



Analysis of flexural fatigue failure of concrete made with 100% Coarse Recycled Concrete Aggregates



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HIGHLIGHTS

- Flexural fatigue performance of concrete made with 100% RCA has been investigated.
- Fatigue life distributions for concrete made with 100% RCA established.
- Higher variation in the fatigue life of concrete made with RCA has been observed.
- Lower two million cycles endurance limit for concrete made with RCA observed.

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ABSTRACT

The paper presents results of an investigation carried out to analyze the flexural fatigue performance of concrete beams made with 100% Coarse Recycled Concrete Aggregates (RCA) and its comparison with that of concrete made with 100% Coarse Natural Aggregates (NA). The fatigue performance of concrete beams made with RCA as well as NA has been assessed in terms flexural fatigue life distributions and two-million cycle endurance limit. Experiments were conducted to obtain the flexural fatigue lives of concrete beam specimens made with 100% RCA as well as 100% NA under different stress levels and further compared with literature available on NA. Specimens of size 100 mm × 100 mm × 500 mm were tested under four point flexural fatigue loads applied at a frequency of 10 Hz. It has been shown that the fatigue life distributions of concrete mixes made with 100% RCA and 100% NA can be modeled by the two-parameter Weibull distribution. The values of the shape parameters of the Weibull distribution obtained for concrete made with RCA have been found to be smaller than that of concrete made with NA in present investigation and previous studies on NA, thus indicating higher variability in the distribution of flexural fatigue life of concrete made with RCA viz. a viz. concrete made with NA. The two-million cycles endurance limit for concrete made with 100% RCA has been found to be 50%, which is about 8% and 7% lower than that of concrete made with NA in present and previous studies respectively.

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1. Introduction

Concrete industry uses 12.6 billion tonnes of raw materials each year and thus is the largest user of the natural resources in the world [26]. The global market for construction aggregates is expected to increase 5.2% per year until 2015, up to 48.3 billion tonnes [8]. In the USA, the Environmental Protection Agency [9] estimated that the generation of debris, from construction, demolition, and renovation of residential and non-residential buildings in 2003, was close to 170 million tonnes. According to Eurostat [11], the total amount of waste generated in the European Union, in 2010, was over 2.5 billion tonnes, of which almost 860 million

tonnes belonged to construction and demolition activities. India produces 23.75 million tonnes of construction and demolition waste annually. Dumping of construction and demolition waste requires lot of space and is becoming a severe environmental problem. Since maintenance and protection of environment is vital for the survival of human race, the demolished concrete waste materials can be converted into valuable coarse aggregates by breaking or crushing into suitable sizes, rather than dumping these on open land.

About 75% aggregates are required for the production of concrete, out of which coarse aggregates form 65%. It may be noted that the production of one tonne of Coarse Natural Aggregates (NA) results the emission of 4600 tonnes of carbon, whereas, production of one tonne of Coarse Recycled Concrete Aggregates (RCA) produces 2400 tonnes of carbon. Considering the global consumption

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Notations

α	shape parameter	L_N	survival probability
σ	standard deviation of the data sample under consideration	N	number of cycles to failure
$\Gamma()$	gamma function	P_f	probability of failure
μ	mean of the data sample	R	stress ratio = $f_{\min}/f_{\max}$
CoV	coefficient of variation of the data sample at a given stress level	S	stress level = $f_{\max}/f_r$
$f_{\max}$	maximum fatigue stress	u	scale parameter
$f_{\min}$	minimum fatigue stress	RCA	Coarse Recycled Concrete Aggregates
f_r	static flexural strength	NA	Coarse Natural Aggregates

of 10 billion tonnes per year of aggregates for concrete production, the carbon footprint can be determined for NA as well as for RCA [33].

When compared to NA, the density of RCA is generally lower as the density of adhered mortar is less than the underlying rocks [25]. As reported earlier, there is about 17% difference between the bulk densities of RCA and NA, with values of 2394 and 2890 kg/m³ respectively. Some authors have reported the density of RCA to be 7–9% lower than that of NA [24,37]. Also the water absorption of RCA and NA has been reported to be 4.9–5.2% and 1.0–2.5% respectively. The gradation curves for RCA lie in the range which is required for aggregates to be accepted for use in the concrete production [38]. The strength features of source concrete, effectiveness of crushing procedure, crushing method and particle size of RCA are signified by the amount of adhered mortar. The quality of RCA is inversely related to this adhered mortar [5]. The presence of attached mortar makes the RCA surface texture rough with an irregular shape. RCA possesses inferior mechanical properties such as low crushing strength, low impact resistance and low abrasion resistance than natural aggregate [17,24,37]. The characteristics and the amount of RCA in concrete can influence the strength properties of concrete. It has been reported that concrete made by replacing of 25% NA with RCA has comparable properties to concrete made with 100% NA at the same w/c ratio. However, to obtain the same compressive strength with 50–100% replacement of NA with RCA, w/c ratio needs to be lowered by 4–10% [10]. It is reported that the percentage reduction in the compressive strength of concrete made with 100% RCA ranges from 15% to 30% compared to that of concrete made with 100% NA [6,7,22]. It has also been observed that the splitting tensile strength of concrete made with RCA is less affected by RCA content. Investigations indicated that concrete made with RCA either shows comparable or superior split tensile strength than that of concrete made with NA [50,51]. This enhanced performance in tensile strength is attributed to the increased absorption by adhered mortar layer on recycled aggregates as well as an effective ITZ, consequently improving the bond between aggregates and the mortar matrix [10]. Improvement in tensile strength of concrete made with RCA has also been correlated to the higher strength of concrete source from which RCA is produced [52].

Majority of the research reported in literature on concrete made with RCA has been directed on rheological properties of fresh and mechanical properties of hardened concrete under statically applied loads. Concrete made with RCA can offer huge benefit to the construction industry by reducing the overall cost of the project. The applications of concrete made with RCA can be in bridge decks and piers, pavements, high rise buildings, rapid transport systems, tunnel linings, dams, precast structural elements, storage tanks, etc. Many of these structures are influenced by the fatigue

loading, thus necessitating the need to investigate the performance concrete under fatigue loads.

For the last many decades, several research studies have been conducted to investigate the fatigue behavior of concrete made with NA. Major properties investigated are S-N relationships; Weibull parameters; endurance limit; mean and design fatigue lives [1]. Analysis of various prediction models were carried out in these investigations for evaluating the fatigue performance of concrete. It has been established that the range of stress influences the fatigue strength of concrete considerably [3,19,28,30,31]. The influence of the frequency of loading has been investigated by a number of researchers [2,3,4,12,21,35,43]. In general, variation in the loading frequency in the range of 1–30 Hz has insignificant effect on the fatigue behavior of concrete if the maximum stress level is kept less than about 75% of the static strength [3,36].

Reduction of variability in the distribution of fatigue life of concrete containing cement additives as compared to control concrete has been reported [20]. It was investigated that at 75% of the maximum flexural stress level, the number of repetitions to failure was 2000 and 20,000 cycles for lean mixtures of cement and cement-fly ash concretes, respectively [13]. Similarly, it was reported that concrete with equivalent or higher compressive and fatigue strength could be obtained with cement replacement of 25% by weight of low-calcium fly ash or 50% by weight of high-calcium fly ash [45]. It has also been evaluated that the fatigue limit values were 0.65 for no-fly ash concrete and 0.70 for high-volume Class F fly ash concrete. Moreover, the plain concrete had compressive fatigue strength ratio of 56% in air at the same level of survival [32]. Static flexural and flexural fatigue strength of concrete have been found to decrease when cement replacement with fly ash increased from 15% to 55% by weight. The decrease was smaller for the 15% fly ash mixture [29].

However, very limited research has been carried out on the fatigue performance of concrete made with RCA. It has been shown that the endurance limit decreased as expected with increase in replacement of NA with RCA [18,44,47,48]. It may be noted that relatively less number of specimens have been tested in these investigations. Due to statistical nature of fatigue phenomenon, large variability usually occurs in the fatigue life data of concrete, at a given stress level, even under carefully controlled test procedures. Therefore, in investigations wherein the probabilistic analysis of the fatigue data is the prime objective, as in this work, it is desirable to test relatively more number of specimens at a given stress level to obtain data which is statistically significant. This approach has been adopted by previous investigators i.e. [27,31,40,42] for concrete made with NA.

Keeping in view the wide potential of demolished concrete as source of RCA, the investigations on its fatigue behavior still lags behind and thus the present investigation has been carried out to

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