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Research Paper

Flexural Fatigue Analysis of Concrete made with 100% Recycled Concrete Aggregates

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ABSTRACT

The paper presents results of an investigation to study the flexural fatigue performance of concrete beams made with 100% Coarse Recycled Concrete Aggregates (RCA). Experimental investigation has been carried out to obtain the flexural fatigue lives of concrete beam specimens of size 100 × 100 × 500 mm at various stress levels under four points flexural fatigue loading. The test data is used to plot the S-N curves and a simple regression analysis is used to propose an equation to estimate the flexural fatigue strength of concrete made with 100% RCA. The flexural fatigue performance of concrete made with 100% RCA has been assessed in terms of its mean and design fatigue lives. Two million cycles fatigue strength/endurance limit has also been estimated and compared with the previous studies available on Coarse Natural Aggregates (NA).

1 Introduction

Concrete is the most widely used construction material. Aggregates, the building blocks of the concrete globally, makes up to three - quarters of total concrete volume. However, increasing demand of coarse natural aggregates (NA) has set up an alarm to find substitutes to meet up the needs of construction industry. Simultaneously, a lot of waste aggregates produced from demolition of old civil infrastructures (C & D waste), buildings or highways are accumulating rapidly worldwide. Out of 48 million tons of solid waste generated in India, annual C & D waste makes up 25% [1]. The total quantum of C & D waste generated in India is estimated to be 11.4 to 14.69 million tons per annum, out of which seven to eight million tons consists concrete and brick waste [2].

Over last few decades, the use of coarse recycled concrete aggregates (RCA) is being explored as coarse aggregates in order to achieve sustainable construction [3]. Investigations have been carried out by researchers on the mechanical properties of concrete using 100% RCA as coarse aggregate, with same water–cement ratio, volume of aggregates and with

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same amount of cement and water as used in concrete made with NA. A large number of experiments are usually required to decide a suitable mix for obtaining the desired requirements of concrete made with recycled concrete coarse/fine aggregates. This is because of wide range of variability of engineering properties of RCA [4]. In this research the mechanical performance of concrete made with RCA under static loadings has been studied, by replacing NA partially and fully with RCA [5]. It is widely recognized that compressive strength of concrete containing recycled aggregate is generally lower than normal concrete with the same water/cement ratio because fracture process in concrete of recycled aggregate is not identical to normal concrete [6]. It is reported with the help of SEM observations that the normal strength RCA-cement interfacial zone consisted mainly of loose and porous hydrates whereas high performance RCA-cement interfacial zone consisted of dense hydrates [7]. To improve the strength of concrete made with RCA, a method has been investigated i.e. by applying acoustic emission technique for detecting micro-cracking in concrete under compression [8]. The compressive strength and stress–strain curves of recycled aggregate concrete (RAC) with different replacement percentages of RCA by experiments and proposed analytical expressions for the peak strain and the stress–strain relationship are obtained [9]. Similarly concrete made with RCA gives lower strengths (1-15%), lower modulus of elasticity (13-18%) and reduction in the fracture energy (27-45%) when compared with concrete made with NA [10].

Enormous literature is available on the rheological properties of fresh and mechanical properties of hardened concrete made with RCA under statically applied load. It has been found that concrete made with RCA can offer huge number of benefits to the construction industry by decreasing the problem of land filling as well as reducing the overall cost of the project. The applications of concrete made with RCA can be in bridge decks & piers, precast structural elements, pavements and high rise buildings. Since most of these structures are subjected to dynamic loading thus there is a call for investigating the performance of concrete made with RCA under fatigue loading.

In the past five decades, considerable research has been dedicated to investigate the fatigue behavior of concrete made with NA. For example, the fatigue behavior of plain concrete has been investigated by testing 462 cylindrical specimens under static and dynamic compression [11, 12]. Empirical expressions between the stress level (S), number of cycles (N) and probability of failure (P_f), S-N-P_f relationships, were derived on the basis of fatigue strength results [11]. The effect of variable stress levels on the fatigue behavior of concrete containing NA was investigated under flexure loading and it was reported that the Palmgren-Miner hypothesis might give conservative or unsafe predictions of the fatigue strength, depending on the loading schemes [12, 13].

Many researchers adopted a relationship between stress level S (S= f_{max}/f_r; f_{max} = *maximum fatigue stress,* f_r = *static flexural stress*) and the number of cycles to failure N [14, 15, 16]. The relationship established, known as the Wholer's equation, is as follows:-

$$S = \frac{f_{\max}}{f_r} = A + B\log_{10}(N) \tag{1}$$

where A & B are the experimental coefficients. These coefficients were calculated by various researchers for plain concrete as well as for fibre reinforced concrete. It has been concluded that the statistical distribution of fatigue life of plain concrete can be described by two-parameter Weibull distribution approximately [16]. The values of the coefficients *A & B* the Eq. (1) have been obtained as 1.1339 & -0.0889 for respectively in for concrete made with NA [17].

Researchers have also derived the modified form of fatigue equation, in which stress ratio R (f_{max}/f_{min}) is incorporated to the Wholer's equation, for calculating the fatigue life of conventional concrete. The modified form of Wholer's equation is given as:

$$S = \frac{f_{\max}}{f_r} = 1 - \beta(1-R)\log_{10}(N) \tag{2}$$

Where, β is material coefficient in Eq. (2). The R term is incorporated to simulate the loading conditions in actual structures where the minimum value of repeated stress is not zero. The values of coefficients β in Eq. (2) have been obtained as 0.0690, 0.0685 and 0.0630 for concrete made with NA [16, 17, 18].

The third form of the fatigue equation given by Eq. (3) is a power formula that has been used by the pavement researchers [19].

$$S = C_1(N)^{-C_2} \tag{3}$$

The distinctive feature of Eq. (3) is that the value of N increases as S becomes small. This equation satisfies the extreme boundary condition by having *N* approach infinity as *S* approaches zero. The values of coefficient C_1 & C_2 of Eq. (3) have been estimated as 1.2476 and 0.0516 respectively [17]. It has also been reported that there is diminution in variability in the distribution of fatigue life of concretes containing cement additions [20]. The stress range has been found to influence the fatigue performance of concrete considerably [12, 16, 21, 24].

However, very few studies have been carried out on the fatigue performance of concrete made with RCA. These studies have shown that the fatigue life decreases as the percentage of RCA is increased in replacement with NA [3, 22]. Thomas concluded that, quality of recycled concrete aggregates as well as new concrete made with RCA, both are observed to be influential on the fatigue response of concrete [23]. Since the fatigue test data of concrete made with RCA shows significant spread, even larger than plain concrete made with NA, and is unsystematic in nature. Attempts have been made to apply the probabilistic approach to predict its flexural fatigue strength. Keeping in view the wide potential of demolished concrete as source of quality aggregate, the number of investigations on fatigue behavior still lags behind and so the present investigation has been carried out to evaluate the flexural fatigue behavior of concrete beam specimens made with 100% RCA.

2 Experimental Procedure

In present study the NA were fully replaced with RCA. The mix containing RCA was cast in several batches and each batch consisted of seven beam specimens of size 100mm × 100mm × 500mm and 3 cube specimens of size 150mm × 150mm × 150mm. Out of seven beam specimens four were tested for flexural fatigue and three complementary static flexural tests were conducted under four point loading. Compressive strength tests were carried out on the three cube specimens under compressive testing machine.

2.1. Material used

In the present investigation, well graded RCA with maximum size of 12.5 mm, specific gravity value as 2.47 and aggregate crushing value around 25% were used as coarse aggregates, after processing in the Concrete Laboratory of the authors Institute. The gradation of RCA was intentionally made equivalent to the NA used in previous studies. Comparison between the grading curves of RCA and NA is shown in Figure-1 [17, 25]. It is observed that the gradation of RCA is similar to that of NA used in previous studies. Locally available coarse sand was used as fine aggregates in this study. Ordinary Portland cement (OPC) of grade 43 was used with value of specific gravity as 3.15 and Blain's surface area as 234 m^2/Kg. Cement was partially replaced with Class F fly ash upto 30% by weight. To obtain required workability of fresh concrete, polycarboxylic ether based superplasticizer was used as chemical admixture. Different mix proportions of concrete made with RCA are shown in Table-1.

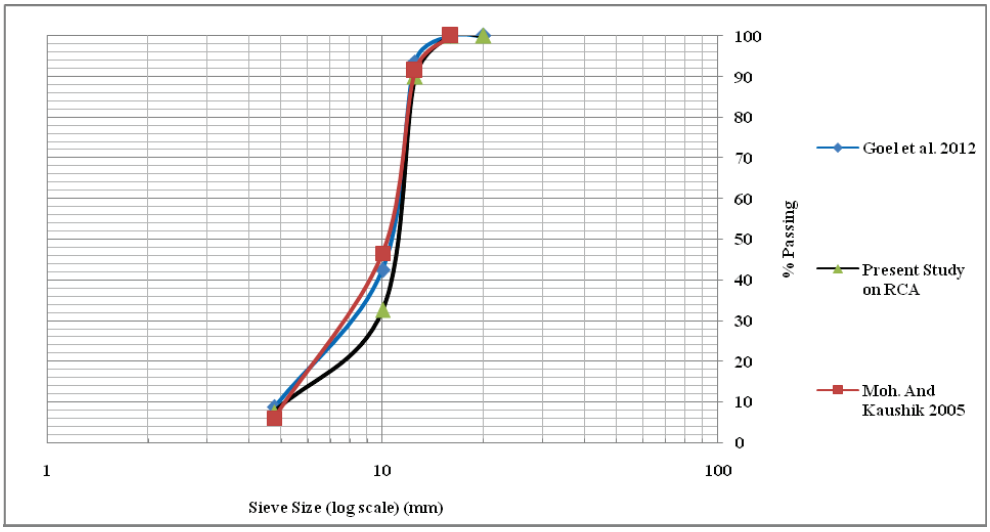

Fig. 1 – Comparison of grading curve of RCA with grading of NA in previous studies

Table 1- Mix proportions of Concrete made with RCA

Cement	Fly Ash	Fine Aggregates	Coarse Aggregates	Water	Super Plasticizer
343Kg	148 Kg	762 Kg	935 Kg	206 liters	0.25% by wt. of Cementitious Material

2.2. *Casting of specimens*

In the present study, workability of fresh concrete was tested using slump test. Slump values of mixes were observed to be in the range of 70 - 100mm. The specimens were cast in batches. Each batch constituted 7 beam specimens of size 100mm × 100mm × 500mm to investigate flexural properties and 3 cube specimens of size 150mm × 150mm × 150mm to test the compressive strength of concrete made with RCA. Mixing of concrete was done using drum mixer. Table vibrator was used for compaction of concrete specimens and vibrations were given at the rate of 3600rpm. Specimens were demoulded 24 hours after casting and then cured in laboratory conditions for more than 90 days in order to avoid any possible increase in the strength during the fatigue tests. The value/quality of each batch of concrete made with RCA was controlled by acquiring its 28- day compressive strength. Compressive strength of various batches of concrete made with RCA is shown in Table-2. Average of 28- day compressive strength values of all batches was obtained as 31.7 MPa.

Table 2- Compressive strength and static flexural strength test results of Concrete made with RCA

Batch No.	*28 days Compressive Strength (N/mm^2)*	*Static Flexural Strength (N/mm^2)*
1	*30.24*	*4.59*
2	*32.09*	*4.84*
3	*34.52*	*4.17*
4	*32.87*	*4.89*
5	*31.66*	*4.66*
6	*31.10*	*4.29*
7	*30.56*	*3.98*
8	*30.47*	*4.79*
Average	***31.7***	***4.53***

2.3. *Static flexural and flexural fatigue testing*

The estimation of static flexural strength was required prior to the selection of minimum and maximum stress limits for calculating fatigue tests. The static flexural strength tests on a particular batch of concrete made with RCA were conducted prior to the fatigue testing. Three specimens from each batch were tested under four point static flexural loads and the mean flexural strength was obtained as 4.53MPa for concrete beam specimens made with RCA and the same is tabulated batch-wise in Table-2. The left over beam specimens from each batch were tested for flexural fatigue. Servo controlled actuator (100kN) was used to conduct static flexural and flexural fatigue tests. The loading points were the same as for the static tests (i.e. four points loading) and the span was 450 mm. Flexural fatigue tests were conducted at different stress levels, S (S $= f_{max}/f_r$; f_{max} = *maximum fatigue stress*, f_r = *static flexural stress*), ranging from 0.85 to 0.55. The fatigue stress ratio, R (R $= f_{max}/f_{min}$), was kept constant at 0.10 throughout the investigation. All the tests were conducted at constant amplitude with sinusoidal loads applied at a frequency of 10 Hz. The number of cycle to failure of each beam specimen under fatigue loading was displayed on the cycle counter of MTS machine. The test was terminated as and when the specimen suffered the failure or an upper bound of 2×10^6 cycles was attained. The maximum limit of 2 million cycles was so chosen that if the specimen can sustain this much of cycles then it can be applicable for all the practical applications of concrete structures. The other factor was the testing of large number of specimens, so to make the testing less time consuming as well as economical, an upper limit of 2×10^6 cycles was chosen [25, 26, 27]. Table-3 shows the number of specimens tested at each stress level and the corresponding flexural fatigue results of concrete made with RCA.

Table 3- Laboratory fatigue life data (number of cycles to failure N) for concrete made with RCA

		Fatigue life data 'N'			
Stress Level S →	**Sample No.**	**0.85**	**0.75**	**0.65**	**0.55**
Concrete made with RCA	1	567	192[a]	67225	478640[b]
	2	789	4353	68738	567390[b]
	3	1054	5615	88969	763984[b]
	4	1188	9382	90371	1167919[b]
	5	1345	9792	120805	
	6	1765	12829	189763	
	7	1897	13702	249867	
	8	2098	14045	261009	
	9	2156	23020	319551	
	10	2354	26079	409876	

[a] Rejected as outlier by Chauvenet's Criterion, not included in analysis.
[b] Used for S-N curves only.

3 Results and Discussion

3.1. *Fatigue test results and S-N relationship*

The detailed representation of number of cycles to failure for each beam specimen under different stress levels is tabulated in Table-3. Some data points which gave drastically heterogeneous values were considered as outlier. Chauvenet's Criterion was applied to all the data points at different stress levels and the identified data points were then excluded from further analysis. The same criterion has been applied for the rejection of outliers in various studies on fatigue behaviour of conventional and self compacting concrete [27,28].

The relationship between the applied maximum stress f_{max} and number of load cycles *(N)* to failure of a specimen is represented by the *S-N* curves. The equation used for this relationship is given by Eq. (1). Figure-2 summarizes the test results in the form of *S-N* curves obtained from this study for concrete made with 100% RCA. Least square method based linear regression was used to calculate the values of coefficients A & B. The material coefficients calculated for concrete made with 100% RCA by using Eq. (1), are $A = 1.152$, $B = -0.098$.

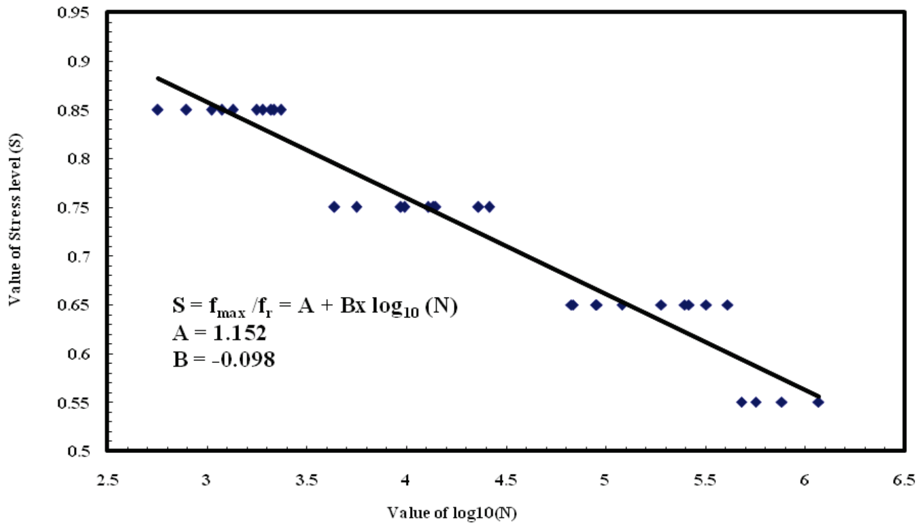

Fig. 2 – Calculation of coefficients A and B of Eq.(1) Concrete made with 100% RCA

The value of material coefficient β, estimated from the fatigue test data, makes the Eq. (2) applicable for the calculation of flexural fatigue strength of concrete made with 100% RCA. By utilizing the values of stress level (S), stress ratio (R) and number of cycles to failure $\log_{10}$ (N), the values of coefficient β were determined for each fatigue test. The average value of β for concrete made with 100% RCA was obtained as 0.0680 with a standard deviation of 1.17% and a coefficient of variation of 17.21%.

The coefficients C_1 and C_2 given in Eq. (3) can also be explored from the fatigue test data of concrete made with 100% RCA obtained in this study. Taking logarithm on both sides of Eq. (3), following expression is obtained

$$\log_{10}(S) = \log_{10}(C_1) - C_2 \log_{10}(N) \tag{4}$$

By regression analysis of Eq. (4) against the fatigue test data of concrete made with 100% RCA, the coefficients C_1 and C_2 of Eq. (3) can be determined. Figure-3 shows the analysis to obtain the values of coefficients C_1 and C_2 for concrete specimens. The calculated values of coefficients C_1 and C_2 for concrete made with 100% RCA are 1.309 and 0.060 respectively.

Thus, Eq. (1)-(3), can be used to estimate the flexural fatigue strength of concrete made with RCA, limited to the type of material used and size of specimens examined in this investigation.

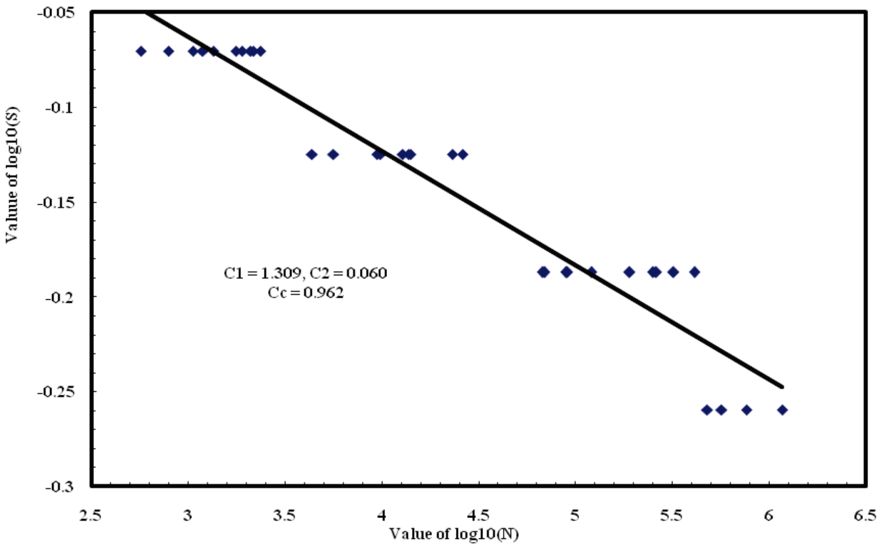

Fig. 3 – Calculation of coefficients C1 & C2 of Eq.(3) for Concrete made with 100% RCA

3.2. Fatigue life distributions of concrete made with RCA

A number of mathematical models have been used till date by various researchers to statistically depict the fatigue data. Weibull distribution is most commonly used for the statistical description of fatigue data of concrete due to its physically valid assumptions and sound experimental verification [16, 24, 29]. Thereafter, two-parameter Weibull distribution has been used persistently to determine the fatigue life distribution of plain as well as fibrous concrete mixes [25, 28, 30]. In the present study, the two-parameter Weibull distribution has been verified for the fatigue life distribution of concrete made with RCA and then distribution parameters were obtained by using S-N relationships.

This paper only used the results of Graphical method for verification of two parameter Weibull distribution for fatigue life of concrete made with RCA at various stress levels *(S)*.

3.3. Graphical method for verification of Weibull distribution

The reliability function L_N *(N)* may be written as follows [16, 24, 28, 29, 31, 32]:

$$\mathrm{L}_N(\mathrm{N}) = \exp\left[\frac{n}{u}\right]^{\alpha} \tag{5}$$

Where, n is the specific value of random variable N. α = shape parameter at stress level S; u = characteristic life at stress level S.

A graph is plotted between ln[ln(1/L_N)] and ln(n) and if at a particular stress level S the test data follows approximately a linear path then there is clear indication that the two-parameter Weibull distribution is an obvious assumption for the statistical description of fatigue life data at that stress level. Figure-4 shows the typical plot of fatigue life data of concrete made with 100% RCA at stress level (S) 0.85, 0.75 and 0.65. Figure-4 also indicates that the two-parameter Weibull distribution is a clear assumption for the distribution of fatigue life of concrete made with 100% RCA, as it gives approximately straight lines at all three tested stress levels.

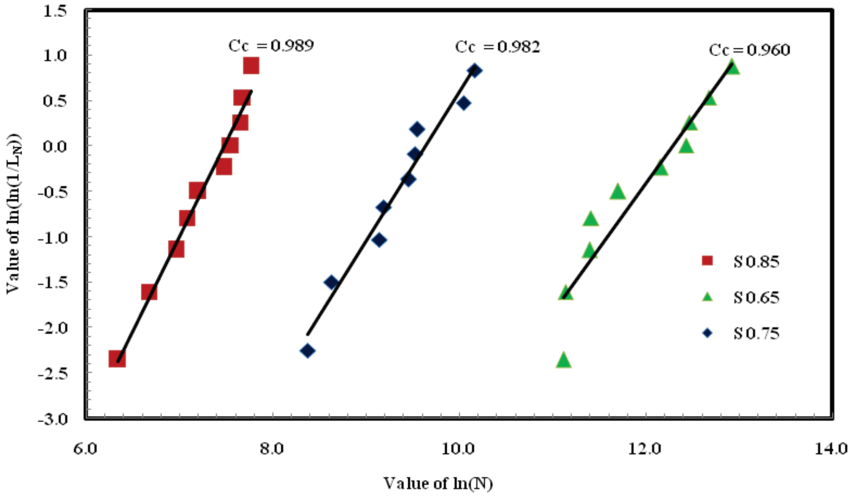

Fig. 4 – Graphphical analysis of Fatigue life data of concrete made with 100% RCA at different stress levels S

The corresponding values of correlation coefficient C_c were obtained as 0.9894, 0.9832 and 0.9602 for fatigue life data of concrete made with RCA at stress levels 0.85, 0.75 and 0.65 respectively. The validity of two parameter Weibull distribution was further verified as the values of correlation coefficients were more than 0.96.

3.4. Probability distribution parameters from S-N relationship

It has been shown in the previous section that the probability distribution of fatigue life of concrete made with RCA, at all stress levels, obtained in this investigation follows two-parameter Weibull distribution. Weibull distribution parameters have been estimated by various researchers by employing different methods at different stress levels on plain as well as fibrous concretes [16, 17, 25, 28]. However, there is a simpler method for obtaining distribution parameters, based on an approximate assumption of constant variance for all values of stress levels, i.e; from S-N relationship [16, 28]. Following S-N relation may be used for obtaining distribution parameters [16]:

$$N\left(\frac{f_{\max}}{f_r}\right)^{-m} = C \tag{6}$$

Where, m and C are empirical constants. Eq. (6) is more reasonable in the sense that the stress term is treated as a non dimensional form and thus may have wider applicability.

Taking logarithm on both sides of the Eq. (6):

$$\log_{10}(N) = \log_{10}(\mathrm{C}) - m\log_{10}\left(\frac{f_{\max}}{f_r}\right) \tag{7}$$

Eq. (7) can be written as:

$$Y = a + bX \tag{8}$$

where, $\mathrm{Y} = \log_{10}(N)$

$$X=\log_{10}\left(\frac{f_{\max}}{f_r}\right);\ a=\log_{10}(C),\ \text{and}\ b=-m$$

The regression analysis of the fatigue life data of concrete made with 100% RCA was carried out to obtain the values of the empirical constants ‘m’ and ‘C’ using Eqs.(6–8). The S–N relationship as shown in Eq. (6) can be represented as follows:

$$N\left(\frac{f_{\max}}{f_r}\right)^{-15,38}=134,58\quad \text{for concrete made with 100\% RCA} \tag{9}$$

If the fatigue life *(N)* is assumed to follow the Weibull distribution, the distribution parameters (α and u) can be evaluated using the following expressions [16, 27, 28].

$$\alpha^2=\frac{\pi^2}{6(\sigma)^2} \tag{10}$$

$$l_n(u)=\frac{0.5772}{\alpha}+l_n\left[C\left(\frac{f_{\max}}{f_r}\right)^{-m}\right] \tag{11}$$

Where, σ is the estimate of standard deviation or standard error of estimate of Y given X. The calculated value of standard error of estimate (σ) is 1.015925 for concrete made with 100% RCA which is slightly more than the standard error of estimate (σ) i.e, 0.98533, obtained from the fatigue data of concrete made from NA [33].

3.5. *Mean and design fatigue life*

For a given stress level, the mean fatigue life is estimated by the following relation.

$$E(N)=C\left(\frac{f_{\max}}{f_r}\right)^{-m}\exp\left[\frac{0.5772}{\alpha}\right]\Gamma\left(1+\frac{1}{\alpha}\right) \tag{12}$$

Where $\Gamma(\ )$ is a Gamma function, and *E(N)* is the mean fatigue life.

Table-4 shows the values of distribution parameters (α and *u*) and mean fatigue life (E[N]) obtained for different stress levels. The mean fatigue life of concrete made with 100% RCA obtained in the present investigation has been plotted and compared with that of concrete made with NA [16] in Figure-5. It can be seen that the mean fatigue life of concrete made with 100% RCA lies in a comparable range with that of concrete made with NA [16].

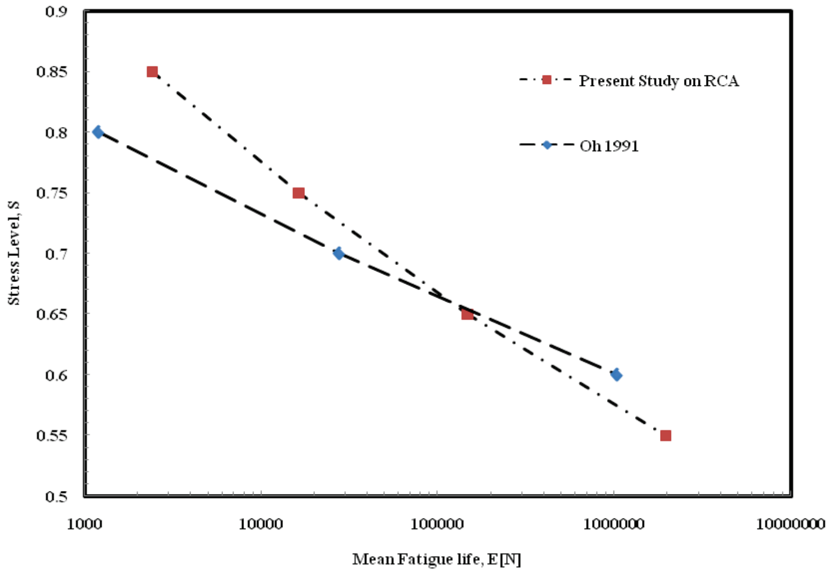

Fig. 5 – Mean fatigue life of concrete containing 100% RCA

Table 4- Values of Weibull distribution parameters and mean fatigue life at different stress levels

Mix	**Shape Parameter, α**	**S**	**0.85**	**0.75**	**0.65**	**0.55**
RCA(100)	1.261805	***u***	2590	17751	160350	2093622*
		E[N]	2407	16498	149029	1945812

The fatigue life data obtained for concrete made with 100% RCA in the present study exhibit large heterogeneity and lesser uniformity, which is usually expected in case of plain concrete at given stress level even under ideal laboratory conditions. Therefore, selection of design fatigue life N_D should be carried out in a manner that the probability of fatigue failure is low. The design fatigue lives of plain concrete and fibre reinforced concrete made with NA for different probabilities of failure (P_f) have been estimated in previous studies [16, 27, 28]. The design reliability may be expressed as L_N [N > N_D] = 1 - P_f, in which P_f is the probability of failure. Hence, for an allowed value of P_f, the corresponding design fatigue life N_D can be obtained using Eq. (13):

$$N_D = u\left[l_n \frac{1}{1-P_f}\right]^{\frac{1}{\alpha}} \tag{13}$$

The design fatigue lives have been calculated corresponding to acceptable probabilities of failure (P_f) i.e. 0.01, 0.05, 0.10, 0.15 and 0.25 so chosen by utilizing the distribution parameters values (α and u) obtained from Eq. (10 & 11), for the fatigue life data of concrete made with 100% RCA at different stress levels (S). Smaller acceptable probabilities of failure or higher reliability require the design fatigue life to be small. Table -5 shows the design fatigue life of plain concrete made from 100% RCA corresponding to selected acceptable failure probabilities at various stress levels. The design fatigue lives at all stress levels for various acceptable probabilities are plotted and compared with the literature available on concrete made with 100% RCA in Figures-6 (a-c). The comparison illustrates that the concrete made with 100% RCA shows sign of decrement in design fatigue life for various stress levels. Since fatigue test results show large scatter so to get more reliable values of design fatigue lives, the number of specimens required for testing should be large.

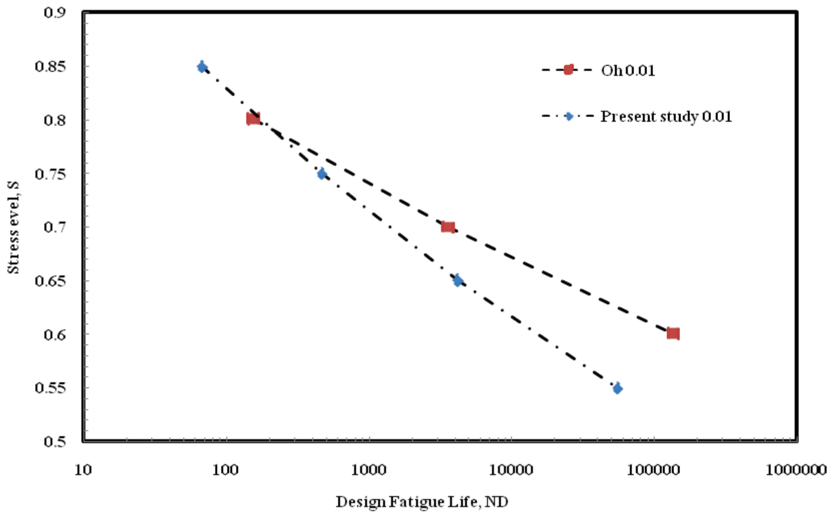

Fig. 6(a) – Comparison of design fatigue lives of plain concrete containing NA and RCA at $P_f = 0.01$

Table 5- Design fatigue lives 'N_D' at different probabilities of failure P_f for concrete made with 100% RCA

P_f _ Stress	**0.01**	**0.05**	**0.1**	**0.15**	**0.25**
			Design Fatigue Life		
0.85	68	246	435	614	965
0.75	463	1686	2983	4206	6613
0.65	4186	15233	26948	37993	59738
0.55	54651	198885	351848	496052	779971

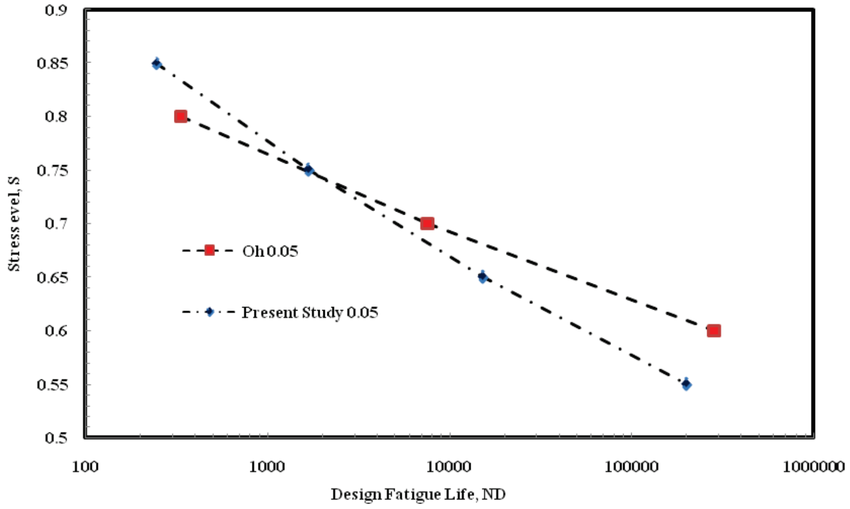

Fig. 6(b) – Comparison of design fatigue lives of plain concrete containing NA and RCA at $P_f = 0.05$

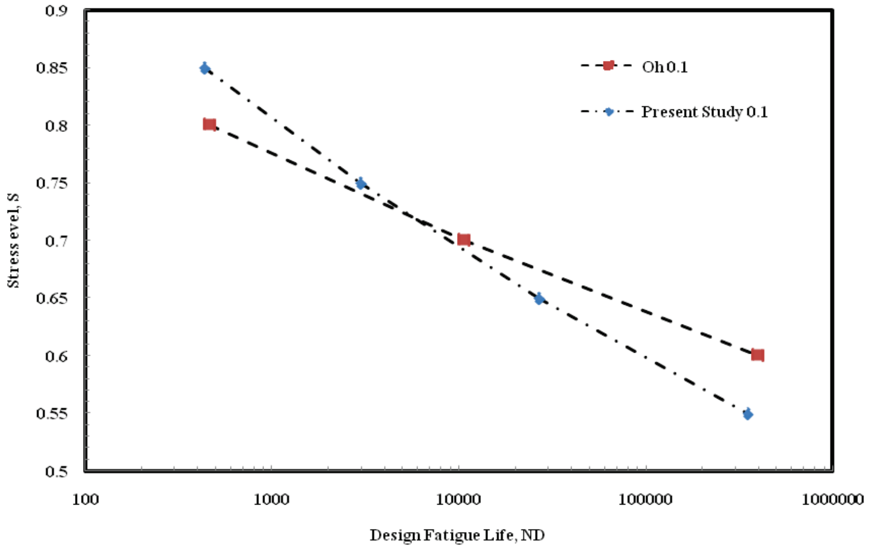

Fig. 6(c) – Comparison of design fatigue lives of plain concrete containing NA and RCA at $P_f = 0.1$

3.6. Two million cycles fatigue strength/endurance limit

Fatigue limit/endurance limit and flexural fatigue strength are necessary design parameters in almost all the important concrete structures like bridge decks, harbors, docks, multi-storey buildings, highways or airfield pavements etc. The design of these structures is based on the fatigue phenomenon i.e. the number of fatigue load cycles a concrete structure can withstand without failure.

A number of researchers interpret the endurance limit as the maximum stress on which the concrete can sustain two million cycles of repetitive loading. If the specimen could withstand the two million cycles without failure, it could last for all practical applications of concrete forever. Thus the upper limit chosen in the present study was two million cycles.

The fatigue performance, in the present investigation, has been obtained in terms of two million cycles fatigue strength/endurance limit by using S-N relationships. In previous studies on concrete made with NA [26, 27, 34], two approaches have been used to calculate the endurance limit, i.e. in terms of the applied maximum fatigue stress, expressed as a percentage of corresponding static flexural strength and in terms of actually applied fatigue stress. Both the approaches have been used in this investigation to analyze the fatigue performance of concrete made with RCA.

S-N diagram has been plotted in a semi logarithmic format by carrying out a linear regression on each set of fatigue data. Figure-7 represents the fatigue test results of concrete made with 100% RCA in terms of S-N relationship with actually applied fatigue stress. Similarly, S-N diagram for concrete made with 100% RCA was plotted with maximum fatigue stress expressed as a percentage of the average static flexural strength in Figure 8 and the same is compared with concrete made with NA [24, 25, 27]. The two million cycles fatigue strength/endurance limit obtained for concrete made with 100% RCA is 2.3 MPa in terms of actually applied fatigue stress and approximately 50% of its average static flexural strength in the present investigation.

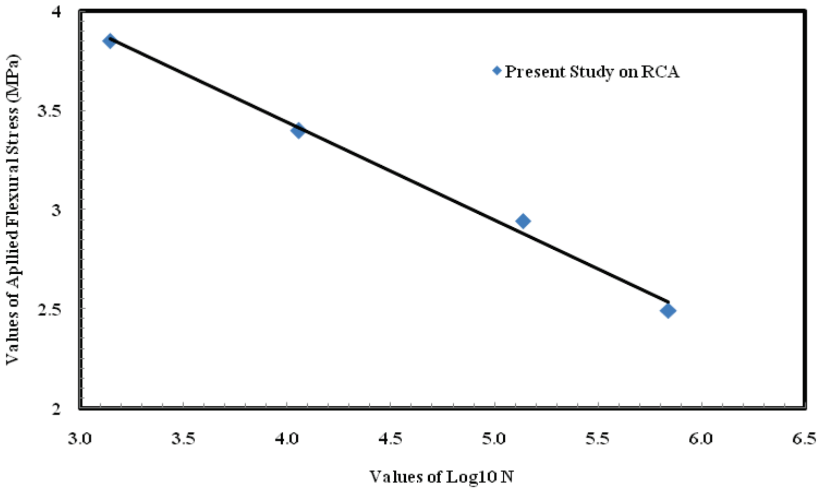

Fig. 7 – S-N relationship for fatigue strength/endurence limit based on actually applied fatigue stress for concrete made with 100% RCA

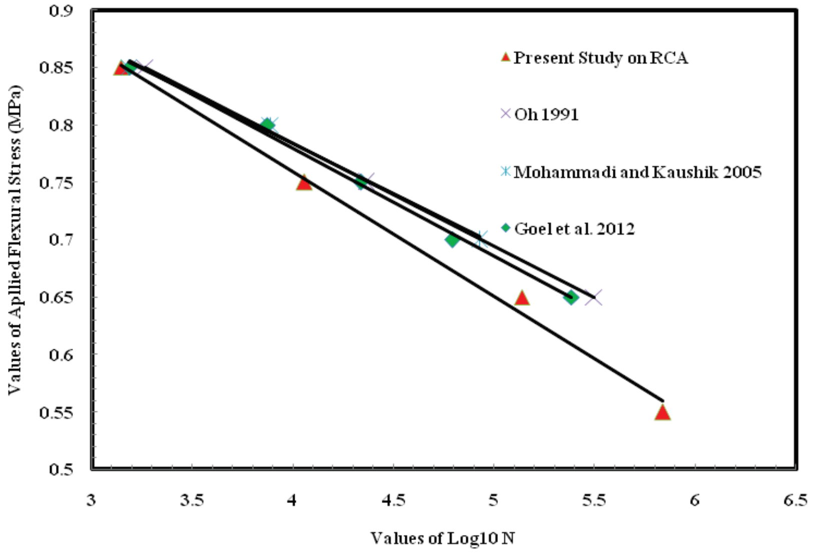

Fig. 8 – Comparison of fatigue strength/endurence limit based on percentage of average static flexual strength of plain concrete containing 100% RCA with concrete containing 100% NA

4 Conclusion

Fatigue behavior is becoming very important design parameter while designing multi storey buildings, bridges, decks, harbor and pavements etc. This is due to the fact that the flexural stresses induced in these structures are very critical in nature.

The present experimental investigation has been carried out to study the fatigue behavior of concrete made with 100% RCA. The flexural fatigue lives of concrete made with 100% RCA are obtained for various stress levels. S-N curves are generated using the fatigue data, and a regression analysis is carried out to predict flexural fatigue strength of the concrete made with 100% RCA. Subsequently the mean fatigue life of concrete made with 100% RCA, corresponding to different stress levels, has been obtained and compared with concrete made with 100% NA [24]. The design fatigue lives of concrete made with 100% RCA have also been calculated at all acceptable probabilities of failure corresponding to different stress levels and the results were compared with the design fatigue lives of concrete made with 100 % NA [24]. The two million cycles fatigue strength/endurance limit was also estimated for concrete containing 100% RCA and compared with the previous studies on NA [17, 24, 25]. The endurance limit obtained in the present study is 50% of the average flexural strength.

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