UTILIZATION OF IRON ORE TAILINGS AS REPLACEMENT TO FINE AGGREGATES IN CEMENT CONCRETE PAVEMENTS

B N Skanda Kumar[1], Suhas R[2], Santosh Uttam Shet[3], J M Srishaila[4]

[1]*Assistant Professor, Department of Civil Engineering, DSCE, Bangalore, India*
[2]*Assistant Professor, Department of Construction Technology and Management, DSCE, Bangalore, India*
[3]*Student, M.Tech, Highway Technology, DSCE, Bangalore, India*
[4]*Assistant Professor, Department of Civil Engineering, DSCE, Bangalore, India*

Abstract

From the stage of quarrying the raw materials to the completion of project has resulted in stripping of earth for the use of exhaustible resources and has caused an adverse effect on the nature. This has resulted in an acute shortage of fine as well as coarse aggregates, obligating to explore the replacement for these materials without compromising the quality, environmental and economic factors. In recent years, almost every mineral producing country is facing the problem of better utilization of mine waste because of its accumulation and lack of suitable storage space. In the present study Iron Ore Tailings (IOT) procured from Kudremukh Lakya Dam site (KIOCL Ltd.) are used as partial replacement to fine aggregates at levels of 10, 20,30,40,50 percent and the basic material properties, strength parameters are studied. It is found that as the IOT percentage increases in the mix workability is reduced. At 40percent replacement level the 28days compressive strength is more than the reference mix and other replacement percentage mixes. Flexural strength is observed maximum for reference mix. Quality of concrete mixes is found good from Ultrasound Pulse Velocity test). Flexural fatigue analysis is carried out on mix with 40percent IOT replacement at stress ratios 0.65, 0.7 and 0.75 compared with IRC model for number of repetitions using log normal distribution. Up to 0.7 stress ratio it showed more number of repetitions than IRC and at higher stress ratio mix with IOT achieved failure earlier.

Keywords: *Iron Ore Tailings, Flexural fatigue, Pulse velocity, Stress ratio.*

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1. INTRODUCTION

India is one of the important iron ore producers and exporter in the world. However, the rapid growth in production, especially from large surface mines, have already caused ecological imbalance in their respective regions and emerge as the source of main environmental hazards. The waste/tailings that are ultra-fines or slimes, having diameter less than 150 μm, are not useful and hence are discarded. In India approximately 10 – 12 million tons of such mined ore is lost as tailings. The safe disposal or utilization of such vast mineral wealth in the form ultra-fines or slimes has remained a major unsolved and challenging task for the Indian iron ore industry. In future, the proportion of iron ore wastes generated is likely to increase due to higher demand for iron ore as a number of steel plants have been planned for future in many parts of the country. In order to reduce the adverse impact of indiscriminate mining of natural sand, iron ore tailings which is the waste products of mining industries is used as an alternative to the river sand in the manufacturing of concrete. The KIOCL company which was a leading company in India in the mining activities of iron ore has dumped about 200 million metric tons of iron ore tailings at Lakya Dam. The company conducted mining for more than 25 years in Kudremukh until it stopped mining in 2005. In the process of beneficiation, it has dumped iron ore tailings in Lakya Dam, which was constructed as an ecological dam for this purpose.

1.1 Objectives

- Determining the properties of iron ore tailings and comparing the results with the conventional sand.
- Partial replacement of iron ore tailings with the conventional sand.
- Determining the strength properties of concrete for 3, 7, 28 and 56days.
- Development of fatigue model by log normal distribution and comparing with IRC.

2. LITERATURE REVIEW

2.1 General

An attempt is made with Iron Ore Tailings as a partial replacement of fine aggregate in the concrete. The main aim of this section is to present an overview of research work carried out by various researchers in the field of Iron Ore Tailings and replacement of fine aggregates.

Sujing Zhao et al (2014) [10] investigated that 100% replacement of natural aggregate by the tailings significantly decreased the workability and compressive strength of the material. Also showed, when the replacement level was no more than 40%, for 90 days standard cured specimens, the mechanical behavior of the tailings mixes was comparable to that of the control mix, and for specimens that were steam cured for 2 days, the compressive strengths of the tailings mixes decreased by less than 11% while the flexural strengths increased by up to 8% compared to the control mix. Concluded stiffness and hardness of the tailings were on average lower than those of the natural sand. Incorporation of the tailings into the mix increased the water demand and lowered the flow ability of the fresh material due to the high specific surface area and rough surface of the tailings.

Xiaoyan Huang et al (2013) [12] used iron ore tailings powder as cement replacement for developing green ECC (Engineered Cementitious Composite) and concluded that the replacement of cement by less reactive IOTs in ECC reduces the matrix fracture toughness. Increasing the replacement of cement beyond 40% replacement ratio reduces the compressive strength of ECC.IOTs in powder form are used to partially replace cement to enhance the environmental sustainability of ECC. Mechanical properties and material greenness of ECC containing various proportions of IOTs are investigated. The newly developed versions of ECC in the study, with a cement content of 117.2–350.2 kg/m3, exhibit a tensile ductility of 2.3–3.3%, tensile strength of 5.1–6.0 MPa, and compressive strength of 46–57 MPa at 28 days. The replacement of cement with IOTs results in 10–32% reduction in energy consumption and 29–63% reduction in carbon dioxide emissions in green ECC compared with typical ECC.

Aravindkumar.B.Harwalkar et al (2012) [1] studied on fatigue behavior of high volume fly ash concrete (HVFAC) and conventional concrete (PCC) under constant amplitude fatigue loading. Comparative studies on total number of 95 prism specimens of HVFAC and 100 prism specimens of PCC were tested under constant amplitude fatigue loading. All prism specimens were of size 75mm×100mm×500mm and were tested under flexural fatigue loading using haiver sine wave loading. Frequency of fatigue loading was kept at 4Hz. Studies indicated that lognormal model was acceptable for fatigue life distributions at all stress levels for both HVFAC and PCC. The parameters of distribution exhibited dependency on stress levels and type of concrete. Relations between stress level and fatigue life were developed for both HVFAC and PCC. These relations were found to be dependent on type of concrete. A total number of 24 prism specimens were tested under compound fatigue loading. It was found that Miner's hypothesis gives both unsafe and over safe predictions of failure. Miner's sum was found to be dependent on type of compound loading and sequence of loading.

3. MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1 Cement

Ordinary Portland cement of Grade 53(Birla Super) conforming to IS: 12269-1987 is used in the present studies. The tests performed on this cement according to IS:4031-1998 is summarized in table 3.1

Table 3.1 Properties of cement

Sl. No.	Characteristics	Results	As per IS:12269-1987
1	Normal Consistency (%)	32	-
2	Initial setting time(minutes)	60	Not less than 30
3	Final setting time(minutes)	330	Not more than 600
4	Specific gravity	3.10	3.15

3.1.2 Coarse Aggregates

Coarse aggregates are those which are retained on IS sieve size 4.75 mm. In the present study, aggregates of size 20mm and 10mm in the proportion 55 % and 45% by weight respectively are used. Proper grading of aggregates is essential to get required strength as per design mix. Tests conducted to check the physical properties and there results are tabulated in Table 3.2.

Table -3.2: Physical properties of Coarse aggregates.

Sl. No.	Tests	Results	Requirements	IS Codes
1	Specific gravity	2.63	-	IS-2386 part III
2	Crushing value	28.6%	Max 30%	IS-2386 part IV
3	Abrasion value	28.0%	Max 30%	IS-2386 part IV
4	Impact value	26.25%	Max 30%	IS-2386 part IV
5	Water absorption	0.45%	-	IS-2386 part III
6	Combined elongation and Flakiness Indices	29%	Max 30%	IS-2386 part I

3.1.3 Fine Aggregates

River sand conforming to IS: 383-1970 (reaffirmed 1997) is used for the present investigation as fine aggregate. Tests on sand as per IS specifications are conducted and results are as shown in table 3.3.

Table-3.3: Physical properties of Fine aggregates

Sl. No.	Characteristics	Value
1	Specific gravity	2.53
2	Water absorption	0.88
3	Moisture content (%)	1.905
4	Fineness modulus	3.629
5	Grading zone	Zone II

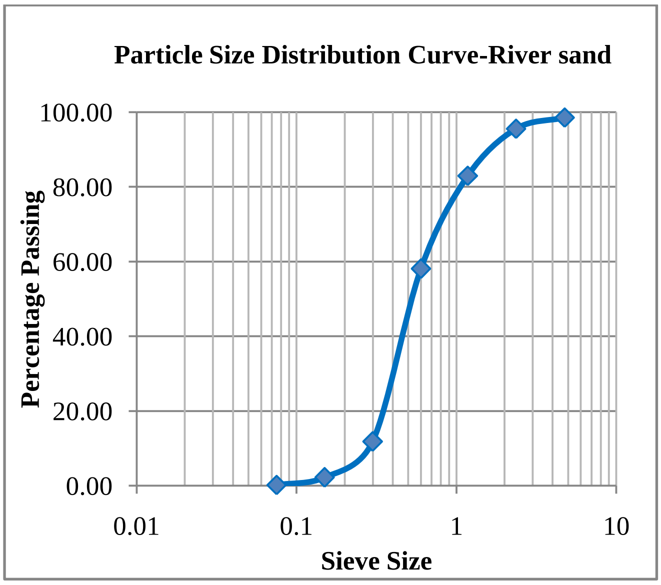

Fig 3.1 Particle size distribution curve for conventional river sand

3.1.4 Iron Ore Tailings

Tailings are the materials left over, after the process of separating the valuable fraction from the worthless fraction of an ore. Tests on Iron Ore Tailings procured from Kudremukh, Lakya Dam site were conducted. The properties of the IOTs are indicated in table 3.4

Fig 3.2 Iron Ore Tailings

Table -3.4: Physical properties of Iron Ore Tailings

Sl. No.	Characteristics	Value
1	Specific gravity	3.33
2	Water absorption	3.97
3	Moisture content (%)	6
4	Fineness modulus	2.545
5	Grading zone	-

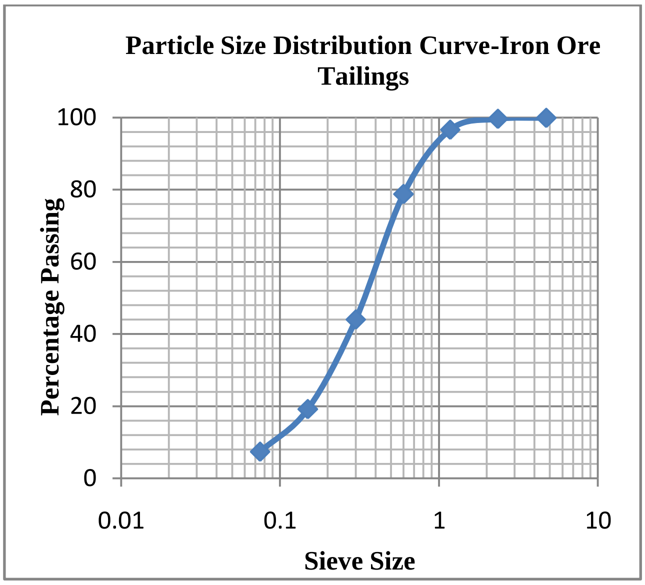

Fig 3.3 Particle size distribution curve for IOT

4. RESULTS AND DISCUSSIONS

The results of fresh properties of concrete such as slump and compaction factor are determined and hardened properties such as Compressive Strength, Ultrasound Pulse Velocity, Flexural Strength and fatigue life are presented and discussed below.

4.1 Rheology of Concrete

Fresh Concrete or Plastic Concrete is a freshly mixed material which can be moulded into any shape. The relative quantities of cement, aggregate and water mixed together to control the properties of concrete in the wet state as well as in the hardened state.

4.2 Measurement of Workability

Tests adopted for measurement of workability in the present investigation are

1. Slump Test
2. Compaction factor Test

Table 4.1: Measurement of Workability

Designation of mix	Slump in mm	Compacting Factor
NC	67	0.90
Mix1	55	0.90
Mix2	38	0.88
Mix3	25	0.89
Mix4	25	0.88
Mix5	23	0.87

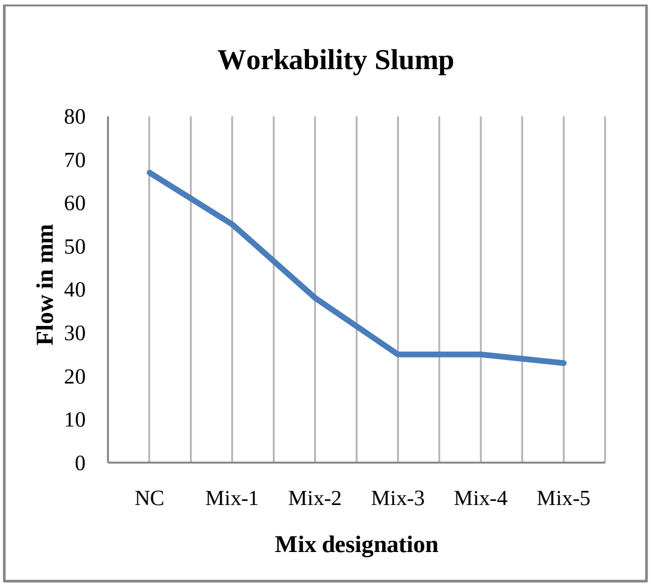

Fig 4.1 Slump chart

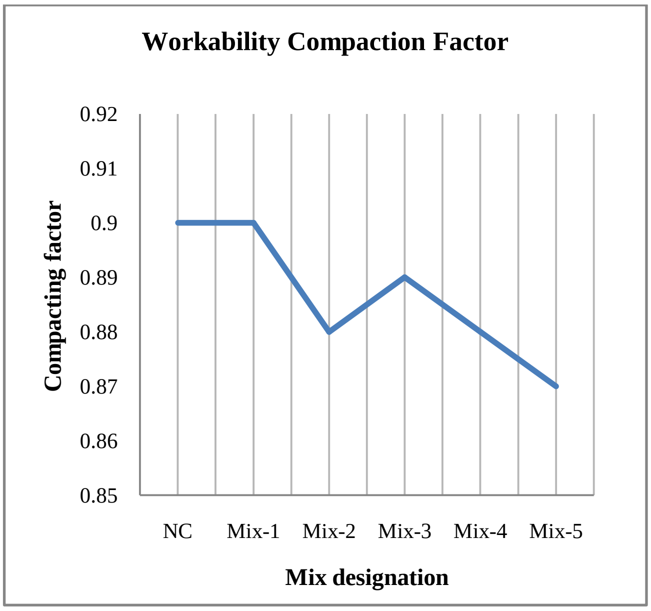

Fig 4.2 Compaction factor chart

4.3 Compressive Strength

The cube specimens were tested in Compression Testing Machine as given in annexure3 after specified curing period for different percent of IOT replacement Mix1(10%IOT),Mix2(20%IOT),Mix3(30%IOT),Mix4(40% IOT) and Mix5(50%IOT) and for normal concrete mix. The compressive strengths after respective curing periods are noted in table 4.2.

Table 4.2: Compressive strength

Composition	Compressive strength in N/mm^2			
	3day	7day	28day	56day
NC	23.83	27.17	38.58	41.05
Mix1	23.03	32.92	49.28	50.22
Mix2	21.65	34.15	50.27	53.13
Mix3	24.27	35.02	51.59	55.13
Mix4	26.08	32.48	55.10	56.59
Mix5	25.94	38.91	53.76	54.10

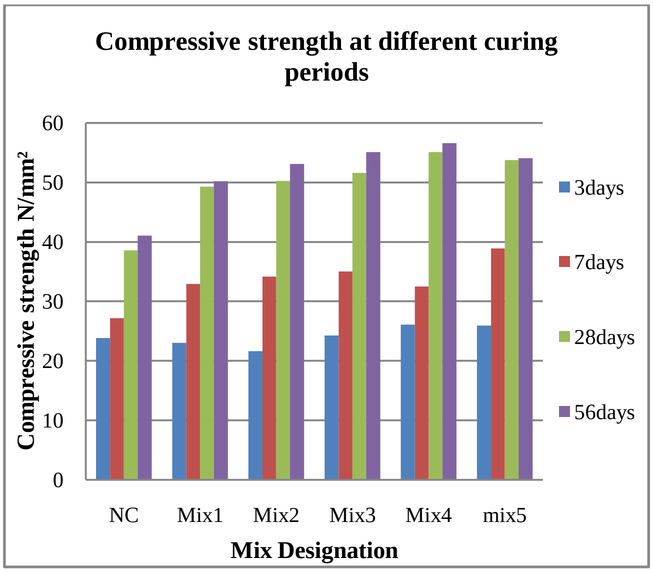

Fig 4.3 Graphs showing Compressive Strength Development of Different Mixes

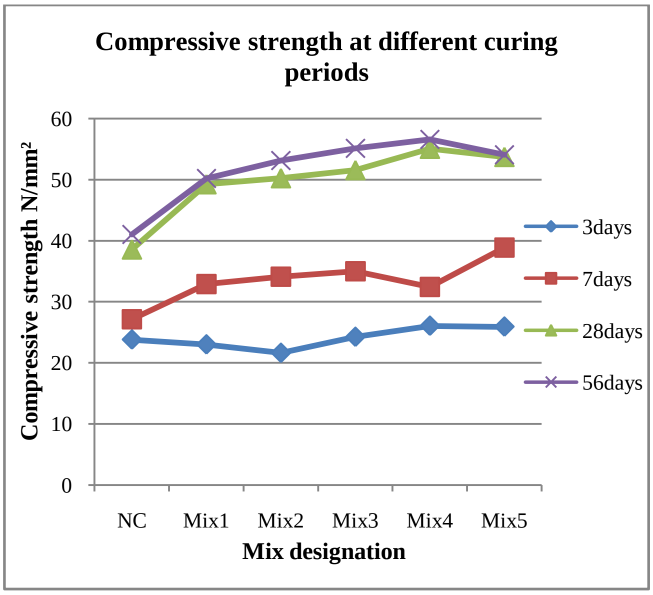

Fig 4.4 Graphs showing Compressive Strength Development of Different Mixes

4.4 Flexural Strength

The specimens were tested in flexural testing machine as per IS codes and the flexural strength is calculated depending on the failure plane position from the supports. Values obtained for concrete with different IOT replacement levels and for the normal concrete mix are as note in table 4.3.

Table 4.3: Flexural strength

Composition	Flexural strength in N/mm^2			
	3day	7day	28day	56day
NC	6.86	7.6	10	10.33
Mix1	6.53	6.8	8.65	8.67

Mix2	5.13	6.6	7.5	7.67
Mix3	5.27	5.5	8.8	8.93
Mix4	5	7.2	9.2	9.27
Mix5	5.4	6.1	7.4	8

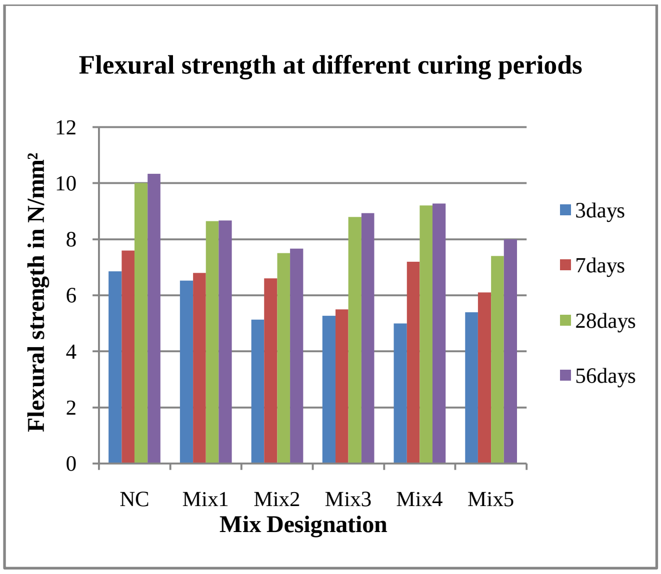

Fig 4.5 Graphs showing Flexural Strength Development of Different Mixes

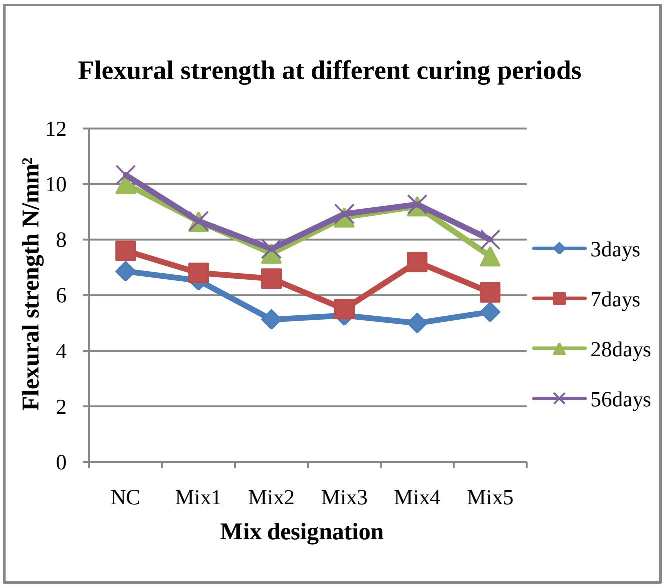

Fig 4.6 Graphs showing Flexural Strength Development of Different Mixes

4.5 Ultrasonic Pulse Velocity

This test is done to assess the quality of concrete by ultrasonic pulse velocity method as per IS: 13311 (Part 1) – 1992. The method consists of measuring the time of travel of an ultrasonic pulse passing through the concrete being tested. Comparatively higher velocity is obtained when concrete quality is good in terms of density, uniformity, homogeneity etc. The Basic formula for estimating the pulse velocity is given by

Pulse velocity = (Path length/Travel time)

Table4.4 Interpretations of Present UPV Results

Composition	Pulse velocity(km/s)	Grading
NC	4.25	GOOD
Mix1	3.83	GOOD
Mix2	4.28	GOOD
Mix3	4.31	GOOD
Mix4	4.30	GOOD
Mix5	4.23	GOOD

Derivation of Modulus of Elasticity from UPV Data

The dynamic Young's Modulus of Elasticity (E) may be determined from pulse velocity and dynamic Poisson's Ratio (µ) from the following Equation obtained from IS: 13311-Part I-1992.

$$E = [\rho\ (1+\mu)\ (1-2\mu)\ /\ (1-\mu)]*V^2$$

Where E = Young's Modulus in N/mm^2
ρ = Density of Concrete in kg/m^3
μ = Poisson's Ratio = 0.15
V = Pulse Velocity in m/s

The E-values calculated using the above equation are given in Table 3.5.

Table 4.5 E-Values obtained from UPV Results

Type of mix	Pulse velocity (m/s)	E-value MPa
NM	4250	396901.29
Mix1	3830	325115.36
Mix2	4280	409246.87
Mix3	4310	418293.53
Mix4	4300	419630.67
Mix5	4230	409249.62

4.6 Flexural Fatigue Testing

The beam specimens are marked in the same way as for the static flexure test. The load cell is brought in contact with the loading frame placed on the specimen. The computer system and other instrumentations are kept ready. Specimen is marked with a chalk/pencil. The support points at 400 mm apart from the bottom and 133.33 mm from the top. The load is then applied on the frame by giving data entries in the computer.

4.6.1 Development of Fatigue Models

In the present investigations, the flexural fatigue tests are done on Conventional M30 grade concrete (PQC) with fine aggregates replaced with IOT. The prism specimens are of size 100X100X500 mm. The specimens are subjected to accelerated half sine wave form of cyclic loading tests at three stress levels 65%, 70% and 75% of static flexure load results got by the Static Flexural Strength with a rest period of 1s and frequency of load application being 2 Hz i.e., two cycles per second. Prediction of fatigue life using statistical models is attempted for Log Normal Distribution.

The flexural static failure loads are obtained as average flexural strength of three specimens and the values are shown in Table 4.6.

Table4.6 fatigue loads at different stress ratios

Type of mix	Flexural Load	SR=0.65	SR=0.7	SR=0.75
Mix4	23 KN	14.95 KN	16.1 KN	17.25 KN

The number of repetitions to failure of Concrete at different stress levels is given in Table 4.7.

Table 4.7 Fatigue Testing Results for Mix4

Sl. No.	No. of repetitions to failure		
	SR=0.65	SR=0.7	SR=0.75
1	86	38	15
2	780	263	184
3	1164	454	240
4	3918	1234	508
5	4900	1580	592
6	8706	3785	1910
7	10352	6254	2722
8	18132	9880	4724
9	25468	17524	9382

4.6.2 Log Normal Distribution Model

A Log Normal Distribution model which is also a linear regression model of the form (Y=aX+b) is attempted using present experimental results in which stress ratio (SR) is taken on Y-axis and Log (N) values are taken on X-axis. The scatter diagram and the linear relationship have been shown in Fig 3.7. The linear regression model considering all the values are given by Equation 3.1

y = -0.0165x + 0.7525……………. (3.1)

With R^2 = 0.1123, R^2 being the Regression Co-Efficient

In this case, y = S, the stress ratio and x = Log N. Then the equation becomes

$$\text{Log N}=\frac{0.7525-SR}{0.0165}$$

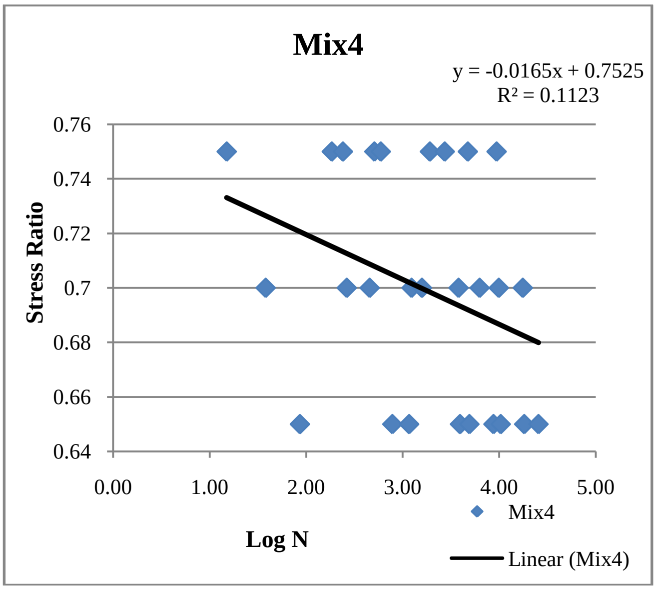

Fig 4.7 Relationship between Stress Ratio (SR) and number of repetions N

From the results obtained for 9 specimens in the Linear Regression Model shown above, the R^2 value obtained is 0.1123 which clearly shows that there is a lot of scatter among the number of repetitions. Applying the correction by omitting lowest values, Linear Regression model considering 6 specimens per stress ratio is developed. The corrected model is shown in equation 3.2 and the relation is shown in Fig 4.8.

y=-0.0492x+0.8795……………. (3.2)

With R^2 = 0.3332

$$\text{Log N}=\frac{0.8795-SR}{0.0492}$$

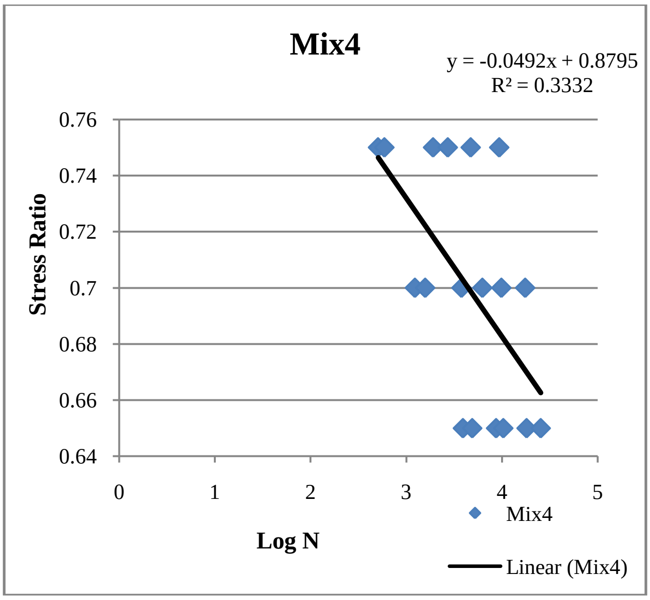

Fig 4.8 Relationship between Stress Ratio (SR) and number of repetitions N with omitted Values

4.6.3 Fatigue Equation as Per IRC 58:2011

The fatigue equation given by IRC: 58 - 2011 code is used to compare the developed linear regression model for Mix4. The models suggest by IRC are shown below.

N = Unlimited for SR < 0.45

$$N=\left[\frac{4.2577}{SR-0.4325}\right]^{3.268}$$

Where 0.45≤ SR ≤ 0.55

$$Log_{10}N=\frac{0.9718-SR}{0.0828}$$

Where SR > 0.55

Similarly for Mix4 with SR being > 0.55, the equation becomes

$$Log_{10}N=\frac{0.8795-SR}{0.0492}$$

All test data for PQC is used to compare the number of repetition to failure with IRC model. The comparison is shown in Table 4.8 and Figure 4.9.

Table4.8 Comparison of No. of Repetitions to Failure of both the models

SR	No. of repetitions to failure	
	IRC	Mix4
0.55	124223	4979142
0.6	30927	479617
0.65	7700	46199
0.7	1917	4450
0.75	477	429
0.8	119	41
0.85	30	4

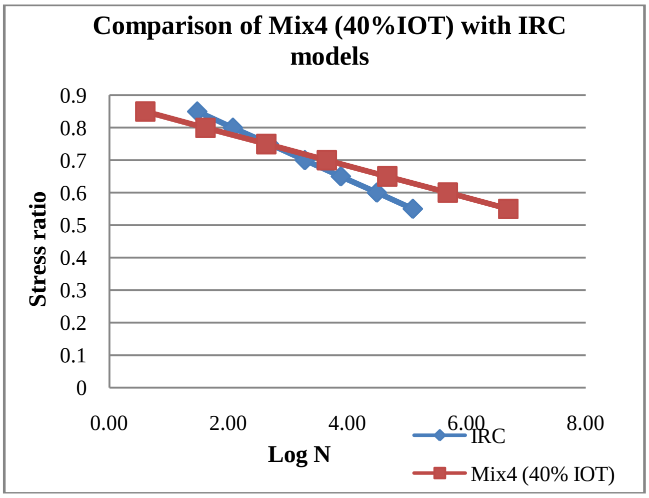

Fig 4.9 Comparison of Mix4 (40%IOT) with IRC models

5. CONCLUSIONS

From the tests conducted on materials for assessing properties and tests on hardened concrete to arrive at strength properties such as compressive and flexural the following conclusions are made.

1. As the IOT percentage increases workability of mix reduces hence for better workability needs use of superplasticizers is recommended.
2. Replacement of 40% IOT gives maximum compressive strength which is more than the reference mix (NC) and other replacement percentages.
3. Reference mix shows maximum flexural strength more than the IOT replaced mixes.
4. The number of repetitions to failure obtained for Mix4 is more than IRC (reference mix NC) up to 0.7 stress ratio. This shows that IOT replaced concrete can be used for pavements; in particular it is recommended for village roads with lower traffic loads.

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