Evaluation of Geotechnical Properties in Weak Soils Stabilized by Combined Application of Lime, Fly-Ash, Geopolymer, and Scrap Tires

Mehrdad Aminizade[1], Mehdi Mokhberi[2*], Mehdi Momeni Roghabadi [3]

[1]Department of Civil Engineering, Estahban Branch, Islamic Azad University, Estahban, Iran
[2]Department of Civil Engineering, Estahban Branch, Islamic Azad University, Estahban, Iran
[3]Department of Civil Engineering, Kerman Branch, Islamic Azad University, Kerman, Iran

* mehdi.mokhberi@iau.ac.ir

ABSTRACT

A lot of civil engineering projects must be constructed on weak or problematic soils. In some cases, road subgrades or building foundations often consists of soft clays or windblown sands that necessitate soil improvement for usability. Lime has been served as a conventional stabilizer, with combined lime-fly ash applications further enhancing soil cohesion. These traditional materials are widely used in desert and arid environments to mitigate foundation settlement and strengthen road subgrades.

Recently, scrap tires have gained traction in soil stabilization due to their reduced environmental impact. However, the synergistic effects of rubber components (crumb rubber powder and rubber fibers) with traditional stabilizers remain unexplored, primarily because rubber incorporation weakens lime mortar strength. This study examines the influence of combined crumb rubber powder (0–30% at 4% increments) and rubber fibers (0–2%: 0%, 1%, 1.5%, 2%) on the mechanical properties of lime-treated and lime-fly ash-stabilized soils.

Results indicate that crumb rubber powder slightly reduces the compressive strength of stabilized soil, whereas rubber fibers significantly improve compressive strength, ductility, failure strain, elastic modulus, bulk modulus, resilience modulus, and shear strength across all curing periods. Furthermore, the optimal combination is achieved with 12% crumb rubber and 1% rubber fibers added to lime-fly ash mixtures.

KEYWORDS:

Rubber powder, rubber fibers, fly ash, lime, weak soils

1. Introduction

In many civil engineering activities, it is often necessary to use locally available weak and problematic soils. Clayey soils and wind-blown sands in desert and arid regions are among the problematic soils in road construction and building projects. As a result, geotechnical engineers seek practical and cost-effective techniques to address these challenges. Stabilizing such soils using various additives is a common practice, as replacing foundation materials with high-quality soils is often expensive. The most widely used additives for stabilizing clayey soils and enhancing their properties, from the past to recent years, have been lime and cement, due to their proven effectiveness in clayey soil improvement.. [1, 2].

Growing environmental concerns have recently shifted research focus toward sustainable alternatives, particularly recycled waste materials like tire derivatives. While studies have examined crumb rubber's effects on mechanical properties[3, 4], significant knowledge gaps remain regarding hybrid systems combining traditional stabilizers with recycled components.

The current literature reveals two critical limitations, firstly, insufficient investigation of mechanical performance in lime-fly ash systems incorporating both crumb rubber and rubber fibers, and secondly the practical barriers to tire waste implementation due to strength reduction concerns in lime-stabilized soils [5, 6]. These researches address these gaps through an extensive experimental program evaluating includes Multiscale mechanical behavior of lime-treated and lime-fly ash composites, Synergistic effects of crumb rubber, rubber fibers, Curing time dependencies.

2. Materials and methods

2.1. Materials

The soil used in the lime stabilization mixture was obtained from the sand and gravel mine in Kerman city, with geographical coordinates 57.380 and 30.289. Based on the ASTM classification standards, the soil is classified as low-plasticity clay (CL) and had 2.47 specific gravity and 33% liquid limit. The lime used in this study is hydrated lime with a high percentage of hydrated elements **(**C25-19, 2019**).** The fly ash was obtained from the Zarand factory in Kerman**.** The fly ash classificated as SW-SM, based as ASTM 2487-11 (2011) which had 0.1 Effective size (D_{10}) and 27% liquid limit.

The rubber particles used were purchased directly from the Baraz Tire Factory in Kerman, with diameters ranging between 0.2 to 2 mm. Additionally, the rubber fibers had a diameter of 0.2 mm, length of 2 to 25 mm, tensile strength of 180 MPa, and a melting point of 220°C. In accordance with previous research recommendations, tap water was used for molding the specimens, while distilled water was employed for property testing [7, 8].

2.2. Research methods

Unconfined compressive strength (UCS) tests were conducted on all specimens. ASTM D5102 provides guidelines for performing uniaxial tests on stabilized soils (ASTM, 1996). The bulk modulus (K) and the shear modulus (G) were used to evaluate the lime-stabilized soil's resistance to deformation using the equations (1) and (2)**[9].**

$$K(\mathrm{MPa}) = \frac{\sigma}{\frac{\Delta V}{V}} = \frac{\sigma}{\varepsilon_{xx} + \varepsilon_{yy} + \varepsilon_{zz}} = \frac{E_s}{3(1-2\nu)} \quad (1)$$

$$G\,(\mathrm{MPa}) = \frac{\sigma_{xy}}{\varepsilon_{xy} + \varepsilon_{yz}} = \frac{\sigma_{xy}}{2\varepsilon_{xy}} = \frac{\sigma_{xy}}{\gamma_{xy}} = E_s \frac{\mathrm{MPa}}{2\,(1+\vartheta)} \quad (2)$$

Weak clay soil was mixed with different proportions of fly ash, rubber fibers, and waste tire rubber, and the mechanical characteristics of each composite were evaluated. Table (1) shows the mix design for additive materials with studied soil.

Table 1: The amount of mix materials for studies program (kg/m^3)

Mix design	additive amount	Sand	Clay	Lime – Test series (1)	Lime – Test series (2)	polymer
No additive	0	1000	230	85	170	85
Rubber powder	4	960	230	85	170	85
	8	920	230	85	170	85
	12	880	230	85	170	85
	16	840	230	85	170	85
	20	800	230	85	170	85
	25	750	230	85	170	85
	30	700	230	85	170	85
Rubber fibers	0.5	995	230	85	170	85
	1	990	230	85	170	85
	1.5	985	230	85	170	85
	2	980	230	85	170	85

3. Discussion

This study has been caried out to evaluate the influence of rubber powder and rubber fiber contents on the mechanical behavior of lime-treated and lime-fly ash-treated soils under different curing periods. It can be concluded that lime-treated specimens demonstrate enhanced mechanical properties due to pozzolanic reactions and cementation phenomena during the curing period. The UCS analysis reveals an inverse relationship between rubber powder content and strength development in lime-stabilized soil across all curing durations. Figures 1 and 2 shows the behavior of stabilized weak soils after adding the rubber components. While higher rubber percentages consistently yield lower strength than the control, all mixtures exhibit curing-dependent strength enhancement. The 4% rubber addition demonstrates the least strength reduction, suggesting this proportion offers the best compromise between waste utilization and mechanical performance. The effect of different rubber powder percentages on the failure strain of lime-stabilized soil at various curing times was investigated. The results demonstrate that, across all curing periods, mixtures containing rubber powder exhibit higher failure strain compared to the pure lime-stabilized soil (control). This indicates enhanced ductility in rubber-modified samples. On the other hand, the incorporation of rubber fibers yields a significant increase in maximum compressive strength compared to both lime-stabilized soil and rubber powder-modified specimens. Optimal strength improvement was observed at 0.5-1% fiber content under identical curing conditions, with strength reduction occurring at higher fiber dosages. This behavior stems are due to the elastic nature of rubber fibers enabling effective energy absorption and dissipation of external stresses, formation of stress-transfer chains within the matrix and Improved stress distribution throughout the composite system. In addition, the fiber caused failure strain characteristics. Therefore, rubber fiber-reinforced specimens exhibited superior failure strain compared to control mixtures, indicating reduced material brittleness, enhanced ductility, improved strain accommodation capacity. On the other hands, Chemically, rubber powder exhibits inert characteristics, precluding participation in either pozzolanic reactions or lime hydration processes. The material's inherent softness and flexibility reduce composite stiffness, with progressive rubber addition diminishing lime-soil adhesion and degrading elastic properties (including various moduli).

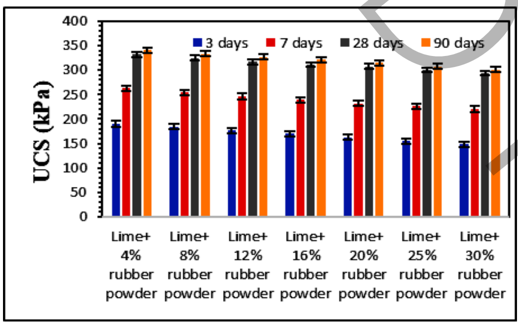

Figure 1: Effects of adding the rubber powder on the maximum compressive strength of lime concrete samples

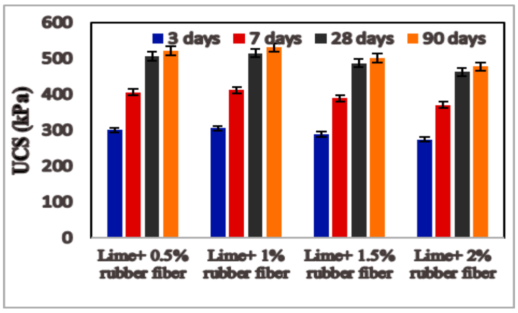

Figure 2: Effects of rubber fibers on the maximum compressive strength of lime concrete at curing times

1. Conclusion

Based on the experimental investigations conducted on lime-stabilized and lime-fly ash stabilized soil samples with various additives, the following conclusions can be drawn:

• The results indicate that the addition of 0.5% and 1% rubber fibers yielded the maximum enhancement in compressive strength, while higher fiber contents led to strength reduction.

• The inclusion of rubber fibers increased the failure strain and ductility of the soil, potentially improving its flexibility against sudden deformations.

• Rubber fibers reduced sample brittleness and stabilized soil behavior through their elastic properties and uniform stress distribution characteristics.

• Among all investigated mixtures, the lime-fly ash stabilized samples containing rubber fibers exhibited the highest failure strain across all percentages and curing periods, indicating their enhanced ductile behavior.

2. References

[1] S. Jahandari, M. Saberian, Z. Tao, S.F. Mojtahedi, J. Li, M. Ghasemi, S.S. Rezvani, W. Li, Effects of saturation degrees, freezing-thawing, and curing on geotechnical properties of lime and lime-cement concretes, J Cold Regions Science Technology

160 (2019) 242-251.
[2] M.R. Malekpoor, M.M. Toufigh, Laboratory study of soft soil improvement using lime mortar-(well graded) soil columns, J Geotechnical Testing Journal

33(3) (2010).
[3] L. Mohammadifar, H. Miraki, A. Rahmani, S. Jahandari, B. Mehdizadeh, H. Rasekh, P. Samadi, B. Samali, Properties of lime-cement concrete containing various amounts of waste tire powder under different ground moisture conditions, Polymers, 14(3) (2022) 482.
[4] B. Phani Kumar, R.S.J.J.o.G. Sharma, G. Engineering, Effect of fly ash on engineering properties of expansive soils, 130(7) (2004) 764-767.
[5] C.H. Signes, J. Garzón-Roca, P.M. Fernández, M.E.G. de la Torre, R.I. Franco, Swelling potential reduction of Spanish argillaceous marlstone Facies Tap soil through the addition of crumb rubber particles from scrap tyres, Applied Clay Science, 132 (2016) 768-773.
[6] P. Singh, V.S.N.S. Goli, D.N.J.E.T.R. Singh, Current practices and the way forward in waste rubber utilization for infrastructural and geoenvironmental engineering applications, 12(1) (2023) 2252164.
[7] A. Afshar, S. Jahandari, H. Rasekh, M. Shariati, A. Afshar, A. Shokrgozar, Corrosion resistance evaluation of rebars with various primers and coatings in concrete modified with different additives, Construction Building Materials, 262 (2020) 120034.
[8] A. Darvishi, H. Vosoughifar, S. Saeidijam, M. Torabi, A.J.I.I.S. Rahmani, An experimental and prediction study on the compaction and swell–expansion behavior of bentonite clay containing various

percentages of two different synthetic fibers, 5 (2020) 1-15.
[9] K.J.J.o.t. Fishman, Testing techniques for measurement of bulk modulus, Journal of testing evaluation 22(2) (1994) 161-167.