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Modeling The Partial Replacement Effect of Coarse Aggregate and Cement With Recycled Concrete Aggregate and Fly Ash

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Abstract

In this investigation, cement is partially replaced with ASTM C 618 Class F Fly Ash (FA) in the range of 0% to 30% and Natural Coarse Aggregate (NCA) is replaced with 20% of Recycled Concrete Aggregate (RCA) under different W/B ratios such as 0.38, 0.40 and 0.42. This paper presents the experimental results of compressive strength of concrete cubes and its durability aspects. The flexural behavior of beams using fly ash as cement replacement and recycled concrete aggregate as coarse aggregate are studied under monotonic two point loading.

A mathematical model was constructed using MS Excel software for the strength characteristics of concrete with replacement. The concrete mix containing 20% of Fly Ash shows consistant result among all replacement levels. These strength characteristics are analyzed using MS Excel software. The percentage variation of fly ash is selected for analysis. % of cement or % of fly ash is kept as independent variable and compressive strength as a dependent variable. The R value obtained from the result shows that the replacement ratios and strength aspects are within the specified value and suitable for construction of structural components with suitable mix design.

Keywords: Recycled concrete aggregate, flyash, compressive strength, flexural strength, Regression analysis, R value.

Introduction

The protection of the environment is a basic factor, which directly connected with the survival of the human race. Parameters like environmental consciousness, protection of natural resourses, sustainable development play an important role in modern requirements for construction works.

Cement concrete is the most widely used construction material in any infrastructure development projects. The production of Portland cement, an essential constituent of concrete, releases large amounts of CO_2 into the atmosphere, i.e. about one tone of CO_2 for every ten tone of Portland cement produced. CO_2 is a major contributor to the greenhouse effect and the global warming of the planet, which is one of the major global environmental issue currently the planet is encountering. On the other hand, in most of the thermal power plants fly ash is obtained as a waste material.

In this scenario, the use of supplementary cementitious materials like fly ash as a replacement for Portland cement in concrete presents one viable solution with multiple benefits for the sustainable development of the construction industry. **Shi Cong Kou et al** (2007) revealed that use of a low w/c ratio or fly ash as an addition of cement is a good way to reduce the potential high drying shrinkage of concrete prepared with recycled aggregate. Drying shrinkage of recycled aggregate concrete tended to decrease with an increase in compressive strength. Reducing the w/c ratio from 0.55 to 0.40 was a more effective way to mitigate the drying shrinkage of concrete compared to adding 25% fly ash in the concrete mix. Chloride ion penetration could be significantly minimized with a proper mix design. Concrete, which had a low w/c ratio and fly ash as an addition of cement, had much better resistance compared to that with high w/c ratio and without fly ash addition.

Very rare literature are found on recycled concrete as a structural component in reinforced concrete structures, they are used as pavement material only. According to **Jitender Sharma, Sandeep Singla (2014)** a suitable code should be drawn to use the recycled concrete aggregate as coarse aggregate. India may also have to seriously think of reusing demolished rubble and concrete for production of recycled construction material. Work on recycled concrete has been carried out at few places in India but waste and quality of raw material produced being site specific, tremendous inputs are necessary if recycled material has to be used in construction for producing high grade concrete. **Jianzhuang Xiao and H. Falknerd (2004)** revealed the bond strength of recycled concrete aggregate and steel bars is similar to the one for normal concrete and steel rebars, which includes micro-slip, internal cracking, pullout, descending and residual stages. Under the condition of the equivalent mix proportion and compared with that of normal concrete, the bond Replacement percentage has a considerable influence on the stress–strain curves of recycled aggregate concrete for all considered cases from 0% to 100%, the stress – strain curves show a similar behavior. Accoding to **Salomon M. Levy, Paulo Helene (2004)** minimum water absorption and total pore volume for the recycled aggregates concrete were observed at 20%. When water absorption and total pore volume are increased, the replacement of recycled aggregate also increases. When the natural aggregate is replaced by 20% of the recycled aggregates from old concrete or old masonry, the resulting recycled concrete will likely present same, and sometimes better. The experimental study made an attempt to evaluate the behavior and failure characteristics of concrete specimen using recycled concrete as course aggregate in different percentages by weight for different mix proportions. **C.S. Poon et al** (2003) revealed that the moisture states of the aggregates affected the change of slump of the fresh concretes. The initial slump of concrete was strongly dependent on the initial free water content of the concrete mixes. To impose the largest negative effect on the concrete strength, which might be attributed to “bleeding’’ of excess water in the pre wetted aggregates in the fresh concrete. It should contain not more than 50% recycled aggregate should be optimum for normal strength recycled aggregate concrete production. The properties of original concrete has significant influence on mechanical properties of recycled aggregate concrete, it is possible to obtain recycled concrete with higher compressive strength than the original one. Mix design of recycled concrete is very similar to the procedure for concrete with natural (new) aggregate, corrections in water content are necessary to obtain proper workability, but the changes in water/cement ratio may be relatively small.

Materials and Methods

Ordinary Portland Cement of grade 43 conforming to IS: 12269-1987 was used. Locally available river sand conforming to grading zone II of IS: 383-1970 was used and crushed stones of nominal size 12.5mm conforming to IS 383-1970 was used. The specific gravity of natural coarse aggregate and recycled concrete aggregate was 2.68 and 2.77 repectively. Recycled concrete aggregate comprised of crushed concrete or stone that can be graded to meet the specific standard. The specific gravity of cement and sand used was 3.15 and 2.65 respectively. Besides this, the byproduct flyash was obtained from Mettur thermal power plant, India. The chemical properties of flyash used is compared with the Indian standard are shown in table1. Constituent of different mix proportions are shown in Table 2.

Table 1: Chemical Properties of Fly ash

Chemical properties	IS:3812-1981	Fly ash from MTPP*
SiO_2+Al_2O_3+Fe_2O_3, min% by mass	70.0	90.5
SiO_2, min% by mass	35.0	58
CaO max % by mass	5.0	3.6
SO_3, max % by mass	2.75	1.8
Na_2O, max % by mass	1.5	2
L.O.I, max 5 by mass	12.0	2
MgO, max %by mass	5.0	1.91
*Mettur Thermal Power Plant		

Table 2: Composition of various mix proportions

Mix	NCA	RCA	Flyash content (%)	Cement content (%)
MI	80	20	0	100
	80	20	10	90
	80	20	20	80

	80	20	30	70
MII	80	20	0	100
	80	20	10	90
	80	20	20	80
	80	20	30	70
MIII	80	20	0	100
	80	20	10	90
	80	20	20	80
	80	20	30	70

Since there is none of the standard available for designing the concrete mixes with recycled coarse aggregate, the mix design proposed by IS was used to design the Conventional Concrete mixes and finally the coarse aggregate was replaced by recycled concrete aggregate to obtain the concrete mixes. The mix proportion is arrived for medium characteristic compressive strength of 30MPa. Super plasticizer upto 3% (Conplast SP-430) has been used to enhance the workability.

Results and Discussions

Compressive Strength Test

The concrete cubes of size 150x150x150mm were tested in the compression testing machine as per ASTM C39 standard (2002). At the age of 28 days the compressive strength of concrete mixes containing Fly Ash up to 20% increased by 3 – 12 % and there after with the increase in Fly Ash, the compressive strength reduced by 3 – 16 % when compared with control mix. Optimum level of cement replacement was found to be 20 % with Fly ash and Optimum level of replacement of natural coarse aggregate was also found to be 20% with RCA as shown in figure 1.

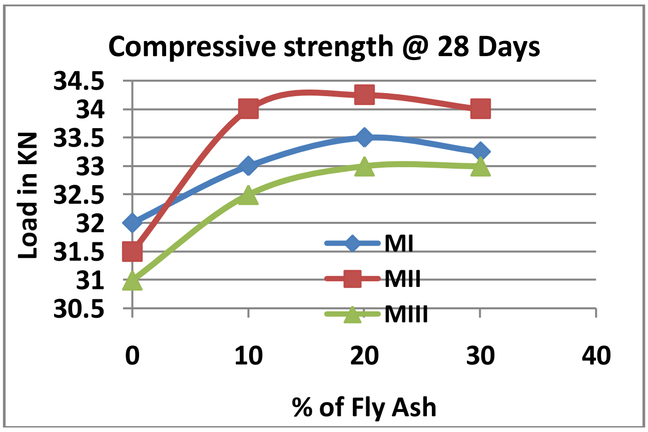


Figure 1: Compressive Strength @ 28 Days

Chloride Resistance Test

The concrete cubes are immersed in a chloride solution prepared with 35mg of sodium chloride in one liter of water. The setup was kept undisturbed for 28 days. The observations were made after taking out the concrete cubes from the solution and cleaned in fresh water. The change in weight and compressive strength of cubes were observed. With the increase in the fly ash content there is a small reduction in weigth of concrete cubes. The % of weight loss and the compressive strength values are obtained. It is known that the % of weight loss is one of the important parameters for durability. Figure 2 shows the variation of % of weight loss with % of Fly Ash. From the figure, it can be observed that the % weight loss increases initially with the increase in % of Fly Ash then decreases and finally increases.

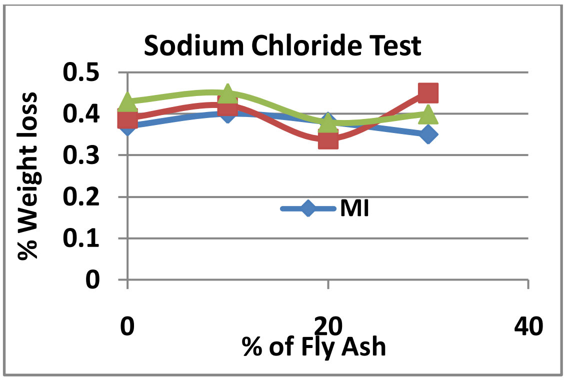


Figure 2: % Weight loss in Acid curing

Sulphate Resistance Test

The concrete cubes are immersed in 3.5% Sulphuric acid for every one liter of water and cured for 28 days after normal curing to simulate the worst possible environmental conditions. Observations were made for loss in weight and compressive strength. The concrete cubes are detoriated mainly at edges and appeared to be of a white colour. With the increase in the fly ash content sulphate resistance of the concrete mixes reduced. It is observed that the percentage weight loss increases with increase in percentage of Fly Ash as in figure 3. The decrease in rate of loss of weight could be due to development of by-product, ettringite, usually formed by a chemical reaction between the cement matrix i.e. calcium hydroxide and sulphate ions and thus the by-products fill up the voids in concrete (Kelham, 1996). The formation of ettringite will be helpful to enhance the concrete strength up to some extent by filling-up of the voids in concrete (Stark, 2002).

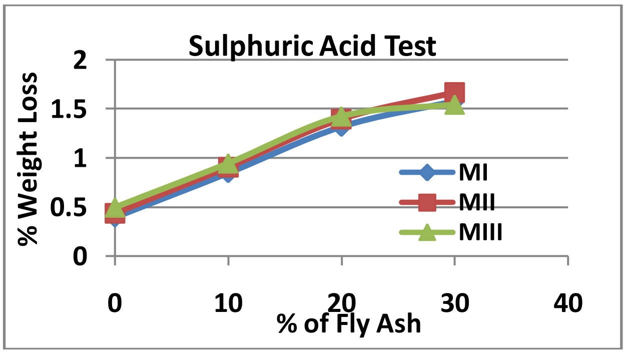


Figure 3: % Weight loss in Acid Curing

Modified Sorptivity

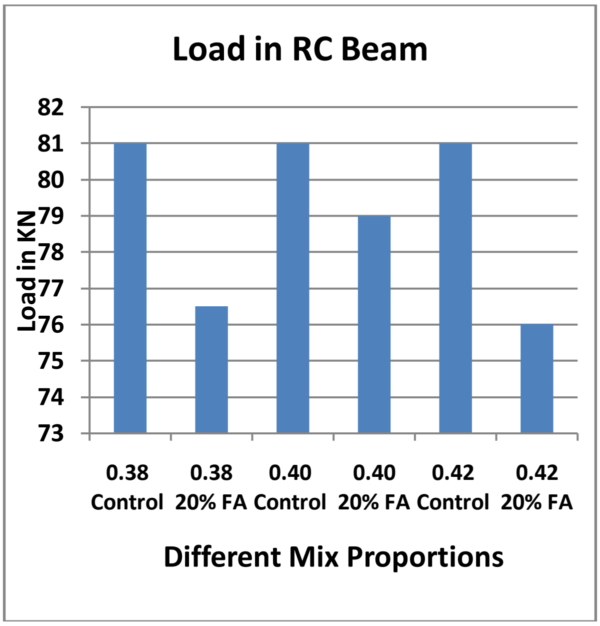
The test for sorptivity was conducted as per ASTM C 642 (1992) by drying the specimens in an oven at a temperature of 105^{o}C to constant mass and then immersing them in water after cooling the specimens to room temperature and measuring the gain in mass at regular intervals of 30 minutes duration, for a period of two hours. The sorptivity was computed by considering the slope of the plot 'p' versus 'SQRT (t)". With the increase in fly ash content sorptivity of concrete decreases and increases at the end.

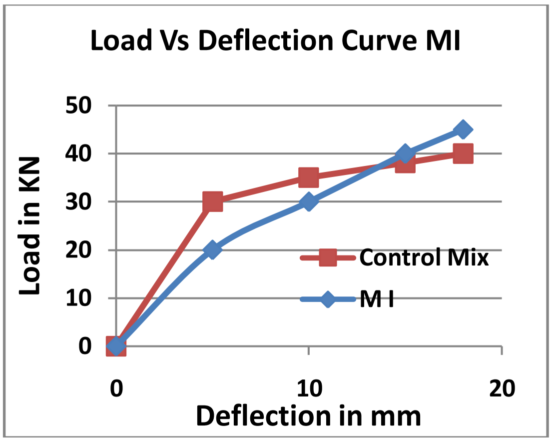
Table 3: Sorptivity Values

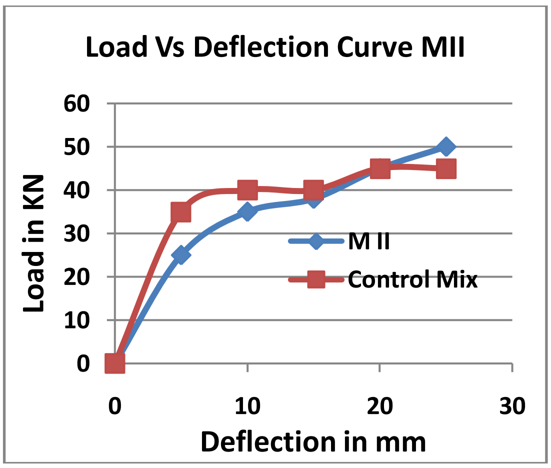
% of Fly ash	Sorptivity in m/sec$^{0.5}$		
	MI	MII	MIII
0	1.61x10^{-4}	1.45x10^{-4}	1.37x10^{-4}
10	1.29x10^{-4}	1.23x10^{-4}	1.19x10^{-4}
20	1.27x10^{-4}	1.22x10^{-4}	1.17x10^{-4}
30	1.28x10^{-4}	1.25x10^{-4}	1.20x10^{-4}

Flexural Behaviour of Beam

An reinforced concrete beam of dimension 2000 * 200 * 150 mm is caste for the mix proportion containing 20% recycled concrete aggregate and 20% of fly ash with different water cement ratio were tested for flexure under a loading frame of capacity 1000kN. These beams were tested on a span of 1500mm centre to centre with simply supported conditions under two point loading. Deflections were measured under the loading point and at the mid span using Linear Variable Differential Transducers (LVDTs). The crack patterns were also recorded at every load increment. All the beams were tested up to failure. The maximum load carried by the reinforced concrete beam and the load Vs deflection curve are shown in figure 4.


Load in RC Beam
Load in KN
82
81
80
79
78
77
76
75
74
73
0.38 Control
0.38 20% FA
0.40 Control
0.40 20% FA
0.42 Control
0.42 20% FA
Different Mix Proportions


Load Vs Deflection Curve MI
Load in KN
50
40
30
20
10
0
0
10
20
Deflection in mm
Control Mix
M I


Load Vs Deflection Curve MII
Load in KN
60
50
40
30
20
10
0
0
10
20
30
Deflection in mm
M II
Control Mix

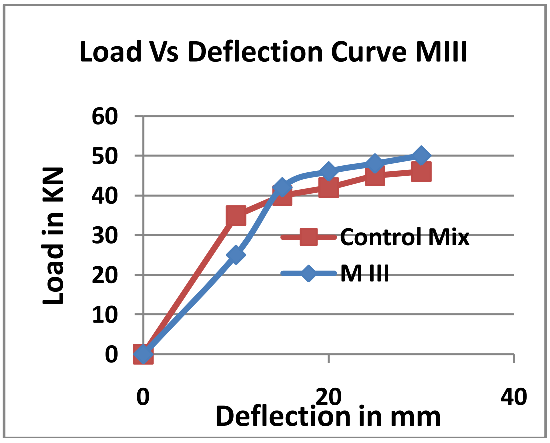


Figure 4: Load Vs Deflection Curve for MI, MII, MIII Mix

Modelling

A model is a simplified representation of an operation or process in which the basic aspects or the most important features of a typical problem under investigation are identified. Modelling is used to analyze a system or is supposed to control a system in the analysis. The engineers can built a descriptive model of system as a hypothesis of how the system could work, or try to estimate how an unforeseeable event would affect a system. Model is a useful tool to solve any specific problem. Model also help in finding avenues for research and improvements in a system. It can reflect complex physical structures and irregular geometric shapes. Correlation analysis is the relationship between the different parameters studied. The coefficient of the correlation can be obtained using following equation.

Correlation coefficient $r=Cov(x,y)/(\sigma_x * \sigma_y)$

The parameters used in this analysis are

X1 Weight of cement (Kg)
X2 Ratio of weight of Cement/Recycled Concrete Aggregate
X3 Weight of Fly Ash (Kg)
X4 Water/Cement Ratio

The table 4 to 9 shows the coding of various parameters and correlation matrix for various mix proportions using MS Excel software.

Table 4: Coding for 28 Days Cube Strength of MI Mix:

CEMENT	C/RA	FLYASH	W/C	$X1^2$	$X2^2$	$X3^2$	$X4^2$	X1*X2	X2*X3	X3*X4	X4*X1
X1	X2	X3	X4								
1.000	1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000	-1.000	1.000	-1.000
0.456	0.459	-0.333	-0.618	0.208	0.211	0.111	0.382	0.209	-0.153	0.206	-0.282

-0.090	-0.085	0.333	-0.136	0.008	0.007	0.111	0.018	0.008	-0.028	-0.045	0.012
-0.632	-0.629	1.000	0.481	0.399	0.396	1.000	0.231	0.398	-0.629	0.481	-0.304
0.731	0.735	-1.000	-0.818	0.534	0.540	1.000	0.669	0.537	-0.735	0.818	-0.598
0.214	0.217	-0.366	-0.418	0.046	0.047	0.134	0.175	0.046	-0.079	0.153	-0.089
-0.303	-0.301	0.267	0.090	0.092	0.091	0.071	0.008	0.091	-0.080	0.024	-0.027
-0.820	-0.819	0.900	0.727	0.672	0.671	0.810	0.529	0.672	-0.737	0.654	-0.596
0.470	0.478	-1.000	-0.618	0.221	0.228	1.000	0.382	0.225	-0.478	0.618	-0.290
-0.170	-0.014	-0.397	-0.181	0.029	0.000	0.158	0.033	0.002	0.006	0.072	0.031
-0.508	-0.507	-0.204	0.363	0.258	0.257	0.042	0.132	0.258	0.103	-0.074	-0.184
-1.000	-1.000	0.806	1.000	1.000	1.000	0.650	1.000	1.000	-0.806	0.806	-1.000

Table 5: Correlation Matrix for 28 Days Compressive Strength of MI Mix:

Parameter	CS	X1	X2	X3	X4	$X1^2$	$X2^2$	$X3^2$	$X4^2$	X1*X2	X2*X3	X3*X4	X4*X1
CS	1.000	0.564	0.564	0.132	-.564	-.173	-.166	-.059	-.139	-.169	0.056	-.128	0.116
X1		1.000	1.000	-.369	-1.000	0.000	0.000	0.172	0.000	0.000	-.109	0.116	0.000
X2			1.000	-.369	-1.000	0.000	0.000	0.172	0.000	0.000	-.109	0.116	0.000
X3				1.000	0.369	-.274	-.277	-.358	-.467	-.274	0.321	-.491	0.329
X4					1.000	0.000	0.000	-.172	0.000	0.000	0.109	-.116	0.000
$X1^2$						1.000	1.000	0.668	0.943	1.000	-.912	0.880	-.987
$X2^2$							1.000	0.669	0.945	1.000	-.912	0.881	-.988
$X3^2$								1.000	0.665	0.669	-.891	0.900	-.664
$X4^2$									1.000	0.943	-.886	0.917	-.972
X1*X2										1.000	-.912	0.880	-.987
X2*X3											1.000	-.973	0.912
X3*X4												1.000	-.895
X4*X1													1.000

Table 6: Coding for 28 Days Cube Strength of MII Mix:

CEMENT	C/RA	FLYASH	W/C	$X1^2$	$X2^2$	$X3^2$	$X4^2$	X1*X2	X2*X3	X3*X4	X4*X1
X1	X2	X3	X4								
1.000	1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000	-1.000	1.000	-1.000
0.456	0.459	-0.333	-0.618	0.208	0.211	0.111	0.382	0.209	-0.153	0.206	-0.282
-0.090	-0.085	0.333	-0.136	0.008	0.007	0.111	0.018	0.008	-0.028	-.045	0.012
-0.632	-0.629	1.000	0.481	0.399	0.396	1.000	0.231	0.398	-0.629	0.481	-0.304
0.731	0.735	-1.000	-0.818	0.534	0.540	1.000	0.669	0.537	-0.735	0.818	-0.598
0.214	0.217	-0.366	-0.418	0.046	0.047	0.134	0.175	0.046	-0.079	0.153	-0.089
-0.303	-0.301	0.267	0.090	0.092	0.091	0.071	0.008	0.091	-0.080	0.024	-0.027
-0.820	-0.819	0.900	0.727	0.672	0.671	0.810	0.529	0.672	-0.737	0.654	-0.596
0.470	0.478	-1.000	-0.618	0.221	0.228	1.000	0.382	0.225	-0.478	0.618	-0.290
-0.170	-0.014	-0.397	-0.181	0.029	0.000	0.158	0.033	0.002	0.006	0.072	0.031
-0.508	-0.507	-0.204	0.363	0.258	0.257	0.042	0.132	0.258	0.103	-.074	-0.184
-1.000	-1.000	0.806	1.000	1.000	1.000	0.650	1.000	1.000	-0.806	0.806	-1.000

Table 7: Correlation Matrix for 28 Days Compressive Strength of MII Mix:

Parameter	CS	X1	X2	X3	X4	$X1^2$	$X2^2$	$X3^2$	$X4^2$	X1*X2	X2*X3	X3*X4	X4*X1
CS	1.000	0.527	0.527	0.227	-.527	-.236	-.230	-.104	-.225	-.233	0.123	-.207	0.188
X1		1.000	1.000	-.369	-1.000	0.000	0.000	0.172	0.000	0.000	-.109	0.116	0.000
X2			1.000	-.369	-1.000	0.000	0.000	0.172	0.000	0.000	-.109	0.116	0.000
X3				1.000	0.369	-.274	-.277	-.358	-.467	-.274	.321	-.491	0.329
X4					1.000	0.000	0.000	-.172	0.000	0.000	0.109	-.116	0.000
$X1^2$						1.000	1.000	0.668	0.943	1.000	-.912	.880	-.987
$X2^2$							1.000	0.669	0.945	1.000	-.912	.881	-.988
$X3^2$								1.000	0.665	0.669	-.891	.900	-.664
$X4^2$									1.000	0.943	-.886	.917	-.972
X1*X2										1.000	-.912	.880	-.987
X2*X3											1.000	-.973	0.912
X3*X4												1.000	-.895
X4*X1													1.000

Table 8: Coding for 28 Days Cube Strength of MIII Mix:

Cement	C/Ra	Flyash	W/C	$X1^2$	$X2^2$	$X3^2$	$X4^2$	X1*X2	X2*X3	X3*X4	X4*X1
X1	X2	X3	X4								
1.000	1.000	-1.000	-1.000	1.000	1.000	1.000	1.000	1.000	-1.000	1.000	-1.000
0.456	0.459	-0.333	-0.618	0.208	0.211	0.111	0.382	0.209	-0.153	0.206	-0.282
-0.090	-0.085	0.333	-0.136	0.008	0.007	0.111	0.018	0.008	-0.028	-.045	0.012
-0.632	-0.629	1.000	0.481	0.399	0.396	1.000	0.231	0.398	-0.629	0.481	-0.304
0.731	0.735	-1.000	-0.818	0.534	0.540	1.000	0.669	0.537	-0.735	0.818	-0.598
0.214	0.217	-0.366	-0.418	0.046	0.047	0.134	0.175	0.046	-0.079	0.153	-0.089
-0.303	-0.301	0.267	0.090	0.092	0.091	0.071	0.008	0.091	-0.080	0.024	-0.027
-0.820	-0.819	0.900	0.727	0.672	0.671	0.810	0.529	0.672	-0.737	0.654	-0.596
0.470	0.478	-1.000	-0.618	0.221	0.228	1.000	0.382	0.225	-0.478	0.618	-0.290
-0.170	-0.014	-0.397	-0.181	0.029	0.000	0.158	0.033	0.002	0.006	0.072	0.031
-0.508	-0.507	-0.204	0.363	0.258	0.257	0.042	0.132	0.258	0.103	-.074	-0.184
-1.000	-1.000	0.806	1.000	1.000	1.000	0.650	1.000	1.000	-0.806	0.806	-1.000

Table 9: Correlation Matrix for 28 Days Compressive Strength of MIII Mix:

Para meter	CS	X1	X2	X3	X4	$X1^2$	$X2^2$	$X3^2$	$X4^2$	X1*X2	X2*X3	X3*X4	X4*X1
CS	1.000	0.463	0.463	0.323	-.463	-.295	-.290	-.188	-.311	-.292	0.199	-.301	0.255
X1		1.000	1.000	-.369	-1.000	0.000	0.000	0.172	0.000	0.000	-.109	.116	0.000
X2			1.000	-.369	-1.000	0.000	0.000	0.172	0.000	0.000	-.109	.116	0.000
X3				1.000	0.369	-.274	-.277	-.358	-.467	-.274	0.321	-.491	0.329
X4					1.000	0.000	0.000	-.172	0.000	0.000	0.109	-.116	0.000
$X1^2$						1.000	1.000	0.668	0.943	1.000	-.912	0.880	-.987
$X2^2$							1.000	0.669	0.945	1.000	-.912	0.881	-.988
$X3^2$								1.000	0.665	0.669	-.891	0.900	-.664
$X4^2$									1.000	0.943	-.886	0.917	-.972
X1*X2										1.000	-.912	0.880	-.987
X2*X3											1.000	-.973	0.912
X3*X4												1.000	-.895
X4*X1													1.000

Modelling Analysis

The predicted value of R for compressive strength as well as for acid test shows that the value is less than one or even negative. Table 10,11 and 12 shows the regression equation, various catagories of R value for compressive strength and R value for acid test is found that the predicted results fall with in the specified value and found suitable for construction. Since the percentage of variance of cement and fly ash content is equal, it gives same R value. So % of fly ash is selected as an independent variable. Compressive strength of different mix proportions are selected as a dependent variable. By altering the % of fly ash or Cement content there is a change in the compressive strength.

Table 10: Regression Equation

Type of Analysis	Equation
Regression Analysis	$A_0 - A_3 X_3 - A_4 X_4 - A_5 X_1^2 + A_7 X_3^2 + A_8 X_4^2 + A_9 X_1 X_2 - A_{10} X_2 X_3 - A_{11} X_3 X_4 + A_{12} X_4 X_1$

Table 11: Comparison between % of fly ash to Compressive strength

Age in Days	Multiple R	R Square	Adjusted R Square	Standard Error
M I				
28 days	0.252633	0.063824	-0.40426	0.974954
56 days	0.453456	0.205622	-0.19157	0.994485
90 days	0.640816	0.410645	0.115968	1.797591
M II				
28 days	0.697589	0.48663	0.229946	0.787639
56 days	0.531854	0.282868	-0.0757	1.203387
90 days	0.285015	0.081234	-0.37815	1.036906
M III				
28 days	0.750355	0.563033	0.344549	1.149163
56 days	0.592388	0.350924	0.026386	1.90307
90 days	0.374470	0.140228	-0.28966	2.736665

Table 12: Comparison between % of fly ash to % of Weight loss due to NaCl & H_2SO_4

	% of Wt loss due to Sodium chloride			
Mix	Multiple R	R Square	Adjusted R Square	Standard Error
M I	0.541879	0.293633	-0.05955	13.28878
M II	0.603569	0.364296	0.046443	12.60659
M III	0.612092	0.374656	0.061984	12.50344
	% of Wt loss due to Sulphuric acid			
M I	0.992821	0.985693	0.978539	1.891241

M II	0.992821	0.985693	0.978539	1.891241
M III	0.994002	0.988039	0.982059	1.729203

Conclusion

The following conclusions could be drawn from the present investigation.

1. Compressive strength of concrete shows that optimum level of replacement of cement by fly ash was 20% and optimum level of replacement of natural coarse aggregate was also found as 20% with RCA.
2. Compressive strength of concrete mixes with partial replacement show minimum percentage of voids.
3. Proposed concrete is environmental friendly as it will reduce the emission of CO_2 content.
4. The concept of this study may considered during mix design.
5. It could be finally concluded that fly ash and recycled concrete aggregate could be very conveniently used in structural concrete.
6. Various catagories of R value predicted using the excel software results fall with in the specified value and found suitable for construction
7. By using RCA the construction wastes can be reduced and a suitable code of practice for recycled concrete aggregates should be prepared in which strength parameters of RCA.

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