USE OF SUPER ABSORBENT POLYMER IN CONCRETE

Submitted in partial fulfilment of the requirements

For the degree ofBachelor of Engineering

By

THONGE AQUIB AZIM (16DCES87)

HABEEB MOHINUDDIN QAZI (16DCES65)

MOHD. ASIF MAZHAR ALI KHAN (16DCES76)

QURESHI AMMAN RIZWAN (16DCES81)

Under the guidance of

PROF. JUNAID MASTE

Department of Civil Engineering

School of Engineering and Technology

Anjuman-I-Islam's Kalsekar Technical Campus

New Panvel, Navi Mumbai-410206

2018-2019

A Project Report on

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PROJECT REPORT APPROVAL FOR B. E.

This project report entitled "**Use of Super Absorbent Polymer in Concrete**" byThonge Aquib Azim (16DCES87), Habeeb Mohinuddin Qazi (16DCES65), Mohd. Asif Mazhar Ali Khan (16DCES76) & Qureshi Amman Rizwan (16DCES81) approved for the degree of "Bachelor of Engineering" in "Department of Civil Engineering".

Examiners

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Supervisors

1. ……………………………

2. …………………………

Chairman (Director)

………………………………

DECLARATION

We declare that this written submission represents ourideas in our own words and where others ideas or words have been included, We have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Thonge Aquib Azim (16DCES87)

Habeeb Mohinuddin Qazi (16DCES65)

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ABSTRACT

As the role of the concrete increases in the construction Industry due to urbanization of cities and development of industrial area concrete will play essential role in the construction of modern structures. As such efficiency of concrete regarding its various characteristics such as strength, durability, impermeability, shrinkage and creep must be improved.

Mitigation of autogenous, drying and plastic shrinkage is the most critical and complex phenomenon of HSC (high strength concrete). In HSC water-binder ratio is low with highly active mineral admixtures such as silica fume widely used in bridges and skyscrapers but it is subjected to early cracking because of intense heat of hydration. This problem could not be solved with traditional external curing because of very low permeability of HSC so after a long research some researchers shifted their attention to internal curing by using polymers, polymers which are capable of absorption and controlled desorption of water within concrete without any other disadvantages like reduction in strength and durability of concrete.

SAP (super absorbent polymer) has been gaining popularity with its use in concrete. SAP is a hydrophilic compound in nature. Acrylic acid and acrylamide of potassium and sodium salts are the most commonly used SAP for the purpose of use in concrete. The hydrophilic group of COOH and NH2 contributes to the high-water absorbing capacity of SAP products some of which have a tendency of absorbing 500 to 1000 times its own weight. The desorption of SAP promotes the hydration of surrounding cement paste and advances the primary hydration heat peak. Hydration of cement is increased by 5% around the cement almost Equal to An Increase of W/C By 0.04. Addition of SAP promoted Ca (OH) 2 which improves alkalinity. SAP Increases the internal curing, reduces autogenous shrinkage and increase the relative humidity. The use of super absorbent polymer in concrete is proven to have many positive effects on the properties of concrete in both of its stages, fresh concrete and harden concrete. SAP increases workability of fresh concrete and also releases water when the internal relative humidity of the hardened concrete decreases which Increases internal curing and produce hydrated cement products which increases the strength of hardened concrete.in this study a critical review has been done to overcome the autogenous shrinkage by addition of sap.

Keywords: super absorbent polymer, autogenous shrinkage, internal curing, and internal relative humidity.

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ABBREVIATION NOTATION

SAP	Super Absorbent Polymer
AUL	ABSORBENCY UNDER LOAD
AA	ACRYLIC ACID
HSC	HIGH STRENGTH CONCRETE
HPC	HIGH PERFORMANCE CONCRETE
SCC	SELF-CONSOLIDATING CONCRETE
SRA	SHRINKAGE REDUCING ADMIXTURE
MHPC	METHYL-HYDROXY PROPYL CELLULOSE
UHPC	ULTRA HIGH PERFORMANCE CONCRETE
DDS	DRUG DELIVERY SYSTEM
W/C	WATER-CEMENT RATIO
C.A.	COARSE AGGREGATE
F.A.	FINE AGGREGATE
MSA	MAXIMUM SIZE OF AGGREGATE
PQC	PAVEMENT QUALITY CONCRETE
CCS	CHARACTERISTIC COMPRESSIVE STRENGTH
SHCC	STRAIN HARDENING CEMENT COMPOSITION

Chapter 1

Introduction

1.1 Introduction

Super absorbent polymer also known as hydrophilic gels or hydrogel they are network of polymer chains and dispersion medium of water, ability to absorb water up to 99% with respect to its own weight. It can be also defined as the polymer which can absorb the water and retaining it for a significant fraction within structure without mixing or dissolving in water.

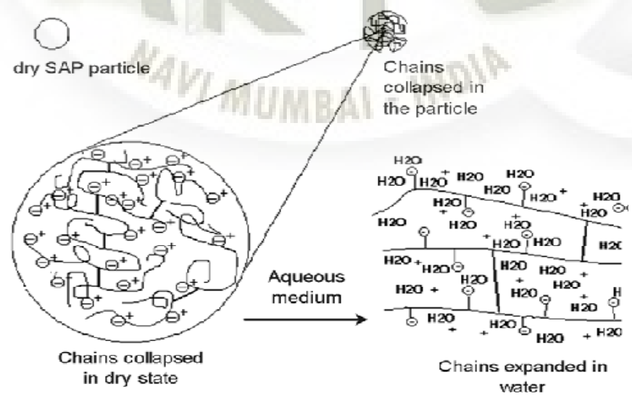

Figure 1.1 Illustration of a typical acrylic-based anionic SAP material: (a) A visual comparison of the SAP single particle in dry (right) and swollen state (left) (b) A schematic presentation of the SAP swelling. Source: viktor et.al

Generally, SAP used in diapers and napkins of kids and female, also they are extensively used as scaffolds in tissue engineering and if they are containing human cells they can be repair human tissues. Environmental sap can sense change in temperature and ph. now a days SAP are used widely in agricultural field their water holding ability can be useful in arid areas to moist soil for longer time period.

SAP is safe and suitable for use in different fields as there are no chemical or toxic reaction, following are the technical features of sap,

- The highest absorption ability with desired rate of absorption depending on requirement.
- The highest absorbency under load (AUL).
- Cheap and economical.
- The highest durability and permeability in the swelling environment and during the storage.
- PH-neutrality after absorption of water.
- Colourless, odourless and nil toxicity.
- Photo stability.
- Re-wetting capability if required.

In 1938 first SAP was made by acrylic acid (AA) divinylbenzene, after that SAP has been gaining popularity with its use in concrete. SAP is a hydrophilic compound in nature. Acrylic acid and acrylamide of potassium and sodium salts are the most commonly used SAP for the purpose of use in concrete.

1.1.1 Chemical properties and production of sap

Superabsorbent polymers (SAPs) are one of the most fascinating materials in modern polymer technology. These polymers are able to absorb up to 1500 g of water per gram of SAP (Figure). They were developed in the late 1980s. The first application of SAPs was in diapers. The market grew very quickly and reached ca. 1 Mio t/a in the last years. Today, the main market for SAPs is still the hygiene industry (baby diapers and adult care articles).

Chemically speaking, SAPs are cross-linked polyelectrolytes which start to swell upon contact with water or aqueous solutions resulting in the formation of a hydrogel. In the hygiene industry only SAPs based on cross-linked poly acrylic acid are used (Figure), which is partially neutralized with hydroxides of alkali metals, usually sodium.

Traditionally the market for SAPs is split into two parts: Hygiene industry and technical SAPs. The latter comprises all applications apart from hygiene products. Technical SAPs, which can be based on acrylamide and acrylic acid, are used for example in landscaping, cable isolation, firefighting, food packaging. Common SAPs for the hygiene industry are hard white granulates with a particle size of app. 150 to 850 µm.

Figure 1.2. Dry and swollen SAP particle (figure with courtesy of BASF) (Source: Viktor Mechtcherine mechtcherine@tu-dresden.de, Hans-Wolf Reinhardt reinhardt@iwb.uni-stuttgart.de, DOI 10.1007/978-94-007-2733-5)

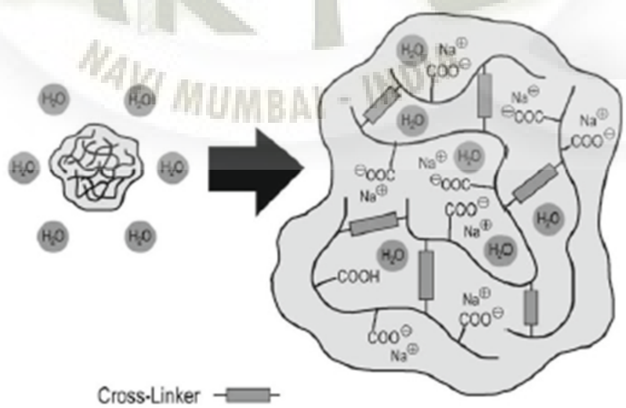

Figure 1.3. SAP based on polyacrylic acid (figure with courtesy of BASF) (Source: Viktor Mechtcherine mechtcherine@tu-dresden.de, Hans-Wolf Reinhardt reinhardt@iwb.uni-stuttgart.de, DOI 10.1007/978-94-007-2733-5)

The main producers of SAPs for hygiene industries are BASF SE, Evonik Stockhausen GmbH and Nippon Shokubai. In the field of technical SAPs other producers include Arkema and SNF Floerger.

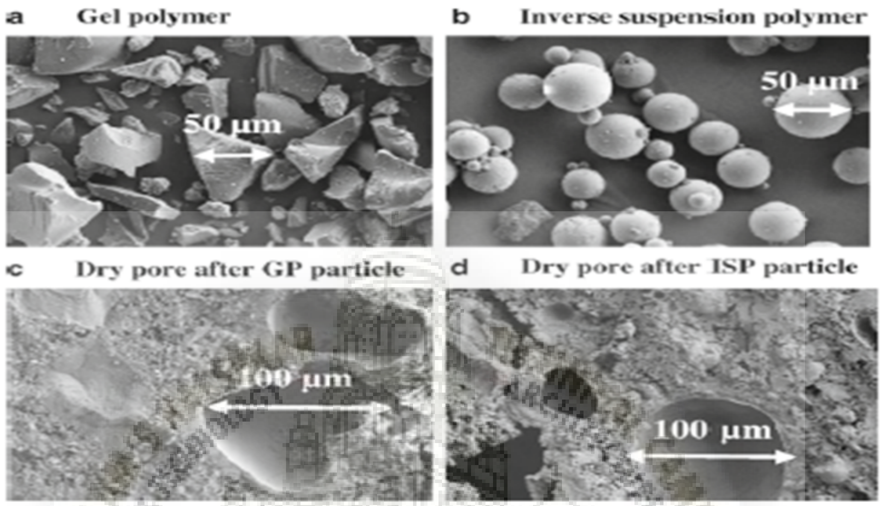

Figure 1.4. Particle shape for polymers made by (a) gel polymerization or (b) inverse suspension polymerization; (c) dry pore left behind by a gel polymerized SAP particle in hardened cement paste after drying; (d) dry pore left behind in hardened cement paste by an SAP particle polymerized via inverse suspension polymerization (figures with courtesy of BASF) (Source: Viktor Mechtcherine mechtcherine@tu-dresden.de, Hans-Wolf Reinhardt reinhardt@iwb.uni-stuttgart.de, DOI 10.1007/978-94-007-2733-5)

1.1.2 Synthesis of SAP polymers:-

According to Buchholz and Graham there are two general methods of synthesis for polyacrylic acid-type super absorbents, either from acrylamide or from acrylic acid. Either synthesis route may be employed to produce either a non-cross linked or a cross linked polymer product.

Synthesis from acrylamide proceeds by polymerization, partial hydrolysis of the polyacrylamide groups to create carboxylic acid side groups, and neutralization of some or all of the carboxylate groups.

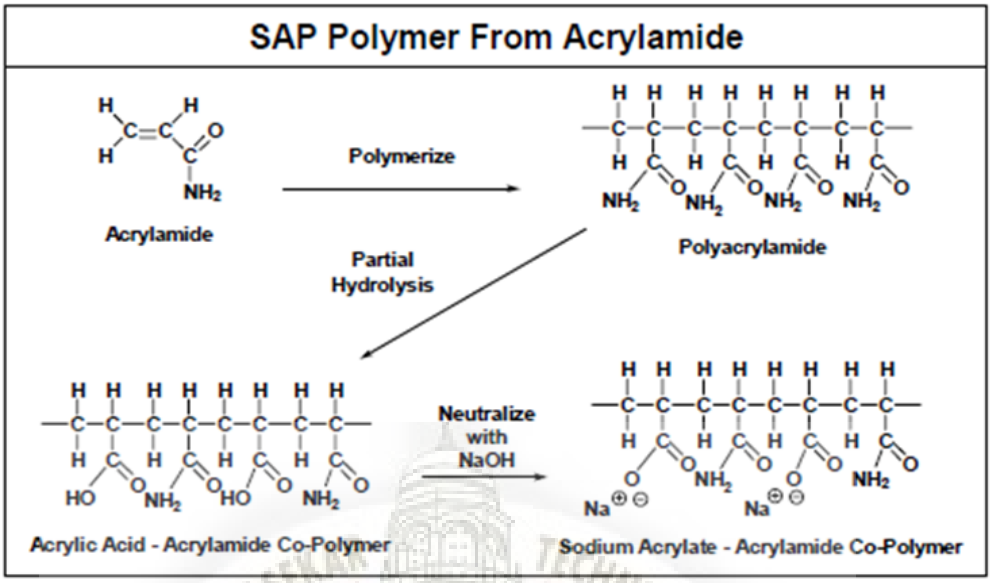

Figure 1.5. SAP polymer from acrylamide (Source: David Cash PhD david.cash@mohawkcollege.ca, Mohawk College, Hamilton ON)

Synthesis from acrylic acid may proceed by polymerization followed by the neutralization of some or all of the carboxylate groups. Or the acrylic acid may be partially or completely neutralized and then polymerized.

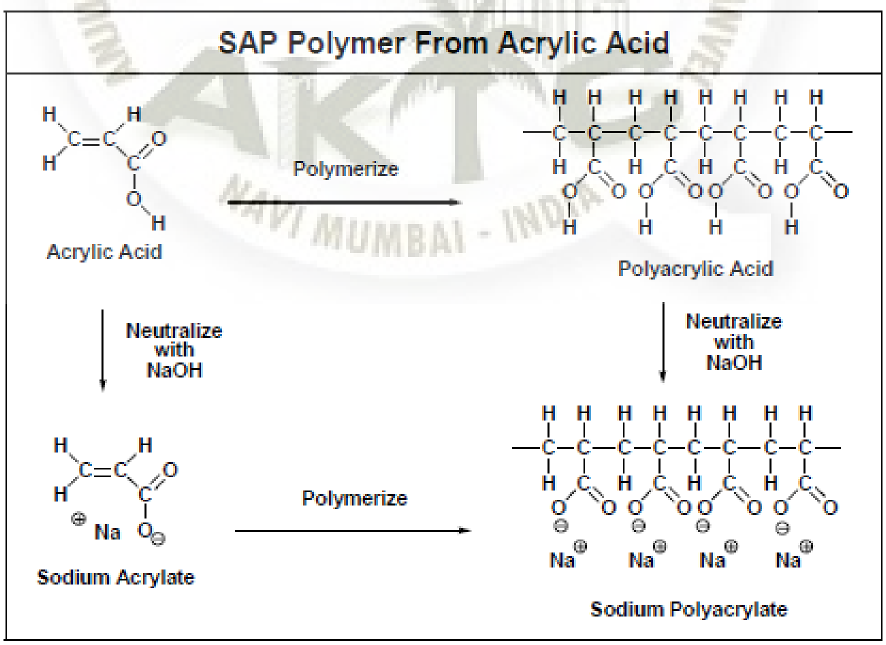

Figure 1.6. SAP polymer from acrylic acid (Source: David Cash PhD david.cash@mohawkcollege.ca, Mohawk College, Hamilton ON)

Production:-

The production of SAPs starts with an aqueous monomer solution with a concentration of 25 to 40 mass per cent. The solution is cooled down to 0 to 10 °C and transferred to the reactor. This can be an endless belt reactor or a kneader. In the case of the endless belt, the monomer solution is poured out at the start of this belt and polymerization is running adiabatically forming a hard rubber-like gel. At the end of the belt an extruder cuts the gel into small pieces, which are then dried. The dry particles are ground to the desired particle size. In the case of the kneader the polymerization and the cutting of the gel are done in one step. Both processes are used on a large scale up to several 100.000 tons per year.

The particles which are made using these processes have an irregular shape and appear like broken glass under a microscope.

An alternative production technology is inverse suspension polymerization. In this process the aqueous monomer solution is suspended in an organic solvent, e.g. hexane or cyclohexane. The polymerization is initiated between 50 and 70 °C and after the polymerization, water can be removed by azeotropic distillation. The product is filtered off and dried. SAPs which are made by this process are spherical (cf. Figure 3.3). They can be single spherical particles or raspberry like agglomerates of smaller spherical particles.

The production of larger volumes of SAPs by inverse suspension polymerization is limited due to higher cost.

The swollen SAP particle keeps its particle shape. (Figure 3.3 c and d) shows the pores formed by SAP particles in cement paste after drying. The gel polymer forms irregular pores, the inverse suspension polymer spherical ones.

1.1.3 Super absorbents in Construction Applications

Right from the invention of SAPs the idea was to use them as additives for constructionapplications. The first patents were written by DOW and Hoechst dealing with dry mortars containing super absorbents. However, such products never were introduced into the market. At the end of the last century the focus was on internal curing of ultra-high performance concrete.

1.1.4 Kinetics of water migration in cement-based systems containing SAP:-

Superabsorbent polymers (SAP) absorb pore solution during mixing ofconcrete and release it when cement paste self-desiccates or is exposed to drying. Knowledge of the kinetics of water migration in and out of the SAP is essential for understanding and optimizing internal curing of concrete. This chapter discussesabsorption of pore solutions in SAP and desorption of the SAP, both in model systemsand in cement paste or concrete. When experimental results about SAP are missing in the literature, results obtained with other internal curing agents are presented and the applicability to SAP is discussed. A final section is dedicated to modelling of internal curing of concrete by SAP and especially to modelling of water migration to and from the SAP.

Figure 1.7.Schematic representation of the evolution in time of the SAP in a cementitious material, after. Left: initial condition, homogenous dispersion of cement particles, water, SAP and aggregates. Centre: the SAP has reached final absorption. Right: the water has been transported into the cementitious matrix and an almost empty pore remains. (Source: Viktor Mechtcherine mechtcherine@tu-dresden.de, Hans-Wolf Reinhardt reinhardt@iwb.uni-stuttgart.de, DOI 10.1007/978-94-007-2733-5)

Superabsorbent polymers (SAP) have recently found application in concrete technology, thanks to their ability to absorb amounts of water many times their own weight, retain it and release it when the conditions change. In most applications, SAP have been added in the dry state to the concrete mixture. When dry SAP particles come into contact with water during mixing of concrete, they rapidly absorb it and form water-filled cavities (Fig. 7, left). The kinetics of absorption and the amount of fluid absorbed by the SAP depend both on the nature of the SAP and of the cement paste or concrete, in particular on the pore solution composition. Once the SAP have reached their final size, they form stable, water-filled inclusions (Fig. 7, centre), from which the water is subsequently sucked into smaller capillary pores and consumed by hydration of cement.

1.1.5 Sap as A New Additive in Concrete

Chemical additives are very reactive; a small quantity can dramatically improve crucial characteristics of concrete. In recent decades there are many advances has been made in concrete technology. These additives are mixed with concrete and improve its properties in fresh and hardened state.

Control over water cement ratio is key considerations in concrete technology, controlling autogenous shrinkage, internal cracking, or other concrete parameters are very difficult because of intense heat of hydration and improper internal curing in high strength concrete. If any how we can provide water internally in concrete after casting, it can be help full to reduce heat of hydration and early cracking of high strength concrete. As above mentioned super absorbent polymer can hold water within structure and release it as per requirement introduction of SAP in concrete as a new component for the production of concrete materials offers a number of new possibilities with respect to water control and, as a result to the control over the rheological properties of fresh concrete.

The most common problem occurring in concrete is due to the formation of air pockets called as Honey combing, thereby reducing compressive strength of concrete along with decrease durability of concrete. To overcome this problem air entrainment agents are widely used. However, the entrained air voids frequently are not stable enough to tolerate transport, compacting or in some other methods like spraying. In other hand SAP-addition seem to remain stable regardless of the consistency of the concrete, of the method of placement and compacting.

However, in early 1980's down and Hoechst are the first researchers to perform test on dry mortar with SAP and patented. After that many researches has been done on sap to improve rheological behaviour, shrinkage, strength, durability, and other properties of concrete.

1.1.6 Effect of Sap on Autogenous Shrinkage

Autogenous shrinkage is defined as a dimensional reduction of concrete volume occurring without moisture transfer to the environment. It is the outcome of the internal chemical and structural reactions of the concrete components. The contribution of autogenous shrinkage has previously been viewed as insignificant in typical concrete mixtures due to the dominant role of drying shrinkage. In recent years the increasing use of high-performance concrete has led to the re-introduction of autogenous concerns as the mixtures are using more special cements and multiple admixtures while reducing water. The combination of a variety of material properties provides a basis for evaluating and quantifying the early age autogenous shrinkage to the total performance of concrete.

Use of High strength concrete (HSC) has increased tremendously nowadays. High strength concrete (HSC) structures experience early age shrinkage cracking due to volume changes in concrete structures and controlling early age shrinkage cracking is essential to obtain long-term durability. Shrinkage cracking is common in high strength concrete because of its high cement content and low water-cement ratio which are used to make the concrete, this leads to autogenous shrinkage induced by self-desiccation. Unlike drying shrinkage autogenous shrinkage cannot be reduced significantly by external curing, because of the dense microstructure of High Strength Concrete (HSC), it allows only a short amount of water to transport. Thus, by introducing SAP in the concrete mix which serves as an internal curing agent. SAP evenly distributes across the volume of concrete that serves as a small water reservoir, which absorbs the water from the fresh concrete. As the hydration process advances, SAP releases water as a result of under pressure in the surrounding matrix, thus leads to proper hydration of the remaining cement content. The addition of SAP as internal curing agent was first suggested by Jensen and Hansen. Later, the effectiveness of this approach was demonstrated by a number of research groups in different countries and as a result of the RILEM Round Robin Test performed by thirteen labs all over the world.

The first constructed example in the world using SAP-modified, high-performance concrete in the pavilion consisting of slender precast elements built for 2006 FIFA World Cup in Kaiserslautern, one of the host cities. It was designed for filigreed, thin-walled structure with a very slender column (minimum wall thickness of 20mm) and no conventional reinforcement.

In order to meet the rigorous design requirements (including reduced autogenous shrinkage, high durability, enhanced ductility, self-compaction, and high-quality surface), self-compacting fibre-reinforced, high-performance concrete with internal curing was developed.

1.1.7 Sap as an Internal Curing Agent

Internal curing refers to the process in which the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water. Additional Internal water can be provided by the Means of SAP. Curing is said to happen 'from the outside to inside'. Conventional Methods of Curing is Applying water at the concrete surface at regular interval to keep it Saturated. This Method Is necessary to prevent the drying shrinkage of concrete surface and compensate for the water that is lost to the atmospheric condition during the Hydration process of concrete Surface. In contrast, 'internal curing' which is also known as 'self-curing' is allowing for curing 'from the inside to outside' through the internal reservoirs of water by means of SAP. Internal Curing is required in the case of High-Performance Concrete to mitigate the autogenous shrinkage found mainly in HPC. Autogenous Shrinkage is caused due to Chemical Shrinkage in Fresh concrete and due to self-desiccation in the hardened concrete.

When mixing water is in contact with cementitious material hydration starts. During hydration some part of the mixing water gets chemically bonded with hydration product, some water is absorbed at the surface of hydration product and the rest remains in solution at the capillary pores formed during hydration. Cementitious material gets water from capillary pores to promote hydration which generates surface tension that result in volumetric reduction known as autogenous shrinkage caused due to Chemical Shrinkage. Chemical shrinkage occurring during cement hydration, creates voids within the cement paste, leading to a reduction. In HPC, it is nearly impossible to supply curing water from top surface because the rate at which water is required to satisfy the ongoing chemical shrinkage is high, and due to the extremely low permeability water can't reach inside. Concrete microstructure is more and the rate at which water gets absorbed into the concrete matrix is comparatively less. Therefore, we turn to alternate materials which can absorb, hold and supply water as required, the water molecules present in these materials are pulled due to the pressure exerted by the concrete matrix as water is been used up during the curing process. For High strength concrete Ultimate degree of hydration will never reach 100% compare to normal strength concrete whose degree of hydration will reach 100% eventually after 6 months to 2 year depending upon the constituent of concrete. HSC's degree of hydration doesn't reach 100% because there is not enough water to hydrate all the cementitious material because of low water-to-cement ratio of high strength concrete. When all the water is absorbed the relative humidity of concrete matrix decreases which causes self-Desiccation. Thus, the water is drawn out of the capillary pore's spaces between the solid, which causes autogenous shrinkage due to self-Desiccation. SAP present in concrete can release the water when the internal relative humidity of concrete decreases which can prevent shrinkage due to Self- Desiccation.

1.1.8 Further Use of Sap in Concrete-

1.1.8.1 Shrinkage Reduction:-

In the present study, self-consolidating concrete (SCC) within 28 days gives compressive strength of 110 MPa was fabricated. Its workability, hydration heat evolution, chloride penetration resistance, and other mechanical properties were analysed. To enhance its volume stability, shrinkage-reducing admixture (SRA) and super-absorbent polymer (SAP) were used, and their effect on autogenous shrinkage and drying shrinkage of the concrete were evaluated. The results indicate that high-strength SCC can be achieved using a carefully designed ternary binder system (made with cement, fly ash, and silica fume), water-reducing admixture, and low water-to-binder ratio (W/B = 0.20). Addition of shrinkage reducing admixture (SRA) and super absorbent polymer (SAP) into the concrete significantly reduced autogenous shrinkage and slightly reduced drying shrinkage. SAP is more effective in reducing autogenous shrinkage at later age, and it can effectively use as water-entraining agent in high performance concrete to provide internal curing water that is needed to maximize cement hydration with negligible adverse effects on other engineering properties.

Controlling early-age cracking due to volume changes in concrete structures isessential to obtain long-term durability. Today, many concrete structures experience early-age shrinkage cracking. This is more common when high cement contents and low water-cement ratios are used to make the concrete, leading to autogenous shrinkage induced by self-desiccation. As SAP can be effectively used as a water-entraining agent in high-performance concrete to provide internal curing water that is needed to maximize cement hydration and minimize self-desiccation, with negligible adverse effects on other engineering properties.

1.1.8.2 Frost Resistance:-

Frost resistance been recently demonstrated in the lab by Reinhardt et al. and Laustsen et al. where mixtures containing specific types of SAP were found to provide increased resistance to freezing and thawing in the presence of de-icing chemicals. It was hypothesized that SAP may have interacted with the superplasticizer to increase the air content, or very small air bubbles adhered to the SAP particles during mixing. The first practical application of SAP worldwide as an additive to increase the frost resistance of concrete was conducted in summer 2011, when SHCC developed at the TU Dresden was used to repair the upper water reservoir of the pumping hydraulic power station Hohenwarte II in Thüringen, Germany, Since the reservoir walls are exposed to high water saturation and considerable changes in water level, the danger of frost damage is considerable. In practice the use of conventional air entrainment agents is possible with SHCC, but not when the spraying technique is applied. For this reason, SAP was introduced as a new additive to improve the frost resistance of the repair layer.

The production of concrete that is resistant to freezing and thawing requires special attention to some specific material parameters, including the air-void system, of which effectiveness is controlled by the volumetric air content, spacing and size of the air voids. To this effect, SAP particles can be engineered to provide an adequate pore system, since SAP particles can unswell during cement hydration and leave gas-filled voids, according to Jensen. In fact, this concept has been recently demonstrated in the lab by Reinhardt et al. and Laustsen et al., where mixtures containing specific types of SAP were found to provide increased resistance to freezing and thawing in the presence of de-icing chemicals. It was hypothesized in that SAP may have interacted with the superplasticizer to increase the air content, or very small air bubbles adhered to the SAP particles during mixing. The authors demonstrated the advantages of SAP-based technology over traditional chemical air entrainment, which are: stability of the air void system and improved control of both the amount of added air and the air void size. Their results clearly showed that the amount of scaled material depended solely on the amount of air voids in the concrete created by SAP, whereas the spacing factor was found to have only a minor influence.

As reported in, air entrainment with conventional air-entraining admixtures often encounters technical difficulties such as coalescence of air bubbles in fresh concrete, loss of air during consolidation or pumping, and chemical incompatibility with superplasticizers. Again, the use of SAP as an air-entraining agent could solve some of these difficulties in practice, since this technology is uninfluenced by the pumping and placing procedures.

1.1.8.3 Rheological Modification of Shotcrete:-

The use of SAP to increase the viscosity and decrease the rebound of shotcrete was the subject of 1991 patent application from Snashall. The difficulties can be avoided by the dry addition of SAP in the nozzle during shotcreting. The concrete had an initial water cement ratio of 0.4 and contained 0.4% SAP with a water absorption near 15g of water per gram of dry SAP. It was observed that the uptake of water by SAP created a change in viscosity during placing and allowed the build-up of thick layers without the use of a set-accelerating admixture. In this case, SAP was added to shotcrete as a rheology modifier, however, other benefits is particularly intriguing because it is very difficult to control the air entrainment of placed shotcrete. As shotcrete is placed, major changes in the air void structure will occur if it is based on a normal air-entrained admixture with SAPs, however, it is possible to accurately design the final air void structure which will be unaffected by the pumping and placing procedure.

Rheological Behaviour of Mortar Assessed From Rheometer Tests

Paiva *et al.* investigated the rheological behaviour of single-coat render mortarscontaining SAP as a water retaining agent. A single-coat render is a mortar that is applied to an external wall surface in one layer. The hardened render must provide a durable weather resistant finish layer enhancing the performance of the building surface. The strength and durability depend on the absorbency by the support material and the environmental exposure at the moment the mortar is applied. It is important that the mortar retain the mixing water long enough to allow an adequate curing. The most commonly water retaining agents used are based in cellulose ethers.The rheological results obtained for the mortar containing commercial SAP are compared by the authors with those obtained using MHPC (a water retaining agent based in cellulose methyl–hydroxypropyl).

The single-coat render mortar basic composition involved white Portland cement and siliceous sand with a particle size distribution below 1.25 mm. Mortars were produced with a binder/aggregate weight ratio of 1:5 and water content of 21% by weight. The water retaining agents (SAP and MHPC) were added in powder form in contents of 0% (Ref), 0.05%, 0.08%, 0.10% and 0.15% of the total weight of the dry mortar. SAP had particle size distribution below 0.250 mm in the dry state.

The studied mortars should maintain their spreading in the range of 135–145 mm measured by the slump flow test using the mortar standard cone. The rheological properties (yield stress and a plastic viscosity) of the mortars were determined usinga mortar Rheometer (Viskomat PC, Schleibinger). The apparent density of the freshmixtures was also determined.

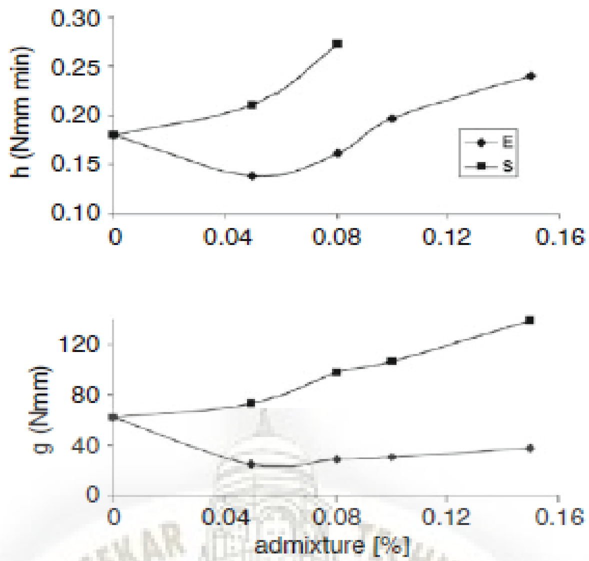

Figure 1.8. Effect of admixtures content on the rheological parameters h and g of the mortar (0 minutes of test).Mixtures containing SAP are represented by "S" and containing MHPC by "E" (Source: Viktor Mechtcherine mechtcherine@tu-dresden.de, Hans-Wolf Reinhardt reinhardt@iwb.uni-stuttgart.de, DOI 10.1007/978-94-007-2733-5)

Results showing the influence of SAP and MHPC on the values h (value related to the plastic viscosity and g (value related to yield stress) of the mortars are presented in Figure SAP addition is equivalent to removing water from the system increasingthe rheological parameter values and causing a thickening action. According to the authors, the increase in SAP content is equivalent to removing water from the system. For the same water retaining agent dosage, mixtures with MHPC presented smaller values of the plastic viscosity (cf. h) and the yield stress (cf. g).

Rheological Behaviour of Concrete Assessed From Rheometer Tests

Dudziak and Mechtcherine examined the rheological behaviour of fibre-free finely grained UHPC by means of Rheometer and V-funnel tests. The measuring procedure for the Rheometer test included operating the equipment in alternate modeof rotation (6.5 min), oscillation (45 min) and again rotation (6.5 min). Flow timeobtained from the V-funnel test was derived continuously until the age of approximately 1 hour at intervals of about 15 minutes.

Studied UHPC concretes were composed of the same basic ingredients as used in previous studies. Designated for examination were control mixture F-R (0% SAP, w/c=0.22, slump flow measured with small cone 263 mm) and SAP enriched mixtures containing extra water for internal curing: mixture F-S.3.045 (0.3% SAP, w/c=0.22+0.0345, slump flow 267 mm), mixture F-S.4.06 (0.4% SAP, w/c=0.22+0.06, slump flow 264 mm). Furthermore, mixtures containing 0.6% SAP and varied amount of extra water (as given in their designations) were tested: F-S.6.08 (slump flow 224 mm), F-S.6.085 (slump flow 251 mm) and F-S.6.09 (slump flow 277 mm).

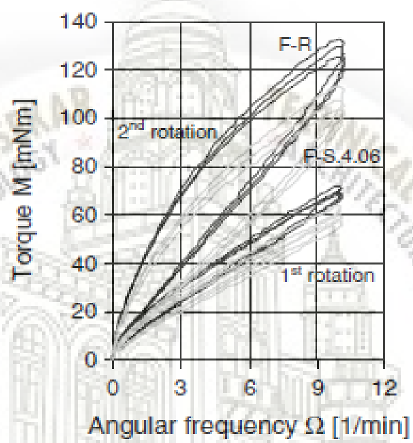

Figure 1.9. Torque variation for primary reference F-R and F-S.4.06 containing 0.4% SAP with angular frequency in first and second rotational mode (Source: Viktor Mechtcherine mechtcherine@tu-dresden.de, Hans-Wolf Reinhardt reinhardt@iwb.uni-stuttgart.de, DOI 10.1007/978-94-007-2733-5)

Exemplary results for the first and second testing in rotational mode for mixtures F-R and F-S.4.06, fairly equal in measure of slump flow, are presented in Figure. It can be clearly recognized that the mixture with SAP addition was less viscous at both testing times. Results of the measurements in oscillation mode led to the same conclusion. Furthermore, the SAP-enriched mixture showed for all investigated time point after mixing lower values of V-funnel time in comparison to the reference mixture F-R, which was a finding consistent with the results from the Rheometer tests. As a reason for this behaviour, authors indicated positive influence of spherical shape of each SAP particle that retains after absorption of water and produce a kind of ball-bearing effect. This effect might be further increased due to a higher air content in the mixtures with SAP. In conclusion, the effect of SAP addition was regarded as beneficial.

Figurepresents the results for mixtures with different content of extra water but the same amount of SAP. The presentation is limited here to the second rotational cycle, however in the first cycle a similar trend was observed. It was pointed out by authors that an underestimation of the amount of water absorption by SAP led to pronounced increase of torque, therefore pronounced loss of workability asalready observed in previous studies. For instance, the loss of workability by mixture F-S.6.08 became so dramatic that the second rotational mode could not be processed. On the other hand, even a slight overestimation of the SAP absorption provoked a pronounced decrease in concrete viscosity, cf. mixture F-S.6.09.

1.1.8.4 Control Release and Self-Healing:-

Concrete cracks due to its low tensile strength. The presence of cracks endangers the durability as they make a pathway for harmful particles dissolved in fluids and gases. Without proper treatment, maintenance costs will increase. Self- healing can prevail in small cracks due to precipitation of calcium carbonate and hydration of concrete. Therefore, the use of microfibers is proposed to control the crack width and to promote the self-healing efficiency. In the current research crack sealing is also enhanced by the application of superabsorbent polymer. This swelling reaction seals the crack from intruding harmful substances. Mortar mixed with micro-fibres with and without superabsorbent polymers were investigated on their crack sealing and healing efficiency. Regain in mechanical properties on crack healing was investigated by the performance of four-point bending tests and the sealing capacity of the superabsorbent polymer was measured through a decrease in water permeability. Current commercial uses of SAP in this field are for pesticides, fertilizers and pharmaceuticals. A possible use of SAP as a controlled release agent in concrete could be for particular plasticizing admixtures that are more effective if they are first released shortly after initial contact between water and cement, at which time the pH of fresh concrete is relatively high.

SAP may also be used to control the release of substances other than water that aredissolved in the SAP particles. Substances that are initially at a higher activity in the polymer will diffuse out of the particles into the surroundings, according to Buchholz and Graham. Compared to other absorbent polymers, superabsorbent polymers have a special feature: their swelling depends on the pH of the swelling medium, which is a feature that may be used as switches for controlled release. Current commercial uses of SAP in this field are for pesticides, fertilizers and pharmaceuticals. As suggested in, a possible use of SAP as a controlled release agent in concrete could be for particular plasticizing admixtures that are more effective if they are first released shortly after initial contact between water and cement, at which time the pH of fresh concrete is relatively high.

SAP can be for blocking cracks in concrete. A special type of SAP that can hardly absorb alkaline water in fresh and hardened concrete was used to absorb neutral or acidic water infiltrating through cracks. In this case, SAP particles remain dormant (unswollen) within the concrete until a crack exposesthem to the surface and water flowing through the crack causes them to swell. Theeffectiveness of the SAP was confirmed by the reduced permeability measured inthe healed concrete.

A similar concept was proposed, in which a precursor solution of acrylic acid-co-acrylamide was injected into the concrete cracks together with an initiator and a cross-linker. The precursor was then activated with infrared radiation to initiate copolymerization. Preliminary tests on concrete cracks filled with large SAP particles (0.63-1.25 mm) showed reduced permeability of the repaired concrete. The swelling ratios of SAP in water, acidic, saline and basic solutions were also measured before and after accelerated ageing by ultraviolet radiation. In another study, in-situ polymerization of SAP as a concrete surface treatment to improve sulphate resistance.

1.1.8.5 Water Proofing:-

The volume increase of a gel of water saturated, swollen SAP can be used to form a barrier to water flow. Sealing composites made by blending modified SAP into rubber (Tsubakimoto et al) or a thermoplastic elastomer have been developed for sealing the joints of various building materials. The composite may be used as mortar in joints and, if any gaps were left during construction or created after construction due to settlement, the SAP swells when in contact with leaking water and forms a seal, as suggested by Shimomura and Namba. According to such a composite was used in the construction of the Channel Tunnel between France and England.

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1.2 Aim and Objectives

1.2.1 Aim

Use of Super Absorbent Polymers to enhance the properties such as Strength, Durability and Workability.

1.2.2 Objective

1. To Study the Chemical Composition of SAP.
2. To Study the influence of SAP on properties of concrete such as Strength, Workability and Durability.
3. To Study the effect of SAP on Autogenous Shrinkage.

1.3 Literature Review

1.3.1 General

According to mohd. J. zohuriaan-mehr et al, following are the advancements are done in past years.

- 1938 – First SAP was made by polymerizingAcrylic acid (AA) with divinylbenzene.
- 1950 – First generation of hydrogel appeared.
- 1970 – First commercial sap was made.
- 1978 – First commercial sap was made in japan which was used in baby and female diapers and napkins.
- 1980-1990 – world production of SAP resins wasmore than one million tons

1.3.2 Findings

1. **Effect of Sap on Workability and Hydration Process in Fly Ash and Other Cementitious Composites is written by Sikora And Klemm in the year 2015.**He described that the effects of superabsorbent polymers on rheology, autogenous shrinkage, and microstructure strongly depend on SAP type and water absorption/desorption kinetics. He also described that In general, SAPs with high water absorption capacity (minimum 10 g of water per 1 g of polymer in pore solution) proved to be efficient in diminishing autogenous shrinkage. These polymers are able to retain part of the absorbed water and release it gradually during a period of 4 weeks. Superabsorbent polymers with low water absorption capacity (5 g of water per 1 g of the polymer) have a limited effect on microstructure alteration and hence autogenous shrinkage. The vast majority of the absorbed water is released during the first hours after mix preparation. Non uniform distribution of water and/or permanent

retention of some water molecules inside the polymer network may lead, in some cases, to a small increase in autogenous shrinkage.

2. **Influence of Superabsorbent Polymers on The Surrounding Cement Paste is written by Wang et al. in the year 2015.** He discussed that the formation of affected zone around SAP, using large spherical SAP particles with a dry particle size of 1.5–2 mm to magnify the zone influenced by SAP. The hydration kinetics, degree of hydration, capillary pore structure, micro hardness and microstructure of the affected zone are also discussed, based on the desorption behaviour of SAP in cement paste. He also stated that the Desorption of Sap Promotes the Hydration of Its Surrounding Cement Paste and Advances the Primary Hydration Heat Peak. the Degree of Hydration Around Sap Is Increased by About 5%, almost Equal to an Increase of W/C by 0.04.

3. **Effect of Internal Curing by Using Sap-internal Relative Humidity is written by Song et al. in the year 2016.** He stated that the Different types of alkali activators produced differences in the strength development of alkali-activated GGBFS mortar. The strengths of the ANC series were smaller than those of the AWN series due to differences in the pH between the alkali activators. As the pH of the alkali activator increased, the solubility of GGBFS increased, accelerating the hydration rate and strength development. In addition, the compressive strength of AWN-S0.0 was higher than that of NPC-S0.0 at early ages, whereas it was comparable to that of NPC-S0.0 at 28 days. The early-age and 28-day strengths of ANC-S0.0 were lower than those of NPC-S0.0. strength of all the specimens decreased. However, the strength increase ratio from 7 days to 28 days was larger in the specimens with SAP than in specimens without SAP. This is because of the internal curing effect by SAP, which helped continue hydration of the specimens by releasing its absorbed water.

4. **The Mechanical Strength, Degree of Hydration, And Electrical Resistivity of Cement Pastes Modified with SAP is written by Farzanian et al. in the year 2016.** He stated that the effect of mechanical pressure on the absorption of SAPs was evaluated and shown to notably influence the absorption behaviour this indicates the

importance of considering the constraint effect of the cementitious matrix on SAP's behaviour during initial mixing. For the SAPs and mix designs examined in this study, the incorporation of SAPs was generally found to decrease the compressive strength of the cement pastes, especially in the cases where SAPs resulted in increased formation of macro voids in the cement pastes. The degree of hydration of cement pastes with slow desorbing SAP1 and SAP2 showed a slight decrease compared to that of the control cement pastes up to 28 days. The effect of SAP1 on the compressive strength and electrical resistivity of the cement pastes was more pronounced at water/cement ratios of 0.35 and 0.4 than at 0.5. It was suggested that the electrical resistivity of cement pastes with slow desorbing SAP1 and SAP2 was influenced by two opposing effects corresponding to pore structure densification due to a lower effective water/cement ratio and increased macro void formation.

5. **Mitigation of Early Age Cracking of Concrete Based on New Gel Type Sap is written by Liu et al. in the year 2017.** He stated that the experimental results show that the cracking area of concrete was greatly reduced when up to 41 kg=m3 gel-type ICA was used in concrete with a w/c ratio of 0.5, With a dosage of ICA up to 41 kg=m3, the initiation time of surface cracking of concrete was delayed by more than 10 h, the initial declining points of the IRH curves for ICC were delayed compared with those of the control samples, and the rates of decline of the IRH curves of ICC were slower than those of conventional concrete. By applying different curing conditions, it was found that the curing temperature was the key factor that governs the crack initiation, however, the crack pattern, crack width, and crack length were found to be governed by the relative humidity and Field applications show that the gel-type ICA mitigated the early-age cracking not only of hard-to-cure structures but also of concrete exposed to extreme weather conditions.

6. **Combined Effect of Shrinkage Reducing Admixtures and Sap on The Autogenous Shrinking, Hydration and Properties of Cementitious Materials is written by Wehve et al. in the year 2017.** He stated that the Addition of SRA was shown to decrease the absorption of SAP in the extracted pore solution as well as in the microstructure of cement pastes. The cement paste with both SAP and SRA

showed a higher shrinkage than the cement paste with SAP possibly due to lower initial absorption and later on lower desorption of SAP when SRA is present.It was shown that the hydration temperature peak of the cement paste with both SRA and SAP occurred sooner than that of the cement paste with SRA. The non-evaporable water content measurement indicated a higher degree of hydration in the cement paste with both SRA and SAP than in the cement paste with SRA at later ages, due primarily to internal curing effect of SAP. The combined effect of SRA and SAP was found to generally result in a reduction in the compressive strength and electrical resistivity of the cement paste compared to the cement paste with SRA or cement paste with SAP. It appeared that the addition of SAP promoted Ca(OH)2 formation in hydration product as determined from the TGA and XRD analyses. SEM examination indicated a narrow rim of higher porosity around the SAP macro voids in the cement paste with SAP and the cement paste with SAP and SRA. Interestingly, a distribution of micro voids in the range of 10–20 lm was observed in the microstructure of the cement paste with SAP and SRA at 28 days, which could be responsible for a lower compressive strength of the cement paste with SAP and SRA compared to the cement paste with SAP at this age.

7. **Mixing Design and Micro Structure of Ultra High Strength Concrete with Manufacture Sand is written by Shen et al. in the year 2017.** He stated that the new mixing proportion method is based on gradation optimization and phase volume analysis, the mix proportion has less surplus of paste and mortar, so it has less cementitious materials content. This method can be applied to design concrete with C120 degree with MS or RS, UHSC prepared with MSs have higher strength than UHSC made with RS, so it is not necessary to regard the MS as a low quality succedaneum of RS. Microstructure of MS UHSC is very dense and the size of the hydration products e.g. AFt, CH and AFm and C-S-H gel become very fine. There is no obvious element enrichment at the micro scale of the UHSC paste.

8. **Efficiency of Internal Curing by Sap is written by Fernando et al. in the year 2018.** He stated that the Mortars with SAP can significantly reduce autogenous shrinkage, especially with higher GGBS contents. After max shrinkage (up to 200

mm/m) in the first weeks, mortars with high GGBS level modified by SAPs slightly swell due to the filling of nano pores with later hydration slag products. Further CSH is formed due to the availability of water supplied by SAP and a presence of space created by collapsed SAPs. Also, GGBS reaction is activated by CH formed in PC hydration; the max relative expansion takes place at the end of week-6, when the max amount of portlandite is formed. Both studied SAPs are able to supply water for longer GGBS hydration. Its products can be deposited into the smaller pores (under 20 nm of diameter) formed by high contents of GGBS. It is because smaller pores have greater water affinity due to their higher surface area. SAP Y is more efficient in decreasing the number of smaller pores due to its higher capacity to absorb and also to provide water for later hydration. Pores with diameter greater than 500 nm may be formed by addition of polymer. SAP Y, with higher water absorption capacity, is able to produce larger pores than SAP X. However, this increment of porosity by SAP does not affect compressive strength for low GGBS contents at 90 days (considering the same w/b ratio). Reduction in mechanical properties can be observed for substitution levels above 50% when compared to the reference samples. Overall, although SAP increases total porosity in PC-GGBS mortars, it reduces autogenous shrinkage, extends GGBS hydration, and keeps the same level of compressive strength (for low GGBS contents) when compared to the reference samples with the same w/b ratios.

1.3.3 Summary

- After all the literature study following are the results and uses of super absorbent polymer are found out.
- Used in making napkins ad diapers of kids and female.
- Used for agricultural purposes.
- Used as admixtures in concrete to reduce autogenous shrinkage and increase strength of concrete.
- SAP can be used as biosensors as well as drug delivery system (DDS)
- Used in tissue engineering where SAP contains human cells to repair tissues.
- Hydrogel can sense environmental changes and release the stored products.

Chapter 2

Materials and Methodology

2.1 Materials

2.1.1 Materials required for making concrete

- Cement:- 53 Grade ordinary Portland cement conforming to IS 12269
- Aggregate:- Aggregates shall comply with the requirements of IS 383. As far as possible preference shall be given to natural aggregates. The nominal maximum size of coarse aggregate should be as large as possible within the limits specified but in no case greater than one-fourth of the minimum thickness of the member, provided that the concrete can be placed without difficulty so as to surround all reinforcement thoroughly and fill the comers of the form. For most work, 20 mm aggregate is suitable. Where there is no restriction to the flow of concrete into sections, 40 mm or larger size may be permitted. In concrete elements with thin sections, closely spaced reinforcement or small cover, consideration should be given to the use of 10 mm nominal maximum size.
- **Sand (< 4.75 mm) zone 2:-**Sand (zone 2) conforming is: 383-1970.

Table 2.1. Grading of sand.

GRADING LIMITS FOR FINE AGGREGATES

Sieve Size	Percentage of Passing For			
	Grading Zone-I	Grading Zone-II	Grading Zone-III	Grading Zone-IV
10 mm	100	100	100	100
4.75 mm	90 – 100	90 – 100	90 – 100	95 – 100
2.36 mm	60 – 95	75 – 100	85 – 100	95 – 100
1.18 mm	30 – 70	55 – 90	75 – 100	90 – 1000
600 micron	15 – 34	35 – 59	60 – 79	80 – 100
300 micron	5 – 20	8 – 30	12 – 40	15 – 50
150 micron	0 – 10	0 – 10	0 – 10	0 – 15

- Super absorbent polymer (SAP) - POTASSIUM SALT

This is a speciality polymer, especially designed for use in concrete. This super absorbent material can retain 500 to 1000 times water to its weight. Super Absorbent Polymer increases the water retention capacity in concrete effectively

Figure 2.1- Sap in powder form

- Super plasticizers (water reducer):-

Admixture, is comply with IS 9103. Previous experience with and data on such materials should be considered in relation to the likely standard of supervision and workmanship to the work being specified, Admixtures should not impair durability of concrete nor combine with the constituent to form harmful compounds nor increase the risk of corrosion of reinforcement.

To fulfil above code requirement, water reducer plasticizers are used based on SNF (naphthalene formaldehyde). CAC-Super flow 40(PQC) is used as W\R.

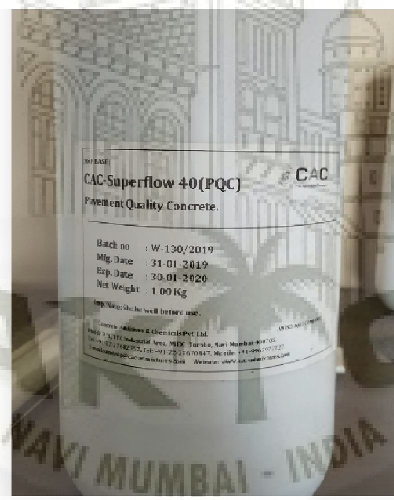


Figure 2.2. CAC-Superflow 40(PQC) [Super plasticizer]

- Water (tap water):-

Water used for mixing and curing shall be clean andfree from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. Potable water is generally considered satisfactory for mixing concrete.

2.1.2 Equipment required for concrete casting

- Moulds:-

Cube Mould- 'The mould shall be of metal, preferably steel or cast iron, and stout enough to prevent distortion. It shall be constructed in such a manner as to facilitate the removal of the moulded specimen without damage, and shall be so machined that, when it is assembled ready for use, the dimensions and internal faces shall be accurate within the following limits: 'The height of the mould and the distance between opposite faces shall be the specified size + 0·2 mm. The angle between adjacent internal faces and between internal faces and top and bottom planes of the mould shall be 90° +0-5°. The interior faces of the mould shall be plane surfaces with a permissible variation of 0·03 mm. Each mould shall be provided with a metal base plate having a plane surface.

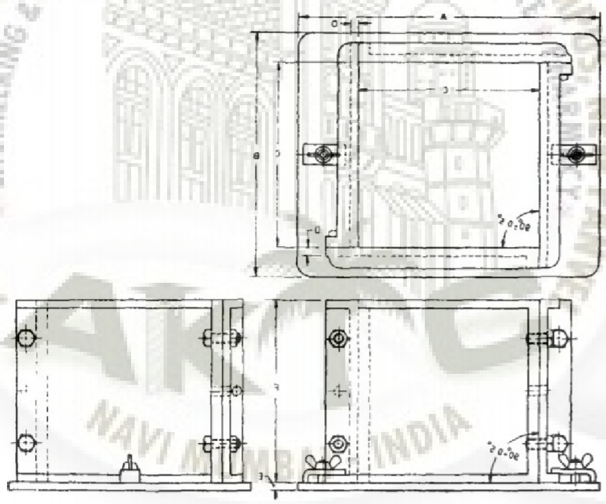


Figure 2.3. Cube mould

The base plate shall be of such dimensions as to support the mould during the filling without leakage and it shall be preferably attached to the mould by springs or screws, the parts of the mould when assembled shall be positively and rigidly held together. And suitable methods of ensuring this, both during the filling and on subsequent handling of the filled mould, shall be provided.

Size of mould is 150x150x150 mm is used for casting cubes.

Cylinder-The cylindrical mould shall be of metal which shall be not less than 3 mm thick. Each mould shall be capable of being opened longitudinally to facilitate removal of the specimen and shall be provided with a means of keeping it closed while in use. The ends shall not depart from a plane surface, perpendicular to the axis of the mould, by more than 0·05 mm. When assembled ready for use, the mean internal diameter of the mould shall be 15·0 cm ±0·2 mm and in no direction shall the internal diameter be less than 14·95 cm or more than 15·05 cm. The height shall be 30-0 cm ±0-1 cm, each mould shall be provided with a metal base plate, and with a capping plate of glass or other suitable material. The base plate and the capping plate shall be at least 6·S mm thick. And such that they do not depart from a plant' surface by more than 0·02 mm, the base plate shall support the mould during filling without leakage and "hall be rigidly attached to the mould. The mould and base plate shall be coated with a thin 611n of mould oil before use. In order to prevent adhesion of the concrete.

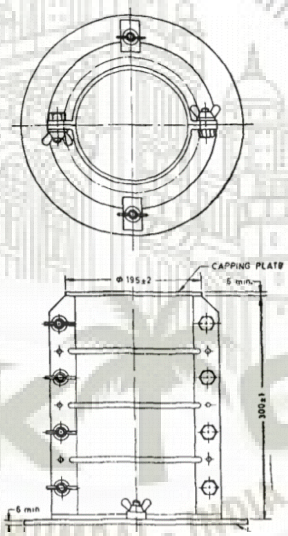


Figure 2.4. Cylinder mould

- Concrete Mixer:-

Figure 2.5. SMM - 1 (10/7) Concrete Mixer with Mechanical Hopper

- Weighing machine:-

Figure 2.6.Weighing machine

- Vibrating table:-

Figure 2.7. Vibrating table

This machine used to firm and good compaction of concrete with the help of this concrete we can reduces air voids in concrete.

- Curing tank:-Cubes were cured in AIKTC concrete lab's curing tank.

Figure 2.8. Curing tank

2.2 Methodology

2.2.1 Design of M40 concrete (IS CODE METHOD)

CONCRETE MIX DESIGN M40

USING NOMINAL MIX DESIGN METHOD

ACCORDING TO IS-10262:1982

DESIGN PARAMETERS
Fck=40mpa
MSA=20mm + 10mm
Shape of Coarse Aggregate=Angular
Degree of Workability=0.92
Degree Of Quality Control=Very Good
Degree Of Exposure=Severe
Slump Cone=25mm - 50mm

DATA ON MATERIAL
Cement Used=53 Grade Conforming To Is 12269-1987
Specific Gravity of Cement=3.15
Specific Gravity of Sand (Fine Aggregate) = 2.6
Specific Gravity of Coarse Aggregate = 2.7
Coarse Aggregate=20mm And 10mm Mix In the Ratio of 60:40
Fine Aggregate (Sand) = Conforming To Zone II

SEIVE ANALYSIS (CLASUE NO. 43 – IS 383 -1970)

STEP 1: DETERMINE TARGET MEAN STRENGTH

Ftm=Fck+ (k.S)
=40+ (1.65x5)
=48.25 N/mm^2

STEP 2: DETERMINATION OF WATER-CEMENT RATIO

W/C = 0.38
From Table, 3.8 (For Cement) and Graph 1 (For W/C)
W/C for M40 Grade = 0.40
Cement Content (Minimum) = 360 Kg/M^3

STEP 3: DETERMINATION OF AIR CONTENT

FROM IS-10262: TABLE 3
M= 2%

STEP 4: DETEMINATION OF WATER CONTENT

FROM TABLE 3.1 IS-10262

Required Water Content = 180 + (3.6/100) X 180

= 186.48 Kg/M^3> 186Kg/M^3 (O.K)

Percentage of Sand = 25%
= 25 – 4.4 = 20.6 %

STEP 5: CALCULATION OF CEMENT CONTENT

W/C RATIO = WATER CONTENT/CEMENT CONTENT

CEMENT CONTENT = WATER CONTENT/ (W/C RATIO)

= 186.48/0.38 = SAY 490 kg/m^3

Check for Minimum Cement Content for M40 Grade

Minimum 360 Kg/M^3< 490 Kg/M^3 (O.K.)

STEP 6: DETERMINATION OF TOTAL VOLUME OF CONCRETE

We Know That,
Total Volume of Concrete for 1m3 (V) = 1- M
Where M = % of Entrapped Air

V = 1- (2/100)
= 0.98 M^3

STEP 7: DETEMINATION OF FINE AGGREGATE CONTENT

$$V = \left[W + \frac{c}{S_c} + \frac{1}{p}\frac{f_a}{S_{fa}}\right] x \frac{1}{1000}$$

$$0.98 = \left[186.1 + \frac{490}{3.15} + \left(\frac{1}{0.206}\frac{f_a}{2.6}\right)\right] x \frac{1}{1000}$$

F.A. = 341.89 kg/m^3

STEP 8: DETERMINATION OF COARSE AGGREAGATE CONTENT

$$V = \left[W + \frac{c}{S_c} + \frac{1}{1-p}\frac{C_a}{S_{ca}}\right] x \frac{1}{1000}$$

$$0.98 = \left[186.1 + \frac{490}{3.15} + \left(\frac{1}{1-0.206}\frac{C_a}{2.7}\right)\right] x \frac{1}{1000}$$

C.A. = 1368.48 kg/m^3

STEP 9: CORRECTION FOR ABOVE INGREDIENTS

The Above Proportions Are Now Required To Be Corrected To Suit the Site Conditions

Correct For "Bulking Of Sand" At 2% and For "Absorption of Water" In Case Of Coarse Aggregate At 0.5%

1) QUANTITY OF WATER IS TO BE REDUCED FOR MOISTURE PRESENT (BULKING IN SAND) = 2 % OF F.A.
   = (2/100) x 341.89
   = 6.83 KG OR LITRE

2) EXTRA QUANTITY OF WATER TO BE ADDED FOR ABSORPTION OF WATER IN THE CASE OF C.A. = 0.5 % OF C.A.
   = (0.5/100) x 1368.48
   = 6.48 KG OR LITRE

THEREFORE, THE ACUTAL QUANTITY OF WATER REQUIRED TO BE ADDED = 186.48 – 6.48 + 6.83
= 186.47 kg/m^3

THEREFORE, THE ACUTAL QUANTITY OF SAND REQUIRED TO BE ADDED = 341.89 + 6.83
= 348.73 kg/m^3

THEREFORE, THE ACUTAL QUANTITY OF C.A. REQUIRED TO BE ADDED = 1368.48 – 6.84
= 1361.64 kg/m^3

STEP 10: MIX PROPORTION

INGREDIENTS	WEIGHT (kg/m^3)	RATIO
WATER	186.48	0.38
CEMENT	490	1
SAND (F.A.)	348.73	0.71
C.A. : 60% OF 20mm	816.98	1.66
C.A. : 40% OF 10mm	544.65	1.11

2.2.2 Absorption & Desorption Capacity of Sap

AIM: to find the absorption & desorption capacity of sap

MATERIALS REQUIRED

APPARATUS REQUIRED: flask (500 ml), jar (1000 ml), cylinder (250 ml) and weighing machine.

CHEMICAL REQUIRED: sap (potassium salt of acrylic acid)

PROCEDURE:-

FOR ABSORPTION CAPACITY
1. Take a Bucket and fill it with 5000 grams of water
2. Prepare a tea bag with a permeable cloth (which allows liquid to pass through it)
3. Take the dry weight of tea bag (empty)
4. Take the saturated weight of tea bag
5. Take 5 grams of Super Absorbent Polymer
6. Seal the top of the tea bag just below the hole
7. Hang all the bag completely immersed in the water bucket
8. After 24 hours remove the tea bag and allow the excess water to drop (don't apply external pressure on tea bag to remove excess water)
9. Weight the tea bag

FOR DESORPTION CAPACITY
1. Hang the tea bag for an extended interval of time away from sun light and let the water desorb
2. Weight the tea bag at regular interval

$$\text{Absorbent capacity} = \frac{W_{immersion} - W_{dry} - W_2}{W_{dry} - (W_{empty} - W1)}$$

2.2.3 WORKABILITY TEST

Workability test is done by two methods as per (IS 1199: 1959)

A) Slump cone method

B) Flow table method

A) Slump cone test :-

This method of test specifies the procedure to be adopted, either in the laboratory or during the progress of work in the field, for determining, by the slump test, the consistency of concrete where the nominal maximum size of the aggregate does not exceed 38 mm.

Apparatus

a) Mould - The mould for the test specimen shall be in the form of the frustum of a cone having the following internal dimensions:

Table 2.2. Slump cone dimensions

Dimensions	**cm**
Bottom Diameter	20
Top Diameter	10
Height	30

The mould shall be constructed of metal (brass or aluminium shall not be used) of at least l-6 mm (or 16 BG) thickness and the top and bottom shall be open and at right angles to the axis of the cone. The mould shall have a smooth internal surface. It shall be provided with suitable foot pieces and also handles to facilitate lifting it from the moulded concrete test specimen in a vertical direction as required by the test. A mould provided with a suitable guide attachment may be used. A typical mould without the guide is shown in Figure

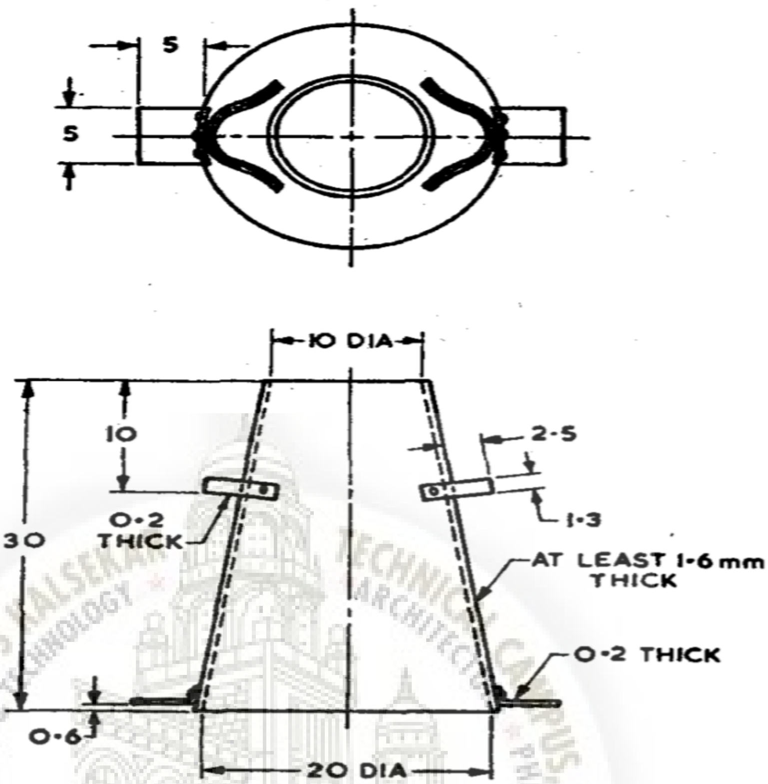


Figure 2.9. Slump cone

b) Tamping rod - The tamping rod shall be of steel or other suitable material, 16 mm in diameter, 0.6 m long and rounded at one end.

NOTE - To facilitate the Wing of the mould in a vertical direction, it is recommended that suitable guide attachments be provided. Any rivets used in the construction of the mould shall be countersunk flush on the inside of the cone. Attachments should preferably be welded to the mould.

Sampling – If this test is being carried out in the field, the sample mixed concrete shall be obtained as described in 3. In the case of concrete containing aggregate of maximum size more than 38 mm, the concrete shall be wet-sieved through 1.5 in screen to exclude aggregate particles bigger than 78 mm.

Procedure – The internal surface of the mould shall be thoroughly cleaned and freed from superfluous moisture and any set concrete before commencing the test. The mould shall be placed on a smooth, horizontal, rigid and non-absorbent surface, such as a carefully levelled metal plate, the mould being firmly held in place while it is being filled. The mould shall be filled in four layers, each approximately one-q6arter of the height of the mould. Each layer shall be stamped with twenty-five strokes of the rounded end of the tamping rod. The strokes shall be distributed in a uniform manner over the cross-section of the mould and for the second and subsequent layers shall penetrate into the underlying layer. The bottom layer shall be tamped throughout its depth. After the top layer has been rodded, the concrete shall be struck off level with a trowel or the tamping rod, so that the mould is exactly filled. Any mortar which may have leaked out between the mould and the base plate shall be cleaned away. The mould shall be removed from the concrete immediately by raising it slowly and carefully in a vertical direction. This allows the concrete to subside and the slump shall be measured immediately by determining the difference between the height of the mould and that of the highest point of the specimen being tested. The above operations shall be carried out at a place free from vibration or shock, and within a period of two minutes after sampling.

Slump - The slump measured shall be recorded in terms of millimetres of subsidence of the specimen during the test. Any slump specimen which collapses or shears off laterally gives incorrect result and if this occurs the test shall be repeated with another sample. If, in the repeat test also, the specimen should shear, the slump. Shall be measured and the fact that the specimen sheared, shall be recorded.

NOTE-Some indication of the cohesiveness and workability of the mix can be obtained, if after the slump measurement has been completed, the side of the concrete is tapped gently with the tamping rod; a well-proportioned concrete which has an appreciable slump will gradually slump further, but if the mix has been badly proportioned, it is likely to fall apart.

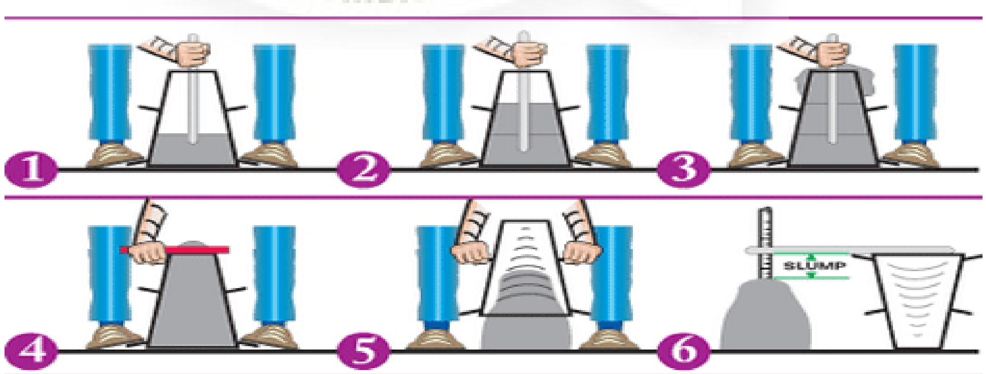


Figure 2.10. Slump cone test

B) Flow table method:-

This method of test specifies the procedure for the use of the flow table to determine the fluidity of concrete, where the nominal size of the aggregate does not exceed 38 mm.

Apparatus

a) Mould - The mould shall be made of a smooth metal casting, as shown in Fig. 3 in the form of the frustum of a cone with the following internal dimensions. A base 25 cm in diameter, upper surface 17 cm in diameter, and height 12 cm; the base and the top shall be open md at right angles to the axis of the cone. The mould shall be provided with handles.

b) Flow Table - Flow table shall conform to the design shown in fig and shall be mounted on and bolted to a concrete base having a height of 40 to 50 cm and weighing not less than 140 kg

Samplings - Samples for test shall be obtained by the methods specified under 3. In the case of concrete containing aggregate of maximum size more than 38 mm, the concrete shall be wet-sieved through 1.5 in screen to exclude aggregate particles bigger than 38 mm. They shall be transported to the place of moulding of the specimen, and to counteract segregation, the concrete shall be mixed with a shovel until it is uniform in appearance.

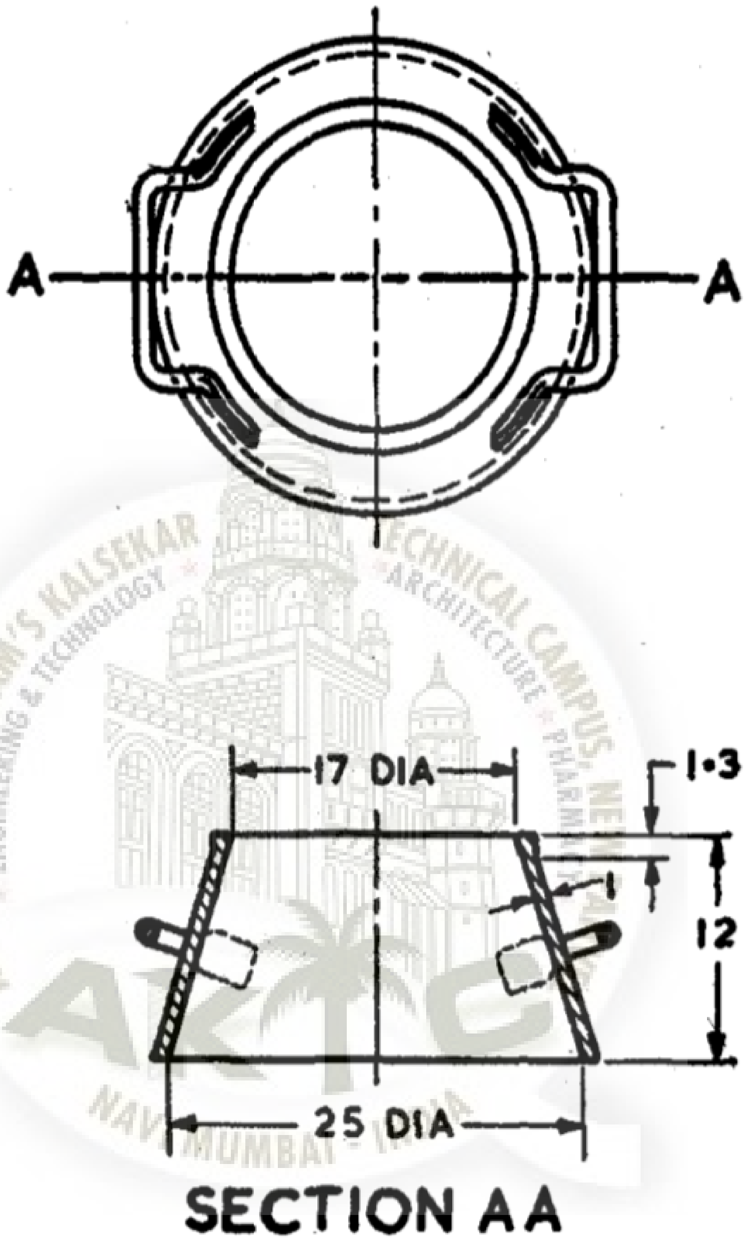
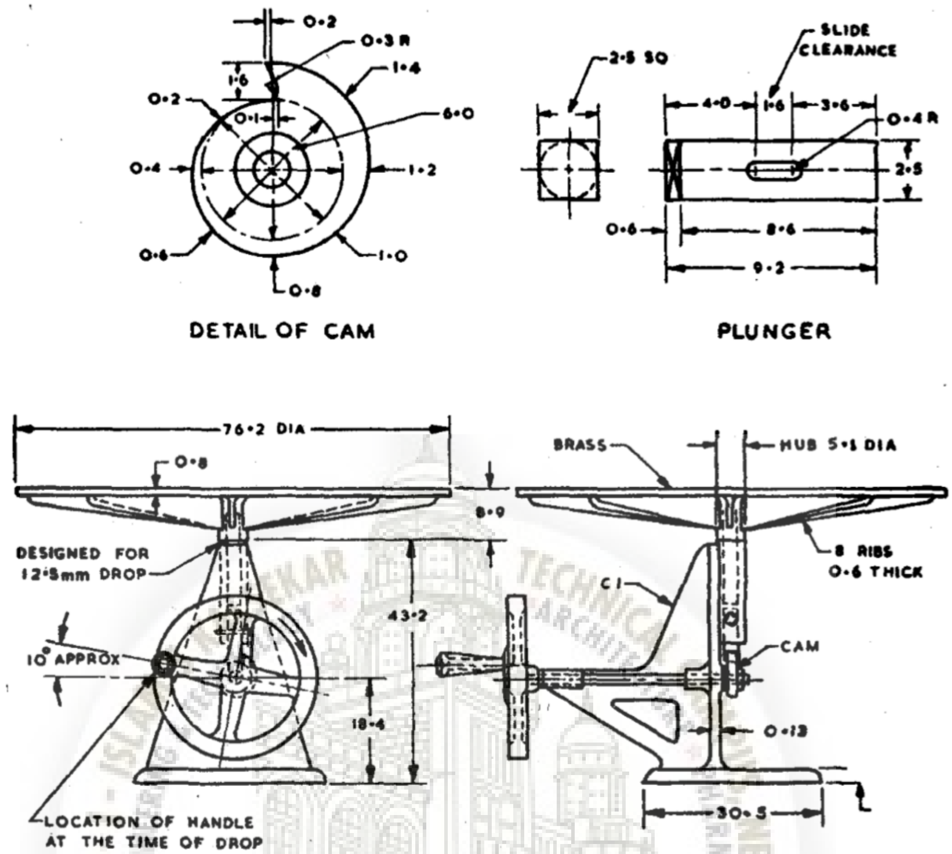


Figure 2.11. Mould for flow table



All dimensions in centimetres.

Figure 2.12. Flow table apparatus

Procedure - Immediately preceding the test, the table top, and inside of the mould shall be wetted and cleaned of all gritty material and the excess water removed with a rubber squeezer. The mould, cantered on the table, shall be firmly held in place and filled in two layers, each approximately one-half the volume of the mould. Each layer shall be rodded with 25 strokes of a straight round metal rod 1.6 cm in diameter and 61 cm long, rounded at the lower tamping end. The strokes shall be distributed in a uniform manner over, the cross-section of the mould and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, the surface of the concrete shall be struck off with a trowel so that the mould is exactly filled. The excess concrete which has overflowed the mould shall be removed and the area of the table outside the mould again cleaned. The mould shall be immediately removed from the concrete by a steady upward pull. The table shall then be raised and dropped 12.5 mm, 15 times in about 15 seconds. The diameter of the spread concrete shall be the average of six symmetrically distributed calliper measurements read to the nearest 5 mm

Recoding -The flow of the concrete shall be recorded as the percentage increase in diameter of the spread concrete over the base diameter of the moulded concrete, calculated from the following formula:

$$\text{Flow percent} = \frac{\text{spread diameter in cm} - 25}{25} \times 100$$

2.2.4 Marsh cone test

AIM: - Finding the optimum dosage of plasticizers and superplasticizers

APPARATUS: - A conical brass vessel held on a wooden stand with a diameter of 5 or 8mm at its bottom. (Given in below figure), Stopwatch and Mortar mixer to mix the cement paste with the desired water-cement ratio.

PROCEDURE:-

1. First, you need to prepare a cement paste of 1L with a desired water-cement ratio by adding 2kg of cement to them.
2. While preparing the cement paste, the mixing should take place in the mortar mixer. The mortar mixer is used to avoid the formation of lump at the bottom of the vessel.
3. You can take water cement ration ranging from 0.1 to 0.8.

4. 70 percent of water is added at the beginning of mixing in the first step and the remaining water is added in the second step with superplasticizers. The dosage of superplasticizer will be 0.1 percentage of the weight of cement.

5. Take 1L slurry and pour into marsh cone by closing the aperture with a finger.

6. Start the stop and remove the finger. Note the time taken in seconds for complete flow out of cement paste. This time in seconds is called marsh cone time.

7. Repeat the above steps with different amount of plasticizer with the desired water-cement ratio. The Saturation point is the dose at which marsh cone time is lowest. This dose is the optimum dose of superplasticizer of plasticizer for that brand or type of cement.

8. From the above the procedure you can plot a graph between marsh cone time in the x-axis and superplasticizer dosage percentage on the y-axis as given below.

2.2.5 Test on hardened concrete

2.2.5.1 Compression test (IS: 516 -1959)

AIM: - To determine compression strength of concrete cube with and without sap

MATERIAL AND EQUIPMENT: - cement, sand, aggregate, water, super plasticizer, SAP, moulds, mixer, weighing machine, tray, flasks, etc.

Workability - Each batch of concrete shall be tested for consistency immediately after mixing, by one of the methods described in IS: 1199-1959. Provided that care is taken to ensure that no water or other material is lost, the concrete used for the consistency tests may be remixed with the remainder of batch before making the test specimens. The period of re-mixing shall be as short as possible yet sufficient to produce a homogeneous mass.

Size of Test Specimens -Test specimens cubical in shape shall be 15 X 15 X 15 cm. If the largest nominal size of the aggregate does not exceed 2 ern, 10 cm cubes may be used as an alternative. Cylindrical test specimens shall have a length equal to twice the diameter. They shall be 15 cm in diameter and 30 cm long. Smaller test specimens shall have a ratio of diameter of specimen to maximum size of aggregate of not less than 3 to 1, except that the diameter of the specimen shall be not less than 7·5 cm for mixtures containing aggregate more than 5 percent of which is retained on IS Sieve 480.

Apparatus:-

Testing of Machine - The testing machine may be of any reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 5.5. The permissible error shall be not greater than ± 2 percent of the maximum load. The testing machine shall be equipped with two steel bearing platens with hardened faces. One of the platens (preferably the one that normally will bear on the upper surface of the specimen) shall be fitted with a ball seating in the form of a portion of a sphere, the centre of which coincides with the central point of the face of the platen. The other compression platen shall be plain rigid bearing block. The bearing faces of both platens shall be at least as large as, and preferably larger than the nominal size of the specimen to which the load is applied. The bearing surface of the platens. When new, shall not depart from a plane by more than 0·01 rom at any point, and they &ban be maintained with a permissible variation limit of 0·02 mm. The movable portion of the spherically seated compression platen shall be held OD the spherical seat, but the design shall be such that the bearing face CUI be rotated freely and tilted through small angles in any direction.

Age at Test - Tests shall be made at recognized ages of the test specimens, the most usual being 7 and 28 days. Ages of 13 weeks and one year are recommended if tests at greater ages are required. Where it may be necessary to obtain the early strengths. Tests may be made at the ages of 24 hours ± 1\2 hour and 72 hours ± 2 hours. The ages shall be calculated from the time of the addition of water to the dry ingredients.

Number of Specimens - At least three specimens, preferably from different batches, shall be made for testing at each selected age.

2.2.5.2 Split tensile strength of concrete

SCOPE- This standard covers the procedure for determining the splitting tensile strength of moulded concrete cylinders.

APPARATUS - Universal Testing Machine

Any compression machine of reliable type, of sufficient capacity for the tests and capable of applying the load at the rate specified in 7.5 shah be used. It shall comply with the requirements given in IS 516 as far as applicable except that the bearing faces of both platens shall provide a minimum loading area of 12 mm x the length of the cylinder or cube, as the case may be so that the load is applied over the entire length of the specimen. If necessary, a supplementary bearing bar or plate of machined steel may be used.

AGE AT TEST- Tests shall be made at the recognized ages of the test specimens, the most usual being 7 and 28 days. Tests at any other age at which the tensile strength is desired may be made, if so required. The ages shall be calculated from the time of the addition of water to the dry ingredients. The age at test shall be reported along with the results.

NUMBER OF SPECIMENS- At least three specimens shall be tested for each age of tests.

RATE OF LOADING- The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2 N/ (mm*/min) to 2.4 N/ (mm/min). Maintain the rate, once adjusted, until failure. On manually controlled machines as failure is approached the loading rate will decrease; at this stage the controls shall be operated to maintain as far as possible the specified loading rate. The maximum load applied shall then be recorded. The appearance of concrete and any unusual features in the type of failure shall also be noted.

The rate of increase of load may be calculated from the formula: (1.2 to 2.4) x 7r/2 x I x d N/min

PROCEDURE- Specimens when received dry shall be kept in water for 24 h before they are taken for testing. Unless other conditions are required for specific laboratory investigation specimen shall be tested immediately on removal from the water whilst they are still wet. Surface water and grit shall be wiped off the specimens and any projecting fins removed from the surfaces which are to be in contact with the packing strips.

CALCULATION-The measured splitting tensile strength of the specimen shall be calculated to the nearest 0.05 N/mm2 using the following formula:

$$f_{ct} = \frac{2P}{\pi \, l\mathrm{d}}$$

Where, P= peak load in (N)

L= length of cylinder in (mm)

D= cross-sectional diameter in (mm)

Chapter 3

Results and discussion

3.1 Tests on sap

3.1.1 Absorption & Desorption Capacity of Sap

RESULT:-

Absorption Capacity
Dry Weight of Tea Bag = 9.91 grams
Wet Weight of Tea Bag = 15 grams
Weight of SAP = 5 grams
Total Weight of Tea Bag (SAP + Wet Tea Bag) = 20 grams
Total Weight of SAP after 24 hours (SAP + Wet Tea Bag) = 1260 grams
Total Weight of Saturated (Wet) SAP = 1240 grams

Desorption Capacity
Total Weight of SAP = 1125 grams
After 1 Hours = 1115 grams
After 24 Hours = 1055 grams
After 15 Days = 530.09 grams
After 20 Days = 270.09 grams

3.1.2 Optimum Percentage of Sap by Trail & Error Method

Table 3.1.Optimum Percentage of Sap

SAMPLE NAME	PERCENTAGE OF SAP (%)	COMPRESSIVE STRENGTH (7 DAYS)
A	0	30.4 N/mm^2
B1	0.2	40.7 N/mm^2
B2	0.4	32.3 N/mm^2
B3	0.6	40.2 N/mm^2
B4	0.8	45.6 N/mm^2
B5	1.0	49.2 N/mm^2
B6	1.5	47.9 N/mm^2
B7	2.0	44.2 N/mm^2

RESULTS: Taking 1% as Optimum SAP Dosage

3.2 Test on admixture

3.2.1 Marsh cone test

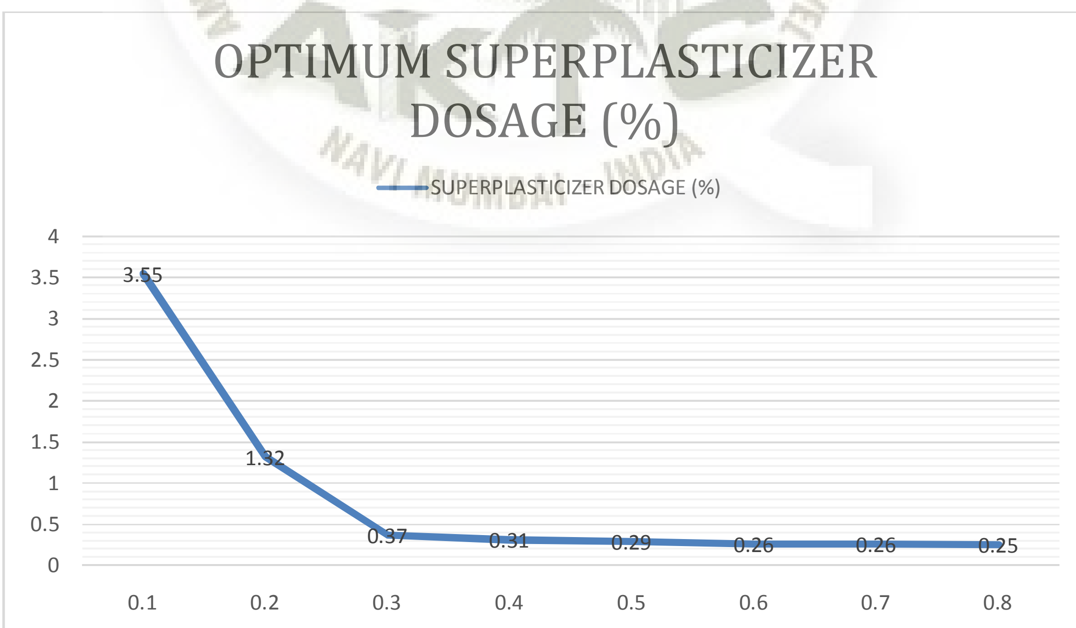


Figure 3.1. Optimum Dosage of Super Plasticizer

RESULT:-

Optimum Admixture % = 0.4%

3.3 Tests on concrete

- Workability test
- Compression test
- Tensile test

3.3.1 Tests on fresh concrete

A) Slump cone test:-

RESULT:-

The slump (Vertical settlement) measured shall be recorded in terms of millimetres of subsidence of the specimen during the test.

Slump for the given sample= 0 mm i.e., It's a true slump

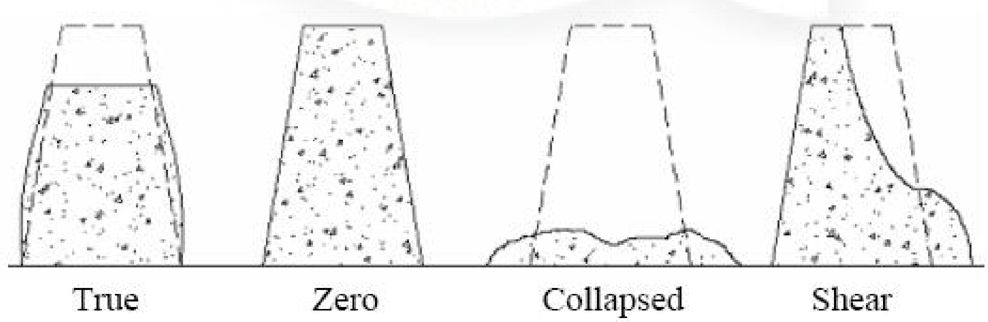


Figure 3.2. Slump types

- **True Slump** – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown in figure-1.
- **Zero Slump** – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. These type of concrete is generally used for road construction.
- **Collapsed Slump** – This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
- **Shear Slump** – The shear slump indicates that the result is incomplete, and concrete to be retested.

B) Flow table method:-

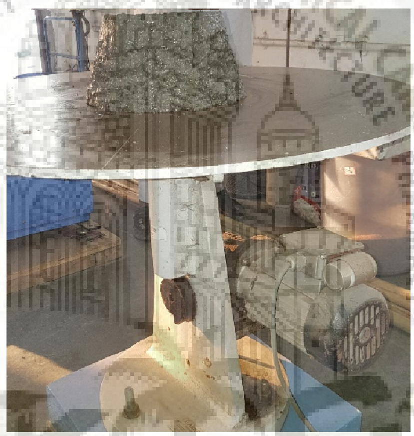


Figure 3.3. Flow Table

Result:-

1st Flow Percent – 90

2nd Flow Percent – 82

3rd Flow Percent – 80

3.4 Test on hardened concrete

3.4.1 Compression test (IS: 516 -1959)

Observations and Calculations:-

Table 3.4. Compression strength of cube with SAP (1% of cement)

SAMPLE NO.	SAP (SAMPLES)	3 DAYS	7 DAYS	28 DAYS	56 DAYS
	CUBES – COMPRESSIVE STRENGHT				
01	INITIAL WEIGHT	8.78 Kg	8.58 Kg	8.63 Kg	8.74 Kg
	FINAL WEIGHT	8.92 Kg	8.76 Kg	8.74 Kg	8.85 Kg
	STRENGHT	41.7 Mpa	56.6 Mpa	76.7 Mpa	81 Mpa
02	INITIAL WEIGHT	8.55 Kg	8.71 Kg	8.61 Kg	8.80 Kg
	FINAL WEIGHT	8.67 Kg	8.89 Kg	8.74 Kg	8.90 Kg
	STRENGHT	43.2 Mpa	58.4 Mpa	75.7 Mpa	80.1 Mpa
03	INITIAL WEIGHT	8.68 Kg	8.66 Kg	8.66 Kg	8.62 Kg
	FINAL WEIGHT	8.81 Kg	8.86 Kg	8.79 Kg	8.75 Kg
	STRENGHT	43.1 Mpa	59.2 Mpa	68.6 Mpa	88 Mpa

Table 3.5. Compression strength of cube without SAP

SAMPLE NO.	NON SAP (SAMPLES)	3 DAYS	7 DAYS	28 DAYS	56 DAYS

	CUBES – COMPRESSIVE STRENGHT				
01	INITIAL WEIGHT	8.49 Kg	8.5 Kg	8.78 Kg	8.85 Kg
	FINAL WEIGHT	8.61 Kg	8.62 Kg	8.89 Kg	8.94 Kg
	STRENGHT	36.1 Mpa	53.4 Mpa	72.6 Mpa	78.46 Mpa
02	INITIAL WEIGHT	8.54 Kg	8.39 Kg	8.85 Kg	8.74 Kg
	FINAL WEIGHT	8.65 Kg	8.56 Kg	8.96 Kg	8.82 Kg
	STRENGHT	35 Mpa	52.1 Mpa	69.2 Mpa	83 Mpa
03	INITIAL WEIGHT	8.6 Kg	8.5 Kg	8.75 Kg	8.76 Kg
	FINAL WEIGHT	8.72 Kg	8.63 Kg	8.87 Kg	8.86 Kg
	STRENGHT	37 Mpa	53.2 Mpa	71.3 Mpa	78.5 Mpa

- Compression between two samples of cube with SAP and without SAP

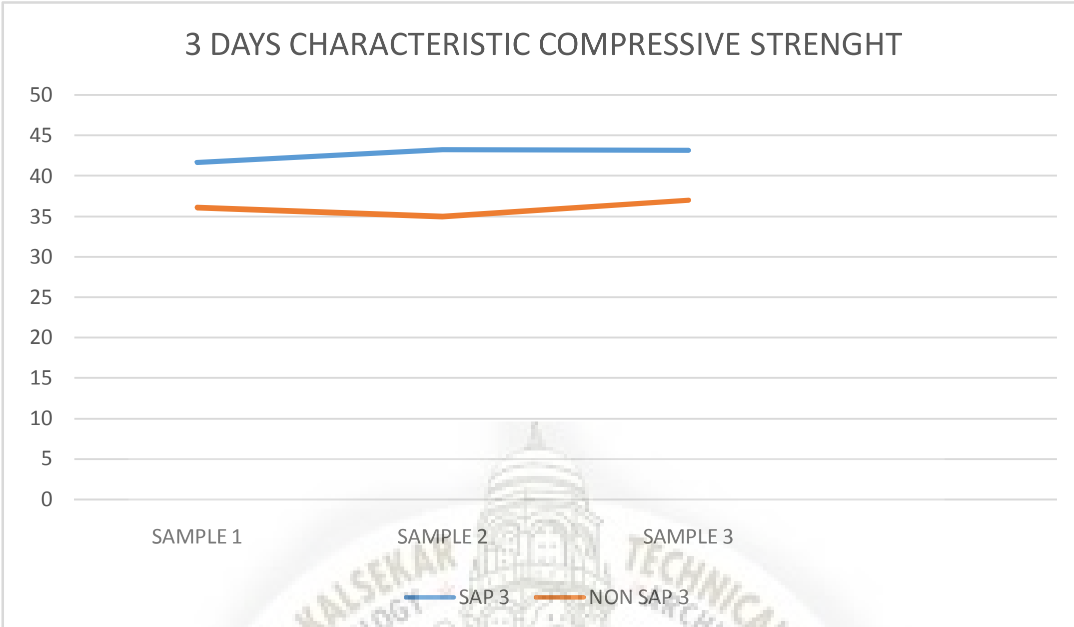


Figure 3.3. 3 days CCS

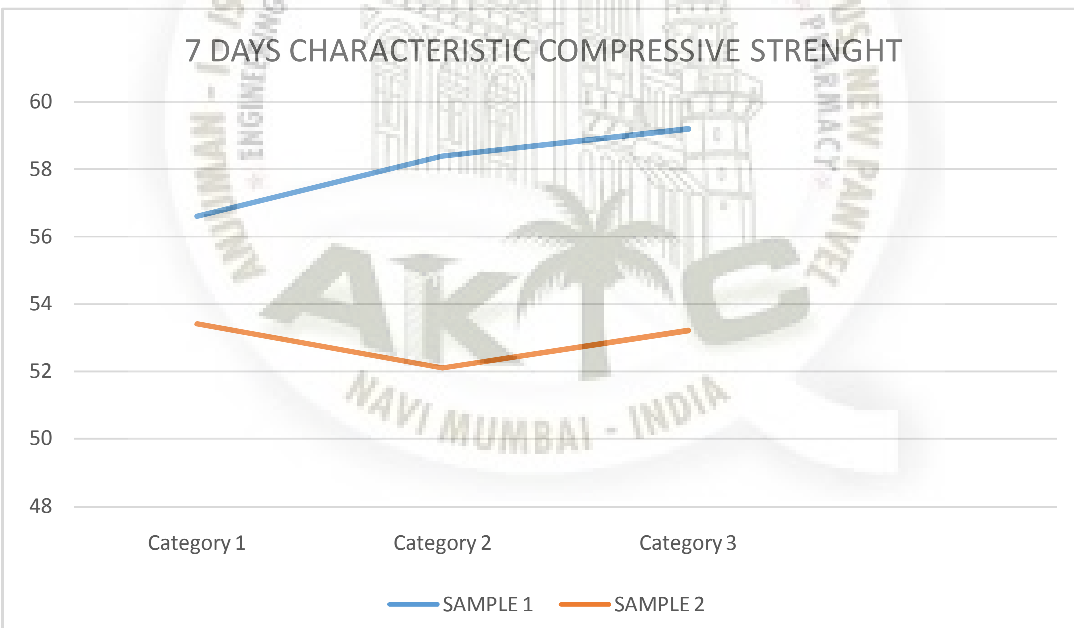


Figure 3.4. 7 days CCS

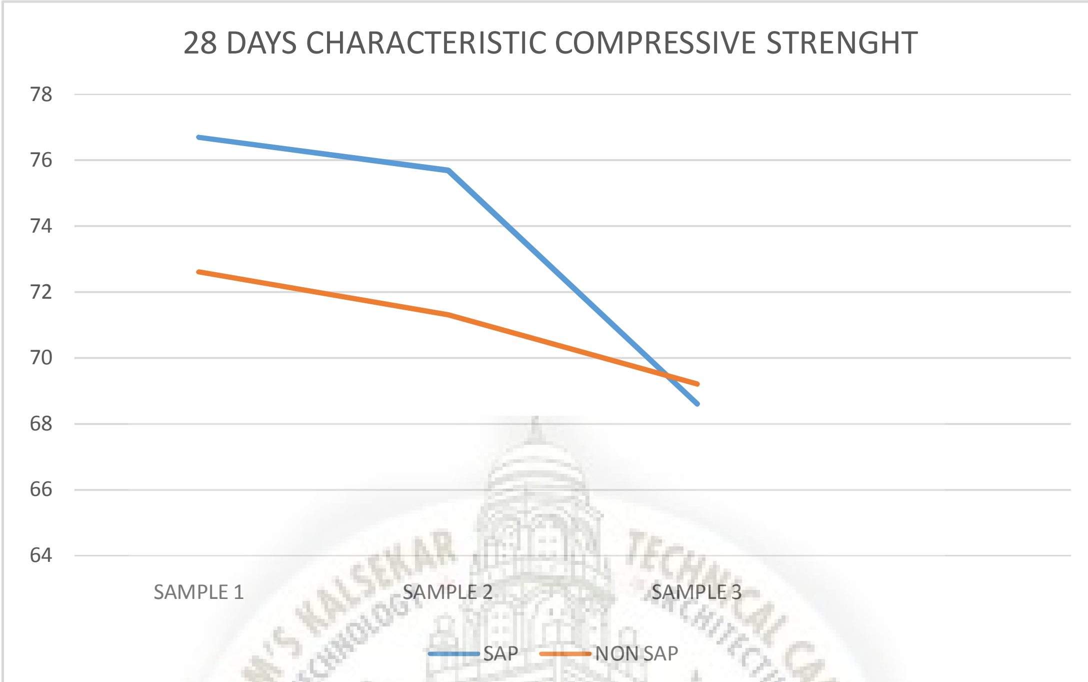


Figure 3.5. 28 days CCS

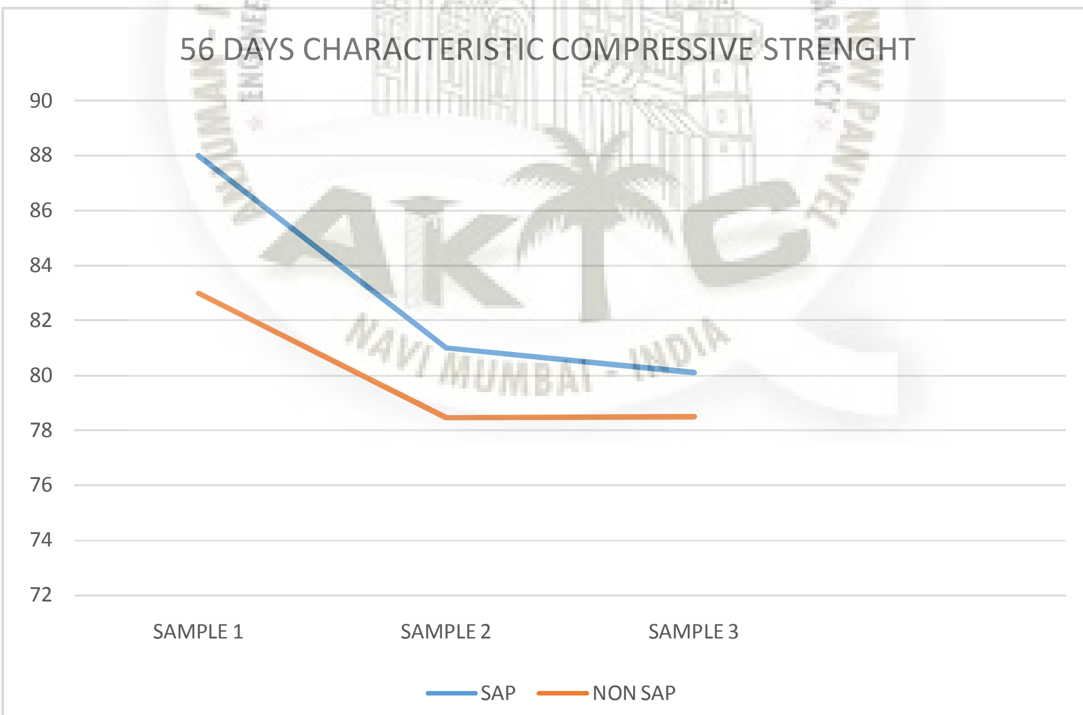


Figure 3.6. 56 days CCS

Results:-

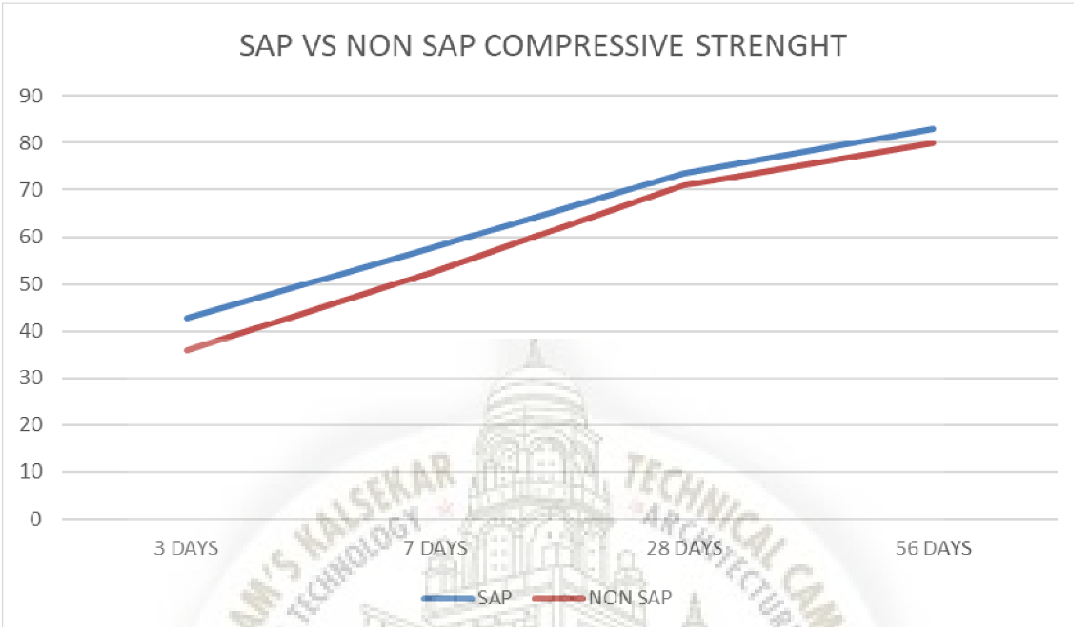


Figure 3.7. SAP VS NON SAP

Table 3.6. Result for compression test (SAP)

DESCRIPTION (CUBE)	RESULTS (AVERAGE)
SAP3	42.67 N/mm^2
SAP7	58.06 N/mm^2
SAP28	73.67 N/mm^2
SAP56	83.03 N/mm^2

Table 3.7. Result for compression test (NON SAP)

DESCRIPTION (CUBE)	RESULTS (AVERAGE)
NON-SAP3	36.03 N/mm^2
NON-SAP7	52.90 N/mm^2
NON-SAP28	71.03 N/mm^2
NON-SAP56	79.98 N/mm^2

3.4.2 Split tensile strength of concrete

Observation table:-

Table 3.8. Cylinder – Tensile Strength (SAP)

CYLINDER – TENSILE STRENGHT	SAP3	SAP7	SAP28	SAP56
INITIAL WEIGHT	13.49 Kg	13.45 Kg	13.49 Kg	13.48 Kg
FINAL WEIGHT	13.68 Kg	13.63 Kg	13.62 Kg	13.62 Kg
STRENGHT	3.631 Mpa	4.698 Mpa	5.07 Mpa	5.43 Mpa

Table 3.9. Cylinder – Tensile Strength (NON SAP)

CYLINDER – TENSILE STRENGHT	NON-SAP3	NON-SAP7	NON-SAP28	NON-SAP56
INITIAL WEIGHT	13.57 Kg	13.58 Kg	13.52 Kg	13.44 Kg
FINAL WEIGHT	13.74 Kg	13.76 Kg	13.62 Kg	13.57 Kg
STRENGHT	2.941 Mpa	4.01 Mpa	4.484 Mpa	4.521 Mpa

Result:-

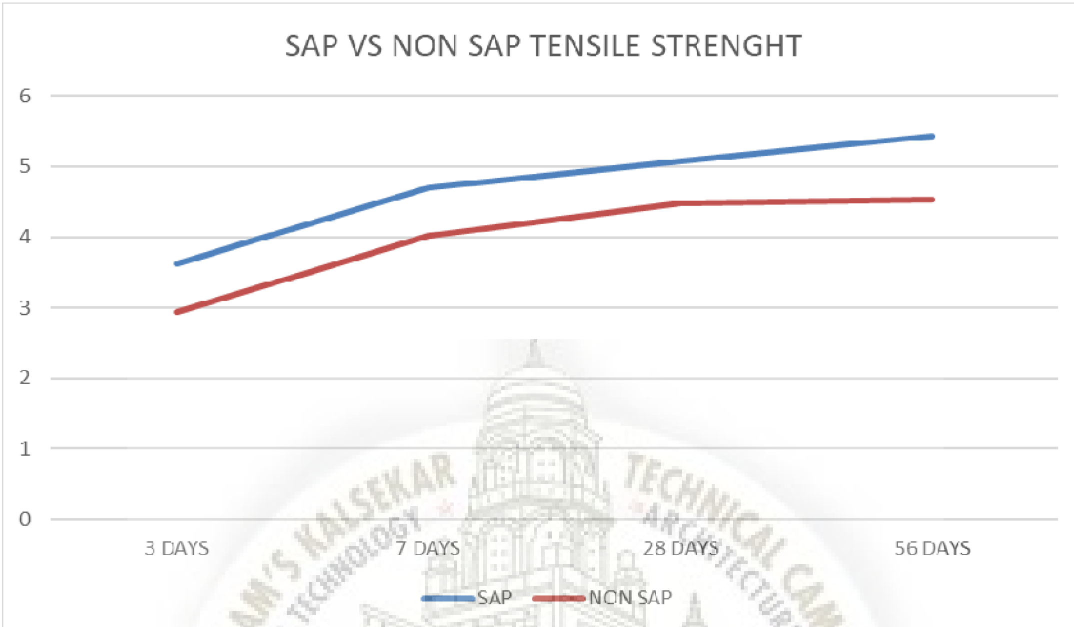


Figure 3.8. SAP VS NON SAP TENSILE STRENGTH

Table 3.10.Result for tensile test (SAP)

DESCRIPTION (CYLINDER)	RESULTS (AVERAGE)
SAP3	3.63 N/mm^2
SAP7	4.69 N/mm^2
SAP28	5.07 N/mm^2
SAP56	5.43 N/mm^2

Table 3.11.Result for tensile test (NON SAP)

DESCRIPTION (CYLINDER)	RESULTS (AVERAGE)
NON-SAP3	2.94 N/mm^2
NON-SAP7	4.01 N/mm^2
NON-SAP28	4.48 N/mm^2
NON-SAP56	4.52 N/mm^2

3.5 Discussions

1. Super absorbent polymer (SAP) are polymers which can absorb water 1000 times with respect to its own weight. Also, they can hold water for longer period then other normal absorbing material like cotton, Sponge, etc.

2. In other hand they can desorbs the water with control.

3. Because of this principle property of SAP, it can be used in construction industry to overcome various weakness and defects of concrete like autogenous shrinkage, internal curing, crack healing, fire resisting, etc.

4. Due to High Density and low permeability of High-Performance Concrete Conventional Method of curing (surface curing) cannot be utilized because water can't reach inside and also, the rate at which water is required is very high due to ongoing internal chemical reaction. So, water can be supplied by means of SAP when the internal Relative Humidity of concrete decreases.

5. Autogenous shrinkage is likely to appear mostly in High Strength Concrete (HSC); thus, introduction of SAP can serve as an internal curing agent which reduces the early-age cracking.

6. In addition of shrinkage reducing admixture and SAP into concrete there is significantly reduce in autogenous shrinkage and slightly reduce in drying shrinkage.

7. The use of conventional air-entrainment agent is possible with strain hardening cement composition (SHCC) but not when the spraying is applied. For this reason, SAP was introducing as a new additive to improve the frost resistance of the repair layer.

8.While doing shortcreting there will be major change in air void structure if it is based on a normal air-entrained admixture with SAP however.it is possible to accurately design the final air void structure which will unaffected by pumping and placing procedure.

Chapter 4

Conclusion

As the `focus of our study was to introduce SAP (which acts as an internal curing agent) and to study its various effects on concrete in terms of its shrinkage, strength and durability and comparing the specimen with SAP to its counterpart which doesn't have sap but is of identical specifications. After performing the compression and tension test on cubes and cylinder respectively we came to a conclusion that cubes with SAP on average gave 18.42 % more compressive strength after 3 days then the cubes without sap, and likewise 7 days cubes gave 9.75 % more strength, 28 days cubes gave 3.75 % more strength and 56 days cubes gave 3.81 % more strength.

Tension test performed on cylinders also gave the results in the same vein of compression test. Sap at 3 days gave 23.46 % more tensile strength, at 7 days 17.15 % more strength, at 28 days 13.06 % more strength and at 56 days 20.10 % more strength than compare to cylinders without SAP.

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