REPLACEMENT OF WHITE CEMENT WITH ORDINARY PORTLAND CEMENT IN CONCRETE SPECIMENS

< Rahul Ranjit Pulparambath>[1]

[1]Heriot-Watt University, The School of Built Environment,
Academic city Road, Dubai, United Arab Emirates
rahul.ranjit11@gmail.com

Abstract: The project investigates the strength of concrete using the blends of Ordinary Portland Cement and White Cement under varying mix proportions. The concrete specimens casted with White Cement and Ordinary Portland Cement in different ratios are tested for mechanical properties. Ordinary Portland Cement (OPC) is partially replaced by White Cement in quantities of 0%, 10%, 25%, 50 % and 75% of the weight of OPC. The tests on concrete specimens using blends of OPC and White Cement are carried out as per British EN standards. Tests are performed to compare compressive and tensile strengths of the blends and finding an optimum value at which use of the combination is economically viable. Study was done to also compare concrete strengths when aggregates are dry crushed against saturated surface dry.

1. Introduction

White Cement is used for decorative, architectural and aesthetic purposes, a key advantage to using white cement is that it provides a neutral tinting base and has consistent color throughout a mix. Every color combination is possible with its use from pure white to bright colors. White Cement is abundantly found in North America, White cement is manufactured to conform to ASTM C 150, Specifications for Portland cement. Type 1 and type 3 are the most commonly used white cement. Another advantage of using white cement for decorative and architectural concrete is that it provides homogenous color results. Every color option is possible with it, from pure whites to bright and pastel colors.

The following report consists of various tests performed on cement and concrete materials that are made using blends of White Cement and Ordinary Portland Cement. The project is done to acquire and understand how the type of aggregates used affects the strength of concrete as well as for finding an optimum mix combination between white cement and grey cement which is economically viable having desired characteristic strength.

1.1 Tests performed

Tests carried out to determine the properties of cement.

- *Chemical composition of cement mix.* (BS EN 196-2:2013)
- *Standard Consistency test.* (BS EN 196-3:1995)
- *Determination of Initial and Final Setting time of Cement*. (Vicat Apparatus) (BS EN 196-3:1995)
- *Fineness of cement.* (Air Permeability Method – Blaine Method) (BS EN 196-3:1989)
- *Determination of Soundness.* (Lechatelier's Apparatus) (BS EN 196-3:1995)

Slump Test. (BS EN 12350 – 2:2009) is performed on fresh concrete for testing its workability using blends of white cement and Ordinary Portland Cement.

Tests on Mechanical properties of Hardened concrete specimens to be conducted are shown below:

- *Compressive Strength on concrete cubes.* (BS EN 12390-3:2001)
- *Splitting Tensile Strength on cylinder.* (BS EN 12390 – 6:2000)

1.2 Concrete Mix Design

Following Values are to be achieved by the concrete mix:

- Characteristic Compressive Strength, f_{ck} = 40 N/mm^2, with 2.5% defective rate.
- OPC Grade 42.5N
- Slump Required = 30mm - 60mm
- Max Size of Crushed Aggregate = 20mm
- Max Free W/C ratio = 0.55

Mix design Calculation:

Safety Margin, m = consistency factor x Standard Deviation

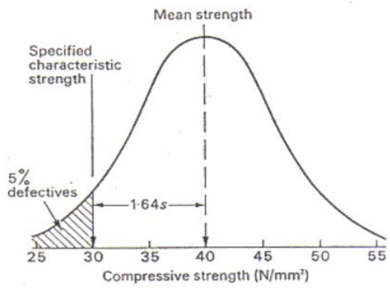


Figure 1: Standard deviation plot for consistency factor (What is the meaning of 1.65 in concrete mix design? Quora, Nidhi, 2017, pg. 1)

The constant **K** can be derived mathematically from the above normal distribution graph and has an increasing trend as the proportion of defective specimens increase.

Defective Percentage, K %	Value of standard deviation, S
10%	1.28
5%	1.65
2.5%	1.96
1%	2.33

Table 1: Standard deviation table, (table 8 of I.S. 456 -2000)

Thus,
Consistency factor, k = 1.96 (for 2.5% defective rate)

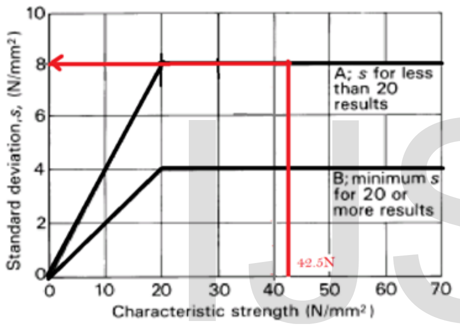


Figure 2: Relationship between standard deviation and characteristic Strength. (Concrete mixed design method, CE Blog, Happy World, 2011)

Standard Deviation = 8
Therefore, m = 1.96*8 = 16 N/mm^2
Characteristic mean strength, $f_m = f_{ck} + m$
=40+16
= 56 N/mm^2

Actual Water–Cement Ratio:

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm²) Age (days) 3	7	28	91
42.5 OPC	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Throughout this publication concrete strength is expressed in the units N/mm².
1 N/mm² = 1 MN/m² = 1 MPa. (N = newton; Pa = pascal.)

Figure 3: Approximate compressive strength (N/mm^2) of concrete mixes made with a water/cement ratio of 0.5(Concrete mixed design method, CE Blog, Happy World, 2011)

Compressive strength for crushed aggregates = 49N/mm^2

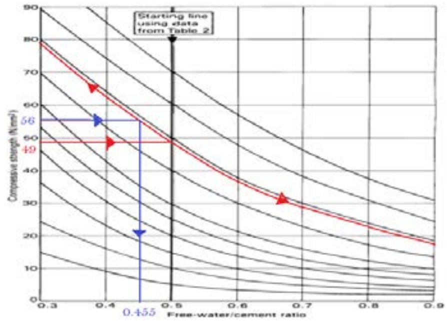


Figure 4: Relationship between compressive strength and water/cement ratio. (Concrete mixed design method, CE Blog, Happy World, 2011)

49 N/mm^2 being approximate compressive strength at 28 days for crushed aggregates having maximum size of 20mm. 56 N/mm^2 being the calculated characteristic mean strength of concrete.
Hence, Free Water cement Ratio = 0.455< 0.5, Take 0.455 as new W/C ratio.

Approximate Water Content for Variable workability:

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Note: When coarse and fine aggregates of different types are used, the free-water content is estimated by the expression:
$\frac{2}{3} W_f + \frac{1}{3} W_c$
where W_f = free-water content appropriate to type of fine aggregate
and W_c = free-water content appropriate to type of coarse aggregate.

Figure 5: Approximate free-water contents (kg/m^3) required to give various levels of workability. (Concrete mixed design method, CE Blog, Happy World, 2011)

Approximate water content = 210 kg/m^3

Cement Content:
W/C = 0.455
210/0.455 = C
Cement Content = 461.54 kg/m^3

Wet Density of Fully Compacted Concrete:

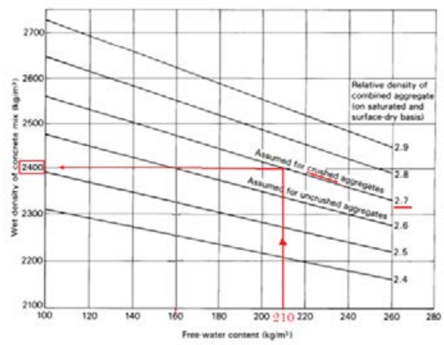


Figure 6: Estimated Wet Density of fully compacted concrete. (Concrete mixed design method, CE Blog, Happy World, 2011)

By graph wet density =<u>2400 kg/m^3</u>

Density of aggregates to be used:

Wet density = Density of water + Density of cement + Density of Fine Aggregates, Coarse Aggregates, (Mix Design of concrete, B.Bhattacharjee, IIT Delhi, page 17)

2400 = 210 + 462 + Density of F.A, C.A
Density of F.A, C.A = 2400 - (210+462)≈<u>1728 Kg/m^3</u>

Proportion of Fine Aggregate:

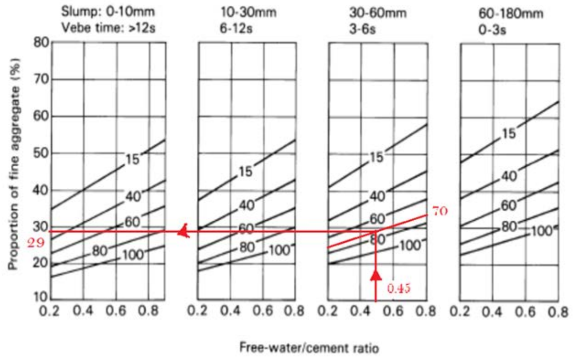


Figure 7: Recommended proportions of fine aggregate according to percentage passing a 600 µm sieve. (Concrete mixed design method, CE Blog, Happy World, 2011)

Proportion of Fine Aggregates to be used ≈ 29 %
Density of F.A = 29/100 * 1730 = <u>505kg/m^3</u>
Density of C.A = 1730 – 505 = <u>1225 kg/m^3</u>

Mix Ratio (Cement: F.A: C.A):

(1:1.09: 2.652) approximate.

1.3 Quantifying for each concrete specimen as per mix design calculated:

#	Cement (Kg)	Water (Kg)	Fine Aggregate (Kg)		Coarse Aggregate (Kg)	
Per m^3	462	210	505		1225	
			Dune Sand (25%) ≈ 126Kg	Black Sand (75%) ≈379Kg	(10 mm) = 410Kg	(20mm) = 815Kg
1 cube - 0.003375m^3	1.56	0.71	0.43	1.28	1.40	2.75
1 cylinder – 0.005299m^3	2.45	1.113	0.67	2.01	2.17	4.90

Table 2: Quantifying Amount of material required for each Specimen.

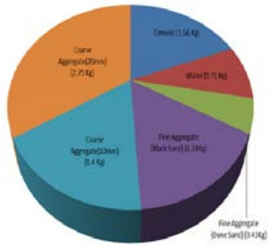


Figure 8: Concrete composition in one cube

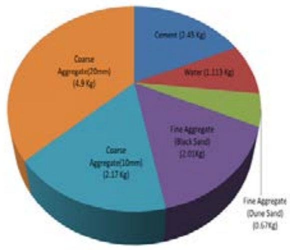


Figure 9: Concrete composition in one cylinder

1.4 Methodology

The various ingredients such as white cement, ordinary Portland cement, fine aggregate, coarse aggregate and water were mixed in different ratios. The prepared blends were used for casting cement concrete specimen (cubes and cylinders) and are tested for the mechanical properties at different time intervals. The ingredients were tested as per BS EN standard codes. British EN standards were also used to test cement and concrete specimens casted.

Material collection and storage:
White Portland Cement 52.5N ASTM C – 150 Type 1(JK White Cement) was provided by manufacturing plant JK cement, Fujairah for the project.

Figure 10: White Portland cement 52.5N ASTM C – 150 Type 1(JK White Cement)

Ordinary Portland cement (OPC) 42.5N ASTM C – 150 Type 1(Ultra Tech Cement) was provided by our university for this project.

Figure 11: OPC 42.5N ASTM C – 150 Type 1(Ultra Tech Cement)

Coarse aggregates(crushed) of sizes 10mm and 20mm was provided by the university which was used for casting the concrete specimens.

Figure 12: 10mm Coarse Aggregate (Crushed)

Figure 13: 20mm Coarse Aggregate (Crushed)

Fine aggregates; Black Sand of 2.5mm size and Dune sand of 0.5mm size was provided to us by the university to carry out the test.

Figure 14: Dune Sand Fine Aggregate

Figure 15: Black Sand Fine Aggregate

Other apparatuses provided by the university included the slump cone apparatus for calculation of slump values of fresh concrete. Mixer for mixing large amount of concrete for casting. Cubical and cylindrical moulds having dimensions in relation with EN BS 12350-1:2000. Hand held compaction device for compaction of fresh concrete. Weighing scale having an accuracy of 0.005 kg. Curing Tank able to control the temperature of water at $(20 \pm 3)℃$.

- Tests on fresh concrete such as the slump cone test done in accordance with BS EN 12350-2:2009; Testing fresh concrete.
- Tests on dry concrete compressive strength test done in accordance with British Standard EN 12390-2:2001; Determination of strength and tensile strength of dry concrete test done in accordance with BS EN 12390-6:2000.
- Soundness and setting time tests on cement carried out in accordance with BS EN 196-3:1995; Determination of setting time and soundness.
- Determination of cement strength carried out in accordance with BS EN 196-1:1995; Determination of strength.
- Fineness characteristic of cement carried out in accordance with BS EN 196-6:1989; Method of testing cement, Determination of fineness.

2. Test on Aggregates

2.1 Water Absorption Test

Water Absorption test gives us a general idea of the strength of the aggregates that are used in the concrete mix. Generally, Aggregates that have more water absorption rate are more porous and are unsuitable for a concrete mix unless they are found to be acceptable on the basis of their strength, impact and hardness tests performed.

Objective:

- To determine water absorption of Fine aggregates (Black Sand and Dune Sand).
- To determine water absorption of Coarse aggregates (10mm crushed and 20mm crushed).

Apparatus:

- Oven that can be thermostatically controlled to maintain a temperature between $100℃$ and $110℃$.
- A container for soaking the aggregates.
- A Balance of capacity of minimum 5kg, having an accuracy of 0.5g and able to weigh wet and dry aggregates.
- Steel trays and absorbent cloth for using in the oven and for surface drying of the aggregates.

Water Absorption Test Results:

Water Absorption (W_A):

$$W_A = \frac{W_1 + W_2}{3} \text{ grams}$$

Water Absorption Test Results								
		Saturated Surface Dry Aggregates		Oven Dry Aggregates		Water Absorption of Sample 1 (g) (W_1)	Water absorption of Sample 2 (g) (W_2)	Average Water Absorption for 500g Sample (W_A)
		Sample 1 (g)	Sample 2 (g)	Sample 1 (g)	Sample 2 (g)			
Fine Aggregate	Black Sand	1000	500	981.1	489.4	18.9	10.6	9.83
	Dune Sand	1000	500	985	492.8	15	7.2	7.40
Coarse Aggregate	10mm	1000	500	976	491.6	24	8.4	10.80
	20mm	1000	500	982	493.5	18	6.5	8.17

Table 1: Water Absorption Test Results

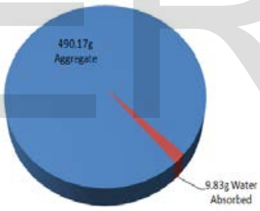


Figure 5: Water absorbed by a 500g sample of Black Sand

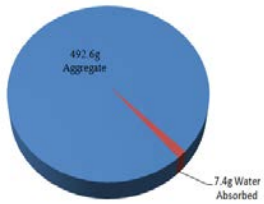


Figure 6: Water absorbed by a 500g sample of Dune Sand

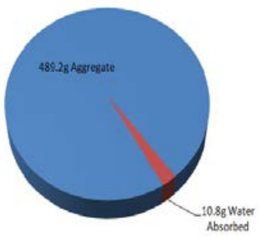


Figure 5: Water absorbed by a 500g sample of 10mm crushed aggregate

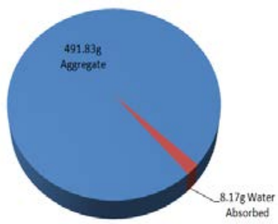


Figure 6: Water absorbed by a 500g sample of 20mm crushed aggregate

#	Cement (g)	Water (g)	Fine Aggregate (g)		Coarse Aggregate (g)	
Per m^3	462000	210000	505000		1225000	
			Dune Sand (25%) ≈ 126Kg	Black Sand (75%) ≈379Kg	10 mm = 410Kg	20mm = 815Kg
1 cube - $0.003375m^3$	1560	710	430	1280	1400	2750
1 cylinder – $0.005299m^3$	2450	1113	670	2010	2170	4900

Table 2: Reference to table 2(Introduction), Materials required for casting concrete specimen.

- If for 500g of Dune sand water absorbed = 7.4g; then for 430g of Dune sand water absorbed = 6.364g
- If for 500g of Black sand water absorbed = 9.83g; then for 1280g of Black sand water absorbed = 25.164g.
- If for 500g of 10mm coarse aggregate water absorbed = 10.8g; then for 1400g of 10mm coarse aggregate water absorbed = 30.24g.
- If for 500g of 20mm coarse aggregate water absorbed = 8.17g; then for 2750g of 20mm coarse aggregate water absorbed = 44.9354g.

Dune Sand		Black Sand		10mm		20mm	
430g	6.364g	1280g	25.1648g	1400g	30.24g	2750g	44.935g
670g	9.916g	2010g	39.5166g	2170g	46.872g	4900g	80.066g
Extra Water to be added :	For 1 Cube		106.7038 g				
	For 1 Cylinder		176.3706 g				

Table 3: Amount of water absorbed by aggregates for each cube/cylinder.

Amount of water absorbed by aggregates when a single cube is casted = 6.364 + 25.1648 + 30.24 + 44.935 = 106.7038g
Amount of water absorbed by aggregates when a single cylinder is casted = 9.916 + 39.5166 + 46.872 +80.066 = 176.3706g

3. Cement Testing

3.1 Chemical Analysis of Cement

Test Principle:
Chemical analysis was done on the cement samples to determine the percentage of chemical components/ingredients that form up the cement. We use a mechanical device known as the XRF (X-Ray Fluorescence) machine to determine the percentage of each constituent such as SiO_2, Al_2O_3, Fe_2O_3, CaO, etc. within the cement sample used.
EN 196-2:2013, Methods of Testing Cement- Part 2: Chemical Analysis of Cement is the code used to perform the physical tests for finding the chemical compositions.

Figure 1: Mould For Testing Cement

Figure 2: Section of the mould used

Figure 3: XRF Machine for Chemical Analysis of Cement

Results:
The following table shows the all the constituents present in the cement and their percentage:

Fineness for Ultra Tech Grey & JK White Cement				
Percentage Composition of Each Constituent (%)	**Test-I** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	**Test-II** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	**Test-I** JK White Cement CEM 1 52.5N	**Test-I** JK White Cement CEM 1 52.5N
SiO_2	19.05	18.91	21.19	21.15
Al_2O_3	4.76	4.70	4.33	4.37
Fe_2O_3	3.21	3.26	0.26	0.26
CaO	62.15	62.05	65.82	65.83
MgO	2.13	2.16	1.08	1.05
I.R.	0.24	0.25	0.16	0.16
SO_3	2.94	2.95	3.33	3.32
K_2O	0.53	0.51	0.41	0.41
Na_2O	0.18	0.18	0.16	0.16
Chloride	0.017	0.017	0.016	0.016
Na2O.equiv.	0.53	0.52	0.43	0.43
L.O.I	4.71	4.82	2.85	2.79
LSF	98.29	98.81	98.13	98.26
Silica Modulus	2.39	2.38	4.62	4.57
Aluminium Modulus	1.48	1.44	16.65	16.81
C_3S	61.96	62.92	65.21	65.31
C_2S	7.87	6.75	11.56	11.37
C_3Al	7.19	6.95	11.04	11.14

Table 4: Chemical Analysis Results

Silica (SiO2): Silicon Di-Oxide also known as silica has the chemical formula SiO_2. Silica is one of the major ingredients in cement and usually holds up to 19%-23% of cement mass. Silica content impacts directly on the strength of cement. From the test result white cement has about 2% more silica present in the composition thus giving a higher strength to its cement.

Alumina (Al_2O_3): Aluminium oxide also known as Alumina has the chemical formula Al_2O_3. Alumina too is one of the major ingredients in cement and is responsible for the quick setting property of the cement. Cement approximately contains about 2%-6% of alumina by mass. Temperature of clinkering is lowered by presence of predetermined quantity of alumina. Excess amount of Alumina reduces the strength of cement. From the test results we can infer that quantity of Alumina present in the cement is almost equal in both the samples.

Ferric Oxide (Fe_2O_3): Ferric Oxide also known as Iron Oxide has the chemical formula Fe_2O_3. Cement contains approximately 0.5%-0.6% of iron oxide by mass. Iron oxide imparts grey colour to the cement also acting as a flux. At high temperatures iron oxide reacts with aluminium and calcium to form tri-calcium alumina-ferrite which impacts the strength and hardness of the cement. From the test results we see that iron oxide is about 3% more in the grey cement

ISSN 2229-5518

when compared to the white cement which is responsible for the
colour.

Lime (CaO): Calcium Oxide also known as Lime has the chemical formula CaO. Lime is the main ingredient in cement composition and contains up to 61%-67% by mass of cement. There must be enough lime in the cement composition to accommodate formation of silicates and aluminates of calcium. Strength of cement is directly proportional to the amount of lime present in the cement, its deficiency causes cement to have a faster setting time. Excess amount of lime causes the cement to be unsound it also causes the cement to expand and disintegrate. From the test results we can infer that lime percentage in white cement is approximately 3% more than the grey cement but within the limit of 67% thus we can deduce that white cement will have greater strength and has a better chemical composition in terms of lime content.

Magnesia (MgO): Magnesium oxide also known as Magnesia has the chemical composition MgO. Cement should not have more than 2% magnesia as mass, excess magnesia causes reduction in cement strength. From the test results we can infer that magnesia content in white cement is well within excess limit thus having better strength than grey cement.

3.2 Standard Consistency Test

Apparatus:

Figure 4: Vicat Apparatus

Vicat apparatus shown in Figure 4 with plunger shown in Image 21 is used to accomplish the consistency test. The plunger(Image 21) that is used shall be of non-corrodible metal in the form of a right cylinder of (50 $\pm$1) mm effective length and diameter of (10.00$\pm$0.05)mm. Total mass of parts that move shall be (300$\pm$1)g. Movement of the plunger should be truly vertical and without appreciable friction having their axis coinciding with all other parts.

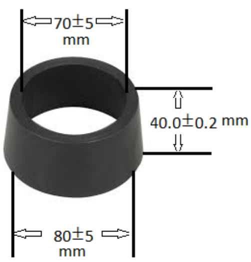


Figure 5: Vicat Mould (Vicat apparatus conical mould, Gilson Company, 2018, page 1)

Vicat Mould see Figure 5 needs to contain all the cement paste under the hard rubber. It shall be of truncated conical form (40.0$\pm$0.2) mm deep and should have an internal diameter of (70$\pm$5) mm, (80$\pm$5) mm top and bottom respectively. The apparatus has to be adequately rigid and should be provided with a glass base-plate that is larger than the mould having a thickness of at least 2.5mm.

3.3 Determination of Setting Time

Test Principle:

European standard EN 196-3:1994 has been adopted for the determination of setting time of cements. The above standard is applicable to all types of cements covered by ENC197-1. EN 196-3:1994 describes the basic procedures: it also provides alternate procedures if results aren't affected significantly. When in dispute, only the reference standards provided in the standard should be applied, excluding all alternatives.

Setting time of cement is determined by the observation of penetration of a needle into a cement paste (conforming to standard consistency) until the needle drops to a specified value.

Cement paste prepared must be of standard consistency which has a specified resistance to penetration of the needle. Water required for making the paste is determined by trial and error with different water content.

Requirements for the test:

Laboratory

Laboratory in which cement samples are to be prepared and tested must be maintained at a temperature of (20$\pm$2)$^\circ C$ and relative humidity of the room should be kept above 65%.

Apparatus

- Balance: weighing accuracy of 1g.
- Graduated Cylinder: Capable of measuring to the nearest 1% of volume measured.
- Mixer: Conforming to EN 196-1.
- Vicat Apparatus set according to EN standard.

Materials used

Distilled water shall be used at all stages of mixing, storing and boiling specimens.

Normen sand, CEN standard sand (0.08-2.00)mm, max moisture content of 0.2%.

Ordinary Portland cement, JK White cement used to make and test the specimen shall be kept at a temperature of (20$\pm$2)$^\circ C$ and a relative humidity not less than 90%.

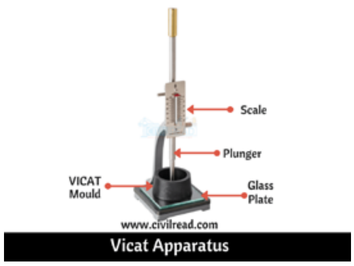


Figure 6: Vicat Apparatus (Standard or normal consistency of cement – VICAT Apparatus, Civil Read, Krishna, 2017)

Result:

Setting Time for Ultra Tech Grey & JK White Cement				
Setting Time (minutes)	**Test-I** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	**Test-II** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	**Test-I** JK White Cement CEM 1 52.5N	**Test-II** JK White Cement CEM 1 52.5N
Initial Setting Time (minutes)	220	215	125	120
Final Setting Time (minutes)	265	265	205	200

Table 5: Setting Time Results

Cement setting time should neither be too rapid nor too slowly. If the cement tends to have rapid setting time, there might not be enough time for it to be transported and placed on the concrete before it becomes too rigid. If the setting time is too slow it will result in slow up of work unduly, it postpones the defined use of the structure as there is inadequate strength at the desired age.
Setting time should not be confused with hardening, i.e. mechanical strength gain but it is the required time for the stiffening of cement paste to a desired consistency.
Initial setting time is the time when the cement paste starts to lose its plastic property. The initial setting time determines the time duration to delay the process of hardening.
Final Setting time is defined as the time at which the cement paste completely loses its plasticity. Time taken for the cement paste to harden sufficiently and attain the shape of the mould it is placed in.
Test results showed that JK white cement has a much faster initial setting time of almost 100 minutes than the Ultra Tech grey cement. This impacted during the process of casting concrete cubes where it was observed that Cubes with higher percentage of White Cement set much faster within 8-10 hours unlike the standard 24 hours required for setting.

3.4 Determination of Strength

Test Principle:
EN 196-1:1995, Methods of Testing Cement- Part 1: Determination of Strength is used for the following test.
The method comprises the determination of the compressive strength of prismatic test specimens 40 mm × 40 mm × 160 mm in size. These specimens are cast from a batch of plastic mortar containing one part by mass of cement and three parts by mass of standard sand with water/cement ratio of 0.50. Standard sands from various sources and countries may be used provided that they have been shown to give cement strength results which do not differ significantly from those obtained using the CEN reference sand.

Apparatus:
Mechanical Mixer (Hobart Mixer), Moulds, Mortar (Consists of CEN Reference Sand, Cement Water, Jolting Apparatus, Compressive Strength Machine.

Figure 7: Mechanical Mortar Mixer

Figure 8: Mould

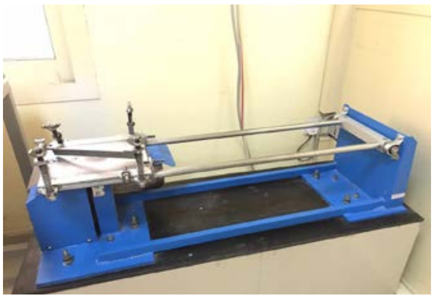


Figure 9: Jolting Apparatus

Results:

Compressive Strength for Ultra Tech Grey & JK White Cement				
Compressive Strengths (N/mm^2)	**Test-I** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N (N/mm^2)	**Test-II** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N (N/mm^2)	**Test-I** JK White Cement CEM 1 52.5N (N/mm^2)	**Test-II** JK White Cement CEM 1 52.5N (N/mm^2)
2 Days	19.9	20.1	33.4	34.3
7 Days	37.5	38.1	47.9	48.6
28 Days	50.4	50.9	58.6	59.3

Table 6: Compressive strengths results

Compressive Strength of cement is used to determine capacity of load that can be withstood by the cement specimen. It directly affects the tensile and compressive strengths of concrete specimens casted using the cement.
Test Results show that JK white cement have considerably higher compressive strength of approximately 10N/mm^2 when compared to Ordinary Portland Cement for each of the tested ages of the cement specimen. This will result in a direct effect on the compressive and the tensile strengths of the casted concrete specimens.

3.5 Determination of Soundness

Test Principle:
Soundness of cement sample refers to its ability to retain its volume after setting without delayed destructive expansion. (PCA, 1988). The expansion of the cement specimen is mainly caused by excessive amounts of free lime (CaO) or magnesia (MgO).
Soundness of a cement specimen is determined by observing the volume expansion of cement paste of standard consistency indicated by the relative movement of the two needles in Le-Chatelier Apparatus.

Apparatus:
Le-Chatelier Apparatus: The Le-Chatelier mould is made of spring brass with 2 indicator needles and must be of dimensions shown in figure 10. A pair of plane glass base and cover plates are provided for each of the moulds. The cover plate should have a mass of at least 75g else an

ISSN 2229-5518

additional small mass maybe placed to satisfy the requirement.

Water-Bath: Should have means of temperature control to increase temperature from (20±2)℃ to boiling in (30±5) minutes and must be capable of immersing the Le-Chatelier specimen.

Humidity control Cabinet: Must be of adequate size maintained at (20±2)℃ and having relative humidity of no less than 98%.

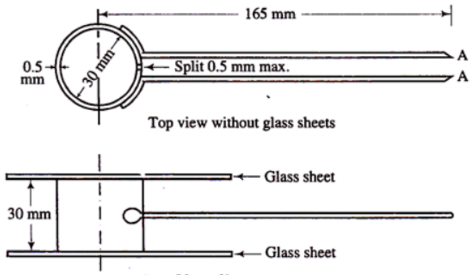


Figure 10: Le-Chatelier Apparatus for the Determination of Soundness of cement sample. (How to test and check the quality of cement?, Engineer notes, Susmita B, 2013)

Results:

Soundness Value for Ultra Tech Grey & JK White Cement				
Soundness of cement sample (mm)	**Test-I** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	**Test-II** Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	**Test-I** JK White Cement CEM 1 52.5N	**Test-II** JK White Cement CEM 1 52.5N
D2-D1(mm)	0.5	0.5	1.0	1.0

Table 7: Soundness (L1-L2) Results

Soundness test is performed to assess the possible risk of late expansion due to hydration of free Calcium oxide/Magnesium Oxide within the cement specimen.

Test results showed twice the volume expansion in JK White Cement when compared to Ultra Tech Grey Cement. From the values we can infer that there are twice as much uncombined CaO/ MgO radicals within JK White Cement.

3.6 Determination of Fineness

Test Principle:

Fineness of cement test is performed in accordance with EN 196-6: 1989, Methods of Testing Cement; Determination of Fineness.

Fineness or particle size of Portland cement affects hydration rate and thus the rate of strength gain. The smaller the particle size, the greater the surface area-to-volume ratio, and thus, the more area available for water-cement interaction per unit volume. The effects of greater fineness on strength are generally seen during the first seven days (PCA, 1988).

Fineness of cement is measure by observing the time required for a fixed quantity of airflow through a compacted cement bed of stated dimensions and porosity. Two methods are used to determine fineness of cement i.e. Sieve method and Air permeability test (Blaine Test). Air permeability test is used to determine the fineness of our cement specimens.

Figure 11: Blaine's Apparatus for Air Permeability Test

Apparatus:

Permeability Cell, Perforated Disc, Plunger, Manometer, Manometer Liquid, Timer, Balance, Pycnometer.

Materials Required:

Mercury, Light Oil, Circular Discs, Light Grease.

Laboratory Conditions for the performing the test:

Laboratory in which the Air Permeability test is to be carried out shall be maintained at a temperature of (20±2)℃ and having a relative humidity not exceeding 65%. All the materials used during the test must be kept at the same temperature of the laboratory and care must be taken that all specimens are to be protected from atmospheric absorption.

Formula Used:

$$S = \frac{K}{\rho} x \frac{\sqrt{e^3}}{(1-e)} x \frac{\sqrt{t}}{\sqrt{(0.1\eta)}} \ (cm^2/g)$$

(BS EN196-6, Method of Testing Cement; Determination of Fineness, pg 7, 1989)

Where,

- S, Specific surface of the cement under test.

$$S = \frac{\rho_o}{\rho} x \frac{(1-e_0)}{(1-e)} x \frac{\sqrt{e^3}}{\sqrt{e_0{}^3}} x \frac{\sqrt{0.1\eta_o}}{\sqrt{0.1\eta}} x \frac{\sqrt{t}}{\sqrt{t_0}} x S_0$$

(BS EN196-6, Method of Testing Cement; Determination of Fineness, pg 8, 1989)

- S_0, specific surface of the reference cement(cm^2/g)
- K, apparatus constant $= \frac{S_o \rho_o (1-e)\sqrt{(0.1\eta_o)}}{\sqrt{e^3}\sqrt{t_o}}$

(BS EN196-6, Method of Testing Cement; Determination of Fineness, pg 8, 1989)

- ρ_o, density of the reference cement in g/cm^3.
- t_o, mean of three measured times in seconds.
- η_o, air viscosity at the mean of three temperatures in Pascal seconds.
- ρ, density of cement.
- e, porosity of bed.
- t, measured time.
- η, air viscosity of the test temperature.

Result:

Fineness for Ultra Tech Grey & JK White Cement				
	Test-I Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	Test-II Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	Test-I JK White Cement CEM 1 52.5N	Test-II JK White Cement CEM 1 52.5N
Fineness of Cement in (m^2/kg.)	349	346	352	354

Table 8: Fineness Results

Test Results showed approximately same values of fineness in both the cement specimens used. Fineness has high influence in the bleeding and modulus of elasticity of casted concrete specimens. Higher the fineness lower the bleeding and modulus of elasticity of the concrete specimens casted.

4. Concrete Testing

4.1 Testing Fresh Concrete-Slump Test

General:

European standard EN 12350-2: 2009 standard specifies the method for determining the consistence of fresh concrete by performing the slump test. Slump test is subjected to change depending on the consistence of concrete mixed, which corresponds to the slumps between 10mm and 210mm beyond which other methods are to be used for calculation of consistency.

Slump test cannot be performed to check for consistency when the aggregates used are over 40mm in size or if the slump continues to change after 1 minute of de-moulding.

Principle:

Fresh concrete prepared is compacted into a mould in the shape of a frustum of a cone. The cone is then withdrawn upward leaving the concrete mix and the distance the concrete slumps is noted which provides a measure of the consistency of the concrete.

Apparatus:

Mould to form the test specimen: Should be made of metal and should not chemically react with the cement paste added and must not be thinner than 1.5mm. Interior must be smooth and free from dents and projections.

Mould should be in the form of a hollow frustum of a cone having dimensions in accordance with figure 3.1.1.

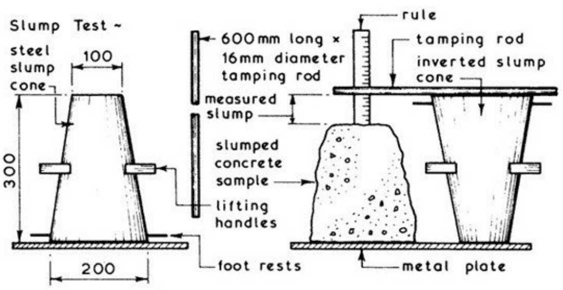


Figure 1: Section of mould for slump test (How to find out workability of concrete (Slump Test), Basic Civil Engg. All Details, Manjunath, 2017).

Compacting rod: Having a circular cross section, diameter (16$\pm$1) mm and length of (600$\pm$5) mm with rounded edges.

Ruler: Having graduations from 0mm to 300mm having intervals of not more than 5mm.

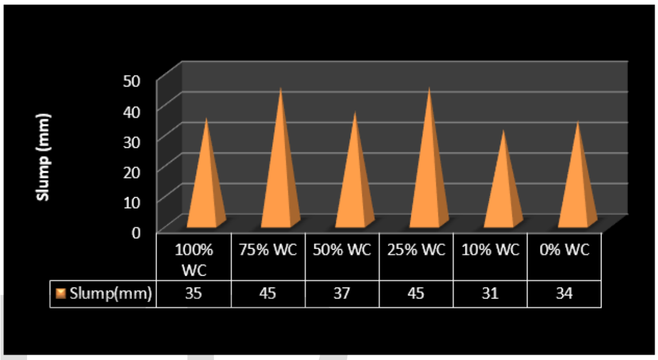
Base plate/surface: Rigid, flat, Non-absorbent plate surface on which the mould is placed.

Results:

1) Slump results for samples with dry crushed aggregates.

	100% WC	75% WC	50% WC	25% WC	10% WC	0% WC
OPC	0	4.39	8.778	13.167	15.792	17.55
White Cement	17.55	13.167	8.778	4.39	1.764	0
WATER	7.98+6	7.98+3	7.98+4	7.98+5	7.98+5.25	7.98+2
Dune Sand	4.8	4.8	4.8	4.8	4.8	4.8
Black Sand	14.38	14.38	14.38	14.38	14.38	14.38
10mm C.A	15.66	15.66	15.66	15.66	15.66	15.66
20mm C.A	32.76	32.76	32.76	32.76	32.76	32.76
Slump (mm)	**35**	**45**	**37**	**45**	**31**	**34**

Table 1: Slump Values for Wet Concrete Samples with Dry Crushed Aggregates



Graph 1: Slump Values for Different Blends with Dry Crushed Aggregates

Water Was Added to the above mixes in order to get required slump values for improving the workability of the samples being casted.

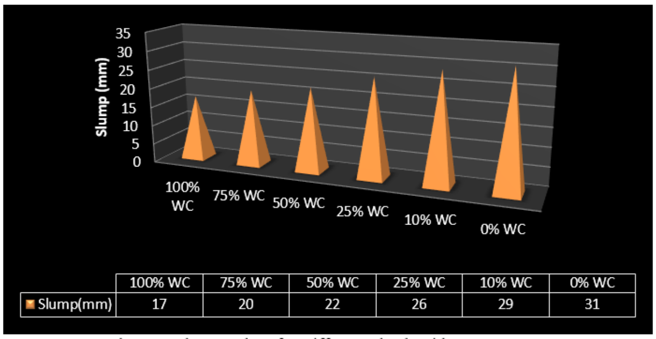
Workability of freshly prepared concrete is the ability to work with concrete, the ease of compacting, placing and finishing the concrete depends on its workability.

6 litres of water had to be added to Mix containing only white cement to get the desired slump value (35mm) whereas normal OPC required only 2 litres extra for slump value 34mm.

2) Slump values for concrete mixes with Saturated Surface Dry aggregates.

	100% WC	75% WC	50% WC	25% WC	10% WC	0% WC
OPC	0	0.901	1.802	2.703	3.2436	3.604
White Cement	3.604	2.703	1.802	0.901	0.3604	0
WATER	1.6401	1.6401	1.6401	1.6401	1.6401	1.6401
Dune Sand	0.985	0.985	0.985	0.985	0.985	0.985
Black Sand	2.9524	2.9524	2.9524	2.9524	2.9524	2.9524
10mm C.A	3.234	3.234	3.234	3.234	3.234	3.234
20mm C.A	6.36	6.36	6.36	6.36	6.36	6.36
Slump (mm)	**17**	**20**	**22**	**26**	**29**	**31**

Table 2: Slump Values for Concrete Mixes with SSD aggregates



Graph 2: Slump Values for Different Blends with SSD Aggregates

The Above chart represents the slump values that were obtained for concrete mixes that were casted using saturated surface dry samples.

White Cement Showed low workability having only 17mm slump whereas those cubes casted with OPC had a desirable slump value of 31mm.

The setting time of those cubes containing white cement had much faster setting time (approx. 2 hours) than compared to those with OPC (approx. 5 hours).

4.2 Making and curing specimens for strength tests

General:

The national annex of BS EN: 12390-2:2000 describes the conditions that are traditional for the curing of concrete specimens that are intended to be used for compression tests and while testing the tensile strength of the material to be casted.

Curing Conditions:

After Preparation, the specimen shall be conditioned in moulds in a closed room at draught-free location, protected from loss of moisture (e.g. by covering with polyethylene sheeting), for (24+/-2) hours at a temperature of approximately 22℃. During hardening, environment should be free of any sort of vibrations.

After (24+/-2) hours, the specimen shall be de-moulded, placed on gratings and cured for six days in water at a temperature of (20+/-2) ℃.

Seven day and twenty-eight days after preparation, the specimen shall be removed from the water cabinet, place on gratings and allowed to dry after which compression tests can be done.

Apparatus:

Figure 2: Mould for Cubes (150mm*150mm)

Figure 3: Mould for Cylinders (300mm*150mm)

Tamping rod (600mm): Used During slump test for Compaction into 3 layers.

Ruler: For measuring Height of slump with an accuracy of 0.5mm.

Mixer: Having a capacity of 90Kg for mixing the aggregates thoroughly and keeping the mix homogenous so that it can be casted in each cube separately and give almost equivalent results.

Hand Held Compacter: For compacting the wet concrete placed inside the cube moulds.

Figure 4: Hand Held compactor

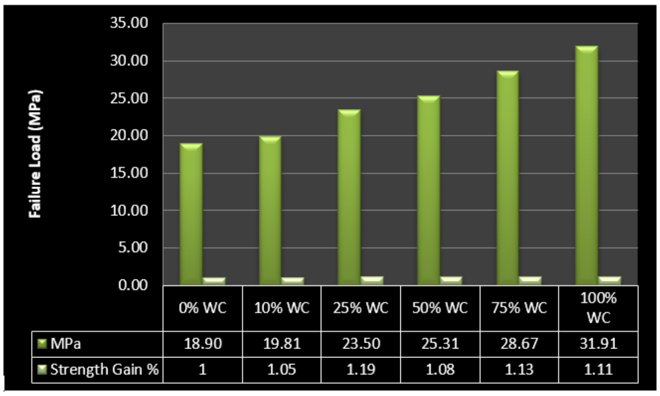
Shovel: For removing the excess content off the mould and to make the surface flat.

Results:

1. 7-Day Compression Test Results for cubes with Dry Crushed Aggregates:

7 Day compressive test										
Specimen	Cube 1			Cube 2			Cube 3			Average	
	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	KN	MPa
0% WC	7.48	405.1	18.04	7.5	444.1	19.61	7.51	426.3	19.04	**425.17**	**18.90**
10% WC	7.63	445.9	19.82	7.69	443.0	19.69	7.66	448.3	19.92	**445.73**	**19.81**
25% WC	7.82	530.2	23.56	7.68	516.1	22.94	7.73	540.3	24.01	**528.87**	**23.50**
50% WC	7.84	565.4	25.13	7.87	573.2	25.47	7.81	570.3	25.34	**569.63**	**25.31**
75% WC	7.82	626.8	27.84	7.99	658.7	29.33	7.88	649.2	28.85	**644.90**	**28.67**
100% WC	7.53	702.1	31.26	7.54	733.4	32.42	7.57	718.7	32.05	**718.07**	**31.91**

Table 3: 7-Day Compression Test Results for Concrete Cubes with Dry Crushed Aggregates



Graph 3: 7-Day Compression test for Concrete Cubes with Dry Crushed Aggregates

Compression Tests were done at the end of 7 days from curing for all the mixes with white cement replacement.

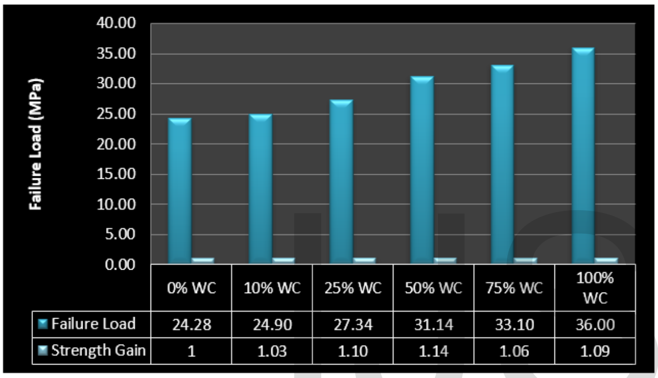
The above Graph shows a considerable difference between the concrete cubes casted with only OPC having a failure load of 18.90MPa while concrete cubes casted with only White Cement Shows a much higher strength with a failure load of 31.91MPa.

Maximum compressive strength increment was observed in Cubes Casted with 25% white Cement where the increase in strength was 1.19% of the previous casted specimens.

2. 28-Day Compressive Test Results for Cubes with Dry Crushed Aggregates:

28 Day compressive test											
Specimen	Cube 1			Cube 2			Cube 3			Average	
	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	KN	MPa
0% WC	7.77	547.4	24.33	7.81	552.9	24.57	7.83	538.7	23.95	546.33	24.28
10% WC	7.69	554.2	24.65	7.78	561.4	24.96	7.77	564.7	25.10	560.12	24.90
25% WC	7.82	614.8	27.35	7.69	622.8	27.69	7.71	606.4	26.97	614.67	27.34
50% WC	7.91	686.4	30.51	7.83	692.8	30.79	7.85	722.9	32.13	700.70	31.14
75% WC	7.91	751.8	33.41	7.97	737.9	32.83	8.04	743.6	33.05	744.43	33.10
100% WC	7.85	827.2	36.84	7.83	805.4	35.87	7.84	792.5	35.29	808.4	36.00

Table 4: 7-Day Compression Test Results for Concrete Cubes with Dry Crushed Aggregates



Graph 4: 28-Day Compression test for Concrete Cubes with Dry Crushed Aggregates

Compression Tests were done at the end of 28 days from curing for all the mixes with white cement replacement.

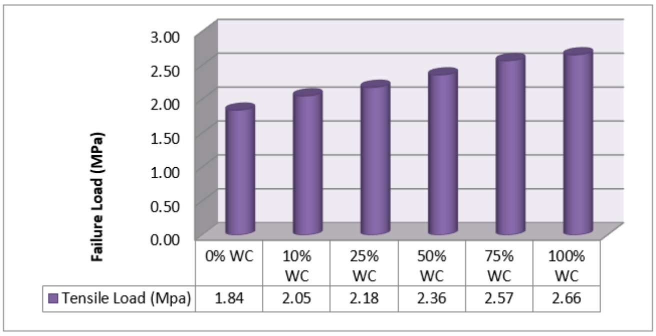
The above Graph shows a considerable difference between the concrete cubes casted with only OPC having a failure load of 24.28MPa while concrete cubes casted with only White Cement Shows a much higher strength with a failure load of 36.00MPa.

Maximum compressive strength increment was observed in Cubes Casted with 50% white Cement where the increase in strength was 1.14% of the previous casted specimens.

3. 28-Day Tensile Strength Results for Cylinder Samples:

28 Day Tensile Test											
Specimen	Cylinder 1			Cylinder 2			Cylinder 3			Average	
	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	KN	MPa
0% WC	12.00	129.1	1.83	12.10	130.6	1.87	11.90	128.4	1.82	129.37	1.84
10% WC	11.99	136.9	1.93	12.00	140.4	2.02	11.80	155.3	2.20	144.20	2.05
25% WC	11.95	152.8	2.16	12.00	156.7	2.24	12.10	151.4	2.13	153.63	2.18
50% WC	11.99	160.5	2.31	12.05	161.8	2.34	12.10	171.8	2.43	164.70	2.36
75% WC	12.20	186.4	2.61	12.30	182.7	2.57	12.30	179.0	2.53	182.70	2.57
100% WC	12.15	191.8	2.66	12.20	192.3	2.67	12.00	189.8	2.64	191.30	2.66

Table 5: 28-Day Tensile Test Results for Concrete Cylinders with Dry Crushed Aggregates



Graph 5: 28-Day Tensile Strength for Cylinder Samples with Mix Combinations

Tensile Tests were done at the end of 28 days from curing for all the mixes with white cement replacement.

The above Graph shows a considerable difference between the concrete cubes casted with OPC having a tensile failure load of 1.84MPa while concrete cubes casted with o White Cement Shows a much higher strength with a tensile failure load of 2.66MPa.

Maximum tensile strength increment was observed in Cubes Casted with 10% white Cement where the increase in strength was 1.12% of the previous casted specimens.

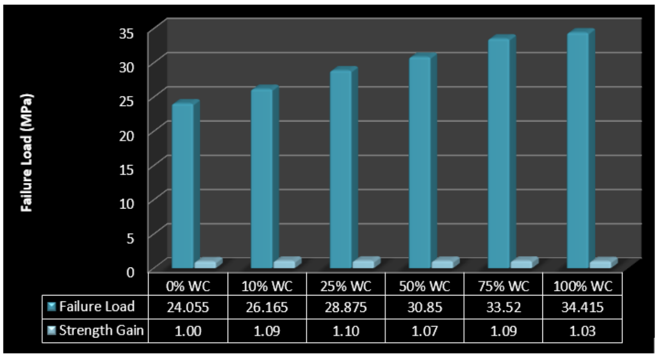
It was observed that Cylinders that were casted exclusively of white cement showed much better tensile strength than those casted using normal OPC.

In the market, most cylinders casted show a tensile failure load ranging from 1.8-2.5 MPa.

4. 7 Day Compression Test Results for cubes with Saturated Surface Dry Aggregates:

Specimen	Cube 1			Cube 2			Average	
	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	KN	MPa
0%	7.48	536.6	23.97	7.50	540.6	24.14	538.6	24.055
10%	7.63	580.9	25.84	7.69	596.3	26.49	588.6	26.165
25%	7.82	637	28.21	7.68	668.6	29.54	652.8	28.875
50%	7.84	703.9	31.03	7.87	695.4	30.67	699.7	30.85
75%	8.35	764.4	33.58	8.23	761.5	33.46	763.0	33.52
100%	7.53	781.2	34.29	7.54	787.1	34.54	784.2	34.415

Table 6: 7-Day Compression Test results for cubes with Saturated Surface Dry aggregates



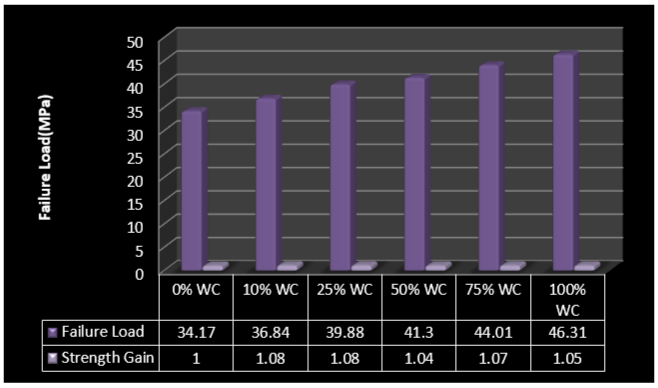
Graph 6: 7-Day Compression test for Concrete Cubes with Saturated Surface Dry Aggregates

Compression Tests were done at the end of 7 days from curing for all the mixes with white cement replacement.
The above Graph shows a considerable difference between the concrete cubes casted with only OPC having a failure load of 24.055MPa while concrete cubes casted with only White Cement Shows a much higher strength with a failure load of 34.415MPa.
Maximum compressive strength increment was observed in Cubes Casted with 10% and 75% white Cement where the increase in strength was 1.09% of the previous casted specimens.

5. 28-Day Compressive Test Results for Cubes with Saturated Surface Dry Aggregates

Specimen	Cube 1			Cube 2			Average	
	Wt.(Kg)	KN	MPa	Wt.(Kg)	KN	MPa	KN	MPa
0%	8.13	774.8	34.47	8.16	761.1	33.87	**778.4**	**34.17**
10%	8.11	851.5	37.86	8.03	805.3	35.82	**841.6**	**36.84**
25%	8.08	907.2	40.32	8.11	887.2	39.44	**913.7**	**39.88**
50%	8.19	919.1	40.85	8.10	939.5	41.75	**947.3**	**41.3**
75%	8.03	962.8	42.78	8.24	1018.5	45.24	**1008.7**	**44.01**
100%	8.09	1045.4	46.43	8.15	1039.9	46.19	**1042**	**46.31**

Table 7: 28-Day Compression Test results for cubes with Saturated Surface Dry aggregates



Graph 7: 7-Day Compression test for Concrete Cubes with Saturated Surface Dry Aggregates

Compression Tests were done at the end of 28 days from curing for all the mixes with white cement replacement.
The above Graph shows a considerable difference between the concrete cubes casted with only OPC having a failure load of 34.17MPa while concrete cubes casted with only White Cement Shows a much higher strength with a failure load of 46.31MPa.
Maximum strength increase was observed in Cubes Casted with 10% and 25% white Cement where the increase in strength was 1.08% of the previous casted specimens.

6. Cost Consideration

- *Cost For 1 bag (50Kg) of JK White Cement CEM 1 52.5N =* 33 AED

(http://www.800cement.com/products/jk-white-cement/white-cement/white-cement-cem1-jk-white-cement, 800 Cement, White Cement CEM1 –JK WHITE CEMENT, 2018)

- *Cost for 1 bag (50Kg) of Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N =* 14 AED

(http://www.800cement.com/products/star-cement/opc/ordinary-portland-cement-opc-star-cement,800 Cement, OPC – STAR CEMENT, 2018)

Costing with Blends:

Cement Blends	Ultra Tech Grey Cement. ASTM C-150 Type 1 42.5N	JK White Cement CEM 1 52.5N	Cost (AED)	Compressive Strength (Mpa)	Tensile Strength (Mpa)
OPC	14 AED	0	**14**	**34.17**	**1.84**
10% WC	12.6 AED	3.3 AED	**15.9**	**36.84**	**2.05**
25% WC	10.5 AED	8.25 AED	**18.75**	**39.88**	**2.18**
50% WC	7 AED	16.5 AED	**23.5**	**41.3**	**2.36**
75% WC	3.5 AED	24.75 AED	**28.25**	**44.01**	**2.57**
WC	0	33 AED	**33**	**46.31**	**2.66**

Table 1: Cement blends vs Cost

Graph 1: Cost Vs Strength Evaluation

Cement Blends	Cost (AED)	Compressive Strength (Mpa)	Tensile Strength (Mpa)
OPC	1.000	1.000	1.000
10% WC	1.136	1.078	1.114
25% WC	1.339	1.167	1.185
50% WC	1.679	1.209	1.283
75% WC	2.018	1.288	1.397
WC	2.357	1.355	1.446

Table 2: Cement Blends cost and strengths compared to OPC

From Table 2 we can infer that:
Concrete specimens casted with cement blends of 25% White Cement and 75% OPC has a cost increase of 0.339% from using normal OPC. Compressive strength of cubes casted with this blend have 0.167% better compressive strength at this cost increase which is not significant in any other blends considering cost.
Concrete specimens casted with cement blends of 50%

White Cement and 50% OPC has a cost increase of 0.679% from using normal OPC. Tensile Strength of cubes casted with this blend have 0.283% better tensile strength at this cost increase which is not significant in any other blends considering cost.

7. Conclusion

- 2-day compressive strength of White cement showed 14.2 (N/mm^2) higher strength than OPC implying that white cement has a higher early strength gain when compared to OPC.
- 28 Day compressive strength of White Cement was 8.4(N/mm^2) greater than the OPC that was tested signifying that white cement has substantially higher compressive strength when compared to OPC.
- Slump values of fresh concrete tested showed a decreasing graph as the quantity of white cement added to the blend increased. This suggests that the workability of white cement when compared to that of OPC was very low thus making mixing, transportation and compaction of white cement a complication.
- From the 7-day testing of concrete blends it was observed that Maximum compressive strength increase was in Cubes Casted with 10% and 75% white Cement replacement where the increase in strength was 1.09% of the previous casted specimens.
- From the 28-day testing of concrete blends it was observed that Maximum compressive strength increase was in Cubes Casted with 10% and 25% white Cement where the increase in strength was 1.08% of the previous casted specimens.
- From the 28-day testing of concrete blends it was observed that Maximum tensile strength increment was observed in Cubes Casted with 10% white Cement where the increase in strength was 1.12% of the previous casted specimens.
- By using saturated surface dry aggregates in the concrete mix, 28-day compressive strength of cubes casted had 10.31MPa higher strength than the cubes that were casted using dry crushed aggregates.
- Concrete cubes that were casted even after satisfying the water content that was absorbed by dry crushed aggregates still showed a lower strength of about 8MPa when compared to those cubes that were casted with saturated surface dry aggregates. This suggests that even after water deficit has been satisfied concrete cubes will not give a desired compressive strength unless the aggregates are saturated surface dry.
- When dry crushed aggregates are used in the concrete mix, water added to the mix is partially absorbed by these aggregates and there will be a deficit of water for the cement, thus, influencing the water-cement ratio that was pre-calculated so that the concrete specimens achieve their strength. While using saturated surface dry aggregates approximately all the water that is added into the concrete mix reacts with the cement alone without disturbing the water-cement ratio.
- Concrete specimen casted with 25% replacement of white cement has an approbative compressive strength favourable to the cost of cement material used.
- Concrete specimen casted with 50% replacement of white cement has an approbative tensile strength favourable to the cost of cement material used.

8. References

[1] H. World, "Concrete Mixed Design Method (BS Method)," September 2011. [Online]. Available: http://advancedcivilengineering.blogspot.com/2011/10/concrete-mixed-design-method-bs-method.html.

[2] Unsourced, "White Portland Cement," March 2007. [Online]. Available: https://en.wikipedia.org/wiki/White_Portland_cement.

[3] s. tv, *Concrete Mix design by DOE method.*, Youtube, 2016.

[4] S. S. D. B. E. Temple Nwofor, "A Comparative Study of the Methods of Concrete Mix Design Using Crushed and Uncrushed Coarse Aggregates," 2015.

[5] C. Technology, "Concrete Mix Design," 2015. [Online]. Available: http://www.sginstitute.in/Downloads/Civil_Downloads/LectureNo_19.pdf.

[6] J. M. Syam Mohan.m, "Study on Mechanical Properties of Concrete with Partial Replacement of Cement By China Clay," vol. 03, no. 07, July-2016.

[7] Suryakanta, "SPECIFIC GRAVITY & WATER ABSORPTION OF AGGREGATE (IS:2386-PART 3-1963)," 8 5 2013. [Online]. Available: http://civilblog.org/2013/05/08/specific-gravity-water-absorption-of-aggregate-is2386-part-3-1963/.

[8] Santhu, "SCRIBD," 2016. [Online]. Available: https://www.scribd.com/doc/40206526/Bs-Mix-Design-Doe-Method.

[9] A. R. M. D. R. N. R. I. S. GOPINATH, "OPTIMISED MIX DESIGN FOR NORMAL STRENGTH AND HIGHPERFORMANCE CONCRETE USING PARTICLE PACKING METHOD," Vols. v.10169-011-0026-0, no. 10.2478, 2011.

[10] S. S, "DOE Methods of Concrete Mix Design | Concrete Technology," [Online]. Available: http://www.engineeringenotes.com/concrete-technology/mix-design/doe-methods-of-concrete-mix-design-concrete-technology/31826.

[11] S. ROMAN, "SR EN 12350-6," September 2002. [Online].

[12] Nidhi, "What is the meaning of 1.65 in concrete mix

design?," 6 March 2017. [Online]. Available: https://www.quora.com/What-is-the-meaning-of-1-65-in-concrete-mix-design.

[13] G. Mishra, "Specific Gravity and Water Absorption Tests on Aggregates," [Online]. Available: https://theconstructor.org/building/aggregates-specific-gravity-water-absorption-test/1358/.

[14] G. Mishra, "Concrete Slump Test for Workability - Procedure and Results," [Online]. Available: https://theconstructor.org/concrete/concrete-slump-test/1558/.

[15] Krishna, "Standard or normal consistency of cement – VICAT Appartus," [Online]. Available: https://civilread.com/normal-consistency-cement-vicat-appartus/.

[16] B. S. Institute, "BS EN 196-7," [Online].

[17] B. S. Institute, "BS EN 196-6," 1989. [Online].

[18] B. S. Institute, "BS EN 196-3," 1995. [Online].

[19] B. S. Institute, "BS EN 196-2," 2013. [Online].

[20] B. S. Institute, "BS EN 196-1," 1995. [Online].

[21] B. S. Institute, "BS EN 12350-4," 2000. [Online].

[22] B. S. Institute, "BS EN 12350-2," 2009. [Online].

[23] B. S. Institute, "BS EN 12350-1," 2000. [Online].

[24] A. Henikish, "BS -CONCRETE MIX DESIGN (DOE," [Online]. Available: http://www.academia.edu/25183260/BS_-CONCRETE_MIX_DESIGN_DOE.

[25] Z. Haimei, Building Materials in Civil Engineering, New Delhi - 110002: Woodhead, 2011.

[26] I. S. Code, "Specific Gravity and Water Absorption Test," *IS:2386* , Vols. Part - 3.

[27] I. S. Code, "IS 456," 2000. [Online].

[28] G. Cement, "White Cement Review," 19 November 2014. [Online]. Available: http://www.globalcement.com/magazine/articles/890-white-cement-review.

[29] U. Biswas, "Design Of Experiments(DoE) in Concrete Mix Design," 20 August 2016. [Online]. Available: https://www.linkedin.com/pulse/design-experimentsdoe-concrete-mix-uttam-biswas.

[30] B.Bhattacharjee, "IIT DELHI," 2015. [Online]. Available: http://web.iitd.ac.in/~bishwa/LEC_PDF_774/LEC11.pdf.

[31] P. C. Association, "What is white cement?," [Online]. Available: http://www.cement.org/docs/default-source/fc_mat-app_pdfs/arch-deccon/what-is-white-cement-wc001.pdf?sfvrsn=4.

[32] "FREE MOISTURE AND WATER ABSORPTION IN AGGREGATE FOR CONCRETE," TXDOT DESIGNATION, 1999.