Utilization of Aggregate Quarry By-Product Stabilized with Ladle Furnace Slag for Sustainable Pavement Foundation

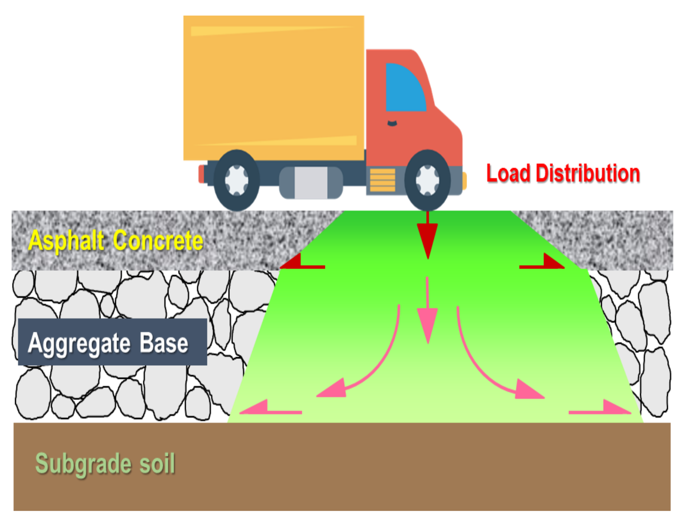
Taeyun Kong[1] and Erol Tutumluer, Ph.D., Dist.M.ASCE[1]

[1]Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign

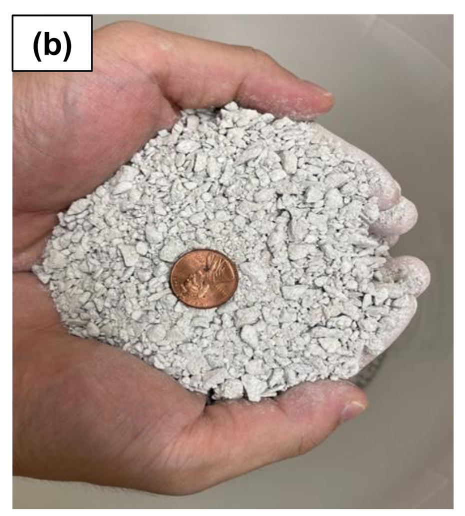
INTRODUCTION

❑ Background

- Strong pavement foundations (i.e., base & subbase layers) are essential for distributing heavy vehicular loads over a broader area on subgrade soils and providing a robust foundation for the asphalt concrete surface course
- Quarry by-products (QB), residual materials obtained from quarry operations, pose significant challenges to aggregate producers in terms of stockpiling and disposal (192 million US tons of annual production; NCHRP, 2013)
- QB utilization has been studied at the Illinois Center for Transportation (ICT) over the past decade and has shown a promising and sustainable alternative as aggregate resource for pavement base/subbase applications, especially when stabilized with a small amount of binder (e.g., 3% cement by weight)



Pavement structure load distribution



(a) Aggregate quarry by-products (QB) stockpiled at quarry sites, and (b) close-up picture of sand-sized QB materials

❑ Objective

- Develop more sustainable alternatives for QB applications in pavement foundations by examining chemical and mineralogical properties of ladle furnace slag (LFS) and investigating its use as a stabilizing agent for strength development in stabilized QB specimens

MATERIALS AND METHODS

❑ Aggregate QB Physical and Chemical Properties

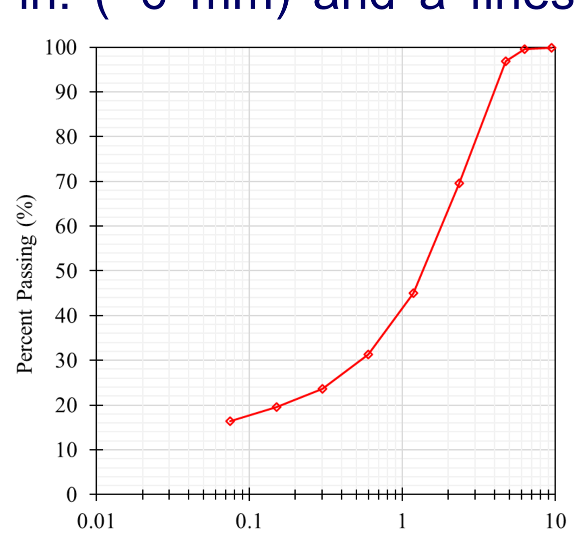
- QB materials consist of well-graded, sand-sized particles, exhibiting a typical particle size distribution with sizes smaller than ¼ in. (~6 mm) and a fines content (< 75 μm or passing the No.200 sieve size) ranging from 10% to 20%.
- Atomic absorption spectroscopy (AAS) analysis and the Rietveld refinement analysis from the x-ray diffraction (XRD) results show that QB used in this study is a highly dolomitic aggregate.

Mineral quantification from XRD analysis

	Dolomite	Quartz	Total
QB	95.6%	4.6%	100%

MgO content from AAS

	MgO
QB	19.5%



Particle size distribution

MATERIALS AND METHODS (Cont'd)

❑ Chemical and Mineralogical Properties of Ladle Furnace Slag

- LFS, a by-product of the secondary steel refinement process, demonstrates variations in its chemical composition depending on the steel plant source
- X-ray fluorescence (XRF) analysis indicates the LFS has potential as a supplementary cementitious material due to its high CaO and Al_2O_3 content
- Mineralogical analysis using XRD reveals that mineral phases present in the LFS exhibit cementitious or binder-like behavior upon hydration
- Presence of Katoite in XRD results indicates that a significant amount of C_3A (fast-reacting, cementitious phase) was present in freshly produced LFS

Elemental composition of the LFS studied

	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
LFS	2.02	20.1	2.69	0.347	2.75	0.0185	69.4	0.307	0.351	1.88
Typical Range*	3-10	4-35	2-35	-	-	-	30-70	-	-	0.5-13

Note: All values are expressed in weight percent (%). *(Jacob, 2023)

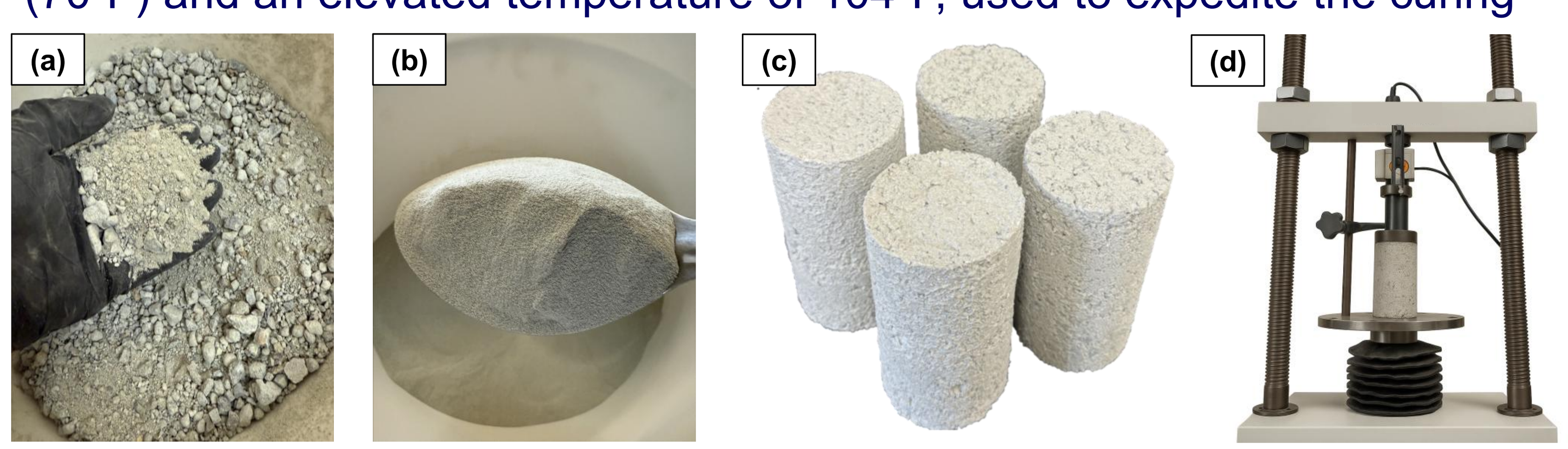
Rietveld refinement of XRD results of the studied LFS

	Tricalcium Aluminate (C_3A)	Chlor-mayenite	Larnite	Katoite	Periclase	Minor phases	Amorphous
LFS	9.15	6.7	4.93	24.74	2.9	14.7	36.88

Note: All values are expressed in weight percent (%).

❑ Sample Preparation and Strength Test Results

- The LFS was ground until the powder passed the No.100 sieve (< 150 μm) to ensure its effectiveness as a stabilizer
- Various stabilizer combinations incorporating LFS were used as follows:
  - 20% LFS – to assess its effectiveness as a standalone binder
  - 20% LFS + 2.4% cement – to assess its potential to reduce cement content
  - 20% LFS + 3% cement – to evaluate its ability to enhance strength relative to a baseline cement dosage known to provide adequate base strength
- QBs were compacted at optimum moisture content into cylindrical specimens (2.8 in. × 5.6 in.) and tested for unconfined compressive strength (UCS) after 7 and 28 days of curing under two temperature conditions: room temperature (70˚F) and an elevated temperature of 104˚F, used to expedite the curing

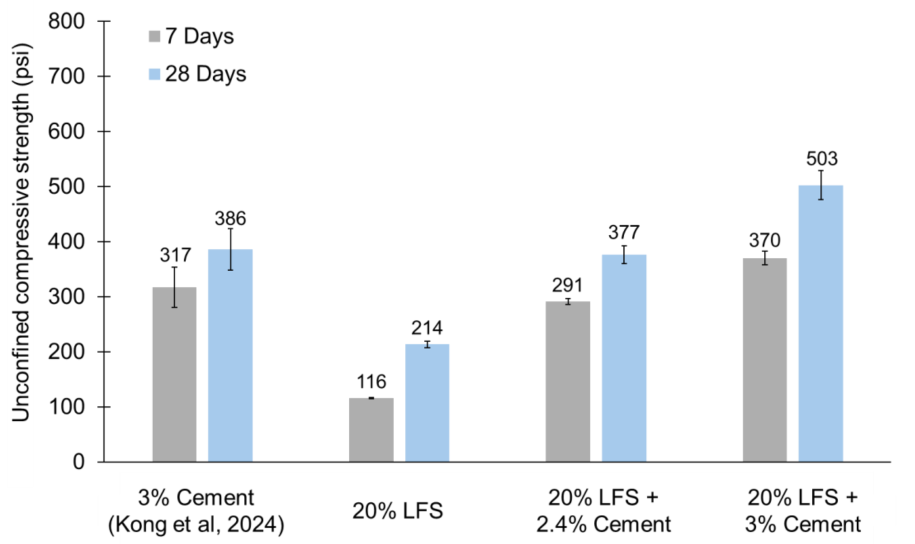


(a) LFS sample, (b) ground LFS used as stabilizer, (c) stabilized QB specimens, and (d) UCS testing

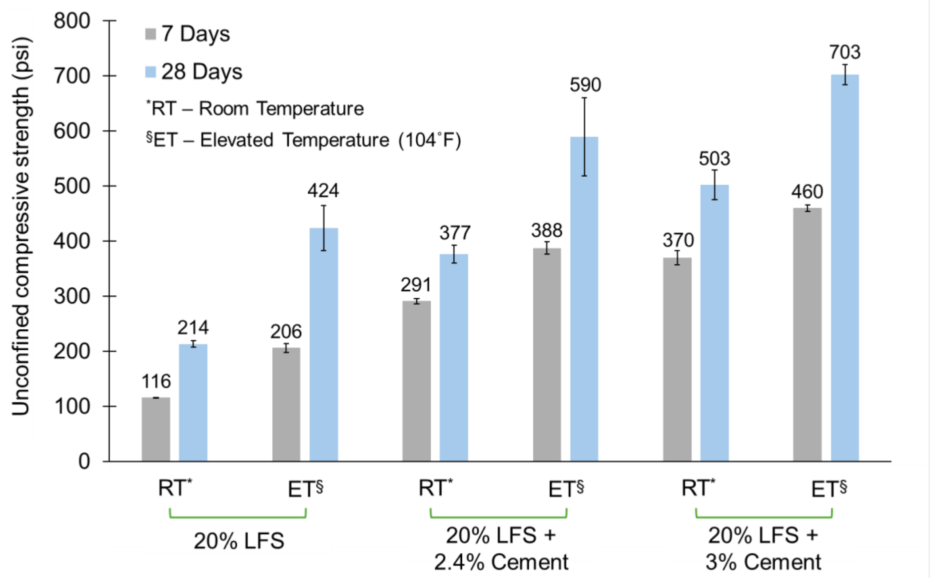
RESULTS

❑ Unconfined Compressive Strength (UCS) Test

- 20% LFS alone provided a significant improvement in UCS compared to untreated (virgin) QB's UCS of approximately 4 to 5 psi
- Incorporating 20% LFS with 2.4% cement produced a UCS comparable to that of 3% cement alone, allowing a 20% reduction in cement content
- Blending 20% LFS with the baseline 3% cement further enhanced the early strength development, with a strength increase of up to 30%
- Specimens subjected to accelerated curing showed significant strength gains, indicating potential long-term performance under extended field conditions



UCS results for various stabilizer combinations



UCS results for different curing conditions

CONCLUSIONS

- LFS shows a great potential as a supplementary cementitious material and stabilizing agent based on its chemical and mineralogical properties
- Stabilizing quarry by-product (QB) with LFS significantly improves strength and allows for cement reduction without compromising performance
- Accelerated curing reveals substantial strength gains in QB stabilized with LFS & cement, indicating strong long-term performance in field applications
- Incorporating LFS with QBs promotes a more sustainable and cost-effective approach to pavement construction by utilizing both industrial by-products

POTENTIAL STUDIES

- Studying various LFS from multiple steel plants with varying chemical and mineral compositions would help optimize its use with QBs
- Evaluating LFS fineness up to cement-like grade could enhance its chemical reactivity and effectiveness as a stabilizer, thereby promoting its use
- High MgO in LSF was seen as a drawback due to its expansive behavior, but recent studies show it forms hydrotalcite with cement, enhancing strength by filling voids. Analyzing MgO in LFS may help optimize its stabilizing potential.

Authors gratefully acknowledge Levy Co. for providing the LFS

Scan for references

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