EFFECT OF FLY ASH ON STRENGTH OF PAVEMENT QUALITY CONCRETE

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EFFECT OF FLY ASH ON STRENGTH OF PAVEMENT QUALITY CONCRETE

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Declaration of Originality

I, Arunima Pradhan, Roll Number 214CE3464 hereby declare that this dissertation entitled *Effect of Fly Ash on Strength of Pavement Quality Concrete* presents my original work carried out as a doctoral student of NIT Rourkela and, to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference" or "Bibliography". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

June 1

NIT Rourkela

Arunima Pradhan

Dedicated to

My Parents

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Arunima Pradhan

ABSTRACT

Now-a-days with the growing industries large amount of waste products are produced. Disposal of these waste materials are required as they cause harm to human and other life. For its disposal large area is covered. As the production of waste is increasing day by day we need to find a substitute to overcome this problem. Fly ash is a waste product produced due to burning of coal in power generating plants.

Concrete consists of cement, sand, fine and coarse aggregate. Production of cement emits large quantity of green house gases. Due to increase in construction work, demand for cement will also increase. So to avoid production of green house gases and to produce environment friendly concrete, cement is replaced with certain percentage of fly ash. Replacement of cement with certain percentage of fly ash is to improve the strength of pavement concrete. The fly ash used in this study is from Rourkela Steel Plant (RSP), Rourkela, Odisha and is of Class F.

In the experimental study the replacement of OPC (Ordinary Portland Cement) with fly ash is done and to get the desired workability and strength. Polymer based superplasticizer is used for all grades of concrete. The compressive and flexural strength of PQC (Pavement Quality Concrete) with different percentage of fly ash has been studied for 3, 14 and 28 days. From the experimental results it has been noted that without superplasticizer the compressive strength of Pavement Concrete is less for both 7days and 28 days. With the use of superplasticizer the desired compressive strength is achieved. But in case of flexural strength even without superplasticizer concrete attains the required strength and with superplasticizer the flexural strength of PQC achieve higher strength.

Key words: PQC, RSP Fly ash, superplasticizer, compressive and flexural strength

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LIST OF ABBREVIATIONS

ASTM : American Society for Testing and Materials

CA : Coarse Aggregate

FA : Fly Ash

S : Sand (Fine Aggregate)

C : Cement

OPC : Ordinary Portland Cement

OPCC : Ordinary Portland Cement Concrete

RSP : Rourkela Steel Plant

HVFAC : High Volume Fly Ash Concrete

PQC : Pavement Quality Concrete

IS : Indian Standard

IRC : Indian Road Congress

m : Meter

cm : Centimeter

mm : Millimeter

KN : Kilo Newton

MPa : Mega Pascal

min : Minute

G : Specific Gravity

rpm : Rotation per minute

Chapter 1

Introduction

1.1.General

Fly ash concrete is extensively used among various industries. Use of such concrete is increasing because of higher performance, environment friendly and conserves natural resources. By adding admixture to concrete makes the concrete mix workable with lower water cement ratio and improves the strength of concrete.

1.2. Fly Ash

It is a fine grey powder produced by burning coal in power generating industries. It consists of iron, silica, calcium and alumina. It is a pozzolanic material which has almost negligible cementitious property. It shows cementitious property when react with cement in the presence of moisture. Only because of this reason it can be used as a substitute of cement in concrete mix with many advantages.

Ash generation from Thermal power plants is increasing day by day. In the year 1993-1994 the production of ash was 40 million ton which increased to 110 million ton during 2005-2006 and expected to increase further in the coming years as the need of power generation increases in India. Disposal of fly ash is required as it pollutes environment and causes serious health issues. As maximum number of power generating plant uses coal they ultimately produces large amount of fly ash. So for disposal of fly ash many acres of land are occupied by ash ponds.

ASTM categorizes fly ash into two types and they are: Class C & Class F. Composition of both fly ashes differentiates them from each other which mainly include content of silica, calcium, iron and alumina. The chemical property of fly ash mainly depends on burned coal.

Class F Fly ash:

It is produced from burning anthracite and bituminous coal. It has little or no cementitious property. It has pozzolanic property with lime content less than 20%. As it is pozzolanic material produces cementitious material when react with lime with certain moisture content.

Class C Fly ash:

Burning of lignite or sub-bituminous coal produces Class C fly ash. Being a pozzolanic material it has cementious property. It can gain strength in the presence of moisture. In this fly ash lime content is more than 20%. It also has higher content of sulfate and alkali. Class C fly ash can replace higher percentage of cement than Class F fly ash.

The chemical property of fly ash mainly depends upon the property of coal being burnt and also depends upon storage and handling of coal. There are four types of coal with varying chemical composition, heating value, geological properties and percentage of ash. They are lignite, anthracite, bituminous and sub-bituminous. The calcium content in Class F fly ash varies from 1% to 12% whereas in Class C fly ash it varies between 30%-40%. The sulphate content and alkalis content in Class C fly ash is higher than in Class F fly ash.

1.3. High Volume Fly Ash Concrete

Many researches show that partial replacement of cement with fly ash improves the property of fresh as well as hardened concrete. So it helps in recycling the waste from power generating industries instead of filling in ash ponds. Earlier the replacement was limited to 20- 30% but now it is being replaced with higher percentage of fly ash. Using fly ash in such a higher percentage creates green concrete and environment friendly. Studies show that during manufacture of cement 7% of green house gases are emitted to the atmosphere. Fly ash being a byproduct of burning coal doesn’t produce green house gases. So replacement with a higher percentage reduces the emission of green house gases from cement production as demand for cement reduces. Fly ash delays the setting time of concrete. Admixture can accelerate the setting time of concrete having fly ash. There are many types of admixture like water reducing, air entraining, plasticizer, superplasticizer etc.

1.4. Aim of the Research

Fly ash is generally produced in large quantitities due to increase in power generation capacity. Its production is going to increase further in near future. As its disposal will create problem we need to utilize large amount of fly ash so it is used in cement concrete. A lot of researches show that earlier its replacement was limited to 20-30% but now it is increased to more than 50%

replacement. Here focus is mainly on producing concrete with high fly ash replacement and determining various physical properties of material used, flexural and compressive strength of cube and prism.

1.5. Objective and Scope of Work

Fly ash has been used to certain extend to replace cement in preparation of concrete for various applications. An attempt has been made in this study to utilize fly ash in varying quantities for preparation pavement quality concrete and study the effect of fly ash on strength properties of this type of concrete. In this study fly ash obtained from the nearby thermal power station belonging to Rourkela Steel Plant (RSP).

To achieve the above objective the following scope of work has been planned.

- To determine the physical properties of ingredient materials such as Ordinary Portland Cement (OPC) grade-43, RSP fly ash, aggregate and sand. .
- To develop mix design for concrete with and without fly ash in varying percentage.
- To perform compressive strength and flexural strength test on both cube and prism specimen for all type of concrete mix samples.
- To study the effect of fly ash replacement on strength characteristics of concrete.

1.6. Organization of the Thesis

The thesis consists of five chapters. Information regarding each chapter can be found below.

Chapter 1 is the introduction to the thesis. It contains brief background of fly ash as a material used as substitute to cement. It also contains objective and scope of work and aim of research work.

Chapter 2 is the literature review which contains brief review on HVFAC of recent past studies carried out in laboratory on concrete mixes with varying fly ash content.

Chapter 3 is the experimental methodology which is carried out to determine the properties of varies materials used in PQC using fly ash, compressive strength and flexural strength of fly ash concrete mix.

Chapter 4 is the analysis of the test results and discussion carried out for compressive and flexural strength on PQC using fly ash.

Chapter 5 gives the summary of present work with conclusion and also contains suggestion for future work.

Chapter 2

Literature Review

2.1. Introduction

This chapter focuses on a vast literature study on both field and laboratory works which are conducted in the recent past to observe the compressive and flexural strength of pavement quality concrete using fly ash and HVFAC for higher percentage of fly ash.

2.2. Past Studies on High Volume Fly Ash Concrete

Tan and Pu (1998) they studied the use of supplementary material such as fly ash to improve various properties of concrete like strength and permeability. Being eco friendly it reduces heat of hydration, cost of production, and use of water due to use of admixture. Using admixture also improves the strength of concrete at higher period of curing. Many studies show that use of slag along with fly ash increases the strength.

Marceau (2002) shows that earlier fly ash used in concrete vary between 15% and 25%. It is taken by the mass of the cementitious material. The quantity of fly ash used actually depends on the place of application, fly ash property and the geographic location and climatic condition. Higher percentages of fly ash (30% to 50%) have been used in large structure such as foundations and dam so that it will control the rise in temperature. Many researchers have shown that higher percentage (more than 50%) of fly ash can be used in structures having sound properties and being economical.

Prusinski et al (1993) presented that various things are considered for quantity of fly ash to be used in concrete and the amount of total cementitious material used they are type of fly ash, geographic and climatic condition, qualities of cement, type of admixture used.

Best (1980) presented that the fly ash used in concrete is of high quality having, higher fineness and low percentage of carbon which will help in reducing the water content. It produces fly ash concrete of same workability as that of normal Portland cement concrete. The reduction percentage varies with the type of fly ash used and various other parameters. The concrete using fly ash should be such that it will have same workability as well as slump. Fly ash helps in reducing the segregation of concrete and improves cohesiveness.

Camoes (2004) presented that fly ash can used with a higher percentage of replacement with cement. The strength of concrete using fly ash improves the 28 days compressive strength by 45-55 Mpa. Fly ash having higher percentage of carbon content makes the concrete workable. It may affect the strength if it is not properly cured.

Malhotra and Mehta (2002) defined High Volume Fly Ash Concrete according to the following characteristics:

Characteristics defining HVFA concrete are as follows:

- Amount of fly ash is more than 50% by mass of total cementitious matter.
- Water amount should not be more than 130kg/m3.
- Cement content should not exceed 200kg/m3.
- The 28-day compressive strength of concrete for 30MPa or higher, slumps should be more than 150 mm, and water-to-cementitious materials ratio should be 0.30, and compulsory use of water reducing admixture.
- Air entrain admixture is used for the freeze and thaw condition which results in adequate air void spacing factor.
- The 28-day compressive strength of concrete not exceeding 30 Mpa with slump less than 150mm, water to cementitious ratio should be of order 0.4 without addition of superplasticizer.

In the year 2002 they presented that fly ash replacement with a lower or higher percentage does not affect the compressive strength, flexural strength, tensile strength and elastic modulus. They also point out that the tensile strength and flexural strength of high volume fly ash concrete improves with age because the pozzolanic reaction taking place improves the bond of aggregate and paste. The fly ash particle which doesn’t react, act as a filler material like sand as it has low porosity in the interfacial zone and ultimately improves the elastic modulus.

Malhotra (2005) and Atis (2003) presented that in case of Portland cement concrete cracking occur due to drying shrinkage. Factors affecting for such problem are mainly amount of water used, water cementitious ratio and proportion of aggregate used. In case of fly ash concrete as the amount of water used for concrete is reduced as fly ash being used ultimately reduces the chance of shrinkage crack. It is found that drying shrinkage in case of high volume fly ash concrete is less as compared to Portland cement concrete. As amount of water used in high volume fly ash concrete is less so the cement paste formed is about 25% whereas in case of Portland cement concrete cement paste formed is about 29.6%. HVFA concrete shows bleeding which can be prevented by covering it with heavy plastic sheets. If precautions are not taken they there are chances of plastic shrinkage cracks mainly in hot and windy season.

Structural Engineering Research Institute (2005) presented that high volume fly ash concrete shows higher strength at later age and flexural strength is also higher in case of HVFAC. But in case of bond strength in embedded rebar strength is nearly same for conventional Portland cement concrete and HVFAC.

P. Vipul Naidu and Pawan Kumar Pandey (2014) presented that using fly ash reduces the cost of construction and heat of hydration. It improves the durability of concrete and forms green concrete. Use of admixture improves the property of concrete like higher workability, early age strength and reduces water content. With the use of other binding materials it reduces water cement ratio. From various trials he concluded that fly ash can be replaced upto 65% and with this much of replacement the workability also get improved and reduces the cost of construction.

Mini Soman and Sobha.K (2014) they presented that workability of concrete improves by using fly ash and contributing to a sustainable development. The tests are performed on concrete beams. The strength of concrete with 50% fly ash shows reduction in strength of about 20% at an age of 7 days but at 28 days it acquire the required strength. HVFA concrete can carry larger load than Portland cement concrete. From the various studies it is found that HVFAC are more crack free than OPCC. It helps in reducing the cost of construction about 24% with a replacement of 50%.

Jino John and M. Ashok (2014) they presented the mechanical properties of HVFAC. The mechanical properties of HVFAC are studied with replacement of cement about 50%, 60% and 70% of fly ash. The HVFAC attains less compressive and tensile strength as compared to the ordinary Portland cement concrete. The various other mechanical properties of HVFAC shows lesser value than that of OPCC.

Carette et al. (1990) studied the use of fly ash in concrete as a cementitious material. The fly ash being used in concrete with a replacement over 55% with cement. It also studied the mechanical properties of fly ash concrete with a water cement ratio of 0.3 and 0.35 in order to get required workability super plasticizer is also added to concrete. The evaluation of physical properties of high volume fly ash was done and they are modulus of elasticity, particle size and pore size distribution, electron-microscopically observation, compressive strength and non-evaporable water. The water cement ratio of concrete paste formed with fly ash and cement affects the porosity of paste and hydration of cement. The reaction of fly ash and $CaOH_2$ begins between 3 and 7 days as large amount of fly ash as a cementitious material is used in concrete as a replacement of cement. A concrete mix with low water cement ratio with low $CaOH_2$ content produces stronger concrete. In another study developed the concrete mix using ASTM class F fly ash with a replacement of 55% to 60%. The result of eight different fly ash concrete mixes shows better performance in mechanical property, workability, temperature rise, bleeding and setting time.

Malhotra (1990) presented study on durability of high volume fly ash concrete using Class F fly ash. It mainly focuses on chloride permeability, limestone aggregate, thaw cycles and freeze. The percentage of replacement varies between 54% and 58%. In order to improve workability of fly ash concrete mix super plasticizer was added. The results obtained are satisfactory.

Carette and Malhotra (1990) presented that shape and size of fly ash affects the property of concrete in plastic form. Fly ash helps in improving resistance of concrete to sulphate attack in any type of cement. It is one of the advantages of using fly ash as cementitious material. Calcium hydroxide is produced due to hydration of cement which ultimately increases the permeability of concrete. When sulpahte attack takes place calcium hydroxide reacts with sulphate to form gypsum in sea water. Then gypsum formed occupies larger volume than that of calcium hydroxide which results in disintegration of concrete. Addition of fly ash in concrete helps in reducing disintegration as silica present in ash combine with calcium hydroxide to produce cementitious material. This ultimately reduces the amount of calcium hydroxide available for the formation of gypsum and thus improves the impermeability of concrete. It results in improving the sulphate resistance of concrete.

Sivasundaram et al. (1990) studied the concrete with high replacement of cement with fly ash. The fly ash used is Class F with a replacement of 58%. They found that as high percentage of fly ash is used in concrete they don't perform like the conventional cement concrete. Superplazticizers are used so that it will increase the workability of concrete but it increases the setting time mostly those concrete mix having higher cementious material.

Ravina et al. (1986) they studied the behavior of Class C and Class F fly ash with 30% and 50% replacement. From the result they observed that rate of volume of bleeding water was almost same to the normal concrete mix without adding fly ash. But setting time of fly ash concrete is higher than the normal concrete mix without fly ash. Rate and amount of bleeding increases due to use of Class F fly ash. The fly ash containing higher percentage of cementious material takes longer time to set. So, Class C fly ash takes longer time than Class F fly ash.

Thomas (1992) presented that at same water cement ratio the rate of carbonation increases due to the fly ash addition. The rate of carbonation increases in case of higher percentage cements replacement with fly ash and concrete which is not cured properly. The concrete with higher fly ash replacement shows higher carbonation rate when compared with concrete of equal strength

T.P. Singh (2007) presented that at early age the compressive strength of HVFA concrete is less but eventually compressive strength increases at later age. Not only in case of compressive strength HVFAC perform better in case of flexural and tensile strength and elastic modulus.

Claudia Ostertag (2005) presented that Fly Ash Concrete produce sustainable concrete as well as reduces negative effect on environment. Class F and Class C fly ash is being used. The need of cement is increasing as the development increases so by using fly ash in place of cement will reduce the cost of construction. Researches show that HVFAC with a replacement of approx. 50% can be used in places where strength at initial days is less required. Even strength at initial age can be obtained by adding superplasticizer to concrete mix having lower water to cementitious material ratio. HVFAC reduces the cost of construction and give better surface finish. Fly ash can be used even in a higher percentage of about 60%-80% with proper mix design. In such cases Class C fly ash is used as it contain high lime and have high cementitious property than Class F.

Pattanaik and Saba (2010) presented that fly ash can be used as a cementitious material in concrete. In this study fly ash produced by NALCO, angul, Odisha with varying percentage of superplasticizer is used and it can replace cement about 30-35%. The target strength at 28 days can be achieved by 30% replacement of fly ash. As fly ash concrete has low early age strength it can be improved by adding superplasticizer to concrete mix. It even helps in reducing water to cementitious ratio and improves workability of mix.

Naik et al. (2003) presented the investigation carried out on performance of Class F and Class C fly ash. They prepared concrete mix using fly ash upto 70% for Class C and 67% for Class F. Density of concrete doesn't get affected by any of the factors like type or amount of fly ash used. Concrete containing Class C fly ash shows early age strength as compared to concrete containing Class F fly ash. Required flexural and tensile strength can be achieved by Hcase of long term Class F fly ash gives higher strength both in case of compressive and pozzolanic contribution as compared to the Class C fly ash.

University of Nebraska (2002) presented the investigation with the use of fly ash in large quantity from a power plant in Omaha, Nebraska. The replacement of cement with fly ash as cementitious material was 40%, 50% and 60%. The results shows compressive strength of fly ash concrete at 28 days is almost same even better than those without any fly ash.

Ghosh et al. (1990) studied the fatique behavior of fly ash concrete using fly ash as cementitious material in construction. Study is carried out on both plain concrete as well as fly ash concrete. Mix proportion of plain concrete is 1:4:8(cement: sand: coarse aggregate) and for fly ash concrete 1:3.5:3.5:14(cement: sand: fly ash: coarse aggregate). Specimen prepared for flexure strength for 28 days is (7.5 x 10 x 50 cm) size and load is applied at a frequency of 74cycles/min. For precise measurement of strain the load was applied through third point loading. From the results it is obtained that number of repetitions to failure was 2 X 103 for plain cement concrete and 2 X 104 for fly ash concrete. Under repeated loading condition both plain concrete and fly ash concrete shows similar fatigue behavior.

Tse et al. they studied on HVFA concrete and the fatigue behavior of HVFA concrete. They used both type of fly ash i.e Class C and Class F with a cement replacement of 0%, 25%, 50%

and 75%. The water cementitious ratio varies for both type of fly ash. For Class C fly ash concrete mix w/c ratio varies from 0.3-0.37 and 0.26-0.45 for Class F fly ash concrete mix. Around 350 samples concrete are tested after 28 days of curing and tested for flexure. The range of stress applied differs from zero to certain maximum stress as percentage of compressive strength (55%-95%). Result shows that the flexural strength varies with the type of fly ash and percentage of replacement of cement by fly ash. The various test result shows that the maximum flexural and compressive strength can be obtained with 25% cement replacement by Class F fly ash and 50% cement replacement by Class C fly ash.

Ramakrishnan et al. they studied on both plain concrete as well as on HVFA concrete. In case of HVFA concrete superplasticizer is used. In case of air entrained HVFA concrete flexural strength and endurance limit are studied and same for plain concrete. Fly ash concrete is formed with cement replacement of 58% with low Class F. W/C ratio was 0.32 and workable concrete mix is formed by adding naphthalene based superplasticizer. Total 40 beams are prepared, 20 beams of 75mm X 100mm X 400mm for each test are subjected to third point loading for flexure. Test on beam was performed with a non reversal fluctuating load. The constant lower limit was taken as 10% of the flexural static strength, and the upper limit varied from about 90% of the static strength down to the fatigue limit. The fatigue test was run between lower load limit (10%). The test result reveals that endurance limit of high volume fly ash concrete is higher (7%) than that of plain concrete. But flexural strength and modulus of rupture of plain concrete is higher than high volume fly ash concrete. It also shows that static flexural strength of both plain and fly ash concrete increases by 15% - 30%.

Chapter 3

Experimental Methodology

3.1. Introduction

In this chapter brief description of experimental works are carried out in the present work. It is divided into three sections. The first section deals with the material used, second with the tests carried out on materials and last section with the procedure of mix design.

3.2. Materials

3.2.1. Cement

The cement used in concrete mixes is Ordinary Portland Cement of grade 43, as it is fine in nature, having nice particle size distribution, it gives higher strength to the structures. The other laboratory property of Ordinary Portland Cement of grade 43 exceeds the properties of OPC 43 Grade.

3.2.2. Fly Ash

Rourkela Steel Plant Fly ash is used for the concrete mix and it is of class F. It is a fine grey powder byproduct from power generating plants obtained by burning coal. It is also commonly known as Pulverized Fuel Ash. Fly ash is mainly consisting of calcium oxide and silicon dioxide, used as replacement of cement as it contains cementitious material. Fly ash is a Pozzolanic material which means it has binding property which keeps all the materials together. Fly ash being cementitious material gives strength, durability and sustainability. The concrete formed using fly ash known as green concrete as it reduces the emission of carbon dioxide into the atmosphere. The concrete using fly ash is eco friendly as it is uses fly ash because disposal of fly ash is also creating problem.

3.2.3. Aggregate

Aggregates are one of the important ingredients of the concrete. They impart strength to the concrete. It is used as economical space filler. These are of two types:

- Fine aggregate
- Coarse aggregate

The maximum nominal size of coarse aggregate is 20mm is used.

3.2.4. Admixture

Polymer based admixture is used for the concrete mixes. It is a superior quality super plasticizer. It is light coloured and does not change the colour of concrete mix. It increases the workability of concrete mix without adding water in excess amount. It reduces the water content which ultimately helps in achieving higher strength.

3.2.5. Water

It is one of the important ingredients of concrete. It helps in distributing the cement evenly and helps in lubricating the concrete paste. W/C ratio is a vital parameter which controls the amount of water required to add to the concrete mixture. Variation in water content affects various properties. If water content is increased then durability, cohesiveness and strength reduces whereas workability increases. For the concrete portable water is used.

3.3. Tests on Material

3.3.1. Specific Gravity and Water Absorption

Specific Gravity helps in measuring the quality of aggregate used. It is defined as the ratio of mass of any substance to the mass of equivalent volume of water. Aggregates having lower specific gravity are considered as weak than the aggregates having higher specific gravity. If the water absorption value of aggregates is high then they are weak and porous. It is determined as per IS: 2386 (Part III) –1963.

In case of coarse aggregates the specific gravity is obtained by using wire basket. About 2kg of coarse aggregates are tested. The aggregates are kept in the wire basket and submerged in water. Air entrapped on the surface of aggregate shall be expelled by gentle disturbance or by rapid clockwise and anti-clockwise movement of wire basket. The basket and aggregate remain submerged in water for 24 hrs. Then the aggregates are surface dried and weighed. After that the aggregates are oven dried.

$$\text{Specific gravity} = \frac{W_4}{W_3-(W_1-W_2)} \tag{3.1}$$

$$\text{Apparent Specific gravity} = \frac{W_4}{W_4-(W_1-W_2)} \tag{3.2}$$

$$\text{Water absorption} = \frac{W_3-W_4}{W_4} \times 100 \tag{3.3}$$

where

W_1 = weight of wire basket containing sample and filled with distilled water, gm

W_2 = weight of wire basket filled with distilled water only, gm

W_3 = weight of saturated and surface-dry aggregate, gm

W_4 = weight of oven-dry aggregate, gm

In case of fine aggregate pycnometer is used for determinating specific gravity as per IS: 2386 (Part III) –1963. Sample of weight 500gm is taken for test. Saturated surface dry aggregates are used for the testing. These aggregates are then deposited in pycnometer and distilled water is filled to the top so that water in the hole is flat and its weight is taken. Weight of pycnometer is taken when it is filled with water. Then fine aggregate is oven dried.

$$\text{Specific gravity} = \frac{W_4}{W_1-(W_2-W_3)} \tag{3.4}$$

$$\text{Apparent specific gravity} = \frac{W_4}{W_4-(W_2-W_3)} \tag{3.5}$$

$$\text{Water absorption} = \frac{(W_1-W_4)}{W_4} \times 100 \tag{3.6}$$

where

W_1 = weight of saturated and surface-dry fine aggregate, gm

W_2 = weight of pycnometer containing fine aggregate and filled with distilled water, gm

W_3 = weight of pycnometer filled with distilled water, gm

W_4 = weight of oven-dried fine aggregate, gm

In case of cementious material specific gravity is obtained by using Le-chatelier flask. Kerosene oil or Naptha is filled in the flask in between 0 and 1 ml. Specific gravity of cementitious material is determined as per IS: 4031 (part XI)- 1988.

(Source: www.civilblog.org)

Figure 3.1: Le-chatelier Flask

Initial reading is noted down. Using funnel cementious material is filled in the flask of about 60 gm. The final reading is taken. Specific gravity is given by,

$$G = \frac{\text{Mass of cement ,gm}}{\text{Displaced volume ,cm}^3} \qquad (3.7)$$

3.3.2. Aggregate Crushing Test

Aggregate crushing test is carried out to determine the strength of aggregate. It is determined as per the IS: 2386 (Part IV) -1963. Surface dry aggregate is used which passes through 12.5 mm IS sieve and retain on IS sieve 10 mm is filled in three equal layers in a mould of cylindrical shape, each layer being ramped 25 times by the tamper. The plunger is placed on the top of specimen and a load of 40 tones is applied at certain rate by the compression machine. The crushed aggregates are sieved through 2.36 mm IS sieve. Strong aggregate give low aggregate crushing value.

$$\text{Aggregate crushing value} = \frac{W_2}{W_1} \times 100 \text{ percent} \qquad (3.8)$$

Where

W_1 = weight of surface dry aggregate

W_2 = weight of crushed aggregate passing 2.36 mm IS sieve.

3.3.3. Aggregate Impact Test

This test carried out to determine the toughness or resistance of aggregate to fracture under repeated impacts. It is determined as per IS: 2386 (Part IV) -1963.

(Source: www.civilblog.org)

Figure 3.2: Impact Testing Machine

The aggregates which passes 12.5mm sieve and retain on 10mm sieve is filled in a mould of inner diameter 10.2cm and depth 5cm in three layers and giving each layer 25 blows. The hammer of weight 13.5-14 kg is lifted to a ht. of 380mm above the top surface of mould in which aggregates are placed and allowed to drop on the specimen. The aggregates are subjected to 15 blows with 1 sec interval. The crushed aggregates are sieved through 2.36mm.

$$\text{Impact value} = \frac{W_2}{W_1} \times 100 \text{ percent} \tag{3.9}$$

Where

W_1 = weight of surface dry aggregate

W_2 = weight of crushed aggregate passing 2.36 mm sieve.

3.3.4. Aggregate Abrasion Test

This test is carried out to determine the hardness of aggregates. The test is carried out as per IS: 2386 (Part IV) -1963. Los Angeles abrasion testing machine is used for the testing which is a hollow steel cylinder closed at both ends and having internal diameter of 700mm and length of 500mm. A steel shelf is radially projected 88mm for the full length of cylinder. Specified weight of aggregate depending upon the gradation is placed in the machine. The machine rotates at a speed of 33rpm for specified number of rotation as per grading. Then the aggregates are taken and sieved through 1.7mm sieve.

(Source: testinglabequipments.com)

Figure 3.3: Los Angeles Abrasion Testing Machine

$$\text{Abrasion value} = \frac{W_2}{W_1} \times 100 \qquad (3.10)$$

Where

W_1 = weight of surface dry aggregate

W_2 = weight of crushed aggregate passing 1.7 mm sieve.

3.3.5. Consistency of Cementious Material

Consistency is the percentage of water required for cement paste at which viscosity of the paste becomes such that the plunger in a Vicat's apparatus penetrates a depth of 5 to 7mm, measured from the bottom of Vicat mould. Consistency of cementious material is determined as per IS: 4031 (Part IV) – 1988. In this test measured quantity of cementitious material is mixed with measured quantity of potable or distilled water, care should be taken such that the gauging time should not be less than 3 minutes and not more than 5 minutes. The gauging time is the time of mixing water to dry cemetitious material up to the commencing of filling the mould. The Vicat mould is kept on non porous plate. Mould is filled with cement paste and leveled using trowel.

(Source: civilblog.org)

Figure 3.4: Vicat's Apparatus

Mould is slightly shaken to expel air. Plunger is attached to the apparatus and allowed to rest on the surface of the test mould. Then the plunger is quickly released to sink into the mould. This procedure is repeated until plunger penetrates 5 to 7 mm from the bottom by adjusting the quantity of water added.

$$\text{Consistency} = \frac{A}{B} \times 100 = P \qquad (3.11)$$

Where

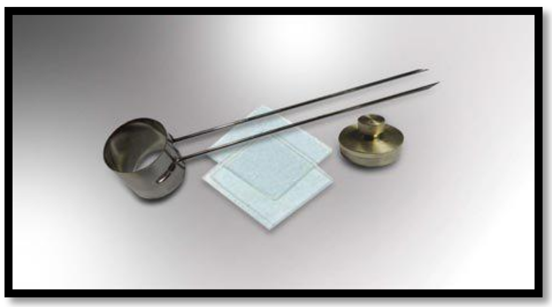
A = quantity of water added

B = quantity of cementitious material used

3.3.6. Soundness

Test is carried out to detect the presence of uncombined lime in *cement*. It is the property by virtue of which the cement does not undergo any appreciable expansion (or change in volume) after it has set, thus eliminating any chances of disrupting the mortar or concrete. The apparatus used for soundness test is Le-chatelier apparatus. Soundness test is carried out as per IS: 4031 (Part III) - 1988.

The mould and glass sheets are lightly oiled and cement paste formed by adding cement with 0.78 times the water required to form paste of standard consistency is placed in the Le chatelier's mould by placing a glass sheet below and holding the two edges together.



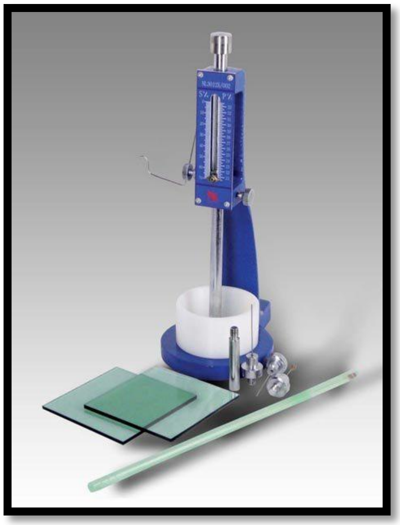
(Source: civilblog.org)

Figure 3.5: Le-chatelier Apparatus

The Le-chatelier mould is covered with other glass sheet and a weight is placed over the whole assembly. Immediately submerge the whole assembly in water for 24 hours. The distance between the two indicators is measured. Again immerse the sample in water and boil for 3 hours and distance between both indicators are noted. The difference of both the reading indicates the expansion of cement.

3.3.7. Initial and Final Setting Time

Initial setting time is the time period that elapses from the time when water is added to the cementitioua material and the needle for initial setting time ceases to penetrate 5 to 7 mm from bottom of the Vicat's mould.



(Source: civilblog.org)

Figure 3.6: Vicat's Apparatus

Final setting time is the time period that elapses from the moment water is added to the cementitious material and the needle for final setting time with annular collar at the tip of needle just makes an impression on the paste.

Initial and final setting time of cementitious material is determined as per IS: 4031(PART V) – 1988. For this test measured quantity of cementitious material is taken and mixed with 0.85times the water required to form standard consistency paste. Gauging time is maintained. Needle is used for initial setting time and for final setting time needle with annular attachment is used.

3.3.8. Fineness

The degree to which cementious material is drawn to smaller and smaller particles is called fineness. Finer the material higher the rate of radiation and do faster the development of strain. It is because finer material offers greater surface area of particles for hydration. Fineness is determined by Blaine's Air Permeability method as per IS: 4031 (Part II) – 1988. Blaine's air permeability apparatus consists essentially of a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The fineness is expressed as a total surface area in square centimeters per gram. In this method density of cementitious material, bed volume and apparatus constant are determined first.

(Source: civilblog.org)

Figure 3.7: Blaine's Air Permeability Apparatus

Fineness of cementious material is obtained by using the formula

$$S = \frac{521.08K\sqrt{t}}{\rho}\ cm^2/gm \qquad (3.12)$$

Where,

S = Specific surface area

K = Apparatus constant

ρ = Density of cement

t = Time

3.3.9. Flakiness and Elongation Index

The flakiness and elongation index is determined as per IS: 2386 (Part IV) -1963. The flakiness index of an aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The test is not applicable to sizes smaller than 6.3 mm. The thickness gauge is used for flakiness of aggregate. The gauge used for flakiness and elongation are shown in fig.

(a) (b)

(Source: civilblog.org)

Figure 3.8: (a) Thickness gauge **(b)** Length gauge

The measured quantity of material is sieved through the sieve size mentioned in the metal gauge and collected separately as per range. Then the fraction of material is gauged through thickness in metal gauge. The total mass of each size fraction of the sample also shall be determined. The mass of material passing the respective gauge to the total mass of aggregate retained on 6.3mm sieve gives the flakiness index of aggregate which is expressed in percentage.

Elongation index of an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than one and four-fifths times their mean dimension. Normally, the properties of interest to the engineer are sufficiently covered by the flakiness or angularity tests. The elongation test is not applicable to sizes smaller than 6.3 mm. The fraction of material is gauged through length in metal gauge. The total weight of material retained in every range to the total weight of material retained.

3.3.10. Sieve Analysis of Aggregates

This method is adopted to determine the particle size distribution of fine and coarse aggregate. It is carried out as per IS: 2386 (Part I) – 1963. Set of sieves are used for analysis of both fine and coarse aggregates which are arranged in descending order. Measured quantity of air dry aggregates are used. Aggregates are passed through the set of sieves and material retained on each sieve is weighed. The result is calculated as cumulative percentage by weight of the total sample passing each of the sieves, to the nearest whole number. The result is represented graphically.

3.3.11. Compression Test

Compression test is performed on concrete cube to determine the compressive strength. The test is performed on Compression testing machine. The test is performed as per IS: 516 – 1959. The prepared concrete mix should be workable and poured in layers in the cube and compacted by hand using tamping rod. The cubical mould is of cast iron or steel of 15 X 15 X 15 cm size. After filling to the mould is kept on vibratory table for 2 min for full compaction so that no air voids will be there.

(www.testinglabequipments.com)

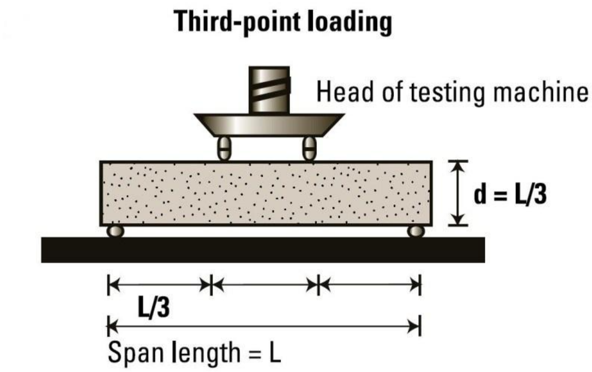
Figure 3.9: Compression Testing Machine

Then the mould is kept for 24 ± $\frac{1}{2}$hr without any disturbance. After this period specimen is removed from the mould and submerged in water and kept there until taken out just prior to test. The testing is done after 7, 14, and 28 days curing period.

$$\text{Compressive Strength} = \frac{\text{Load (KN)}}{\text{Cross sectional area (mm}^2\text{)}} \quad (3.13)$$

3.3.12. Flexure Test

The flexure test is performed to determine the flexural strength as per IS: 516 - 1959. *Flexural* strength is defined as the maximum stress developed at the outermost fiber on either the compression or tension side of the specimen. This test is performed on prism specimen submerged in water and kept until test is performed. The size of prism mould is 10 X 10 X 50 cm. The specimen is placed in the testing machine such that the load acts on the upper surface of prism along two lines at a spacing of 13.3cm center to center. The specimen is placed on rollers at a distance of 40cm. 3 point load is done for flexure test. The testing is done after 7, 14, and 28 days curing period. The load is applied at a rate of 180 kg/min for the 10.0 cm specimens.



(a) (b)

(Source: testinglabequipments.com)

Figure 3.10: (a) Three point loading diagram, **(b)** Flexure Testing Machine

The Flexural Strength or modulus of rupture (**f_b**) is given by

$$f_b = \frac{pl}{bd^2}$$ (when **a** > 20.0cm for 15.0cm specimen or > 13.0cm for 10cm specimen)

or (3.14)

$$f_b = \frac{3pa}{bd^2}$$ (when **a** < 20.0cm but > 17.0 for 15.0cm specimen or < 13.3 cm but > 11.0cm for 10.0cm specimen.) (3.15)

Where,

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen

b = width of specimen (cm)

d = failure point depth (cm)

l = supported length (cm)

p = max. Load (kg)

3.4. Concrete Mix Design as per IRC 44: 2008

The process of selecting various ingredients and their amount for producing concrete of required strength, workability and durability as well as economical is termed as concrete mix design. The compressive strength of hardened concrete is one of the important properties it depends upon the quality and quantity of cement, water cement ratio, type of aggregate, batching, mixing, placing, compaction and curing. In PQC the cement is replaced by fly ash with a higher percentage and reducing the water cement ratio by adding admixture and making the mix in workable condition.

3.4.1. Procedure

- The mix design of concrete is done as per IRC 44.
- Determine the target mean strength f'_{ck} using characteristic compressive strength at 28 days as per IS: 456 is as follows:

$$f'_{ck} = f_{ck} + 1.65S \qquad (3.16)$$

Where,

f'_{ck} = target mean compressive strength at 28 days, N/mm^2

f_{ck} = characteristic compressive strength at 28 days, N/mm^2

S = standard deviation, N/mm^2

The standard deviation of various grades of concrete are assumed as per the table given below.

Table 3.1: Assumed Standard Deviation

Sl. No.	Grade of Concrete	Assumed Standard Deviation (N/mm^2)
1	M25	4
2	M30	5
3	M35	
4	M40	
5	M45	
6	M50	
7	M55	
8	M60	

- Determine the flexural strength of concrete as per IS: 456 is as follows:

$$f_{cr} = 0.7 \text{ x } \sqrt{f_{ck}} \tag{3.17}$$

Where,

f_{cr} = flexural strength, N/mm^2

f_{ck} = characteristic compressive strength at 28 days, N/mm^2

- After determining the strength water cement ratio is obtained as per the grade of concrete the table given below.

Table 3.2: Preliminary selection of w/c ratio for given grade of concrete

Sl. No.	Grade of Concrete	Approximate W/C Ratio
1	M25	0.5
2	M30	0.45
3	M35	0.42
4	M40	0.38
5	M50	0.34
6	M60	0.28

Cementitious material is also considered in w/c ratio calculation and the w/c ratio is limited to 0.5 for all grades of concrete.

- The water content of concrete mix is influenced by many factors such as shape and size of aggregate, water cement ratio, texture of aggregate, type and content of cement and cemetitious material. Use of admixture like plasticizer and superplasticizer also affects the water content. The water content is obtained depending upon the maximum nominal size of aggregate given in the table below:

Table 3.3: Approximate Water Content for Nominal Maximum Size of Aggregate

Nominal Maximum Size of Aggregate (mm)	Suggestive Water Content (kg)
10	208
20	186
40	165

- The table above is for angular coarse aggregate and slump = 20mm ± 5mm and w/c ratio= 0.50.

- The cement content or cementitious material content can be calculated using water to cementitious ratio and water content. The obtained cemetitious content should be less than the maximum cement content i.e 425 kg/cm^3 and should be greater than minimum cement content of 325 kg/cm^3.

- The volume of coarse aggregate per unit volume of total aggregate is obtained using the table below for which nominal maximum size of aggregate and sand of different zones are required.

Table 3.4: Volume of coarse aggregate per unit volume of total aggregate for different zones of fine aggregate as per IS: 383

Nominal Maximum Size of Aggregate(mm)	**Volume of Coarse Aggregate Per Unit Volume of Total Aggregate for Different Zones of Fine Aggregate**			
	Zone IV	Zone III	Zone II	Zone I
10	0.5	0.48	0.46	0.44
20	0.66	0.64	0.62	0.6
40	0.75	0.73	0.71	0.69

The above table valid for water cement ratio of 0.50. With every decrease of 0.05 w/c ratio the ratio of coarse to total aggregate increases by 1 percent.

- All the ingredients are estimated except fine and coarse aggregate content. These two are obtained by determining the volume of water, admixture and cementitious material. Then dividing their mass by their respective specific gravity, multiplying by 1/1000 and subtracting the summation of result from unit volume.
- The mix proportion for concrete is formed for first trial mix.
- The concrete specimens are prepared for compressive strength test as well as for flexural test in the form of cube of 150 x 150 x 150mm and prism of 100 x 100 x 500mm size. The test is performed at 7, 14 and 28 days curing.
- The mix proportion is adjusted till the required strength is achieved from both cube and prism.

Chapter 4

Results and Discussion

4.1. Introduction

In this chapter all the results of experimental tests on various materials used in Pavement Quality Concrete for cube and prism specimen are presented to improve the mechanical properties. Replacement of cement with fly ash is being done with varying percentage. Polymer based superplasticizer is used in fly ash concrete. The results are discussed in details in the following section.

4.2. Tests Conducted on Cement

Various physical tests are performed on OPC Grade- 43. The results obtained from the tests are given in the following table and not presented for the publication purposes.

Table 4.1: Physical properties of cement with standard value.

4.2.1. Compressive strength test on cement

Table 4.2: Compressive strength test on cement

4.3. Tests Conducted on RSP Fly Ash

The various tests on physical property of Rourkela Steel Plant (RSP) Fly Ash are conducted. The results obtained are listed below.

Table 4.3: Physical properties of RSP Fly ash with standard values

4.3.1. Sieve Analysis on RSP Fly Ash

For Fly Ash it is performed by Hydrometer Analysis and Particle Distribution Curve is not presented for publication purposes.

Figure 4.1: Particle size distribution curve of RSP Fly Ash

4.4. Tests Conducted on Fine and Coarse Aggregate

4.4.1. Water Absorption and Specific Gravity of Aggregates

Table 4.4: Specific gravity and water absorption value of coarse and fine aggregate

4.4.2. Tests carried out on Coarse Aggregate

Table 4.5: Physical test values of coarse aggregate

Tests on Coarse Aggregate	Obtained Value	Standard Value
Crushing Value	14.7%	Not more than 30%
Impact Value	14.9%	Not more than 30%
Abrasion Value	22.7%	Not more than 30%
Flakiness Index	9.1%	Not more than 15%
Elongation Index	18.7%	Not more than 15%

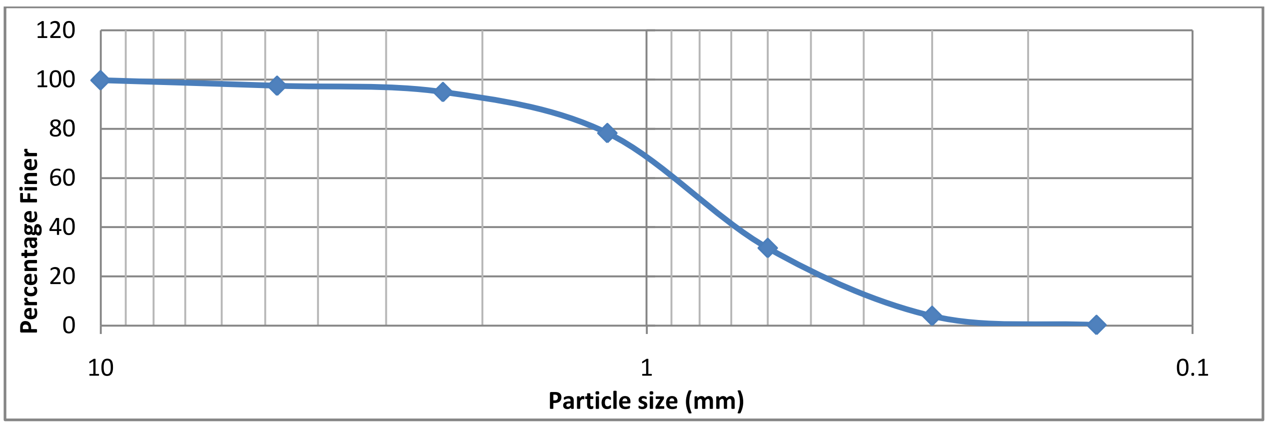


Figure 4.2: Particle size distribution curve of Fine Aggregate

The sieve analysis of fine aggregate shows that it is well graded.

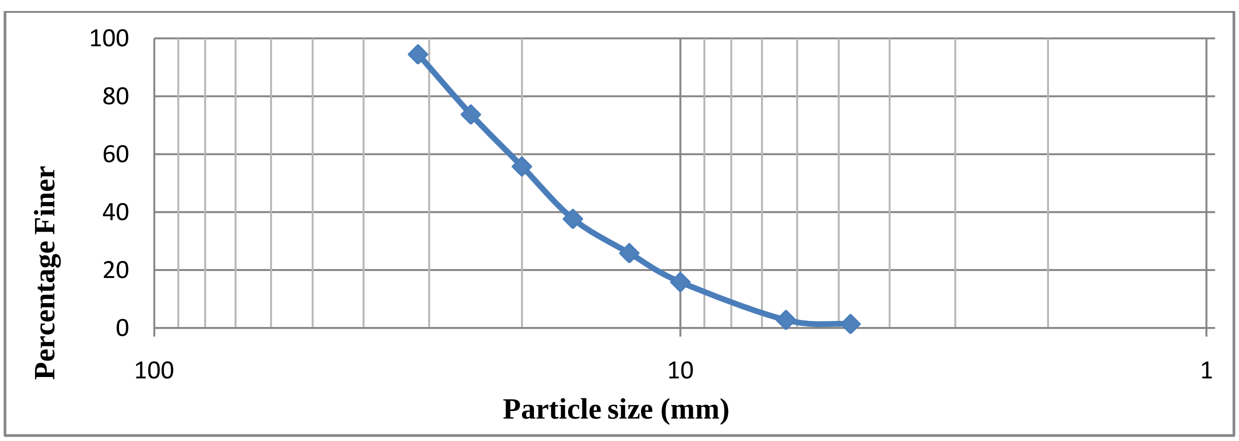


Figure 4.3: Particle size distribution curve of Coarse Aggregate

The sieve analysis graph shows that coarse aggregate is well graded.

4.5. Mix Design of Concrete

Design of M35 grade of Concrete

In the first trial mix design of M35 is done.

4 cubes and 2 prisms are casted. The compressive strength of concrete in 7, 14 and 28 days was obtained. As the strength obtained at 28 days of cube without any fly ash content is less than the expected strength at 28 days then the mix proportion is redesigned.

Design of M40 grade of Concrete

4 cubes and 2 prisms are casted for 0% replacement and their compressive and flexure strength will be obtained at their respective curing period. Same procedure is adopted for 5% and 10% replacement.

Table 4.6: Test results of M35 and M40 having Fly ash 0%, 5% & 15% without superplasticizer

Test results have not been presented for the publication purposes.

In next trial the mix proportion of M35 is modified and has not been presented for the publication purposes.

Table 4.7: Test results of M35 R_1 and M35 R_2 without superplasticizer

Test results have not been presented for the publication purposes.

In next trial for M35 polymer based superplasticizer is used and water content is reduced.

The compressive and flexure strength of concrete cube and prism of 5% and 10% replacement will be carried out after their respective curing periods.

Design of M35 grade of Concrete

In the next trial for M35 the quantity of superplasticizer is further reduce. The test results are not presented for publication purposes.

Table 4.8: Test results of M35 R_1, M35 R_2 and M35 R_3 with superplasticizer

a) Mixing of concrete ingredients

b) Concrete mix filled in mould

c) Compression testing on cube

d) Flexure testing on prism

e) Failure of prism

f) Failure of cube

Figure 4.4: a) Mixing of concrete ingredients, b) Concrete mix filled in mould, c) Compression testing on cube, d) Flexure testing on prism, e) Failure of prism and f) Failure of cube

Likewise same trial is conducted on M40 grade of concrete. The results have not been presented for the publication purposes.

Table 4.9: Test results of M40 R_1, M40 R_2 and M40 R_3 with superplasticizer

The results have not been presented for the publication purposes.

The design mix of M50 is prepared with reduced water content. The results have not been presented for the publication purposes.

Table 4.10: Test results of M50 R_1, M50 R_2 and M50 R_3 with superplasticizer

The results have not been presented for the publication purposes.

The design of fly ash concrete is prepared with varying percentage of fly ash on M40 grade of concrete.

Table 4.11: Test results of M40 with 5%, 10% and 15% fly ash replacement

The results have not been presented for the publication purposes

Table 4.12: Test results of M50 with 5%, 10% and 20% fly ash replacement

The results have not been presented for the publication purposes

Chapter 5

Conclusion

5.1. Introduction

This chapter covers the conclusion of the experimental work carried on Pavement Quality Concrete (PQC) having certain percentage of fly ash. The scope for future work on PQC with fly ash is also discussed in this chapter.

5.2. Conclusion

- The compressive strength of normal concrete improves with the use of superplasticizer.
- The compressive and flexural strength of concrete with fly ash improves with the use of superplasticizer.
- Satisfactory flexural strength of Pavement Quality Concrete is achieved with fly ash.

5.3. Future Work

- The percentage of fly ash replacement can be increased further.
- Repeated load test for beam specimen should be conducted to establish the suitability of replacement of fly ash in concrete.

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