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Baligar Santosh
Postgraduate Student, Department of Civil Engineering, Goa College of Engineering, Farmagudi, Goa, India

Dr. KG Guptha
Head of Department, Department of Civil Engineering, Goa College of Engineering, Farmagudi, Goa, India

Corresponding Author:
Baligar Santosh
Postgraduate Student, Department of Civil Engineering, Goa College of Engineering, Farmagudi, Goa, India

Studies on high density concrete using iron ore for the production of washing machine ballasts

Baligar Santosh and Dr. KG Guptha

Abstract
Concrete has a broad task to carry out in both development and improvement of structural buildings and foundations. Based on its mass occupied per unit volume it can be classified as lightweight, ordinary or heavyweight concrete, each having its own unique applications. Heavy weight or high density concrete offers dependable, cost-effective radiation protecting and can be utilized as protective materials to amplify security in the accessible space. Generally unit weight more than 2.6 t/m3 is classified as high density concrete. Densities as high as 6 t/m3 is also referred in literature. Apart from the variety of uses discussed, this investigation focuses on the use of high density concrete using iron ore for the productions of counterbalances utilized in washing machines. These counter balances are known as ballasts. These act as stabilizers in washing machine and require a definitive weight in other words deliver desired weight in a given volume. High density aggregates are the key ingredients in its production. Other aggregates used to accomplish the required densities are Haematite, Limonite, Magnetite and Steel. Haematite with density varying from 3.4-3.6 t/m3 is used in the present study. Efforts are made to maintain desired density of 3.1 t/m3 by carrying out Mix design to accomplish a minimum compressive strength of 35 N/mm2 in just seven days of curing.

Keywords: Ballasts, haematite, high density aggregate, high density concrete

1. Introduction
High density concrete is used mainly in radiation shielding in hospitals, store nuclear waste and as counter weights in washing machines broadly. Concrete density higher than 2.6t/m, 3 is termed as high density concrete as per code. High density concrete requires heavy weight aggregate such as barites, iron- ore, steel shots and haematite with specific gravity more than 4.0 normally. Barites and haematite show significantly higher specific gravity in the range of 3.5 to 4.5 in naturally available minerals [1]. Heavy weight aggregates have low impact strength and tensile strength as compared to normal conventional aggregates. Concrete to withstand elevated temperatures and aggressive environment when used in nuclear plants for radiation shielding [2], [3]. Fibers are dispersed into concrete during mixing to improve tensile strength, ultimate strength and control shrinkage cracks. ACI 544, 3R-2008 recommends, fiber volume fraction used in concrete in the range of 0.5 to 1.5 %. Beyond which may pose problems in workability of mix and formation of balls or mat [4]. It also recommends aspect ratio in range of 20 to 100. Addition of fibers into concrete reduces cracking and protection from impact and shrinkage [3]. Several studies on high density concrete with fibers revealed improvement in mechanical and physical properties of concrete. This effort is an outcome of the existing mix which had many issues in achieving desired output. These parameters are discussed in results at length.

2. Haematite Ore
Haematite is a type of iron oxide having chemical composition of Fe2O3. It is a mineral which is shaded dark to steel or silver-grey, reddish brown to brown or red in colour [5]. It is mined as the primary metal of iron. Unadulterated haematite has a density in the range of 4.9 and 5.5t/m3. The physical properties of rocks in which haematite is the primary constituent may change extensively and the density of haematite minerals can go somewhere in the range of 3.2 and 4.3t/m3. The chemical and physical properties of haematite are listed in Table 1 and Table 2 respectively.

Table 1: Chemical properties of haematite

Compound	Percentage %
Fe2O3	80.16
MnO	0.15
MgO	1.67
TiO2	0.07
Al2O3	0.65
CaO	4.92
SiO2	4.26

(***Source***: Athira Suresh and Rajan Abraham)

Table 2: Physical properties of Haematite

Properties	Values
Particle size	10mm to fines
Specific gravity	3.95
Bulk density	3188 kg/m3
Water absorption	0.6%

Haematite iron ore in crushed form was used. Relevant tests were conducted and results are tabulated in Table-2. Graphical representation of particle size distribution of haematite ore is shown in Fig. 1.

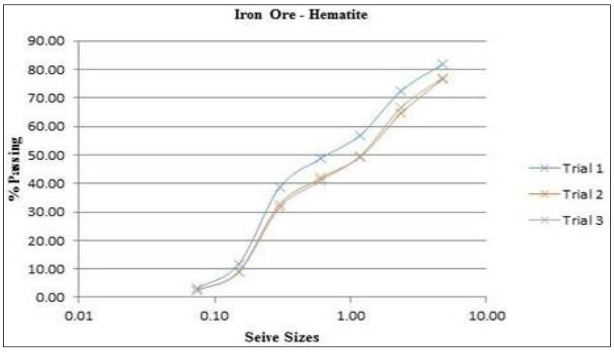

Fig 1: Particle size distribution of iron ore

3. Role of counterbalances in washing machine

Washing machines are generally provided with counterweights which serve as means for ballasting the same machines so as to reduce the dynamic stresses that are imparted during rotation of the drum during washing and, above all, the high-speed spin traction phases of the clothes washing process. These are generally secured to the exterior of the wash tub and are made in a variety of manners and shapes. Traditionally, they are formed by concrete blocks that are given appropriate shapes according to the position in which they are to be mounted.

4. Cement

Ordinary Portland cement of grade 43 was used and its physical properties are presented in Table 3.

Table 3: Physical properties of Cement

Properties	Values
Specific gravity	3.015
Standard consistency	35%
Initial setting time	60 minutes
Final setting time	310
Brand	Ultratech Cement
Week No	40 week 2018
Grade of Cement	43

5. Polypropylene fiber (PPF)

Mapei fiber IT 39 NV fibers are characterized by their 60 form ratio and special wavy shape were used. This helps to obtain a high level of adhesion in the cementetious paste, thereby increasing the ductility of concrete in the post-failure phase. The type and special geometry of the fibers help maintain the workability of concrete compared with concrete mixes without fibers without modifying the rheological properties of the mix. The special shape of it helps prevent them floating to the surface, particularly on large areas. The properties of fibers are listed in Table 4.

Table 4: Properties of polypropylene fiber (PPF)

Appearance	Monofilaments
Colour	Orange
Length (EN 14889-2) (mm)	55 ± 5%
Equivalent diameter (EN 14889-2) (mm)	0.91 ± 5%
Shape	Wavy
Density (kg/m³)	1000
Tensile strength (EN 10002-1) MPa	560
Modulus of elasticity (EN 10002-1) GPa	3.9
Water absorption (%)	<0.01

6. Ground granulated blast furnace slag (GGBS)

GGBS is a mineral admixture used to improve durability of mix and to provide certain special properties to the concrete. It extends the life span of the structure and produce less heat of hydration. In the present study GGBS is used as a makeup material for density. Its properties are listed in Table 5.

Table 5: Properties of GGBS

Properties	Values
Specific gravity	2.85
Bulk density	1050 kg/m3
Initial setting time	60 minutes
Final setting time	310 minutes
Make	JSW
Fineness	275 m2/kg

7. Water

Potable tap water was used for mixing of concrete.

8. Chemical admixtures

The Chemical admixtures used and their respective purpose is indicated in Table 6.

Table 6: Chemical admixtures

Name	Function
Dynamon SP 508	To provide High workability, Act as accelerator
EPKO KP 200	Corrosion inhibitor.
Mapei fluid IF 328	Blister controller
MYK Remicrete PC 30	To impart High early strength
MYK Bond Latex	To provide initial bonding agent

9. Methodology

The process involved for different trials is given below in Fig.2.

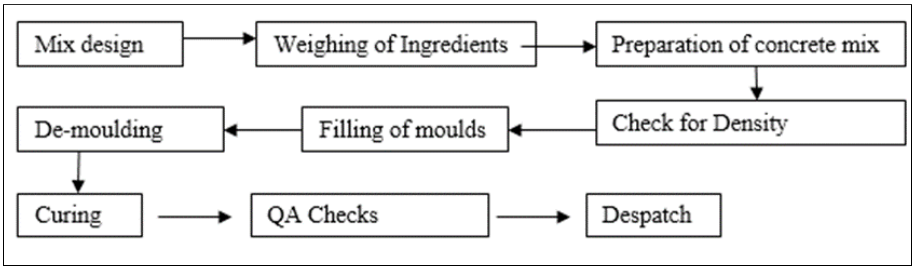

Fig 2: Process flow diagram

Following the process flow diagram, mix design was prepared keeping the required density as the target. Ingredients were mixed in a baby mixer of 0.3 m3 capacity. Care was taken to avoid formation of balls in the mixer (as the aggregates are heavy). Use of MYK Remicrete PC30 provide ease of mixing. Normal standards as per code were followed for rpm of the mixer and time of mixing in a mixer. The mix was tested for slump and density. Improvement in density was achieved with cement addition and lowering of density was through GGBS. Desired density of 3.1 was checked and moulds were filled. Standard procedure was followed for stabilization of concrete for the first 24 hrs. and specimen were kept for curing after de-moulding. Minor marginal variations in quantities are shown in Table 7.

Number of trials using mix design and adding various percentages of super plasticizers and corrosion inhibitor were tried. Selected proportions of ingredients after several trials, is used for final mixing. Properties of fresh state of concrete is checked by using slump cone test and hardened properties like compressive strength of trial mix results are given in below. Various mix proportion trials tried to achieve the required density of 3.1 accurately. Trial 4 was considered to be optimum to satisfy the design stipulations of the industry.

Table 7: Mix proportions for various trials

Sr. No.	Material	Trial 1	Trial 2	Trial 3	Trial 4
		Mass (Kg/m3)	Mass (Kg/m3)	Mass (Kg/m3)	Mass (Kg/m3)
1	Cement	715	791.67	783.33	791.88
2	GGBS	618.5	116.67	116.67	86.25
3	Iron ore	2432	2350	2350	2383.13
4	Water	375	333.33	283	256.25
5	Mape Fibre IT 39 NV	1.32	1.32	1.32	1.33
6	Dynamon SP 508	8.72	6.67	3.33	3.33
7	MYK Remicrete PC 30	2.86	3.33	3.33	4.17
8	Mapefluid IF 328	2.86	3.33	3.33	3.33
9	EPKO KP 200	-	-	3.33	3.33
10	MYK Bond Latex	-	-	-	3.33

10. Results

The main objective of the work was to develop exact required density of 3100 kg/m3 for a given volume. It was observed that once the moulds dry, they lose some weight. This is around 1-1.25%. The existing mix although could maintain density but could not achieve desired strength in 7 days. Present study could achieve this and economize the mix also. Results are tabulated in Table 8 and table 9. Fig. 3 and Fig. 4, indicates Comparison of Compressive Strength and Density achieved respectively.

Table 8: Comparison of compressive strength

Sr. No.	Parameter	Trial 1	Trial 2	Trial 3	Trial 4
1	One Day comp. Strength, MPa	17.04	10.64	11.47	6.54
2	Three Day comp. Strength, MPa	33.67	18.50	24.46	28.47
3	Seven Day comp. Strength, MPa	30.98	27.90	33.01	37.50

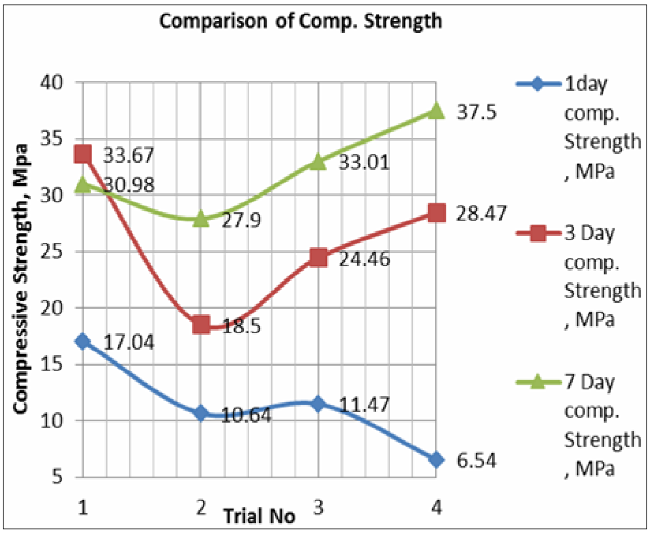

Fig 3: Comparison of comp. strength

Table 9: Density Achieved

Sr. No.	Trial No.	Density, Kg/m3
1	1	2942
2	2	3095
3	3	3200
4	4	3140

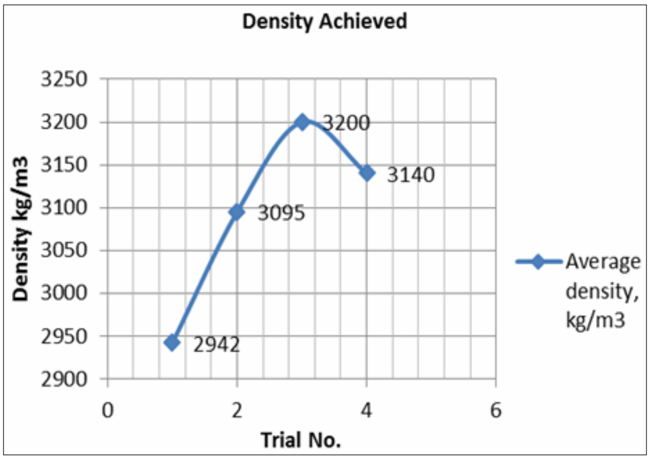

Fig 4: Density Achieved

11. Conclusions

Following conclusions were drawn based on the results obtained:

a. Minimum one day assured strength of 7 Mpa as against existing mix which takes minimum 48 hrs. to demould to attain the same strength.
b. Ballasts can come on line after 72 hours of casting as against 21 days in existing mix.
c. No ballast need be cured beyond 7 days (Water Curing) as against 21 days in existing mix.
d. Steel fibers are totally eliminated as these were hurting the workers.
e. Ballast is made free from corrosion as against the existing mix.
f. Ballasts are almost free from blisters.
g. Use of bond latex enhances setting time and hence one day strength is comparatively low.

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