic reaction is suggested as a significant mechanism in CKD-clay stabilization process (based on the observations made in this study)
- Other mechanisms that may contribute to the significant improvement in the engineering properties of CKD treated clays compared to the lime treated clays were identified as presence of ettringite and gypsum in the CKD-treated clays

Acknowledgements

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