Predicting Compressive Strength of Recycled Aggregate Concrete using Analysis of Variance

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Abstract— *A step-by-step statistical approach is proposed to obtain optimum proportioning of concrete mixtures using the data obtained through a statistically planned experimental program. The utility of the proposed approach for optimizing the design of concrete mixture is illustrated considering a typical case in which trial mixtures were considered according to a full factorial experiment design involving three factors and their three levels. A total of 27 concrete mixtures with three replicates were considered by varying the levels of key factors affecting compressive strength of concrete, namely, w/c ratio, recycled coarse /natural coarse aggregate ratio, and recycled fine/ natural fine aggregate ratio .The experimental data were utilized to carry out analysis of variance (ANOVA) and to develop a polynomial regression model for compressive strength in terms of the three design factors considered in this study. The developed statistical model was used to show how optimization of concrete mixtures can be carried out with different possible options.*

Keywords— ANOVA, C&D, Optimization, recycled concrete, regression.

I. INTRODUCTION

1.1 Optimization

Optimization is the selection of a best element (with regard to some criteria) from some set of available alternatives. The generalization of optimization theory and techniques to other formulations comprises a large area of applied mathematics. More generally, optimization includes finding "best available" values of some objective function given a defined domain (or a set of constraints), including a variety of different types of objective functions and different types of domains. The empirical model obtained for compressive strength can be used for optimization of concrete mixture proportions using any suitable optimization method/tool. The developed compressive strength model was utilized for optimization of concrete mixture design corresponding to the following options (i.e., constraints) typically using the Microsoft Excel Solver.

1.2 Literature Review

The article by Yong-Huang Lin, Yaw-Yauan Tyan, Ta-Peng Chang, Ching-Yun Chang [3] adopts Taguchi's approach with an L16 (215) orthogonal array and two-level factor to reduce the numbers of experiment. Using analysis of variance (ANOVA) and significance test with F statistic to check the existence of interaction and level of significance, and computed results of total contribution rate, an optimal mixture of concrete qualifying the desired engineering properties with the recycled concrete aggregates can easily be selected among experiments under consideration.

The article by Shamsad Ahmad and Saied A. Alghamdi [4] showed that a step-by-step statistical approach is proposed to obtain optimum proportioning of concrete mixtures using the data obtained through a statistically planned experimental program.

Jason R.F. Lalla, Abrahams Mwasha [5] intended to highlight the result of comparisons of compressive strengths of recycled aggregate concrete (RAC) and its source material. Compressive strength testing was conducted according to ASTM C39 and correlations on the data obtained from testing were determined using the one way ANOVA statistical method.

Niyazi Ugur Kockal, Turan Ozturan [8] presented the influence of characteristics of four aggregate types (two sintered lightweight fly ash aggregates, cold-bonded lightweight fly ash aggregate and normal weight crushed limestone aggregate) on the strength and elastic properties of concrete mixtures. Different models were also used in order to predict the strength and modulus of elasticity values of concretes.

Bibhuti Bhusan Mukharjee, Sudhirkumar V Barai [9] studied recycled coarse aggregate (%), Nano-silica (%) and Specimen Type were selected as factors and each having two levels. Four numbers of mixes with three replicates are designed and compressive strength at seven and 28 days are selected as responses. Analyses of Variance (ANOVA) of experimental results were carried out to study the influence of factors and various plots are used to demonstrate the results of the analysis.

II. EXPERIMENTAL WORK AND TESTS RESULTS

The materials used for carrying out different tests are as follows:

- Cement(OPC Grade 43)
- Recycled aggregate
- Natural aggregate

Table.1 Trial Mix Proportion and 28 days compressive strength

RATIO	W/C RATIO	MASS OF C.A. (kg/m^3)	MASS OF F.A. (kg/m^3)	VOLM. OF CEMENT	W C (kg/m^3)	28 DAYS COMPRESSIVE STRENGTH (MPA)
1:0.1	0.45	1088.46	558.55	437.77	197	29.7
1:.0.5	0.45	974.68	558.55	437.77	197	28.8
1:1	0.45	832.45	558.55	437.77	197	29.1
0.5:0.1	0.45	1088.46	582.26	437.77	197	24.1
0.5:0.5	0.45	974.68	582.26	437.77	197	28.2
0.5:1	0.45	832.45	582.26	437.77	197	30.6
0.1:0.1	0.45	1088.46	541.22	437.77	197	24.2
0.1:0.5	0.45	974.68	541.22	437.77	197	24.6
0.1:1	0.45	832.45	541.22	437.77	197	25.8
1:0.1	0.48	1094.46	522.41	410.41	197	21.9
1:.0.5	0.48	977.95	522.41	410.41	197	27.4
1:1	0.48	837.04	522.41	410.41	197	28.5
0.5:0.1	0.48	1094.46	598.12	410.41	197	21.9

The data given in Table.4.11 were utilized for statistical analysis to examine the significance of the mixture factors and subsequently to obtain a regression model for compressive strength in terms of the factors considered.

Statistical Analysis of Data and Fitting of the Compressive Strength Model. Analysis of variance (ANOVA) [13] was carried out to pinpoint the individual and interactive effects of variable factors on the dependent variable. ANOVA of the test results in the present study was done with the software named MATLAB [14].

Table.2. Analysis of Variance Results

Source	Sum sq.	Degree of freedom	Mean sq.	F value	P value	Significance
W/c	71.781	2	35.8904	35.46	0	YES
Rc/tc	137.961	2	68.9803	68.16	0	YES
Rf/tf	0.714	2	0.3571	0.35	0.707	NO
Error	20.241	20	1.012			
Total	230.697	26				

W/cm and CA/TA have significant effects on compressive strength as their levels of significance, P values, are less than 0.05. Therefore, these two significant variables should be considered for obtaining the regression model for compressive strength, fc. Although the effect of FA/TA on compressive strength is found to be insignificant, it is considered in the regression analysis as cement remains an indispensable material in concrete production.

The polynomial regression model obtained for compressive strength using the data is presented as follows:

fc=62.02-(72.22*w/c)-(6.10*rc/tc)-(0.39*rf/tf)

Where, f c is the 28-day compressive strength in MPa. w/cm is the w/c materials ratio by mass. rc/tc is recycled coarse to total coarse aggregate and rf/tf is recycled fine to total fine aggregate.

III. OPTIMIZATION

Optimization [15] of Concrete Mixture Proportions Using Compressive Strength Model. The empirical model obtained for compressive strength can be used for optimization of concrete mixture proportions using any suitable optimization method/tool. The developed compressive strength model was utilized for optimization of concrete mixture design corresponding to the following options (i.e., constraints) typically using the Microsoft Excel Solver:

Table.3. Optimization of concrete mixture design

W/c	Rc/tc	Rf/tf	Fc
0.496497	1.003927	0.1	20
0.469	1.001605	0.1	22
0.441503	0.999282	0.1	24
0.494353	1.003746	0.5	20
0.466856	1.001424	0.5	22
0.439359	0.999101	0.5	24
0.491672	1.00352	1	20
0.464175	1.001197	1	22
0.436678	0.998875	1	24

TABLE.4 shows optimizing the levels of the w/cm &CA/TA for achieving different target compressive strengths at different values of FA/TA within the selected range (i.e., 0.1, 0.5 and 0.5).

Table.4. Optimization of concrete mixture design

W/c	Rc/tc	Rf/tf	Fc
0.45	1	0.1	23.382
0.45	1	0.2	23.343
0.45	1	0.3	23.304
0.45	1	0.4	23.265
0.45	1	0.5	23.226
0.45	1	0.6	23.187
0.45	1	0.7	23.148
0.45	1	0.8	23.109
0.45	1	0.9	23.07
0.45	1	1	23.031

W/c	Rc/tc	Rf/tf	Fc
0.45	0.1	0.1	28.872
0.45	0.1	0.2	28.833
0.45	0.1	0.3	28.794
0.45	0.1	0.4	28.755
0.45	0.1	0.5	28.716
0.45	0.1	0.6	28.677
0.45	0.1	0.7	28.638
0.45	0.1	0.8	28.599
0.45	0.1	0.9	28.56
0.45	0.1	1	28.521

The optimization results, presented in Table 4.16, indicate that the maximum compressive strength corresponding to a lower RF/TF. Further, the maximum compressive strength at RF/TF (0.5) is higher than that RF/TF (1.0). This indicates that, at the same optimum values of w/cm and CA/TA, the compressive strength is more at lower RF/TF. At all levels of RF/TF, maximum compressive strengths correspond to minimum water/cement ratio (0.45) and minimum coarse/total aggregate ratio (0.1) within their ranges of variation considered in the present work.

From Table 4.16, the concrete mixture having a maximum compressive strength of 28.872 MPa at lower ratio of RC/TC OF 0.1, w/c ratio of 0.45, and fine/total aggregate ratio of 0.1 can be typically selected as the optimum mixture. However, in cases where the compressive strength requirement is less than the maximum, a set of W/C ratio, RC/TC, and RF/TF aggregate ratio other than the optimum one can be selected for achieving the workability and durability requirements.

IV. CONCLUSION

Following important conclusions are drawn from the present work:

- The aggregates obtained from C&D waste can be used as a replacement of natural aggregates.
- Flakiness index of coarse recycled aggregate (CRA) is 39.42% approximately around the limit while elongation index of CRA is 53.48%.
- Fineness modulus for Coarse recycled aggregate is 7.82 and for fine recycled aggregates is 4.15, whereas in case of natural aggregates it is 3.12 and 2.36 respectively.
- Bulk density is found to be good as it is less than required for the coarse and approximately same as that of the fine.
- Specific Gravity for coarse recycled aggregate and fine recycled aggregates is found to be 1.99 and 2.07 and water absorption is 3.35% aand 11.11 % respectively , whereas specific gravity and water absorption of natural aggregates is 2.67and 7.23&%.
- The Crushing value for recycled aggregate is found to be 36.42%.
- The abrasion value for the recycled aggregate is found to be 24.57%.
- The proposed statistical approach of ANOVA has indicated the significant effects of w/c ratio, recycled coarse/total coarse aggregate ratio on compressive strength of concrete.
- The equation derived from regression model for compressive strength of concrete is as follows:-
  Fc=-62.02-(72.22*w/c)-(6.10*rc/tc)-(0.39*rf/tf)
- The optimum value of w/c ratio & recycled coarse/ total coarse aggregate ratio has higher compressive strength at lower recycled fine/total fine aggregate ratio.
- The optimum value of w/c ratio & recycled coarse/ total coarse aggregate ratios can be predicted for different target values of compressive strength.
- As the w/c ratio and rc/tc aggregate ratio increases, compressive strength of concrete decreases i.e. at w/c ratio 0.45 and recycled coarse/total coarse 0.10, we get the optimum value for compressive strength of concrete as 28.87 MPA.
- Predicting compressive strength of concrete using ANOVA is very effective and it consumes less time.

The proposed procedure provides a systematic statistical way for selecting an optimal mixture proportioning.

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