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Correlation between flexural strength of natural aggregate concrete and recycled aggregate concrete

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ABSTRACT - ***This paper presents the outcome of an experimental investigation to establish relation between the flexural strength of natural aggregate concrete (NAC) and recycled aggregate concrete (RAC). The relation between flexural strength of NAC and RAC is established for different percentage replacement of natural coarse aggregates by recycled coarse aggregates. This relation holds good for concretes having strength values between M20 and M30 grade. The correlation is generated for each percentage replacement in the form of linear equation. The high values of coefficient of correlation obtained for the flexural strength indicate a good degree of correlation.***

Key Words: *recycled aggregate concrete, correlation, flexural strength*

1. INTRODUCTION

The applications of recycled aggregate in the construction areas are wide and they have been used since long time ago. In the past, recycled aggregates were used mainly in low utility applications such as general fill. Recently, these aggregates started to be used for intermediate utility applications such as foundations for building and roads. Nowadays, the aggregates are used, to a very limited extent, in high utility applications such as for the elements of buildings or structural layers of roads [4].

None of the previous results indicated that recycled aggregate concrete is unsuitable for structural applications. Recent investigations on the performance of beams, columns, beam-column joints, and slabs made from recycled aggregate concrete all gave positive results, which further supports and encourages the possibilities of applying recycled aggregate concrete in civil engineering structures [5].

Numerous research and development projects on the reuse and recycling of demolished concrete and addition of by-products to concrete have been conducted. However, successful cases are limited to some exceptional materials. The several reasons why it is difficult to extend the sustainable use of concrete materials are: lack of suitable laws, lack of codes, specifications standards and guidelines, cost, poor image, lack of experience, low quality, variations in quality, too many kinds and too large amounts of by-products, inefficient supply system, lack of proper information [2].

In the present investigation, an attempt is made to establish a correlation for flexural strength between natural aggregate concrete and recycled aggregate concrete.
Concrete of M20 and M30 grade are tested for flexural strength, based on the results, a data base is developed and some novel equations for describing the correlation for flexural strength between natural aggregate concrete and recycled aggregate concrete are derived by using a statistical regression analysis.
This relation shall be established for concretes having strength values between M20 and M30 grade. The different percentage replacements of natural coarse aggregates by recycled aggregates considered are 0%, 10%, 20%, 30%, 40%, 50%, 80% and 100%..

2. RESEARCH SIGNIFICANCE

The flexural test is usually preferred for quality control of concrete for highway and airport pavements, where the concrete is loaded in bending rather than in axial tension [3]. It is essential to develop new information on the use of demolished concrete in structural applications and broaden its use in concrete industry [1]. An important aspect in the use of recycled aggregate in making concrete is to have an idea of the probable strength by replacing natural coarse aggregate by certain percentage of recycled coarse aggregate.

This article presents the correlation for flexural strength between natural aggregate concrete and recycled aggregate concrete for different percentage replacement of natural aggregate by recycled aggregate. The correlation equations established can be used in the designing the concrete mix proportions with recycled aggregate; the flexural strength of natural coarse

aggregate corresponding to a required flexural strength of recycled aggregate concrete (with a particular percentage replacement) serves as a target strength for designing the concrete mix proportions.

3. EXPERIMENTAL PROGRAM

3.1. MATERIALS

Ordinary Portland cement conforming to 43 grade as per IS: 8112-1989 with specific gravity 3.15 was used. The fine aggregate used was locally available natural sand conforming to zone-II grading requirements of IS 383-1970 with specific gravity 2.62 and fineness modulus 2.53, and the natural coarse aggregates used are 20 mm down size.

The recycled coarse aggregates used in the experimental study are obtained from field demolished reinforced cement concrete slab, beam and columns. The conversion of waste concrete into aggregates was carried out in plants meant for production of crushed aggregate from natural rock. The crushed product was screened and sizes below 4.75mm were rejected. The recycled coarse aggregates used in the experimental study were 20 mm down size. The recycled coarse aggregate was standardized to satisfy the grading requirements as per Indian standard I.S.383-1970.The physical properties of natural coarse aggregates and recycled coarse aggregates are given in table 1.

Table 1: Physical properties of natural coarse aggregates and recycled coarse aggregates

Properties	Natural coarse aggregates	Recycled coarse aggregates
Fineness modulus	7.70	7.74
Specific gravity	2.91	2.37
Water absorption (percentage)	0.40	2.50
Bulk density in loose state (kg/m^3)	1534	1337
Bulk density in compacted state (kg/m^3)	1776	1642
Impact value (percentage)	6.61	19.20
Crushing value (percentage)	21.42	32.50
Los Angles abrasion value (percentage)	8.36	25.79

3.2. MIX PROPORTION

The experimental investigation was based on M20 and M30 grade concrete. On the basis of the material properties, the proportioning of concrete mix was carried out in accordance to IS 456-2000 and as per the guidelines of IS 10262:2009. The mix proportions for the two concrete grades are given in table 2.

Table 2: Concrete mix proportions

Concrete grade	**Mix proportion** (Cement : Fine aggregate : Coarse aggregate)	**Water cement ratio**
M20	1 : 2.02 : 3.66	0.55
M30	1: 1.83: 3.30	0.50

3.3. PREPARATION OF SPECIMENS

The concrete ingredients were weighed according to their mix proportion and they were dry mixed. All the aggregates were maintained in saturated surface dry (SSD) state. The recycled aggregates were subjected to pre-wetting. The natural coarse aggregates were replaced by recycled aggregates in the proportion of 0%, 10%, 20%, 30%, 40%, 50%, 80%, and 100%, by absolute volume method. All the ingredients were dry mixed homogeneously. To this dry mix, the required quantity of water was added and mixed thoroughly in a pan mixer.

To establish a relation between flexural strength of normal aggregate concrete and recycled aggregate concrete, in addition to M20 concrete, M30 grade concrete mix is cast and its flexural strength determined. The test results of the two concrete grades were used to generate correlation between flexural strength of normal aggregate concrete and recycled aggregate concrete by performing regression analysis. To determine the flexural strength, nine beam specimens of size 100x100x500mm for each variation were cast and cured for 28 days. While testing the beam specimens as per IS:516-1959, two point loading was adopted on an effective span of 400 mm to get pure bending.

4. RELATIONSHIP BETWEEN FLEXURAL STRENGTH OF NAC AND RAC

The test results of M20 and M30 grade concrete with different percentage of recycled aggregates are used to establish the relations. The concrete without recycled aggregates (0% recycled aggregates) serves as natural aggregates concrete. The test results for each percentage of recycled aggregates is separately plotted against the test results of natural aggregates concrete (0% recycled aggregates). The correlation is generated for each percentage replacement in the form of linear equation

using Microsoft Excel software, which uses the transformed regression model method of analysis.

Table 3 gives the overall flexural strength test results for M20 and M30 grade concrete with different percentage replacement of natural aggregates by recycled aggregates, showing 0% replacement results as concrete with natural aggregates. Fig.1 to Fig.7 show the regression curves in the form of linear equation generated for different percentage of recycled aggregates.

The summary of the regression analysis output is given in table 4. The table gives the correlation for flexural strength between natural aggregate concrete (denoted by x) and recycled aggregate concrete (denoted by y), in the form of linear for different percentages of recycled aggregates. The table also gives the coefficient of correlation (r).

Table 3: Flexural strength results for M20 and M30 grade concrete with different percentage replacement of natural aggregates by recycled aggregates

Concrete grade	Flexural strength of concrete for different percentage replacement of natural aggregates by recycled aggregates (MPa)							
	0%	10%	20%	30%	40%	50%	80%	100 %
M20	4.96	4.88	4.84	4.64	4.44	4.40	3.88	3.72
	4.96	4.84	4.60	4.56	4.32	4.28	3.88	3.64
	4.92	4.80	4.72	4.48	4.48	4.24	3.84	3.60
	4.84	4.96	4.56	4.68	4.40	4.32	3.68	3.52
	5.00	4.84	4.80	4.60	4.40	4.24	3.76	3.52
	5.08	4.76	4.92	4.52	4.40	4.20	3.64	3.48
	4.88	4.88	4.88	4.60	4.36	4.24	3.68	3.56
	4.88	4.92	4.84	4.56	4.40	4.32	3.80	3.56
	5.04	4.80	4.60	4.52	4.48	4.36	3.76	3.52
M30	5.84	5.56	5.40	5.12	5.12	4.80	4.28	4.00
	5.80	5.60	5.24	5.16	4.96	4.80	4.20	4.08
	5.60	5.72	5.60	5.08	5.16	4.88	4.40	4.04
	5.92	5.52	5.68	5.28	5.08	4.84	4.40	4.04
	5.68	5.68	5.60	5.20	5.04	4.84	4.24	4.00
	5.56	5.80	5.20	5.20	5.04	4.96	4.48	4.16
	5.76	5.56	5.40	5.24	5.08	4.92	4.24	4.00
	5.60	5.76	5.52	5.12	5.00	4.84	4.32	4.08
	5.84	5.60	5.56	5.16	5.00	4.88	4.32	4.12

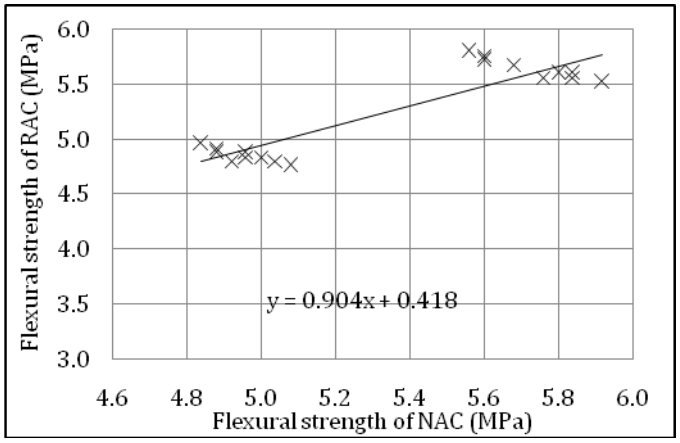

Figure 1: Regression curve to establish the flexural strength of concrete with 10% recycled aggregate.

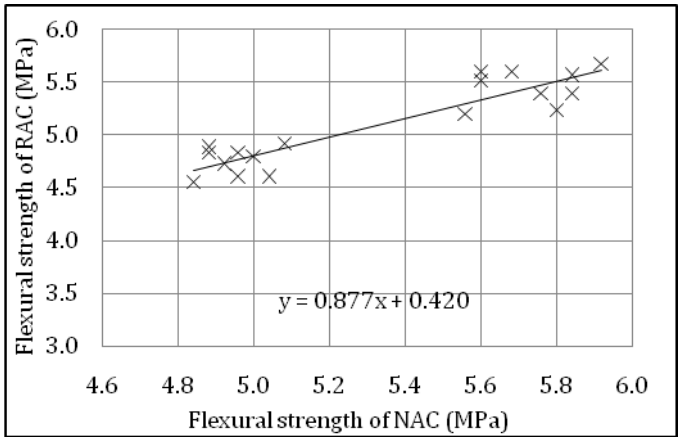

Figure 2: Regression curve to establish the flexural strength of concrete with 20% recycled aggregate.

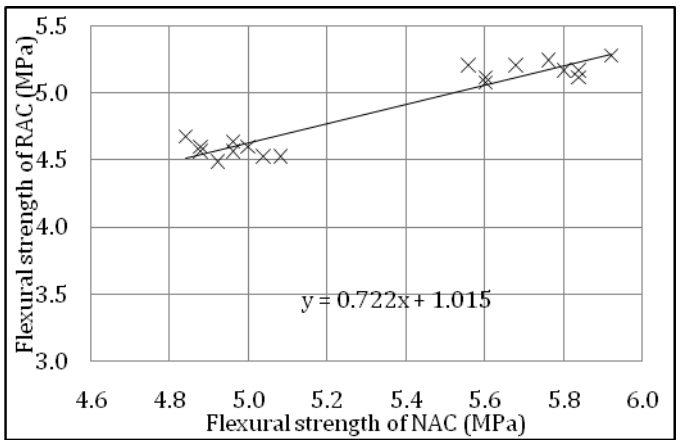

Figure 3: Regression curve to establish the flexural strength of concrete with 30% recycled aggregate.

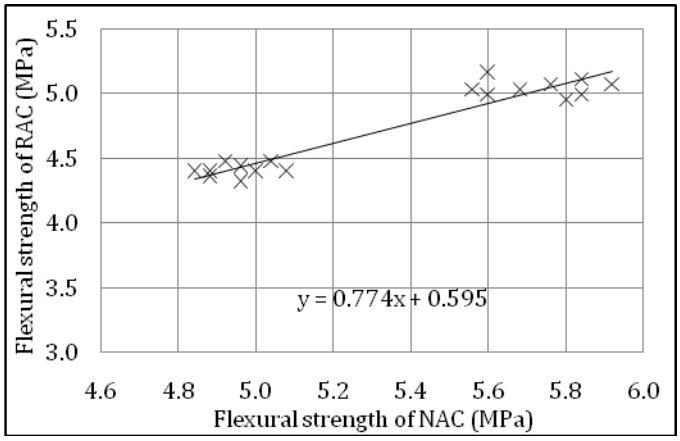

Figure 4: Regression curve to establish the flexural strength of concrete with 40% recycled aggregate.

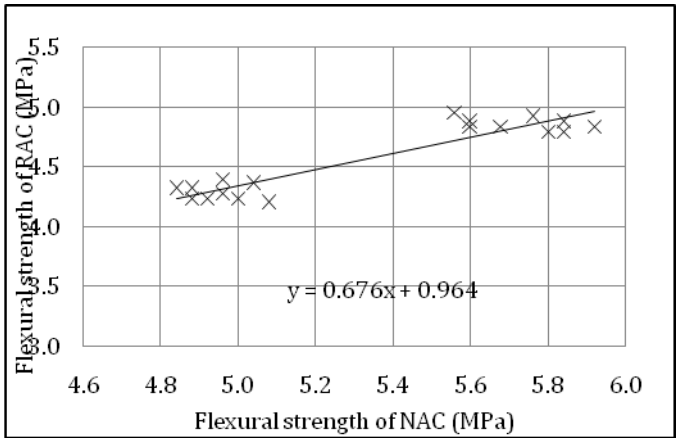

Figure 5: Regression curve to establish the flexural strength of concrete with 50% recycled aggregate.

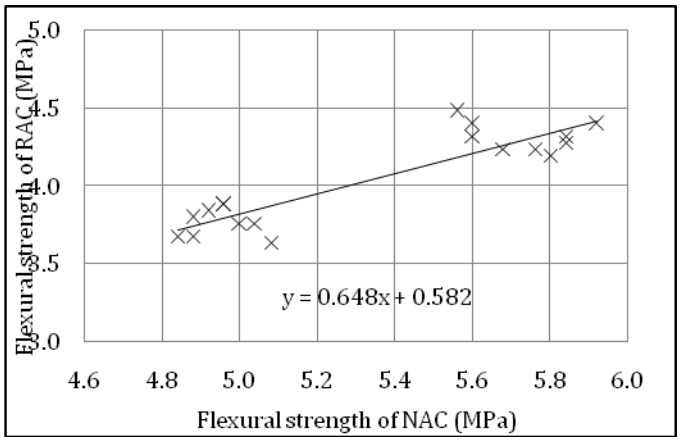

Figure 6: Regression curve to establish the flexural strength of concrete with 80% recycled aggregate.

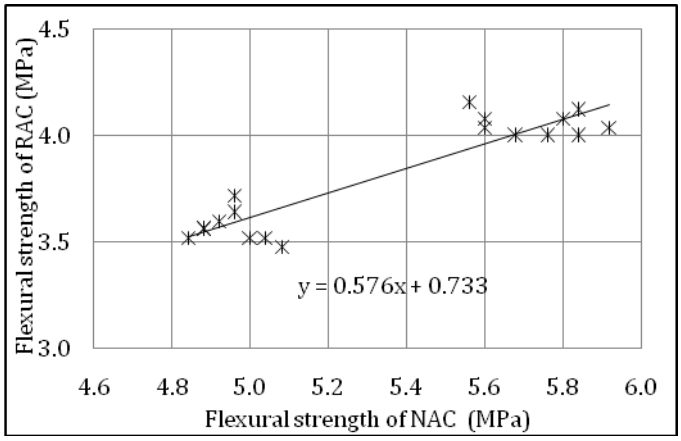

Figure 7: Regression curve to establish the flexural strength of concrete with 100% recycled aggregate.

Table 4: Summary of regression analysis and correlation between flexural strength of natural aggregates concrete and recycled aggregates concrete for different percentages of recycled aggregates

Percentage replacement of natural aggregates by recycled aggregates	Correlation between flexural strength of NAC and RAC	Coefficient of correlation 'r'
10%	y = 0.904x + 0.418	0.906
20%	y = 0.877x + 0.420	0.919
30%	y = 0.722x + 1.015	0.953
40%	y = 0.774x + 0.595	0.957
50%	y = 0.676x + 0.964	0.934
80%	y = 0.648x + 0.582	0.907
100%	y = 0.576x + 0.733	0.922

In the above table 'y' represents flexural strength of recycled aggregate concrete, and 'x' represents flexural strength of natural aggregate concrete.

5. OBSERVATIONS AND CONCLUSIONS

From the regression analysis it is observed that for any percentage of recycled aggregates, the coefficient of correlation is higher than 0.906 for the various percentage replacement considered.

Following conclusions may be drawn based on the test results, for concretes having strength values between M20 and M30 grade:

- It can be concluded that a linear relationship gives higher values for coefficient of correlation and may be preferred for its simplicity and suitability.

- The high values of coefficient of correlation obtained for the flexural functions indicate a good degree of correlation.
- The correlation equations established are useful in designing concrete mixes for different percentage replacement of natural aggregate by recycled aggregate.

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