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Empirical approach for strength prediction of geopolymer stabilized clayey soil using support vector machines

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HIGHLIGHTS

- SVR technique for strength estimation of geopolymer stabilized clayey soil is presented.
- Experimental database of 213 soil samples stabilized with slag based geopolymer binder is used.
- A comparative study of different kernel function on SVR model performance is discussed.
- A parametric study with SVR model is conducted to evaluate the effect of input parameters on UCS.
- An empirical approach for strength prediction of slag based geopolymer stabilized clayey soil is proposed.

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ABSTRACT

Potential of support vector machine regression (SVR) technique for strength estimation of geopolymer stabilized clayey soil has been investigated in the present paper. A comprehensive experimental database of 213 soil samples stabilized with ground granulated blast furnace slag (GGBS) based geopolymer binder were used to develop the SVR model. The database contains 28 day unconfined compressive strength (UCS) results of soil samples generated with different combinations of experimental parameters. A comparative study of different kernel function on SVR model performance is discussed. The study showed that SVR is an effective tool for strength prediction of geopolymer stabilized clayey soil. Subsequently, a parametric study with SVR model was conducted to evaluate the effect of input parameters on UCS. Trends of the result obtained from parametric study were found to be in good agreement with previous research findings. Finally, using the SVR model, an empirical approach for strength prediction of GGBS based geopolymer stabilized clayey soil is proposed for practical application purpose.

1. Introduction

In recent years, geopolymer has emerged as a major alternative to Portland cement (PC) in concrete industry and presents an attractive opportunity to convert industrial waste and by products into a value added construction material. Geopolymerization is the process of activating any source material rich in alumina (Al) and silica (Si) with a strong alkali solution. Geopolymerization mechanism involve dissolution of solid aluminosilicate source in alkali solution which is believed to take place at the surface of the particles to liberate Al and Si species [1,3–5]. Al and Si precursor species in the solution then undergoes gelation followed by reorganization, polymerization and finally hardening of gel phase to form solid three dimensional polymeric chain and ring like structures consisting of Si—O—Al—O bonds, as given below [1,3,4]

$$M_n[-(Si-O_2)_z - Al - O]_n \cdot wH_2O$$

where M is the alkaline element, z is 1, 2, or 3 and n is the degree of polycondensation [2].

It is to be noted here that strength development mechanism of geopolymer is different from that of PC as geopolymeric reaction yields Si—O—Al—O bonds contrary to hydration reaction which produces C-S-H/C-A-H gel [3].

Although chemical composition and formation manner of geopolymers are same as that of zeolites but geopolymers are amorphous compared to crystalline microstructure of zeolite [4–7].

A large variety of minerals and industrial byproducts have been used as raw materials for geopolymer synthesis such as pozzolana [8,32], natural clay minerals like kaolin [7,9,10], calcined clay like

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Nomenclature

List of abbreviations used in the study

SVM	support vector machine
UCS	28 day unconfined compressive strength
RBF	radial basis kernel function
ERBF	exponential radial basis kernel function
RMSE	root mean squared error
GGBS	ground granulated blast furnace slag
ANN	artificial neural network
SVR	support vector regression
SRM	structural risk minimization
POLY	polynomial kernel function
R	correlation coefficient
MAPE	maximum absolute percentage error
FA	fly ash
PC	Portland cement

List of symbols used in the study

M	molar concentration of alkali solution
LL	liquid limit
Na/Al	atomic ratio of Na to Al
UCS_{emp}	empirical UCS in MPa
F_C	correction function
C_{PI}	correction factor for PI
C_M	correction factor for M
$C_{Na/Al}$	correction factor for Na/Al
$L_\varepsilon(y)$	loss function
ξ_k, ξ_k^*	slack variables
$\langle\cdot\rangle$	dot product operator
q_3, q_1	75th and 25th percentiles of model error
n	number of error observation
x	input parameter
y	output
α_k, α_k^*	Lagrange multiplier
d	degree of polynomial function
W	molecular weight of sodium based alkali solution (i.e. for NaOH = 40 gm, Na_2SiO_3 = 212 g)
Y	percentage of Al_2O_3 in source material
A/B	alkali to binder ratio
PI	plasticity index
Si/Al	atomic ratio of Si to Al
UCS_{chart}	UCS value in MPa to be read off from chart given in Fig. 5
w^2	Euclidian norm of weight vector
C_{LL}	correction factor for LL
$C_{A/B}$	correction factor for A/B
$C_{Si/Al}$	correction factor for Si/Al
$f(x)$	regression function
L	Lagrangian function
ε	allowable error in the loss function
q_2	error median
w	weight vector
x_r, x_s	support vectors
b	bias
σ	width of RBF
C	penalty parameter
N	valency of Na in alkali activator (N = 1 for NaOH and 2 for Na_2SiO_3)
Z	percentage of SiO_2 in source material

metakaolin [9,11,12], industrial by products like fly ash [2,7,13,14,71], ground granulated blast furnace slag [15–18], blend of fly ash and ground granulated blast furnace slag [19,20], blend of fly ash and metakaolin [9,21,22], blend of fly ash and kaolinite [23], red mud [24,25], granite wastes [26], bagasse (waste from sugar industry) [27] etc. Recently, geopolymerization of demolition materials such as recycled crushed aggregate, crushed bricks and reclaimed asphalt pavement have been investigated in pavement base/subbase applications [28–31].

Properties of geopolymer vary greatly with raw material selection and processing condition [3–5,7]. Depending upon the type and nature (i.e. reactivity and mineralogical composition) of starting raw material, geopolymer reaction mechanism differs significantly and can exhibit wide variation in terms of mechanical, microstructure, shrinkage and durability (such as acid attack resistance, fire resistance and thermal conductivity) properties of final geopolymeric product [3,4,7].

Influence of alkali activator is crucial in geopolymer reaction mechanism [3,4,6]. Dissolution extent of aluminosilicate source significantly depends upon type and concentration of alkali solution [3]. Generally Sodium/potassium based alkali activators are used. Nonetheless, sodium based alkalis are preferred over potassium based alkalis primarily due to (a) sodium hydroxide is cheaper compared to potassium hydroxide (b) sodium hydroxide possesses greater capacity of leaching silicate and aluminate monomers compared to potassium hydroxide [32]. Sodium silicate is also used often along with sodium hydroxide as the presence of silicate enhances reaction kinetics of geopolymerization [2].

Application of geopolymer technology in soil stabilization is relatively new and till date limited literatures are available on geopolymer stabilization of soil. A range of soil types including, marine clay [35,36,41], loess clay [38], marginal soil [39] etc., treated with geopolymer have been investigated. As source material, fly ash have been mostly reported in available literatures for manufacturing geopolymer treated soil [33–40]. Among the various factors studied in soil fly ash geopolymer, curing period and curing temperature were found to be most crucial parameters affecting the strength development in treated soil. Significant strength enhancement of fly ash treated soil sample was observed in either of the following cases, firstly, when the samples were cured at an elevated temperature in the range of 60–80 °C and secondly, after curing for a long period (as long as one year in some cases) when samples were cured at ambient temperature [33–35]. In another study, Zhang et al. [41] illustrated the effectiveness of metakaolin as a geopolymer binder for stabilizing clayey soil. Results obtained from the study indicated that with geopolymer concentrations, mechanical properties of stabilized specimens such as compressive strength, failure strain and Young's modulus increases and shrinkage strains during curing decreases. Recently, Yaolin et al. [42] have examined the feasibility of GGBS based geopolymer for stabilizing marine soft clay. The study [42], mainly focuses on use of different alkali activator in influencing stabilization efficacy of marine soft clay in deep soil improvement technique (i.e. grouting process). Investigation results indicated that binder activated by most alkaline activator (i.e. NaOH), yielded highest strength. Though, cement and lime based treatment have been mostly employed for improving marine clay [46,48–50,52–54] in past decades, geopolymer stabilization of marine clay has proved to be a viable alternative method with promising results [40,42]. Detail study on the effect of geopolymer mix parameters such as binder