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Modeling Fire Effect of Reinforced Recycled Aggregate Concrete Beams by Regression Analysis

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ABSTRACT: In this research article numerical modeling for evaluating effect of fire on reinforced green concrete beams using multi-variable regression analysis is performed. Experimental results of Buller *et al* were used as input data to regression model. Bothe Microsoft Excel and NCSS were used for the purpose. Concrete mix, dosage of recycled aggregates and fire duration were used as independent variables to develop numerical equation for flexural strength. To validate the numerical equation four reinforced concrete beams with 50% dosage of recyclable aggregates were cast and cured for 28 days. Two beams were then exposed to fire at 1000°C for 2 and 4 hours, followed by testing in universal load testing machine under central point load. Comparison of the results shows that the numerical equation predicted by regression analysis gives comparable results with maximum of 18% error. Therefore, the numerical equation can be used to predict the flexural strength of green concrete beams exposed to fire as an alternative to the experimental investigations for flexural strength.

Keywords: Fire Effect, Flexural Strength, Recycled Concrete Aggregates, Numerical Modeling, Regression Analysis, Green Concrete.

I. INTRODUCTION

Numerical modeling is one of the alternatives of the laboratory investigation, which is not only time consuming but also expensive. Among several options for the purpose, regression analysis is one of the options. Regression analysis is statistical method used to examine the influence of one or more independent variables on dependent variable. To determine the influence of variable, comprehensive dataset is required, which in the case of present study is the results of laboratory investigations.

The literature reports the use of the technique for various properties and parameters of the conventional concrete [1-2]. Green concrete being environment friendly has become need of the day and is topic of active research among the researchers around the globe. Green concrete is the concrete developed by making use of waste material along with conventional ingredients of concrete or by replacing partially one or more conventional ingredients of concrete. On the other hand, faster pace of development particularly construction of new high-rise infrastructures in place of old and short height buildings leads to large quantum of the demolishing waste. Generally, this waste goes to landfills but the problem of space for the purpose poses another problem and, in many cases, increases the overall cost of the project. Therefore, utilization of demolished concrete as coarse aggregates in new concrete is also actively researched. In addition to laboratory investigations0, numerical modeling of various properties of green concrete; made by using full or partial replacement of natural coarse aggregates with demolished concrete; has also been reported in literature [6].

Numerical modeling of cubical and cylindrical strength of green concrete made by 50% replacement of natural coarse aggregates has been done by Buller et al [3]. The authors used regression analysis to develop numerical equation giving relationship between cubical and cylindrical strength of green concrete. Validation of test results of 400 samples showed good agreement between two sets of the results. Oad *et al* performed regression analysis to develop numerical equation for compressive strength [7] and tensile strength [4] of green concrete based on its weight. In both of the studies the authors used three modes of compaction; i.e. no compaction, compaction by rodding and compaction by table vibrator. The comparison of test results of 90 specimens in each study with those obtained by the numerical expression showed less than 5% error between two sets of the results. Concrete strength has also been studied [8] for different ages using nonlinear regression analysis. From the analysis authors observed correlation coefficient of 0.995 and 0.994 for 7- and 28-day curing age. The coefficients show good validity of the model.

Multivariable regression analysis and neural network has been used to develop the numerical equation for predicting the strength of concrete with mineral admixtures [9-10]. The author used blast furnace slag and fly ash to cast and cure the specimens from 3 to 180 days, followed by non-destructive testing to develop the dataset for the analysis. From the obtained results authors observed that the artificial neural network performs well than regression models. The author also concluded that the said technique is good for calculating nonlinear relationship which otherwise is difficult to determine from other methods. Artificial neural network has also been used by Hasancebi and Dumlupinar [11] for T-beam bridges, Imam *et al* [10] for corroded reinforced concrete beams and Kim *et al* [12] for estimating and comparison of construction cost. In these studies models developed for the purpose performs well with respect to experimental investigations / case studies.

Delivery and placement of concrete have considerable effect on the concreting process and final quality. The relationship between two parameters by linear regression analysis has been studied by Dunlop and Smith [13] using data from 202 different processes. Validation of developed model proved its good efficiency on different other data sets from various other processes. In another research work, Yoo and Banthia [14] performed regression analysis for the flexural response of metallic fiber reinforced concrete. The independent variables of the model [15], dosage of metallic fibers. In multiple regression analysis attempts, dependent variables were post-cracking, modulus of elasticity, flexural strength. Comparison of results reveals good agreement between numerical and experimental results [16].

Estimation of compressive strength of green concrete with and without fly ash using regression models has been addressed by Chopra *et al* [17]. The authors used different mix proportions, dosage of fly ash and curing ages; 28-,56- and 9-day; as independent variables. The developed models gave excellent correlation coefficient showing the good performance of the model.

Above discussion of available literature reveals that good quantum of work has been done on both numerical and experimental sides for conventional and green concrete but very less work is traced in available state-of-art regarding numerical modeling of green concrete; particularly made with demolished concrete as coarse aggregates; exposed to fire. Therefore, this research work is designed to perform regression analysis to predict the flexural strength of reinforced green concrete beams exposed to fire at 1000^{o}C for 6, 12, 18 and 24 hours [18-22].

II. METHODOLOGY

The regression analysis is the statistical process of finding / predicting the future values of required variable. This method depends upon the two terms such as: Dependent Variable and Independent Variables.

Dependent Variable is the main part which is predicated. Independent Variable(s) is the part where we use the data set i.e. from experimental data, survey data etc. The process of the analysis may be summarized as is given in Fig. 1.

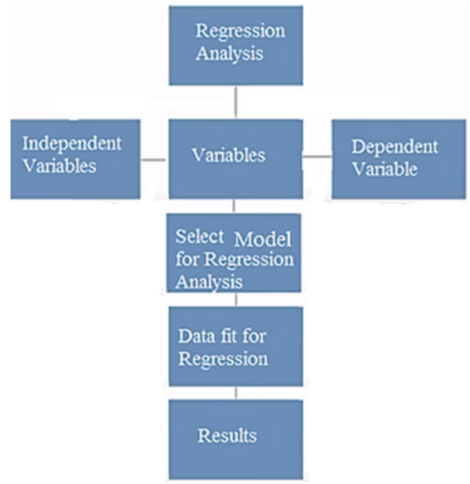

Fig. 1. Process of regression analysis.

The dataset for regression analysis is used from the experimental investigation published by Buller *et al* [23] The authors studied effect of fire on reinforced green concrete beams made by using 50% dosage of demolished concrete as coarse aggregates [22]. The specimens were cast using both normal and rich mix concrete and cured for 28 days. Additionally, control specimens cast from all-natural aggregates were also used to compare the results. All the specimens were then exposed to fire for 0, 6, 12, 18 and 24 hours at 1000^{o}C followed by testing the beams in universal load testing machine under central point load. For the purpose of present research, the test results are regrouped based on mix type, dosage of recyclable aggregates and fire duration and are shown in Fig. 2 to Fig. 5. For the purpose of analysis, flexural strength of the beams was taken as dependent variable and concrete mix type (normal mix=1, rich mix=2), dosage of recyclable aggregates (0 or 50) and fire duration (0, 6, 12, 18, 24) were considered as independent variables.

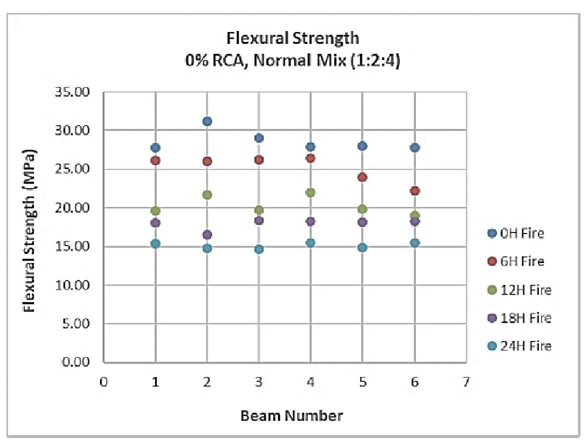

Fig. 2. 0% RCA normal mix beams.

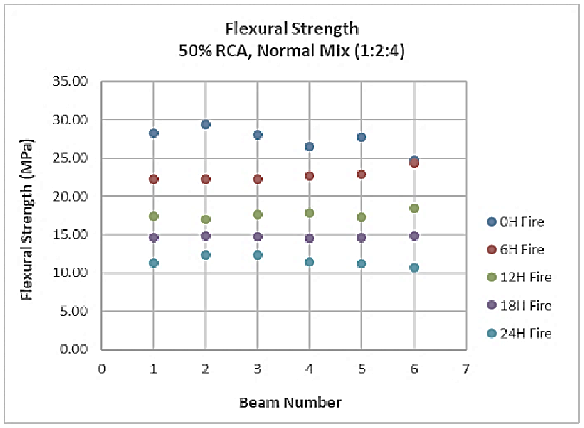

Fig. 3. 50% RCA normal mix beams.

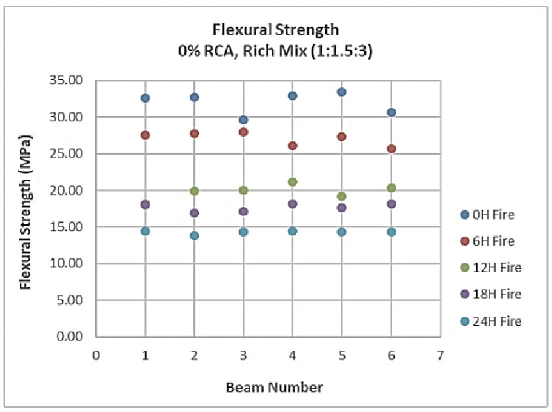

Fig. 4. 0% RCA rich mix beams.

The regression analysis is offered by several softwares. For present work the statistical capabilities of NCSS and Microsoft EXCEL were used. NCSS since its development in 1981 has got wide acceptance for statistical analysis and at present it offers various functions including regression analysis.

Microsoft EXCEL is a product of Microsoft Company. Basically, it is spread sheet solution but also offers several statistical functions including multivariable regression analysis.

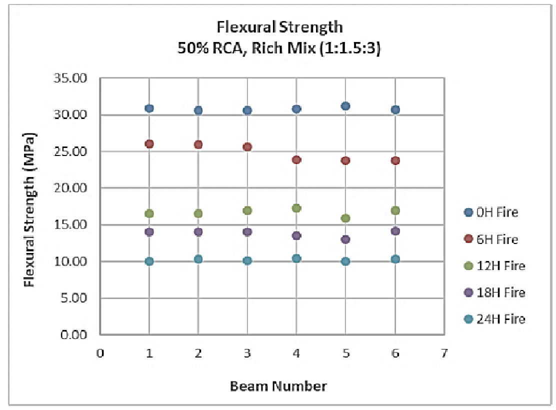

Fig. 5. 50% RCA rich mix beams.

Following the set procedure for regression analysis by the software variables were declared and dataset was fed individually in both software's. Coefficients for numerical expression generated by NCSS along with standard errors are given in Table 1. Whereas, the same generated by Microsoft EXCEL are given in Table 2.

Using the coefficients given in Table 1, numerical equation for predicting the flexural strength is written as

$$f_S = 29.47175 - 0.7129861 * F_H - 0.05481 * D_{RCA} + 0.5788333 * M_{Type} \quad \ldots(1)$$

Where, f_S represents flexural strength, F_H is duration of fire in hours, D_{RCA} is dosage of recyclable aggregates (0 for 0%, 50 for 50% etc.) and$M_{Type}$is used for type of concrete mix (1 for 1:2:4 mix and 2 for 1:1.5:3 mix).

Table 1: NCSS generated coefficients and standard error.

Independent Variable	Regression Coefficient	Standard Error	Lower 95% Conf. Limit	Upper 95% Conf. Limit
Intercept	29.47175	0.5485743	28.39	30.56
Fire Hour	-0.7129861	0.0179307	-0.75	-0.68
RCA%	-0.05481	0.0060859	-0.07	-0.04
Mix	0.5788333	0.3042943	-0.02	1.18

Table 2: Microsoft EXCEL generated coefficients and standard error.

Description	Regression Coefficients	Standard Error	P-value	Lower 95%	Upper 95%
Intercept	29.47146333	0.549	8.43E-84	28.385	30.558
Fire Hour	-0.712978056	0.018	2E-69	-0.748	-0.677
RCA %	-0.054812533	0.006	5.03E-15	-0.067	-0.043
Mix	0.57896	0.304	0.049578	-0.024	1.182

Similarly, the coefficients of table 2; generated by Microsoft EXCEL are used to write the numerical expression as given in equation (2).

$$f_S = 29.47146 - 0.7129781 * F_H - 0.0548125 * D_{RCA} + 0.57896 * M_{Type} \quad \ldots(2)$$

For the purpose of comparing the efficiency of the developed equations, four reinforced green concrete beams cast with 50% dosage of recyclable aggregates using normal mix were cast and cured for 28 days. Then two beams were exposed to fire at 6000C for 2-hour duration and remaining two beams for 4-hour duration (10000C). After exposure to fire the beams were tested in universal load testing machine under central point load in accordance with ASTM C293. The beams were observed carefully till failure. The obtained results were compared with those obtained from the numerical equations and are presented in next section.

III. DISCUSSION OF RESULTS

This section presents discussion on the results obtained from both of the software used for the purpose and those obtained from laboratory investigation.

A. Regression analysis by NCSS

After the completion of regression analysis, the software produced several tables and graphs. The summary report of the analysis is given in Table 3. It may be observed from the table that the R-square values (co-efficient of determination) computed is equal to 0.93, which shows the 93% of the dataset values are around the mean. Normal probability plot generated by the software is shown in Fig. 6. The graph also shows that the maximum values of the data set fall in the band.

B. Regression analysis by EXCEL

Analogous to NCSS, Excel also gave tables and graphs as results of the regression process. The summary of analysis generated by the software is given in Table 4. It may be observed that R-square values computed by the software are similar to that of NCSS. For better performance of the equation generated by regression analysis, significance F value should be nearly equal to 0. The value obtained from the analysis is equal to 1.2966 x 10-68. Also, the p-value for all variable used in the analysis should be less than 0.05. It may be observed from table 2 that p-value for all variables are less than 0.05. These parameters show the reliability of the equation generated by the software. The normal probability plot generated by the software is given in Fig. 7.

Table 3: Summary Report (NCSS).

Item	Value
Dependent Variable	F_S
Number Ind. Variables	3
Weight Variable	None
R^2	0.93
Adj R^2	0.93
Coefficient of Variation	0.08
Mean Square Error	2.77785
Square Root of MSE	1.66669
Ave Abs Percentage Error	6.95

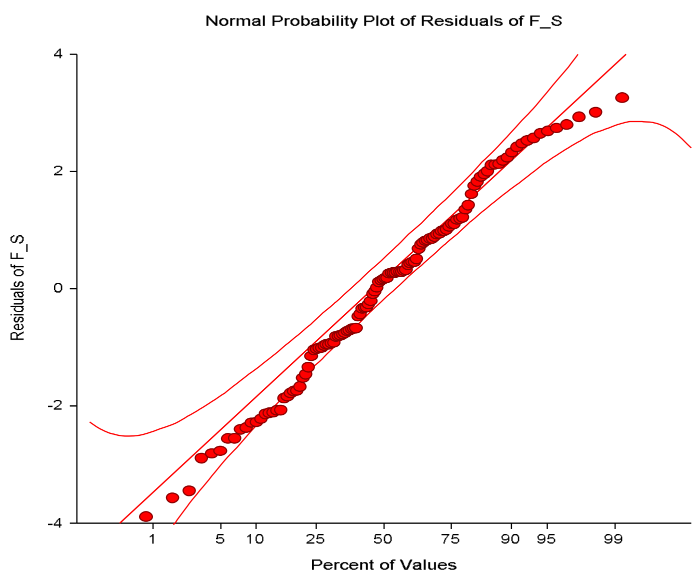

Fig. 6. Normal probability plot (NCSS).

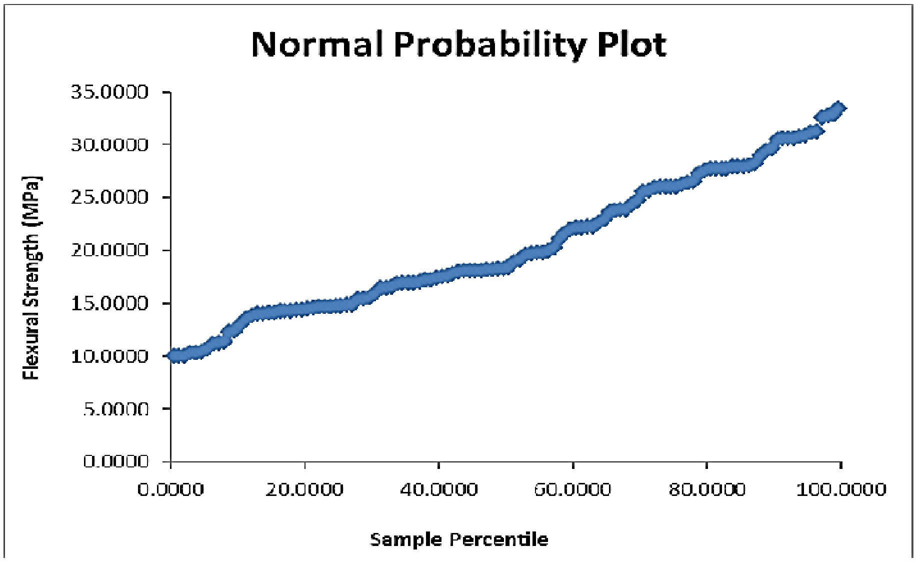

Fig. 7. Normal probability plot (EXCEL).

Table 4: Output summary of Regression Statics (EXCEL).

Regression Statistics	
Multiple R	0.966898926
R Square	0.934893533
Adjusted R Square	0.933209745
Standard Error	1.666754639
Observations	120

The numerical equations using both sets of analysis were observed almost same with very minor difference. This shows power and validity of even Microsoft Excel for the purpose. Theses equations were used to predict the flexural strength data for all reinforced concrete beams. Based on the comparison of the computed results with the laboratory test results, minimum, maximum and average errors were evaluated and are given in Table 5. From this table it may be observed that the error percentage computed for both sets of numerical results is almost same.

Table 5: Extreme values of error percentage.

#	Error	Regression Analysis By	
		EXCEL	NCSS
1	Minimum	-21.667	-21.6682
2	Maximum	17.6895	17.6883
3	Average	-0.7344	-0.3334

The maximum error in predicted values of flexural strength is about 18%. Indeed, it is because of few beams which might be having some problem due to old aggregates or casting issues otherwise predicted results of all other reinforced concrete beams exposed to different fire durations remained in good agreement with the experimental results. This proves the validity of the equation for the purpose. It not only saves from going through experimental procedures but also quickly gives the results using simple arithmetic.

In addition to above, four beams were prepared and tested to check further effectiveness of the developed equations. The independent variables for the equation and computed results along with experimental observations are listed in Table 6. It may be observed from this table that the computed results are in good agreement with the laboratory observations as the error percentage in the computed results from equations developed for the purpose is maximum of 9.35%. This shows the validity of the developed equation even beyond the data set used. Therefore, the developed equation for flexural strength of reinforced green concrete beams exposed to fire can be used to have firsthand information of the parameter without performing any laboratory investigations.

Table 6: Data and results for test beams.

#	Independent Variables			Flexural Strength - f_S(MPa)		
	F_H	D_{RCA}	M_{Type}	Lab	NCSS	EXCEL
B1	2	50	1	27.657	25.8841	25.8838
B2	2	50	1	28.014	25.8841	25.8838
B3	4	50	1	26.462	24.4581	24.4579
B4	4	50	1	26.981	24.4581	24.4579

IV. CONCLUSION

Numerical modeling through regression analysis for the effect of fire on flexural strength of reinforced green concrete beams is presented in this research article. NCSS (dedicated statistical analysis software) and Microsoft EXCEL were used for the purpose. Dataset published by Buller *et al* [18-21] was used as input of the regression model. The equations developed were counter checked with the laboratory investigations of the dataset and four beams prepared and exposed to fire at 1000°C for 2 and 4 hours. The comparison shows that the equations developed by both software's are almost same. Flexural strength computed numerically differed maximum of about 18% with the experimental observations of the dataset and 9.35% with the experimental observations of the four beams cast and tested. Therefore, the equation developed can be used as alternative to laboratory investigation for the flexural strength of fire exposed reinforced green concrete beams.

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