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Application of SVM for Investigation of Factors Affecting Compressive Strength and Consistency of Geopolymer Concretes

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ABSTRACT

A solution for synthesizing environmentally friendly concrete is to reduce the conventional Portland cement (OPC) content and utilize activated pozzolanic binders. Geopolymers are a sort of mineral polymers, so that their chemical composition resembles zeolites and their microscopic structure is not crystalline, but rather amorphous. In this study, it is attempted to address the behavior of synthetic geopolymers through the investigation of their base materials, e.g. blast furnace slag, metakaolin, fly ash, and other curing agents such as potassium hydroxide or sodium hydroxide solutions. It is tried to study the behavior of geopolymer concrete (GPC) at different contents of curing agents and base materials using the literature review and, eventually, make an SVM model to find out whether the results of compressive strength and consistency of GPCs can be estimated using support vector machine or not. The research results suggest that it is possible to estimate the compressive strength and consistency of GPCs using SVM. Also, there is a significant relationship between molarity and compressive strength of concrete at different ages, molarity and consistency of concrete, ratio of sodium hydroxide to sodium silicate, compressive strength and liquid limit (LL) of concrete.

Keywords: SVM, compressive strength, geopolymer concretes, metakaolin, fly ash

1. INTRODUCTION

Geopolymers have been considered as the latest tsunami among concrete modifiers; so that curing agents along with base materials such as metakaolin, slag and fly ash can be a good substitution for cement to produce concrete. It can be argued that the quality of concrete mostly relies upon its activators and base material. According to the literature review, the research on GPC has boomed considerably since 2016, so that geopolymers can be now considered as a base material in constructions [1-2]. Many researchers performed numerical and experimental tests on geopolymers; for example, Dao et al. (2019) estimated the compressive strength of geopolymers using numerical methods, e.g., neural networks and genetic algorithms, with the aim of finding an optimum mix design [3]. Chidambaram (2018) investigated the geopolymer curing temperature during hardening and its impact on the compressive strength of GPC. In this research, the concentration of sodium hydroxide was considered variable (74%, 76%, 78%, 80% and 82%) In this research, the curing temperature was also variable and the behavior of concrete was evaluated [4]. The study showed that increasing the curing temperature to 90 °C and 12M sodium hydroxide can provide better results compared to other alternatives [3]. Suppiah (2019) studied the uniaxial behavior of geopolymer under static loading for oil well cements. Yadollahi et al (2015) estimated the compressive strength of GPCs using neural networks method. In this study, it is found that parameters such as silica modulus, Na2O content, w/b ratios and curing dramatically affect the behavior of geopolymers and their variation may change the compressive and tensile strength of GPC. In this study, the compressive strength of different GPCs is estimated using artificial neural networks (ANN) [5]. Zivica (2014) examined the high strength geopolymers based on geopolymer materials. The results can be applied for metahalloysite-based geopolymer properties. In this study, a compressive strength of 300 MPa is obtained for a low water to metahalloysite ratio (0.08). This substance used along with sodium hydroxide and sodium silicate may affect the strength properties of geopolymer [6]. Vora et al. (2013) conducted a parametric study on compressive strength of geopolymers. A variety of parameters are examined in this study, e.g., alkali to fly ash ratio, sodium hydroxide concentration, sodium silicate to sodium hydroxide ratio, annealing time, annealing temperature, resting time and excess water content in the mixture. The test results suggest that the compressive strength rises as annealing time, annealing temperature, resting time and sodium hydroxide solution concentration increase and the ratio of water to geopolymer solids decreases [7]. Since the low calcium fly ash-based GPC is a suitable choice for cement-based concrete, nanomaterials can also affect it. A trial program was performed on M25 grade low calcium fly ash-based GPC having 16M activator liquid. There were various contents of nanomaterials. Nano-silica, nano-carbon tube and titanium dioxide were also employed to study the effect of nanomaterials on GPC. The geopolymer concrete having 1% titanium dioxide exhibits a considerable improvement in compressive strength, although the pH is almost the same for whole cases [8]. Li (2019) addressed the chemical behavior of metakaolin in GPCs; metakaolin is used for GPCs in three steps, i.e., initial chemical shrinkage, subsequent chemical expansion and ultimate chemical shrinkage. In this study, experimental techniques (XRD, FTIR and NMR) and theoretical calculations were used to detect the mechanisms of chemical deformation of metakaolin and, eventually, a chemical model was proposed for the behavior of geopolymers after production [9]. Many researchers commonly estimated the results for experimental data of concrete; for example, Naseri et al. (2017) estimated the results of compressive strength of concrete using SVM. In this study, they used nano-CuO at different contents in self-compacting concrete and examined the impact of this additive on concrete by SVM [10]. Khotbehsara et al. (2018) estimated the compressive strength of concrete having SnO2, ZrO2 and CaCO3 nanoparticles. In this study, they utilized both SVM and ANFIS to estimate the results and assessed the effect of these three nanoparticles on concrete. The research results indicated that it is possible to estimate the compressive strength of concrete using SVM and ANFIS [11]. Badarloo et al. (2018) estimated the relationship between compressive and tensile strengths of concrete using MATLAB software and probabilistic methods, where the error of data estimated by experimental data equaled almost zero [12]. The variety of experimental studies leads to no numerical classification; hence in this study, some results of experimental researches are summarized and the relationship between known variables, e.g., content of activators, molarity, compressive strength and LL of concrete is addressed; so that readers can reach comprehensive information by studying the article. On the other hand, the SVM used for estimation of results can effectively help estimate significant relationships between experimental results.

2. MATERIALS AND METHODS

Geopolymers belong to a category of inorganic minerals which contain alkali-activated aluminosilicates and consist of fluid units [13-14]. They were first introduced in 1972 by French researcher Professor Davidovits. Similar to the mix design of conventional concrete, the mix design of GPCs is selected based on their future performance. The fly ash-based geopolymer concrete is prepared using the alkali to base material mass ratio of 0.3 to 0.45, mixing time of 4 min and steam curing at 60 °C or curing in water bath for 24 h after formwork [15-16]. Many studies demonstrated that different contents of sodium hydroxide lead to the diversity of compressive strengths in concrete specimens. The variation of sodium hydroxide to sodium silicate ratio cause changes in the compressive strength and LL of concrete specimens [17-18]. In previous studies, these factors were discussed frequently and the compressive strength of concrete specimens was calculated for various contents of sodium hydroxide and sodium silicate. In this study, the relationship between the compressive strength and LL of concrete specimens and the discussed factors are assessed in order to find out whether there is a relationship between these factors and compressive strength and LL of concrete or not and also how prediction methods can be influential in the estimation of results.

2.1. ESTIMATION METHOD OF SVM

In this section, the SVM is applied to estimate the strength of geopolymer concrete. Accordingly, the results of studies on GPC are collected and the results are then estimated using SVM. Support vector machine (SVM) is a supervised learning approach used for classification and regression [19-20]. This method is a relatively new technique that has recently shown a good efficiency for classification in comparison with previous methods. The SVM classifier is based on linear classification of data. In the linear classification of data, it is attempted to choose a line which has higher margin of safety. The equation is solved by finding the optimum line for the data using quadratic programming (QP) methods which are popular approaches to solve constrained problems. When the data of DPCs are collected and classified based on the curing agent (sodium hydroxide to sodium silicate ratio) and base material, the results are estimated using SVM in this study to find out whether the effect of sodium silicate and sodium hydroxide on GPC can be examined, or the approach is inefficient for the estimation of results.

3. RESULTS AND DISCUSSION

3.1. SUMMARY OF RESULTS

Herein the results of compressive and tensile strength of geopolymers are summarized in Table 1. It is aimed to investigate the tensile and compressive behavior of GPC and estimate the tensile and compressive strengths of concrete specimens from the content of base materials and the total mass of curing agents. In Table 1 a,b,c., it is tried to represent the results of geopolymer specimens and then estimate the results using SVM.

Table 1. Results of compressive strength and LL of concrete for literature review **(a)**

Gum Sung Ryu, 2013 [21]													
			Molarity for SH						Compressive strength				
			6 M	9M	12 M			Flow (mm)	Ages				
Samples	FA	water	SH	SH	SH	SS			1 days	3 days	14 days	28 days	91 days
FASH6SS50	1600	160	400			400	1	185	0	9.9	18.4	25.9	28.2
FASH9SS50	1600	160		400		400	1	183	17.2	18.2	27.8	43.1	47.3
FASH12SS50	1600	160			400	400	1	180	28.4	29.5	42.9	44.8	47.5
FASH0SS100	1600	160	–	0		800		175	5.3	8.6	11.9	13.1	15.5
FASH25SS75	1600	160		200		600	3	180	14.2	14.6	24.9	32.3	35.2
FASH50SS50	1600	160		400		400	1	183	17.2	18.2	27.8	43.1	47.3
FASH75SS25	1600	160		600		200	0.33	180	7.9	8.6	17.6	22.8	24.1
FASH100SS0	1600	160		800		0	0	193	0	2.9	10.1	13.8	15.2

(b)

Malkawi [22]									
Sample	FA [g]	Sand [g]	SS	NaOH [g]	SS/SH	NaOH Molarity [Molar]	compressive strength		
N1	300	600	82.5	82.5	1	8	49.7	53.3	61.2
N2	300	600	99	66	0.666666667	8	57.7	65.3	74.1
N3	300	600	110	55	0.5	8	69.5	78	74.4
N4	300	600	117.9	47.1	0.399491094	8	71.2	76.1	78.2
N5	300	600	82.5	82.5	1	10	59.7	64.3	71.1
N6	300	600	99	66	0.666666667	10	65.3	71	79.9
N7	300	600	110	55	0.5	10	69.1	75.1	75.9
N8	300	600	117.9	47.1	0.399491094	10	75.1	79.3	84.3
N9	300	600	82.5	82.5	1	12	65.2	68.1	70.2
N10	300	600	99	66	0.666666667	12	69.3	75.1	77.2
N11	300	600	110	55	0.5	12	71.6	73.6	77.9
N12	300	600	117.9	47.1	0.399491094	12	77.2	79	79.1

(c)

	S Usha [23]								
Mix ID	Molarity	SS/SH ratio	Sand	Na2SiO3 solution	NaOH pellet	SS/SH	Water		
Unit	M	-	gm	gm	gm		gm	compressive strength	
G1	5	2.5	600	114.3	7.62	15.00	38.1	7	12
G2	10	2.5	600	114.3	13.06	8.75	32.65	20	24
G3	11	2.5	600	114.3	13.97	8.18	31.75	25	27
G4	12	2.5	600	114.3	14.83	7.71	30.89	23	25
G5	15	2.5	600	114.3	17.14	6.67	28.57	20	23
G6	20	2.5	600	114.3	20.32	5.63	25.4	15	14

3.2. ESTIMATION OF COMPRESSIVE STRENGTH USING SVM

In this section, the relationship between the inputs and outputs is investigated. A consequence of this research is to find out how the SVM can establish a mathematical relationship between the known factors affecting the synthesis and compressive and tensile strength of geopolymers and whether the results can be estimated or not. Therefore, the sodium hydroxide to sodium silicate ratio and fly ash content are represented on the vertical axis and the tensile and compressive strengths are represented on the horizontal axis and the results are estimated using SVM, as illustrated in Figures 1 to 4. Figure 1 demonstrates the results of 7- and 28-day compressive strength of concrete. In the figures below, a relationship between compressive strength and molarity of concrete is estimated. The estimation error of results is obtained for both testing and training data, which is below 0.5 and relatively acceptable. On the one hand, the correlation coefficient of results is above 0.8, which indicates that the results are correlated. On the other hand, the sodium hydroxide content rises as the compressive strength of concrete increases. Given the slope of estimated line, the distribution of data between compressive strengths is considerable; so it can be debated that the SVM is able to predict the strength of concrete within a wide range of strengths. The correlation coefficients and computational errors are almost the same for the data of 7- and 28-day compressive strength. Given the results of Table1 and Figures 1 and 2, it is possible to utilize the approach for the estimation of the compressive strength of concrete.

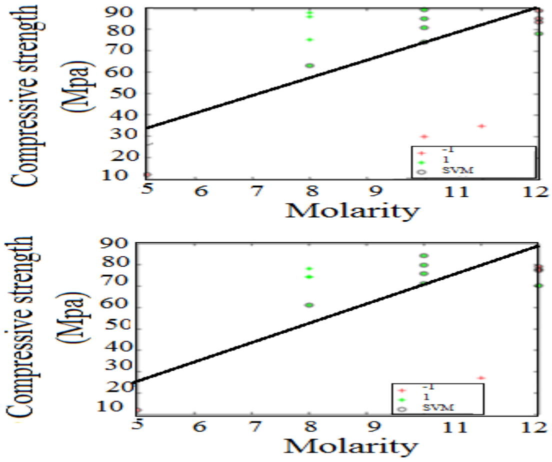

Figure 1. Estimation of results using SVM for compressive strength versus molarity

Figure 2 represents the values predicted by SVM. The SVM estimates the results as 1 and -1, i.e., the data is classified as two training and testing data categories and the results are estimated through the approach. According to Figure 2, the SVM can estimate most of assigned data at a correlation coefficient of 0.84, which implies that this approach is appropriate to estimate the relationship between compressive strength and molarity of GPCs.

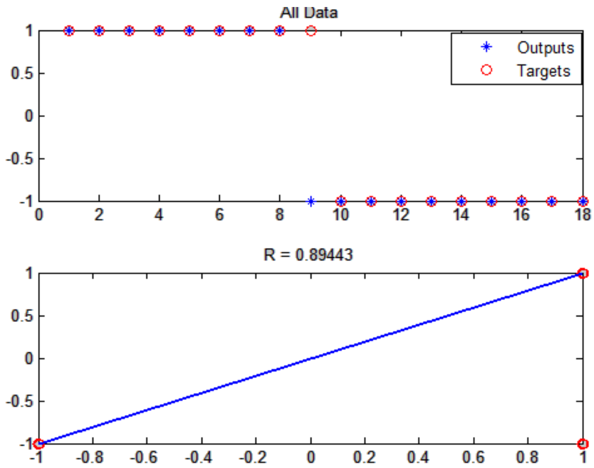

Figure 2. Estimation of correlation coefficient relationship between actual and predicted results

3.3. ESTIMATION OF LIQUID LIMIT (LL) USING SVM

Figure 3 illustrates the relationship between LL and compressive strength data of concrete. According to the Figure 1, the SVM plays an effective role in estimating the LL results of concrete and there is a significant relationship between the molarity and the consistency of concrete. In this study, the error of SVM approximately equals zero and this approach is able to estimate the data suitably in both testing and training data categories.

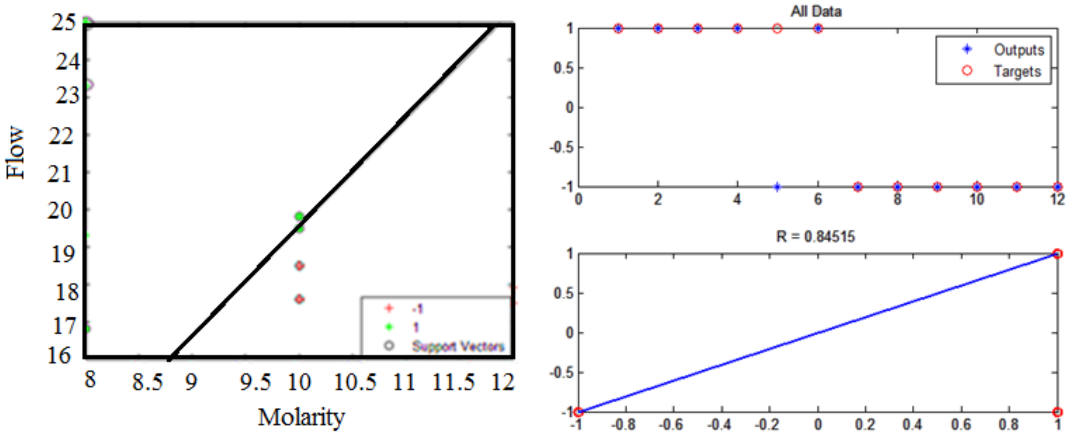

Figure 3. Estimation of correlation coefficient relationship between actual and predicted results for consistency of concrete

3.4. INVESTIGATION INTO EFFECT OF SODIUM SILICATE TO SODIUM HYDROXIDE RATIO ON COMPRESSIVE STRENGTH OF CONCRETE USING SVM

The literature review demonstrates that numerous researchers sought to assess the content of sodium hydroxide, its ratio to sodium silicate and its effect on compressive strength of GPCs; hence the effect of sodium silicate to sodium hydroxide ratio on compressive strength of concrete is addressed in this section. Firstly, the compressive strength of concrete is estimated using SVM and the correlation coefficient is calculated, which equals 0.7. The compressive strength ranges between 10 and 45 for this variable and the error of numerical model equals almost zero. In this section, the SVM has poorer performance in the estimation of results in comparison with previous sections Figure. 4 illustrates the results of estimated values in comparison with actual values.

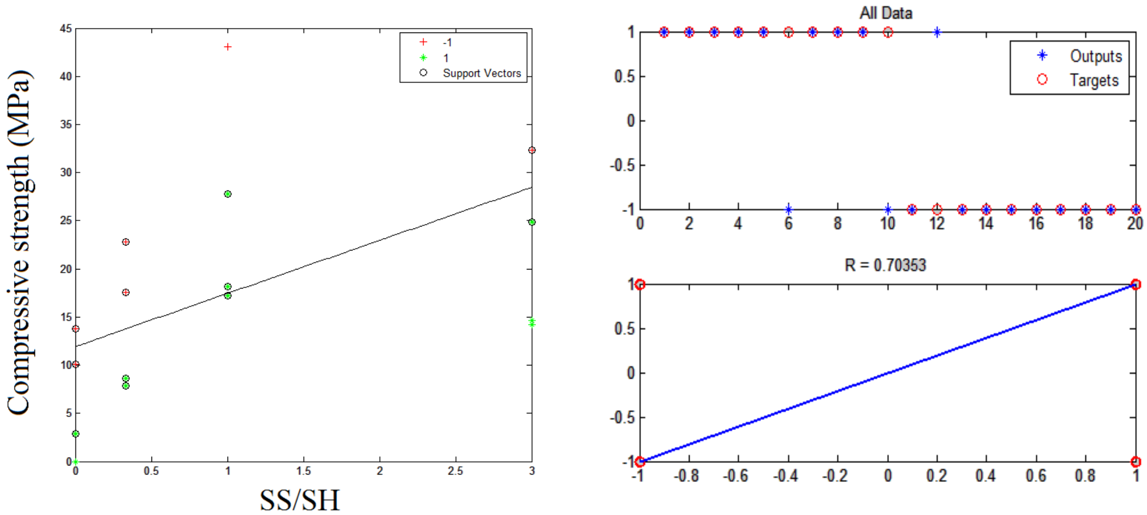

Figure 4. Effect of sodium silicate to sodium hydroxide ratio on compressive strength of concrete

Table 2 represents the approximate errors between the experimental and estimated data for entire models, which are less than 1 and close to 0 for whole models.

Table 2. Guide to selection of mix design of geopolymer concrete (GPC)

7 and 28 days (molarity)			
	Train Data	Test Data	All Data
MSE	0.26	0	0.22
RMSE	0.51	0	0.47
MAE	0.19	0	0.11
MPE	0.933	1	0.94
Flow			
MSE	0.4	0	0.33
RMSE	0.63	0	0.53
MAE	0.2	0	0.16
MPE	0.9	1	0.91
SS/SH			
MSE	0.75	0	0.6
RMSE	0.86603	0	0.7746
MAE	0.375	0	0.3
MPE	0.8125	1	0.85

4. CONCLUSION

In this study, the compressive strength of concrete is estimated using SVM and the research results suggest that as molarity of sodium hydroxide solution rises, the compressive strength of concrete increases, and its liquid limit (LL) decreases. On the other hand, it is possible to estimate the compressive strength of concrete and its relationship with molarity and sodium hydroxide to sodium silicate ratio using SVM. This approach can also estimate the strength of specimens with high distribution. In this study, the correlation coefficient and computational error are reasonable for the whole models. According to the research results, this approach can be applied to estimate the compressive strength and other parameters of GPCs in experimental studies. The distribution of compressive strengths estimated for the specimens range from 20 to 90 and the distribution of LL for GPC specimens is reported between 15 and 20 in previous studies; the results of this study are summarized as below:

- The correlation coefficient of estimated and experimental values is calculated 0.84 on average, which seems reasonable.
- The MSE, RMSE and MPE errors are almost zero for all computational and numerical specimens.
- The SVM is able to estimate most data of concrete and there is a slight difference between the values and actual data.

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AUTHORS CONTRIBUTION

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CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

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