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Prediction of Properties of SCC Incorporating Waste Materials Using Machine Learning Techniques: A Review

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Abstract—*This paper focuses on review of self-compacting concrete along waste supplementary cementitious materials such as Fly ash, Silica fumes and Metakaolin as a replacement of cement along with role of machine learning based regression models to predict Fresh, hardened and durability properties. A large dataset from the literatures is collected and is used to predict different properties of SCC using different regression algorithms. The regression techniques used are ANN, Random Forest, Random Tree, and Gaussian regression. The regression models consist input parameters as cement content, fine aggregates, coarse aggregates, fly ash, silica fumes, metakaolin, water-cement ratio, superplasticizers and one output parameter which includes slump flow, compressive strength, strength loss and weight loss due to acid and sulphate ingress as individual outputs. The modelling of data showed that the gaussian regression technique performed better on the data set collected from different literatures.*

Keywords: *Artificial Neural Network (ANN), Random Forest, Random Tree, Gaussian regression, Durability.*

INTRODUCTION

Research into developing new predictive models that can predict concrete quality has expanded due to the construction industry's ongoing desire for new forms of concrete, which is manufactured swiftly. Since it could help designers adhere to various design norms and standards, forecasting the mechanical properties and workability of SCC has been a key area of research. Fundamental approaches for forecasting durability, rheological, mechanical, and other features of SCC were backed by scientific links discovered by quantitative analysis of experimental data using nonlinear and linear regression models. Regression analysis is utilised in these models to create analytical equations and identify the unknown coefficients that affect the relationship between concrete strength and other variables. These equations are frequently shown in the following format:

$$y = f(b_i, x_i)$$

Where x_i and b_i stand for specific characteristics and regression coefficients, respectively, and y is the value of mechanical strength or workability, f is a nonlinear or linear function, and so forth. In the open literature, several regression models have been presented for evaluating the mechanical properties and workability of SCC, including tensile strength, compressive strength, shear strength, and slump flow.

Machine learning (ML) techniques have recently been demonstrated as a promising contender for evaluating self-compacting concrete mechanical strength and workability, making up for the shortcomings of traditional nonlinear and linear regression models. Such prediction algorithms can save time and money by eliminating the need for time-consuming and expensive trial batches and supporting experimental efforts to achieve the necessary concrete strength. The two basic types of machine learning techniques are supervised and unsupervised learning. The former is more usually used to assess the workability and mechanical characteristics of self-compacting concrete. In supervised learning, machine learning models are computer programmes that build patterns and hypotheses from a given data set to forecast future values.

Although several models have been presented to achieve the same purpose, i.e., the prediction of self-compacting concrete compressive strength and workability, their structure and method might vary considerably. ANN and RF are the two types of machine learning algorithms can be used to estimate self-compacting concrete strength and workability are reviewed in this study. In general, the dataset and the number of input factors might influence which model is best. In addition, each model's performance is assessed using several statistical metrics that compare actual and predicted results.

PREDICTION OF PROPERTIES OF SELF-COMPACTING CONCRETE

The mechanical, fresh, and durability properties of SCC have frequently been predicted using machine learning algorithms. For training, validation, and testing, such models are frequently used on a significant set of data that has been divided into subgroups. Using the training set, the model is trained. By stopping the learning process when erroneous levels spiked validation data prevented model overfitting and made it possible to evaluate the model's fit to the training set objectively. The model is then put to the test on actual data to evaluate how accurate it is at forecasting outcomes.

Literature survey on fresh properties

Rashwan et al. (2022) investigates the physical qualities of natural stone wastes as a substitute for cement, as well as their chemical and mineralogical composition, and how those elements affect the properties of freshly-poured and hardened SCC. According to the results, SCCs' workability performance improved a little to noticeably as the percentage of stone wastes rose. Compared to the reference mix, utilising up to 40% stone wastes resulted in an improvement in flow- and passage abilities of at least 1.45% and 4.88% and a reduction in filling times of at least (7.14% and 30%), with only a little evidence of bleeding and no signs of segregation or clogging. Even the use of 10% waste rock results in insignificant decreases of density, compressive, flexural and splitting strength values at older ages (1.64%, 0.42%, 3.65%, 3.88% and 10.51%), respectively. [1]

Table 1: Experimental Data [1]

Compositions	Range (kg/m^3)
Cement	300-500
Coarse aggregates	750
Fine aggregates	920-971
Silica fumes	25
w/b ratio	0.357
superplasticisers	5.3-7.5
Slump flow	690-710 mm

Martins et al. (2022) studies the mixes with up to 40% WFES gives higher compressive strength than control mix in terms of acid resistance. By adding 30% WFES as a sand substitute, particle compaction reduces capillarity and the permeability of concrete to harmful substances. Their analysis shows, up to 40% of WFES can be utilised as a partial replacement of natural sand in SCC without compromising compressive strength and durability. [2]

Table 2. Experimental Data [2]

Compositions	Range (kg/m^3)
Cement	455.2
Coarse aggregates	739.92
Fine aggregates	517.94-863.24
Silica fumes	27.11
w/b ratio	0.37
superplasticisers	3.76
Slump flow	780-800 mm

Silva and Delvasto (2021**)** presented the experimental and the results of an experiment on the efficiency of self-compacting concretes (SCC) using masonry residue (RM) obtained from construction and demolition waste (CDW). Portland cement was substituted in various ratios with RM, including 0, 25, and 50% (vol.). The proportioning method utilised, known as RM, has no effect on the dynamics of self-compacting concretes in their fresh state. The three self-compacting concrete combinations Control, SCC 25% RM, and SCC 50% RM met the fluidity, flowability, and segregation resistance criteria. Self-compacting concrete is now more resistant to sulphates (Na2SO4 and MgSO4) since Portland cement has been substituted with RM. This reduces the expansion by more than 50% while increasing the compressive strength. [3]

Chinthakunta et al. (2020) presents experimental study in which the first series includes control concrete and three-component cement concretes containing FA and nano TiO2, as well as control concrete. With 3% TiO2, the highest compressive strength is achieved in all mixtures. Compared with 3% Nano TiO2 concrete and normal concrete, the compressive strength of F20T3, S10T3 and F20S10T3 increased by 18.9%, 19.2% and 10.4% respectively.[4]

Vijaya, Ghorpade and Sudarsana Rao (2018) concluded that, it is possible to conclude that producing plastic fibre reinforced self-compacting concrete waste with an aspect ratio of 50 from a fibre content of more than 1.4% is difficult. Based on the hardening property test findings, the highest compressive strength, split tensile strength, and flexural strength can be obtained with 1.0% residual plastic fibres for an aspect ratio of 50. As a result, 1.0% residual plastic fibres can be deemed the ideal amount in terms of strength for self-compacting concrete supplemented with plastic trash. It was discovered that as the proportion of fibres increases, so does the compressive strength.[5]

Table 3: Experimental Data [5]

Compositions	Range (kg/m^3)
Cement	280
Coarse aggregates	734
Fine aggregates	920-971
GGBFS	197.5-220
w/b ratio	0.34-0.35
superplasticisers	1.68-2.4
Slump flow	750-800 mm

Asteris et al. (2016) investigated the mechanical properties of SCC using ANNs to forecast the properties. ANN models were employed to estimate the 28-day compressive strength of SCC based on the experimental data that was available and the literature that was acquired from the publications. By contrasting the results with those from trials and testing the use of back propagation neural networks, the compressive strength of SCC was predicted to be trustworthy, hopeful, and precise.[6]

LITERATURE SURVEY ON DURABILITY PROPERTIES

Shiva Srikanth and Lalitha (2022) works with crushed glass to improve the durability properties of self-adhesive concrete. The results of sulfuric acid impact tests show that an alloy with more glass is more resistant to acid attack. After immersion in sulfuric acid, concrete loses 40% less weight and strength than normal concrete. Loss of weight and strength is 3.8 and 4.85% by weight before immersion with 40% waste glass content. The results of hydrochloric acid impact tests show that the increased glass content of the mixture increases the resistance to acid attack. When exposed to hydrochloric acid, concrete with a waste content of 40% glass mud loses less weight and strength than a normal content. Before immersion, the strength and weight loss at 40% are 2.56% and 6.08%. The use of glass reduces the permeability of hardened concrete.[7]

Table 4: Experimental Data [7]

Compositions		Range (kg/m^3)
Cement		390
Fly ash		90
Coarse aggregates		759.86
Fine aggregates		482.81-804.68
Alccofine		120
w/b ratio		0.3
superplasticisers		4.8
Acid attack	% weight change	2.56-5.77
	% strength change	6.08-9.04
Sulphate attack	% weight change	3.8-6.31
	% strength change	4.85-11.29

Sharma and Khan (2021) investigated the effect of copper slag replacement as fine aggregates on self-compacting concrete's sulphate resistance was investigated. Substitution of copper slag as fine aggregate increases early strength by up to 60%, and substitution of silica fumes and metakaolin with fly ash significantly improves compressive strength. For the purpose of understanding the changes in compressive strength, microstructural investigation was carried out. When exposed to sulphate solution, the change in mass is increased in mixes where copper slag is used to replace fine aggregate, whereas it is decreased in mixes where silica fumes and metakaolin are used to replace fly ash. Against sulphate assault, the metakaolin SCC mixes outperform the silica fumes SCC mixes. [8]

Table 5: Experimental Data [8]

Compositions		Range (kg/m^3)
Cement		330
Fly ash		165-220
Coarse aggregates		700
Fine aggregates		0-1020
Silica fumes		0-55
metakaolin		0-55
Copper slag		0-1422
w/b ratio		0.45
superplasticisers		2.2-6.6
Sulphate attack	% weight change	0.0297-0.3087
	% strength change	-2.801-12.9054

Sharma and khan (2017) investigate the durability of self-compacting concrete with fine particles of copper slag Six SCC mixes with w/b ratios of 0.45 and copper slag replacement rates of 0%, 20%, 40%, 60%, 80%, and 100% were cast. A 20% copper slag was found to have the highest compressive strength. We found that 20% CS gave the highest compressive strength over the rest of the set time, whereas substitution of 60% CS caused a decrease in strength. The increase in the free water content after the significant replacement of sand by CS was the reason for the decrease in strength. [9]

Kristiawan, Sunarmasto and Tyas (2016) presented an experimental study and found that increasing the use of fly ash to replace part of the cement can lessen SCC degradation owing to sulfuric acid attack as assessed by compressive strength and diameter change. The level of reduced degradation becomes increasingly obvious at later ages. Lower cement concentration, pozzolanic reaction, and refinement of interparticle gaps could explain how fly ash content impacts SCC sulfuric acid resistance. The amount of hydrated cement attacked by sulfuric acid decreases with decreasing cement concentration. The strength of the concrete increases as an outcome of the pozzolanic reaction, ultimately reducing the likelihood that sulfuric acid attack will cause the concrete to crumble. The spaces between the particles can be finished because they cannot withstand the internal reaction caused by the expansion of the plaster. [10]

Table 6: Experimental Data [10]

Compositions	Range (kg/m^3)
Cement	221-369
Fly ash	369-516
Coarse aggregates	703
Fine aggregates	569
w/b ratio	0.285-0.286
superplasticisers	7.37
Acid attack, % strength change	-1.406-25.32

Singh and Siddique (2016) conclude that the multifaceted and rough surface of the iron slag aggregate may be responsible for the poor workability of the SCC mixture caused by the increased iron slag content. Both age and the amount of iron slag present enhances the compressive strength of SCC mixtures. There is a 21% increase in strength after 28 days compared to control SCC. At all hardening ages, the water uptake of the SCC combinations containing iron slag was lower than that of the control SCC blends. In terms of external sulphate attack, the SCC mixture lacking iron slag outperformed the SCC blend with iron slag. The accumulated charge transferred through the slag mixture was lower compared to the SCC combination without slag. [11]

Table 7: Experimental Data [11]

Compositions	**Range (kg/m^3)**
Cement	455
Fly ash	45
Coarse aggregates	760
Fine aggregates	576-960
Iron slag fine aggregates	0-384
w/b ratio	0.44
superplasticisers	6
sulphate attack, % strength change	1.779-3.244

Kavitha et al. (2016) focuses on the utilisation of pozzolanic materials to reduce energy use and CO2 emissions into the atmosphere while enhancing structural characteristics utilising vibration-free concrete. We investigated the durability of SCC in terms of water absorption, sulphate attack, and chloride permeability to investigate the indirect environmental benefits. MK alters the pore structure of concrete, increasing its resistance to water penetration and chloride ion transport, resulting in matrix degradation. SCC having 10% MK has excellent resistance to sulphate attack, chloride penetration, and water permeability. [12]

Table 8: Experimental Data [12]

Compositions		Range (kg/m^3)
Cement		425-500
Coarse aggregates		650
Fine aggregates		900
Metakaolin		0-75
w/b ratio		0.38
superplasticisers		3-5
Sulphate attack	% weight change	0.1774-1.693
	% strength change	20.192-32.038

LITERATURE SURVEY ON MECHANICAL PROPERTIES

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Table 9: Experimental Data [8]

Compositions	**Range (kg/m^3)**
Cement	330
Fly ash	165-220
Coarse aggregates	700
Fine aggregates	0-1020
Silica fumes	0-55
metakaolin	0-55
Copper slag	0-1422
w/b ratio	0.45
superplasticisers	2.2-6.6
Compressive strength	27.44-39.83 N/mm^2

Wongkeo et al. (2014) investigated SCC properties while using SF and high calcium fly ash as both binary and ternary mixed cement at high volume replacement. SF appears to have an adverse impact on SCC through lowering voids and water absorption. At all test ages, SCC compressive strength dropped with increasing FA content and was lesser than SCC control. At the same replacement level, the compressive strength of SCC with ternary incorporated Portland cement was larger than SCC with binary blending Portland fly ash cement after 7 days and increased with increasing SF percentage. To generate high strength self-compacting concrete, SF was blended with high calcareous fly ash at a high replaceable cement level. [13]

Gill and Siddique (2018) examine the self-compacting concrete (SCC) composed of the mineral metakaolin and the rice husk Ash in terms of its strength and microstructural properties. The use of MK and RHA improved the compressive strength at 28, 90, and 365 days by 27%, 42%, and 48%, respectively, over the control combination. When 10% MK and 10% RHA were combined, the loss of compressive strength after 365 days was only 4.8% compared to 17.9% for the control mixture. [14]

Table 10: Experimental Data [13]

Compositions	Range (kg/m^3)
Cement	135-600
Fly ash	0-420
Coarse aggregates	595-640
Fine aggregates	908-1166
Silica fumes	0-60
w/b ratio	0.3-0.4
superplasticisers	0.12-1.8
Compressive strength	31.7-100.5 N/mm^2

Kapoor, Singh, and Singh (2016) deals with the durability of RCA, which is utilised as a partial or full substitute for natural coarse aggregate (NCA) in self-compacting concrete (SCC). When SF or MK were added to SCC made with RCA at a dose of 10% by weight of PC, the strength loss was reduced by 8% and 3%, respectively. Chloride ion penetration was much lower in SCCs prepared with RCA replacing all natural aggregates when MK or SF was added with 10% by weight of PC than in a reference concrete made with lacking the foregoing additives and containing only NCA. [15]

Table 11: Experimental Data [15]

Compositions	Range (kg/m^3)
Cement	430
Fly ash	0-185
Coarse aggregates	560-602
Fine aggregates	846
Silica fumes	0-57
metakaolin	0-67
w/b ratio	0.45-0.56
superplasticisers	3.44-5.16
Compressive strength	33.35-42.69 N/mm^2

Kannan (2018) The researchers investigated how the ternary system influences the corrosion response of self-compacting concrete containing metakaolin (MK) and self-combusted rice husk ash (SCRHA). Rice husks can be efficiently handled, with self-combustion yielding up to 82.05% reactive silica. Using OPC in SCC, the compressive strength and splitting tensile strength of SCRHA and MK mixed concrete improved to 15% SCRHA, 15% MK, 20% SCRHA, and 20% MK. The compressive strength and splitting tensile strength of 15% MK SCC were greater (44.78 N/mm^2 and 3.2 N/mm^2, respectively). [16]

CONCLUSIONS

Several recent researches have been performed to estimate Mechanical Strength and Workability of SCC, examining advantages and disadvantages of various methodologies. Thus, following conclusions can be observed:

1. Because typical statistical and experimental models take a long time to develop and are erroneous, it has been difficult to predict the strength of complex SCC blends. Researchers have therefore created ML models to solve these problems.
2. In this study, ML models two technique explain as: ANN and RF. The use of such models to determine mechanical strength and workability of self-compacting concrete has been studied. The benefits and limitations of the methodologies adopted have also been properly compared and discussed.
3. The performance of the models is affected by several of parameters, including the nature of the connection between the components in self-compacting concrete mixtures and their strength and workability, size of the training dataset, and variety of features shown in the model.
4. Engineers may choose suitable models for calculating the mechanical strength and workability of SCC with the help of this study's review of the effectiveness of machine learning methodologies, as well as their benefits and drawbacks. More research is required to determine the accuracy of ML models in forecasting the properties of novel, revolutionary types of concrete like SCC since they can accurately anticipate the mechanical strength and workability of SCC.
5. Since the beginning of the ML study, different properties of an SCC, such as predicting mechanical strength and workability of the Self compacting concrete, have been studied. It was observed that as accuracy of the research increased, the error in all the studies decreased. The findings will be more accurate if more data sets were applied to train the AI model. There have been a variety of materials used to replace the cement, admixture, course and fine used in the SCC.

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