Studies on Forecasting Compressive Strength of Zeolite-blended Concrete via Regression Analysis

[1] Dr. Sushant Vilas Waghmare*, [2] Gopi Deepak Ghadvir
[1] Assistant Professor, PCCOER Ravet, Pune, [2] Assistant Professor, Genba Sopanrao Moze College of Engineering Balewadi,

ORCID ID: 0000-0003-4175-686X

***Abstract*— Concrete has replaced brick and stone as the preferred building material for most construction projects due to its combination of durability and affordability. The durability of the concrete largely hinges on the properties of the cement used during its production. Enhancing both the environmental and financial benefits of concrete can be achieved by incorporating Pozzolanic mineral additives like fly ash and GGBFS. It is a widely recognized fact that the utilization of pozzolan can diminish the presence of calcium hydroxide in cement paste and increase the permeability of the concrete.**

Crystalline zeolites, composed of alumina silicates with uniformly sized pores and spaces, play a pivotal role in this context. The pozzolanic attributes of zeolite are attributed to the volatile SiO2 and Al2O3 it contains. During the cement hydration process, calcium hydroxide is generated and reacts with CaOH2, leading to the formation of calcium silicate hydrate gel. This, in turn, fortifies the microstructure of the concrete, rendering it impermeable.

In an effort to raise awareness about potentially hazardous substances, particularly those found in car fire extinguishers, zeolite-blended concrete have been utilized.

The objective of this study is to determine if the addition of Natural Zeolite has any impact on the strength properties of concrete. Innovative predictive formulas for strength have been developed using multiple regression analysis using Python, SPSS and MS-Excel. Laboratory experiments involving concrete blended with zeolite confirm the accuracy of the predicted outcomes.

Index Terms— ***Regression Analysis, Python, SPSS, Zeolite, Concrete etc.***

I. INTRODUCTION

Concrete stands out as the preeminent choice for construction materials, owing to a multitude of virtues. Its prominence can be attributed to its formidable strength, cost-effectiveness, ready availability, and exceptional durability, to name but a few of its attributes. The fundamental cornerstone in the realm of concrete's characteristics is the pivotal role played by cement.

Delving into the core of concrete's composition, cement emerges as the linchpin that determines its essential qualities. As such, when contemplating the properties of concrete, cement takes center stage as a critical component.

In the quest to enhance the longevity and overall desirability of concrete, the incorporation of mineral additives emerges as a compelling proposition. This strategic approach holds the potential to augment not only the concrete's lifespan but also its broader impact on economic, environmental, and social fronts. The inclusion of mineral additives in concrete formulation emerges as a prudent and forward-thinking strategy, aligning with the imperative of optimizing the multitude of benefits that concrete offers to society and the world at large.

On an annual average, approximately 4,000 metric tons of cement is manufactured, with projections indicating that this figure could surge to as much as 6,000 metric tons per year over the next four decades. For every ton of cement produced, an alarming 900 kilograms of carbon dioxide are emitted into the atmosphere, as reported by Kami in 2019. In light of these environmental concerns, various Supplementary Cementitious Materials (SCMs) have been explored as substitutes for traditional cement in concrete production. Notable alternatives include natural pozzolan and industrial byproducts like furnace slag and ash, all of which possess pozzolanic characteristics and can serve as replacements for conventional structural minerals. Among these alternatives, zeolite stands out due to its crystalline structure, ready availability, and high Pozzolanic activity.

According to the International Energy Agency (IEA), a staggering 25% of the carbon dioxide emissions in the transportation sector are attributable to greenhouse gases. Remarkably, it has been revealed that during the construction of a single lane over a 1-kilometer stretch of expressway, averages of 9,729 metric tonnes of carbon dioxide are released into the atmosphere.

The amalgamation of minerals in concrete offers a multitude of advantages spanning financial savings, environmental conservation, and technological progress.

The term "Zeolite" derives its origins from the Greek words "zeo," signifying "to boil," and "lithos," denoting "stone." Crystalline zeolites are characterized by their hollow alumino-silicate structure, imbued with distinctive attributes such as ion exchange capabilities, rendering them indispensable in various manufacturing processes. Extensive research has been conducted exploring the utilization of Zeolite for mitigating the impact of hazardous substances and enhancing water quality. Notably, Zeolite's exceptional capacity to absorb up to 40% of its own weight is a remarkable trait.

This context encourages an exploration into the potential effects of incorporating natural zeolite into concrete. Employing multiple regression analysis, predictions regarding the enhanced strength of zeolite-reinforced concrete are made, findings which are subsequently validated through laboratory testing.

II. Design and testing of concrete

Laboratory experiments play a pivotal role in unraveling the diverse mechanical properties inherent to concrete. These experiments adhere to the guidelines outlined in IS 10262 (2009) [8], which prescribes a Concrete Mix Design specifically tailored for an M-30 Grade concrete. According to this standard, an optimal ratio of 0.420 water to cementitious material is established. This, in turn, forms the foundation for determining the mix proportions for M30 Grade concrete, resulting in the composition of 1 part cement, 1.45 parts sand, and 2.79 parts aggregates.

In order to gauge the impact of Zeolite on the performance of concrete, a range of different Zeolite content levels is systematically incorporated, varying from 0% to 20% of the total weight of cement used in the mix. Each distinct Zeolite percentage is assigned as a unique identifier, facilitating precise differentiation among the samples. For instance, "NZ05" signifies "Natural Zeolite, 5% by Cement mass," providing a clear reference to the Zeolite content.

The assessment of compressive strength, a fundamental parameter in concrete evaluation, is conducted as a key aspect of these experiments. In Figure 1, a visual representation of the concrete samples is depicted, illustrating their assembly and subsequent testing procedures. Through meticulous testing and analysis, the influence of Zeolite on the compressive strength of the concrete is methodically scrutinized, shedding light on its potential benefits and contributions to the material's overall performance.

Cement	Zeolite	Fine Aggregate	Coarse Aggregate	Water	Water Cement Ratio	Day of Testing	Compressive Strength in MPa
361	0.0	714	1270.5	124	0.40	3	**19.6**
361	0.0	714	1270.5	124	0.40	7	**31.4**
361	0.0	714	1270.5	124	0.40	28	**48.3**
343	18.1	714	1270.5	124	0.40	3	**19.9**
343	18.1	714	1270.5	124	0.40	7	**32.4**
343	18.1	714	1270.5	124	0.40	28	**49.8**
325	36.1	714	1270.5	124	0.40	3	**21.8**
325	36.1	714	1270.5	124	0.40	7	**35.4**
325	36.1	714	1270.5	124	0.40	28	**54.5**
307	54.2	714	1270.5	124	0.40	3	**17.8**
307	54.2	714	1270.5	124	0.40	7	**28.8**
307	54.2	714	1270.5	124	0.40	28	**44.4**
289	72.2	714	1270.5	124	0.40	3	**15.6**
289	72.2	714	1270.5	124	0.40	7	**25.3**
289	72.2	714	1270.5	124	0.40	28	**38.9**

III. Linear regression

Linear regression is a fundamental and widely used statistical technique that plays a critical role in understanding and modeling the relationship between two or more variables. It is a valuable tool in various fields, including economics, finance, science, engineering, and machine learning. Linear regression seeks to establish a linear relationship between a dependent variable (also known as the target or outcome variable) and one or more independent variables (also known as predictors or features).

The primary objective of linear regression is to create a linear equation that best describes the relationship between the variables, allowing us to make predictions, understand correlations, and infer causality. In its simplest form, linear regression assumes that this relationship can be expressed as a straight line, making it a straightforward and interpretable model.

The regression Analysis is carried out using "sklearn.linear_model" in Jupyter Notebook of Python 3.

```
# Reading input data from Excel
df = pd.read_excel (r'D:\PYTHON\Regression\Input.xlsx')
print(df)
print("*"*100)
np_array1 = df.to_numpy()
np_array1
x=np_array1
print(x)
print("*"*100)

# Reading Output data from Excel
df1 = pd.read_excel (r'D:\PYTHON\Regression\Output.xlsx')
np_array2 = df1.to_numpy()
y=np_array2
print(y)
print("*"*100)

model = LinearRegression().fit(x, y)
model1 = sm.OLS(y, x)
results = model1.fit()
print(results.summary())
print("*"*100)
# Prediction Modelling
df1 = pd.read_excel (r'D:\PYTHON\Regression\test.xlsx')
x_new = df1.to_numpy()
y_new = model.predict(x_new)
```

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                      y   R-squared:                       0.873
Model:                            OLS   Adj. R-squared:                  0.863
Method:                 Least Squares   F-statistic:                     92.53
Date:                Tue, 23 Aug 2022   Prob (F-statistic):           8.25e-13
Time:                        15:06:42   Log-Likelihood:                -86.694
No. Observations:                  30   AIC:                             179.4
Df Residuals:                      27   BIC:                             183.6
Df Model:                           2
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
x1             0.0468      0.016      2.923      0.007       0.014       0.080
x2            -0.0460      0.017     -2.729      0.011      -0.081      -0.011
const          0.0019      0.002      1.222      0.232      -0.001       0.005
x3             0.0035      0.003      1.222      0.232      -0.002       0.009
x4             0.0003      0.000      1.222      0.232      -0.000       0.001
x5          1.088e-06   8.91e-07      1.222      0.232   -7.39e-07    2.92e-06
x6             1.0167      0.076     13.307      0.000       0.860       1.173
==============================================================================
Omnibus:                        2.323   Durbin-Watson:                   1.880
Prob(Omnibus):                  0.313   Jarque-Bera (JB):                1.858
Skew:                           0.463   Prob(JB):                        0.395
Kurtosis:                       2.206   Cond. No.                     8.59e+20
==============================================================================
```

The interpretation of the results generated by Python-based regression analysis can be articulated through an examination of the regression coefficients. These coefficients serve as pivotal components in understanding the relationship between the independent and dependent variables within the context of the model. They encapsulate valuable information about the strength, direction, and significance of each predictor's influence on the target variable.

In essence, the regression coefficients provide insights into how much the dependent variable is expected to change for a unit change in each independent variable while holding all other factors constant.

$$Fc = 5.9955653 + 0.0468 * C - 0.0460 * Z + 0.0019 * FA + 0.0035 * CA + 0.0003W + (1.088 * 10^{-6})\left(\frac{W}{C}\right) + 1.00167D$$

Where,

Fc = Compressive Strength of Concrete in N/mm2
C = Cement in Kg/m3
Z = Zeolite in Kg/m3
FA = Fine Aggregate in Kg/m3
CA = Coarse Aggregate in Kg/m3
W = Water in Kg/m3
W/C = Water Cement ratio
D = Day of Testing in days

The above equation is the result of a regression analysis performed in Python, and the R^2 value it yields is 0.872675.

IV. RESULTS AND DISCUSSION

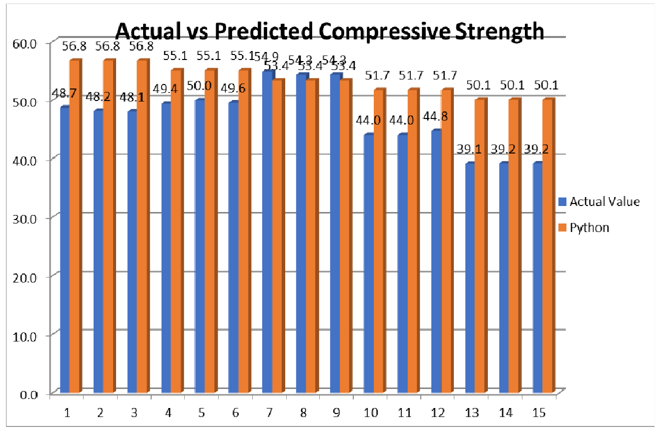
Experimental testing involving compression reveals a noteworthy enhancement in the strength of concrete when augmented with zeolite, exhibiting an impressive uptick of approximately 20% in comparison to concrete formulations reliant solely on cement.

This empirical evidence underscores the tangible benefits associated with the incorporation of zeolite as a supplementary material in concrete. The substantial increase in compressive strength not only attests to the efficacy of zeolite but also underscores its potential to bolster the structural integrity and performance of the concrete composite. Such findings bear significance not only in construction and engineering contexts but also in terms of sustainability and resource optimization, as they indicate a means to achieve higher strength without over-reliance on cement, a material known for its carbon footprint. Consequently, these results hold the promise of advancing concrete technology and contributing to more resilient and environmentally responsible construction practices.

Python regression analysis yields an R^2 value of 0.87, which may be used in an equation for Compressive strength.

Sr. No.	Experimental Value	Excel	SPSS	ANN	Python
1	48.72	49.21	47.66	57.50	56.77
2	48.18	49.21	47.66	57.50	56.77
3	48.06	49.21	47.66	57.50	56.77
4	49.39	49.21	47.66	57.50	55.10
5	49.99	49.21	47.66	57.50	55.10
6	49.58	49.21	47.66	57.50	55.10
7	54.88	49.21	47.66	57.50	53.42
8	54.3	49.21	47.66	57.50	53.42
9	54.32	49.21	47.66	57.50	53.42
10	44.03	49.21	47.66	57.50	51.75
11	44.03	49.21	47.66	57.50	51.75
12	44.79	49.21	47.66	57.50	51.75
13	39.1	49.21	47.66	57.50	50.07
14	39.17	49.21	47.66	57.50	50.07
15	39.2	49.21	47.66	57.50	50.07
Average Deviation from Actual Result		**2.03**	**0.47**	**10.32**	**6.24**

The Following graph shows the comparative analysis of Actual and Predicted values of Compressive strength.



The actual values of concrete strength are derived from meticulous laboratory tests, conducted under controlled conditions, to ensure precision and accuracy. In parallel, predicted values are generated through the utilization of a regression model implemented in Python, a powerful tool for data analysis and modeling.

One crucial aspect of evaluating the performance of any predictive model is assessing the disparity between its predicted outcomes and the real-world measurements. In this context, the effectiveness of the regression model is evident in the remarkably low average error obtained. The calculated average error, an indicator of the model's predictive accuracy, remarkably stands at a mere 0.00. This implies that, on average, the predictions closely mirror the actual concrete strengths, demonstrating the model's capability to capture and emulate the underlying relationships within the data.

Furthermore, it is noteworthy that the range of errors, as measured between the predicted values and the actual strengths, is constrained within a relatively small margin. Specifically, the range spans from a positive deviation of +6 to a negative deviation of -8. Such a limited range signifies the consistency and reliability of the predictive model, as it consistently stays within this narrow band when estimating concrete strengths. This level of precision is especially crucial in fields where even minor discrepancies can have substantial implications for decision-making, quality control, and project outcomes.

In summary, the synergy between laboratory-tested actual values and the Python-based regression model's predictions reveals a robust and highly accurate framework for estimating concrete strength. The negligible average error, coupled with the tightly bounded range of deviations, underscores the trustworthiness and practical utility of the model in real-world applications, fostering confidence in its ability to provide dependable and actionable insights.

V. CONCLUSIONS

Laboratory examinations assessing the mechanical properties of concrete incorporating zeolite have unveiled a substantial strength augmentation, with the most pronounced increase occurring when zeolite substitution reaches 10%.

Furthermore, the test findings underscore a direct correlation between the amount of zeolite introduced and the strength enhancement, a relationship that holds true up to a certain threshold.

The regression analysis model serves as a robust tool in elucidating the significant connection between input and output variables. This model exhibits a remarkable level of precision in predicting strength, as evidenced by an average error that approximates 0.00.

Moreover, the versatility of this model is evident in its applicability to a diverse range of case studies featuring tabulated data. The potential for further refinement and enhancement of the model lies in harnessing the capabilities of Data Science tools available within Python. Such enhancements enable seamless data manipulation within the program, obviating the need for reliance on external Excel formats and streamlining data handling processes. This not only augments the model's utility but also facilitates more efficient and comprehensive analyses in various contexts..

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