ESE 2024

UPSC ENGINEERING SERVICES EXAMINATION

Main Examination

Civil Engineering

Topicwise *Conventional* Solved Papers

Paper-I

25 Years SOLVED PAPERS

- ✓ Thoroughly revised and updated
- ✓ Fully solved with explanations
- ✓ Also useful for State Engineering Services Exams

MADE EASY PUBLICATIONS

www.madeeasypublications.org

MADE EASY Publications Pvt. Ltd

Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 0-9021300500
Visit us at: www.madeeasypublications.org

ESE-2024 : Main Examination
Civil Engineering : Paper-I | Conventional Solved Questions : (1999-2023)

1st Edition : 2010
2nd Edition : 2011
3rd Edition : 2012
4th Edition : 2013
5th Edition : 2014
6th Edition : 2015
7th Edition : 2016
8th Edition : 2017
9th Edition : 2018
10th Edition : 2019
11th Edition : 2020
12th Edition : 2021
13th Edition: 2022 (Feb)
14th Edition: 2022 (Aug)

15th Edition : 2023

B. Singh (Ex. IES)

Director's Message

During the last few decades of engineering academics, India has witnessed geometric growth in engineering graduates. It is noticeable that the level of engineering knowledge has degraded gradually, while on the other hand competition has increased in each competitive examination including GATE and UPSC examinations. Under such scenario higher level efforts are required to take an edge over other competitors.

The objective of **MADE EASY books** is to introduce a simplified approach to the overall concepts of related stream in a single book with specific presentation. The topic-wise presentation will help the readers to study & practice the concepts and questions simultaneously.

The efforts have been made to provide close and illustrative solutions in lucid style to facilitate understanding and quick tricks are introduced to save time.

Following tips during the study may increase efficiency and may help in order to achieve success.

- Thorough coverage of syllabus of all subjects
- Adopting right source of knowledge, i.e. standard reading text materials
- Develop speed and accuracy in solving questions
- Balanced preparation of Paper-I and Paper-II subjects with focus on key subjects
- Practice online and offline modes of tests
- Appear on self assessment tests
- Good examination management
- Maintain self motivation
- Avoid jumbo and vague approach, which is time consuming in solving the questions
- Good planning and time management of daily routine
- Group study and discussions on a regular basis
- Extra emphasis on solving the questions
- Self introspection to find your weaknesses and strengths
- Analyze the exam pattern to understand the level of questions
- Apply shortcuts and learn standard results and formulae to save time

B. Singh (Ex. IES)
CMD, MADE EASY Group

ESE 2024 Main Examination

Civil Engineering
Conventional Solved Questions

Paper-I

Contents

■■■■

1 Building Materials

Revised Syllabus of ESE : *Stone, Lime, Glass, Plastics, Steel, FRP, Ceramics, Aluminum, Fly Ash, Basic Admixtures, Timber, **Bricks and Aggregates:** Classification, properties and selection criteria;*
***Cement:** Types, Composition, Properties, Uses, Specifications and various Tests; Lime & Cement Mortars and **Concrete:** Properties and various Tests; **Design of Concrete Mixes**: Proportioning of aggregates and methods of mix design.*

---

1. Cement

1.1 Describe the hydration of portland cement and outline the ways in which the Vicat apparatus and the Le-Chatelier apparatus can be used to assess the properties of fresh and hardened pastes.
[15 marks : 1999]

Solution:

The chemical reactions that takes place between cement and water is known as **hydration of cement**. On account of hydration certain products are formed. These products are important because they have cementing or adhesive value. The quality, quantity, continuity, stability and the rate of formation of the hydration products are important.

Anhydrous cement compounds when mixed with water, react with each other to form hydrated compounds of very low solubility. The hydration of cement can be visualized in two ways. The first is “through solution” mechanism. In this the cement compounds dissolve to produce a super saturated solution from which different hydrated products get precipitated. The second possibility is that water attacks cement compounds in the “solid state” converting the compounds into hydrated products starting from the surface and proceeding to the interior of the compounds with time. It is probable that both “through solution” and “solid state” types of mechanism may occur during the course of reactions between cement and water. The former mechanisms may predominate in the early stages of hydration in view of large quantities of water being available and the latter mechanism may operate during the later stages of hydration.

The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration. The hydration process is not an instantaneous one. The reaction is faster in the early period and continues indefinitely at a decreasing rate. Complete hydration can not be obtained under a period of one year or more unless the cement is very finely ground and reground with excess of water to expose fresh surfaces at intervals. During the course of reaction of C_3S and C_2S with water, calcium silicate hydrate (C–S–H) and calcium hydroxide $Ca(OH)_2$ are formed. Calcium silicate hydrate is the essence that determines the properties of concrete. It makes up 50-60 per cent of the volume of solids in a completely hydrated cement paste. On the other hand, calcium hydroxide is a compound which is responsible for the lack of durability. The calcium hydroxide also reacts with sulphates presents in soils or water to form calcium sulphate which reacts further with C_3A and cause deterioration of concrete which is known as sulphate attack. The only advantage of $Ca(OH)_2$ is that, being alkaline in nature, it maintain pH value around 13 in the concrete which resist the corrosion of reinforcements.

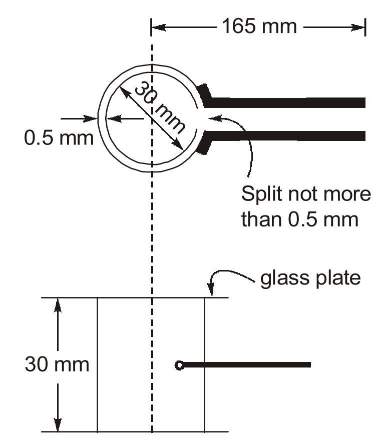
The hydration of aluminates (C_3A) results in a calcium aluminate system $CaO-Al_2O_3-H_2O$. This compound do not contribute anything to the strength of concrete. On the other hand their presence is harmful to the durability of the concrete particularly where the concrete is likely to be attacked by sulphates. As it hydrates fast it may contribute a little to early strength.

On hydration, C_4AF is believed to form a system of the form $CaO-Fe_2O_3-H_2O$. The hydrates of C_4AF also do not contribute anything to the strength but they show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

Vicat apparatus is used for determining the **normal consistency and setting time for cement**. A known weight of cement is taken and a paste is prepared with a weighed quantity of water (24% by weight of cement) for the first trial. The Paste is then filled in a mould and the plunger of the apparatus is brought down to touch the surface of the paste in test block and quickly released allowing it to sink into the paste by its own weight. Similarly, trials are conducted with higher and higher water cement ratios till such time the plunger penetrates for a depth of 33-35 mm from the top. That particular percentage of water is known as the percentage of water required to produce a cement paste of standard consistency.

For setting times the plunger is replaced by a needle (for initial setting time) or a circular attachment (for final setting time).

Le Chatelier apparatus can be used to determine **soundness in cement**. Unsoundness in cement is due to excess of lime, magnesia or sulphates. Cement is gauged with 0.78 times the water required for standard consistency in a standard manner and filled into the mould kept on a glass plate. The mould is covered on the top with another glass plate. The whole assembly is immersed in water at a temperature of 27°C - 32°C and kept there for 24 hours. Now the distance is measured between the indicator points. The mould is again submerged in water and water is heated to brought to boiling point in about 25-30 minutes and it is kept boiling for three hours. The mould is now removed from water and allowed to cool. The distance between indicator points is measured again. The difference between these two measurements represent the expansion of cement. This must not exceed 10 mm. The Le Chatelier test detects the unsoundness due to free lime only.



1.2 **Explain how sulphate resisting cement and rapid hardening portland cement differ from OPC and specific circumstance in which these cements would be used.**

[15 marks : 1999]

Solution:

Sulphate Resisting Cement: Ordinary portland cement is vulnerable to sulphate attack. Sulphate attack is greatly accelerated if accompanied by alternate wetting and drying which normally takes place in marine structures in the zone of tidal variations.

To prevent the sulphate attack, the use of cement with low C_3A content is found to be effective. Such a cement with low C_3A content and comparatively low C_4AF content is known as sulphate resisting cement. In other words, this cement has a higher silicate content than OPC.

It is not often possible (feasible) to reduce the Al_2O_3 content of the raw materials. So Fe_2O_3 may be added to the mix so that C_4AF content increase at the expense of C_3A. Many of the physical properties of sulphate resisting cement are similar to ordinary portland cement.

The use of sulphate resistant cement is recommended under the following conditions:

(i) Concrete to be used in marine conditions.

(ii) Concrete to be used in foundation and basement, where soil is infested with sulphates.

(iii) Concrete used for fabrication of pipes which are likely to be marshy region or sulphate bearing soils.

(iv) Concrete to be used in the construction of sewage treatment works.

Rapid Hardening Cement: This cement is similar to OPC but with higher C_3S content and finer grinding. It gains strength more quickly than OPC, though the final strength is only slightly higher. The one day strength of this cement is equal to three day strength of OPC with the same water-cement ratio. This cement is used where a rapid strength development is required. The rapid gain of strength is accompanied by a higher rate of heat development during the hydration of cement. It is about 10 per cent costlier than OPC.

The use of rapid hardening cement is recommended in the following situations:

(i) In prefabricated concrete construction.

(ii) Where formwork is required to be removed early for reuse elsewhere.

(iii) Road repair works.

(iv) In cold weather concrete where the rapid rate of development of strength reduces the vulnerability of concrete to the frost damage.

1.3 **Name the principal compounds in portland cement, their relative rates of reaction with water and their approximate proportions.**

[10 marks : 1999]

Or

List of the products of hydration and their influence on the properties of cement.

[10 marks : 2001]

Or

Which are the four important compounds formed during the setting action of cement (four principal minerals in ordinary portland cement)? Mention their relative proportions expressed as percentages and also functions of these compounds.

[10 marks : 2007]

Solution:

The principal compounds in portland cement are known as Bogue's compounds. They are as follows:

(i) Tricalcium silicate (C_3S) or Alite

(ii) Dicalcium silicate (C_2S) or Belite

(iii) Tricalcium aluminate (C_3A) or Celite

(iv) Tetracalcium aluminoferrite (C_4AF) or Felite

The reaction of water with C_3A is very fast and in the process **flash setting** i.e. stiffening without strength development can occur because the C-A-H phase prevents the hydration of C_3S and C_2S. To prevent this flash set, gypsum is added at the time of grinding the cement clinker. The hydrated aluminates do not contribute anything to the strength of concrete. On the other hand, their presence is harmful to the durability of concrete particularly, where the concrete is likely to be attacked by sulphates. As it hydrates fast, it may contribute a little to the early strength.

$$C_3A + H_2O \rightarrow C_3AH_6$$

On hydration, C_4AF is believed to form a system of the form C-F-H. A hydrated calcium ferrite of this form is comparatively more stable. This hydrated product also does not contribute anything to the strength. However, the hydrates of C_4AF show a comparatively higher resistance to the attack of sulphates than the hydrates of calcium aluminate.

$$C_3AF + H_2O \rightarrow C_3AH_6 + CFH$$

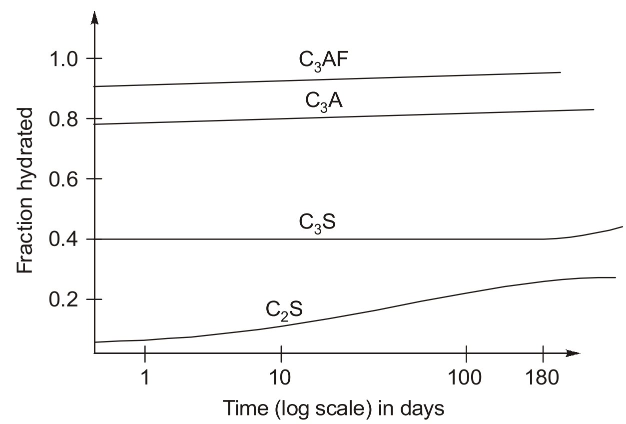
When C_3S and C_2S reacts with water, calcium silicate hydrate (C-S-H) and calcium hydroxide are formed. Calcium silicate hydrates are the most important products. It is the essence that determines the good properties of concrete.

$$C_3S + H_2O \rightarrow C_3S_2H_3 + 3Ca(OH)_2$$

$$C_2S + H_2O \rightarrow C_3S_2H_3 + Ca(OH)_2$$

It can be seen that C_3S produces a comparatively lesser quantity of calcium silicate hydrates and more quantity of $Ca(OH)_2$ than that formed in the hydration of C_2S. C_2S hydrates rather slowly than C_3S.

The relative rates of hydration of Bogue's compounds can be shown with the help of a graph as shown.



Rate of hydration of Bogue's Compounds

The approximate proportions of Bogue's compound are:

Compound	Percentage
C_3S	30-50
C_2S	20-45
C_3A	8-12
C_4AF	6-10

1.4 Explain how do the portland pozzolana cement and super sulphate cement differ from OPC. Under what specific circumstances these cements would be used?

[10 marks : 2000]

Solution:

Portland Pozzolana Cement: It is manufactured either by grinding together portland cement clinker and pozzolana with the addition of gypsum or calcium sulphate or by intimately and uniformly blending portland cement and fine pozzolana. PPC produces less heat of hydration and offers greater resistance to the attack of impurities in water than normal portland cement. However, it is important to appreciate that the addition of pozzolana does not contribute to strength at early ages. Strengths similar to those of OPC can be expected in general only at later ages. In PPC costlier clinker is replaced by cheaper pozzolanic material making it more economical than OPC. PPC consumes calcium hydroxide and does not produce calcium hydroxide as much as that of OPC. It generates lower heat of hydration than OPC and that too at a lower rate. As the fly ash is finer and of lower density, the bulk volume of 50 kg bag is slightly more than OPC. The long term strength of PPC beyond a couple of months is higher than OPC if enough moisture is available for continued pozzolanic action.

The PPC is particularly suitable under the following conditions:

(i) For hydraulic structures.
(ii) For mass concrete structure like dam, bridge piers and thick foundations.
(iii) For marine structures.
(iv) For sewage disposal works, sewers etc.

Super Sulphate Cement: It is manufactured by grinding together a mixture of 80-85 per cent granulated slag, 10-15 per cent hard gypsum and about 5 per cent portland cement clinker. It is rather more sensitive to deterioration during storage than portland cement. Super sulphated cement has a low heat of hydration than OPC. This cement has high sulphate resistance. This cement like high alumina cement, combines with more water on hydration than OPC.

This cement is recommended for the following:

(i) Due to high sulphate resistance, it is particularly used in foundations, where chemically aggressive conditions exist.

(ii) It can be used in marine works.

(iii) It is used in fabrication of reinforced concrete pipes which are likely to be buried in sulphate bearing soils.

1.5 Explain the difference between various grades of OPC.

[10 marks : 2002]

Solution:

The commonly used portland cement in India is branded as **33-grade** (**IS:269-1989**), **43-grade** (**IS:8112-1989**) and **53 grade** (**IS:12269-1987**) having 28 days mean compressive strengths exceeding 33 MPa, 43 MPa and 53 MPa respectively. All the three grades are produced from same materials. The higher strengths are achieved by increasing C_3S content and also by finely grinding the clinker. The fineness of 53-grade OPC obtained by Blaine's air permeability test is specified to be of the order of 350000 mm^2/g. The initial and final setting times are same for all the three grades. The 33-grade cement has virtually disappeared and has been displaced by high strength 43-grade cement. The minimum compressive strengths of the 43-grade cement are 23 MPa and 33 MPa at the end of 3 and 7 days respectively. At higher water cement ratios, the concrete produced with high strength cement has about 80% higher strength and at lower water cement ratios, it has 40% higher strength than that of concrete using 33-grade cement. Greater fineness of 43 and 53 grade cements increase workability due to reduction of friction between aggregates. Moreover, due to shorter setting time and faster development of strength, the stripping time is shorter. Although cements of grade 43 and 53 are desirable for economical design of high grade concretes but they can also be used for lower grade concretes.

1.6 Explain pozzolanic action.

[10 marks : 2003]

Solution:

A pozzolana is a finely ground siliceous material which as such does not possess cementitious property in itself but reacts in the presence of water with calcium hydroxide at normal temperature to form compounds of low solubility having cementitious properties. The action is known as pozzolanic action.

The reaction can be shown as

$$\text{Pozzolana} + Ca(OH)_2 + H_2O \rightarrow \text{C-S-H (gel)}$$

This reaction is called pozzolanic reaction. The characteristic feature of pozzolanic reaction is initially slow, with the result that heat of hydration and strength development will accordingly be slow. The reaction involves the consumption of $Ca(OH)_2$ and not production of $Ca(OH)_2$. It may be noted that on hydration of C_3S and C_2S present in cement, $Ca(OH)_2$ is formed as one of the products of hydration. This compound has no cementitious value and it is soluble in water and may be leached out by the percolating water. It is pointed out that $Ca(OH)_2$, otherwise, a water soluble material is converted into insoluble cementitious material by reaction of pozzolanic materials.

The reduction of $Ca(OH)_2$ also improves the durability of cement paste by making the paste dense and impervious. Pozzolanic materials can be natural or artificial. Clay and shales, opaline cherts, diatomaceous earth and volcanic tuffs are natural pozzolanic materials. Fly ash, blast furnace slag, silica fume, rice husk ash are artificial pozzolanic materials.

The pozzolanic action also reduce the expansion caused by the alkali-aggregate reaction in concrete. Excessive expansion causes pattern cracking of concrete. This expansion can usually be controlled by using of pozzolana ranging from 2 to 35% by mass of cement depending upon the type of aggregate and alkali content of cement.

1.7 List the various laboratory tests for assessing the quality of cement and their importance.

[10 marks : 2008]

Solution:

The following tests are usually conducted in laboratory to assess the quality of cement:

(i) **Fineness test:** The fineness of cement has an important bearing on the rate of hydration and hence on the rate of gain of strength and also on the rate of evolution of heat. Fineness of cement can be tested in two ways viz. by sieving and by determination of specific surface using air permeability apparatus.

(ii) **Setting time test:** In actual construction dealing with cement paste, mortar or concrete, certain time is required for mixing, transporting, placing, compacting and finishing. During this time cement paste, mortar or concrete should be in plastic condition. This time is known as initial setting time. Once the concrete is placed in the final position, compacted and finished, it should lose its plasticity in the earliest possible time so that it is least vulnerable to damages from external destructive agencies. This time is known as final setting time. Setting time test is carried out with the help of Vicat apparatus.

(iii) **Compressive strength test:** The compressive strength of hardened cement is the most important of all the properties. Therefore, it is not surprising that the cement is always tested for its strength in laboratory before the cement is used in important works.

(iv) **Soundness test:** It is very important that the cement after setting shall not undergo any appreciable change of volume. The testing of soundness of cement, to ensure that the cement does not show any appreciable subsequent expansion is of prime importance. Unsoundness in cement is due to excess of lime, excess of magnesia or excessive proportions of sulphates. Unsoundness due to lime can be tested using Le Chatelier apparatus. Unsoundness due to magnesia can be tested using Autoclave test. Unsoundness due to calcium sulphate can be tested using chemical analysis.

(v) **Heat of hydration test:** The reaction of cement with water is exothermic. It is estimated that about 120 calories of heat is generated in the hydration of 1 gm of cement. The total quantum of heat produced in a conservative system such as the interior of a mass concrete dam, a temperature rise of about 50°C has been observed. This unduly high temperature developed at the interior of a concrete dam causes serious expansion of the body of dam and with the subsequent cooling considerable shrinkage takes place resulting in serious cracking of concrete. Heat of hydration test can be easily carried out over a few days by vacuum flask methods, or over a longer period in an adiabatic calorimeter.

(vi) **Chemical composition test:** The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement, in addition to rate of cooling and fineness of grinding. Thus the chemical composition test is carried out in laboratory.

1.8 What are the different types of Portland cement as per Indian code of practice? Discuss any two.

[10 marks : 2011]

Solution:

The commonly used portland cement in India is branded as, 33 grade (IS 269 - 1989), 43 grade (IS 8112 - 1989) and 53 grade (IS 122 - 1989) having 28 days mean compressive strength exceeding, 33 MPa, 43 MPa and 53 MPa respectively.

All the three grades are produced from same materials.

- High strength are achieved by increasing C_3S content and also by finely grinding the clinker.
- The initial and final setting time are same for all the three grades.
- The 33 grade cement has virtually disappeared and has been replaced by high strength 43 grade cement.

43 grade OPC cement: The 43 grade OPC is the most popular general purpose cement in the country today. The production of 43 grade OPC is nearly 50% of total production of cement in country.

43 grade OPC can be used for the following applications:

- General Civil Engineering construction work.
- RCC work (preferably where grade of concrete is upto M30).
- Precast item such as blocks, tiles, pipes etc.
- The minimum compressive strength of 43 grade cement are 23 MPa and 33 MPa, at the and of 3 and 7 days respectively.
- Asbestos products such as sheets and pipes
- Non structural works such as plastering flooring etc.

53 Grade OPC cement: 53 grade OPC is higher strength cement to meet the needs of the consumer for higher strength concrete. As per BIS requirements the minimum 28 days compressive strength of 53 grade OPC should not be less than 53 MPa. For certain specialized works such as prestressed concrete and certain items of precast concrete requiring consistently high strength concrete, 53 grade OPC is found very useful. 53 grade OPC produce higher grade concrete at very economical cement content. In concrete mix design for concrete M20 and above grades a saving of 8-10% of cement may be achieved with the use of 53 grade OPC. 53 grade OPC can be used for the following applications.

- RCC works (preferably where grade of concrete is M25 and above)
- Precast concrete items such as paving blocks, tiles, building blocks etc.
- Prestress concrete component.
- Railways, Concrete road, bridges etc.

  Greater fineness of 43 grade and 53 grade cement increase workability due to reduction of friction between aggregates, moreover due to shorter setting time and faster development of strength, the stripping time is shorter.

1.9 Discuss how consistency of cement is determined.

[5 marks : 2011]

Solution:

The purpose of consistency test is to determine the percentage of water required for preparing cement pastes for other test. **Following procedure is adopted for the test:**

(i) Take 400 gm of cement and add 27% by weight or 108 gm of water to it.

(ii) Mix water and cement on a non-porous surface. The mixing should be done thoroughly.

(iii) Fill the mould of vicat apparatus. The interval between the addition of water to the commencement of filling the mould is known as the time of gauging and it should be 3 min. to 5 min.

(iv) Vicat apparatus consists of a frame to which is attached a movable rod weighing 300 gm and having 10 mm dia and 50 mm length respectively. An indicator is attached to the movable rod. This indicator moves on a vertical scale and it gives the penetration value. The vicat mould is in the form of a cylinder and it can be split into two halves. The vicat would is placed on a non porous plate. These are three attachments square needle, plunger and needle with annular collar. The square needle is used for initial setting time test, the plunger is used for consistency test and the needle with annular collar is used for final setting time test.

(v) The plunger is attached to the movable rod of vicat apparatus. The plunger is gently lowered on the paste in the mould.

(vi) The settlement of plunger is noted. If the penetration is between 5 mm to 7 mm from the bottom of would, the water added is correct. If penetration is not proper the process is repeated with different percentages of water till the desired penetration is obtained.

1.10 What do you understand by the initial and final setting times of cement? What are the typical initial and final setting times of 43 grade OPC cement and Portland Pozzolana Cement (PPC) as per IS code?

[5 marks : 2014]

Solution:

When water is added to cement, the resulting paste starts gaining strength upon hydration. A stage is reached when paste loose its consistency and become stiff. The time to reach this stage is termed as setting time.

The setting time is divided into two parts.

(i) Initial setting time

(ii) Final setting time

Initial and final setting times are determined with the help of vicat's apparatus. To measure these times a cement paste of 0.85 times standard consistency is filled into the vicat's mould in specified manner and time of specified penetration is recorded.

(i) **Initial setting time:** Initial setting time is the time which is measured from the instant water is added to the cement upto the instant when it looses its plasticity. Initial setting time is equal to the time required by the needle to penetrate upto the depth of 33-35 mm from top.

(ii) **Final setting time:** Final setting time is the time which is measured from the instant water is added to the time mix in vicats apparatus achieve sufficient stiffness to resist pressure. Final setting time is equal to the time after which the paste become so hard that annular attachment attached to the needle under standard weight fails to leave any mark on hardened cement paste and needle is able to make a mask.

S.N	Cement	Initial setting time (minutes)	Final setting time (minutes)
1.	43 grade OPC cement	30 minutes	600 minutes
2.	Portland Pozzolana cement (PPC)	30 minutes	600 minutes

1.11 List out eight chemical ingredients of Portland cement and briefly explain their functions.

[12 marks : 2018]

Solution:

Chemical ingredients of portland cement are:

(i) Lime (CaO) : 62-67%

- This is an important ingredient of cement and its proportion is to be carefully maintained.
- Lime in excess makes the cement unsound and causes the cement to expand and disintegrate.
- Lime in deficiency reduces the strength of cement and causes it to set quickly.

(ii) Silica (SiO_2) : 17-25%

- Imparts strength to the cement due to formation of dicalcium and tricalcium silicates.
- If it is present in excess, strength of cement increases but setting time gets prolonged.

(iii) Alumina (Al_2O_3) : 3-8%

- Imparts quick setting property.
- Acts as a flux and lowers clinkering temperature. So, suitable cement type is not formed.
- In excess amount, its presence weakens the cement.

(iv) Calcium sulphate ($CaSO_4$) : 3-4%

- Added in the form of gypsum.
- Increases initial setting time of cement.

(v) Iron Oxide (Fe_2O_3) : 3-4%

- Imparts colour, hardness and strength to cement.

(vi) Magnesia (MgO) : 0.1-3%

- Imparts hardness and colour if present in small amount.
- High content causes unsoundness.

(vii)Sulphur (S) : 1-3%

- Very small amount makes the cement sound.
- If it is in excess, it causes unsoundness in cement.

(vii)Alkalies (Soda and Potash; $Na_2O + K_2O$) – (0.5-1.3%)

- Causes alkali-aggregate reaction, efflorescence and staining.

1.12 What are Bogue's compounds? Briefly mention their functions.

[8 marks : 2018]

Solution:

- The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide.
- These oxides when subjected to high clinkering temperature combine with each other to form complex compounds.
- The identification of major complex compounds is based on R.H. Bogue's work and hence these are called Bogue's compound.

There are 4 Bogue's compounds:

1. **Tricalcium Silicate (C_3S)**

   Chemical formula : 3 $CaOSiO_2$

   Percentage : 30 - 50%

   - It undergoes hydration within a week and is responsible for development of early strength in cement.
   - It is the best cementing material and is well burnt.
   - Increases resistance to freezing and thawing.
   - Renders the clinker easier to grind.
   - Its proportion can be increased where early gain of strength is required.

   Example : Emergency repair work, cold weather concreting, prefabricated construction, etc.

2. Dicalcium silicate (C_2S)

Chemical formula : $2CaOSiO_2$

Percentage : 20-45%

- It hydrates and hardens slowly and takes long time to add to strength (1 year or more).
- Imparts resistance to chemical attack.
- Proportion is increased when early strength is not required and higher heat of hydration should not be there.

Example : dam or bridge construction.

3. Tricalcium Aluminate (C_3A)

Chemical formula : $3CaOAl_2O_3$

Percentage : 8-12%

- Responsible for flash set of cement as it undergoes hydration within 24 hours after water addition.
- Highest heat of hydration and tendency to volume changes causing cracking.
- If present in higher amount, resistance to sulphate attack decreases.

4. Tetracalcium Alumino Ferrite (C_4AF)

Chemical formula : $4CaOAl_2O_3Fe_2O_3$

Percentage : 6-10%

- Responsible for flash set but generates less heat.
- Poorest cementing value.
- Raising its content reduces the strength slightly.

1.13 Explain the products of hydration of C_3S and C_2S (Bogues compounds) giving the relevant equations involving the reactions.

[4 marks : 2019]

Solution:

- The chemical reactions that take place between cement and water is referred to as hydration of cement.
- The hydration of cement can be visualized in two ways viz. “through solution” and “solid state” type of mechanisms
- The reaction of cement with water is exothermic i.e. it liberates a considerable quantity of heat and this liberated heat is called as **heat of hydration**.
- The hydration process is not an instantaneous one. The reaction is faster in the early periods and continues indefinitely at a decreasing rate.
- During hydration, C_3S and C_2S react with water and calcium silicate hydrate (C-S-H) is formed along with calcium hydroxide [$Ca(OH)_2$].
- Calcium silicate hydrate is the most important product of hydration and it determines the good properties of concrete.
- $2(3CaO \cdot SiO_2) + 6H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 2H_2O + 3Ca(OH)_2$

  or it can be written as:

$$2C_3S + 6H \rightarrow C_2S_2H_3 + 3Ca(OH)_2$$
$$100 + 24 \rightarrow 75 + 49$$

The corresponding weights involved are

Similarly,

$$2(2\,CaO{\cdot}SiO_2)+4H_2O \rightarrow 3CaO\cdot 2SiO_2\cdot 3H_2O+Ca(OH)_2$$

or it can be written as:

$$2C_3S+6H \rightarrow C_3S_2H_3+Ca(OH)_2$$
$$100+21 \rightarrow 99+22$$

The corresponding weights involved are:

$$2C_3S+6H \longrightarrow C_3S_2H_3+3Ca(OH)_2$$
$$2C_2S+4H \longrightarrow C_3S_2H_3+Ca(OH)_2$$

1.14 Describe the various tests performed to assess the suitability of Lime as a cementing material.

[8 marks : 2019]

Solution:

Testing of Lime

Visual inspection: (a) A sample of lime is examined for its colour and lumps. (b) Lumps of lime indicate quick lime of unburnt lime

Field Tests: The field tests usually performed on lime at site are as below:

- **Test for physical properties:** Hydraulic limes are brush grey, brown or dark coloured. Hydraulic limestones have a clayey teste and give out earthy smell. White colour of lime is an indication of pure variety of limestone. Shining particles on the surface of limestones indicate the presence of free salt.
- **Workability test:** A handful of mortar (lime sand mortar in the ratio 1 : 3) is thrown on the surface on which it is to be used. The area covered by the mortar and its quantity is recorded. These data indicate the workability of the lime mortar. It is a very crude field test performed with the actual mortar.
- **Impurity test:** A known weight of lime is mixed with water in a breaker. The solution is decanted. The residue is dried for 8 hours in the natural heat of sun and is then weighted. If the residue is less than 10 per cent of the weight of the lime taken initially it is considered to be of good quality. In case, if it is 10-20 percent, the lime is fat and if more than 20 per cent the lime is classed as poor.
- **Heat test:** Limestone is heated for four hours on open fire; CO_2 escapes and it loses weight. From this the carbonate percentage in the limestone can be worked out. Lumpy form indicate quick lime or unburnt limestone. A porous structure may indicate quick lime.
- **Hydraulic acid test:** The test is carried to know the classification and the carbonate content of lime.

  When a teaspoon full of lime is put in a test tube containing 10 ml of 50 per cent hydrochloric acid, effervescence takes place. Too much of effervescence indicates high percentage of calcium carbonate in limestone. The residue at the bottom of the tube indicates percentage of inert materials present in the limestone. Abundant of liberation of CO_2 indicates unburnt lime.

  In case of class-A lime, a good get is formed above the layer of inert material. A thick gel indicate class-B lime and absence of gel means class-C lime.

  For eminently hydraulic lime, the get formed is thick and does not flow. Absence of gel indicates non-hydraulic of fat lime. If get flows, it indicates feebly hydraulic lime.

- **Ball test:** Balls of stiff lime paste are made and left for six hours. They are placed in a basin of water. If expansion and disintegration of balls is observed, the lime is of type C. Little expansion and numerous cracks indicate it to be class-B lime. Class-A lime will have no adverse effect.

Physical Tests

- Sampling of testing lime should be done as quickly as possible so that the material does not deteriorate. From each lot, three test samples are taken for quick lime as well as for hydrated lime.

Fineness Test [IS : 6932 (Part IV)]

- The sieves are arranged one above the other with the coarser sieves at the top and the finer sieves at the bottom. Sieving is done with a gental wrist motion. 100 g of the hydrated lime is placed on the top sieve and is washed through the sieves with a moderate jet of water for not more than 30 minutes. The residue on each sieve is dried at 100 ± 10°C to constant mass and weighted. The result is expressed as a percentage of mass of hydrated lime taken.

Determination of Residue on Slaking of Quick Lime [IS : 6932 (Part III)]

- Sample of quick lime is sieved through 2.36 mm IS sieve and the residue, if any, is broken and sieved again until the whole quantity passes through the sieve. The quantity of water required for slaking is usually 4 times the mass of quick lime, however, it may be as high as 8 times for certain high calcium limes.

Workability Test [IS : 6932 (Part VIII)]

- The test is conducted on a standard flow table and a truncated conical mould. For testing hydrated lime, the lime putty is prepared by thoroughly mixing 500 g of hydrated lime with an equal mass of water at a temperature of 27 ± 2°C and kept for 24 hours. The soaked material is then thoroughly mixed and knocked up to produce a plastic putty, by passing the material twice through the mixer.

Setting Time Test

- The initial and final setting times of hydrated lime are determined using Vicat's apparatus in the same way as that for Portland cement. Here in this test lime putty is used instead of cement mortar.

Soundness Test [IS : 632 (Part IX)]

- The test is done to find the quality, i.e., the unsoundness or disintegration property of lime using the Le-chatelier apparatus.

Popping and Pitting Test [IS : 6932 (Part X)]

- To determine the soundness of fat lime, pats are prepared by mixing hydrated lime, Plaster of Paris and water. The pats are subjected to steam and then tested for disintegration, popping and pitting. If any of these occurs the lime is considered to be unsound.

1.15 Write briefly about the following:
(A) Air Entraining admixtures
(B) Role of Fly ash as a part replacement of cement

[10 marks : 2019]

Solution:

(A) **Air Entraining Admixture:** This cement is manufactured by mixing small quantity of air-entraining agent like alkali salts of natural wood resins, synthetic detergents of alkylaryl sulphate type, sodium salts of sulphonates, calcium lignosulphate, salts of fatty acids, etc., with ordinary Portland cement or Portland blast furnace slag cements. These agents in powder or in liquid forms are added to the extent of 0.025 to 0.100 per cent by weight of OPC cement clinker at the time of grinding. At the time of mixing concrete ingredients, these cements produce tiny, discrete noncoalescing air bubbles in the concrete mass which enhances workability and reduces tendency to segregation and bleeding. The air entrainment increases the frost and sulphate water resistance of concrete.

(B) **Role of Fly ash as a part replacement of cement:** The fly ash or Pulverised Fuel Ash (PFA) is the residue from the combustion of coal collected by the mechanical dust collectors or electrostatic preceptors or separators from the fuel gases of thermal power plants. Like Portland cement, fly ash contains oxides of calcium, aluminium and silicon, but the amount of calcium oxide is considerably less. The properties of fly ash depend on the type of coal burnt. In general, silicious fly ash is pozzolanic, while calcareous fly ash has latent hydraulic properties.

The pozzolanic activity is due to the presence of finely divided glassy silica and lime which produce calcium silicate hydrate as is produced in hydration of Portland cement. The carbon content is fly ash should be as low as possible, whereas the silica content should be as high as possible.

The fly ash obtained from Electrostatic Precipitators (ESP) is finer than the Portland cement. The most important mineral aspect of fly ash is the presence of 60-90 per cent glassy spherical silicon dioxide (SiO_2). The fly ash is generally used in the following three ways:

1. **As a part replacement of cement:** This simple replacement of Portland cement up to 60 per cent by mass reduces the strength at ages up to 3 months.
2. **As a simultaneous replacement of cement and fine aggregate:** This replacement enables the strength as a specified age to be equalled depending on the water content.
3. As a part of cement in the form of blended cement.

1.16 **Describe how the compounds of clinker affect the properties of cement.**

[12 marks : 2020]

Solution:

The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide.

These oxides when subjected to high clinkering temperature combine with each other to form complex compounds.

The identification of major complex compounds is based on R.H. Bogue's work and hence these are called Bogue's compound.

There are 4 Bogue's compounds:

1. **Tricalcium Silicate (C_3S)**

   Chemical formula : $3\ CaOSiO_2$

   Percentage : 30 - 50%

   - It undergoes hydration within a week and is responsible for development of early strength in cement.
   - It is the best cementing material and is well burnt.
   - Increases resistance to freezing and thawing.
   - Renders the clinker easier to grind.
   - Its proportion can be increased where early gain of strength is required.

     Example : Emergency repair work, cold weather concreting, prefabricated construction, etc.

2. **Dicalcium silicate (C_2S)**

   Chemical formula : $2CaOSiO_2$

   Percentage : 20-45%

   - It hydrates and hardens slowly and takes long time to add to strength (1 year or more).
   - Imparts resistance to chemical attack.

- Proportion is increased when early strength is not required and higher heat of hydration should not be there.

Example : Dam or bridge construction.

3. Tricalcium Aluminate (C_3A)

   Chemical formula : $3CaOAl_2O_3$

   Percentage : 8-12%

- Responsible for flash set of cement as it undergoes hydration within 24 hours after water addition.
- Highest heat of hydration and tendency to volume changes causing cracking.
- If present in higher amount, resistance to sulphate attack decreases.

4. Tetracalcium Alumino Ferrite (C_4AF)

   Chemical formula : $4CaOAl_2O_3Fe_2O_3$

   Percentage : 6-10%

- Responsible for flash set but generates less heat.
- Poorest cementing value.
- Raising its content reduces the strength slightly.

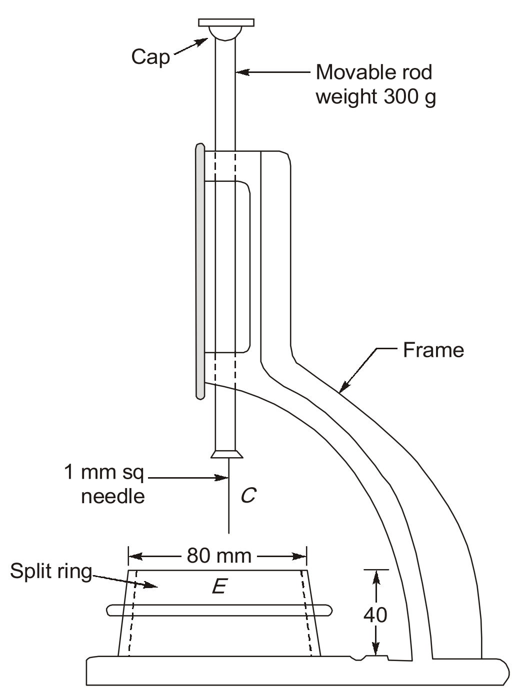
1.17 What do you mean by normal consistency of cement? What is its significance? How is it tested?

[8 marks : 2020]

Solution

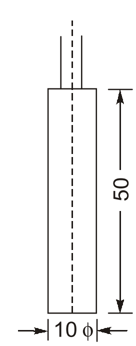
Normal consistency of cement:

- The normal (standard) consistency of a cement paste is defined as that consistency which will permit a Vicat plunger having 10 mm diameter and 50 mm length to penetrate a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom) of the mould.



Side view

Vical apparatus with needle for initial section time test



Plunger for standard consistency test

Significance:

- It is necessary to determine consistency because the amount of water affects the setting time of the cement. It is resistance to shear deformation. Thus, it plays vital role in the determination of compressive strength or workability of concrete.

Vicat Apparatus:

- Vicat apparatus assembly consists of a plunger 300 gm in weight with a length of 50 mm and diameter of 10 mm and a mould which is 40 mm deep and 80 mm in diameter.

Test Procedure:

- To prepare the paste, take weighed quantity (300 g) of cement and place it in a crucible.
- Mix a weighed quantity of water (approximately 24% by weight of cement) for the first trial.
- The time of mixing or gauging should not be less than 3 minutes nor more than 5 minutes and gauging time should be counted from the time of adding water to the dry cement until commencing to fill the mould.
- The Vicat mould is filled with the paste, which is levelled off at its top.
- The mould is placed under the Vicat plunger.
- The vicat plunger is brought down to touch the surface of paste in the mould and quickly released allowing it to sink into the paste by its own weight.
- Take the reading by noting the depth of penetration of the plunger.
- Similarly conduct the trials with increasingly water cement ratio till such time the plunger penetrates for a depth of 33 to 35 mm from the top (or 5 to 7 mm from the bottom).
- That particular percentage of water which allows the plunger to penetrate only to a depth of 33 to 35 from the top (or 5 to 7 mm from the bottom) is known as the percentage of water required to produce a cement paste of normal (standard) consistency.
- This percentage is generally denoted by *P*.
- This test should be conducted at a constant temperature of 27° ± 2°C and a constant humidity of 90%.

1.18 **It is quite common to replace/partially substitute, cement with flyash. However, all the concretes made by cement substituted by flyash may not be used for all the applications. Specify some applications where using flyash concrete is useful and the applications where we should avoid using flyash products and provide reasons.**

[12 marks : 2022]

Solution

- Flyash is pozzolanic material obtained by burning the pulverized coal.
- Replacement of cement with flyash modifies property of cement and concrete and entire cementaneous material is combination of cement clinker and pozzolanic material like flyash.
- Addition of flyash by reduction in amount of basic cement clinker results in reduction in rate and amount of heat of hydration.
- Lesser rate of hydration maintains workability of concrete for a longer time, i.e., concrete will remain with it's internal energy to achieve a higher degree of compaction.

  So, best use of replacement of cement with flyash is found for self compacted concrete, where water powder ratio is kept to be 0.3 with high powder content.
- Flyash does not leach out portlandite while formation of C-S-H gel, so finished structure will not become porous. Moreover, less amount and rate of heat evolution do not cause shrinkage. Hence, overall durability of structure is improved e.g. Mass concreting.
- Due to less amount of C_3A clinker, sulphate resistance can also be improved. Hence, cement with flyash can be used against sulphur attack as well.