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Investigation of Marble Dust added Concrete by Considering Effect of Temperature on Pavement

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Abstract

Concrete pavement has proved to be a versatile solution in terms of long term life, low maintenance while meeting the need of present world without compromising the ability of the future demand to meet its own need. With reference to the focus on sustainable construction practices, researchers around the globe are keenly interested in motivating the use of waste/recycled materials in concrete to reduce dumping of CO2 into the environment. Marble dust is an industrial waste which is developed while cutting of marble blocks into smaller blocks/slates to obtain the desired shape. During this process, about 25% original mass is lost in the form of dust/powder. This marble dust has become a threat to agriculture and human health as it is being dumped in open environment. Hence, utilization of marble dust in construction practices has become essential to prevent environmental pollution. Many researchers have recommended the use of marble dust in the concrete pavement as it enhances mechanical properties of concrete. As concrete pavements are subjected to dynamic loading conditions, the feasibility of marble dust in concrete pavements has not been reported. Hence, an attempt is made to evaluate the performance of marble dust added concrete pavement with reference to fatigue damage guidelines provided by IRC 58:2015. Mechanical properties and realistic temperature differentials are obtained through experimental approach for evaluating fatigue performance. Present research reveals that the realistic temperature differentials are not in agreement with the temperature differential recommended in IRC 58:2015, which leads to overestimation/underestimation in design thickness of pavement slab.

Keywords: Concrete pavement, Marble dust/powder, Fatigue performance, IRC 58:2015, Temperature Differential.

Introduction

In recent years, cement concrete pavements are being adopted in many new road projects in India in view of their longer services lives, lesser maintenance requirement and smoother riding surface. Indian road network of almost 3.5 million km comprising both paved and unpaved surfaces is the world's second largest. A pavement is the layered structure on which vehicles travel. Rigid pavements are helpful to reduce stresses on underlying soils. In this research paper, we have focused on a sustainable construction practice in pavement by using waste/ recycled material (marble dust) in concrete. We exploredthe effect of temperature differential in concrete and allied effect with reference to fatigue performance of marble dust added concrete pavements. There are various methods/guidelines available to design rigid pavements among which most of methods/guidelines are related to computer programs or FEA codes,where analysis can do by inputting the various loading, environmental parameter and properties of material. IRC 58 2015 method/guidelines have been adopted in present study to perform cumulative fatigue damage study for obtaining safe thickness of pavement slab. Input data related to material plays a vital role while deciding the safe thickness. If these properties are not known at design stage, the design and analysis done by any analysis and design tool will be approximate. Hence, initially properties of marble dust added concrete and their effect on mechanical properties have been obtained, so that they may be used for deciding safe PQC (Pavement Quality Concrete). Analysis and design theory of rigid pavements are presented followed by utilization of measured properties of marble dust in concrete. Fatigue analysis guidelines provided by IRC 58 2015 have been adopted to demonstrate the effectiveness of marble dust added concrete in reducing PQC thickness considering the effect of temperature differential available with us, the one recommended by IRC 58 2015 and the other realistic temperature differential recorded from temperature in concrete pavements experimentally.

Marble dust

Marble has been commonly used as a building material since the ancient times. The industry's disposal of the marble powder material, consisting of very fine powder, today constitutes one of the environmental problems around the world. Marble blocks are cut into smaller blocks in order to give them the desired smooth shape. During the cutting process about 25% the original marble mass is lost in the form of dust [1]. Marble dust is settled by sedimentation and then dumped away which results in environmental pollution, in addition to this forming of dust in summer is threatening both agriculture and public health. Therefore, utilization of the marble dust in various industrial sectors especially the construction, agriculture, glass and paper is important. By considering all the aspects related to safe disposal of marble dust and effective utilization in construction sector, this research is dedicated to prepare a mix of M30 grade concrete obtain various mechanical properties and obtaining the realistic temperature on top and bottom of concrete pavement.It is desirable that use of marble dust in concrete will lead to economize the safe PQC thickness of the slab.

Analysis and Design theory

Highway pavements are divided in two broad categories: Flexible pavement and Rigid pavement. Flexible pavement is a multilayered structure resting over the soil subgrade, with inferior quality material at the base. In flexible pavements, wheel loads are transferred by grain-to-grain contact of the aggregate through the granular structure (e.g. bituminous road). On the other hand rigid pavement is made up of concrete, occasionally over a base course. In rigid pavements, wheel loads are transferred to sub-grade soil by flexural strength of the pavement and the pavement acts like a rigid plate (e.g. cement concrete roads). The rigid pavement because of its rigidity and high modulus of elasticity tends to distribute the load over a wide area of a soil by slab made by concrete. Thus, concrete flexural strength is of prime importance in the design of rigid pavement to enhance its structural capacity.

Forces Acting on Rigid Pavement

Various stresses act on rigid pavement due to wheel loads, cyclic changes in the temperature (warping and shrinkage or expansion), changes in moisture and volumetric changes in the subgrade or base course. Due to all these changes intensity of stresses varies widely and deform slab. The stresses acting on a rigid pavement are, i) Wheel load stresses and ii) Temperature stresses.

i. **Wheel load stresses:** Wheel load of vehicle acting on a concrete slab of pavement resting in a perfect contact with an elastic subgrade will cause increase in flexural stress of slab. The slab produces tensile and compressive forces due to wheel load. As concrete is weak in tension and strong in compression, usually tensile stresses

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is critical due to load on slab. Equations for calculations of stresses in such a slab were first developed by Westergaard and later extended by other researcher [2].Westergaard considered three different loading conditions for calculation of stresses, Interior loading, Edge loading and Corner loading.

ii. **Temperature Stresses:**Daily changing temperature causes significant thermal stress and deformations in concrete pavement with laterally fixed planes. These stresses can exceed permissible values in the case of incidental strong thermal differences. Due to the temperature differential between the top and bottom of the slab, curling stresses (similar to bending stresses) are induced at the bottom or top of the slab. Due to the contraction of slab due to shrinkage or due to drop in temperature tensile stresses are induced at the middle portion of the slab [3]. Temperature thus tends to produce two types of stresses in a concrete pavement. These are warping stresses and frictional stresses.

Design Technique Based on Fatigue Cumulative Damage:

Westergaard gave a conventional theory to analyse rigid pavement. New design technique for rigid pavement is developed on the basis of Westergaard findings with certain modification, IRC 58:2015method/guidelines are drafted. The severest combination of different factors that induce the maximum stress in the pavement will give the critical stress condition.Designing of pavement thickness, flexural stress due to combine action of wheel loads and temperature differential between top and bottom fibers of concrete pavement is also considered.

a) Bottom- up cracking

In rigid pavement flexural stresses occur at the bottom layer is maximum during day hours. When the axle loads act midway on the pavement slab while there is positive temperature gradient. Single axles cause highest stress followed by tandem and tridem axles respectively. Spacing between individual axles for tandem and tridem axles varies from 1.30 m to about 1.40 m (IRC 58: 2015).

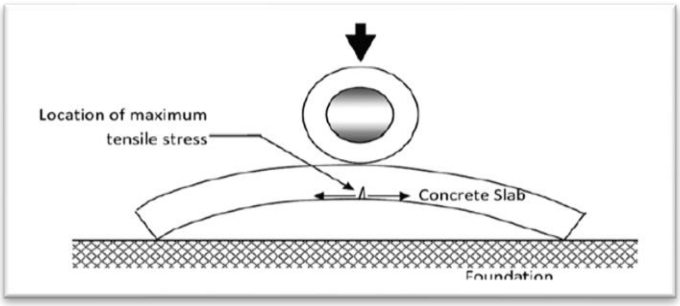

Figure 1: Bottom up cracking(IRC 58 : 2015)

b) Top-down cracking

During the night hours, the top surface is cooler than the bottom surface and the ends of the slab curl up resulting in loss of support for the slab. Temperature tensile stress are caused at the top because of the restraint provided by the self- weight of concrete and by the dowel connections Axle loads when placed close to transverse joint when there is negative temperature gradient during night hours , causes high flexural stresses in the top layer leading to top- down cracking.(IRC 58: 2015)

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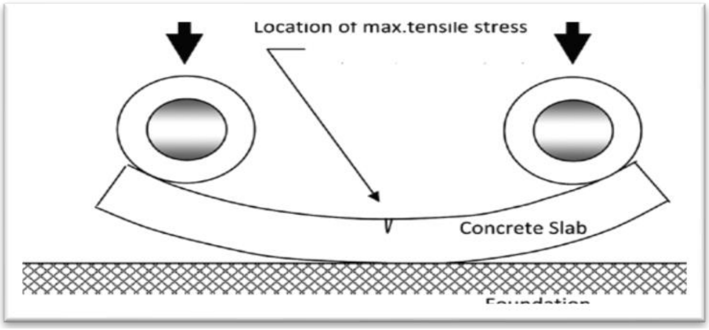

Figure 2: Top- down cracking (IRC 58: 2015)

Experimental Data:

Cement:

The cement used was Pozzolona Portland cement (PCC) grade 53 and confirming to IS 1489-1-1991. Initial and final settling times of cement were 158 min and 345 min, respectively.

Aggregate:

Aggregates are the important constituents in concrete. They give body to the concrete, reduce shrinkage and affect economy. One of the most important factors for producing workable concrete is a good gradation of aggregates.

I. Fine Aggregate:

Those fractions from 4.75 mm to 150 micron are termed as fine aggregate. The river sand is washed and screened, to eliminate deleterious materials and over size particles. Good quality WARDHA river sand was used as a fine aggregate.

Figure 3: Wardha sand

II. Coarse Aggregate:

The material whose particles are of size as retained on I.S Sieve No. 480 (4.75 mm) is termed as coarse aggregate .Coarse aggregate used were 15mm downgraded and 30 mm downgraded.

Figure4: Coarse Aggregate

Marble dust

In India, marble processing industry generates around 7 million tons of wastes mainly in the form of powder during sawing and polishing processes. These are dumped in the open which pollute and damage the environment. In this research we used marble dust from Amravati MIDC area which is dumped as a waste material.

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Figure 5: Marble waste sludge dumped

Super plasticizer

Plasticizer is used for better workability of concrete. During the trial mix the workability was found to be very less so we used plasticizer. It reduces the w/c ratio and ultimately increases the strength of concrete. Plasticizer is added at rate 5ml per litre of water. The plasticizer we used wasAC-MENT-BV-430-A3**,** Super Plasticizer for pump able concrete on PC Base, an Apple chemie industries product.

TESTS ON MATERIAL:

For mix design calculations we required certain data of materials like specific gravity, sieve analysis and water absorption. For which we had conducted the different tests on material which are described below.

Fineness Test:

The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat.

By Sieving:-

Table No.1 Fineness of cement

Sr. No	Weight sample taken (gm)	Weight sample retained on sieve	% Weight retained
1	100 gm	0	0
2	100 gm	2	2
3	100 gm	1	1

Average retained weight = 1

Standard Consistency Test

For finding out initial setting time, final setting time and soundness of cement, and strength a parameter known as standard consistency has to be used.

Table No 2: Standard Consistency

Sr. No.	Water added for different trials in Percentage	Penetration of plunger frombottom in mm
1	30	19
2	35	12
3	40	5

Standard Consistency in percentages = (total water for standard consistency)×100/400

= 160 × 100/400

=40

Standard Consistency is 40%

Specific Gravity Test

Table no 3. Specific Gravity of Coarse Aggregate

Test particulars	sample 1(gm)	sample 2 (gm)	sample 3 (gm)
Empty weight of pycnometer W1(gm)	596	596	596
Weight of pycnometer oven dry soil W2 (gm)	1206	1221	1191
Weight of oven dry silts=W2-W1(gm)	610	625	595
Weight of pycnometer +water +soil W3(gm)	1904	1895	1870
Weight of pycnometer + water W4 (gm)	1502	1502	1502
Specific gravity	2.66	2.69	2.63
Average value of specific gravity	2.66		

Similarly Average value of specific gravity fine aggregate observed is 2.96

Sieve Analysis Test

This is the name given to the operation of dividing a sample of aggregate into various fractions each consisting of particles of same size. The sieve analysis conducted to determine the particle size distribution in a sample of aggregate, which we called gradation.

Table No.4 Sieve analysis

Sieve	Retained on each sieve		Cumulative Retained	Passing through	
	Wt (gm)	%		Wt (gm)	%
80mm	0	0	0	2000	100
40mm	0	0	0	2000	100
20mm	0	0	0	2000	100
10mm	0	0	0	2000	100
4.75mm	278	13.9	13.9	1722	86.1
2.36mm	358	17.9	31.8	1364	68.2
1.18mm	620	31	62.8	744	37.2
600µ	360	18	80.8	384	19.2
300µ	332	16.6	97.4	52	2.6
150µ	84	4.2	101.6		
Pan	18	0.9	102.5		
Total	2000 gm	100%	490.8		

Setting Time Test

The initial and final setting time is calculated by using vicat's apparatus

Table No.5 Setting time of cement

Sr.No	Sample no.	Results
1.	Weight of sample	400gm
2.	Water added in (ml)	160
3.	Time when water added	12.50 PM
4.	Time of initial set	3:28 PM
5.	Time of final set	6:35 PM

6.	Initial set in min(4-3)	158 min
7.	Final set in min (5-3)	345 min

MIX DESIGN

The method we used is popularly known as 'AMBUJA METHOD'. This method has been adopted on several sites in and around Mumbai and has given technically and economically good results. The study carried on the basis of these following objectives:1) To determine the mechanical properties of recycled marble dust in concrete.2) To determine the optimum value of marble dust needed for improvement in compression, flexural and split tensile strength over the plain traditional mix 3) To develop the cost saving concrete, savings fortune in large projects. 4) To develop feasible waste management for waste material.

In this method, for different concrete specification, tables from IS 456-2000were referred. The concrete was designed and tested for different proportion of marble dust individually. The different proportions for testing for marble dust were selected upon reviewing various research papers as available in literature. The selected dosage for marble dust was 5%, 10%, 15% and 20% to be replaced with fine aggregate. The specimens were casted in batches individually for marble dust. The aim is to calculate the optimum dosage for improvement of qualities in concrete. The compressive, flexural and split tensile strength is calculated for specimens for 7 days, 14 days, and 28 days. Design mix for M30 grade concrete was prepared by partially replacing fine aggregate with marble dust is replaced by weight of fine aggregate.

For calculating the various strength and properties of concrete tests were performed on the specimens viz., cubes of size 150mm × 150mm, beams of length 500mm and cross section of 100mm, and cylinder of diameter 150mm of length. Another batch of slabs/sections consisting ofmarble dust added concrete mix M30 was prepared of sizes having cross section 150 × 150mm having varying heights of 150mm, 200mm, 250mm, 300mm, 350mm and 400mm. Temperature at various depth was calculated with the aim to get our experimental temperature differential for pavement design and the results of CFD are compared with IRC given temperature differential values.

TESTS FOR PROPERTIES ON CONCRETE SPECIMEN

Compressive Strength Test

From the result it is observed that Marble dust with pozzolanic properties impart technical advantages along with larger quantities of cement replacement to be achieved. The compressive strength is found increasing with the addition of marble dust, the optimum dosage for marble dust replacement is found to be 15%. The compressive strength of concrete can be calculated using the following formula

Compressive strength = (Load in N/ Area in mm^2) =…N/mm^2 ...(eq. no. 1)

Figure 6: Compression testing machine

Split Tensile Strength Test

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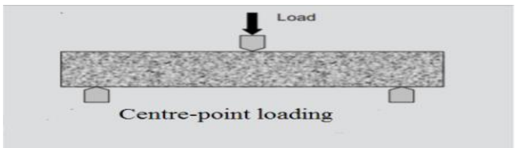
The test was performed on CTM (compression testing machine). The figure 7 shows the setup for split tensile strength test on CTM. The task of this test was performed to find the increase and differences of strength of concrete according the increasing percentage of marble dust %, 10%, 15% and 20%. in the concrete. The indirect tensile strength test was conducted in the laboratory after the concrete specimens were cured for 7, 14 and 28 days respectively.The optimum dosage of marble dust, for best split tensile strength is 15%.

Figure7: Cylinder cracked during split tensile strength test, Split tensile test on cylinder

Flexural Strength Test

Flexural strength of concrete is a measure of its ability to resist bending. Flexural strength can be expressed in terms of 'modulus of rupture'. Types of loadings are Third -point loading and Centre-point loading. Centre-point loading is when the entire load is applied at the centerof span.The maximum stress is present only at the center of the beam. Third-point loading is the when half the load is applied at each third of span length. Maximum stress is present over the center 1/3 portion of beam. We have applied loading in this manner. Use of three-point loading is preferred for determining flexural strength of concrete is shown in Fig.9. It is observed that with the addition of marble dust optimum dosage is found out to be 15%.



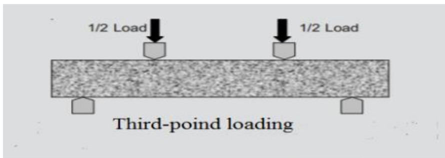


Figure 8: Central-Point Loading Figure 9: Third-Point Loading

Result and Discussion

The experimental tests were carried out to obtain the mechanical properties of marble dust added concrete to use them in the pavements. Effect of replacing the fine aggregate by locally available marble dust on concrete was studied. The replacement of materials was increase in percentages by weight of fine aggregate and cement respectively. Observation for 7, 14 & 28 days curing period were recorded and presented in the form of tables and graphs. Cumulative fatigue damage (CFD) was also performed on slabs/section cased of marble dust added concrete. The temperature variations of 24 hours were recorded after each hour and temperature at top, mid and bottom were recorded to calculate the temperature differential. After incorporating the temperature variation, flexural strength & compressive strength results in CFD data analysis chart/guidelines provided in IRC 58 2015, we get the result regarding obtaining safe pavement thickness.

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For Marble dust added concrete (M30 mix): Marble dust replacement with fine aggregate is done in increasing percentages in concrete and from the tests results obtained for compressive strength, flexural strength and split tensile strength. The percentage replacement was 0, 5, 10, 15 & 20 with fine aggregate. Compressive strength for marble dust added concrete

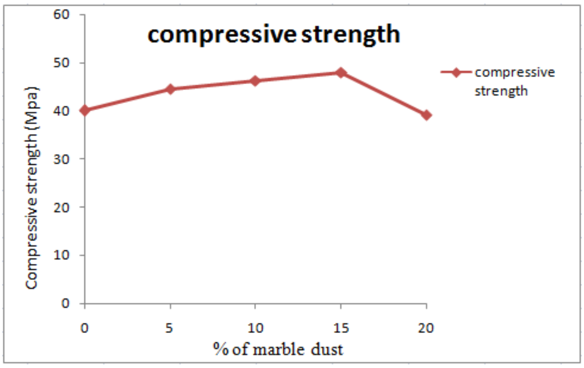

Figure 10: Compressive strength for marble dust added concrete

Flexural strength for marble dust added concrete

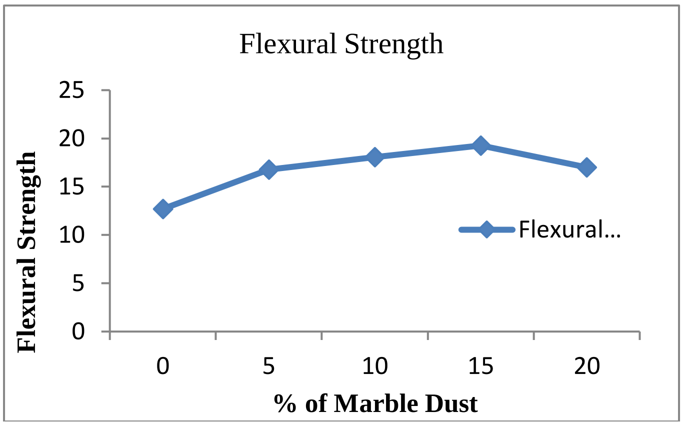

Figure11: Flexural strength for marble dust added concrete

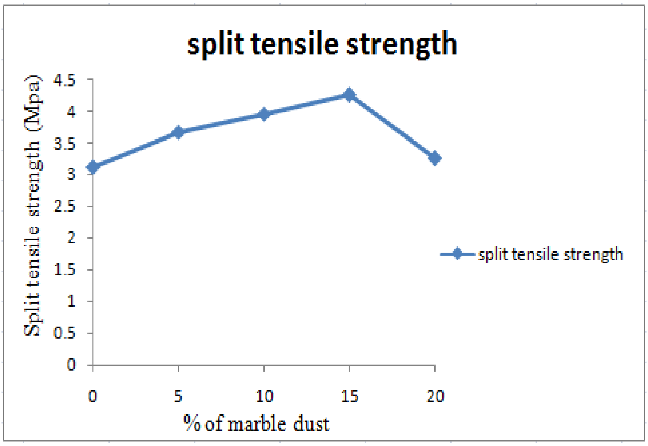

Figure 12: Split tensile strength for marble dust added concrete

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Deflection of beam for marble dust added concrete for 28 days

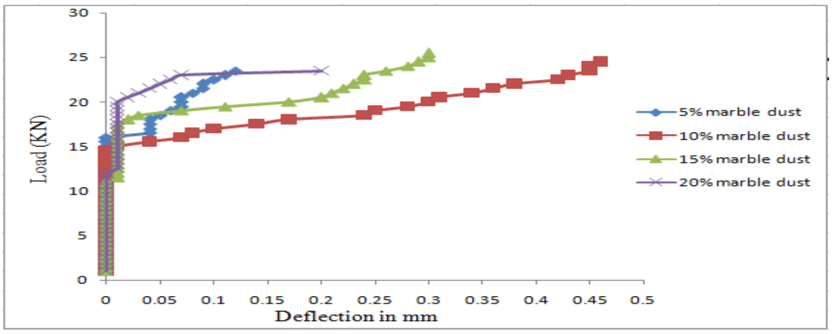

Figure13: Deflection of beam for marble dust added concrete

From the result obtained experimentally different graphs are plotted like compressive strength, flexural strength, split tensile strength and deflection of beam. It is observed that from result 15% of marble dust added in concrete as a fine aggregate improve strength and lowers the deflection.

VARIATION OF TEMPERATURE IN CONCRETE PAVEMENT

For 150 mm depth concrete slab/section

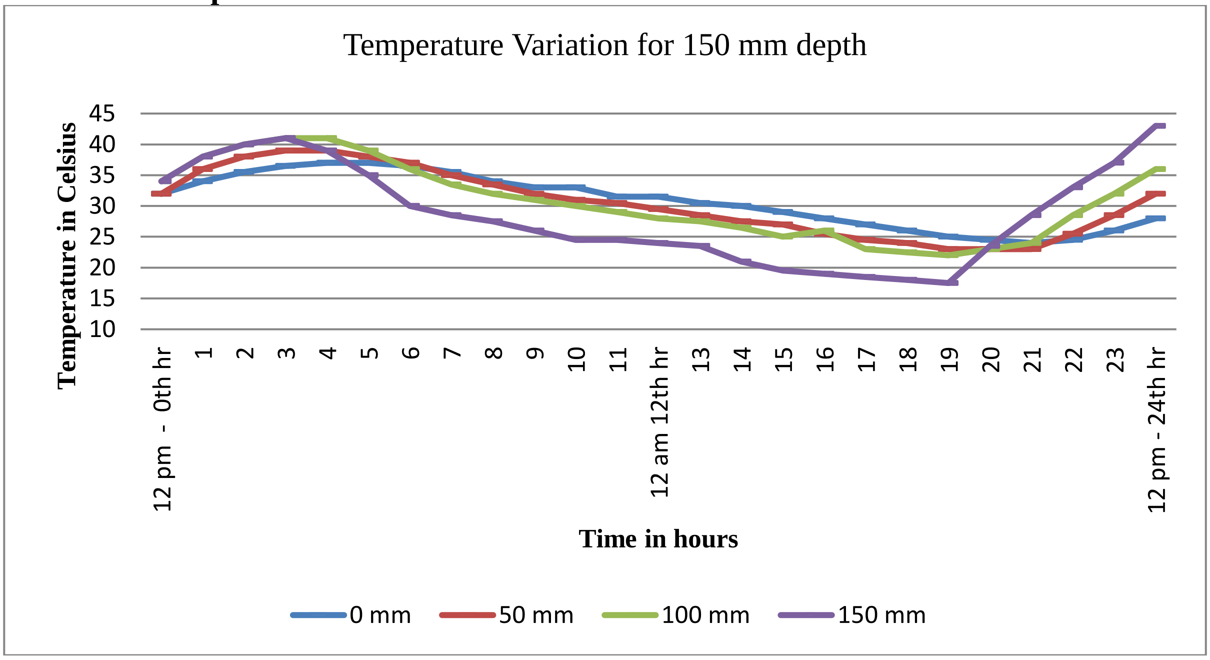

Figure 14: Temperature Variation for 150 mm Thick Slab

Temp. Gradient = Highest temperature at top for 24 hours – Lowest temperature at bottom for 24 hours
Positive temperature gradient for 150mm slab = 43° - 24° = 19°C

For 200 mm depth concrete slab/section

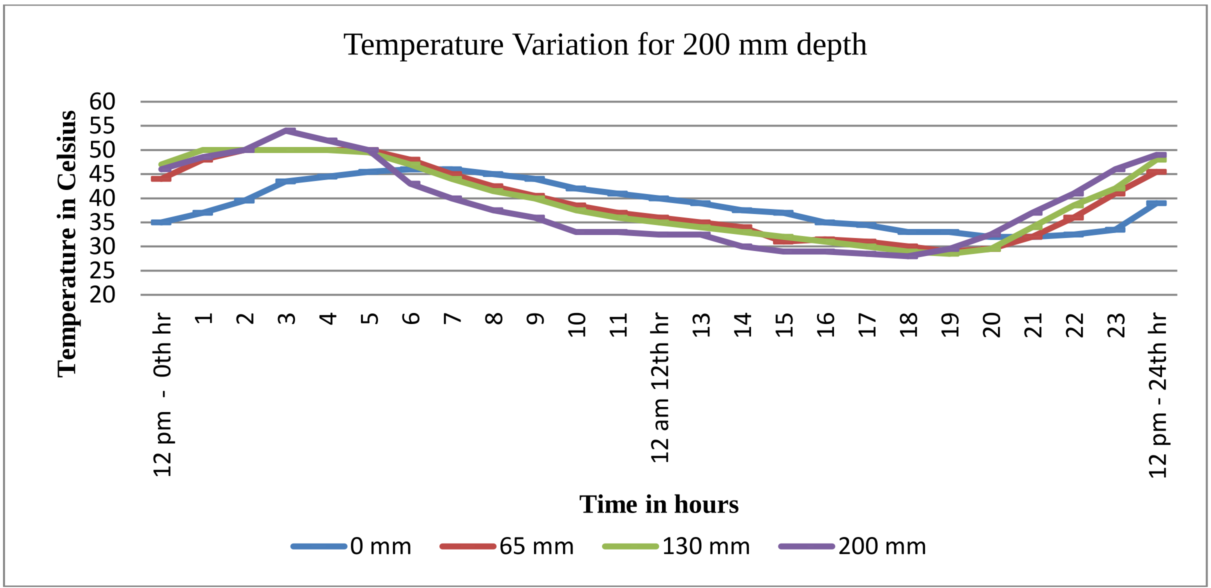

Figure15: Temperature Variation for 200 mm Thick Slab

Temp. Gradient = Highest temperature at top for 24 hours – Lowest temperature at bottom for 24 hours
Positive temperature gradient for 150mm slab = 54° - 32° = 22°C

For 250 mm depth concrete slab/section

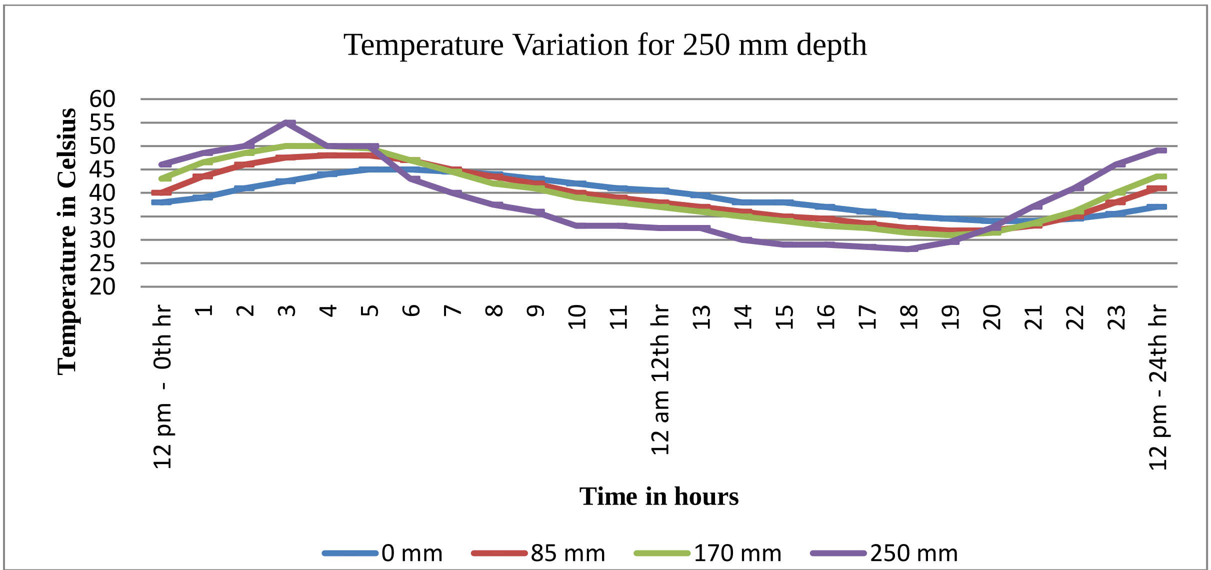

Figure16: Temperature Variation for 250 mm Thick Slab

Temp. Gradient = Highest temperature at top for 24 hours – Lowest temperature at bottom for 24 hours
Positive temperature gradient for 150mm slab = 55° - 34° = 23°C

For 300 mm depth concrete slab/section

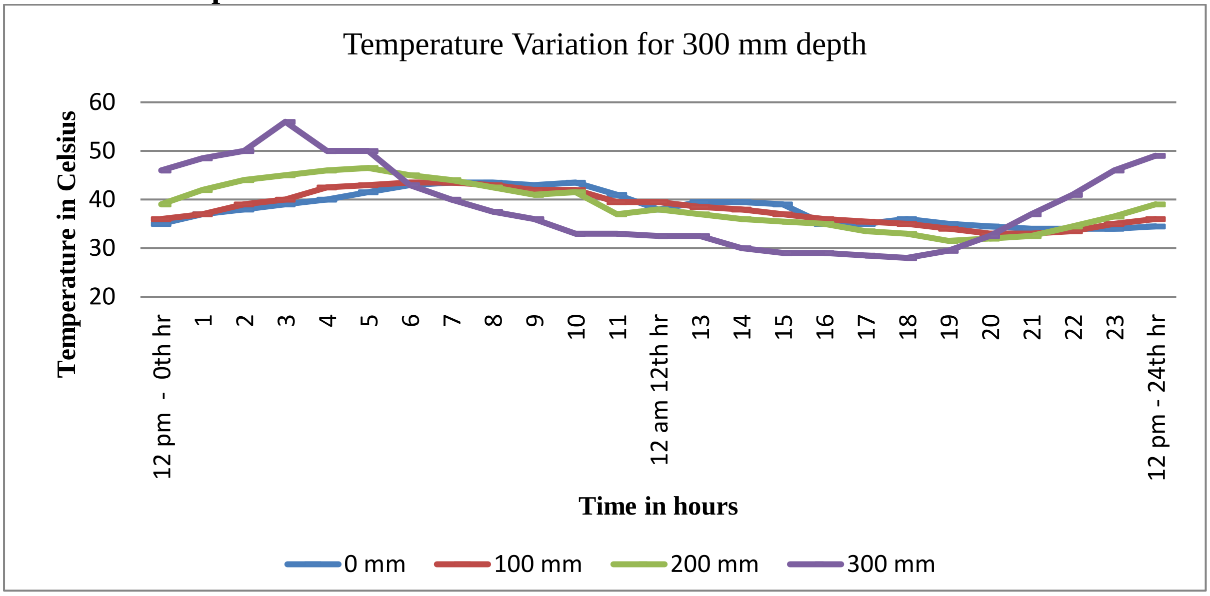

Figure 17: Temperature Variation for 300 mm Thick Slab

Temp. Gradient = Highest temperature at top for 24 hours – Lowest temperature at bottom for 24 hours

Positive temperature gradient for 150mm slab = 56° - 34° = 22°C

For 350 mm depth concrete slab/section

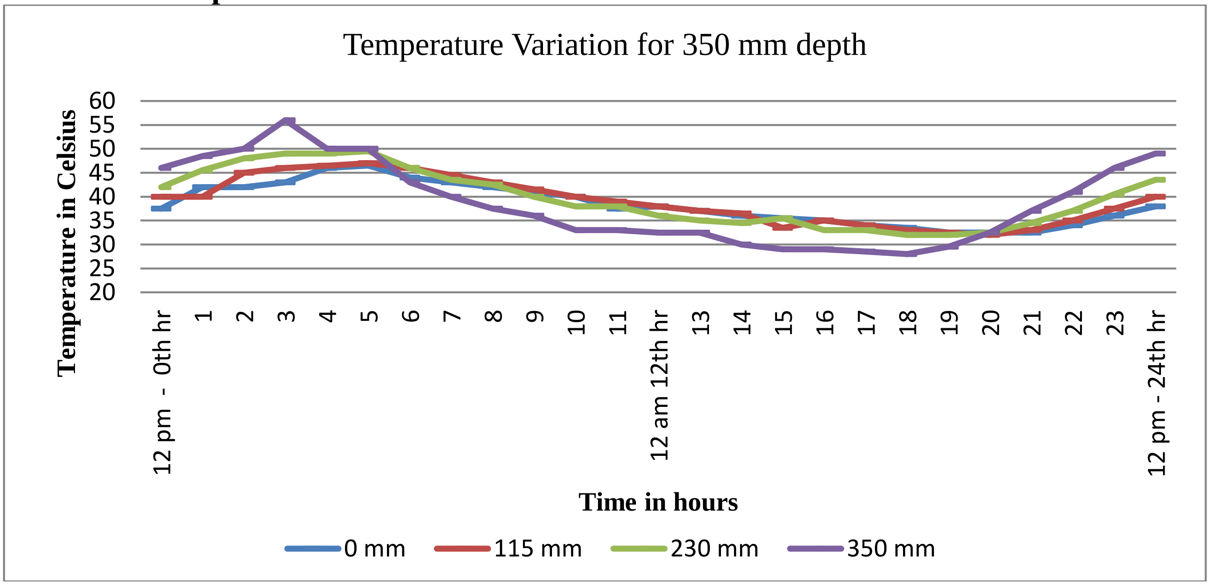

Figure 18: Temperature Variation for 350 mm Thick Slab

Temp. Gradient = Highest temperature at top for 24 hours – Lowest temperature at bottom for 24 hours

Positive temperature gradient for 150mm slab = 56° - 32.5° =23.5°C

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For 400 mm depth concrete slab/section

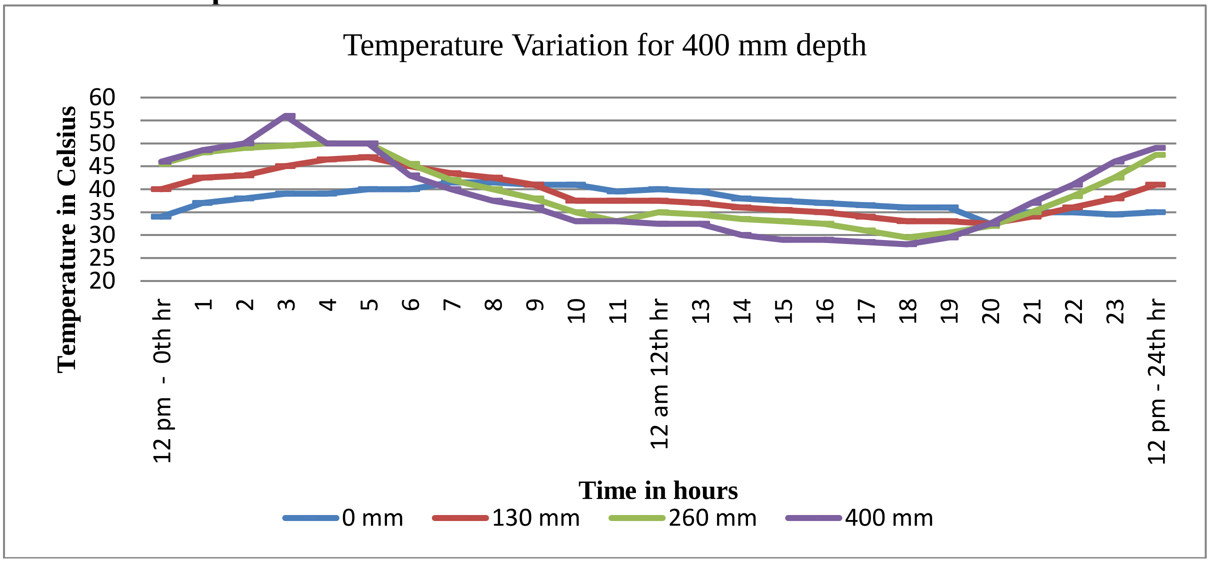

Figure 19:Temperature Variation for 400 mm Thick Slab

Temp. Gradient = Highest temperature at top for 24 hours – Lowest temperature at bottom for 24 hours

Positive temperature gradient for 150mm slab = 56° - 32.5° =23.5°C

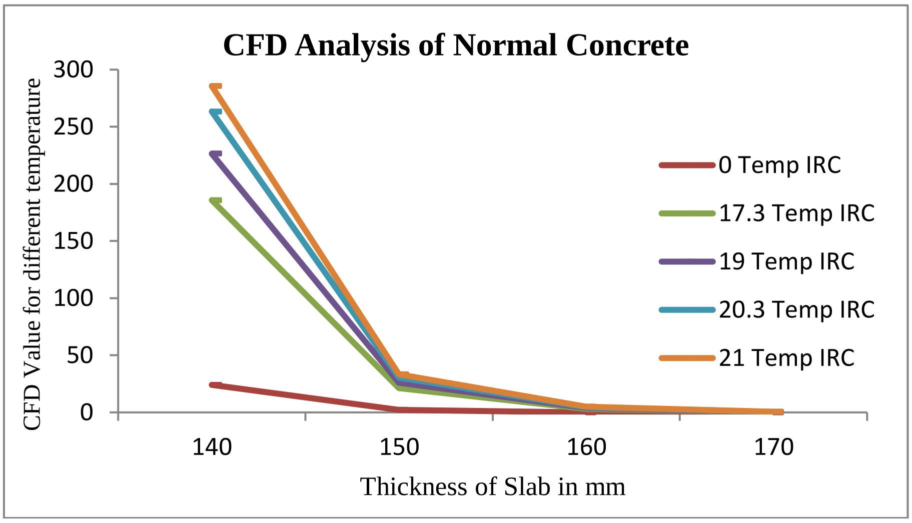

Figure 20: CFD Analysis of Normal Concrete under recommended temperature gradient by IRC 58-2015

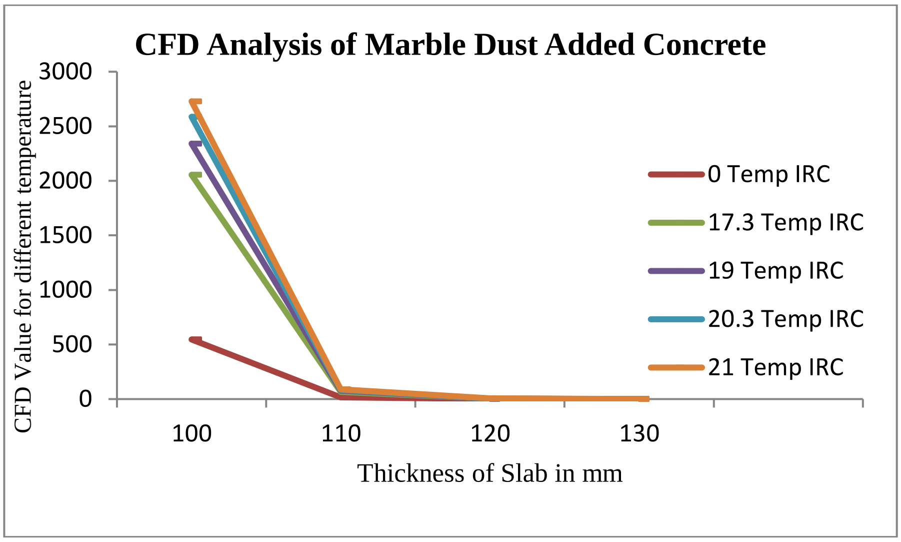

Figure 21: CFD Analysis of Marble dust added concrete under recommended temperature gradient by IRC 58-2015

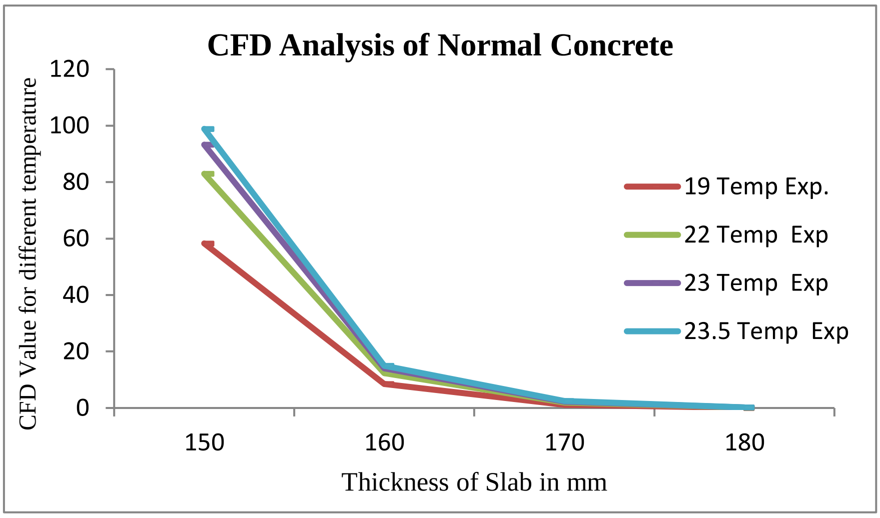

Figure 22: CFD Analysis of Normal Concrete under observed temperature gradient (Experimental Value)

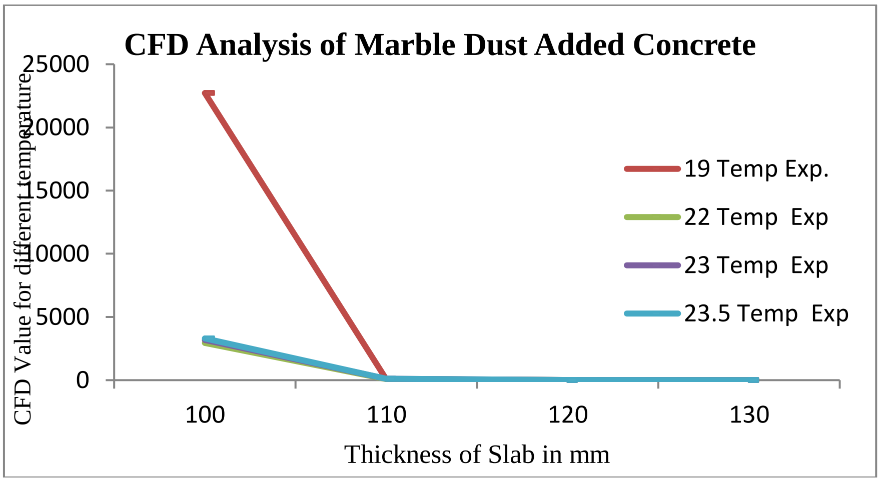

Figure 23: CFD Analysis of Marble dust added concrete under observed temperature gradient (Experimental Value)

Conclusions

In this research paper we studied the usage of waste marble dust materials and their behavior, different mechanical properties and their effects onthe concrete and we also studied about fatigue behavior of cement concrete pavement. The CFD analyses for various temperature differentials of different replacement with respect to PQC have been made. By this analysis the comparison of PQC and concrete having waste materials replacement has been made.

1. From the experimental results, we can conclude that at 15% replacement of marble dust by fine sand shows the highest compressive strength,
2. The flexural strength is found to have highest value for, 15% replacement of marble dust by fine sand
3. At 15% replacement of marble dust by fine sand shows the highest split tensile strength
4. From the experimental results we can conclude that, The optimum percentage of replacement of fine aggregate with waste marble dust comes out to be 15% by weight.
5. Using waste marble dust in concrete mix proved to be very useful to solve environmental problem and produce green concrete. Therefore, it is recommended to re-use waste marble dust in concrete to move toward sustainable development in construction industry.
6. Due to high fineness of marble dust, it proves to be effective in assuring good cohesiveness of concrete in the presence of super-plasticizing admixture (AC-MENT-BV-430-A3), provide that water to cement ratio was just adequate.
7. By CFD analysis as marble dust shows desirable results for fatigue, the replacement of fine sand with marble dust is better.
8. It has been observed that temperature gradient recommended by IRC 58 and those obtained by experimentally differ owing to which safe slab thickness is affected. In additions to this, marble dust added concrete in spite of having more temperature differential gave lesser thick slabs as compared to conventional concrete.

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