Chapter 1

INTRODUCTION

1.1 GENERAL

The present work is in the field of structural engineering for deciding the good proportion of cement and super-plasticizer for getting good strength in the structure. The different brands of cement and super-plasticizers are considered for the analysis and behavioral studies of slurry/ mix. The different manufacturer of PPC cement claims about the strength and utility of their products is best suited for the work of concrete. The recent development has encouraged the use of super-plasticizer for the super-structure for getting good strength in reduced water requirements.

1.2 CEMENT

In the world, every country is progressing very fast. And to get their progress in line, all are having their focus for creating the infrastructure. For this, cement is the backbone for global infrastructural development. As such, the global production of cement has eventually increased, which created start of many cement manufacturing industries. Every cement industry, although of same grade or type, differs by many factors like composition of cement, fineness of cement etc.

Due to the change in composition within same grade or type of cement, super-plasticizers are not showing the same extent of improvement in fluidity. Some cement brand show higher fluidizing effect with a super-plasticizer than other cement brand with same super-plasticizer. There is neither the problem with cement nor with that of super-plasticizer. The fact is that they are just not compatible to show maximum fluidizing effect due to the change of composition or so.

The cement type used for this study is Portland Pozzolana Cement, which is cement with supplementary cementitious materials like fly ash and slag. High fineness, low carbon content, good reactivity are the essence of good fly ash. The fly ash particles are in amorphous state. The amorphous factor greatly contributes to the pozzolanic reaction between cement and fly ash. One of the important characteristics of fly ash is the spherical form of the particles. This shape of particle improves the flowability of cement paste and reduces the water demand. Thus, the incorporation of mineral admixture such as fly ash, slag can make the compatible relation between cementitious material and super-plasticizer more complex. Therefore it becomes must essential consideration for selection of the compatible interacting couple. Hence, here due importance have been given to select that compatible cement- super-plasticizer combination.

1.3 SUPER-PLASTICIZER

The use of super-plasticizer in concrete is an important milestone in the advancement of concrete technology. The practice is to use super-plasticizer to reduce the requirement of water for making concrete of higher workability or more flowing concrete. The use of super-plasticizer reduces the water- cement ratio for the given workability, which eventually increases the strength. Moreover, by reducing the water- cement ratio, the durability of concrete can be improved. Super-plasticizer can also produce homogeneous concrete without any tendency for segregation and bleeding.

The addition of super-plasticizer in concrete gives desired fluidity in the fresh state and, greater compactness and strength in the hardened state. Super-plasticizers are also very complex compounds composed of different molecular weights and of macromolecules of different chain lengths. In addition to this, an admixture can whether be effective or not depends upon various factors such as chemical nature or family of super-plasticizer, dosage of admixture, temperature, molecular weight of the polymer and particle size distribution and composition of cement. All of these enlisted factors play huge role in the mechanism of fluidity of fresh cement pastes and that of concrete.

Currently, with the limited availability of natural resources, admixtures are substituting there places. The admixtures have proved to be economical, as well as they improve some technical performances. The super-plasticizer used is water reducers and are self capable to reduce water-cement ratio requirement. Thus, the concrete made with low water- cement ratio require such suitable and compatible super-plasticizer which can adopt the behavior of cement and can also impart high workability and high consistency to the concrete. During the use of super-plasticizer with cement, there sometime problem arises when cement is not capable of adopting the chemical behavior of super-plasticizer. Consequently, there is incompatible bonding of cement-super-plasticizer resulting to loss of workability and irregularity in slump. The main motive is to select such efficient cement- super-plasticizer combination which is able to impart maximum water reduction, high workability and other technical performances.

The use of super-plasticizer has become very common in India. There has also been increased number of brands of cement, and in the types of cement available. It is very difficult to ensure that an admixture produces all the desirable effect with cement A would do the same with cement B. On the other side, there has also been increase in types of admixture available. These admixtures themselves differ by chemical family, specific gravity etc. Users are now in much difficulty to use which type of cement with which type of super-plasticizer and with how much dosage. Users, who are unaware of compatibility issues, often suffer when the supply of cement and/or admixture is changed midway through a project. Problems arising due to compatibility issues are often mistaken for problems with concrete mix design, because of the lack of information about the subject amongst practicing engineers.

A manufacturer can just only try to adjust the compatibility affecting factors to a certain extent to fit his super-plasticizer to a particular cement and therefore to improve the compatibility between that super-plasticizer and cement. Admixture manufacturers have started formulating project specific chemicals, to overcome the problem. But this is only short term solution. For a more comprehensive approach, a thorough understanding is required and remedies of incompatibility are necessary. This study is dealing with such problems.

1.4 OBJECTIVE OF WORK

The objective of this work is to study the compatibility between cement and super-plasticizer by measuring the fluidity of the cement paste. Consequently, to establish the compatible super-plasticizer with given cement. The compatible cement- super-plasticizer couple implies the couple, in which mutual interaction between cement and super-plasticizer offers high fluidity with low saturation dosage without any much fluidity loss. In addition to the above, the effect and variation of increasing the percentage of admixture has been examined on the cement paste and its fluidity. Giving maximum fluidizing effect for a particular combination of super-plasticizer and cement is very complex, and is hereby dealt with.

The behavioral curve obtained by test procedure will be used to study three essential aspects which may influence the compatibility of cement- super-plasticizer and are expressed as:

1. Determination of saturation dosage corresponding to a break in the curve when further addition of super-plasticizer beyond the saturation point does not improve much fluidity of Cement–Super-plasticizer.

2. Determination of saturation dosage for change of water- cement ratio for the same combination of cement- super-plasticizer.

3. Analysis of behavior of same cement- super-plasticizer couple for different water- cement ratio.

4. Fabrication and arrangement of test equipment.

1.5 ORGANIZATION OF THESIS

This thesis consists of total of seven chapters including this introductory chapter. Chapter-2 presents detailed review of research in the field of cement and super-plasticizer, the compatibility between cement and super-plasticizer and the research work so far in this field conducted, is included. Chapter 3 presents description about different materials and apparatus used for experiment. Chapter 4 presents experiment steps and various combination of cement-super-plasticizer used for experiment. Chapter 5 presents the experimental observations, graphs and discussions for each combination of C-SP. Chapter 6 concludes about the compatibility equations for all cement under observation with different chemical family of super-plasticizer. Chapter 7 presents conclusions and scope of the work.

Chapter 2

LITERATURE REVIEW

2.1 CEMENT AND ADMIXTURE- A REVIEW

2.1.1 INTRODUCTION

Currently, the essential novelty appeared in cement industry is actually the increase use of the mineral admixtures, substituting a part of cement to reduce the carbonic gas emission, to minimize the cement cost and to improve some technical performances. High performances concretes made with low W/C ratio require the use of suitable and compatible super-plasticizers with the new cements which can transform a concrete with high consistency into a concrete with high workability. During the use of super-plasticizers in concrete, certain cements can sometimes present some problems of incompatibility of cement–super-plasticizer; irregularity of slump and rapid workability loss. The principal approach provided to combat against this difficulty is to select the most efficient couple cement–super-plasticizer, enabling to obtain a maximum water reduction, a better workability and an acceptable rheology during the placement and the finishing concrete. The incorporation of some mineral admixtures such as blast furnace slag, fly ash, silica fume or natural pozzolan can make the interaction between the cementitious materials and super-plasticizers more complex, and therefore the selection of the compatible couple requires further consideration.

2.1.2 CEMENT

The product manufactured by burning and crushing to powder an intimate and well proportioned mixture of calcareous and argillaceous materials is called ‘Cement’. Cement is a well known building material and has occupied an indispensable place in the construction works.

The history of cement is very old, in the field of construction, building and other structural work. This important building material was first introduced way back in 1824, where mixture of slagged lime and clay was heated to high temperature and crushed to powder, could produce binding material which would harden in the presence of water. This binding material was first named as ‘Portland Cement’, after hardening it resembled in color to the stone quarried near Portland in England.

The cement is very often the most important because it is usually the delicate link in the sustainable structure. The function of the cement is first of all to bind the structural materials together and second to fill up the voids between them.

It can be seen that cement shows different behavior and characteristics depending upon the chemical composition. The fineness of grinding or the change in oxide composition, cement can be made to show different properties. In the history of development, continuous rigorous efforts were made for producing different kinds of cement which can be suitable for varying situation by changing oxide composition and fineness of grinding. The cements made by varying the oxide composition and fineness of grinding are not found sufficient to work for varying conditions. This enunciated the use of ‘additives’ with the clinker at the time of grinding, or to use various raw materials for the manufacture of cement.

Nowadays, the different types of cement are available by the use of wide variety of additives; change in chemical composition and with the use of different types of raw material. To meet the requirement of construction industry, various kinds of cement are available by above process.

2.1.3 TYPES OF CEMENT-

2.1.3.1 Ordinary Portland cement - Portland cement (often referred to as OPC) is the most common type of cement in general use around the world because it is a basic ingredient of concrete, mortar and most non-specialty grout. It is a fine powder produced by grinding

Portland cement clinker (more than 90%), a limited amount of calcium sulphate (which controls the set time) and up to 5% minor constituents as allowed by various standards

Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates ($3CaO.SiO_2$ and$2CaO.SiO_2$), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. The ratio of CaO to SiO_2shall not is less than 2.0. The magnesium oxide content (MgO) shall not exceed 5.0% by mass.

Portland cement clinker is made by heating, in a kiln, a homogeneous mixture of raw materials to a sintering temperature, which is about 1450 °C for modern cements. The aluminium oxide and iron oxide are present as a flux and contribute little to the strength.

Portland cement manufacture can cause environmental impacts at all stages of the process. These include emissions of airborne pollution in the form of dust, gases, noise and vibration when operating machinery and during blasting in quarries, consumption of large quantities of fuel during manufacture, release of CO_2 from the raw materials during manufacture, and damage to countryside from quarrying.

2.1.3.2 Rapid-Hardening cement-This cement is similar to ordinary Portland cement but an adjustment of its chemical composition to give a higher content of tri-calcium silicate (C_3S) and a finer grinding is its main characteristics. These changes enable it to attain greater strengths at early stages; that is why it is known as High-Early Strength Cement. The magnitude of the increase may be judged from the fact that the strength developed at the age of 3days is about the same as the 7day strength of ordinary Portland cement with the same water-cement ratio.

The use of rapid hardening cement in place of ordinary cement permits the shattering to be struck earlier, thus is effecting a considerable saving in time and money. In the concrete products industry, moulds can be released quickly. This type of cement is lighter to that of ordinary cement.

2.1.3.3 Low Heat cement - This type of Portland cement is so called because it develops less heat of hydration. When concrete is poured in the structure, an increase in temperature occurs and certain amount of heat is evolved. This is due to the chemical reaction which takes place while cement is setting and hardening. The ordinary concrete construction, this generation of heat is of little importance, but in concrete dams and other massive structures such as bridge, abutments and retaining walls, it is a factor of considerable importance. In these cases, the rate at which the heat can be lost from the surface is lower than that which is initially generated by the hydration of the cement. The buildup of heat in structure is dangerous and can lead to serious cracking in structure.

2.1.3.4 Quick Setting cement- This cement sets initially in minutes and finally in less than 30 minutes. It is used only under special circumstances and should be avoided for general use. As the time of mixing and placing is very small, there is a chance of the concrete being placed after the initial set has taken place, as such the desired effect cannot be produced.

2.1.3.5 High Alumina cement- This is special cement mainly comprising of hydraulic calcium aluminates as the major ingredients. Its unique properties are high early strength is imparted to it by the presence of mono-calcium aluminate. This cement also finds utility in emergency repair and construction. This type of cement is not affected by frost since the great heat evolved during setting and hardening prevents the concrete from freezing. Thus it cannot be used in mass concrete work.

2.1.3.6 Blast Furnace Slag cement- This cement is made by inter-grinding Portland cement clinker and blast furnace slag. The proportion of the slag is not less than 25% and not more than 65% by weight of cement. The blending by no means detracts from any desired property of cement. This cement may be used for all purposes of which ordinary cement is used. In addition, in view of its low heat evolution, it can be used in mass concrete structures such as dams, retaining walls, foundations and bridge abutments. It is more resistant to attack of weathering agencies.

2.1.3.7 Portland Pozzalana cement (PPC)- This cement is manufactured either by inter-grinding of Portland cement clinker and pozzolana or by intimately and uniformly blending Portland cement and fine pozzolana. While inter-grinding presents no difficulty, blending tends to result in a non-uniform product. IS Specification stipulated that the latter method should be confined to factories and such other works where intimate blending can be ensured through mechanical means.

The proportion of pozzolana used varies between 10- 25% by weight of cement. Pozzolanas have no cementing values themselves but they have the property of combining with lime to produce a stable lime-pozzolana compound which has definite cementitious qualities. The free lime, which is readily subjected to chemical attack, is thus removed. This is why pozzolana concrete has a higher resistance to chemical attack and also by alkaline sea water. This cement also has lower heat evolution that is why it is widely used in construction of dams.

The pozzolana used in the manufacture of Portland Pozzalana Cement is burnt clay, shale or fly ash. The properties of Portland Pozzalana Cement will depend on the type and quality of pozzolana selected for inter-grinding or blending. When the pozzolana is selected with care and is calcined and ground with Portland cement clinker under controlled condition, the compressive strength of Portland Pozzalana Cement is comparable with that of ordinary Portland cement.

Grading of PPC- In many countries, PPC is graded like OPC depending upon their compressive strength at 28days. In India, so far PPC is considered equivalent to 33 grade OPC, strengthwise, although some brands of PPC is as good as even 53 grade OPC. Many cement manufacturers have requested BIS for grading of PPC, just like grading of OPC. They have also requested for upper limits of fly ash content from 25 to 35%. Recently, BIS has increased the fly ash content in PPC from 10-25% to 15-35%.

2.1.4 ADMIXTURE

In present scenario, there have been enormous increase in the use and research and development in the area of admixtures used in cement. Recent developments in concrete technology over the past decades are essentially due to the use of chemical admixtures. In place of using special purpose cement, it is possible to change or to get the desired effect from the regular cement by adding some special chemical to it, these special chemicals are termed as ‘Admixtures’. The admixtures differ from additives in a way that, additives are added at the time of manufacture of cement whereas, admixtures are added at the time of preparing the mix. The admixtures are added to the concrete mix for improving the properties of concrete. A large number of admixtures (under various trade names, depending upon manufacturer) are available in the market, whose selection can be based on the desired effects which are described by the user.

Nowadays, after 1980 some international manufacturer of admixtures collaborated with Indian companies and started manufacturing admixtures in India. As a part of their business and marketing, they started awareness program among leading consultants, architects, structural engineers and builders. The knowledge given by the manufacturer is not sufficient and is a matter of further analysis and research in the field of admixture. Apart from this, India has also started use of admixture for high rise building and bridges for getting better strength.

The admixtures are classified as given below depending upon the properties or change in the nature of properties of mix;

- Accelerators and accelerating plasticizer
- Retarders and retarding plasticizers
- Plasticizers
- **Super-plasticizers**
- Air-entraining admixtures
- Pozzolanic or mineral admixture
- Damp-proofing and water proofing admixtures
- Gas forming admixtures
- Air detraining admixtures
- Workability admixtures
- Grouting admixtures
- Corrosion inhibiting admixtures
- Bonding admixtures
- Coloring admixtures

2.1.4.1 SUPER-PLASTICIZER

Super-plasticizers are chemical compounds and special class of water reducers i.e. High range water reducers. These are chemically distinct from normal plasticizers and although their action is basically the same.

Super-plasticizers comprises of new and improved category of plasticizers, which was developed in Japan and Germany. These are chemically different from the usual plasticizers which are commonly used. Use of super-plasticizer does not reduce the workability but also reduce the requirement of water up to 30%, which is 15% in case of plasticizers. The use of super-plasticizer increases the flowability of concrete, as well as does not require compacting and leveling. It produces very high strength to the concrete, using normal workability with a very low water- cement ratio. With both of these functional effects, improved plastic and hardened physical properties are achieved with the use of super-plasticizer.

Super-plasticizers are organic polymeric compounds in solution, their action on cement particles hold for a limited period only. The operations of transporting, placing, compacting and finishing on plastic concrete should be completed well within this time period, during which the concrete is still workable. The Super-plasticizer is also called as surface reactive reagents (surfactants). They induce negative charge on each cement particle, so that the particles remain in suspended phase due to repulsion between them. Thus it imparts high mobility to these particles.

An ideal super-plasticizer will be cost effective, does not possess tendency to segregate, bleed or foam, has little interference with hydration, and is compatible with different types of cement and other commonly used additives.

2.1.4.2 TECHNICAL PERFORMANCE OF SUPERPLASTICIZER

1. To produce flowable concrete- The addition of small quantity of super-plasticizer to the normal concrete mix can result into very high workable and flowable concrete, and to produce self-compacting or self-leveling concrete.

2. To produce concrete with very low water-cement ratio- While maintaining the required workability, the water requirement in the concrete mix can be deliberately reduced. With the application of super-plasticizer, water reduction up to 30% can be possible. This produces high strength and durable concrete.
3. To produce high performance concrete- The higher performance of hardened concrete can be achieved by reduction of water and improved workability of plastic concrete cab be achieved by the addition of super-plasticizers. Thus the concrete mix generated imparts better workability than normal workability and possess lower than normal amount of water.

2.1.4.3 DOSAGE LEVEL OF ADMIXTURE

The workability of the concrete increases with the increase in amount of super-plasticizer for the same water-cement ratio. But this does not signifies as to add as much amount of super-plasticizer, this will not be cost effective. In addition to this, the major effectiveness of the super-plasticizer is upto a certain amount of it, beyond which there will not be any significant improvement in the fluidity. Consequently, it becomes essential to achieve that amount of super-plasticizer known as ‘saturation dosage’ or ‘optimum dosage’. On the other side, the addition of excessive amount of super-plasticizer may result to segregation of cement particles.

The saturation or optimum dosage is highly influenced by the change in composition of cement. The more will be the fineness of cement; more will be the requirement of super-plasticizer dosage to achieve the desired workability.

As discussed earlier, the cement grouts containing super-plasticizer are significantly affected by cement fineness, cement composition etc. The effect of such properties on fluidity, point of saturation of super-plasticizer and the loss of fluidity with time of the cement grouts are shown in fig.1.

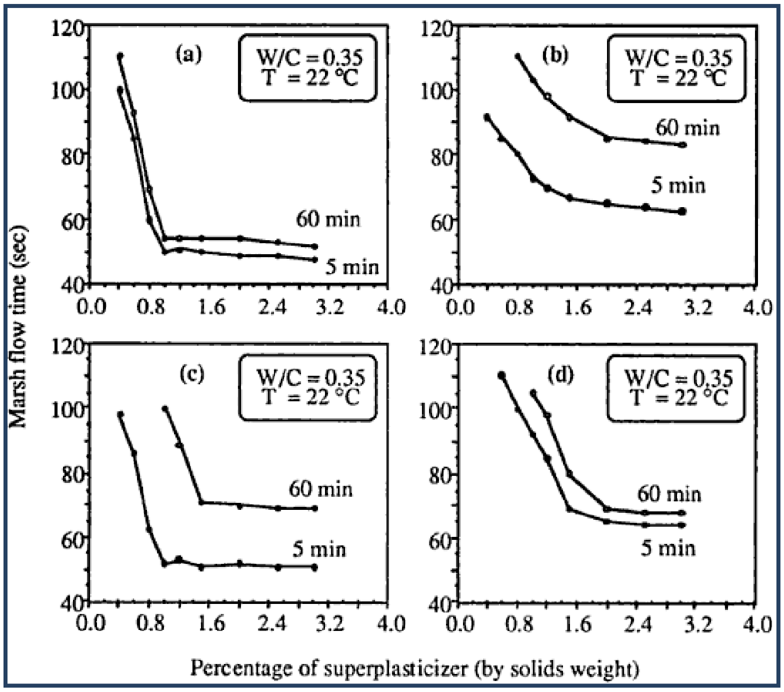


Fig 1 Loss of Fluidity with time with different dosage of super-plasticizer

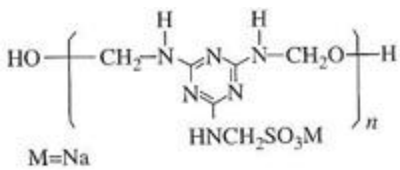
This figure has been taken from reference [11]. While studying the compatibility between cement-super-plasticizer with Marsh cone, following four typical situations can be found from practical point of view, which signifies:

- Fig.1(a) represents the case of a perfectly compatible cement- super-plasticizer combination; the dosage corresponding to the saturation point is low and 60 min curve is close to 5 min curve.
- Fig.1(b) represents the case of an incompatibility between cement and super-plasticizer; the dosage corresponding to the saturation point is very high and there is large gap between the 5 min and 60 min curve. In many cases, the grout stops to flow very rapidly.
- Fig.1(c) represents intermediate case. The 5 min curve is similar to 5 min curve in fig1(a) but 60 min curve is similar to 60 min curve of fig1(b).
- Fig.1(d) also represents intermediate case. The 5 min curve is similar to 5 min curve in fig1(b) but 60 min curve has a relative position to 5 min curve similar to the situation in fig1(a).

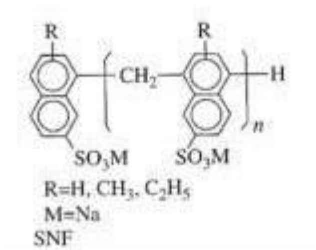
2.1.5 DIFFERENT TYPES OF SUPER-PLASTICIZER

Super-plasticizers can be classified depending upon the chemical base by which they are made. The following are the chemical base used for super-plasticizers:

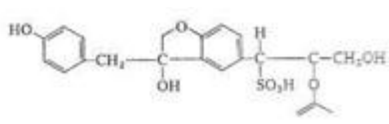
- Sulphonated malanie- formaldehyde condensates (SMF)



- Sulphonated naphthalene- formaldehyde condensates (SNF)



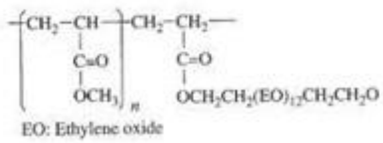
- Modified lignosulphates (MLS)



In addition to these bases, nowadays new super-plasticizer base are also being generated which are as follows:

- Acrylic polymer based (AP)

- Copolymer of Carboxylic acrylic acid with acrylic ester (CAE)
- Cross linked acrylic polymer (CLAP)
- Polycarboxylate ester (PC)



- Multicarboxylate ethers (MCE)
- Combination of above

2.2 CEMENT – SUPERPLASTICIZER COMPATIBILITY

2.2.1 INTRODUCTION

The combination of cement and super-plasticizer (C-SP) that maintains the high slump without any sign of segregation and bleeding is said to be ***compatible*** and this property of C-SP referred as ***compatibility***. Compatibility problems arise even when the material selection and design is supposedly proper. These issues in turn affect the hardened properties of concrete, primarily strength and durability.

Leading researchers have recognized the need to review the acceptance standards for both cements and super-plasticizers since the incompatibility problems are expected to grow with further and more extensive use of high performance concrete [Tagnit- Hamou et al.,1992], and also with the number of cements and chemicals available in the market.

2.2.2 MECHANISM OF ACTION OF SUPER PLASTICIZER (WATER REDUCERS)

Water-reducing chemicals belong to a group of chemicals known as ‘dispersants’. The action of the dispersant is to prevent the flocculation of fine particles of cement. These dispersants are basically surface-active chemicals consisting of long-chain organic molecules, having a polar hydrophilic group (water-attracting, such as $-COO^-$, $-SO_3^-$, $-NH_4^+$) attached to a non-polar hydrophobic organic chain (water-repelling) with some polar groups (-OH). The polar groups in the chain get adsorbed on the surface of the cement grains, and the hydrophobic end with the polar hydrophilic groups at the tip project outwards from the cement grain. The hydrophilic tip is able to reduce the surface tension of water, and the adsorbed polymer keeps the cement particles apart by electrostatic repulsion (The grinding of cement results in the ground particles having a surface charge (zeta potential). The adsorption of the admixture leads to a decrease of the zeta potential, and eventually causes like charges (negative) on the cement particles). With the progress of hydration, the electrostatic charge diminishes and flocculation of the hydrating product occurs.

Lignosulphonates (normal, and sugar-refined), SMF, and SNF based super-plasticizers work on the mechanism of lowering zeta potential that leads to electrostatic repulsion. On the other hand, polymers with backbone and graft chains, such as PCEs, acrylic esters, and cross-linked acrylic polymers, cause dispersion of cement grains by steric hindrance [Uchikawa et al., 1997]. This phenomenon relates to the separation of the admixture molecules from each other due to the bulky side chains. Steric hindrance is a more effective mechanism than electrostatic repulsion. The side chains, primarily of polyethylene oxide extending on the surface of cement particles, migrate in water and the cement particles are dispersed by the steric hindrance of the side chains.

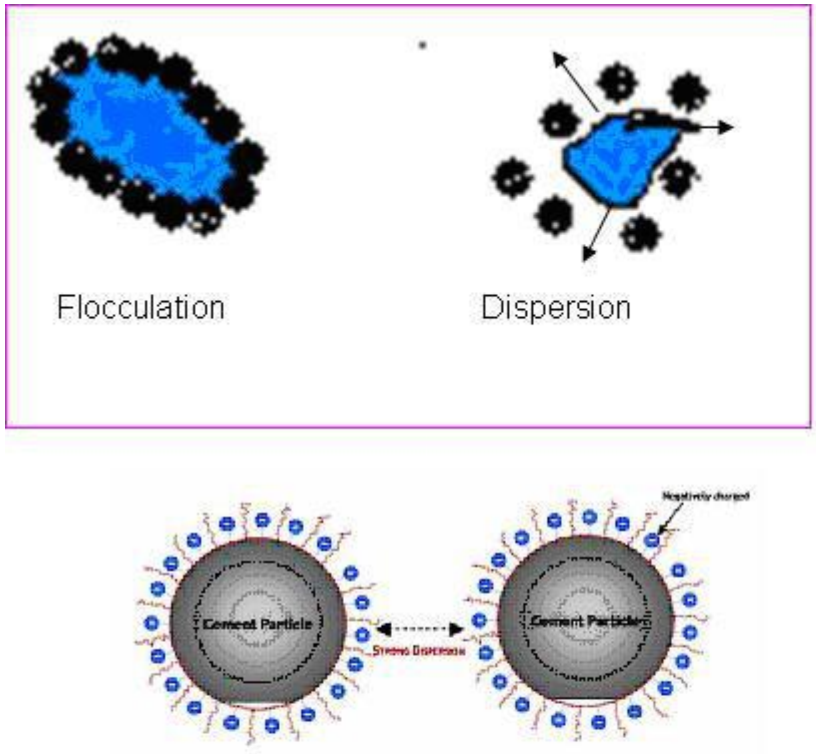


Fig 2 Mechanism of electrostatic repulsion (top) and steric hindrance (bottom)

Electrostatic repulsion depends on the composition of the solution phase and the adsorbed amount of the SP (greater the adsorption, better the repulsion) [Nakajima and Yamada, 2004]. On the other hand, steric repulsion depends on the length of main chain, length and number of side chains [Sugiyama et al., 2003].

In the case of PCE based admixtures, for fluidity retention, the main chain should be short, with large numbers of long side chains [Sugiyama et al., 2003]. Because of the steric repulsion mechanism, PCEs are generally more effective than the sulphonate based admixtures, and generally do not experience much problems at low water to cement ratios. However, they are more sensitive to overdosing, and can lead to problems like excessive air entrainment and retardation.

Additional mechanisms of SP action include dispersion of cement particles by reduction in surface tension of mixing water and a decrease in frictional resistance because of the line-up of linear polymers along the concrete flow direction and lubrication properties produced by low molecular weight polymers [Uchikawa et al., 1995].

Apart from affecting the early age physical properties of concrete, SPs can also cause some changes in the morphology of hydration products. Size of portlandite crystals decreases with addition of admixtures [Grabiec, 1999]. Ettringite in the presence of SPs (at high dosage) crystallizes in small and massive clusters rather than the conventional needle shape [Hanna et al., 2000; Prince et al., 2002]. In general, SPs improve rheological properties by yielding smaller hydrate particles and preventing hydration products from bridging neighboring cement particles. There is also a difference in porosity and pore size distribution of superplasticized concrete compared to normal concrete. Higher numbers of smaller pores are produced in superplasticized mixtures, which could have an influence on the degree of shrinkage. While the mechanism of action of water-reducing chemicals is reasonably well-established, there still exist gaps in the comprehension of why occasionally these chemicals do not work as intended. This is because the problem of cement-super-plasticizer compatibility has many dimensions to it. On the one hand, there is the composition of the water reducer, as discussed above. On the other end of the spectrum is the composition of cement, particularly the relative proportions of C_3A, alkalis and C_3S in the cement. In addition, the type of gypsum available (gypsum, hemihydrate, or anhydrite) has an important role to play. The fineness of cement could also affect its compatibility with a particular admixture. Each of these factors influences the phenomenology of cement-water reducer interaction.

2.2.3 FACTORS AFFECTING COMPATIBILITY-

Interaction problems are caused by the effect of the admixtures on the hydration reaction of cement and due to adsorption of the admixture to the cement particles. The problem of cement-super-plasticizer compatibility has many dimensions to it. The compatibility problems arises as on the one hand, there are many chemical compositions/ chemical bases and also with the combinations of the super-plasticizer are available (discussed above). On the other end of the spectrum, there is the variation in the composition of cement, particularly the relative proportions of C_3A, alkalis and C_3S in the cement. The fineness of cement could also affect its compatibility with a particular admixture.

The w/c ratio of concrete seems to affect the performance of Super-Plasticizers. In general, most compatibility problems only exist at low w/c ratio.

On an India-specific note, cement standards in our country are not very stringent, and enable manufacturers to adjust their product in many different ways. For example, while the minimum fineness is specified for different grades of cement, there is no control on the maximum. Thus, a manufacturer could use the same composition and grind cement to different finenesses, and still have the same end product. Such a situation might lead to incompatibility issues. Additionally, the requirements of chemical composition are also not stringent, and large ranges are acceptable. This could result in significant variability in the cement properties, even from the same manufacturing plant. From the viewpoint of use of super-plasticizer, there is insufficient knowledge among users regarding the limitations of different types of chemicals.

However, in order to keep the discussion focused; this project is restricted to the analysis of incompatibilities resulting from the cement and Super-plasticizer alone.

2.2.3.1 EFFECT OF CEMENT COMPOSITION

Cement is composed of four major compounds, namely, C_3S (tricalcium silicate), C_2S (dicalcium silicate), C_3A (tricalcium aluminate), and C_4AF (tetracalcium aluminoferrite). In addition, a number of minor oxides, such as alkali oxides (K_2O and Na_2O), MgO, and SO_3 – which is contributed by gypsum, which is added in the final stages of cement manufacture as a set regulator.

Influence of C_3A

The C_3A content or more specifically, the C_3A to SO_3 ratio has a profound effect on the early age behavior of cement paste. In a normal hydration process of OPC, the amount of C_3A is such that the end product of aluminate hydration is monosulphate (AF_m). However, in low C_3A cement (sulphate resistant) ettringite remains after the initial hydration.

When the C_3A to SO_3 ratio is very high (or when SO_3 is not easily available in solution), flash setting occurs due to rapid hydration of C_3A. In the case of low C_3A to SO_3 ratio, there is a high possibility of false setting (conversion of calcium sulphate forms to gypsum).

When the C_3A content of cement is high, and the sulphate availability is low, superplasticized concretes experience high rates of slump loss (this aspect is discussed further in the next section). Cements having moderate to high C_3A contents (~ 9%) showed increased slump loss over that of control concrete. On the other hand, when there is less C_3A available, SPs would tend to get adsorbed in higher amounts on C_3S and C_2S, resulting in a reduction in the rate of strength development [Roberts, 1995]. The use of special Portland cement containing less than 10% of interstitial phase (3.6% C_3A and 6.9% C_4AF) was reported to be very economical in terms of SP dosage to make compatible Cement-Super-plasticizer couple at low water/binder ratio.

Influence of Calcium Sulphates

In the early stages of cement hydration, the reactions that dominate are the reaction of C_3S with water to produce CSH and calcium hydroxide, and the reaction of C_3A with gypsum to produce ettringite (that later converts to monosulphoaluminate in ordinary Portland cement paste). It is during this period that the interaction of the SP with cement occurs. SP molecules with sulphonate functional groups have an affinity for the aluminates, which are positively charged. As a result, they compete with the sulphate released from gypsum for the aluminate reaction sites [Ramachandran, 2002; Jolicoeur et al., 1994]. When the solubility of the calcium sulphate is low, the SP molecules tend to get adsorbed first on the aluminate compounds, thus preventing the normal setting reaction involving the formation of ettringite. Based on the raw material for calcium sulphate and on the temperatures attained during the final grinding process, the calcium sulphate present in OPC can be a mixture of dihydrate (gypsum), hemihydrate, or anhydrite. In order to prevent the SP molecules from interfering with the aluminate hydration, it is imperative that the SO_3 becomes available in solution as early as possible. Thus, the solubility of the calcium sulphate is important. While hemihydrate and synthetic anhydrite possess greater solubility than gypsum, natural anhydrite is very slowly soluble. The presence of natural anhydrite has always been found in systems presenting compatibility problems. It must be also noted that the solubility of sulphates would decrease in the presence of SPs with sulphonate functional groups, thus affecting the normal setting process of the cement [Hanna et al., 2000]. In order to avoid such problems, cements usually contain sufficient amounts of quickly soluble alkali sulphates. However, alkalis themselves affect compatibility in a number of ways, as discussed below.

Influence of Alkalis

Alkalis in cement are essential from the point of view of accelerating C_3S hydration. However, excess alkalis could have adverse effects, one of them being the alkali aggregate reaction. Hence, there is typically a strict control on the alkali limits. The use of cements high in alkali causes workability problems in concrete without any admixtures, but cements low in alkali are known to result in poor rheology of the concrete in concretes using sulphonate based admixtures [Jiang et al., 1999]. This is again interconnected with the availability of soluble sulphates, discussed in the previous section. The problem with low alkali cements can be overcome by adding an optimum amount of soluble alkalis, primarily in the metasilicate or sulphate forms [Li et al., 2003]. [Jiang et al. 1999] found that 0.4 – 0.5% soluble alkali content was optimum to maximize fluidity and reduce fluidity loss of the concrete. Higher alkali contents promote the solubility of sulphate ions and decreases the loss of fluidity with SNF [Dodson and Hayden, 1989; Chandra and Bjornstrom, 2002]. However, there are also negative effects – in the presence of high amount of alkalis when using an alkali sulphate rather than calcium sulphate, it is difficult for ettringite to crystallize so that rapid stiffening is experienced [Prince et al., 2002]. Alkalis in the form of K_2O increase reactivity of C_3A whereas Na_2O reduces the reactivity of

C_3A. Also, efflorescence problems are observed when naphthalene and melamine based super-plasticizers are used with cements having high alkali oxide content ($Na_2O + K_2O > 0.75\%$).

2.2.3.2 INFLUENCE OF FINENESS OF CEMENT

The finer the cement, the higher the specific surface area, and consequently, the water demand for a given workability is also expected to be higher. In cases where SPs are used, the amount of SP required for certain workability would be higher for finer cement [Jolicoeur et al., 1994]. The amount of SP adsorbed would also depend on the fineness, with finer cements causing more SP adsorption.

2.2.3.3 EFFECT OF ADMIXTURE TYPE

Organic admixtures (essentially, all super-plasticizers) form organo mineral compounds with C_3S and slow down the precipitation and growth of C-S-H and C-H [Flatt and Houst, 2001]. The formation of these organo-mineral phases reduces the amount of SP available in solution, leading to slump loss.

The surface adsorption of the admixture increases with the molecular weight of the polymer, and the presence of calcium ions promotes this adsorption. This seems to indicate that the manufacturing process can largely dictate the performance of the chemical. It is desirable to use polymers with large fractions of high molecular weight chains. However, this requires a strict control on the process.

Molecular weight of polymer

In the case of the lignosulphonates [Rixom and Mailvaganam, 1999; Mollah et al., 1995], the presence of low molecular weight ingredients is known to cause excessive air entrainment leading to loss of strength. In addition, the high sugar content of these admixtures could cause unnecessary retardation, especially at high dosages. A further unpredictability might arise depending on whether the chemical is a sodium salt or a calcium salt. Reports from the industry indicate that neither type of chemical is compatible with all cements. In order to be effective, lignosulphonates should be modified – the sugars should be removed by fermentation, and low molecular weight matter should be removed by centrifuging. Lignosulphonate admixtures produce a complex salt with Ca^{2+}, thus decreasing the Ca2+ concentration in the liquid phase, resulting in a delay in the hydration of alite, and causing set retardation.

SNF based admixtures are most prone to rapid loss of workability, particularly at low water to cement ratios, which are the norm for most special concretes today. Another common problem with SNF admixtures is excessive retardation, which may be caused because of the blending of these chemicals with lignosulphonates in commercial formulations. Similar to lignosulphonates, the presence of moderate to high molecular weight chain fractions leads to a better performance for SNF admixtures. The low molecular weight fractions cause excessive retardation by covering reactive sites on the cement surface and inhibiting reactions. Another factor affecting SNF effectiveness is the location of the sulphonate ($-HSO_3$) group in the naphthalene structure. It is well accepted that the presence of the sulphonate group in the ß-position leads to a high polymer charge and better electrostatic repulsion.

Compared to lignosulphonates, the adsorption of SNF depends more on the type of cement, thus necessitating its addition in higher quantities [Uchikawa et al., 2002]. [Chandra and Bjornstrom 2002] found that slump loss is lower for mortars with lignosulphonates than with SMF or SNF, since lignosulphonates do not get adsorbed to the same degree as SNF/SMF.

2.2.3.4 OTHER ISSUES AFFECTING COMPATIBILITY

Cement-Super-plasticizer couple at high ambient temperatures adds a new dimension to the problem of incompatibility. Low temperature has been reported to decrease fluidity. This decrease in workability at low temperature cannot be compensated with SP [Gettu et al., 1997]. On the other hand, high temperatures increase SP adsorption which increases fluidity. Conversely, temperature increase causes increase in reactivity of C_3A which causes higher ettringite contents with fine morphology in the presence of SP, thus causing a higher rate of slump loss.

The influence of temperature on cement – SP interaction is closely associated with the cement composition. Cement having low C_3A to SO_3 ratio is more sensitive to temperature variations in fluidity retention characteristics than cements having higher C_3A to SO_3 ratio. Also, cement having higher Equivalent Alkali content is more sensitive to temperature variations.

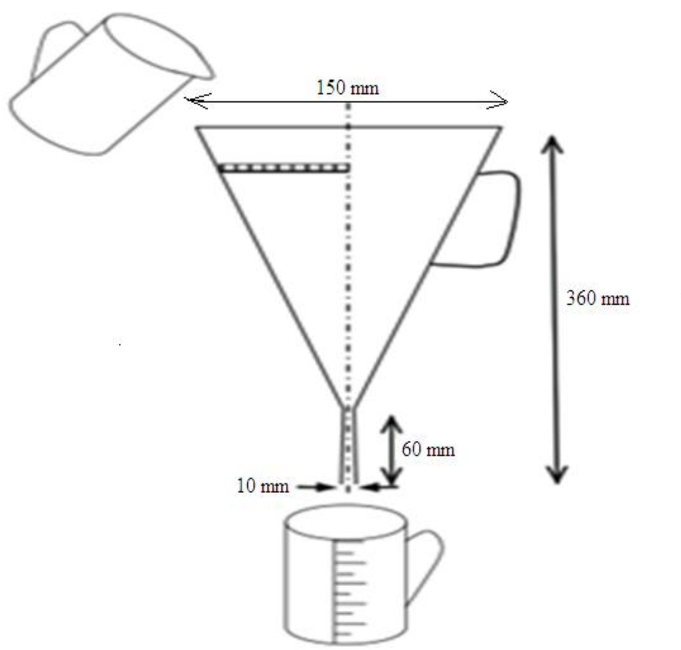
2.2.4 COMPATIBILITY TEST FOR OPTIMUM DOSE

The cement/admixture compatibility problem is becoming more and more frequent, especially in the field of super-plasticizers. While assessing compatibility, the required dosage of the super-plasticizer should be established. It is neither worth to use large dosage of super-plasticizer to achieve very low water- cement ratio nor possible to provide re-dosage of super-plasticizer. The usual approach is to use Marsh cone for the determination of the time required for a specified volume of grout of cement and super-plasticizer to flow through the orifice of the funnel. Generally, this time is known as Marsh flow-time, which decreases with the increase of dosage of super-plasticizer up to certain value beyond which there is little remarkable improvement. While considering economy, an excessive dosage of super-plasticizer is undesirable and it leads to segregation. Also, there will be little difference in workability (as measured by Marsh flow-time graph) at 5 and 60 minutes after mixing of materials. This test on neat cement paste makes it possible to narrow the choice to a few cements compatible with only one or two super-plasticizer which are commercially available in the market.

2.2.4.1 MARSH CONE TEST-

In the marsh cone test, cement slurry is made and its flow-ability is found out. In concrete, it is the cement paste that influences the flow-ability. The presence of aggregates will make the test more complex and often erratic. Although, the quantity of aggregates, its shape and texture will also have some influence but it is the cement paste that will have the greater influence. The using of grout alone will make the simple, consistent and indicative of the fluidifying effect of super-plasticizer with cement.

The **Marsh Funnel** is a simple device for measuring viscosity from the time it takes a known volume of liquid to flow from the base of a cone through a short tube. It consists of a 6inches (152 mm) across and 12 inches in height (305 mm) to the apex of which is fixed a tube of 10 mm internal diameter and of length 60 mm. A mesh is fixed near the top across half the cone.



. Marsh cone used for measurement the cement paste fluidity.

Figure 3 Marsh Cone Apparatus

In use, it is held vertically and end of the orifice is closed with a finger. The cement paste to be measured is poured through the mesh. (This removes any particles which might block the orifice.). To take the measurement after 5 or 60minutes or so, the finger is released as a stop clock is started, and the liquid is allowed to run into a measuring container. The time in seconds is recorded as a measure of the viscosity.

The flow time measured enables to evaluate the fluidity of the cement grout; the longer the flow time will be, the more the grout is viscous and the shorter the flow time, the more the grout is fluid. The flow time was measured at 5min, 60 min, 120 min, 180 min and 240 min after the contact with water. The saturation dosage is defined as the dosage of super-plasticizer beyond which the fluidity of the paste at 5 min does not increase. The difference between the flow time at 60min and 5min expresses the fluidity loss of the paste.

2.2.5 RESEARCH WORK PERFORMED SO FAR IN THIS FIELD:

[Neubauer et al. 1998] noted that super-plasticizer causes the zeta potential of the cement pastes to become increasingly negative; it suggests that this super-plasticizer begins to disperse the cement particles. When new super-plasticizers are developed, an interaction problem must be anticipated, cement and super-plasticizer will be able to cause sharp variation in fluidity and produce stiffness, depending upon the combination of cement and super-plasticizer.

[Swamy et al. 1994] works concluded that it is possible to reduce the content of super-plasticizer by incorporating slag in the cement; the replacement of the cement by 70% slag reduces 10% of the amount of super-plasticizer necessary to get the same workability.

The results conducted by [Duval and Kadri 1998] confirmed that the super-plasticizer adsorption depends both on the amount of C_3A and the presence of soluble alkali sulphates in the cement. It was proved that the incorporation of fly ash in concrete reduces the need of super-plasticizer necessary to obtain a similar slump flow compared with the concrete containing only cement as binder.

On the other hand, [Sone et al. 1998] observed a total loss of fluidity when Portland cement was replaced by blended cement, where super-plasticizer content changes from 0.5% to 1.5%. When the super-plasticizer presents a compatibility with a certain mixture composition, it will lose it as soon as the mineral admixture is substituted.

Similarly, [Bensebti and Houari 2003] found that the fluidity of the cement paste decreases with the introduction of the fillers, this reduction is proportional to their replacement level and type.

According to [Murata and Suzuki, 1997]; [Agullo et al. 1999], the flowability was determined using Marsh Cone, by measuring the time taken for a certain volume of paste to flow through a cone with a small opening. This test was modified by [Jones et al. 2003] in terms of orifice diameter (increased from 8 to 12.5mm) and volume of afflux (1L instead of 200mL) to take into account of fine aggregate particles and classified the consistency based on flow time.

The investigation of cement–super-plasticizer (C–SP) compatibility can be realized by measuring flow time of grout as proposed by several researchers.

2.2.6 COMPATIBILITY EQUATIONS

Compatibility equations help in determining the optimum dose of super-plasticizer of particular chemical family with cement C1, C2 and C3 at w/c ratio of 0.45 and 0.5 respectively. These equations thus helpful for concrete industry to use optimum dose of super-plasticizer without undergoing laboratory test to determine optimum dose for above stipulated cements.

2.2.7 CORRELATION COEFFICIENT (R)

How well does your compatibility equation truly represent your set of data?

One of the ways to determine the answer to this question is to exam the correlation coefficient and the coefficient of determination. The quantity r, called the *linear correlation* *coefficient*, measures the strength and the direction of a linear relationship between two variables.

Positive correlation: If x and y have a strong positive linear correlation, r is close to +1. An r value of exactly +1 indicates a perfect positive fit. Positive values indicate a relationship between x and y variables such that as values for x increases, values for y also increase.

Negative correlation: If x and y have a strong negative linear correlation, r is close to -1. An r value of exactly -1 indicates a perfect negative fit. Negative values indicate a relationship between x and y such that as values for x increase, values for y decrease.

A correlation greater than **0.8** is generally described as *strong*, whereas a correlation less than **0.5** is generally described as *weak*. These values can vary based upon the "type" of data being examined.

2.2.8 COEFFICIENT OF DETERMINATION (R^2)

The *coefficient of determination*, R^2, is useful because it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable. It is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph.

- The *coefficient of determination* is the ratio of the explained variation to the total variation.
- The *coefficient of determination* is such that $0 \leq r^2 \leq 1$, and denotes the strength of the linear association with x and y.
- The *coefficient of determination* represents the percent of the data that is the closest to the line of best fit. For example, if $r = 0.922$, then $r^2 = 0.850$, which means that 85% of the total variation in y can be explained by the linear relationship between x

and y (as described by the regression equation). The other 15% of the total variation in y remains unexplained.

Chapter – 3

EXPERIMENTAL MATERIAL AND APPARATUS

3.1 EXPERIMENTAL MATERIALS

3.1.1 SUPER-PLASTICIZERS USED AND ITS CHEMICAL PROPERTIES:

a) *Chemical Family* - Poly Carboxylate Ether (PCE)

SP1-	Form	:	Liquid
	Specific Gravity (at 30ºC)	:	1.08 ± 0.02
	pH	:	7 ± 01
	DMC (%w/w at 105± 02ºC)	:	24 ± 02
	Ash content (%w/w at 625± 25ºC)	:	5 ± 01
SP2-	Form	:	Liquid
	Specific Gravity (at 30ºC)	:	1.08 ± 0.02
	pH	:	7 ± 01
	DMC (%w/w at 105± 02ºC)	:	21 ± 02
	Ash content (%w/w at 625± 25ºC)	:	5 ± 01
SP3-	Form	:	Liquid
	Specific Gravity (at 30ºC)	:	1.13 ± 0.03
	pH	:	7 ± 01
	DMC (%w/w at 105± 02ºC)	:	40 ± 02
	Ash content (%w/w at 625± 25ºC)	:	5 ± 01

b) *Chemical Family*- Modified Sulphonated Naphthalene Formaldehyde (SNF)

SP4-	Form	: Dark brown liquid
	Density	: 1.22Kg/ litre

SP8-	Form	: Dark brown liquid
	Density	: 1.18Kg/ litre

c) *Chemical Family*- Sulphonated Naphthalene Polymer (SNP)

SP5-	Specific Gravity (at 30°C)	:1.200 to 1.220
	Chloride content	: Nil to IS 456
	Air entrainment	: approx. 1% of additional air entrained

SP6-	Specific Gravity (at 30°C)	: 1.220 to 1.225
	Chloride content	: Nil to IS 456
	Air entrainment	: approx. 1% of additional air entrained

SP7-	Specific Gravity (at 30°C)	: 1.240 to 1.260
	Chloride content	: Nil to IS 456
	Air entrainment	: approx. 1% of additional air entrained

3.1.2 CEMENTS USED ARE:

I. PPC based cement (C1)
II. PPC based cement (C2)
III. PPC based cement (C3)

3.2 APPARATUS USED AND FABRICATED FOR THE COMPATIBILITY TEST-

Various apparatus were required to perform the test. Many apparatus were arranged and some were fabricated. The equipments used are as follows:

a) MARSH CONE APPARATUS-

Its Fabrication- The suggested configuration of Marsh cone apparatus was not available in the local nearby market; as such I had been advised by my guide to get the Marsh cone apparatus fabricated. Keeping in view of its shaping and fabrication difficulties 20 Gauge sheet is selected for making the instrument. The required dimensions are calculated as under:

Calculation for major radius R1 which is also radius of the segment to be used for Marsh cone test apparatus-

i. Using symmetry of triangle in fig 1

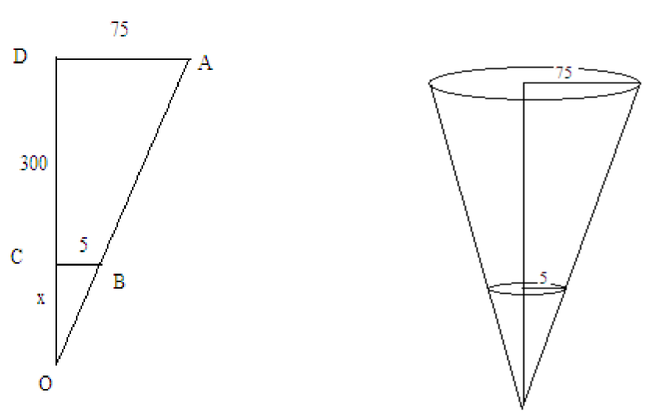


Fig 4 Cone parameters

$$\frac{x}{5} = \frac{x+30}{75}$$

$$75x = 5x + 300 \times 5$$

$$x = 300 \times \frac{5}{70}$$

$$x = 21.43$$

ii. Radius OA=R1

$$R1 = \sqrt{321.43^2 + 75^2}$$

$$R1 = 330.06$$

iii. Radius OB=R2

$$R2 = \sqrt{21.43^2 + 5^2}$$

$$R2 = 22.01$$

iv. Using fig 3 for calculating the length of arc:

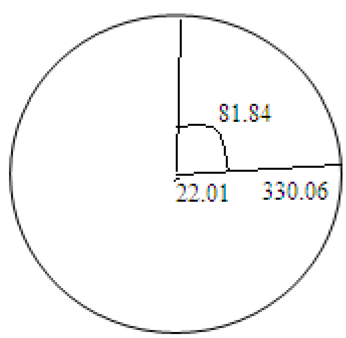


Fig 5 Size of metal sheet

Circumference of cone's upper circle, $=\pi$d

$=\pi \times 150$

Length of arc= circumference of the upper cone'

$$\frac{\theta \times \pi \times 2R1}{360} = 150 \times \pi$$

$$\frac{\theta \times \pi \times 660.18}{360} = 150 \times \pi$$

$$\theta = \frac{150 \times 360}{660.18}$$

$$\theta = 81.8°$$

v. Calculation for the funnel orifice of 10mm diameter and 60mm height:

Circumference of circle, $= \pi \times d$

$= \pi \times 10$

= 31.4

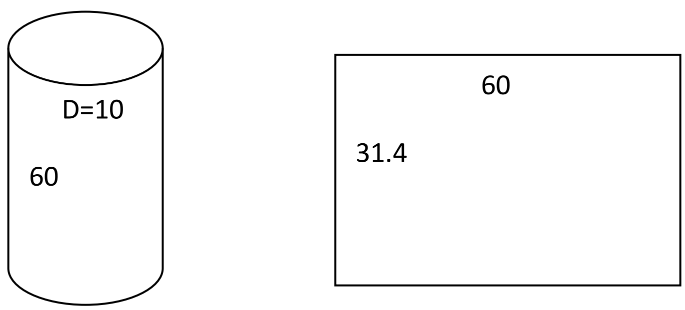


Fig 6 Dimensions of Marsh cone orifice

b) STAND TO HOLD THE MARSH CONE APPARATUS-

The tripod stand is essential to hold the apparatus so as to maintain the height from the orifice. The variation in height can affect the marsh cone flow time, thus it was required to make such a stand to hold strongly the apparatus along with the slurry. The tripod stand was not available; henceforth it was fabricated at home. The stand was made up by waste plywood. The hole was cut by the hacksaw blade and the sheet was kept firmly over the desert cooler stand.

Fig 7. Stand to hold the Marsh Cone

c) WEIGHING MACHINE-

The weighing machine of the accuracy 1/1000th place is used to measure the accurate quantity of cement (2kg).

d) MEASURING FLASK TO MEASURE WATER-

The mug having marking over its wall in mL is used to measure the water corresponding to different w/c ratios.

e) SYRINGE-

The medical syringe of 5mL, 10mL and 20mL has been used to measure the exact and very small quantity of super-plasticizer accurately.

f) SIEVE-

The BIS approved 1.18mm sieve has been brought on loan from Aryabhat Polytechnic. It is used to filter the cement-super-plasticizer slurry to remove if there is any lump formation which can choke the orifice of the Marsh cone.

Fig 8 1.18 mm sieve

g) STOP-WATCH-

The stop-watch of having accuracy to 1/100th place has been used for recording the Marsh flow time.

h) MEDICAL GLOVES-

The medical gloves are used to protect hands from chemical admixture-cement reaction and maintaining accuracy by least loss of mix (which can adhere in hand).

Chapter – 4

EXPERIMENTAL PROGRAM

4.1 INTRODUCTION

The experiment was aimed for the following investigations:

1. Determination of saturation dosage corresponding to a break in the curve when further addition of super-plasticizer beyond the saturation point does not improve much fluidity of Cement–Super-plasticizer.

2. Determination of saturation dosage for change of water- cement ratio for the same combination of cement- super-plasticizer.

3. Analysis of behavior of same cement- super-plasticizer couple for different water- cement ratio.

4.2 TEST PROCEDURE

The test procedure is as follows:

I. Add 2 kg of cement, to be used in the study.
II. Add one litre of water (w/c ratio= 0.5) and say 0.5% of super-plasticizer.
III. Mix them thoroughly in a mechanical mixer for 2 minutes. If hand mixing is done, the cement slurry should be sieved through 1.18 sieve to avoid formed lumps to choke the funnel orifice.
IV. Add one litre of cement slurry and pour it into the funnel by closing the orifice with the help of finger.
V. Close it for that time, for which the reading has to be taken i.e. 5min, 60min….so on.

VI. Start a stop watch and simultaneously remove the finger. Find out the time taken in seconds, for the complete flow out of the slurry. The time is known as “Marsh Cone Time”.

VII. Repeat the test with different dosages of super-plasticizer.

VIII. Plot the graph between Marsh cone time and dosages of super-plasticizer.

The dose at which the Marsh cone time is lowest is called the saturation point. The dose will be the optimum dose for that combination of cement and super-plasticizer. The test is carried out for various combination of cement-super-plasticizer at different w/c ratio.

4.3 COMBINATION OF TESTING

Table 1 Different combination of testing

w/c ratio= 0.5			**w/c ratio= 0.45**		
C1- SP1	C2- SP1	C3- SP1	C1- SP1	C2- SP1	C3- SP1
C1- SP2	C2- SP2	C3- SP2	C1- SP2	C2- SP2	C3- SP2
C1- SP3	C2- SP3	C3- SP3	C1- SP3	C2- SP3	C3- SP3
C1- SP4	C2- SP4	C3- SP4	C1- SP4	C2- SP4	C3- SP4
C1- SP5	C2- SP5	C3- SP5	C1- SP5	C2- SP5	C3- SP5
C1- SP6	C2- SP6	C3- SP6	C1- SP6	C2- SP6	C3- SP6
C1- SP7	C2- SP7	C3- SP7	C1- SP7	C2- SP7	C3- SP7
C1- SP8	C2- SP8	C3- SP8	C1- SP8	C2- SP8	C3- SP8

4.4 FLOW CHART FOR EXPERIMENTAL PROGRAM

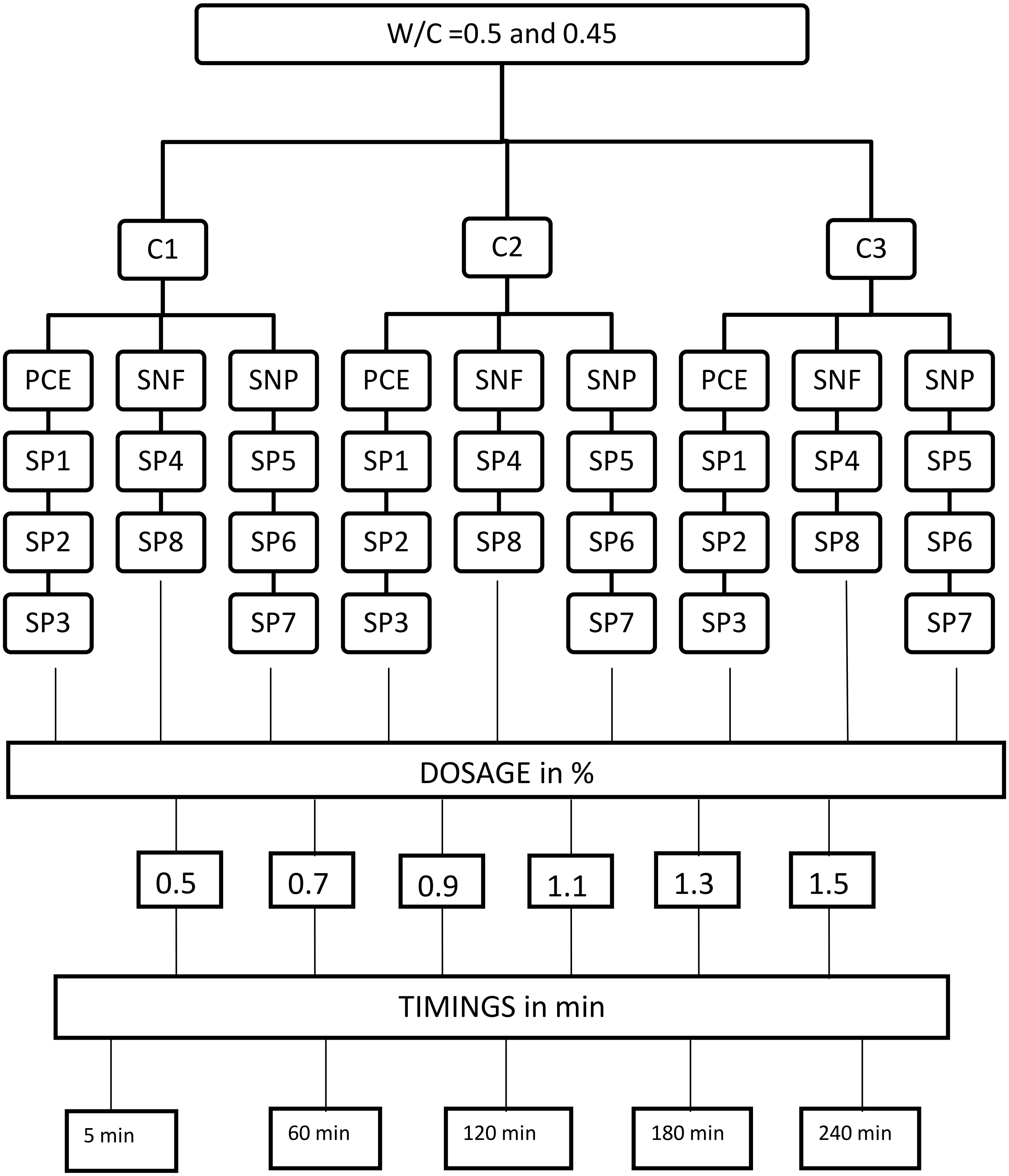


Fig 9 Flow Chart for Experimental program

4.5 PICTORIAL PRESENTATION OF EXPERIMENTAL STEPS

Fig 10 Measuring Super-plasticizer

Fig 11 Quantitative measuring of Super-plasticizer with Syringe

Fig 12 Mixing of Cement, SP and Water

Fig 13 Filtering slurry with sieve

Fig 14 Measurement of 1L of slurry

Fig 15 Pouring slurry into Marsh Cone Apparatus

Fig 16 Slurry held up in Apparatus

Fig 17 Apparatus ready for Marsh flow time recording

Fig 18 Flow of slurry after opening orifice

Fig 19 Recording Marsh Flow Time in Stop-watch

Fig 20 Keeping slurry for next set of reading

Chapter -5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter deals with the experimentation results, graphs for determining the optimum doses of different super-plasticizer for different cement. Graphs are concluded with discussions for each combination of cement super-plasticizer couple.

5.2 OBSERVATIONS FOR C1, W/C = 0.5:

I) C1- SP1

Table 2 Marsh flow time readings for C1-SP1 (W/C = 0.5)

%age of plasticizer	SP1				
	5 min	60 min	120 min	180 min	240 min
0.5%	37.21	139.78	149.38	157.52	171.02
0.7%	25.5	34.34	88.57	104.32	119.56
0.9%	23.34	29.89	62.44	79.62	99.35
1.1%	22.72	29.16	56.83	64.77	82.17
1.3%	22.09	27.69	54.79	65.16	79.46
1.5%	21.54	25.82	53.61	63.27	77.68

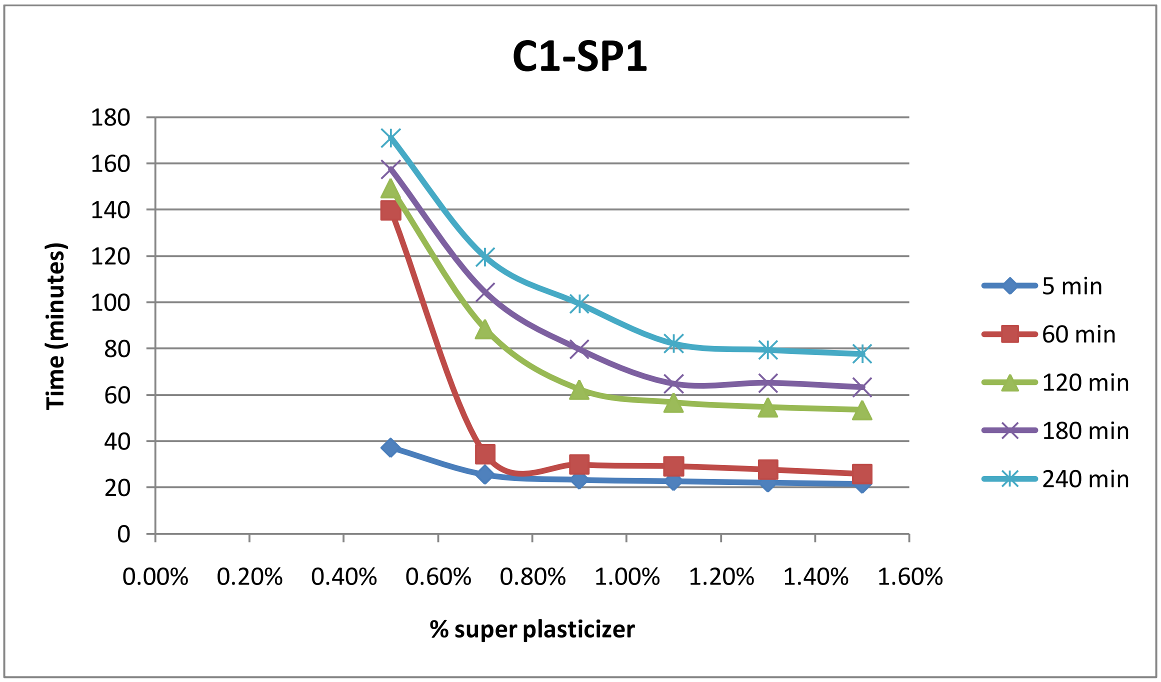


Fig 21 Graph between dosage of SP and Marsh flow time for C1-SP1(w/c =0.5)

DISCUSSION

1. The above graph represents the case of a perfectly compatible cement- superplasticizer combination; the dosage corresponding to the saturation point is low i.e. 0.7% and 60 min curve is close to 5 min curve.
2. It can also be deduced that as flowability of slurry after 5 min and 60 min corresponding to every dosage after saturation point is almost same. Thus if a workable mix for 60 min will be required then 0.7% optimum dosage should be used to make it efficient.
3. As apparent from the curve, 60min and 120min are quiet apart from each other. Thus there will be significant loss of flowability.

II) C1- SP2

Table 3 Marsh flow time readings for C1-SP2 (W/C = 0.5)

%age of plasticizer	SP2				
	5 min	60 min	120 min	180 min	240 min
0.5%	41.2	87.27	89.24	95.56	100.41
0.7%	36.86	51.39	57.44	64.72	74.63
0.9%	29.32	38.24	41.32	58.48	61.24
1.1%	25.96	33.31	36.61	48.39	53.78
1.3%	25.28	31.58	34.82	47.66	54.46
1.5%	24.59	29.28	35.04	45.89	52.88

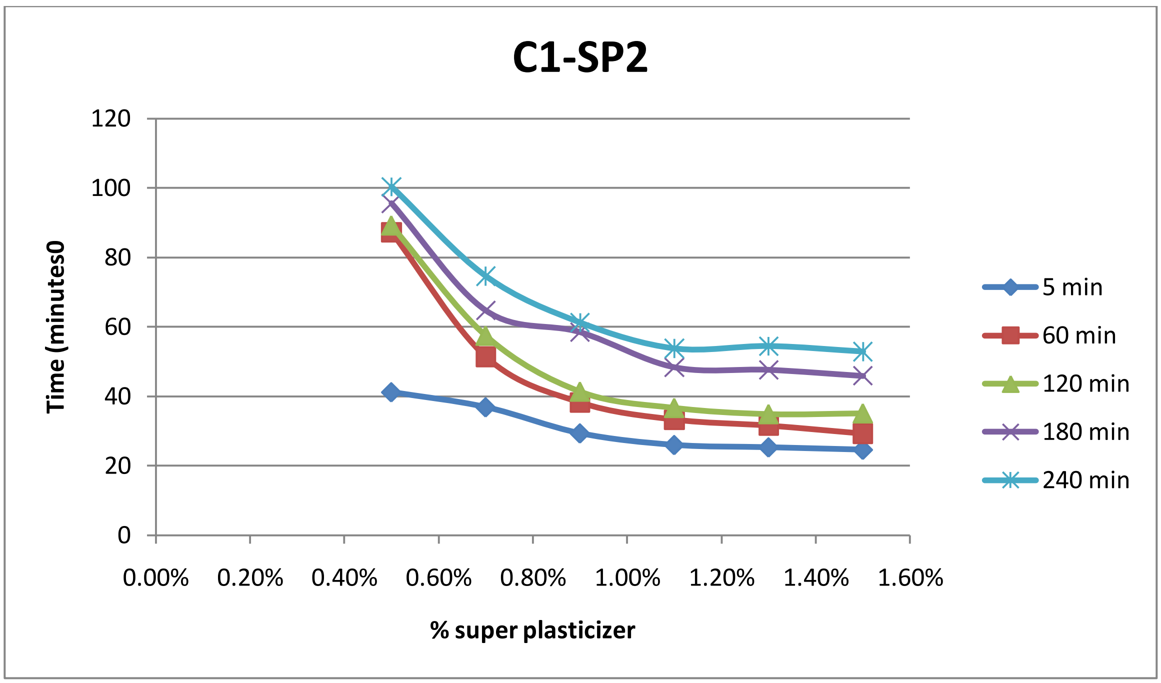


Fig 22 Graph between dosage of SP and Marsh flow time for C1-SP2(w/c =0.5)

DISCUSSION

1. This graph shows the case of compatibility i.e. 5min curve shows the breakage in curve, saturation point clearly at 1.1% and 60 min curve is quite close to 5 min curve.
2. If it is required to manage 60 min of workability in mix, then saturation dosage of 1.1% is quite good enough.
3. The 60min and 120min are very close to each other which show that there will not be any considerable loss of workable mix. Beyond that, there is loss of workable mix till 240min (4hr).

III) C1- SP3

Table 4 Marsh flow time readings for C1-SP3 (W/C = 0.5)

%age of plasticizer	SP3				
	5 min	60 min	120 min	180 min	240 min
0.5%	41.32	94.35	99.26	105.49	119.29
0.7%	35.87	72.87	81.45	87.37	93.18
0.9%	31.75	51.94	72.16	78.23	84.48
1.1%	29.22	35.53	49.55	61.33	69.42
1.3%	27.75	34.81	47.69	59.12	63.81
1.5%	27.47	33.25	48.66	57.97	62.78

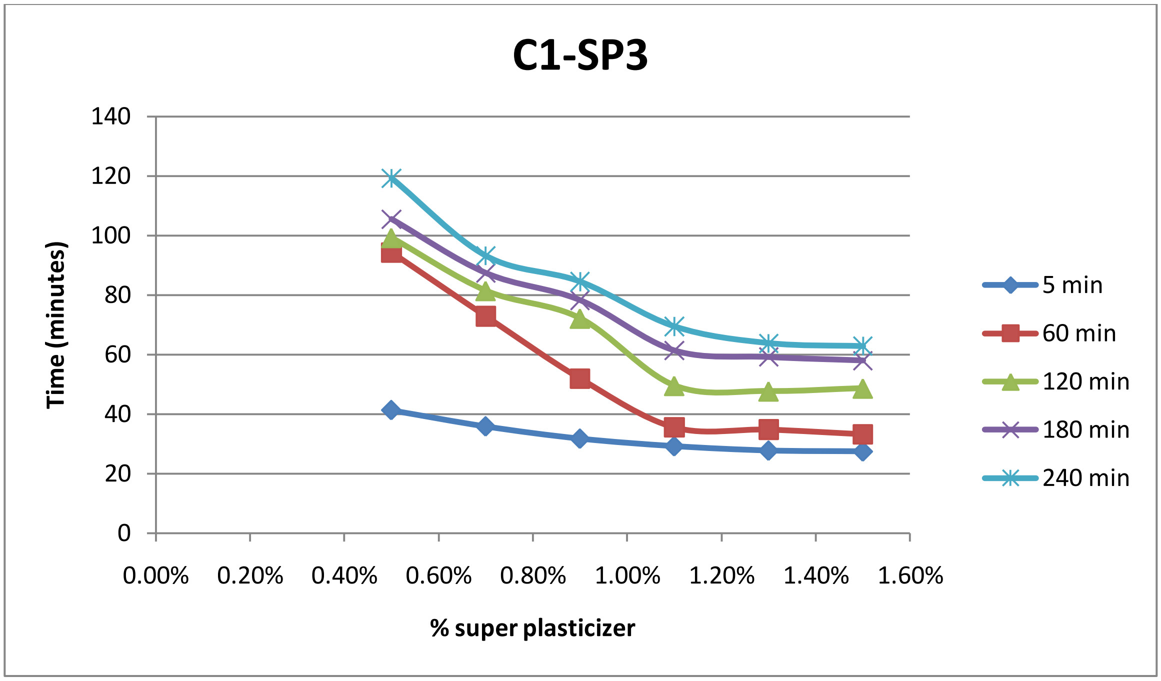


Fig 23 Graph between dosage of SP and Marsh flow time for C1-SP3(w/c =0.5)

DISCUSSION

1. The curve shows that the C1- SP3 combination is compatible. Though the saturation dosage requirement is comparatively low i.e. 1.1%.
2. The 60 min curve is close to 5 min curve after saturation point, imparting that fluidity is not going to decrease much extent.
3. Beyond 60min, there is regular loss of flowable mix till 180min. After that, amid 180min and 240min, there is comparatively lesser loss of flowability.

IV) C1- SP4

Table 5 Marsh flow time readings for C1-SP4 (W/C = 0.5)

%age of plasticizer	SP4				
	5 min	60 min	120 min	180 min	240 min
0.5%	37.72	139.31	141.43	160.58	167.83
0.7%	30.03	42.89	63.28	74.35	81.89
0.9%	27.69	33.78	57.47	65.55	69.56
1.1%	26.44	29.25	49.67	51.86	56.65
1.3%	22.43	26.9	47.77	48.74	51.44
1.5%	17.16	22.58	45.86	49.11	50.23

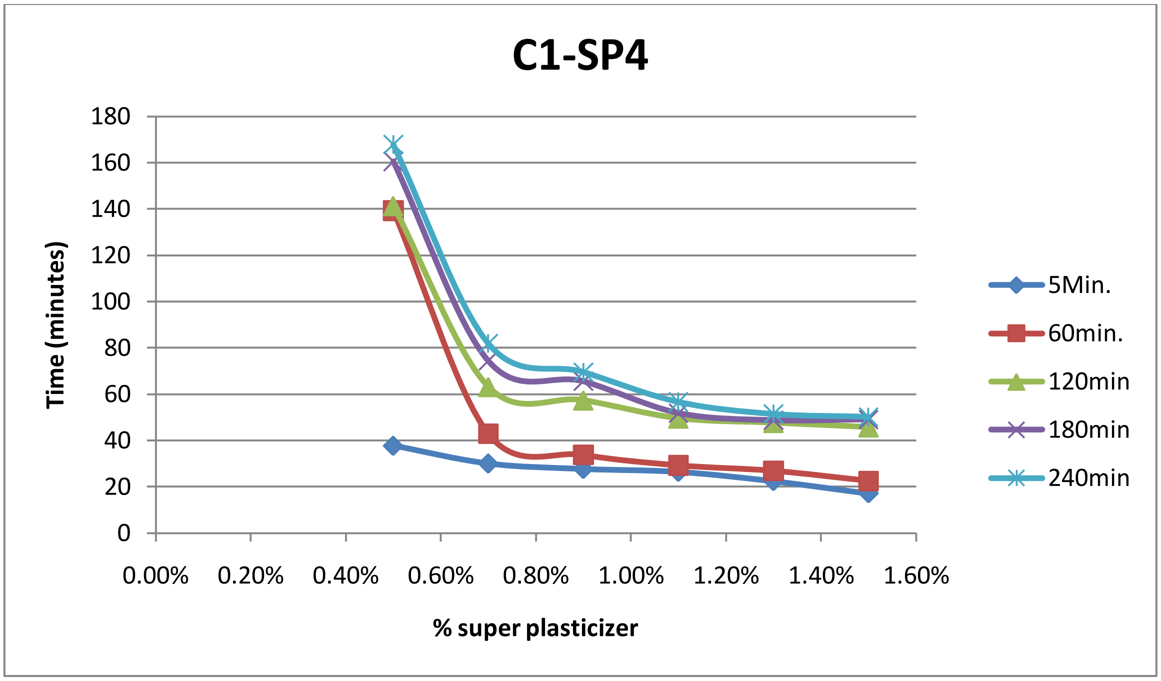


Fig 24 Graph between dosage of SP and Marsh flow time for C1-SP4 (w/c =0.5)

DISCUSSION

1. The above graph represents the case of a perfectly compatible cement- super-plasticizer combination; the dosage corresponding to the saturation point is very low i.e. 0.7%, which is making it economical.
2. The graph also showing 60 min curve is too close to 5 min curve. It can also be interpreted that flowability of slurry after 5 min and 60 min corresponding to every dosage, beyond saturation dosage is almost same. Thus if a workable mix for 60 min is required then of course lower dosage i.e. 0.9% should be used, to make it cost effective.
3. As evident from the curves, 120min, 180min and 240min are too close to each other beyond saturation point. Henceforth, there will not be any considerable loss of flowability.

V) C1- SP5

Table 6 Marsh flow time readings for C1-SP5 (W/C = 0.5)

%age of plasticizer	SP5				
	5 min	60 min	120 min	180 min	240 min
0.5%	86.64	166.79	174.35	189.62	195.07
0.7%	35.94	136.56	147.64	163.56	174.36
0.9%	34.78	89.25	101.51	107.28	118.54
1.1%	31.37	72.68	79.19	88.83	99.49
1.3%	23.47	58.75	72.79	83.66	88.74
1.5%	23.17	55.13	70.66	81.21	87.18

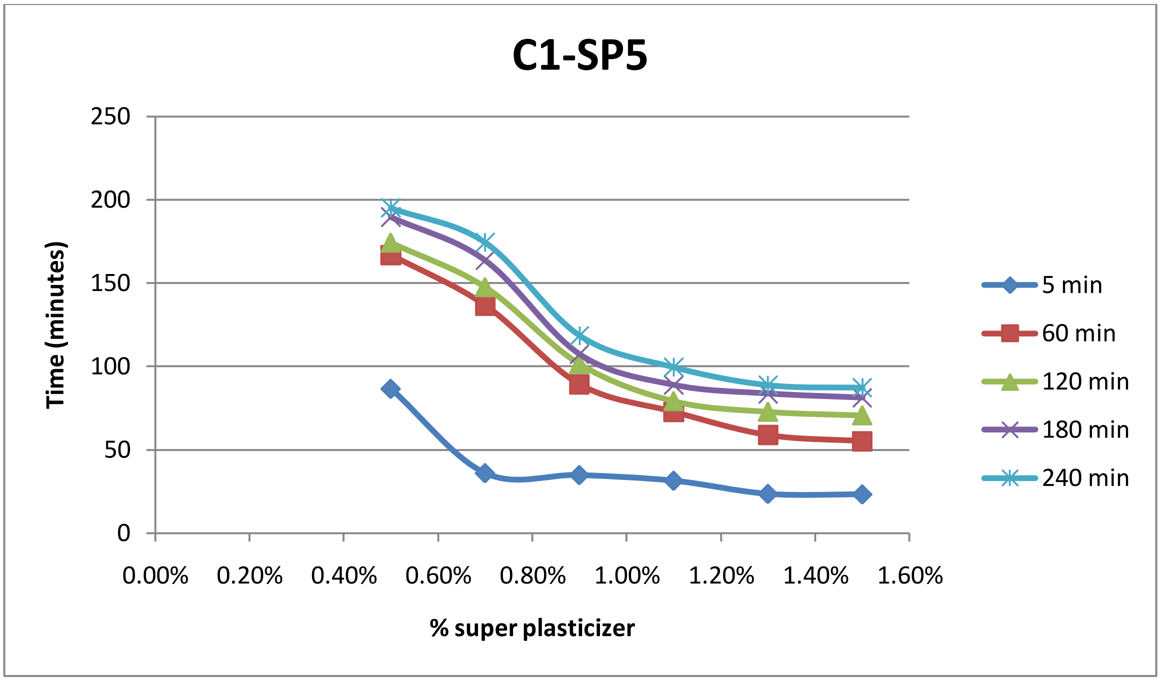


Fig 25 Graph between dosage of SP and Marsh flow time for C1-SP5 (w/c =0.5)

DISCUSSION

1. This combination of cement- super-plasticizer is a compatible combination. The optimum dosage is comparatively high.
2. Moreover, there is huge gap amid 5 min and 60 min curves which shows that flowability will reduce to much extent at any dosage of super-plasticizer.

VI) C1- SP6

Table 7 Marsh flow time readings for C1-SP6 (W/C = 0.5)

%age of plasticizer	SP6				
	5 min	60 min	120 min	180 min	240 min
0.5%	40.5	138.88	147.9	165.56	171.35
0.7%	33.69	69.07	76.78	88.32	93.34
0.9%	29.1	49.89	56.88	72.45	78.76
1.1%	27.63	45.25	51.23	55.89	63.89
1.3%	27.97	43.67	49.78	53.23	57.56
1.5%	26.07	42.54	48.12	51.14	55.34

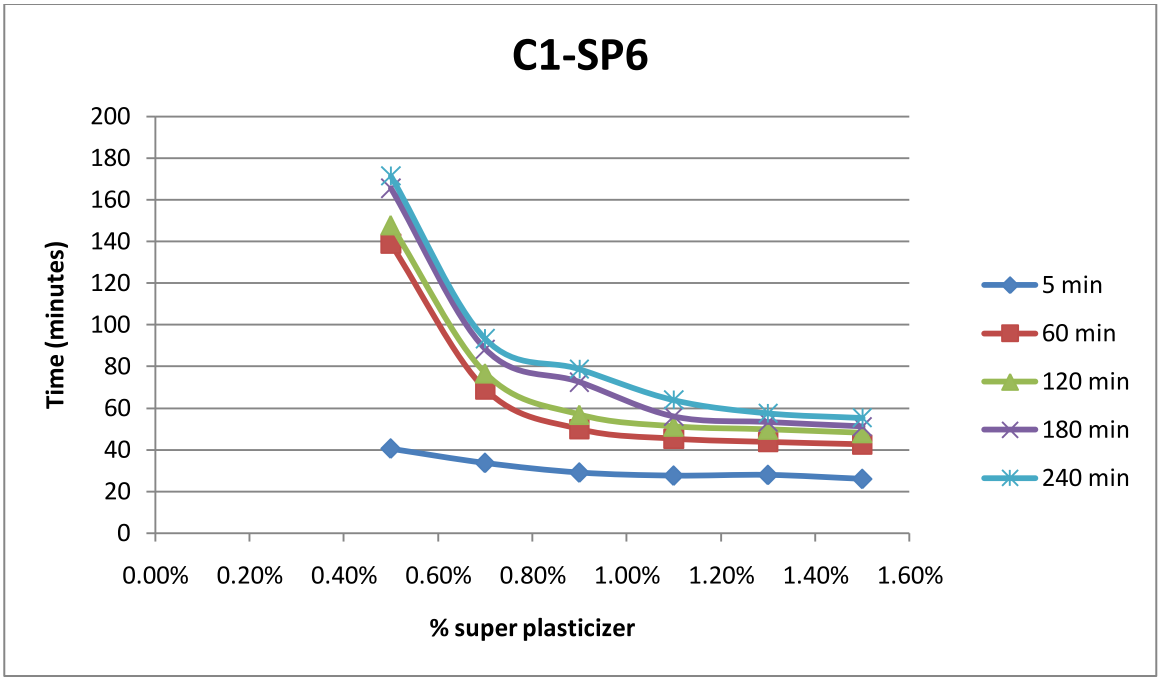


Fig 26 Graph between dosage of SP and Marsh flow time for C1-SP6 (w/c =0.5)

DISCUSSION

1. The above graph shows the case of a perfectly compatible cement- super-plasticizer combination; the dosage corresponding to the saturation point is 0.9% and 60 min curve is quite close to 5 min curve.
2. It can also be interpreted that to achieve flowable mix up to 60 min, a dosage of 0.9% should be applied.
3. As apparent from the curve, 120min, 180min and 240min are quiet close to each other after the addition of saturation dosage. Therefore, there will be minimal loss of flowability.

VII) C1- SP7

Table 8 Marsh flow time readings for C1-SP7 (W/C = 0.5)

%age of plasticizer	SP7				
	5 min	60 min	120 min	180 min	240 min
0.5%	35.16	96.6	119.14	132.46	148.57
0.7%	33.18	52.64	71.26	84.65	96.36
0.9%	24.56	34.81	56.22	63.46	76.59
1.1%	19.66	28.56	47.51	54.33	62.92
1.3%	16.47	24.31	45.83	51.28	53.48
1.5%	16.89	22.97	44.39	49.88	52.13

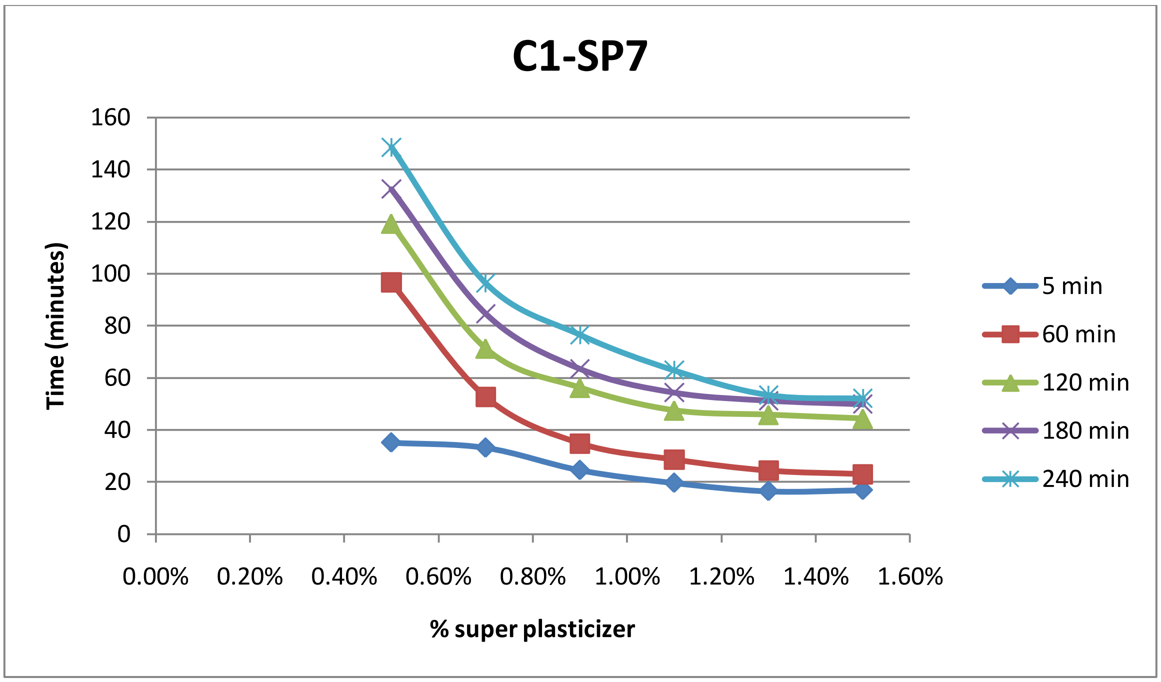


Fig 27 Graph between dosage of SP and Marsh flow time for C1-SP7 (w/c =0.5)

DISCUSSION

1. The curves show the case of a perfectly compatible cement- super-plasticizer combination; though the dosage to the saturation point is quite high 1.3%.
2. To have workable mix even after 60 min, dosage of 1.3% is to be added. Although, the dose corresponding to have workable mix after 5min and 60 min is same, then also there will noticeable decrease in flowability of mix.
3. After 60min, there will be some loss of flowability till 120min. Beyond that, there is not any noteworthy loss in workability.

VIII) C1- SP8

Table 9 Marsh flow time readings for C1-SP8 (W/C = 0.5)

%age of plasticizer	SP8				
	5 min	60 min	120 min	180 min	240 min
0.5%	25.72	151.72	159.68	165.35	173.24
0.7%	22.41	57.91	69.47	73.29	89.81
0.9%	19.06	24.34	48.82	51.78	63.52
1.1%	17.75	23.22	41.64	49.67	56.49
1.3%	17.28	22.82	39.72	44.55	49.27
1.5%	16.69	19.25	37.94	42.76	47.87

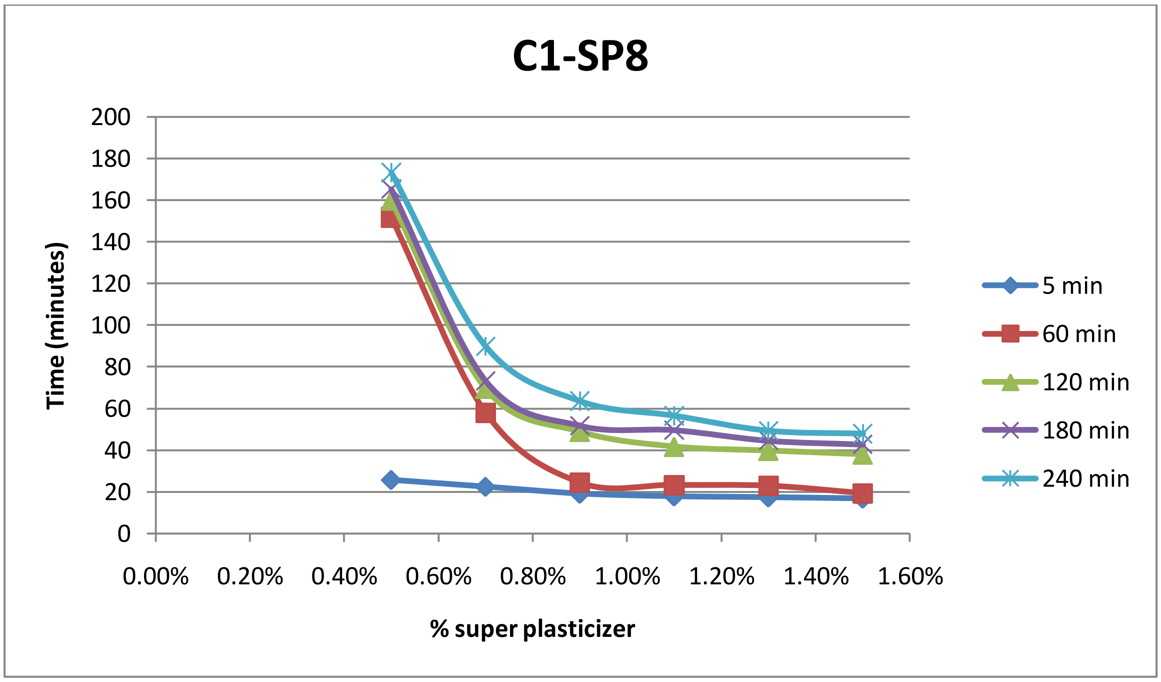


Fig 28 Graph between dosage of SP and Marsh flow time for C1-SP8 (w/c =0.5)

DISCUSSION

1. The above graph represents the case of a perfectly compatible cement- super-plasticizer combination; the saturation dosage is significantly low i.e. 0.9%.
2. It also shows that, 60 min curve is close to 5 min curve. Thus to have flowable mix for 60 min, the super-plasticizer dosage of 0.9% should be used to make it economical.
3. As apparent from the curve, 120min, 180min and 240min are quiet close to each other. Thus there will be minimal loss of flowability.

5.3 OBSERVATIONS FOR C2, W/C = 0.5:

I. C2- SP1

Table 10 Marsh flow time readings for C2-SP1 (W/C = 0.5)

%age of Plasticizer	SP1				
	5 min	60 min	120 min	180 min	240 min
0.5%	75.5	96.34	102.59	111.94	117.19
0.7%	56.13	76.38	86.37	91.32	96.73
0.9%	36.47	49.61	59.78	69.02	72.53
1.1%	33.69	44.97	51.66	57.91	59.94
1.3%	32.17	42.61	45.32	48.96	51.54
1.5%	31.56	41.82	42.67	46.9	50.11

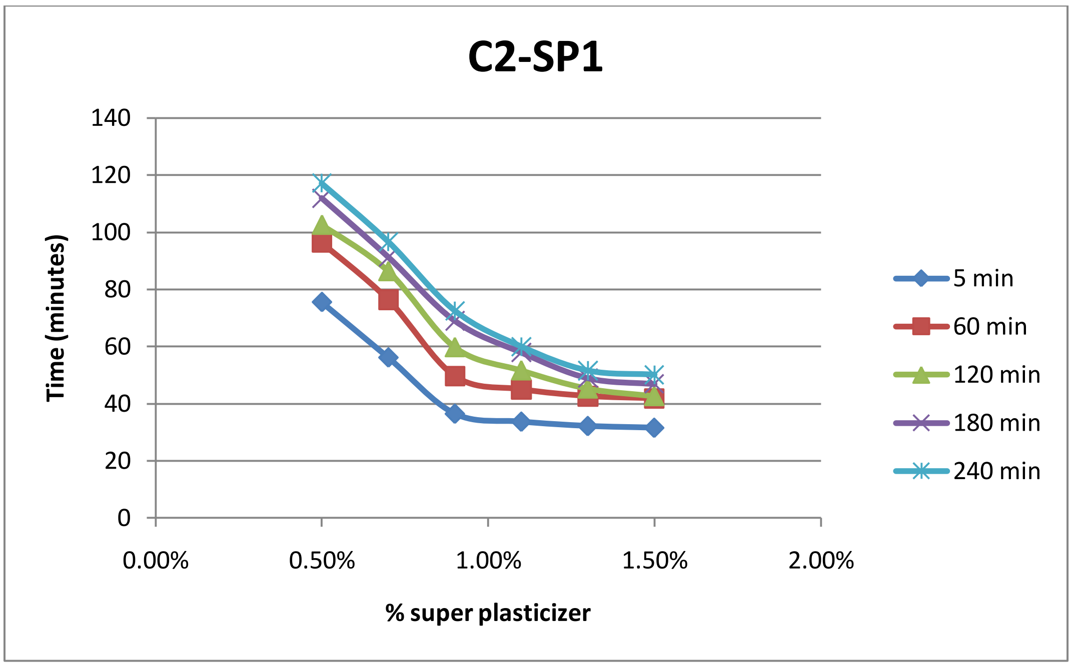


Fig 29 Graph between dosage of SP and Marsh flow time for C2-SP1 (w/c =0.5)

DISCUSSION

1. The graph represents the case of a perfectly compatible cement- super-plasticizer couple; the saturation dosage is significantly low i.e. 0.9% and 60 min curve is almost close to 5 min curve.
2. The curve corresponding to 1.3% and 1.5% shows that flowability of the mix is not increasing too much extent even after 4hr of mixing. Thus, if workability of the mix is required till 240 min (4 hr) then both the dosage will do the work, but it's obvious to use 1.3% to avail cost effectiveness.
3. The behavior of flowability of mix after 180 min and 240 min for every dosage is almost same, and there is not much difference between them.

II. C2- SP2

Table 11 Marsh flow time readings for C2-SP2 (W/C = 0.5)

%age of Plasticizer	SP2				
	5 min	60 min	120 min	180 min	240 min
0.5%	51.53	66.32	78.48	89.21	104.83
0.7%	37.22	43.31	46.56	50.98	57.19
0.9%	30.49	37.94	41.38	46.68	49.35
1.1%	29.94	34.72	36.39	41.97	44.51
1.3%	27.75	30.47	33.21	37.23	41.98
1.5%	21.93	26.18	28.86	32.61	37.65

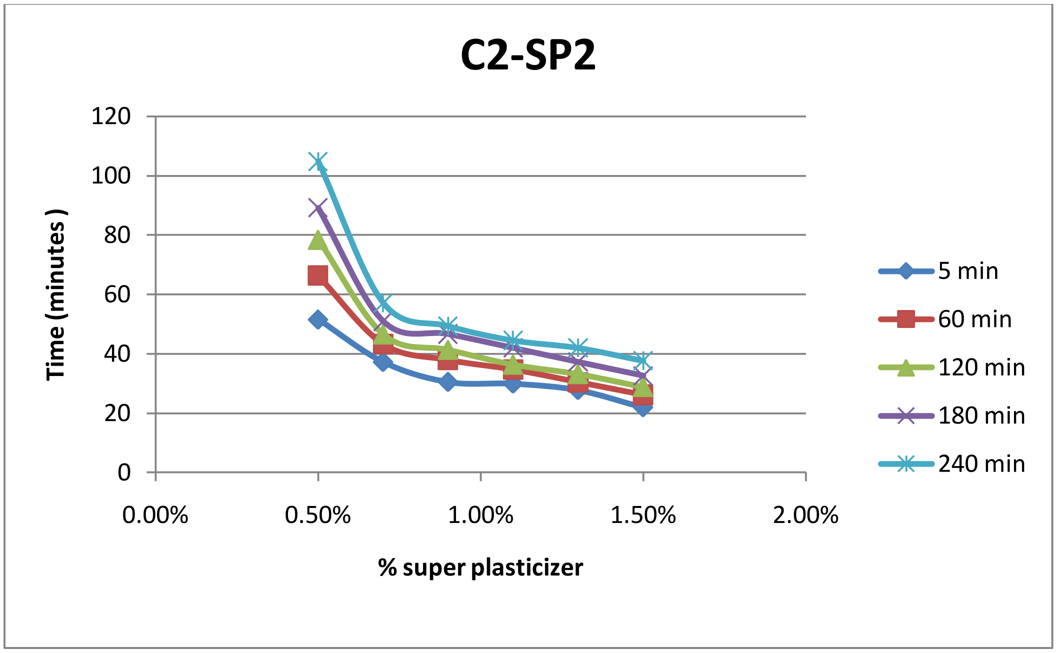


Fig 30 Graph between dosage of SP and Marsh flow time for C2-SP2 (w/c =0.5)

DISCUSSION

1. The above graph represents that the C-SP combination is compatible.
2. The behavior among all the curves for various timings is almost same. Henceforth, the time is not going to affect the compatibility.
3. The dosage of 0.9% in mix can be flowable for any time till 240 min. Though further increased dosages also impart flowability till 240min, but 0.9% is economical.

III. C2- SP3

Table 12 Marsh flow time readings for C2-SP3 (W/C = 0.5)

%age of Plasticizer	SP3				
	5 min	60 min	120 min	180 min	240 min
0.5%	27.06	68.38	77.28	92.31	101.48
0.7%	23.89	52.46	58.41	67.79	71.39
0.9%	23.09	42.82	49.74	54.32	57.21
1.1%	22.24	41.56	45.81	49.84	51.63
1.3%	22.41	40.89	43.19	47.12	49.5
1.5%	22.13	40.13	41.96	43.38	46.33

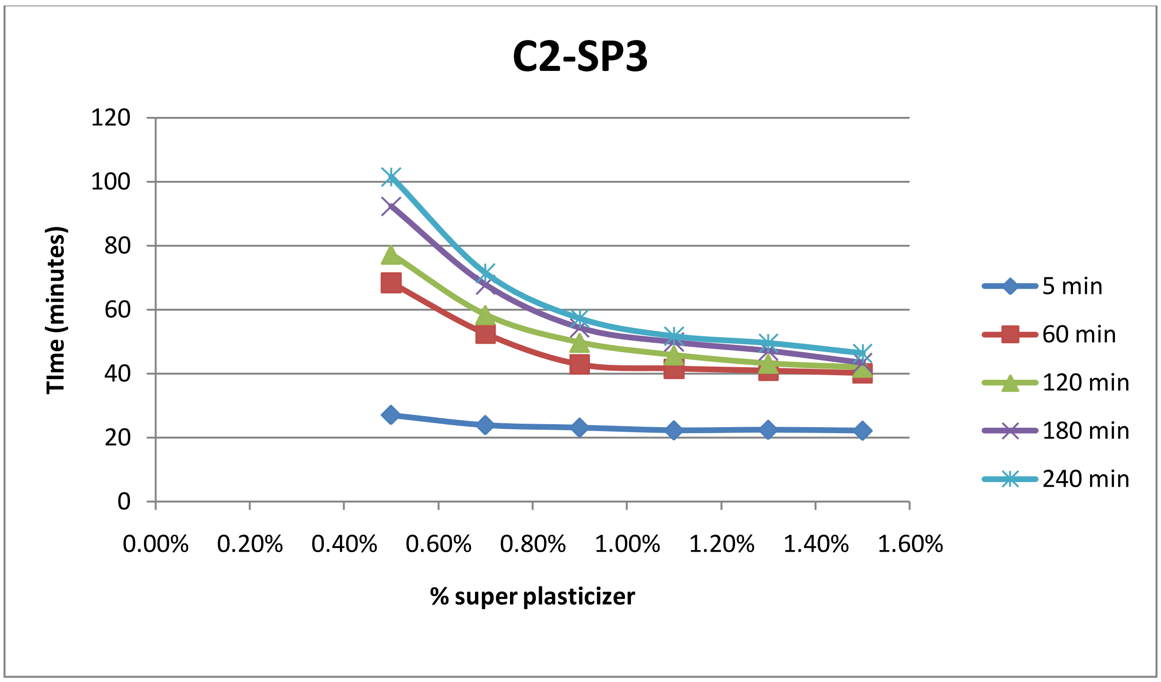


Fig 31 Graph between dosage of SP and Marsh flow time for C2-SP3 (w/c =0.5)

DISCUSSION

1. The above graph represents the case of a compatible cement- superplasticizer combination; the saturation dosage is quite low i.e. 0.9% but 60 min curve is not close to 5 min curve.
2. The dosage of 0.9% in mix can be flowable for any time till 240 min. Though further increased dosages can also give flowability till 240min, but 0.9% is economical.
3. Above all, due to huge difference between 5min and 60 min curves, there will be loss of flowability whether one uses any of the dosage.

IV. C2- SP4

Table 13 Marsh flow time readings for C2-SP1 (W/C = 0.5)

%age of Plasticizer	SP4				
	5 min	60 min	120 min	180 min	240 min
0.5%	41.45	68.03	74.72	79.37	86.47
0.7%	36.31	58.19	61.95	66.55	69.94
0.9%	31.63	51.23	53.37	56.11	59.6
1.1%	25.25	45.13	49.22	50.98	51.56
1.3%	23.92	43.93	45.39	46.21	48.31
1.5%	22.69	42.81	43.65	43.91	46.44

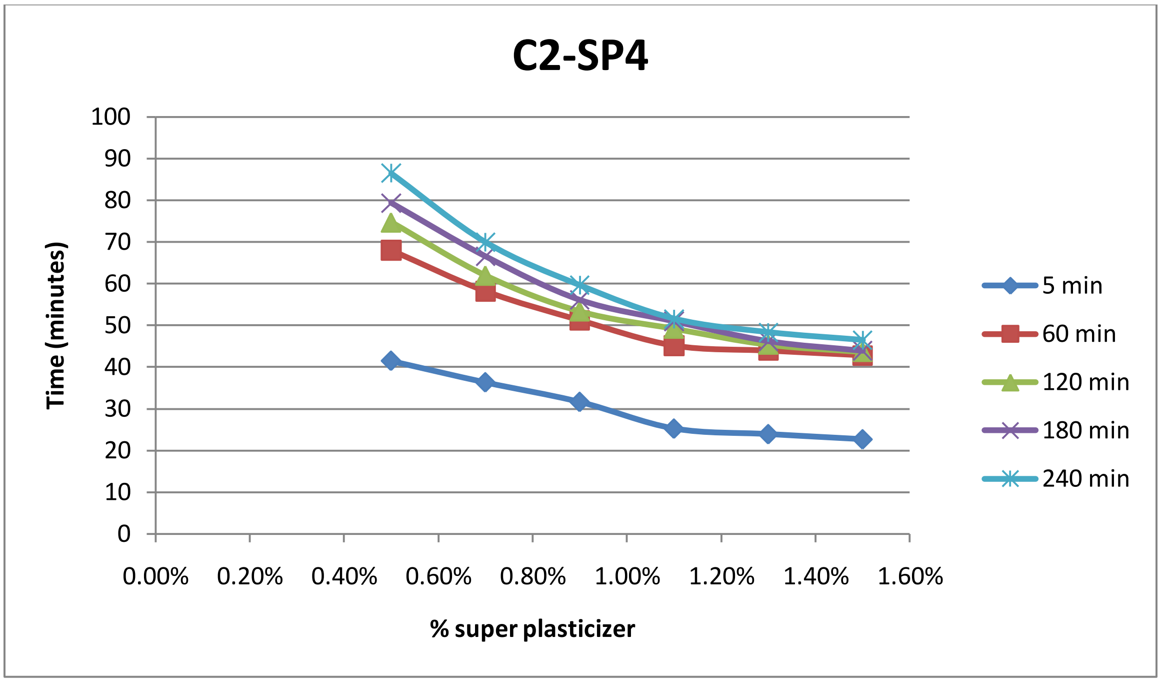


Fig 32 Graph between dosage of SP and Marsh flow time for C2-SP4 (w/c =0.5)

DISCUSSION

1. The graph shows the compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 1.1%.
2. As from the curve, 60 min curve is not close to 5 min curve. Therefore there will be huge loss of flowability for this combination.
3. Though the gap among 5 min and 60 min is much but after 60 min to 240 min, the curves are quite close with each other. Therefore, the optimum dosage of 1.1% in mix will show flowability for 5 min after which there will be loss in flowability. But after 60 min till 240 min there will not be much loss in flowability and will be cost effective.

V. C2- SP5

Table 14 Marsh flow time readings for C2-SP5 (W/C = 0.5)

%age of Plasticizer	SP5				
	5 min	60 min	120 min	180 min	240 min
0.5%	46.72	151.75	165.34	171.81	183.93
0.7%	38.21	62.9	68.09	79.16	85.69
0.9%	35.34	57.21	64.21	72.91	77.07
1.1%	32.25	56.53	63.44	68.47	70.18
1.3%	31.46	56.13	59.51	62.59	64.96
1.5%	30.66	55.25	56.75	59.73	62.64

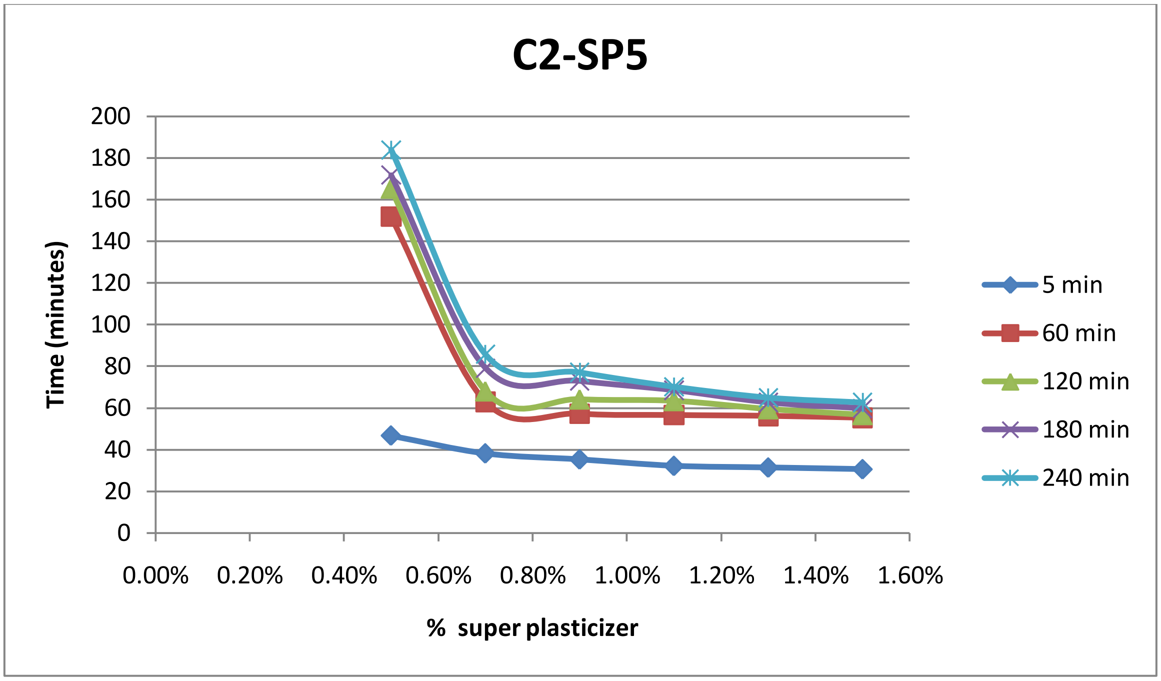


Fig 33 Graph between dosage of SP and Marsh flow time for C2-SP5 (w/c =0.5)

DISCUSSION

1. The above graph represents the compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 0.9%.
2. As from the curve, 60 min curve is comparatively close to 5 min curve. There will be somewhat loss of flowability between this time.
3. The curves for 60min, 120 min, 180min and 240min are quite close. Consequently, the 0.9% optimum dose can give workable mix for 240min, though there will be decrease in workability after 5min. Also, the curves are getting close as the dosage is increasing.

VI. C2- SP6

Table 15 Marsh flow time readings for C2-SP6 (W/C = 0.5)

%age of Plasticizer	SP6				
	5 min	60 min	120 min	180 min	240 min
0.5%	34.57	63.22	79.31	109.87	115.38
0.7%	30.13	52.88	71.43	97.47	104.89
0.9%	27.12	47.31	59.97	82.51	91.53
1.1%	25.13	41.34	46.68	68.24	76.57
1.3%	24.61	39.21	41.51	64.81	69.31
1.5%	23.98	38.46	40.87	62.31	65.97

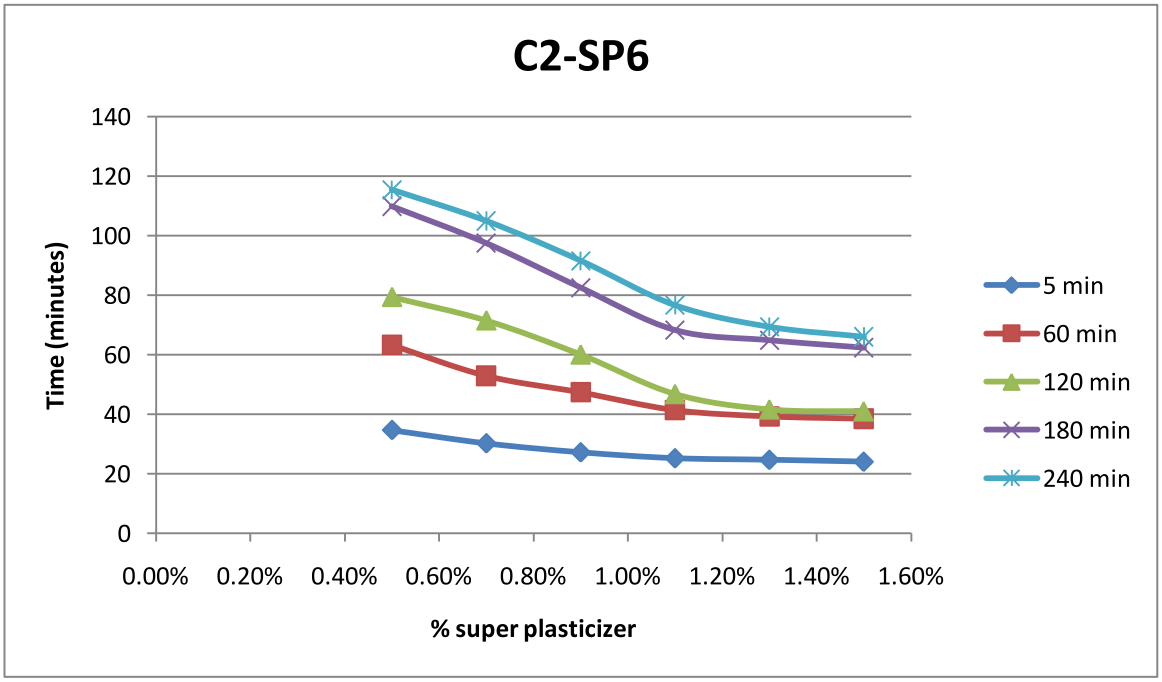


Fig 34 Graph between dosage of SP and Marsh flow time for C2-SP6 (w/c =0.5)

DISCUSSION

1. The graph shows the compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 1.1%.
2. As from the curve, 60min curve is not close to 5min curve. Therefore there will be huge loss of flowability after 5min.
3. The 120min and 60min curve are quite close after saturation point. This shows that the addition of saturation dosage for 60min will also give workable mix for 120min, without loss of workability.
4. It can also be deduced from the graph that after 120min, there will again be loss of workability till 180min. After that, there will not be much loss in workability between 180min and 240min.

VII. C2- SP7

Table 16 Marsh flow time readings for C2-SP7 (W/C = 0.5)

%age of Plasticizer	SP7				
	5 min	60 min	120 min	180 min	240 min
0.5%	37.93	131.41	144.84	164.75	178.81
0.7%	31.75	74.69	83.66	94.78	102.88
0.9%	25.31	52.44	61.89	70.31	78.48
1.1%	24.47	48.29	55.67	62.54	67.57
1.3%	22.03	45.51	49.71	55.52	59.58
1.5%	21.53	42.93	48.49	49.93	53.43

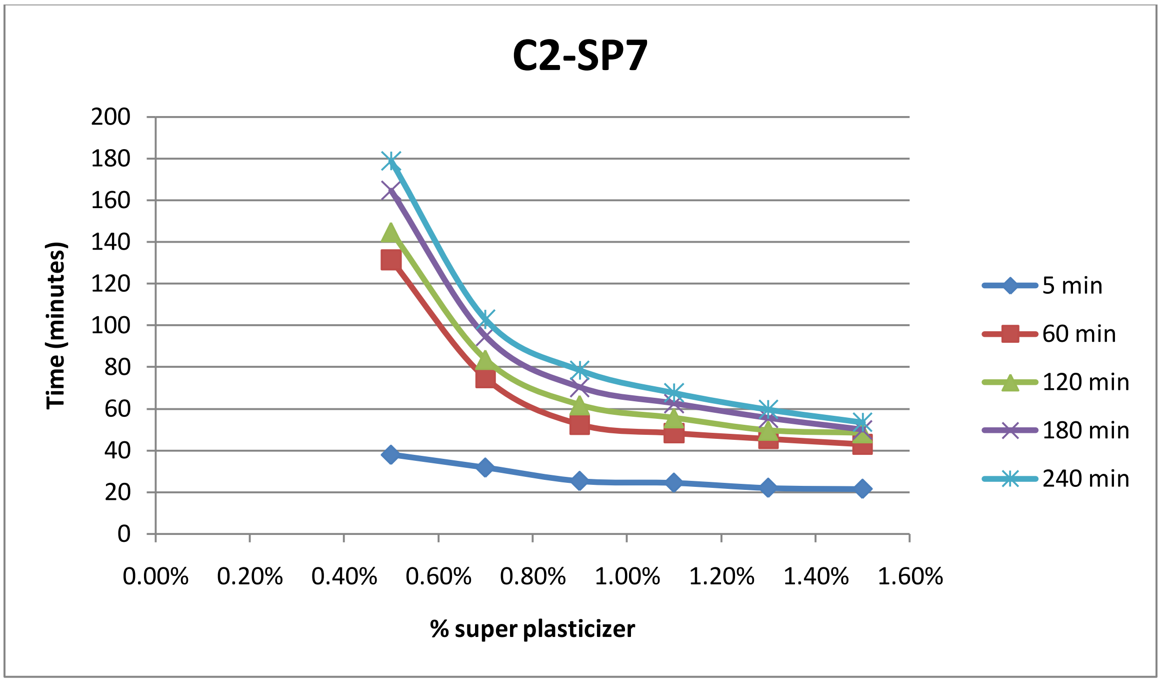


Fig 35 Graph between dosage of SP and Marsh flow time for C2-SP7 (w/c =0.5)

DISCUSSION

1. The graph represents the perfectly compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 0.9%.
2. As evident from the curve, 60min curve is not close to 5min curve. Therefore there will be much loss of flowability after 5min.
3. But after 60min of addition of dosage, there will not be much loss in fluidity for 240min. Thus the optimum dosage can serve for workable mix for 240min.
4. As the dosage of super-plasticizer is increased beyond saturation dosage, the loss in flowability between 60min, 120min, 180min and 240min curves is reducing.

VIII. C2- SP8

Table 17 Marsh flow time readings for C2-SP8 (W/C = 0.5)

%age of Plasticizer	SP8				
	5 min	60 min	120 min	180 min	240 min
0.5%	44.87	144.93	158.81	172.82	201.53
0.7%	34.91	57.94	68.98	77.66	87.47
0.9%	28.63	41.75	53.09	59.59	66.83
1.1%	28.19	37.78	46.38	49.84	58.91
1.3%	27.68	34.41	42.71	45.27	52.26
1.5%	26.74	33.61	41.22	43.34	48.17

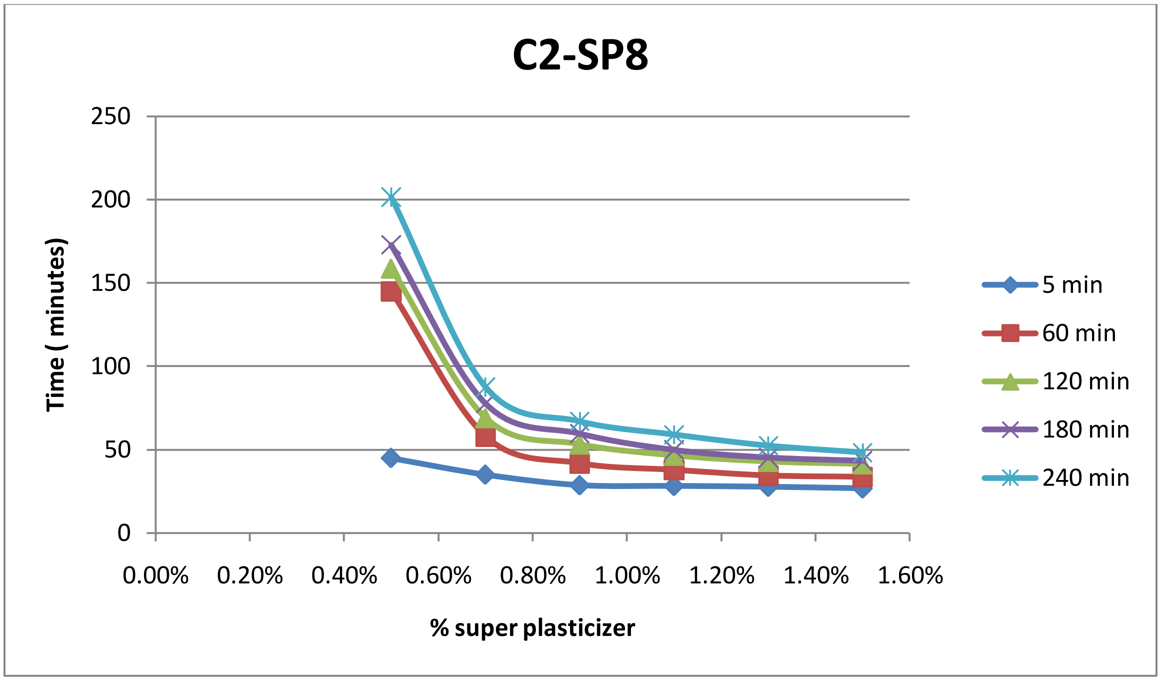


Fig 36 Graph between dosage of SP and Marsh flow time for C2-SP8 (w/c =0.5)

DISCUSSION

1. The graph represents the perfectly compatible cement- super-plasticizer combination; the saturation dosage is low i.e. 0.9%, makes it economical.
2. As apparent from curve, there is not much difference between 5min, 60min, 120min, 180min and 240min curves. Therefore there will not be much loss of flowability after 5min to 240min.
3. As the dosage of super-plasticizer is increased beyond saturation dosage, the loss in flowability between 5min, 60min, 120min, 180min and 240min curves is reducing.

5.4 OBSERVATIONS FOR C3, W/C = 0.5:

I. C3- SP1

Table 18 Marsh flow time readings for C3-SP1 (W/C = 0.5)

%age of plasticizer	SP1				
	5 min	60 min	120 min	180 min	240 min
0.5%	45.77	57.75	81.66	93.91	Sample set. No flowabillity
0.7%	38.62	53.62	70.12	78.08	
0.9%	34.59	48.94	55.59	62.16	
1.1%	31.04	41.43	46.17	56.31	
1.3%	29.21	39.59	44.45	51.82	
1.5%	29.11	39.72	43.5	50.36	

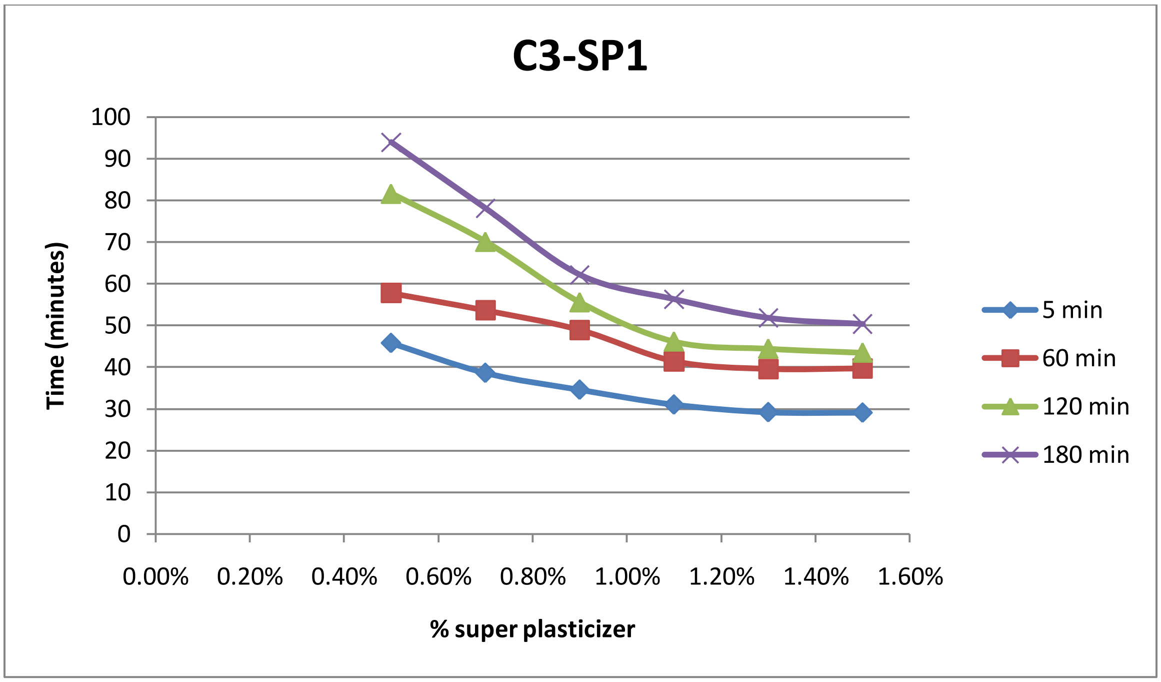


Fig 37 Graph between dosage of SP and Marsh flow time for C3-SP1 (w/c =0.5)

DISCUSSION

1. The above graph shows the compatible cement- super-plasticizer couple; the saturation dosage is quite high i.e. 1.1%.
2. As from the curve, 60min curve is not close to 5min curve. Therefore there will be some loss of flowability after 5min.
3. The 120min and 60min curve are somewhat close after saturation point. This shows that the addition of dosage at and beyond the saturation dosage for 60min, will also give workable mix for 120min without loss of workability.

II. C3- SP2

Table 19 Marsh flow time readings for C3-SP2 (W/C = 0.5)

%age of plasticizer	SP2				
	5 min	60 min	120 min	180 min	240 min
0.5%	28.85	32.88	35.07	38.5	41.75
0.7%	24.97	26.41	29.38	31.93	34.68
0.9%	23.44	24.81	27.38	29.22	32.36
1.1%	23.02	23.93	25.51	27.23	30.71
1.3%	22.33	23.53	24.68	26.71	29.13
1.5%	22.18	22.81	23.91	25.87	28.83

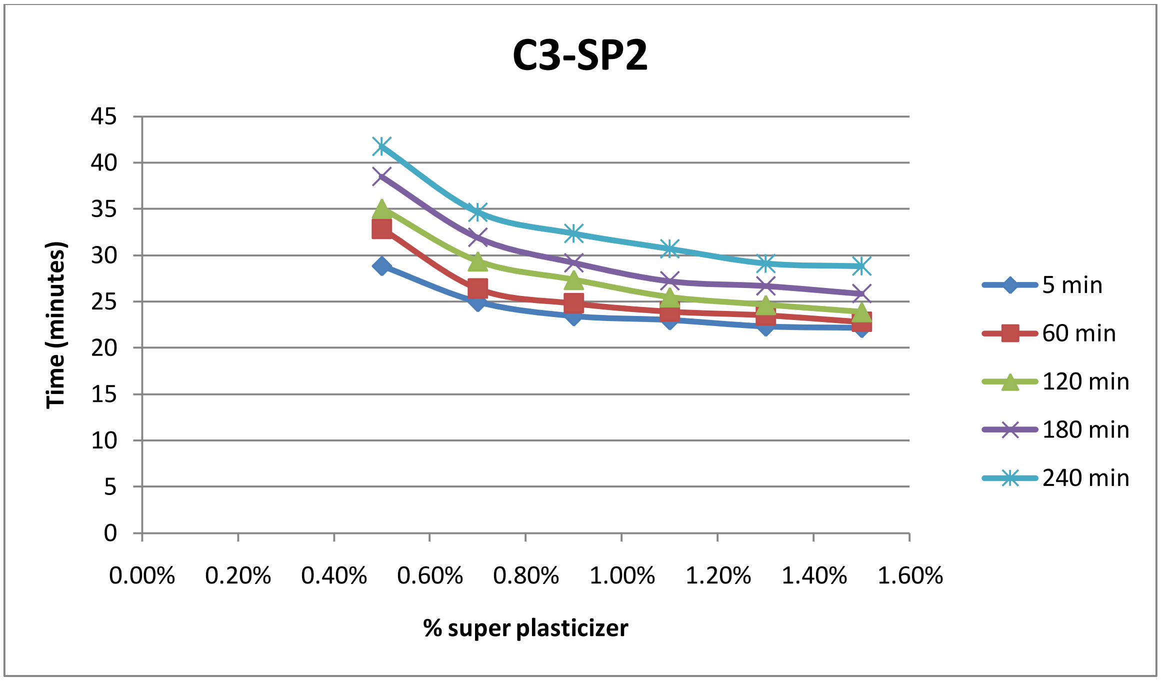


Fig 38 Graph between dosage of SP and Marsh flow time for C3-SP2 (w/c =0.5)

DISCUSSION

1. The graph represents the perfectly compatible cement- super-plasticizer combination; the saturation dosage is low i.e. 0.9%, makes it cost effective.
2. As apparent from curve, the curves for 5min, 60min and 120min curves are very close. Therefore there will not be much loss of flowability after 5min to 120min.
3. Beyond 120min there is comparatively reduction in workability, but not for much extent.
4. As the dosage of super-plasticizer is increased beyond saturation dosage, the loss in flowability between 5min, 60min and 120min curves is reducing.

III. C3- SP3

Table 20 Marsh flow time readings for C3-SP3 (W/C = 0.5)

%age of plasticizer	SP3				
	5 min	60 min	120 min	180 min	240 min
0.5%	32.42	35.02	37.54	40.18	41.25
0.7%	30.38	32.71	34.41	36.27	37.54
0.9%	29.12	31.21	32.77	34.44	35.21
1.1%	28.87	30.46	31.56	32.64	34.15
1.3%	28.61	29.89	31.46	31.83	32.61
1.5%	28.69	29.25	30.32	31.57	31.88

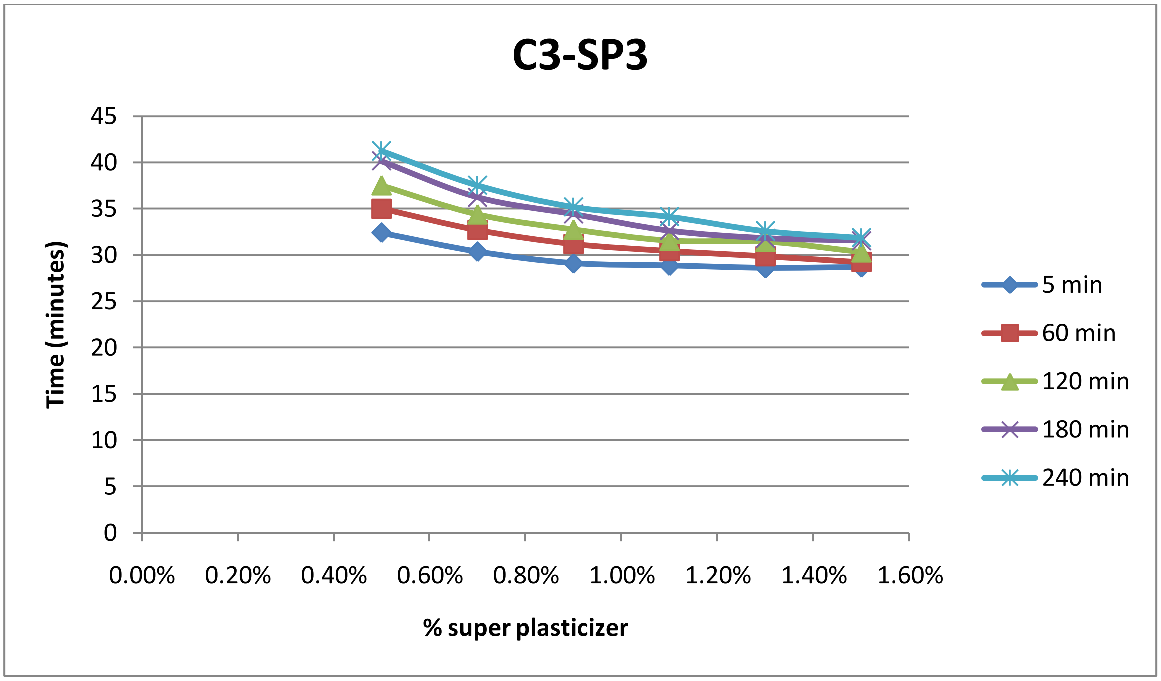


Fig 39 Graph between dosage of SP and Marsh flow time for C3-SP3 (w/c =0.5)

DISCUSSION

1. The above curves shows that the cement- super-plasticizer combination is perfectly compatible; the saturation dosage is low i.e. 0.9%, makes it inexpensive.
2. As noticeable from all curves, there is not much difference between 5min, 60min, 120min, 180min and 240min curves. Therefore there will not be much loss of flowability after 5min to 240min.
3. The 60min and 120min curves are so close to conclude that there will not be any noteworthy loss of flowability.

IV. C3- SP4

Table 21 Marsh flow time readings for C3-SP4 (W/C = 0.5)

%age of plasticizer	SP4				
	5 min	60 min	120 min	180 min	240 min
0.5%	40.94	52.79	61.29	84.91	89.75
0.7%	37.67	49.63	55.58	72.38	77.48
0.9%	35.46	46.81	50.43	63.45	69.22
1.1%	32.02	41.54	45.23	51.69	58.36
1.3%	31.12	39.62	41.19	47.61	53.41
1.5%	29.82	38.27	40.33	45.81	52.37

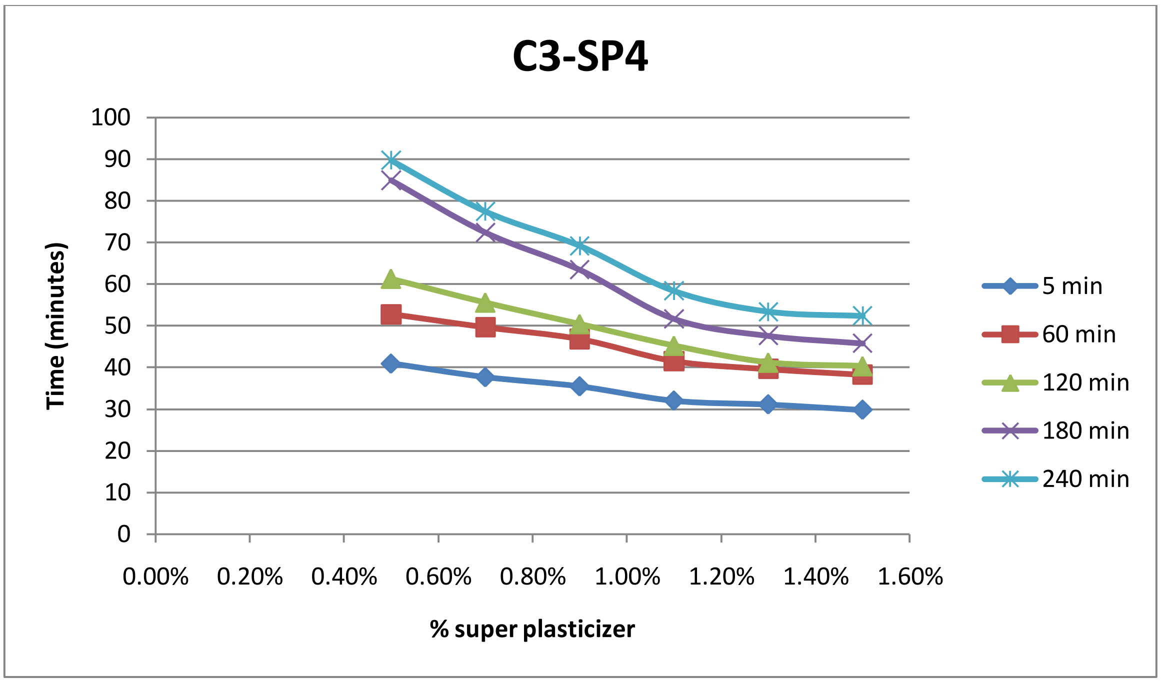


Fig 40 Graph between dosage of SP and Marsh flow time for C3-SP4 (w/c =0.5)

DISCUSSION

1. The graph represents the compatible cement- super-plasticizer couple; the saturation dosage is quite high i.e. 1.1%.
2. As from the curve, 60min curve is not close to 5min curve. Therefore there will be noteworthy loss of flowability after 5min.

V. C3- SP5

Table 22 Marsh flow time readings for C3-SP5 (W/C = 0.5)

%age of plasticizer	SP5				
	5 min	60 min	120 min	180 min	240 min
0.5%	54.39	74.61	82.58	95.19	104.53
0.7%	48.46	59.44	67.72	76.18	86.64
0.9%	39.76	46.73	57.14	61.41	71.59
1.1%	33.87	39.46	43.82	46.63	54.55
1.3%	29.04	36.29	38.88	40.58	48.62
1.5%	28.77	35.91	37.92	39.78	47.55

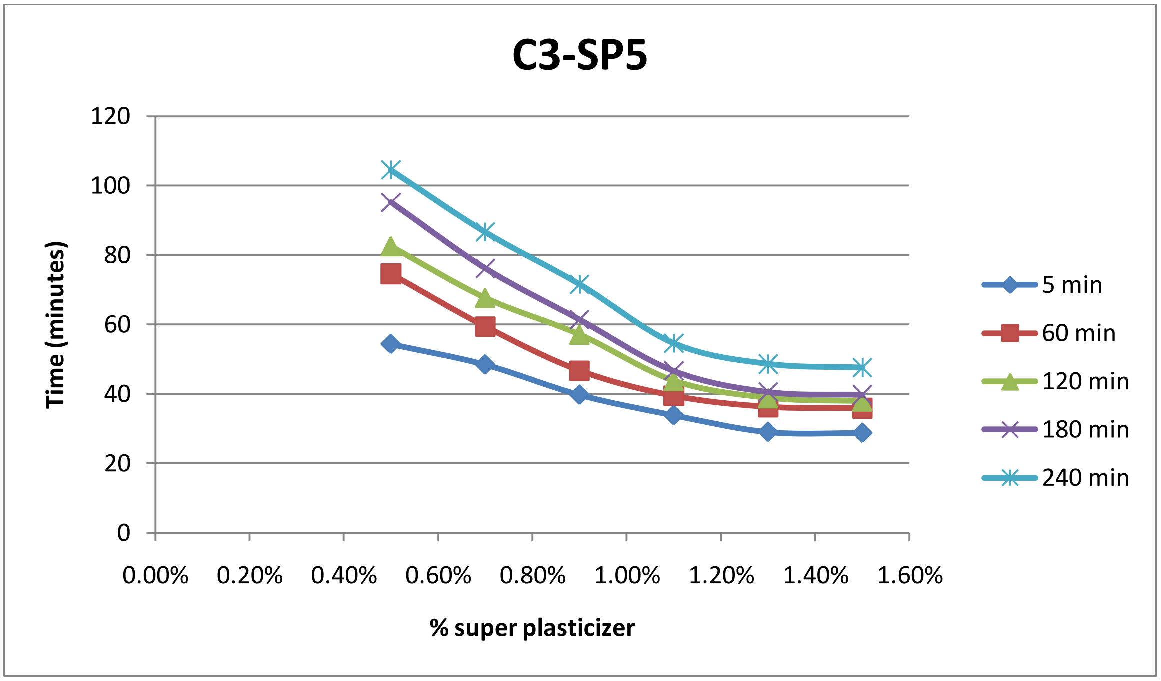


Fig 41 Graph between dosage of SP and Marsh flow time for C3-SP5 (w/c =0.5)

DISCUSSION

1. The above graph represents the perfectly compatible cement- super-plasticizer combination; the saturation dosage is 1.3%.
2. It is evident from the graph, the curves for 60min, 120min and 180min curves are very close. Therefore there will not be visible loss of flowability beyond saturation point.
3. Beyond 180min there is comparatively reduction in workability, but not for much extent.

VI. C3- SP6

Table 23 Marsh flow time readings for C3-SP6 (W/C = 0.5)

%age of plasticizer	SP6				
	5 min	60 min	120 min	180 min	240 min
0.5%	34.59	44.98	52.38	55.19	61.43
0.7%	31.16	39.61	42.93	45.24	52.61
0.9%	30.86	38.73	40.84	43.43	50.59
1.1%	29.95	37.29	39.52	41.23	49.55
1.3%	29.14	36.56	38.78	40.68	48.72
1.5%	28.67	34.41	36.02	38.76	47.45

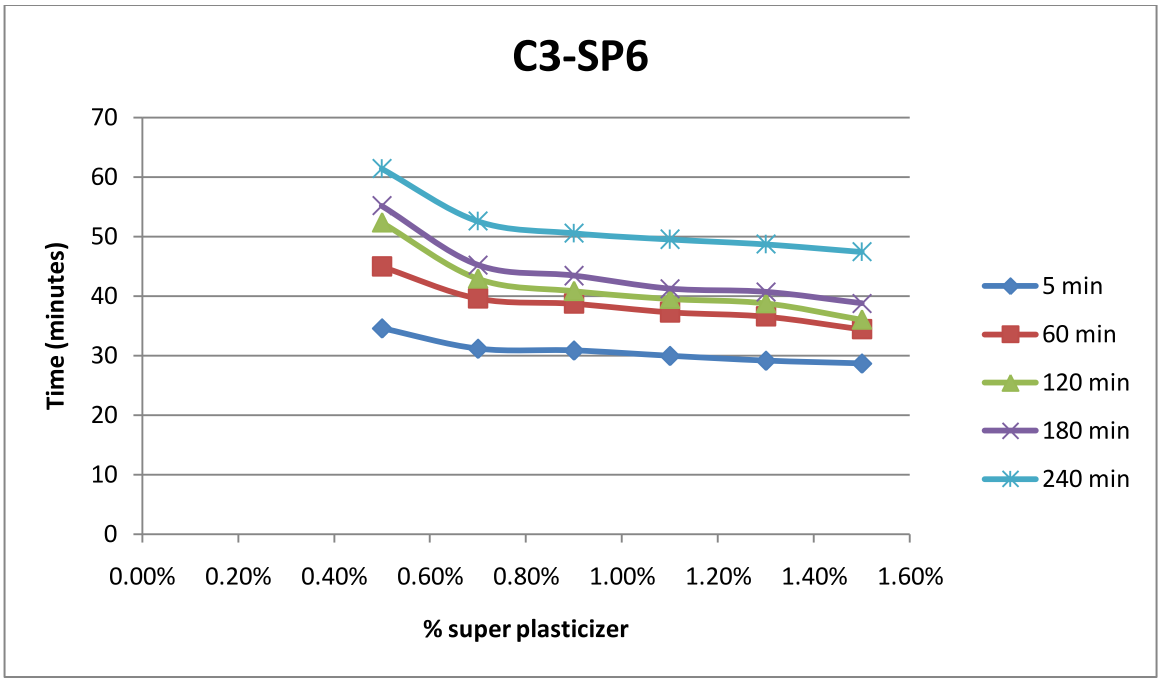


Fig 42 Graph between dosage of SP and Marsh flow time for C3-SP6 (w/c =0.5)

DISCUSSION

1. The above graph represents the compatible cement- super-plasticizer combination; the saturation dosage is very low i.e. 0.7%, is thus cost effective.
2. It is evident from the graph that after 5min of addition of dosage, there is reduction in workability.
3. The curves for 60min, 120min and 180min curves show similar behavior and are fairly close. There is not much loss of flowability.
4. Beyond 180min there is massive reduction in workability.

VII. C3- SP7

Table 24 Marsh flow time readings for C3-SP7 (W/C = 0.5)

%age of plasticizer	SP7				
	5 min	60 min	120 min	180 min	240 min
0.5%	31.59	37.85	43.35	49.49	55.24
0.7%	29.76	34.41	39.89	43.26	49.17
0.9%	27.86	31.79	36.39	39.44	42.29
1.1%	25.94	30.29	33.58	37.21	40.75
1.3%	25.14	29.52	33.36	36.63	38.59
1.5%	24.67	28.76	32.81	35.56	37.88

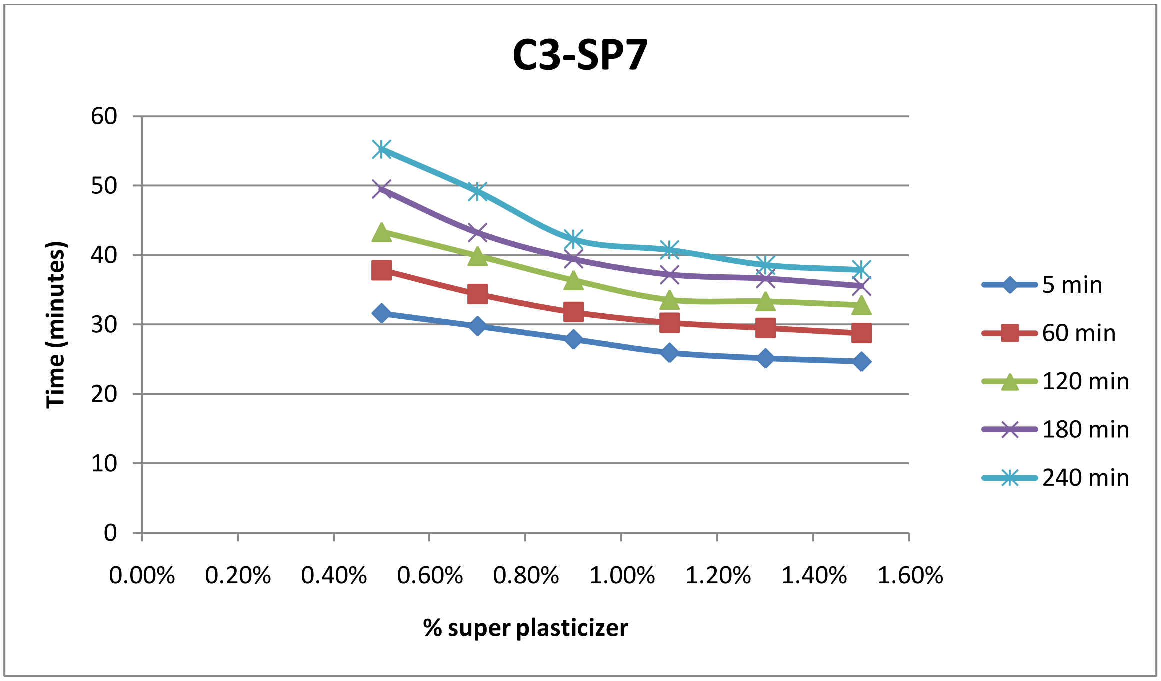


Fig 43 Graph between dosage of SP and Marsh flow time for C3-SP7 (w/c =0.5)

DISCUSSION

1. The graph represents the compatible cement- super-plasticizer couple; the saturation dosage is quite high i.e. 1.1%.
2. As evident from the graph, 5min, 60min, 120min, 180min and 240min curves are showing same behavior for every dosage and after every time interval. This imparts there is regular drop in flowability after 5min and every time interval.

VIII. C3- SP8

Table 25 Marsh flow time readings for C3-SP1 (W/C = 0.5)

%age of plasticizer	SP8				
	5 min	60 min	120 min	180 min	240 min
0.5%	33.69	49.7	56.92	77.49	87.71
0.7%	31.76	45.36	50.08	61.3	64.84
0.9%	30.42	42.18	46.34	52.42	57.24
1.1%	30.2	41.35	45.02	50.07	55.51
1.3%	29.62	39.77	40.81	47.68	53.73
1.5%	29.12	38.15	39.33	45.86	51.49

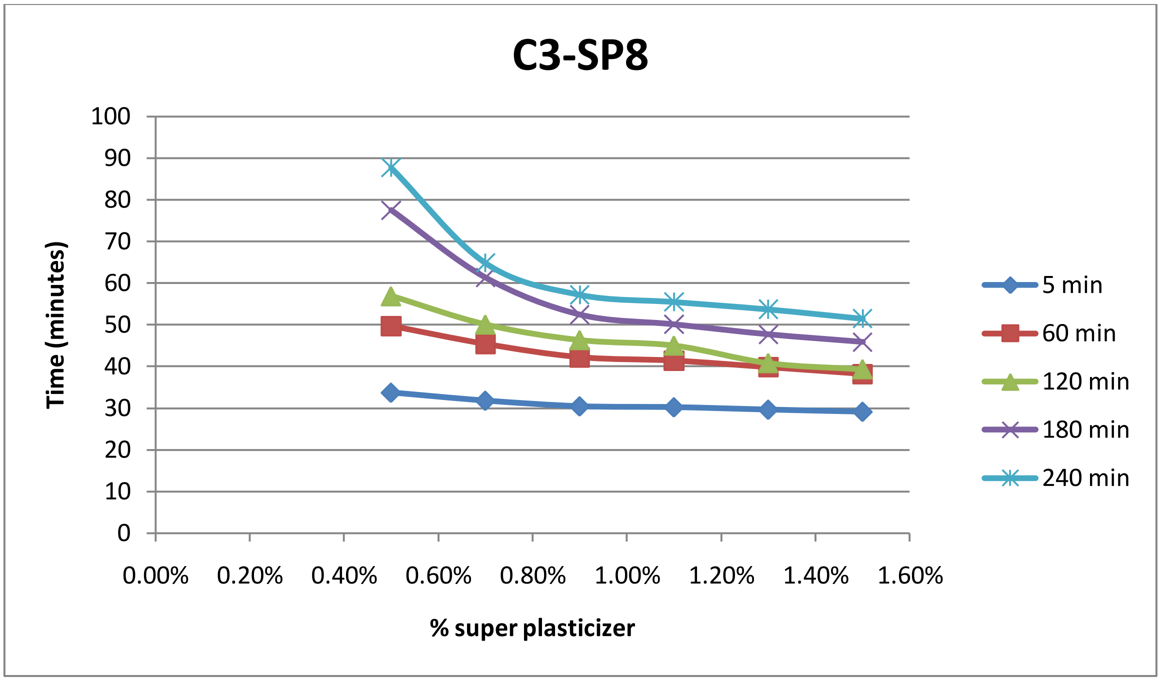


Fig 44 Graph between dosage of SP and Marsh flow time for C3-SP8 (w/c =0.5)

DISCUSSION

1. The above graph represents the compatible cement- super-plasticizer combination; the saturation dosage is relatively low i.e. 0.9%.
2. As from the curve, 60min curve is not close to 5min curve. Therefore there will be noteworthy loss of flowability after 5min.
3. The 120min and 60min curve are quite close after saturation point. This shows that the addition of dosage at and beyond the saturation dosage for 60min, will also give workable mix for 120min. It is also visible that for 1.3% and 1.5% dosage, the flowability is almost same after 60min and 120min.
4. It can also be deduced that after 120min, there is regular drop in loss of workability for 180min and 240min.

5.5 OBSERVATIONS FOR C1, W/C = 0.45:

I. C1-SP1

Table 26 Marsh flow time readings for C1-SP1 (W/C = 0.45)

%age of plasticizer	SP1				
	5 min	60 min	120 min	180 min	240 min
0.5%	69.53	151.78	162.36	172.22	197.06
0.7%	51.62	109.23	136.83	153.64	179.84
0.9%	34.85	79.47	121.39	139.3	157.69
1.1%	32.79	76.71	109.46	128.43	142.56
1.3%	31.58	74.28	108.77	126.58	139.17
1.5%	29.89	73.47	106.95	123.88	137.25

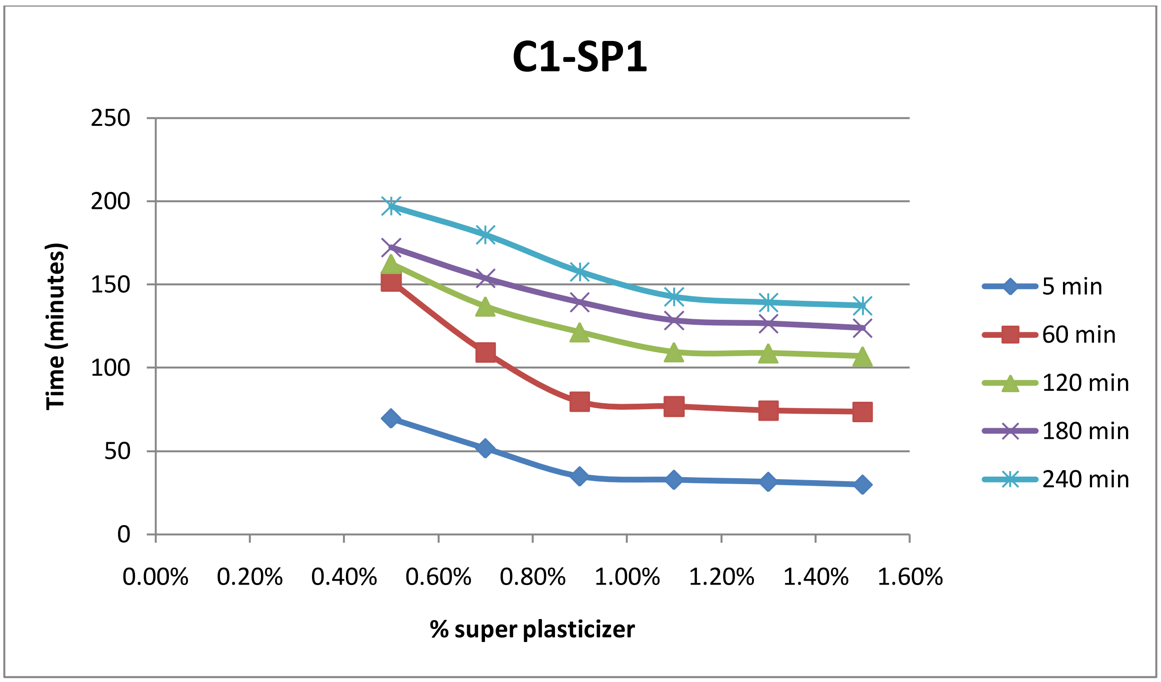


Fig 45 Graph between dosage of SP and Marsh flow time for C1-SP1 (w/c =0.45)

DISCUSSION

1. The above graph represents the case of a compatible cement- super-plasticizer combination; the dosage corresponding to the saturation point is low i.e. 0.9% and 60 min curve is not quite close to 5 min curve.
2. It can also be deduced that there is considerable loss of flowability of slurry after 5 min, 60 min and 120 min. But after 120 min there is not noteworthy loss of flowability.
3. If flowability for 120 min, 180 min and 240 min will be required then 1.1% optimum dosage should be used to make it efficient.

II. C1-SP2

Table 27 Marsh flow time readings for C1-SP2 (W/C = 0.45)

%age of plasticizer	SP2				
	5 min	60 min	120 min	180 min	240 min
0.5%	61.42	89.51	94.68	99.14	103.74
0.7%	49.81	71.46	81.33	87.21	95.03
0.9%	43.36	63.79	72.48	81.44	87.15
1.1%	38.14	58.08	67.52	73.8	81.22
1.3%	37.29	56.53	63.78	69.97	77.14
1.5%	36.74	55.79	62.67	70.09	75.87

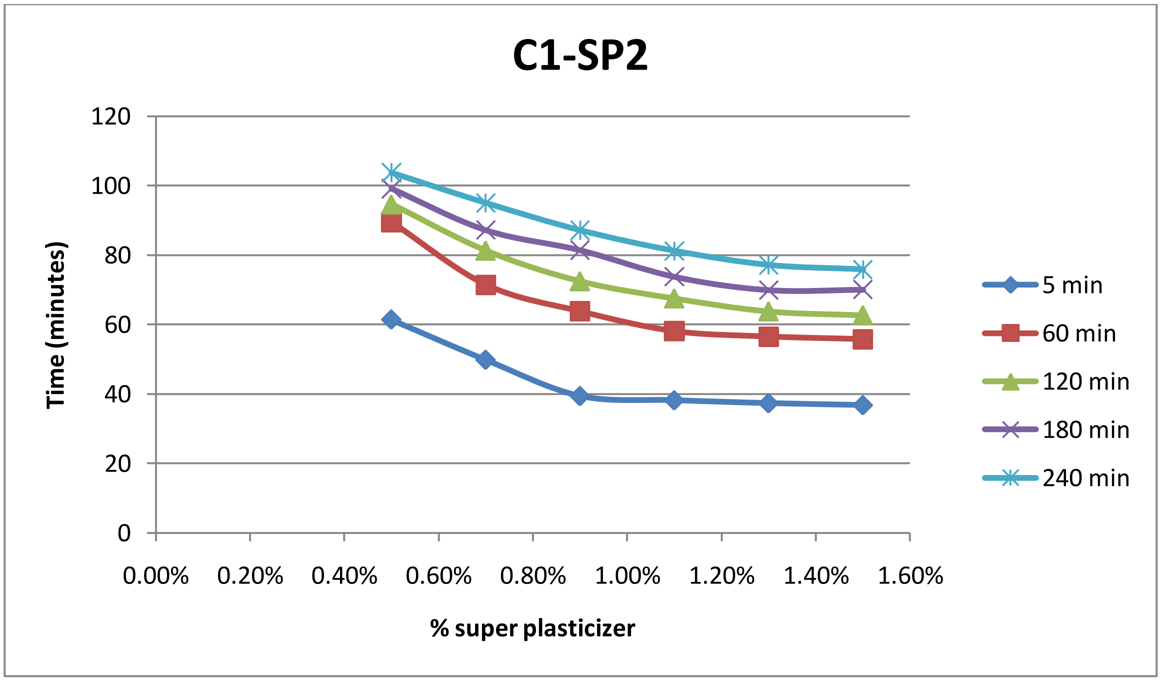


Fig 46 Graph between dosage of SP and Marsh flow time for C1-SP2 (w/c =0.45)

DISCUSSION

1. This graph shows the case of perfect compatibility between C-SP i.e. 5min curve shows the breakage in curve, saturation point clearly at 1.1%.
2. Also, there is not considerable loss of flowability of slurry after 60 min up to 240 min.
3. If it is required to manage 120 min of workability or beyond that in mix, then saturation dosage of 1.3% is quite good adequate.

III. C1-SP3

Table 28 Marsh flow time readings for C1-SP3 (W/C = 0.45)

%age of plasticizer	SP3				
	5 min	60 min	120 min	180 min	240 min
0.5%	57.22	96.51	103.44	118.74	127.18
0.7%	51.82	81.38	92.19	102.68	109.96
0.9%	46.43	74.29	83.36	94.79	99.06
1.1%	43.71	62.56	71.44	86.35	91.46
1.3%	39.87	52.62	69.25	84.55	87.23
1.5%	38.54	50.89	68.52	83.48	85.88

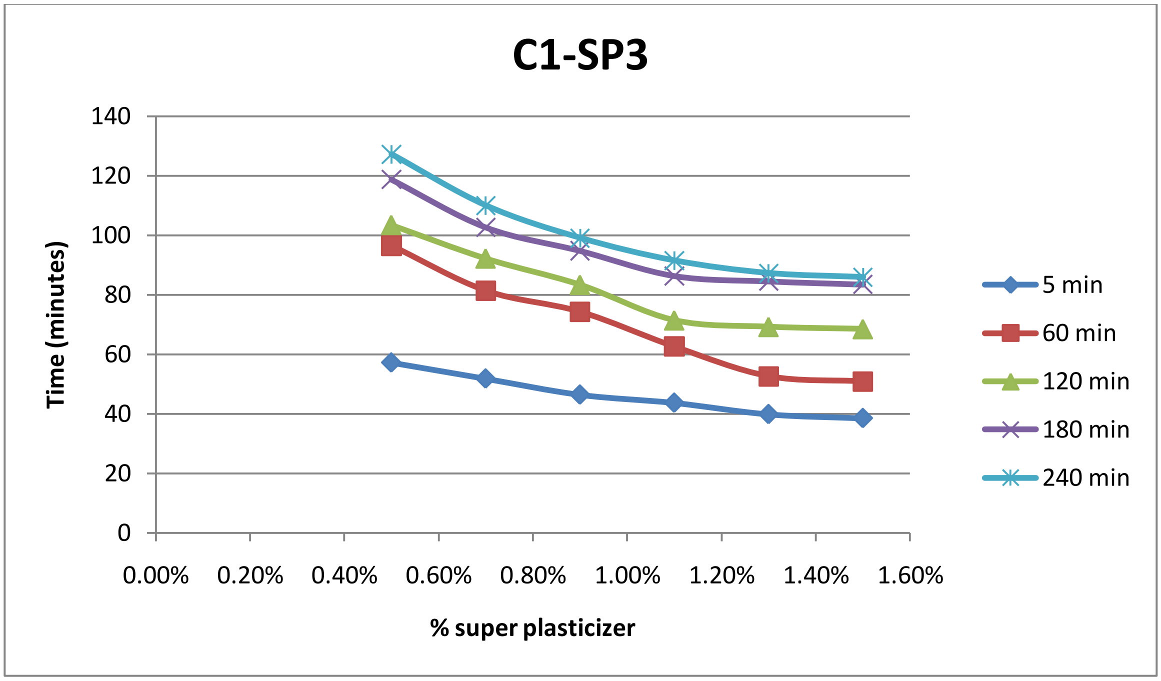


Fig 47 Graph between dosage of SP and Marsh flow time for C1-SP3 (w/c =0.45)

DISCUSSION

1. The curve shows that the C1- SP3 combination is compatible. Though the saturation dosage requirement is comparatively high i.e. 1.3%.
2. The 60 min curve is close to 5 min curve after saturation point, imparting that fluidity is not going to decrease much extent.
3. The 120 min and 180 min of flowability can be achieved by opting for saturation dose of 1.1%.
4. There is very minimal loss in flowability after 180 min thus saturation dosage of 180 min will also work for 240 min. But as for 240 min the saturation dosage is 1.3%.

IV. C1-SP4

Table 29 Marsh flow time readings for C1-SP1 (W/C = 0.45)

%age of plasticizer	SP4				
	5 min	60 min	120 min	180 min	240 min
0.5%	58.76	146.54	160.81	181.34	195.09
0.7%	49.85	107.65	121.17	139.54	152.75
0.9%	33.78	79.37	98.86	104.68	121.12
1.1%	31.63	73.44	81.27	93.74	106.77
1.3%	30.27	71.38	75.62	84.44	98.51
1.5%	29.52	69.97	73.04	82.39	96.66

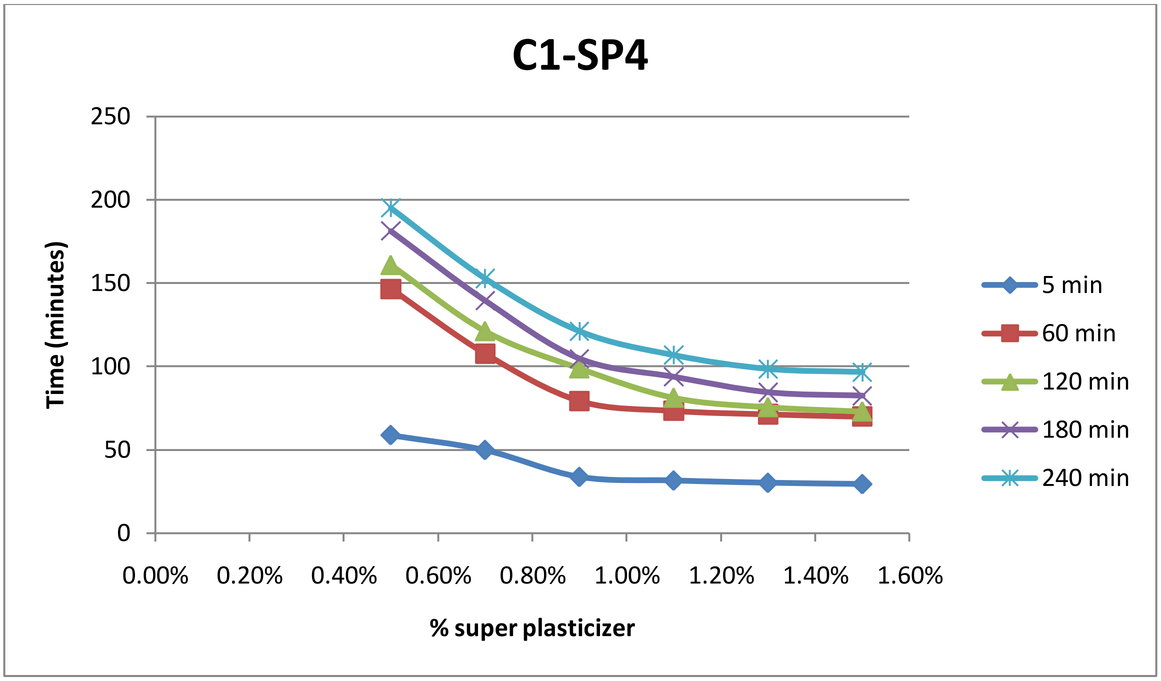


Fig 48 Graph between dosage of SP and Marsh flow time for C1-SP4 (w/c =0.45)

DISCUSSION

1. The graph represents the case of a perfectly compatible cement- super-plasticizer combination; the dosage corresponding to the saturation point is 0.9%, which is making it efficient.
2. The graph also showing 60 min curve is not too close to 5 min curve. There will be considerable loss of workability.
3. It can also be interpreted that flowability of slurry after 60 min is not considerable as compared to the loss between 5 min and 60 min.
4. The saturation dosage for 120 min and ahead of is 1.3%. Thus if a workable mix for 120 min is required then of course lower dosage i.e. 1.3% should be used, which will also serve for up to 240 min.

V. C1-SP5

Table 30 Marsh flow time readings for C1-SP5 (W/C = 0.45)

%age of plasticizer	SP5				
	5 min	60 min	120 min	180 min	240 min
0.5%	98.43	182.36	194.66	210.24	217.81
0.7%	81.35	165.49	181.79	192.46	197.74
0.9%	73.22	149.57	158.36	173.29	178.58
1.1%	61.11	118.43	139.24	156.33	167.28
1.3%	59.72	115.02	121.38	132.19	165.08
1.5%	57.21	113.65	119.81	129.97	161.77

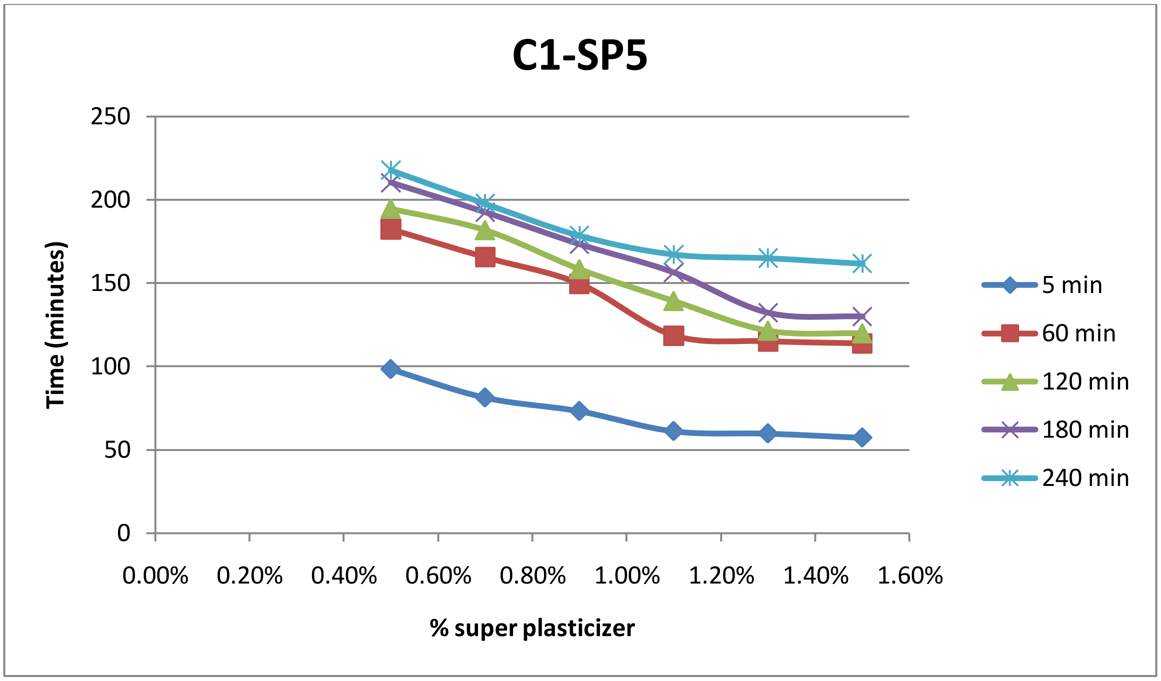


Fig 49 Graph between dosage of SP and Marsh flow time for C1-SP5 (w/c =0.45)

DISCUSSION

1. This combination of cement- super-plasticizer is a compatible combination. Though the optimum dosage is comparatively low i.e. 1.1% but there is enormous decline if flowability between 5 min and 60 min.
2. The saturation dosage for 120 min and 180 min is 1.3%. Moreover, there is not huge gap beyond 60 min curves, as it was amid 5 min and 60 min curves, which show that flowability will not reduce to much extent.

VI. C1-SP6

Table 31 Marsh flow time readings for C1-SP6 (W/C = 0.45)

%age of plasticizer	SP6				
	5 min	60 min	120 min	180 min	240 min
0.5%	74.18	149.28	163.34	171.45	187.72
0.7%	53.22	131.47	142.53	153.68	168.41
0.9%	39.82	114.08	130.29	142.21	157.54
1.1%	38.59	109.85	121.36	128.58	145.27
1.3%	38.12	107.58	119.92	125.89	141.88
1.5%	37.28	106.37	117.46	123.35	139.16

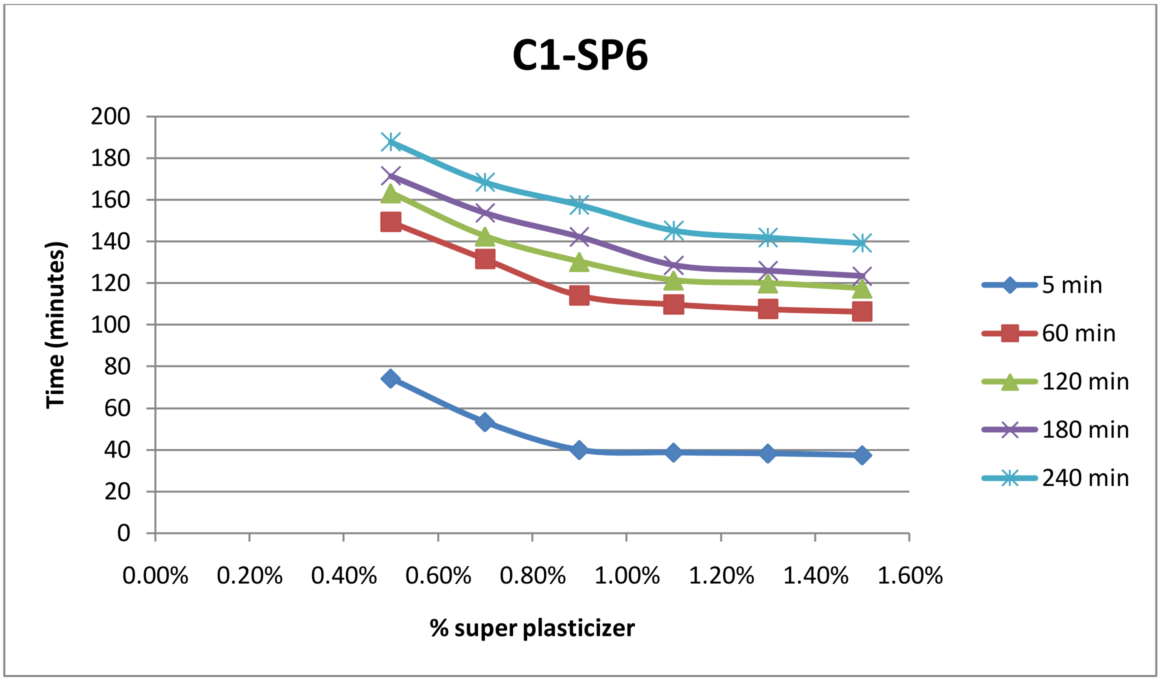


Fig 50 Graph between dosage of SP and Marsh flow time for C1-SP6 (w/c =0.45)

DISCUSSION

1. The curves show the case of a perfectly compatible cement- super-plasticizer combination; the dosage corresponding to the saturation point for 5 min and 60 min is 0.9%.
2. Moreover, there is massive gap among 5 min and 60 min curves which shows that flowability will reduce to much extent at any dosage of super-plasticizer.
3. It can also be interpreted that to achieve flowable mix for 120 min and further on, a dosage of 1.1% should be applied. Also, there is not much loss of flowable mix after 60 min.

VII. C1-SP7

Table 32 Marsh flow time readings for C1-SP7 (W/C = 0.45)

%age of plasticizer	SP7				
	5 min	60 min	120 min	180 min	240 min
0.5%	47.13	110.2	135.11	157.49	183.19
0.7%	39.27	69.33	79.68	94.86	101.55
0.9%	31.83	52.25	62.82	78.05	84.95
1.1%	27.62	41.46	57.35	63.91	67.58
1.3%	25.87	39.38	51.46	57.83	65.46
1.5%	25.03	40.41	49.71	56.69	63.89

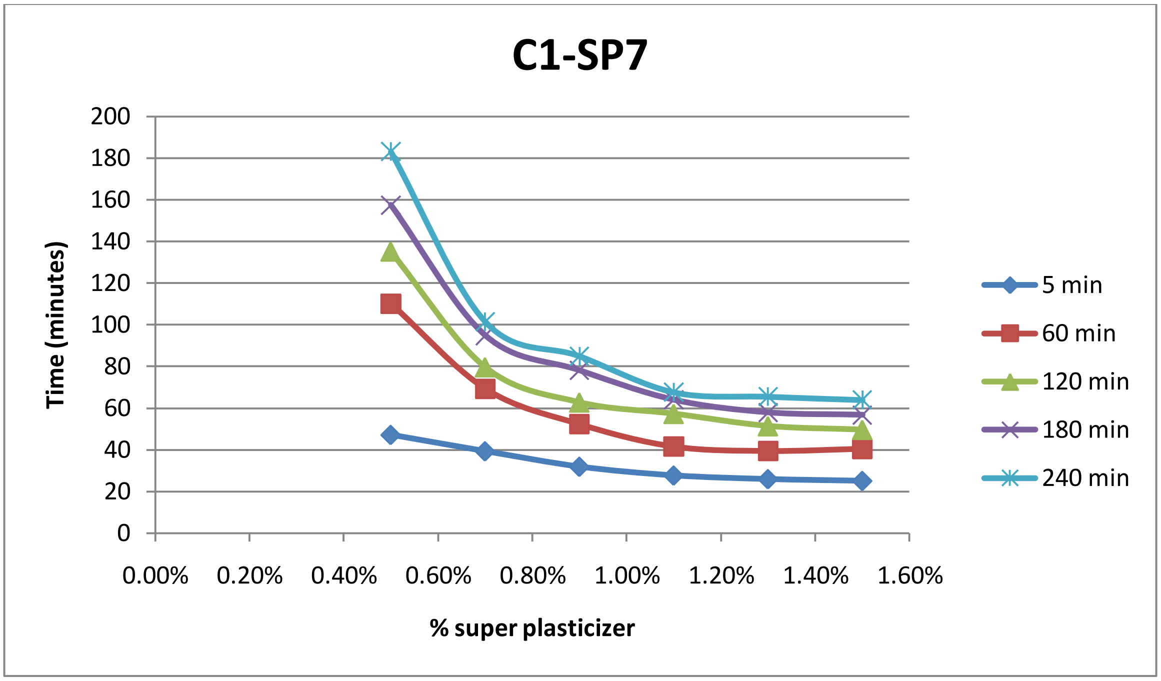


Fig 51 Graph between dosage of SP and Marsh flow time for C1-SP7 (w/c =0.45)

DISCUSSION

1. The curves show the case of a perfectly compatible cement- super-plasticizer combination; 5min curve shows the breakage in curve, saturation point clearly at 1.1% which is quite low and 60 min curve is quite close to 5 min curve.
2. To have workable mix even after 60 min up to 180 min, dosage of 1.3% is to be added. The loss of workable mix amid every curve, corresponding to beyond saturation dose is quite less.

VIII. C1-SP8

Table 33 Marsh flow time readings for C1-SP8 (W/C = 0.45)

%age of plasticizer	SP8				
	5 min	60 min	120 min	180 min	240 min
0.5%	41.46	156.24	168.8	181.17	201.09
0.7%	34.25	114.55	127.47	141.46	172.85
0.9%	27.68	84.47	98.65	112.44	141.52
1.1%	21.73	75.24	82.37	91.24	104.17
1.3%	20.37	73.48	76.02	85.44	99.51
1.5%	19.82	71.77	74.64	85.39	98.86

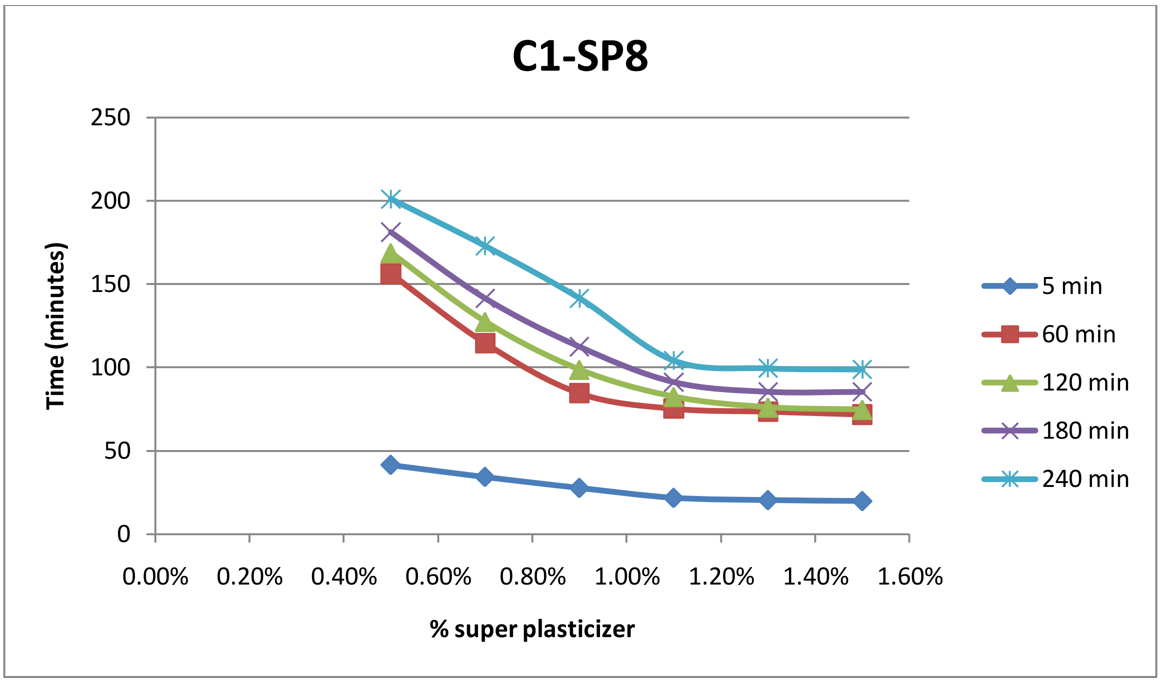


Fig 52 Graph between dosage of SP and Marsh flow time for C1-SP8 (w/c =0.45)

DISCUSSION

1. The graph represents the case of a compatible combination of cement- super-plasticizer; the saturation dosage is significantly low i.e. 1.1%.
2. It also shows that, 60 min curve are quite apart from 5 min curve. Also, there is not any noteworthy loss of workable mix after 60 min.
3. The saturation dosage added for 60 min will also serve for 240 min to have flowable mix which makes it economical.

5.6 OBSERVATIONS FOR C2, W/C = 0.45 :

I. C2- SP1

Table 34 Marsh flow time readings for C2-SP1 (W/C = 0.45)

%age of plasticizer	SP1				
	5 min	60 min	120 min	180 min	240 min
0.5%	91.73	106.31	118.53	137.56	185.76
0.7%	84.55	94.51	105.42	122.68	140.37
0.9%	73.61	84.83	97.73	105.44	109.24
1.1%	59.2	78.09	93.28	96.87	101.49
1.3%	53.36	78.64	91.82	94.16	97.82
1.5%	52.79	77.13	90.49	93.65	96.27

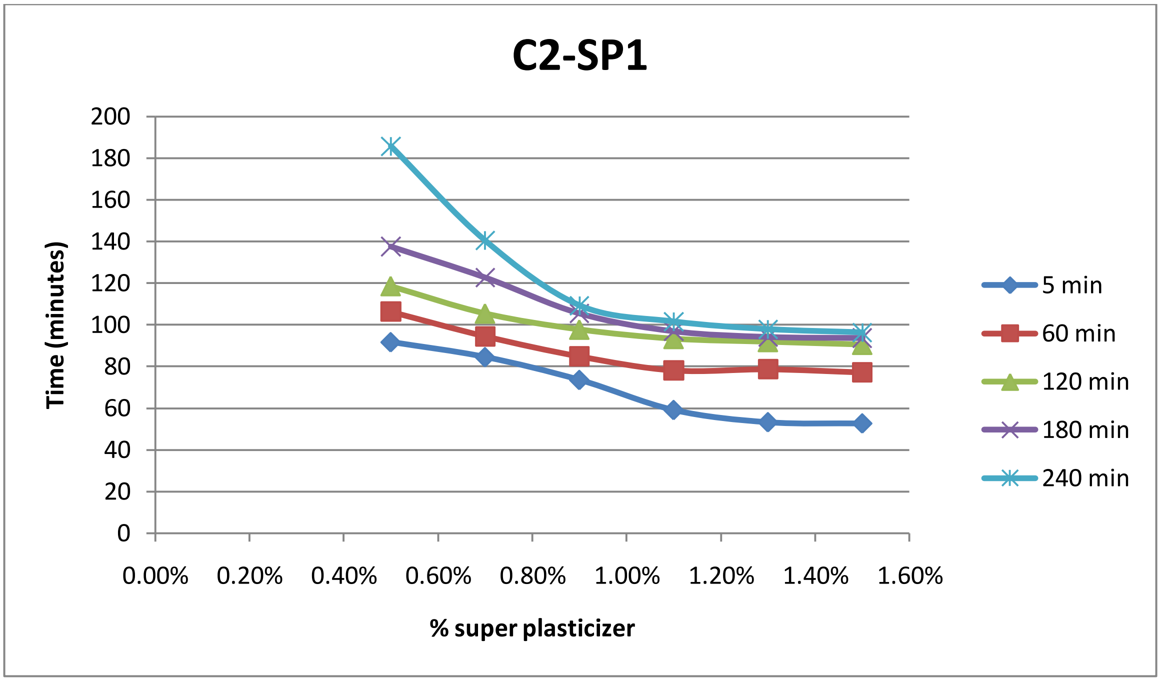


Fig 53 Graph between dosage of SP and Marsh flow time for C2-SP1 (w/c =0.45)

DISCUSSION

1. The graph represents the case of a perfectly compatible cement- super-plasticizer couple; the saturation dosage is significantly low i.e. 1.1% and 60 min curve is almost close to 5 min curve.
2. The curve corresponding to 1.1% shows that flowability of the mix is not increasing too much extent even after 4hr of mixing. Thus, if workability of the mix is required till 240 min (4 hr) then the dosage will do the work, to avail cost effectiveness.
3. The behavior of flowability of mix after saturation dosage of 120 min till 240 min is almost same and there is minimal difference between them.

II. C2-SP2

Table 35 Marsh flow time readings for C2-SP2 (W/C = 0.45)

%age of plasticizer	SP2				
	5 min	60 min	120 min	180 min	240 min
0.5%	59.24	70.71	85.68	97.23	116.17
0.7%	47.35	63.84	69.62	81.27	101.18
0.9%	37.59	52.92	61.31	72.38	90.33
1.1%	34.63	49.04	54.63	64.46	78.62
1.3%	33.28	47.36	52.33	63.71	69.83
1.5%	31.86	46.13	51.62	62.86	67.39

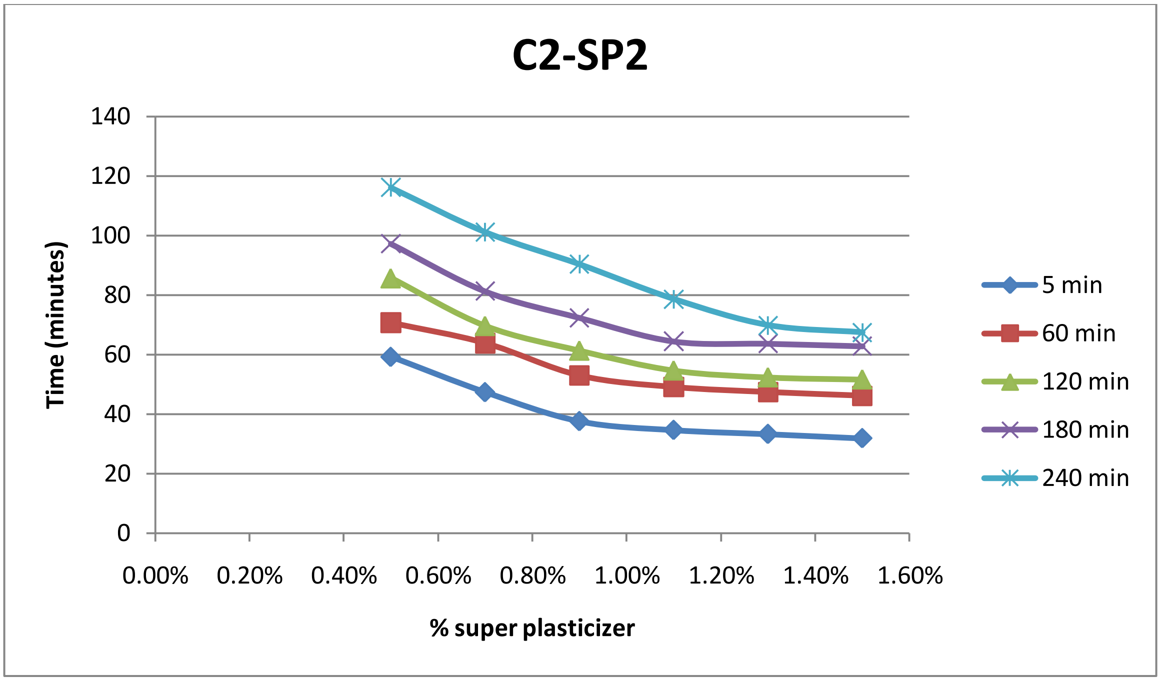


Fig 54 Graph between dosage of SP and Marsh flow time for C2-SP2 (w/c =0.45)

DISCUSSION

1. The graph shows the compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 0.9%.
2. The 120min and 60min curve are quite close after saturation point. This shows that the addition of saturation dosage for 60min will also give workable mix for 120min, without loss of workability.
3. It can also be deduced from the graph that after 120min, there will again be somewhat loss of workability till 240min.
4. The saturation dosage for 120 min and 180 min is 1.1% and that for 240 min is 1.3%.

III. C2-SP3

Table 36 Marsh flow time readings for C2-SP3 (W/C = 0.45)

%age of plasticizer	SP3				
	5 min	60 min	120 min	180 min	240 min
0.5%	47.81	71.28	80.44	97.14	119.08
0.7%	39.75	59.12	69.88	76.62	91.26
0.9%	37.62	51.47	64.32	67.74	83.66
1.1%	32.03	44.78	58.22	61.29	77.54
1.3%	31.57	43.41	53.93	57.43	73.64
1.5%	30.79	42.85	52.86	56.78	71.81

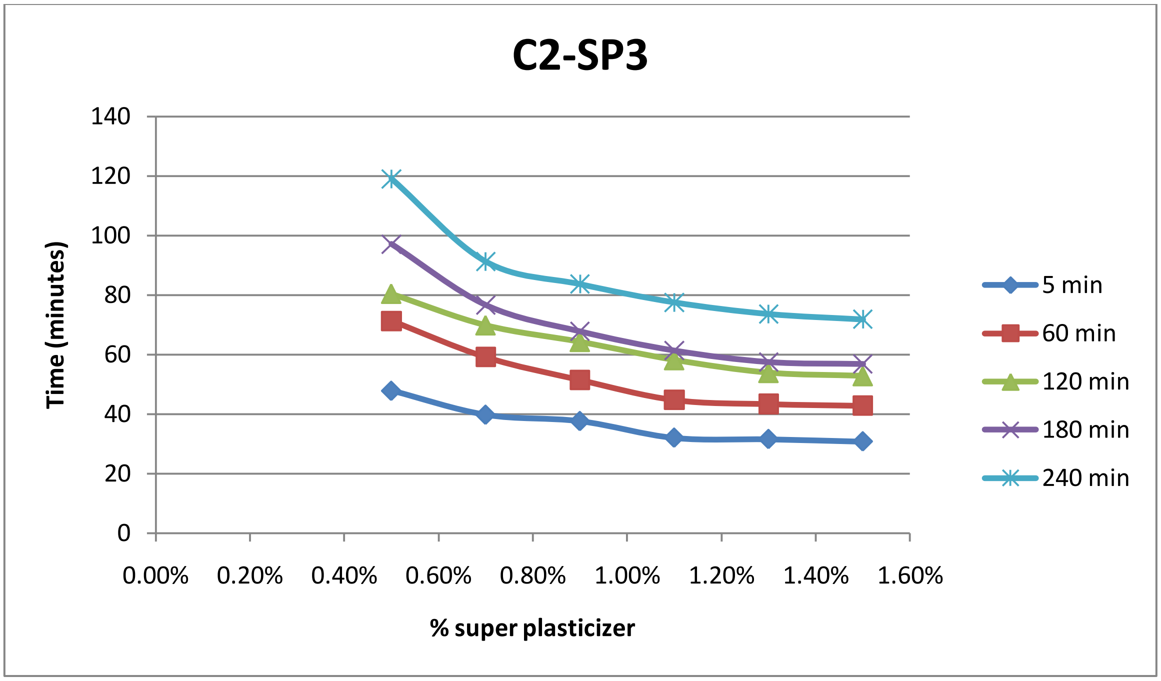


Fig 55 Graph between dosage of SP and Marsh flow time for C2-SP3 (w/c =0.45)

DISCUSSION

1. The graph shows the compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 1.1%.
2. As from the curve, 60min curve is quite close to 5min curve. Therefore there will not be much loss of flowability amid 5min and 60 min.
3. The 120min and 180min curve are very close to each other for every dosage. This shows that the addition of saturation dosage for 120min will also give workable mix for 180min, without any loss of workability. The optimum dosage for both is 1.3%.
4. It can also be derived from the curve that after 180min, there will again be some loss of workability till 240min.

IV. C2-SP4

Table 37 Marsh flow time readings for C2-SP4 (W/C = 0.45)

%age of plasticizer	SP4				
	5 min	60 min	120 min	180 min	240 min
0.5%	53.24	72.38	81.18	93.79	101.53
0.7%	49.82	64.29	69.92	84.57	93.69
0.9%	41.64	52.81	58.86	71.94	82.28
1.1%	33.48	48.33	51.66	63.87	73.72
1.3%	32.42	46.63	49.13	58.34	69.07
1.5%	31.77	45.21	48.38	56.98	68.55

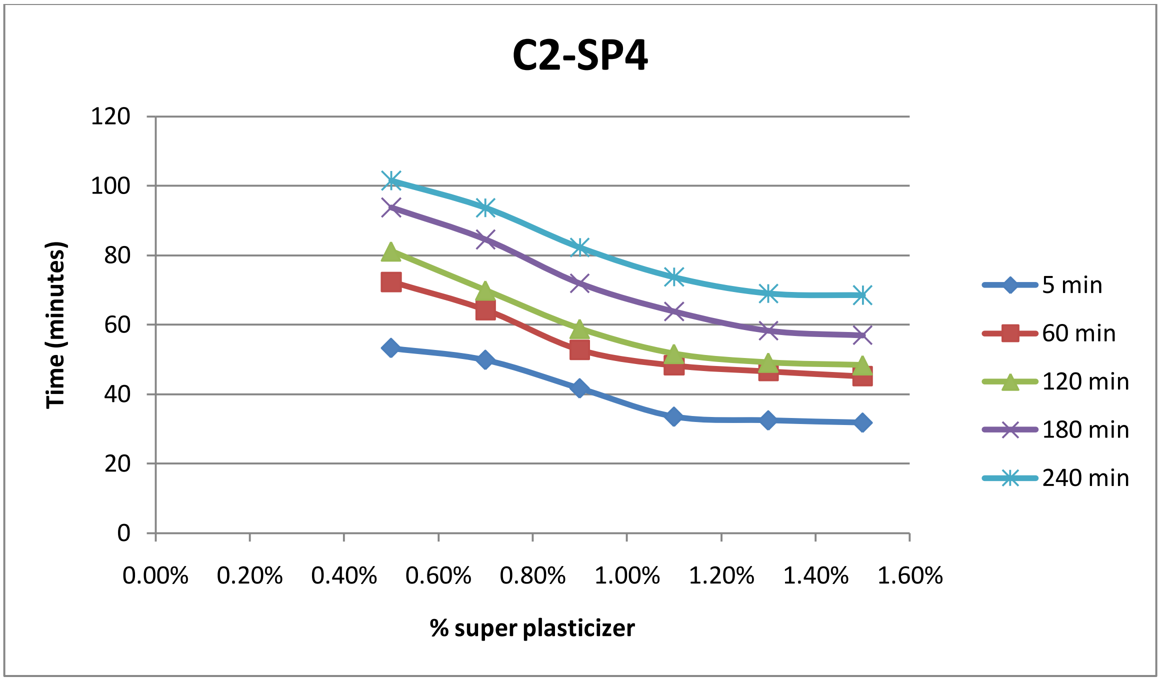


Fig 56 Graph between dosage of SP and Marsh flow time for C2-SP4 (w/c =0.45)

DISCUSSION

1. The curves show the compatibility between cement- super-plasticizer combination; the saturation dosage is relatively low i.e. 1.1%.
2. As from the curve, 60min curve is quite apart to 5min curve. Thus, there will not be any major loss of flowability after 5min to 60min.
3. The 120min and 60min curve are quite close after saturation point. This imparts that the addition of saturation dosage for 60min will also give workable mix for 120min, without any loss of workability.
4. It can also be deduced from the graph that after 120min, there will be some loss of workability till 240min. The saturation dosage for 180min and 240min is 1.3%

V. C2-SP5

Table 38 Marsh flow time readings for C2-SP5 (W/C = 0.45)

%age of plasticizer	SP5				
	5 min	60 min	120 min	180 min	240 min
0.5%	89.41	129.98	159.58	179.77	190.63
0.7%	76.93	94.59	138.02	161.85	171.96
0.9%	66.04	72.61	103.83	142.74	159.63
1.1%	65.33	70.94	91.39	118.52	124.42
1.3%	64.73	69.46	89.11	93.33	101.34
1.5%	64.13	68.89	88.24	92.79	99.67

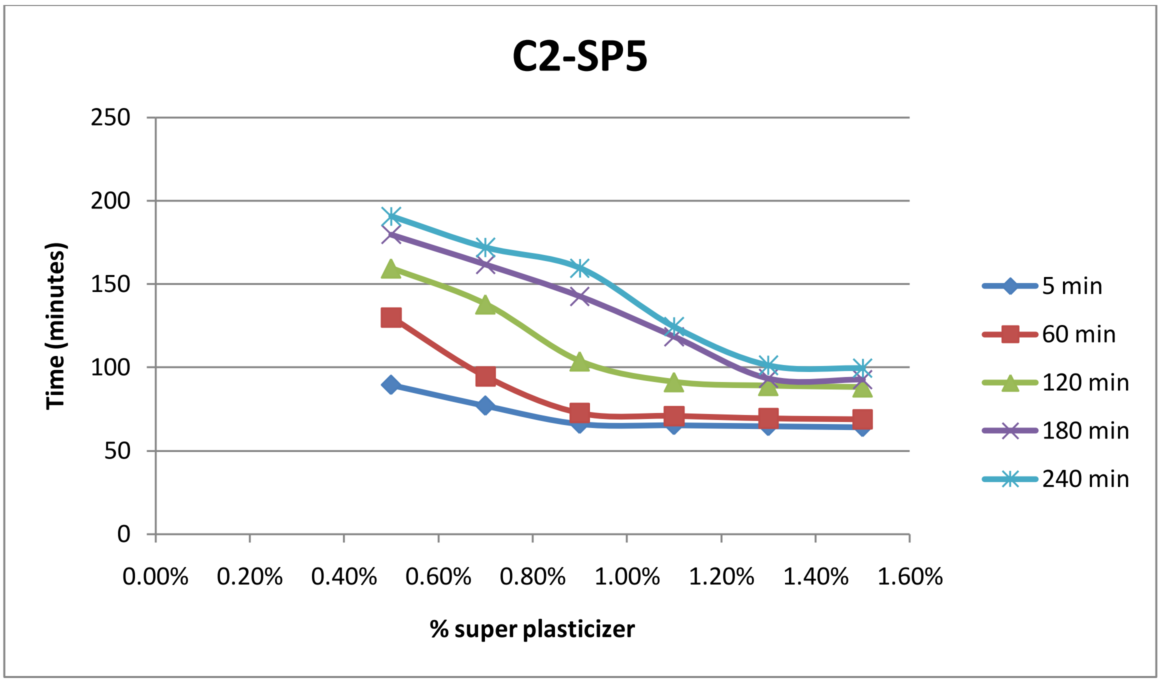


Fig 57 Graph between dosage of SP and Marsh flow time for C2-SP5 (w/c =0.45)

DISCUSSION

1. The graph represents the perfectly compatible cement- super-plasticizer combination; the saturation dosage is low i.e. 0.9%, makes it economical.
2. As apparent from curve, there is some loss of workable mix after 60min till 120min, the saturation dosage for which is 1.1%.
3. The 180min and 240min curves are quite close for every dosage of SP. This imparts that the addition of saturation dosage for 180min will also give workable mix for 240min, without any loss of workability.

VI. C2-SP6

Table 39 Marsh flow time readings for C2-SP6 (W/C = 0.45)

%age of plasticizer	SP6				
	5 min	60 min	120 min	180 min	240 min
0.5%	53.46	72.82	91.27	115.06	127.36
0.7%	41.53	61.73	79.81	93.38	101.33
0.9%	34.64	55.24	64.68	78.82	92.57
1.1%	29.44	46.14	58.92	63.66	84.42
1.3%	28.38	45.47	49.84	59.03	72.29
1.5%	26.87	45.63	47.18	58.74	70.88

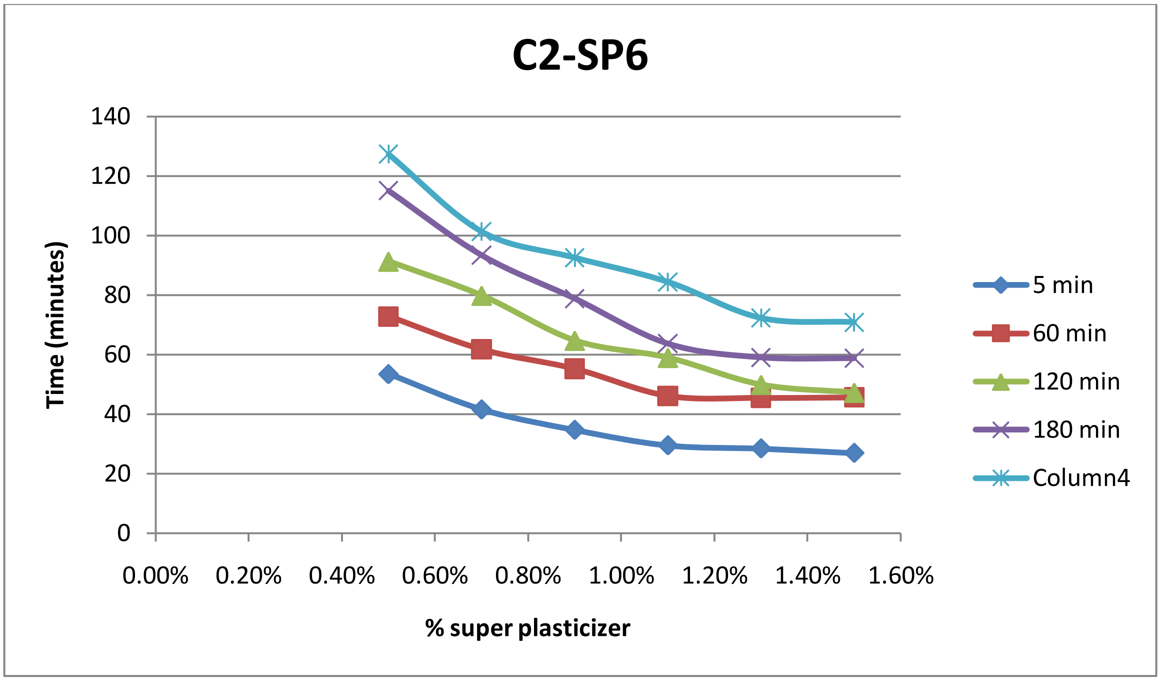


Fig 58 Graph between dosage of SP and Marsh flow time for C2-SP6 (w/c =0.45)

DISCUSSION

1. The curve represents the compatible cement- super-plasticizer couple; the saturation dosage is relatively low i.e. 1.1%.
2. As from the curve, 60min curve is not close to 5min curve. Therefore there will be noteworthy loss of flowability after 5min.
3. The 120min and 60min curve are quite close after saturation point. This shows that the addition of dosage at and beyond the saturation dosage for 60min, will also give workable mix for 120min.
4. It can also be deduced that after 120min, there is regular drop in loss of workability for 180min and 240min.

VII. C2-SP7

Table 40 Marsh flow time readings for C2-SP7 (W/C = 0.45)

%age of plasticizer	SP7				
	5 min	60 min	120 min	180 min	240 min
0.5%	79.7	143.22	156.82	173.91	197.38
0.7%	51.29	123.77	141.37	162.28	179.87
0.9%	34.93	90.25	111.19	149.36	161.25
1.1%	29.41	81.79	92.24	128.64	153.94
1.3%	28.58	79.51	89.85	115.39	151.48
1.5%	26.65	77.12	87.34	114.73	148.96

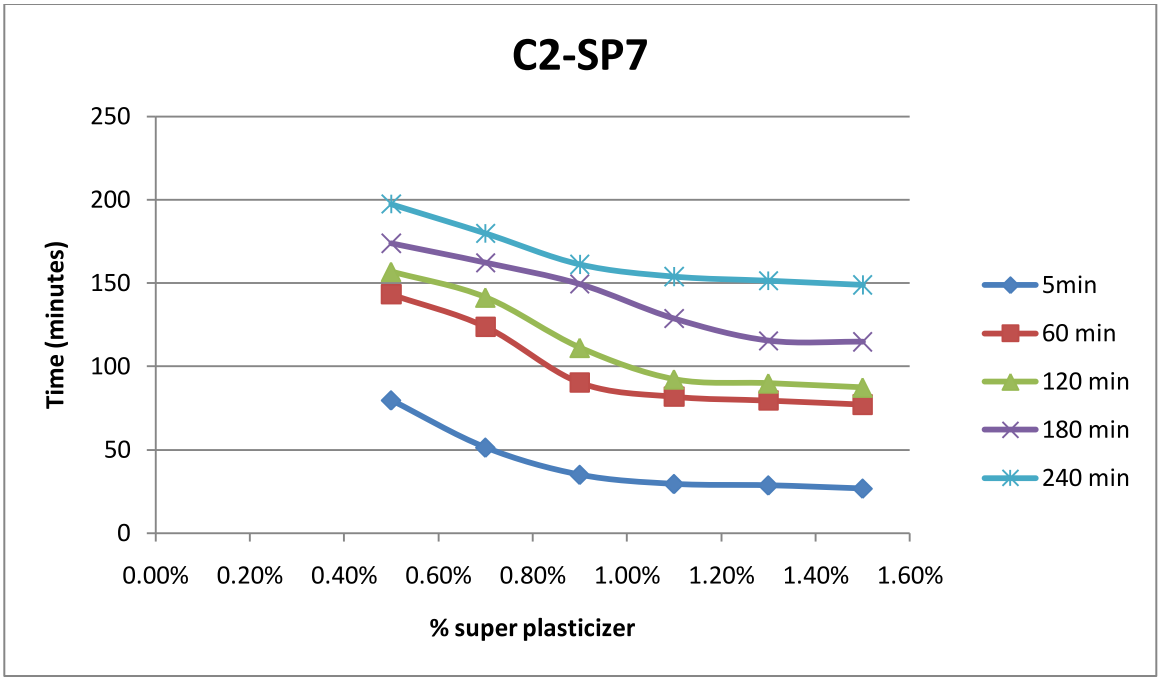


Fig 59 Graph between dosage of SP and Marsh flow time for C2-SP7 (w/c =0.45)

DISCUSSION

1. The graph shows the compatibility among cement- super-plasticizer combination; the saturation dosage is fairly low i.e. 1.1%.
2. As relevant from the curve, 60min curve is not close to 5min curve. Therefore there will be noteworthy loss of workability after 5min.
3. The 120min and 60min curve are getting quite close after saturation dosage of 60min curve. This shows that the addition of dosage at and beyond the saturation dosage for 60min, will also give workable mix for 120min.
4. It can also be deduced that after 120min, there is regular drop in loss of workability for 180min and 240min.

VIII. C2-SP8

Table 41 Marsh flow time readings for C2-SP8 (W/C = 0.45)

%age of plasticizer	SP8				
	5 min	60 min	120 min	180 min	240 min
0.5%	65.17	157.83	171.62	189.03	211.27
0.7%	52.97	132.66	162.94	170.58	199.05
0.9%	41.75	113.21	149.33	153.46	178.24
1.1%	39.68	110.14	137.49	142.17	159.79
1.3%	38.36	109.79	131.34	139.88	157.23
1.5%	37.09	107.38	129.52	138.37	156.77

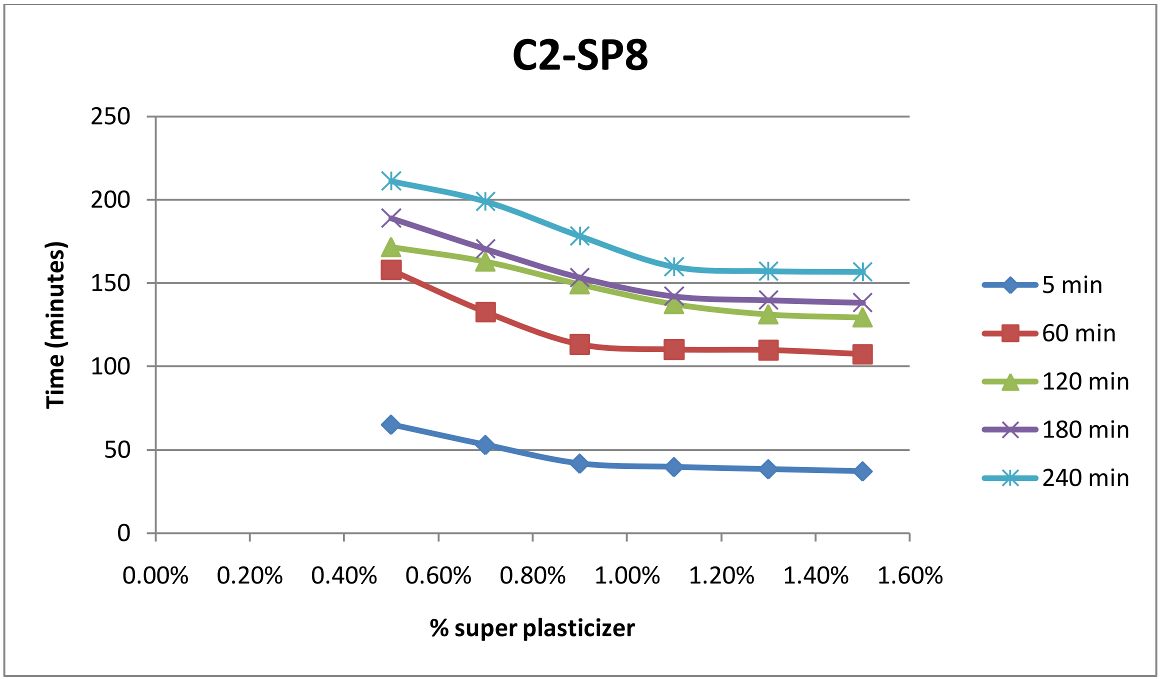


Fig 60 Graph between dosage of SP and Marsh flow time for C2-SP8 (w/c =0.45)

DISCUSSION

1. The curve represents the compatibility among cement- super-plasticizer couple; the saturation dosage is reasonably low i.e. 0.9%.
2. As apparent from the curve, 60min curve is fairly apart from 5min curve. Therefore there will be remarkable loss of workability after 5min.
3. The 120min and 180min curve are quite close for every dosage of SP. This shows that the addition of dosage at and beyond the saturation dosage for 120min, will also give workable mix for 180min, without any loss of workable mix.
4. It can also be deduced that after 120min, there is regular drop in loss of workability amid 180min and 240min curve.

5.7 OBSERVATIONS FOR C3, W/C= 0.45)

I. C3-SP1

Table 42 Marsh flow time readings for C3-SP1 (W/C = 0.45)

%age of plasticizer	SP1				
	5 min	60 min	120 min	180 min	240 min
0.5%	48.86	65.59	82.23	97.37	Sample set. No Flowability.
0.7%	40.08	55.93	71.94	83.88	
0.9%	33.27	45.94	54.86	67.62	
1.1%	31.42	43.67	51.79	56.29	
1.3%	31.36	41.16	49.04	53.51	
1.5%	31.48	40.27	47.47	51.06	

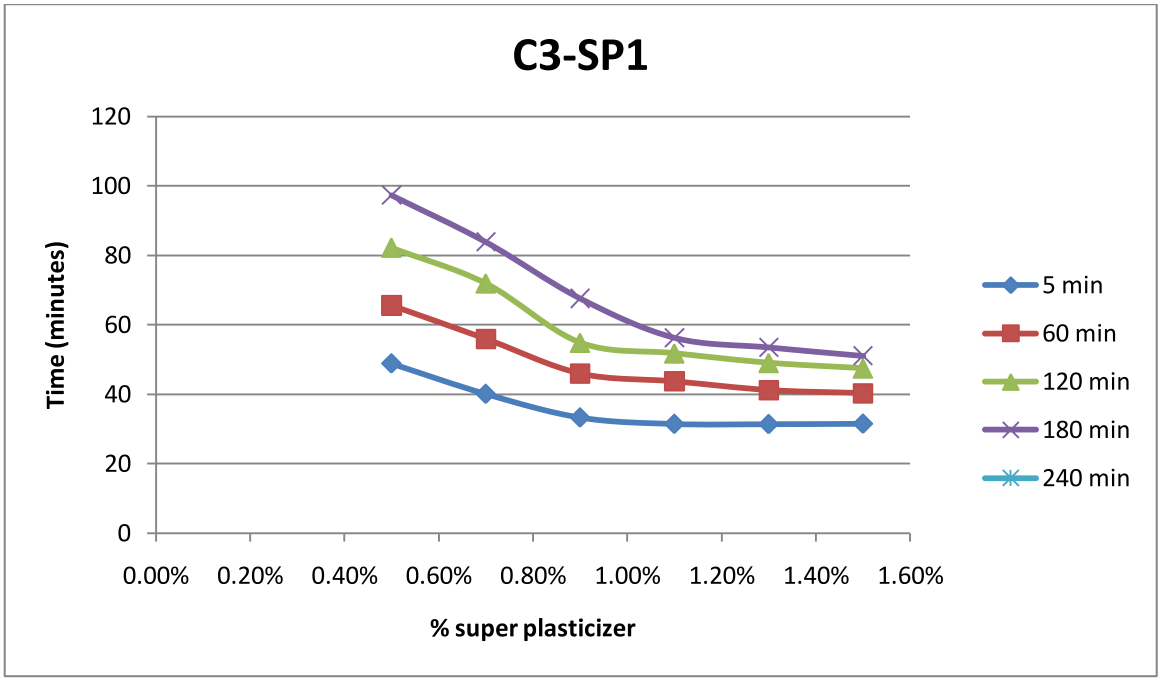


Fig 61 Graph between dosage of SP and Marsh flow time for C3-SP1 (w/c =0.45)

DISCUSSION

1. The graph shows the compatible cement- super-plasticizer couple; the saturation dosage is quite low i.e. 0.9%.
2. As visible from the curve, 60min curve is not close to 5min curve. Therefore there will be some loss of flowability after 5min.
3. The 120min and 60min curve are quite close after saturation point. This shows that the addition of dosage at and beyond the saturation dosage for 60min, will also give workable mix for 120min without loss of workability, the optimum dosage for which is also 0.9%.

II. C3-SP2

Table 43 Marsh flow time readings for C3-SP2 (W/C = 0.45)

%age of plasticizer	SP2				
	5 min	60 min	120 min	180 min	240 min
0.5%	34.26	41.52	45.37	50.17	55.07
0.7%	29.47	33.63	36.92	41.56	49.82
0.9%	25.72	27.04	31.39	35.31	41.23
1.1%	24.66	25.23	28.21	31.85	36.44
1.3%	23.76	24.46	27.48	30.77	33.58
1.5%	23.41	23.81	26.69	29.68	32.23

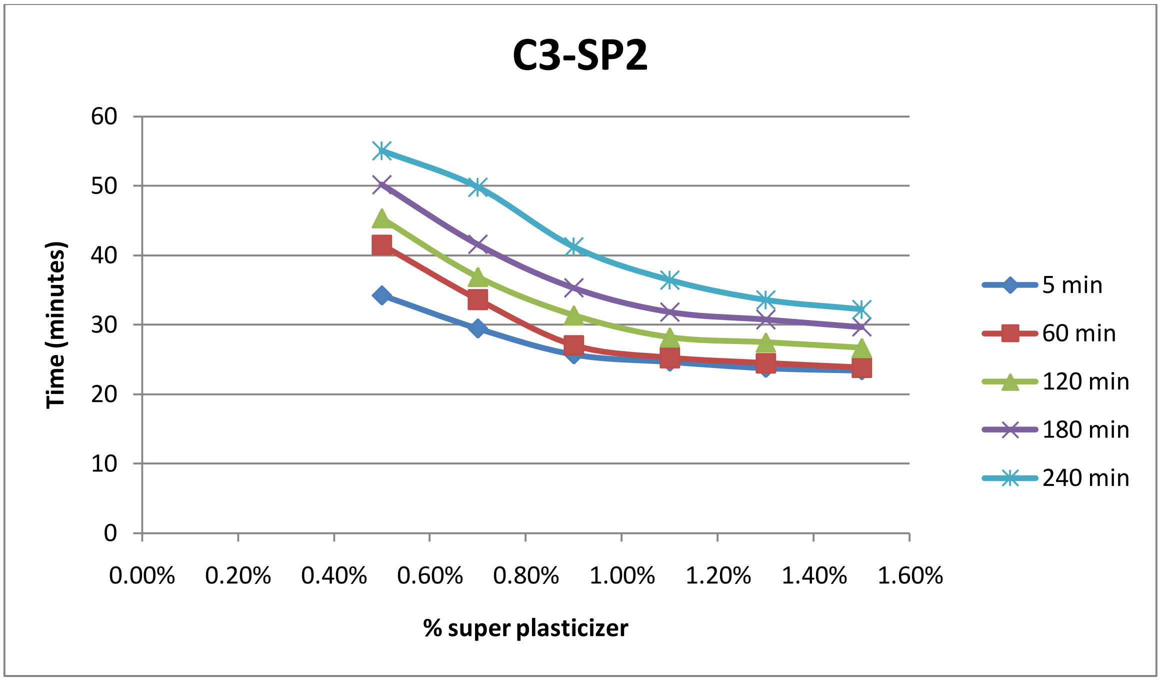


Fig 62 Graph between dosage of SP and Marsh flow time for C3-SP2 (w/c =0.45)

DISCUSSION

1. The curve represents the perfectly compatible cement- super-plasticizer combination; the saturation dosage is low i.e. 0.9%, makes it cost effective.
2. As apparent from graph, the curves for 5min and 60min curves are too close. Therefore there will not be any loss of flowability after mixing till 60min.
3. Beyond 120min there is comparatively reduction in workability, but not for much extent.
4. As the dosage of super-plasticizer is increased beyond saturation dosage i.e. 1.1% for 180min and 1.3% for 240min, the loss in flowability between the curves is reducing.

III. C3-SP3

Table 44 Marsh flow time readings for C3-SP3 (W/C = 0.45)

%age of plasticizer	SP3				
	5 min	60 min	120 min	180 min	240 min
0.5%	35.63	40.73	44.41	49.38	53.03
0.7%	33.29	37.55	40.34	44.81	46.24
0.9%	31.4	33.17	37.72	40.48	43.47
1.1%	30.89	31.62	34.16	36.26	41.32
1.3%	30.13	30.97	33.77	35.31	40.41
1.5%	29.94	30.22	32.86	34.92	39.77

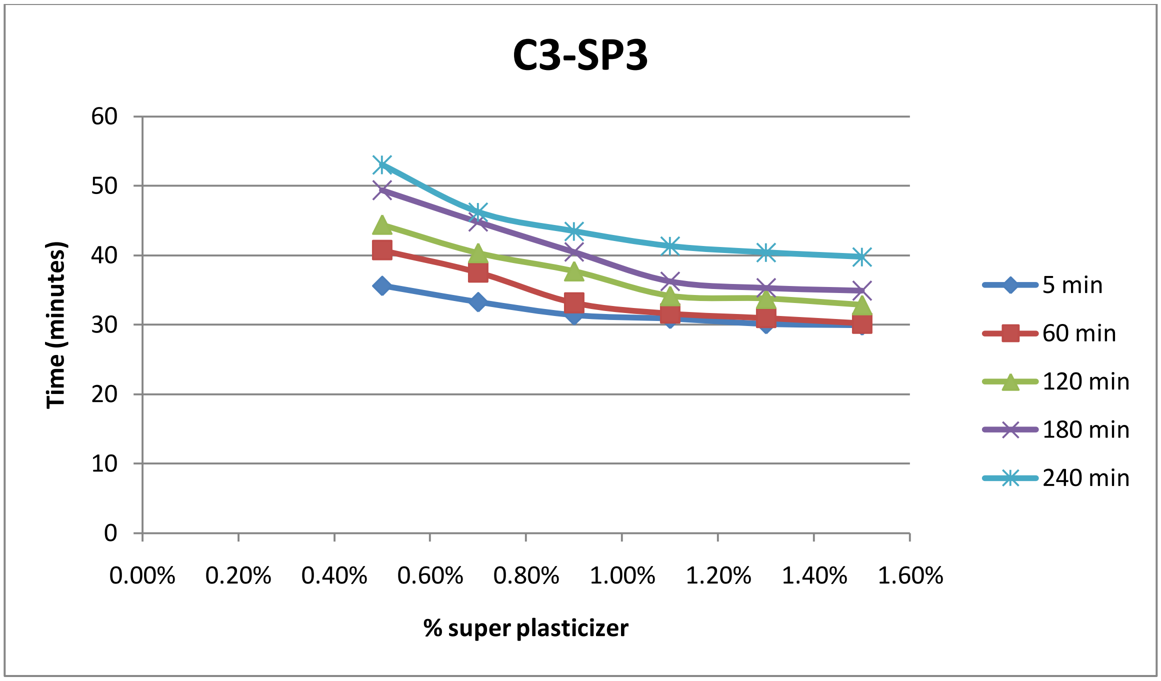


Fig 63 Graph between dosage of SP and Marsh flow time for C3-SP3 (w/c =0.45)

DISCUSSION

1. The curve imparts the perfectly compatible cement- super-plasticizer couple; the saturation dosage is low i.e. 0.9%, makes it economical.
2. It is evident from the graph, the curves for 5min and 60min are too close. Consequently, there will not be any loss of flowability after mixing of slurry till 60min.
3. After 60min there is comparatively lower reduction in workability till 180 min, but not for much extent.
4. As the dosage of super-plasticizer is increased beyond saturation dosage i.e. 1.1% for 180min and 1.3% for 240min, the loss in flowability between the curves is increasing as the curves are getting quite apart.

IV. C3-SP4

Table 45 Marsh flow time readings for C3-SP4 (W/C = 0.45)

%age of plasticizer	SP4				
	5 min	60 min	120 min	180 min	240 min
0.5%	43.52	54.77	66.34	89.45	101.14
0.7%	39.68	49.6	60.56	72.73	91.62
0.9%	36.41	43.89	53.48	61.45	80.13
1.1%	33.6	40.23	43.79	51.09	68.52
1.3%	32.26	37.48	41.42	48.24	64.41
1.5%	31.91	37.03	40.84	47.75	62.88

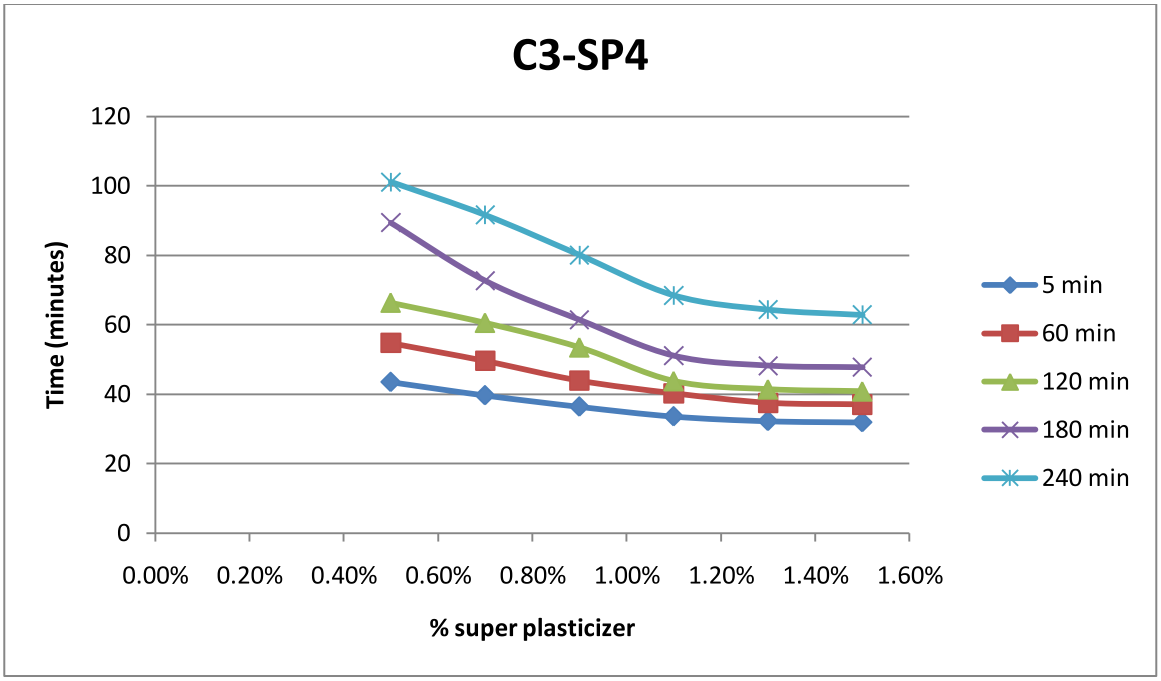


Fig 64 Graph between dosage of SP and Marsh flow time for C3-SP4 (w/c =0.45)

DISCUSSION

1. The curve represents the perfect compatibility between cement- super-plasticizer combination; the saturation dosage is low i.e. 1.1%, makes it cost-effective.
2. It is apparent from the graph, the 5min, 60min and 120 min curves are quite close after addition of saturation dosage. Consequently, there will not be noteworthy loss of flowability after mixing of slurry till 120min.
3. Also, the loss of flowability amid 180min and 240min is comparatively high.

V. C3-SP5

Table 46 Marsh flow time readings for C3-SP5 (W/C = 0.45)

%age of plasticizer	SP5				
	5 min	60 min	120 min	180 min	240 min
0.5%	69.31	78.85	91.79	119.16	129.81
0.7%	57.78	63.46	82.51	106.74	119.02
0.9%	54.23	57.68	69.26	89.77	101.51
1.1%	51.69	54.39	64.58	78.46	85.61
1.3%	50.12	52.11	60.69	74.35	82.18
1.5%	49.79	51.87	61.53	73.27	79.46

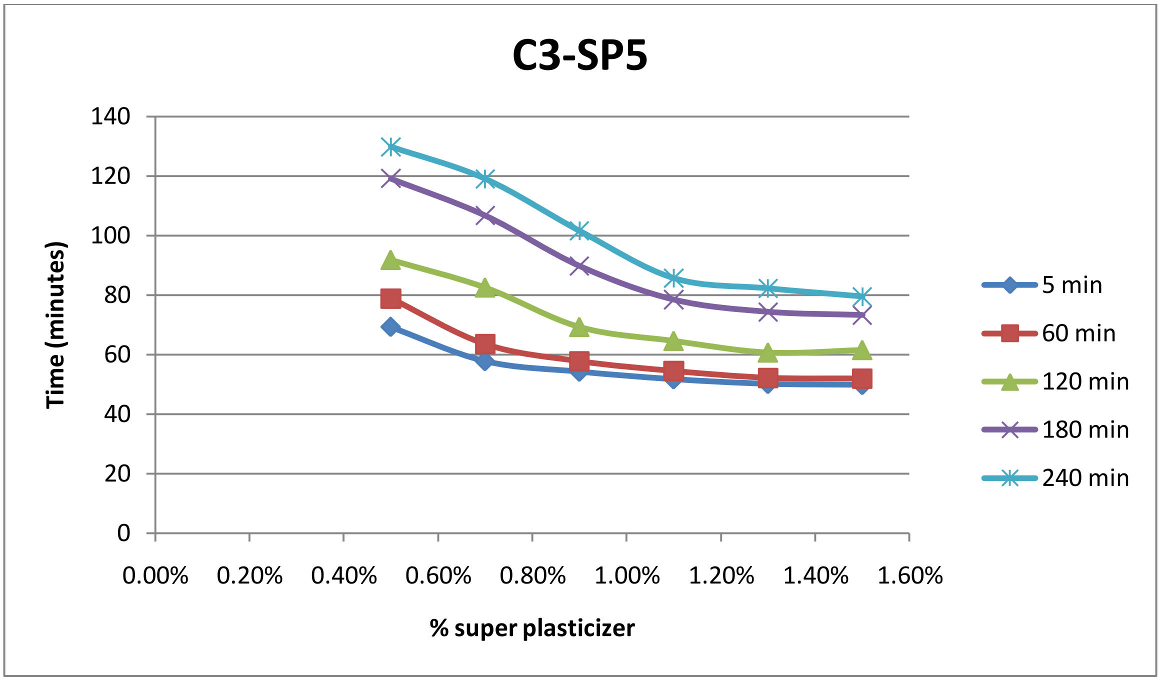


Fig 65 Graph between dosage of SP and Marsh flow time for C3-SP5 (w/c =0.45)

DISCUSSION

1. The curve represents the perfectly compatible cement- super-plasticizer combination; the saturation dosage is low i.e. 1.1%, makes it cost effective.
2. As noticeable from graph, the curves for 5min and 60min curves are very close. Henceforth, there will not be any loss of flowability after addition of SP in mix till 60min.
3. Beyond 120min there is comparatively reduction in workability for 180min.
4. As the dosage of super-plasticizer is increased beyond saturation dosage i.e. 1.3% for 180min and 240min, the loss in flowability between the curves is reducing.

VI. C3-SP6

Table 47 Marsh flow time readings for C3-SP6 (W/C = 0.45)

%age of plasticizer	SP6				
	5 min	60 min	120 min	180 min	240 min
0.5%	48.57	54.72	61.48	65.83	73.29
0.7%	41.62	49.41	57.39	60.74	67.55
0.9%	35.82	42.37	48.26	54.33	58.39
1.1%	34.95	40.52	46.65	51.29	55.56
1.3%	33.87	38.04	44.77	48.82	51.53
1.5%	33.17	37.64	43.48	47.68	50.24

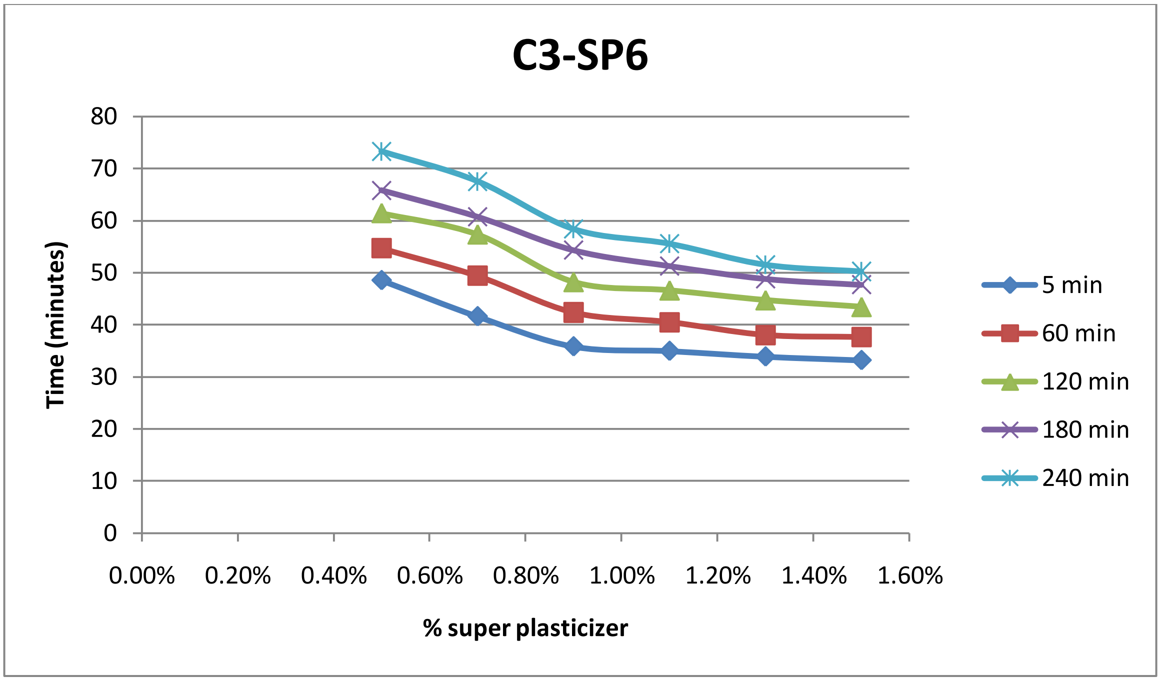


Fig 66 Graph between dosage of SP and Marsh flow time for C3-SP6 (w/c =0.45)

DISCUSSION

1. The graph represents the compatible cement- super-plasticizer couple; the saturation dosage is moderately low i.e. 0.9%.
2. As evident from the graph, 5min, 60min, 120min, 180min and 240min curves are showing almost same behavior for every dosage. This imparts that there is regular drop in flowability after 5min and every time interval.

VII. C3-SP7

Table 48 Marsh flow time readings for C3-SP7 (W/C = 0.45)

%age of plasticizer	SP7				
	5 min	60 min	120 min	180 min	240 min
0.5%	43.65	49.56	55.54	61.47	72.43
0.7%	38.69	45.44	50.35	54.62	63.67
0.9%	34.51	37.93	42.24	47.86	56.94
1.1%	30.5	33.36	36.63	40.18	48.23
1.3%	29.41	30.81	34.78	37.22	45.56
1.5%	28.98	31.08	33.53	36.47	43.74

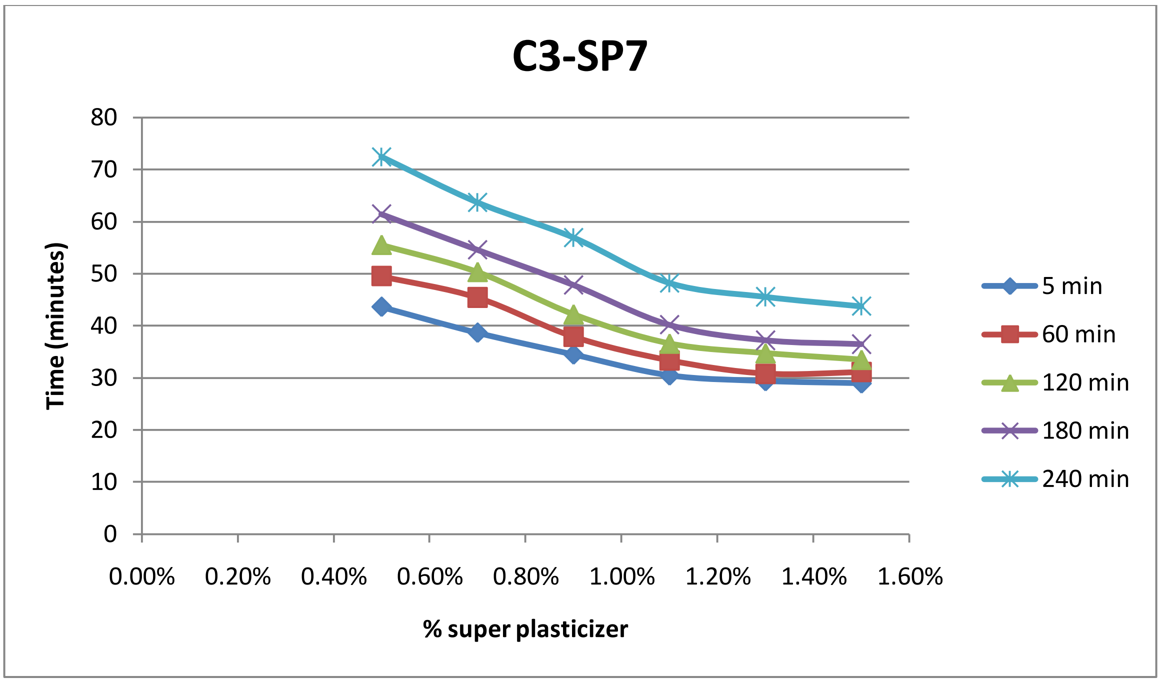


Fig 67 Graph between dosage of SP and Marsh flow time for C3-SP7 (w/c =0.45)

DISCUSSION

1. The curve shows the perfect compatibility between cement- super-plasticizer couple; the saturation dosage is low i.e. 1.1%, makes it cost effective.
2. As noticeable from graph, the curves for 5min and 60min curves are very close. Henceforth, there will not be any loss of flowability after addition of SP in mix till 60min.
3. As evident from the graph, 60min, 120min and 180min curves are very close to each other and are showing almost same behavior for every dosage. This imparts that there is regular drop in flowability after 5min and every time interval.
4. Also, there is some loss of flowability amid 180min and 240min, the optimum dosage for both of which is 1.3%.

VIII. C3-SP8

Table 49 Marsh flow time readings for C3-SP8 (W/C = 0.45)

%age of plasticizer	SP8				
	5 min	60 min	120 min	180 min	240 min
0.5%	58.99	65.36	78.9	94.26	119.21
0.7%	54.12	59.39	70.49	86.73	107.18
0.9%	51.67	54.58	62.66	76.62	93.94
1.1%	50.18	52.57	58.81	70.03	89.88
1.3%	48.71	50.32	56.27	67.68	85.47
1.5%	47.94	49.76	55.16	65.46	84.28

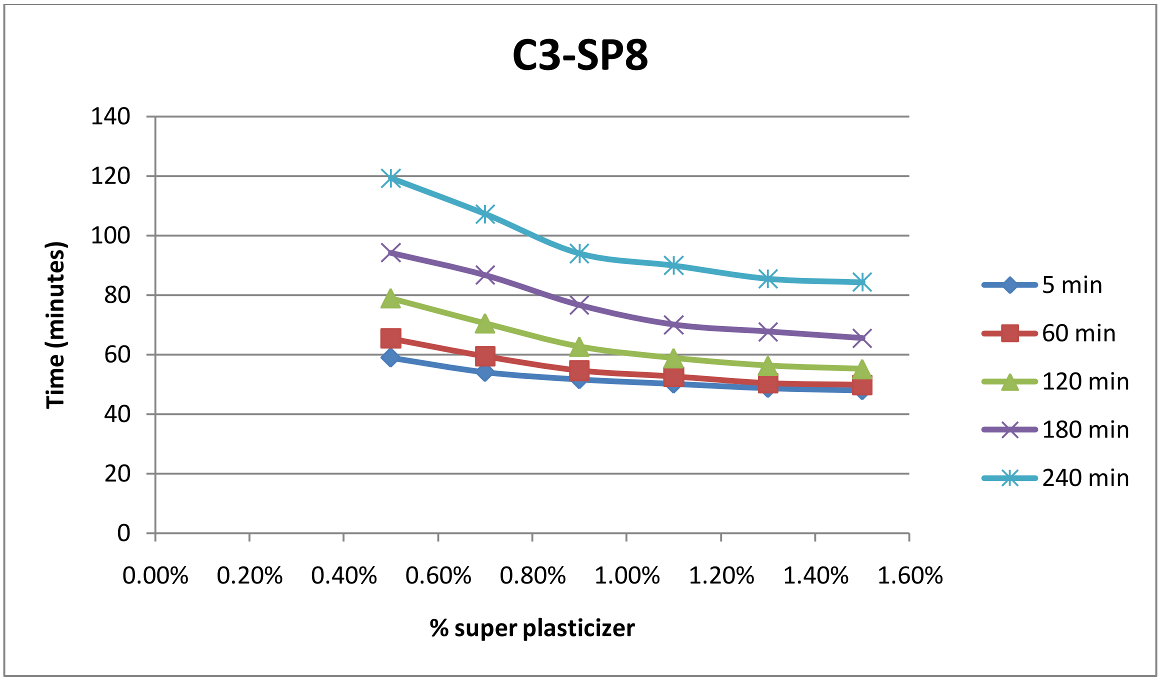


Fig 68 Graph between dosage of SP and Marsh flow time for C3-SP8 (w/c =0.45)

DISCUSSION

1. The curve show the perfectly compatible cement- super-plasticizer couple; the saturation dosage is low i.e. 0.9%, makes it cost-effective.
2. It is evident from the graph; the curves for 5min and 60min are too close and follow the similar behavior for every dosage of SP. Consequently, there will not be any loss of flowability after mixing of slurry till 60min.
3. Beyond 120min, there is considerable loss of workability till 240min, the optimum dosage for which is 1.3%.

Chapter – 6

DEVELOPMENT OF EQUATIONS

6.1 INTRODUCTION

This chapter concludes about the compatibility equations for different cement with different chemical family of super-plasticizer. These compatibility equations are determined from the experimental data and also conclude with corresponding coefficient of correlation.

6.2 COMPATIBILITY EQUATIONS

Included Compatibility equations help in determining the optimum dose of super-plasticizer of particular chemical family for cement C1, C2 and C3 at w/c ratio of 0.45 and 0.5 respectively. These equations thus helpful for Concrete Industry to use optimum dose of super-plasticizer without undergoing laboratory test to determine optimum dose for above stipulated cements.

6.3 COMPATIBILITY EQUATION FOR (C1) AT W/C 0.45 FOR-

a) *Chemical Family* - Poly Carboxylate Ether (PCE)
[SP1, SP2, SP3]

$y = 0.0006x + 1.0861$

$R = 0.950$

$R^2 = 0.9038$

'y'= Optimum dose of Super-plasticizer of Poly Carboxylate Ether family

'x'= Time in minutes

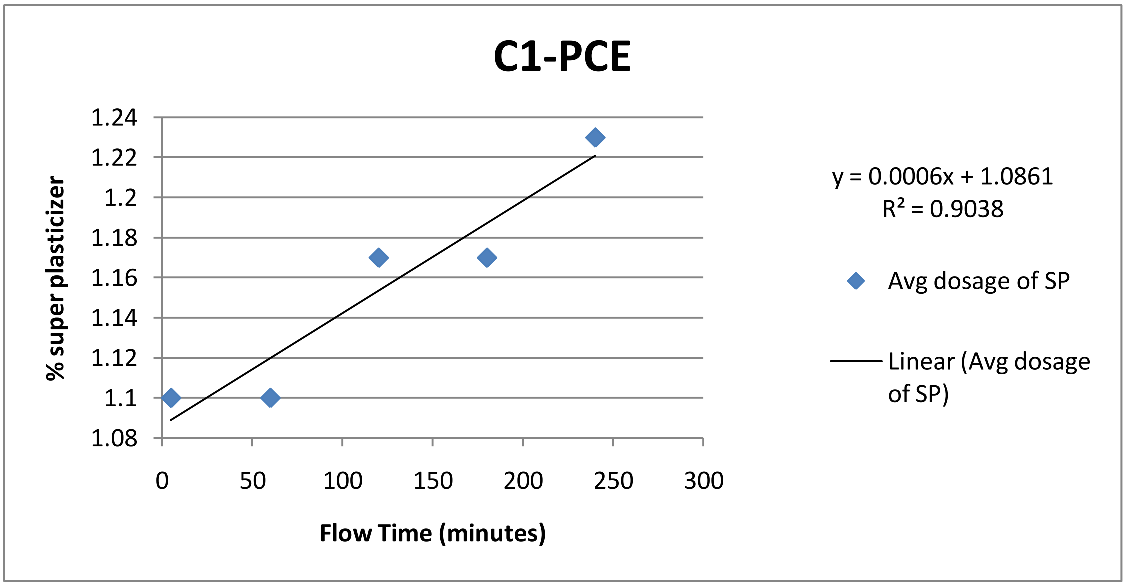


Fig 69 Graph showing trend line for C1 – PCE, w/c = 0.45

Table 50 Optimum Dosage for PCE based SP for C1, w/c = 0.45

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP1	SP2	SP3	
5 min	0.9	1.1	1.3	1.1
60 min	0.9	1.1	1.3	1.1
120 min	1.1	1.3	1.1	1.17
180 min	1.1	1.3	1.1	1.17
240 min	1.1	1.3	1.3	1.23

b) ***Chemical Family-*** **Modified Sulphonated Naphthalene Formaldehyde (SNF)**

[SP4, **SP8**]

y = 0.0015x + 0.9955

R = 0.865

R^2 = 0.7498

'y'= Optimum dose of Super-plasticizer of Modified Sulphonated Naphthalene Formaldehyde (SNF) family

'x'= Time in minutes

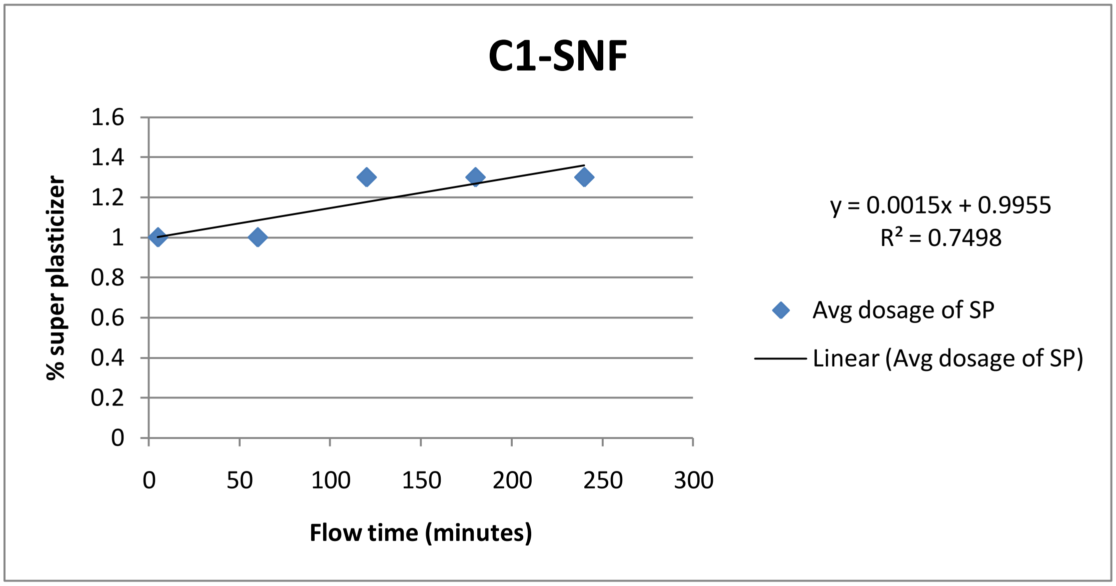


Fig 70 Graph showing trend line for C1 – SNF, w/c = 0.45

Table 51 Optimum Dosage for SNF based SP for C1, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %		Average
	SP4	SP8	
5 min	0.9	1.1	1
60 min	0.9	1.1	1
120 min	1.3	1.3	1.3
180 min	1.3	1.3	1.3
240 min	1.3	1.3	1.3

c) *Chemical Family*- Sulphonated Naphthalene Polymer (SNP) [SP5, SP6, SP7]

y = 0.0014x + 1.0047

R = 0.897

R^2 = 0.8065

'y'= Optimum dose of Super-plasticizer of Sulphonated Naphthalene Polymer (SNP) family

'x'= Time in minutes

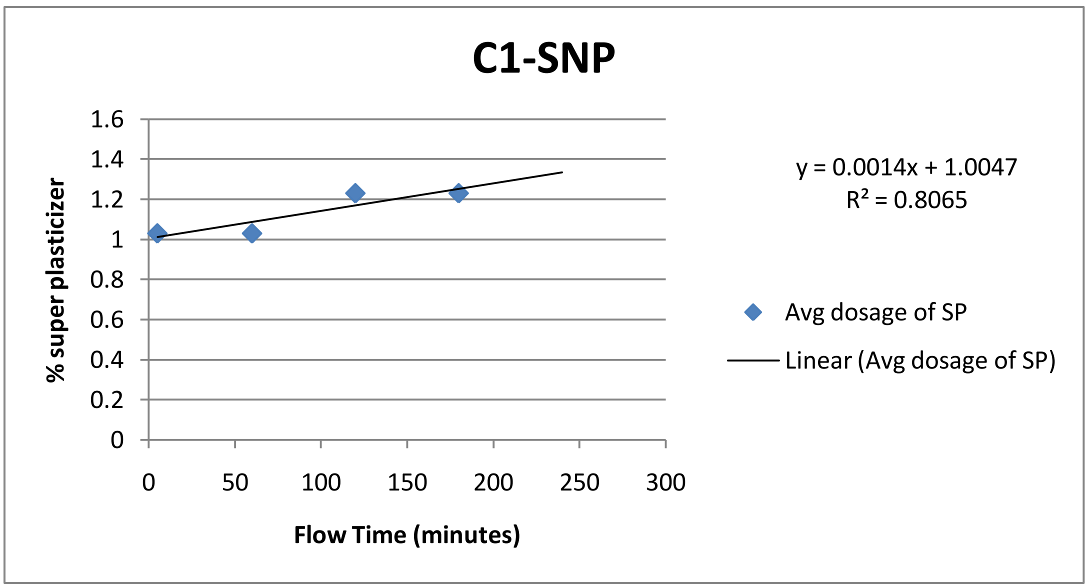


Fig 71 Graph showing trend line for C1 – SNP, w/c = 0.45

Table 52 Optimum Dosage for SNP based SP for C1, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP5	SP6	SP7	
5 min	1.1	0.9	1.1	1.03
60 min	1.1	0.9	1.1	1.03
120 min	1.3	1.1	1.3	1.23
180 min	1.3	1.1	1.3	1.23
240 min	1.1	1.1	1.1	1.1*

***** neglected due to randomness

6.4 COMPATIBILITY EQUATION FOR (C2) AT W/C 0.45 FOR-

a) *Chemical Family* - Poly Carboxylate Ether (PCE)
[SP1, SP2, SP3]

$y = 0.0009x + 1.0151$

$R = 0.939$

$R^2 = 0.8835$

'y'= Optimum dose of Super-plasticizer of Poly Carboxylate Ether family

'x'= Time in minutes

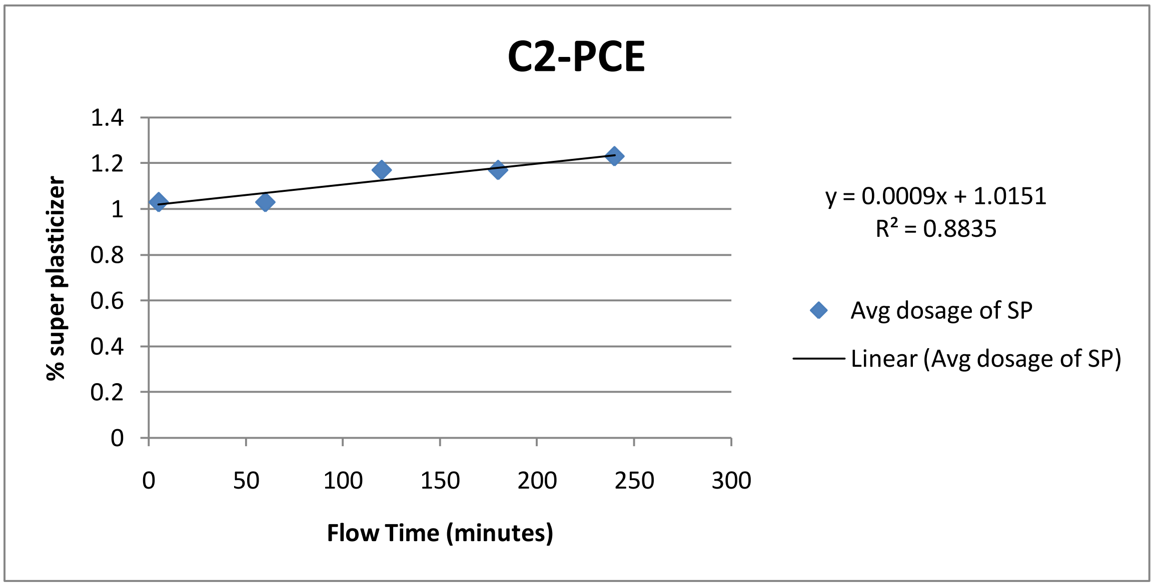


Fig 72 Graph showing trend line for C2 – PCE, w/c = 0.45

Table 53 Optimum Dosage for PCE based SP for C2, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP1	SP2	SP3	
5 min	1.1	0.9	1.1	1.03
60 min	1.1	0.9	1.1	1.03
120 min	1.1	1.1	1.3	1.17
180 min	1.1	1.1	1.3	1.17
240 min	1.1	1.3	1.3	1.23

b) *Chemical Family-* Modified Sulphonated Naphthalene Formaldehyde (SNF)

[SP4, SP8]

y = 0.001x + 0.997

R = 0.865

R^2 = 0.7498

'y'= Optimum dose of Super-plasticizer of Modified Sulphonated Naphthalene Formaldehyde (SNF) family

'x'= Time in minutes

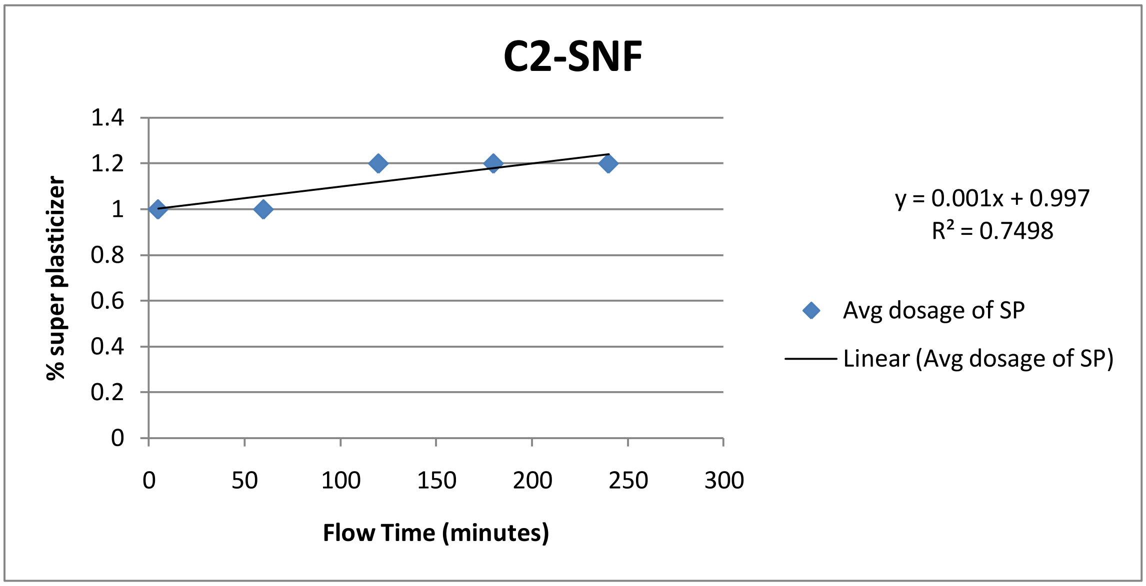


Fig 73 Graph showing trend line for C2 – SNF, w/c = 0.45

Table 54 Optimum Dosage for SNF based SP for C2, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %		Average
	SP4	SP8	
5 min	1.1	0.9	1
60 min	1.1	0.9	1
120 min	1.1	1.3	1.2
180 min	1.3	1.1	1.2
240 min	1.3	1.1	1.2

c) ***Chemical Family*- Sulphonated Naphthalene Polymer (SNP) [SP5, SP6, SP7]**

y = 0.0011x + 1.0144

R = 0.880

R^2 = 0.775

'y'= Optimum dose of Super-plasticizer of Sulphonated Naphthalene Polymer (SNP) family

'x'= Time in minutes

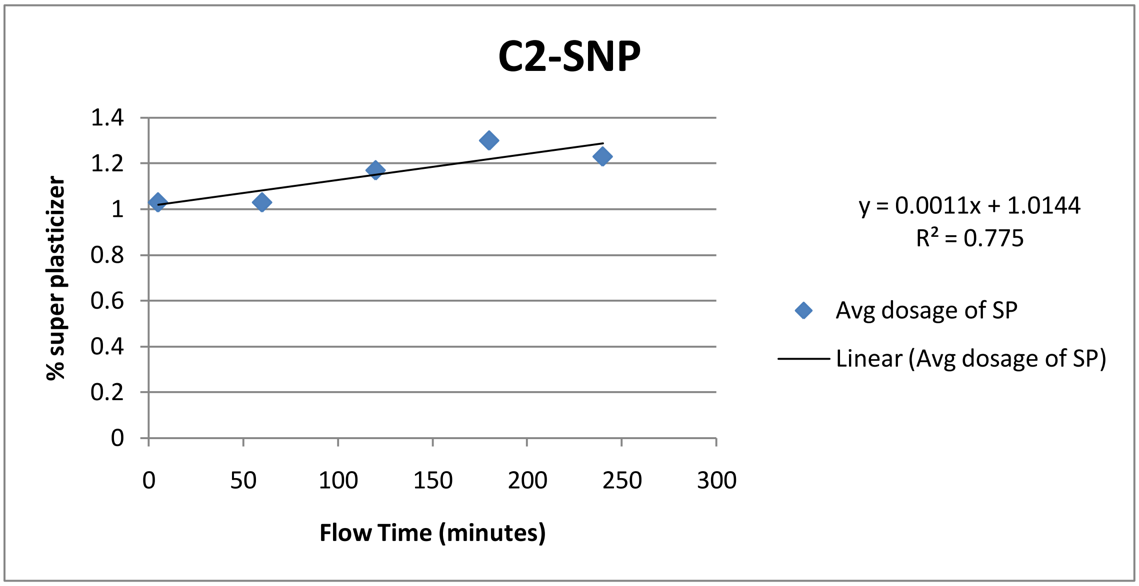


Fig 74 Graph showing trend line for C2 – SNP, w/c = 0.45

Table 55 Optimum Dosage for SNP based SP for C2, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP5	SP6	SP7	
5 min	0.9	1.1	1.1	1.03
60 min	0.9	1.1	1.1	1.03
120 min	1.1	1.3	1.1	1.17
180 min	1.3	1.3	1.3	1.3
240 min	1.3	1.3	1.1	1.23

6.5 COMPATIBILITY EQUATION FOR (C3) AT W/C 0.45 FOR-

a) ***Chemical Family*** **- Poly Carboxylate Ether (PCE)**
[SP1, SP2, SP3]

y = 0.0013x + 0.868

R = 0.953

R^2 = 0.9089

'y'= Optimum dose of Super-plasticizer of Poly Carboxylate Ether family

'x'= Time in minutes

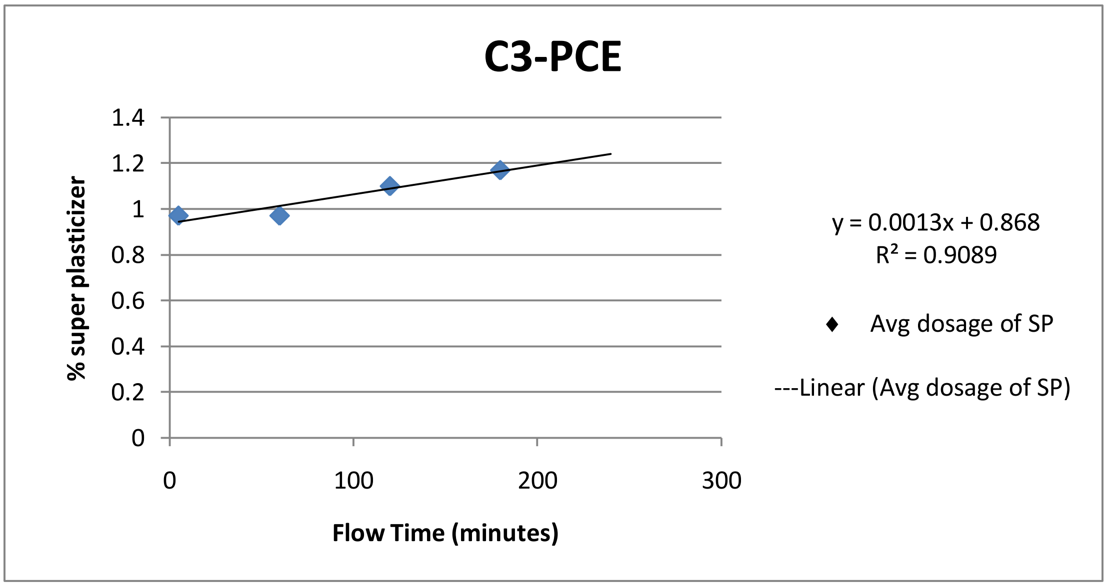


Fig 75 Graph showing trend line for C3 – PCE, w/c =0.45

Table 56 Optimum Dosage for PCE based SP for C3, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP1	SP2	SP3	
5 min	0.9	0.9	0.9	0.9
60 min	0.9	0.9	0.9	0.9
120 min	0.9	1.1	1.1	1.03
180 min	1.1	1.1	1.1	1.1
240 min	-	1.3	1.3	0.87*

***** neglected due to randomness

b) *Chemical Family*- Modified Sulphonated Naphthalene Formaldehyde (SNF)

[SP4, SP8]

y = 0.0012x + 0.9558

R = 0.907

R^2 = 0.8244

'y'= Optimum dose of Super-plasticizer of Modified Sulphonated Naphthalene Formaldehyde (SNF) family

'x'= Time in minutes

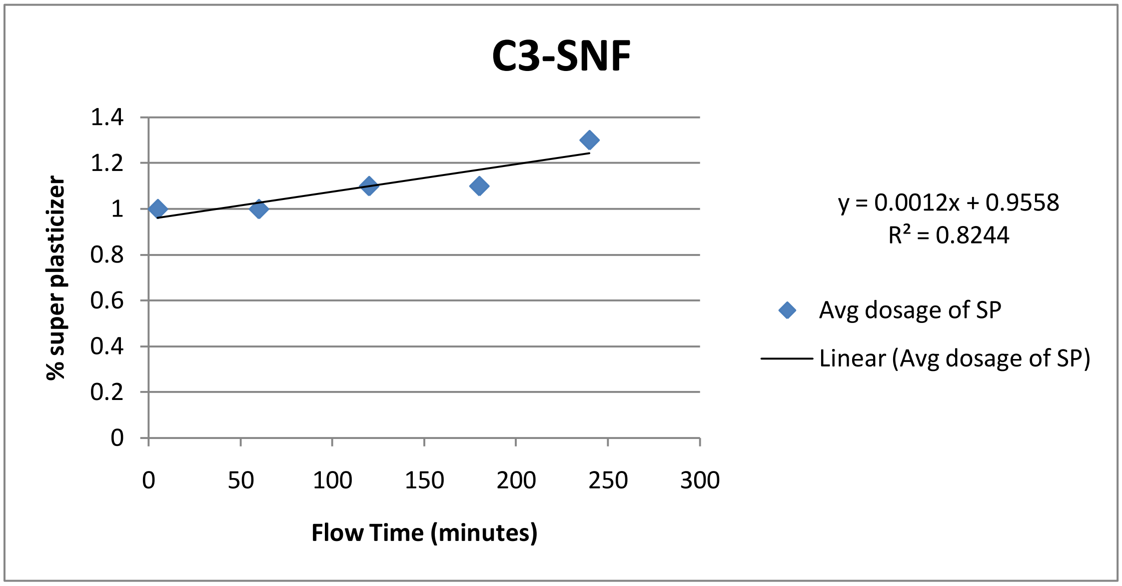


Fig 76 Graph showing trend line for C3 – SNF, w/c = 0.45

Table 57 Optimum Dosage for SNF based SP for C3, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %		Average
	SP4	SP8	
5 min	1.1	0.9	1
60 min	1.1	0.9	1
120 min	1.1	1.1	1.1
180 min	1.1	1.1	1.1
240 min	1.3	1.3	1.3

c) *Chemical Family*- Sulphonated Naphthalene Polymer (SNP) [SP5, SP6, SP7]

y = 0.0014x + 0.9393

R = 0.899

R^2 = 0.8092

'y'=Optimum dose of Super-plasticizer of Sulphonated Naphthalene Polymer (SNP) family

'x'= Time in minutes

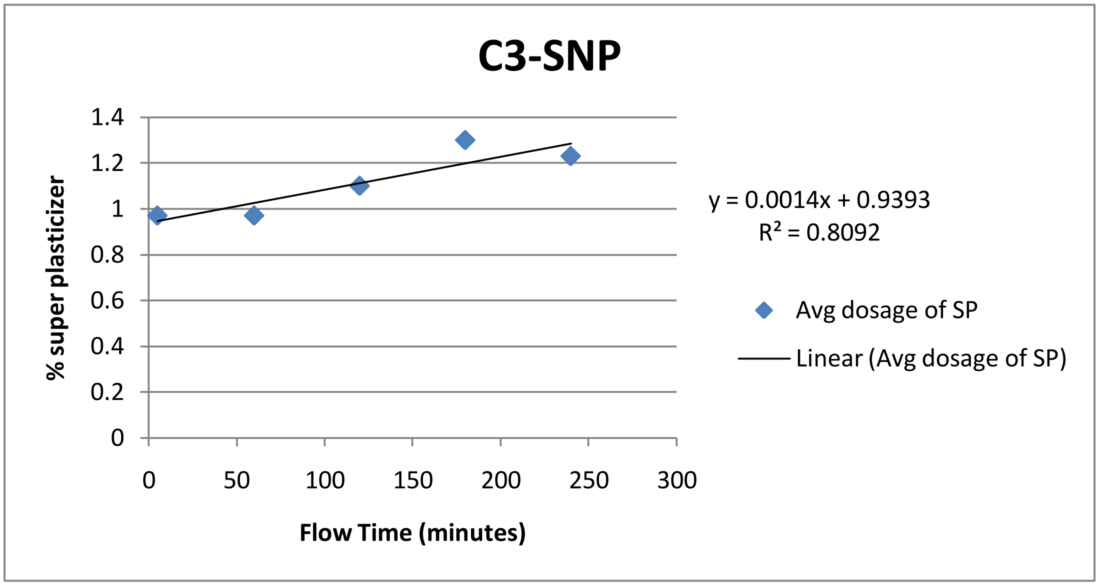


Fig 77 Graph showing trend line for C3 – SNP, w/c = 0.45

Table 58 Optimum Dosage for SNP based SP for C3, w/c 0.45

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP5	SP6	SP7	
5 min	0.9	0.9	1.1	0.97
60 min	0.9	0.9	1.1	0.97
120 min	1.3	0.9	1.1	1.1
180 min	1.3	1.3	1.3	1.3
240 min	1.1	1.3	1.3	1.23

6.6 COMPATIBILITY EQUATION FOR (C1) AT W/C 0.50 FOR-

a) ***Chemical Family*** **- Poly Carboxylate Ether (PCE)**
[SP1, SP2, SP3]

$y = 0.0008x + 1.0012$

$R = 0.913$

$R^2 = 0.8355$

'y'= Optimum dose of Super-plasticizer of Poly Carboxylate Ether family

'x'= Time in minutes

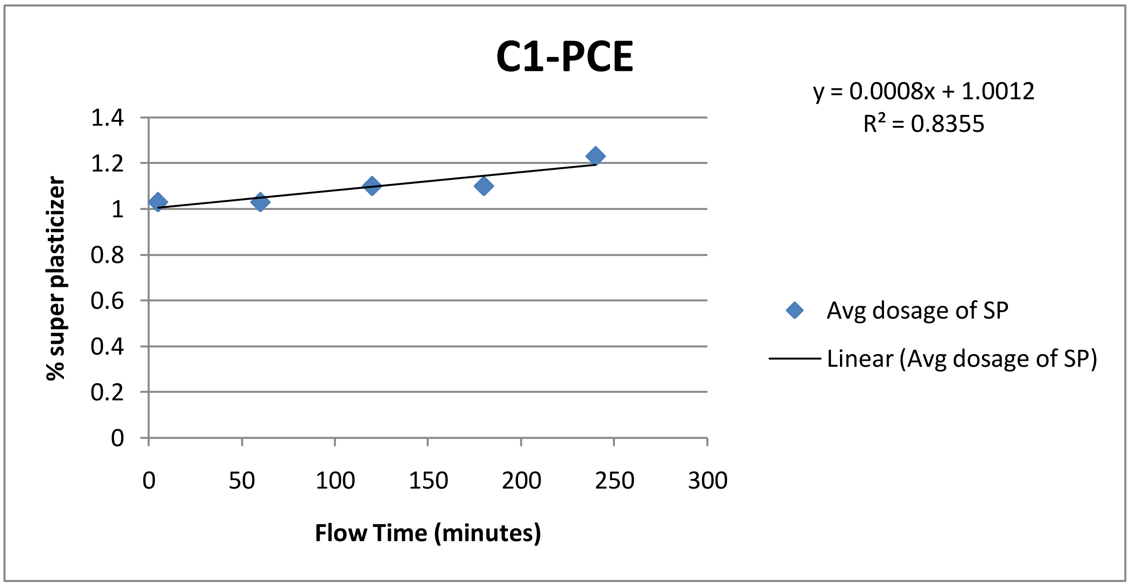


Fig 78 Graph showing trend line for C1 – PCE, w/c = 0.5

Table 59 Optimum Dosage for PCE based SP for C1, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP1	SP2	SP3	
5 min	0.9	1.1	1.1	1.03
60 min	0.9	1.1	1.1	1.03
120 min	1.1	1.1	1.1	1.1
180 min	1.1	1.1	1.1	1.1
240 min	1.3	1.1	1.3	1.23

b) *Chemical Family*- Modified Sulphonated Naphthalene Formaldehyde (SNF)

[SP4, SP8]

y = 0.0019x + 0.8538

R = 0.974

R^2 = 0.9509

'y'= Optimum dose of Super-plasticizer of Modified Sulphonated Naphthalene Formaldehyde (SNF) family

'x'= Time in minutes

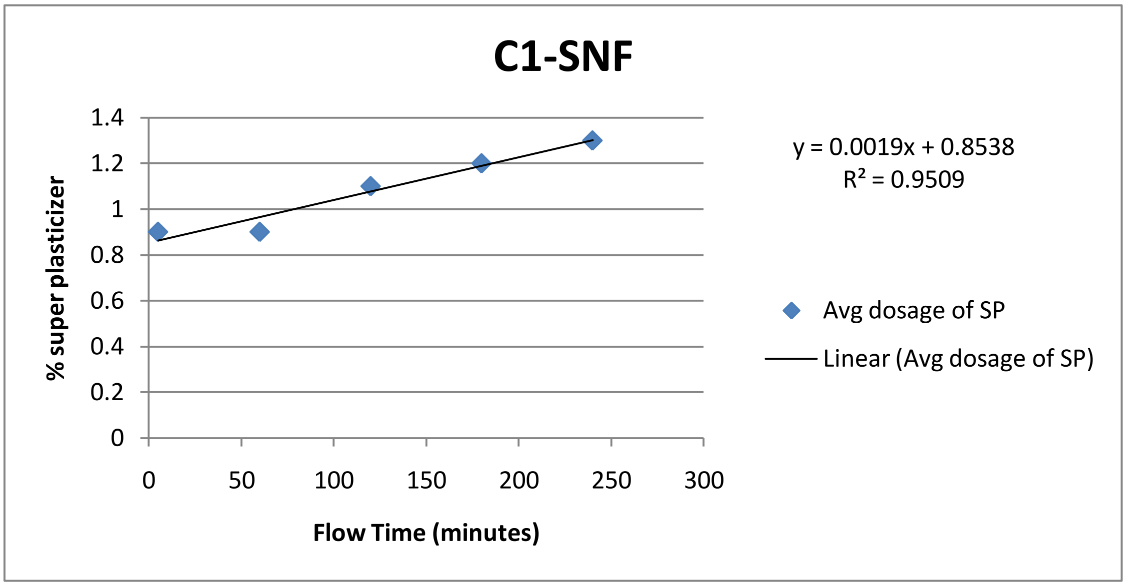


Fig 79 Graph showing trend line for C1 – SNF, w/c = 0.5

Table 60 Optimum Dosage for SNF based SP for C1, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %		Average
	SP4	SP8	
5 min	0.9	0.9	0.9
60 min	0.9	0.9	0.9
120 min	1.1	1.1	1.1
180 min	1.1	1.3	1.2
240 min	1.3	1.3	1.3

c) ***Chemical Family***- **Sulphonated Naphthalene Polymer (SNP) [SP5, SP6, SP7]**

$y = 0.0003x + 1.2208$

$R = 0.974$

$R^2 = 0.9499$

'y'=Optimum dose of Super-plasticizer of Sulphonated Naphthalene Polymer (SNP) family

'x'= Time in minutes

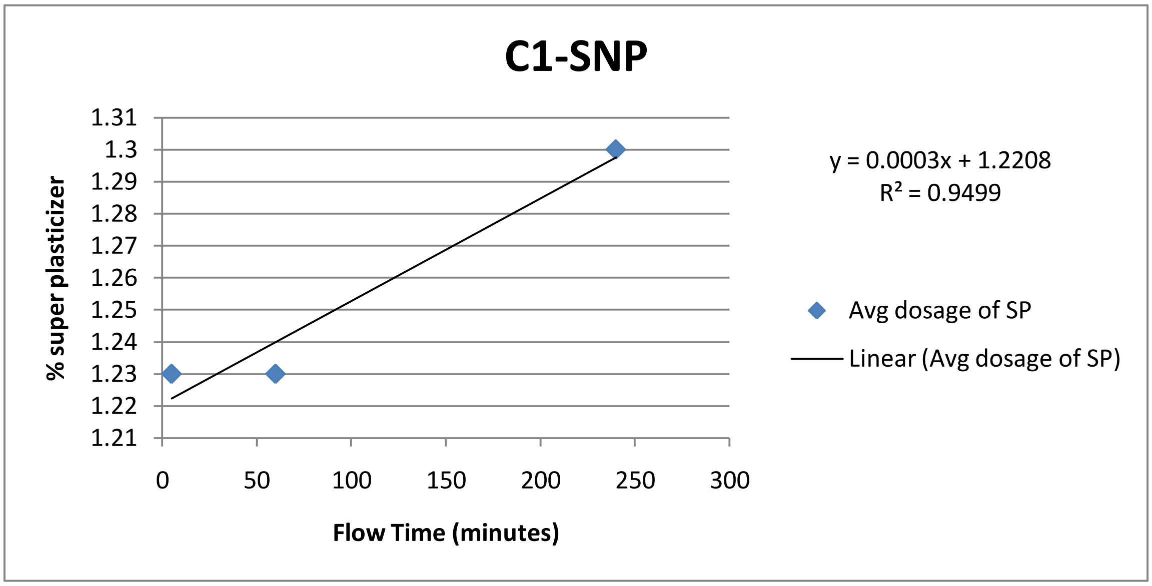


Fig 80 Graph showing trend line for C1 – SNP, w/c = 0.5

Table 61 Optimum Dosage for SNP based SP for C1, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP5	SP6	SP7	
5 min	1.3	1.1	1.3	1.23
60 min	1.3	1.1	1.3	1.23
120 min	1.1	1.1	1.1	1.1*
180 min	1.1	1.1	1.1	1.1*
240 min	1.3	1.3	1.3	1.3

***** neglected due to randomness

6.7 COMPATIBILITY EQUATION FOR (C2) AT W/C 0.50 FOR-

a) *Chemical Family* - Poly Carboxylate Ether (PCE)

[SP1, SP2, SP3]

$y = 0.0013x + 0.8305$

$R = 0.974$

$R^2 = 0.9482$

'y'= Optimum dose of Super-plasticizer of Poly Carboxylate Ether family

'x'= Time in minutes

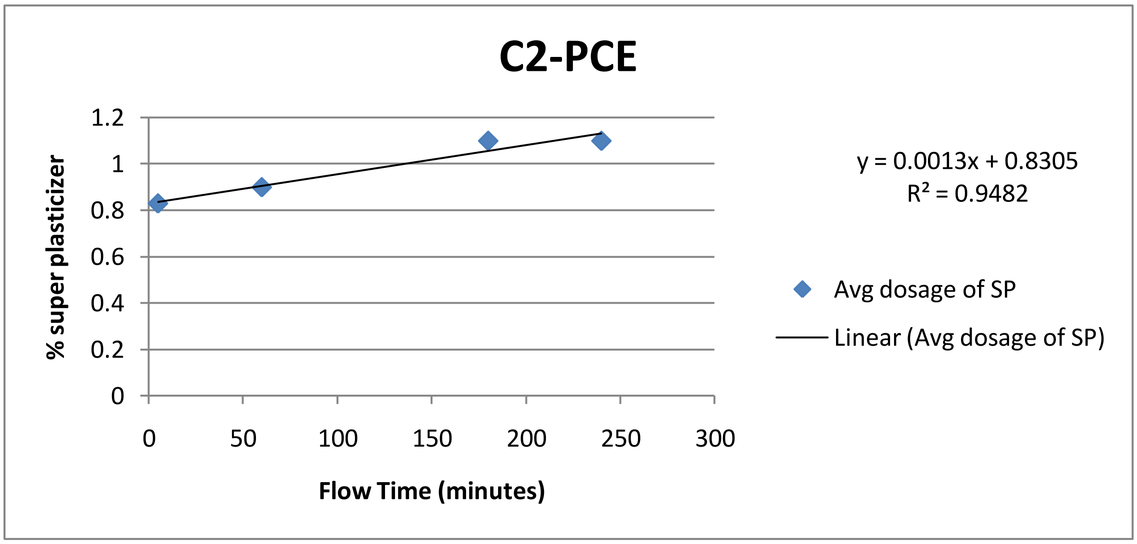


Fig 81 Graph showing trend line for C2 – PCE, w/c = 0.5

Table 62 Optimum Dosage for PCE based SP for C2, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP1	SP2	SP3	
5 min	0.9	0.9	0.7	0.83
60 min	0.9	0.9	0.9	0.9
120 min	1.3	0.9	1.3	1.17*
180 min	1.3	0.9	1.1	1.1
240 min	1.3	0.9	1.1	1.1

***** neglected due to randomness

b) *Chemical Family*- Modified Sulphonated Naphthalene Formaldehyde (SNF)

[SP4, SP8]

y = 0.0015x + 0.9751

R = 0.939

R^2 = 0.8835

'y'= Optimum dose of Super-plasticizer of Modified Sulphonated Naphthalene Formaldehyde (SNF) family

'x'= Time in minutes

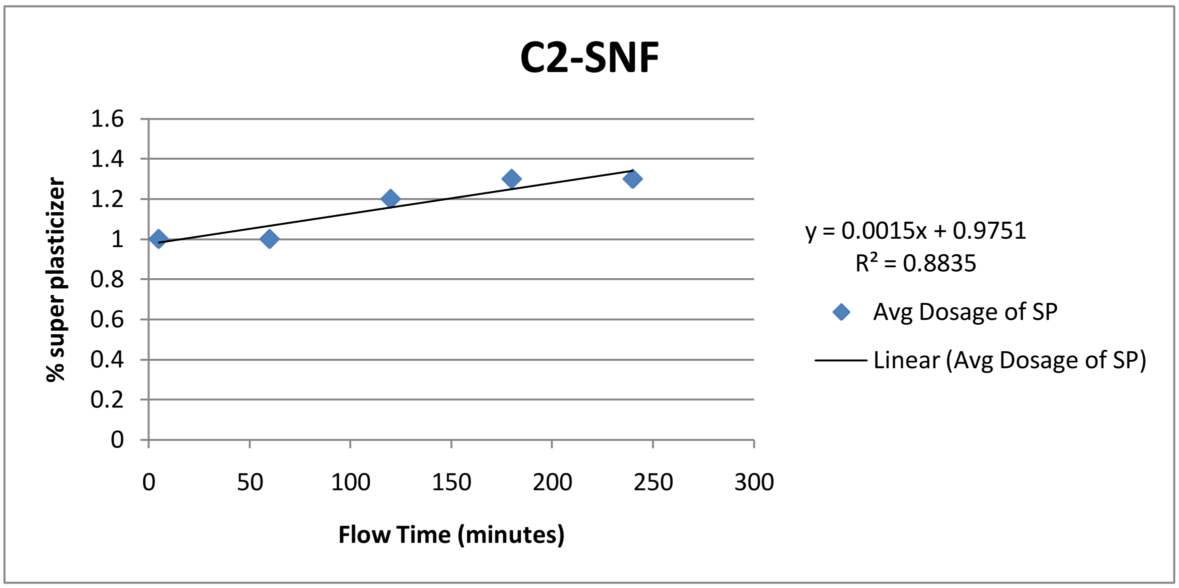


Fig 82 Graph showing trend line for C2 – SNF, w/c = 0.5

Table 63 Optimum Dosage for SNF based SP for C2, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %		Average
	SP4	SP8	
5 min	1.1	0.9	1
60 min	1.1	0.9	1
120 min	1.3	1.1	1.2
180 min	1.3	1.3	1.3
240 min	1.3	1.3	1.3

c) ***Chemical Family*- Sulphonated Naphthalene Polymer (SNP) [SP5, SP6, SP7]**

y = 0.0015x + 0.925

R = 0.973

R^2 = 0.9472

'y'=Optimum dose of Super-plasticizer of Sulphonated Naphthalene Polymer (SNP) family

'x'= Time in minutes

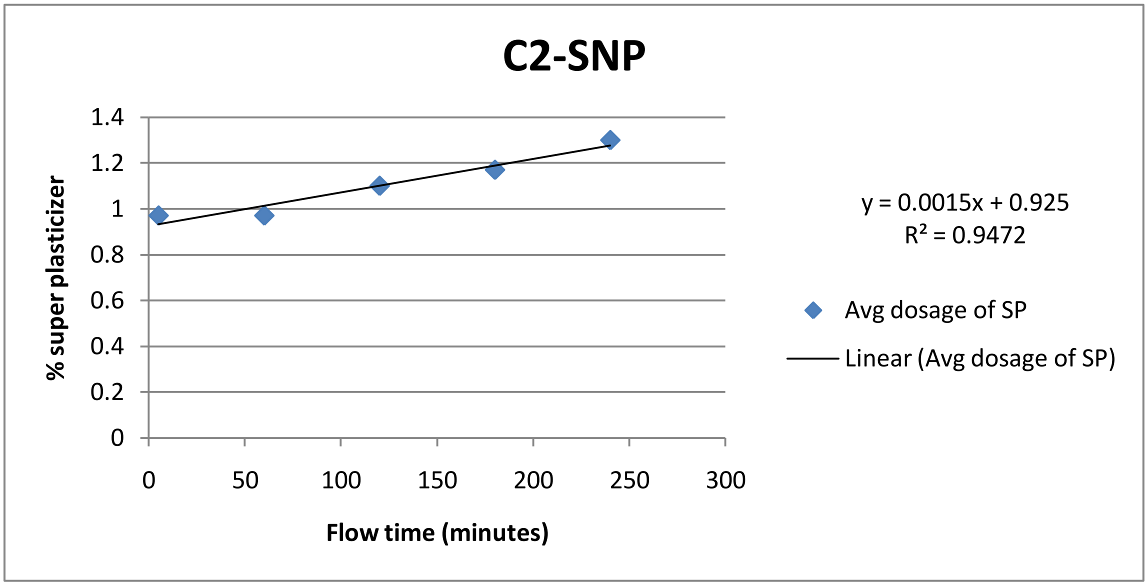


Fig 83 Graph showing trend line for C2 – SNP, w/c = 0.5

Table 64 Optimum Dosage for SNP based SP for C2, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP5	SP6	SP7	
5 min	0.9	1.1	0.9	0.97
60 min	0.9	1.1	0.9	0.97
120 min	1.3	1.1	0.9	1.1
180 min	1.3	1.1	1.1	1.17
240 min	1.3	1.3	1.3	1.3

6.8 COMPATIBILITY EQUATION FOR (C3) AT W/C 0.50 FOR-

a) *Chemical Family* - Poly Carboxylate Ether (PCE) [SP1, SP2, SP3]

$y = 0.0013x + 0.938$

$R = 0.953$

$R^2 = 0.9089$

‘y’= Optimum dose of Super-plasticizer of Poly Carboxylate Ether family

‘x’= Time in minutes

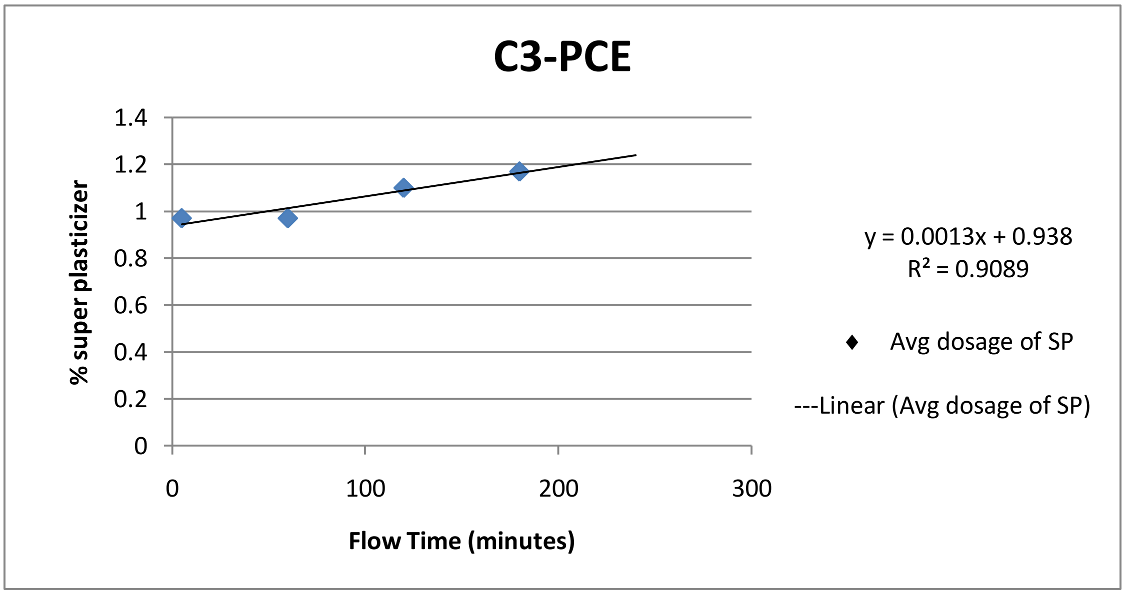


Fig 84 Graph showing trend line for C3 – PCE, w/c = 0.5

Table 65 Optimum Dosage for PCE based SP for C3, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP1	SP2	SP3	
5 min	1.1	0.9	0.9	0.97
60 min	1.1	0.9	0.9	0.97
120 min	1.1	1.1	1.1	1.1
180 min	1.3	1.1	1.1	1.17
240 min	-	1.3	1.3	0.87*

***** neglected due to randomness

b) *Chemical Family*- Modified Sulphonated Naphthalene Formaldehyde (SNF)

[SP4, **SP8**]

y = 0.0015x + 0.9751

R = 0.939

R^2 = 0.8835

'y'= Optimum dose of Super-plasticizer of Modified Sulphonated Naphthalene Formaldehyde (SNF) family

'x'= Time in minutes

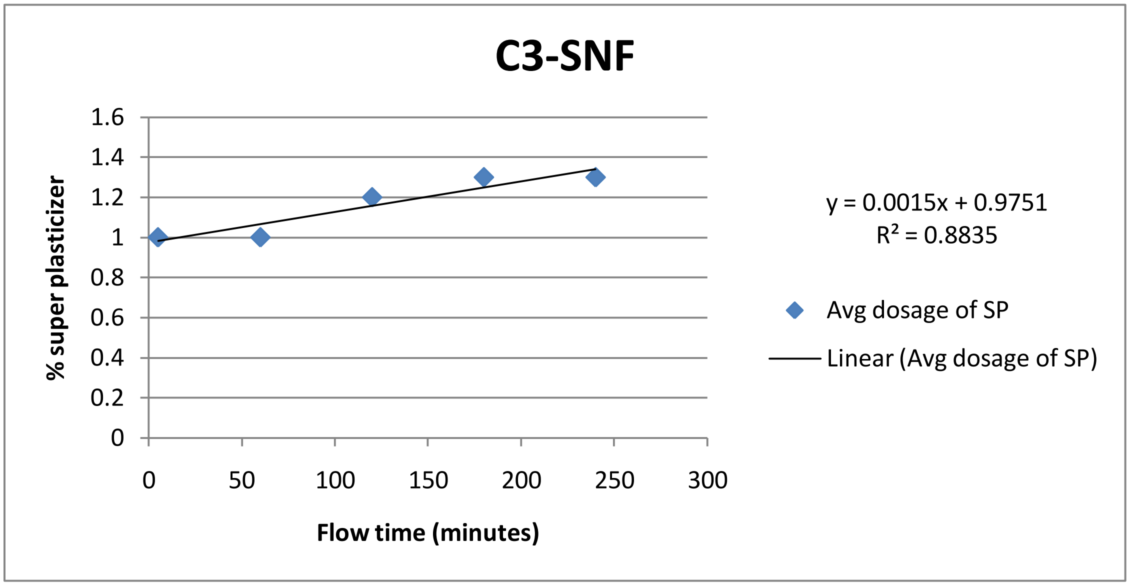


Fig 85 Graph showing trend line for C3 – SNF, w/c = 0.5

Table 66 Optimum Dosage for SNF based SP for C3, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %		Average
	SP4	SP8	
5 min	1.1	0.9	1
60 min	1.1	0.9	1
120 min	1.3	1.1	1.2
180 min	1.3	1.3	1.3
240 min	1.3	1.3	1.3

c) *Chemical Family*- Sulphonated Naphthalene Polymer (SNP) [SP5, SP6, SP7]

y = 0.0012x + 0.9859

R = 0.953

R^2 = 0.9098

'y'=Optimum dose of Super-plasticizer of Sulphonated Naphthalene Polymer (SNP) family

'x'= Time in minutes

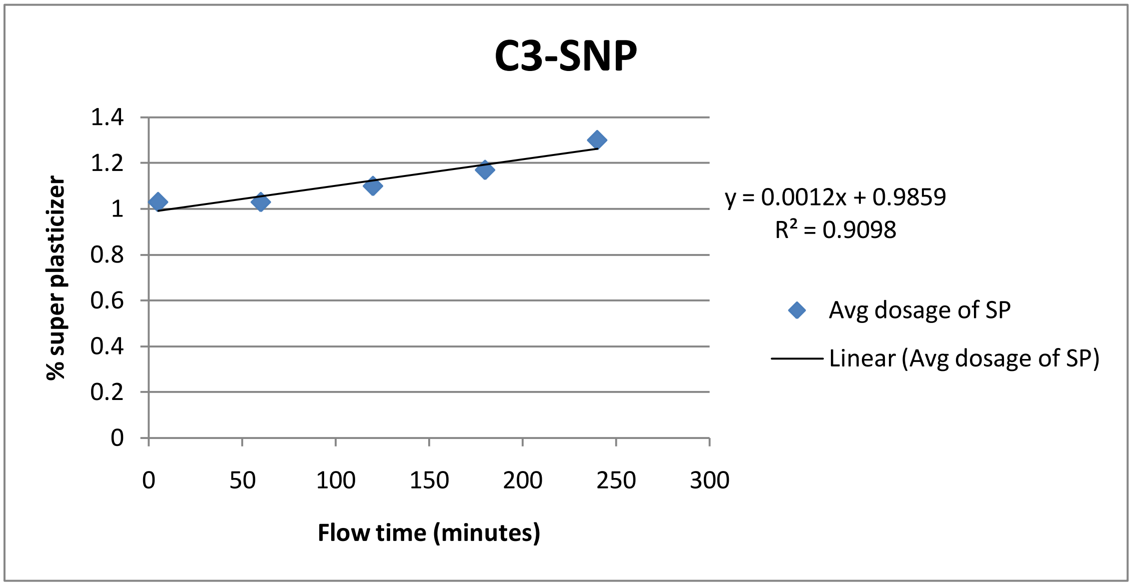


Fig 86 Graph showing trend line for C3 – SNP, w/c = 0.5

Table 67 Optimum Dosage for SNP based SP for C3, w/c 0.5

Time in minutes	Optimum Dose of super-plasticizer in %			Average
	SP5	SP6	SP7	
5 min	1.3	0.7	1.1	1.03
60 min	1.3	0.7	1.1	1.03
120 min	1.3	0.9	1.1	1.1
180 min	1.3	1.1	1.1	1.17
240 min	1.3	1.3	1.3	1.3

6.9 SUMMARY TABLE FOR COMPATIBILITY EQUATIONS

Determined Compatibility equations are in the Linear form i.e. **ax+b**

This table is concluded on the basis of above equations and thus helpful for the users to determine the equations for suitable C-SP (Cement – Super-plasticizer) couple. Column (1) of table shows the w/c ratio, Column (2) represents Cement- Super-plasticizer combination, Column (3) and (4) shows the value of constants 'a' and 'b', respectively.

Table 68 Table of constants for compatibility equations

Equation form: (ax+b)

W/C ratio	Cement - Super-plasticizer couple	a	b
0.45	C1-PCE	0.0006	1.0861
0.45	C1-SNF	0.0015	0.9955
0.45	C1-SNP	0.0014	1.0047
0.45	C2-PCE	0.0009	1.0151
0.45	C2-SNF	0.001	0.997
0.45	C2-SNP	0.0011	1.0144
0.45	C3-PCE	0.0013	0.868
0.45	C3-SNF	0.0012	0.9558
0.45	C3-SNP	0.0014	0.9393
0.50	C1-PCE	0.0008	1.0012
0.50	C1-SNF	0.0019	0.8538
0.50	C1-SNP	0.0003	1.2208
0.50	C2-PCE	0.0013	0.8305
0.50	C2-SNF	0.0015	0.9751
0.50	C2-SNP	0.0015	0.925
0.50	C3-PCE	0.0013	0.938
0.50	C3-SNF	0.0015	0.9751
0.50	C3-SNP	0.0012	0.9859

Chapter – 7

CONCLUSION AND REMARKS

7.1 INTRODUCTION

The chapter deals with the conclusions, limitations, recommendations and scope for future work.

7.2 CONCLUSIONS

The experimentation and results obtained in this project have led to the following conclusions:

1. The method and calculations for fabrication of Marsh Cone test apparatus may be used for future experimental work.

2. For the cement C1 (w/c=0.5), SP1, SP4 and SP8 are most compatible combination among all the combinations. Super-plasticizer with chemical base PCE (SP1) and SNF (SP4 and SP8) is most compatible as compared to super-plasticizer with SNP base. This implies that SNF and PCE groups are most compatible with C1 as compared to SNP with C1.

3. For the cement C2 (w/c=0.5), SP2 and SP8 are most compatible combination among all the combinations. Super-plasticizer with chemical base PCE (SP2) and SNF (SP8) is most compatible as compared to super-plasticizer with SNP base. This implies that those SNF and PCE groups are most compatible with C2 as compared to SNP with C2.

4. For the cement C3 (w/c=0.5), SP2, SP3 and SP5 are most compatible combination among all the combinations. Super-plasticizer with chemical base PCE (SP2 and SP3) and SNP (SP5) is most compatible as compared to super-plasticizer with SNF base. This implies that SNP and PCE groups are most compatible with C3 as compared to SNF with C3.

5. For the cement C1 (w/c=0.45), SP4 and SP7 are most compatible combination among all the combinations. Super-plasticizer with chemical base SNF (SP4) and SNP (SP7) is most compatible as compared to super-plasticizer with PCE base. This implies that SNF and SNP groups are most compatible with C1 as compared to PCE with C1.

6. For the cement C2 (w/c=0.45), SP1 and SP5 are most compatible combination among all the combinations. Super-plasticizer with chemical base PCE (SP1) and SNP (SP5) is most compatible as compared to super-plasticizer with SNF base. This implies that those SNP and PCE groups are most compatible with C2 as compared to SNF with C2.

7. For the cement C3 (w/c=0.45), SP2, SP3 and SP7 are most compatible combination among all the combinations. Super-plasticizer with chemical base PCE (SP2 and SP3) and SNP (SP7) is most compatible as compared to super-plasticizer with SNF base. This implies that SNP and PCE groups are most compatible with C3 as compared to SNF with C3.

8. The saturation dosages have been determined experimentally which has been used for various combinations of cement and super-plasticizer to establish mathematical equation for practical use in field.

7.3 RECOMMENDATIONS AND SCOPE FOR FUTURE WORK

1. This work can also be performed on different types of cement and brands with various chemical family and brands of super-plasticizers available in the market to establish the compatibility between them, also for different water-cement ratio.

2. Consequently, equations for finding saturation dosage can also be derived.

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