Comparative Response of Latex Modified Conventional and Latex Modified Self-Compacting Concrete

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This is to certify that the

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ABSTRACT

Self-compacting concrete has revolutionized the construction industry and the addition of polymer to self compacting concrete (SCC) is a new area of application. In latex modified conventional and latex modified SCC the two processes of polymerization and hydration proceed simultaneously. This simultaneous progress of these two processes has not been studied in detail. The research project aimed to find out the effect of the styrene-Butadiene Rubber (SBR) on conventional and self-compacting concretes. The normal concrete has a water-cement ratio of 0.37. 7% SBR by weight of cement based on the total solid content of the SBR was added to latex modified conventional concrete at the same water-cement ratio of 0.37. 1.8% super-plasticizer was added to latex modified SCC whereas the water-cement ratio and SBR amount were kept constant. Two types of curing methods, water curing and air curing were used. The effect of SBR was observed on the compressive strengths, flexural strengths, durability and calorimetric response of such concrete systems. The improvement in compressive and flexural strengths and durability of latex modified conventional concrete and latex modified SCC was observed. It was also noted that SBR modified conventional and self-compacting concrete yield higher compressive and flexure strengths when they are air cured. The research showed that the latex increases the durability of concrete against the attacks of acids and salts. It was observed that when concrete is treated in alkalis its weight and strength increases. The addition of SBR in normal concrete retards the hydration process but shows higher peak value than the normal concrete. The latex modified self compacting concrete has shown better durability results against the acids and salts attack which makes it feasible to be used in the environment where it is exposed to acids and salts attack.

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LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
C_2S	Di – Calcium Silicate
C_3A	Tri – Calcium Aluminate
C_3S	Tri – Calcium Silicate
C_4AF	Tetra – Calcium Alumino Ferrite
CH	Calcium Hydroxide
CSH	Calcium Silicate Hydrate
SBR	Styrene Butadiene Rubber
SP	Superplasticizer
SCC	Self Compacting Concrete
HCl	Hydrochloric acid
$Ca(OH)_2$	Calcium Hydroxide
$(NH_4)_2SO_4$	Ammonium Sulphate
OPC	Ordinary Portland cement
HP SCCS	High Performance Self Compacting Concrete Systems
HP SCMS	High Performance Self Compacting Mortar Systems
HP SCPS	High Performance Self Compacting Paste Systems
SRMs	Secondary Raw Materials
HPC	High Performance Concrete

CHAPTER 1

INTRODUCTION

1.1 General

The concrete is a composite building material obtained by mixing binder, water, aggregates and admixtures. Concrete has been used as the most suitable construction material for the last 170 years and has gained its popularity over the years because of its economic, durable, and easy to fit into any shape nature. Along with its advantages this best suitable construction material has also several disadvantages like low tensile strength, delay in hardening, low resistance against chemicals and high shrinkage after hardening. Various attempts have been made to overcome these disadvantages. One of the attempts is modifying concrete using polymer additives such as natural polymer cellulose, acacia gum, protein, epoxy resins and rubbers. These polymers have proved to be very helpful in improving the freeze-thaw resistance, workability, resistance against chemicals, resistance against permeability and bonding new concrete with old concrete.

1.2 SBR Latex modified normal Concrete

Polymers are used to improve the properties of concrete because of its high performance and multi-functionality. Various Polymers are used to modify the properties of concrete. Polymers improve the workability, resistance against chemicals, resistance against corrosion, bonding of new concrete with the old ones and resistance against permeability.

The two matrixes of organic polymer and matrix gel are homogenized in a co matrix which is monolithic [1]. It should be understood that when polymers are added to concrete, hydration and polymerization are the two processes that occurs to yield a co matrix in which the products of the two processes are interpenetrated.

1.3 SBR Latex modified Self-compacting concrete:

According to a definition for SCC currently being considered by ACI committee 237R-07

“a highly flow able, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation.”

Self-compacting concrete (SCC) is a flowing concrete mixture which can be compacted into every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction, filling forms completely and producing a void free mass. Another advantage of SCC is that time required for concreting is incredibly reduced as compared to normal concrete. The cost of self-compacting concrete is reduced due to reduced time and less man power required. Self-compacting concrete has also many other advantages including improved durability, easily used in thinner concrete sections and reduced noise level. The necessity of this type of concrete was proposed by Okamura in 1986. Self-compacting concrete is presently used due to its obvious advantage and is described as a milestone in the modern concrete technology. There are a lot of site conditions and working limitations in construction industry that makes self-compacting concrete a better alternative to conventional high slump concrete. Most general are cost savings or performance enhancement of concrete. In order to achieve self-compacting concrete a mineral or admixture is added to the concrete. Introduction of SBR latex in self-compacting concrete is generally a new trend. SBR Latex plays alongside with admixture to achieve required flow necessary for self-compacting concrete. It enhances the properties of self-compacting concrete. SBR Latex improves the durability, strength and workability of self-compacting concrete.

1.3.1 Chemical Admixtures

In self-compacting concrete, super-plasticizers are used as chemical admixtures. The super- plasticizer used is viscocrete 20HE. Viscocrete 20HE is new high range water reduction super-plasticizer based on poly-carboxylic ether. It is specially optimized for high early strength and excellent workability requirements.

1.4 Different Curing Methods

Curing of concrete is most important yet most neglected step in the construction process. “It is the treatment of newly placed concrete during the period in which it is hardening so that it retain enough moisture to immunize shrinkage and resist cracking [2].” Curing of concrete is necessary for the hydration process. Hydration is dependent on the amount of moisture available, time and temperature. A proper curing is the one which provide warm and moist environment for the hydration product resulting in decrease porosity and increase density of the concrete. Two types of curing are used in this project. One is water curing and the other is air curing.

1.5 Styrene Butadiene Rubber

Styrene butadiene rubber latex is type of high polymer dispersion emulsion widely used as a polymer [1]. Styrene, butadiene and water constitute SBR. It is a highly viscous white liquid having a milky appearance. SBR has a water content of 52.7% [3]. SBR is used to overcome the disadvantages of concrete. It has proved to be very efficient when bonding new concrete to old one. It also increases workability and durability of concrete. It has several applications including swimming pools lining, concrete bridge deck overlays and the overlays of parking garages.

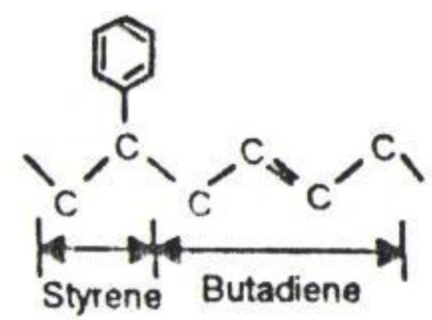


Figure 1-1: Chemical Structure of SBR

1.6 Experimental Techniques:

Some of the experimental techniques to study the comparative response of latex modified normal and latex modified self-compacting concrete are as follow:

1.6.1 Calorimetry:

Cement hydration and SBR latex polymerization are exothermic reactions taking place in a series of stages. Calorimetry is the best procedure for measuring heat of hydration and exothermic polymerization in all the stages. Determination of heat of hydration is very important because it affects almost all the properties of concrete including workability, setting times, strength development rates and pore structure development. Determination of heat of polymerization is also important to know the effect of latex on hydration process. Calorimetry is the technique used to measure the heat production of the cement paste with time and evaluate the hydration kinetics.

1.6.2 Durability Studies:

For durability study both the SBR latex modified normal and SBR latex modified self-compacting concrete samples are treated in salt, alkali and acid solutions. After treatment in these solutions for a specific period of time the weight loss and loss in strength gives the idea about durability of the sample.

1.7 Problem Statement:

The effect of SBR latex in self-compacting concrete is yet to be studied and a hot topic of concrete research. Addition of SBR efficiently enhances the properties of concrete SBR but it requires a systematic and proper study of SBR in concrete. As SCC is replacing the conventional concrete, the steps should be taken to improve its resistance against freeze/thaw cycling.

The problems faced today are listed below:

- The behavior of SCC when SBR latex is used as admixture is unknown.
- Do the different curing methods affect the strength and durability?
- What is the chemical resistance of the latex modified concrete?

1.8 Objectives of Research:

On the basis of the problems that are listed above, the research is focused to find the answers of these questions.

- To study the comparative response of "SBR latex modified normal and SBR latex modified self-compacting concrete."
- To measure the effect of SBR on the strength and durability of SCC.
- To compare the effect of different curing methods on normal concrete, latex modified conventional concrete and latex modified SCC.
- To investigate the hydration kinematics of above mentioned types of concrete.

CHAPTER 2

LITERATURE REVIEW

2.1 Latex modified concrete:

Polymer modified concrete is the most interested topic which has attracted the construction these days in order to achieve multi-functional and high performance construction materials to cope the recent technical innovations in the construction industry. The construction industry is moving towards materials which are ecologically and environmentally friendly. The interest of construction industry in polymer modified concrete has grown stronger in recent years and eight international conferences, workshops and symposiums have been held since 1990. The detail of these are given in the table below

Table 1 Major international congresses, symposiums and workshops on polymers in concrete **[4]**

Year	Venue	Congress, Symposium or Workshop Name
1990	Shanghai,China	International Congress on Polymers in Concrete
1991	Bochum, Germany	International Symposium on Concrete-Polymer Composites
1991	San Francisco, U.S.A.	ACI-ICPIC North American Workshop on Polymers in Concrete
1992	Johannesburg, South Africa	Second South African Conference on Polymers in Concrete
1992	Moscow, Russia	Seventh International

		Congress on Polymers in Concrete
1993	Salvador, Brazil	ICPIC/IBRACON Workshop on Polymers in Concrete
1993	Chuncheon, Korea	First East Asia Symposium on Polymers in Concrete
1994	Oostende, Belgium	Eighth International Congress on Polymers in Concrete

Emulsion polymerization is used to create polymer latexes by dispersing polymer particles in water. The polymer particles are 0.05-5 micro-metre in size. Polymers are used in concrete due to its satisfactory performance and the ability to perform many functions. Concrete modified by polymers have a monolithic matrix in which both the organic matrix and hydration products are interpenetrated [1]. In this monolithic matrix the hydrated product and polymer product are interpenetrated to form a network structure which results in a polymer modified concrete of enhanced quality. The hydration process is very fast at early stages and is assumed to take place first leaving porous products of hydration. As this process proceeds, latex particles coalesce into an interwoven polymer meshes located in large interstitial voids and capillaries having a size greater than 100nM after polymerization [5].

There are various types of polymers in use such as water soluble powder, liquid resins, latex and redispersible powder polymer. Styrene Butadiene rubber is dispersible emulsion type polymer. It has a milky appearance and can be used for binding successfully.

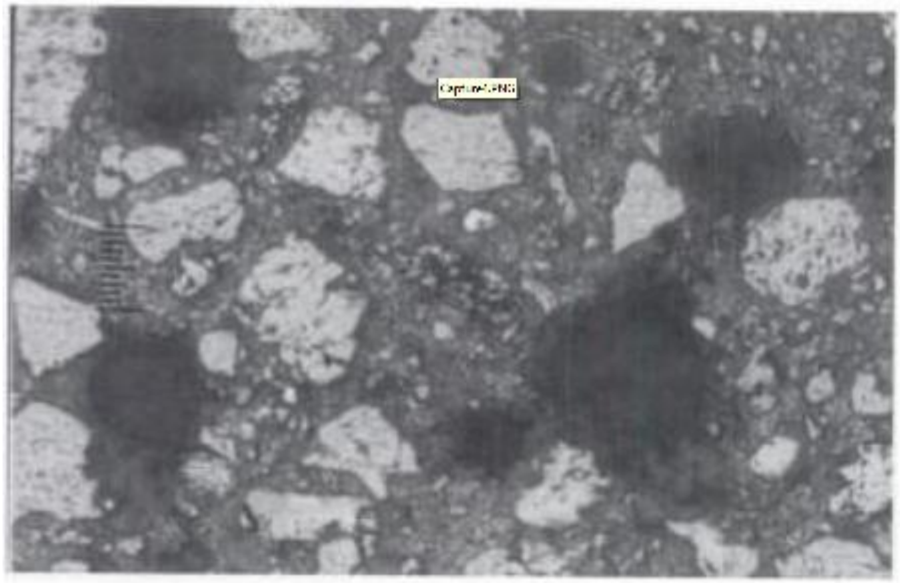


Figure 2: 10% SBR latex modified Concrete

2.1.1 History of latex Polymers in Concrete:

Polymers have been in use in for construction since the fourth millennium BC. Natural polymers were used in mortar to build the walls of Babylonia city. The foundation of the great temple of Ur-Nina was built with 25-35% natural polymer modified mortar, chopped straw and loam. The remains of Mohenjo-Daro and Harappa have shown the historic application of polymers. These cities trace back to 3000 BC. Many natural polymers like albumen, blood, rice paste and other had been used in ancient mortar [6].

In the US, the first patent for polymers to be used in concrete was granted to L. H. Backland in 1909. In 1922, first patent in France was granted to M. E. Varegyas. In UK, L. Cresson's was given patent to modify surfaces of the roads with rubber. In 1924 V. Lefebure's developed the trend to use natural latex in cement [6]. In 1940, due to the increased demand of war effort and the decline in effort and the viability of natural rubber, synthetic polymers were invented. SBR was invented in first in 1930s in Germany but the large scale production was set up by United States prior to WW2. The use of synthetic polymer in concrete started in 1950s [7]. Polymer became a dominant construction material in 1970s in japan and Europe. In United States a boom in its use occurred in 1980s. Today polymer modified concrete is used in almost every country. The liquid resins for polymer mortar in Japan are chiefly methyl methacrylate epoxy resin, unsaturated polyester resin , vinyl ester resin and monomer, and unsaturated polyester resin is common liquid resin in polymer modified concrete. Unsaturated polyester resin, epoxy resins and methyl methacrylate are the more common liquid resins in US and in Western Europe. Unsaturated polyester has the lowest cost in the above mentioned resins. In Russia and in Eastern Europe Furan resin is widely used for polymer modified concrete. [8]

2.1.2 Applications of Latex modified concrete:

1. Polymer modified concrete is used for the new roads and bridges overlays and also for their repairmen.
2. Polymer modified concrete is used for swimming pools lining, water tanks lining and silos.
3. The recently new successful application of polymer in concrete is its use with fibre reinforcing.
4. PMC is used in the prefabricated components of the building like panels, porous and eco concrete, chemical resistance materials and water proofing materials.
5. PMC is also used as cement adhesive material.
6. It is used as pneumatically applied material in short Crete [9].

2.2 Styrene Butadiene Rubber (SBR):

Styrene Butadiene Rubber (SBR) is a synthetic polymer which is produced from and organic compound called styrene and the chemical named Butadiene. The amount of butadiene in the rubber is usually 3 times the amount of styrene. SBR is usually produced by iconic polymerization or through free radical polymerization as emulsion. The later one is also known as emulsion Styrene Butadiene Rubber (R-SBR).

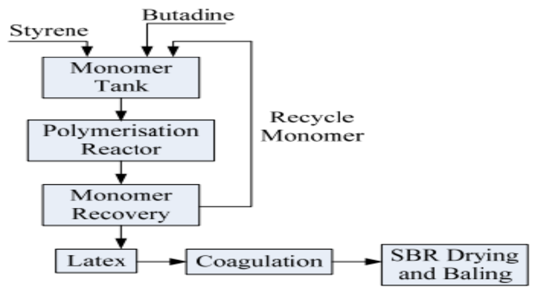


Figure 1-3: Process flow Diagram of SBR Manufacture

2.2.1 History of SBR

This rubber was first created in Germany by I.G.Farbenindustrie. Emulsion procedure was used for the first time in which the polymerization process was used to produce a material having low reaction viscosity but all the properties of natural rubber. It was very cost effective in that time compared to the expensive resources of natural rubber. Its production soon began in other countries and unites states started its production on large scale during World War 2. It had many commercial advantages and the benefit went directly to the United States military. After the war US government sold it to the private industry till 1955, when its industry was completely privatized. The use of SBR in construction industry is growing for the last several years. It modifies the properties of concrete and has many commercial applications.

2.2.2 Benefits of SBR:

- It reduces cracking in the concrete by increasing flexural strength of the mortar.
- Improves the bonding of new concrete to the old one.
- It increases the durability during freeze-thaw cycle.
- It increases the resistance against acid and salts attack.
- It increases the tensile strength of concrete.

2.2.3 Applications of SBR:

1. It improves the surface finishing.
2. Application in swimming pools lining, concrete bridge deck overlay and overlay of parking garages.
3. Application in terrazzo and bonding coats.
4. Application in coating the walls, ceilings and floors that are prone to being damp.

2.3 Latex modified Self-Compacting Concrete

This research also focuses on the effect of SBR on Self-Compacting concrete because Self-Compacting concrete (SCC) is the need of the today's construction industry due to its economical and time saving advantages. There is not much work done on the latex modified self-compacting concrete and objective is to find out the effect of SBR latex on it.

2.3.1 Development History of Self-Compacting Concrete:

The development of self-compacting concrete started in 1980s in Japan. In 1983, the Japanese construction industry was facing serious challenges about the durability and serviceability of concrete structures. To make a durable concrete structure requires proper compaction by skilled labours and mechanical vibration is required to place it at placements where heavy and overcrowded reinforcement is present. These places include heavily reinforced columns, deep foundations, tunnel linings, piers of bridge etc. But the Japanese construction industry faced a severe shortage of skilled labours required for the placement of concrete and for the mechanical vibration. This problem started the need of a new concrete which would not need any skilled labour and mechanical vibration. The idea of this type of concrete was proposed for the first time by Professor Okamura in 1988 and thus this whole scenario led to the development of self-compacting concrete [10]

Separate study was carried out by Professor Ozawa in university of Tokyo. Professor Ozawa completed the first prototype of self-compacting concrete in 1988 [11]. This prototype successfully performed all the characteristics such as heat of hydration, drying and shrinkage etc. Professor Okamura studied its properties in detail and named it "High Performance Concrete" but the name was already adopted by Professor Aticin for his high durable concrete having low water cement ratio [12] so Okamura then adopted the name "Self-compacting high performance concrete" for this type of concrete [11]. Through invention of self-compacting concrete, the need for skilled labour was considerably reduced and concrete could be placed at any area without the need of any mechanical device. By early 1990, the Japan construction industry succeeded in using SCC, that didn't require any manual vibration; instead it flowed under its own weight. This new technology presented economic and environmental benefits over traditional methods of placement of concrete. SCC provided better travel rates of concrete placement, smooth and easy flow of concrete around heavy and dense reinforcement, faster construction and less noise due to the absence of mechanical devices.

Self-compacting concrete has been successfully used in various construction projects since its invention. It was first used in the construction of a building in Japan in June 1990. Later in 1991, it was then used in the construction of the towers of Shin-kiba-Ohashi Bridge. SCC was also used to build the anchorages of Akashi Kaikyo Bridge in 1998 [10]. However, very less literature was available on self-compacting concrete in early 1990's in Japan as this technology was not shared by Japanese companies to keep a commercial and economic advantage over their competitors.

Due to its many advantages ACI formed a committee to further study the SCC and conduct researches. This committee was given the name "ACI 237R–07 Self Consolidating Concrete" [13]. In early 1990s research on SCC started in Europe and Sweden was the first country in Europe which studied the detailed properties of SCC and worked on it. Since SCC requires an admixture therefore with the introduction of third generation polycarboxylate ether based super plasticizers, SCC systems became the centre of attraction of European researchers and they started to analyze their physical and chemical properties. The idea of SCC spread further to United States and production of self-consolidating concrete touched one million cubic meter landmark in 2002 in North America [14]. Many

Professional organizations like American society for testing and materials (ASTM), American concrete Institute (ACI) and Precast/ Pre-stressed Concrete Institute (PCI) started to use SCC systems. Many seminar and conferences were held to spread awareness for this modern and efficient technology. American society for testing and materials (ASTM) formed a sub-committee (C09.47) to standardize nationwide practices and procedure for testing properties of Self-compacting concrete [10]. ACI also published a report on self-compacting concrete in April 2007.

Due to the vast advantages of SCC it has become very popular all over the world and many countries like America, Germany, japan and Sweden have done tremendous research on it. However; research work on self-compacting concrete in Pakistan is in its initial stages and it has been used at a very limited scale in construction industry due to the high prices of chemical admixtures in the market and lack of basic knowledge about SCC systems.

2.3.2 Advantages of Self-Compacting Concrete

- SCC gives high quality surface finish. Its good flow produces smooth surfaces and minimizes the need for additional finish like plaster [15].
- SCC is able to flow under its own weight. Thus, placing the concrete has become affordable due to the elimination of manual vibrators. Now, concrete can be easily placed in areas of high and congested reinforcement [15].
- Self-compacting concrete possesses better qualities as compared to conventional or normal concrete and its use in construction industry improves productivity and working conditions [16].
- The formwork doesn't need to be tighter due to the enhanced cohesiveness of SCC as compared to the conventional vibration requiring concrete [15]. Self-compacting concrete also helps to reduce the noise pollution by removing the use of mechanical vibrators. It has also eliminated the health related problems of workers such as "white fingers" and "deafness" which used to arise due the use of vibrating equipment [17].

2.4 Super Plasticizers (SP):

The high water reducing admixtures generally known as super-plasticizers are artificially prepared water soluble organic substances that are used to significantly decrease the amount of water needed to achieve a certain consistency of concrete which means higher compressive strength and higher workability. Super-plasticizers can be used to serve following purposes:

1. To reduce the water content, this would result in increased strength, better permeability and higher durability.
2. It acts as cement dispersant for the same water content to increase consistency and workability.

Super-plasticizers are a comparatively new category and better version of plasticizer.

Super-plasticizers use was started in Japan and Germany during 1960 and 1970 respectively. The chemical composition of super plasticizers is different from that of normal plasticizers. Using Super-plasticizers can reduce water up to 30% percent without any reduction in workability as compared to normal plasticizers which can only reduce water up to 15%. Super-plasticizers are generally used for the production of high flowing, self-leveling and self-compacting concrete. In American literature, they are termed as High Range Water Reducers (HRWR). Use of Super-Plasticizer has allowed water cement ratio as low as 0.25 or in some cases even lower than that and yet they are able to make concrete of around 120 N/mm2 strength or more [18]. Super-Plasticizers are considered to be the important part of high performance concrete. They are not only used to lower the water demand but also regulate the open time and setting time. Their basic structure resembles a "comb type" molecule. The Poly-carboxylate group forms the main trunk or major chain of the molecule while the polyether groups are connected to poly-carboxylate trunk by chemical bonding. These polyether groups are also knows as "side chains" or "grafts". Their name suggests a likely connection between poly-carboxylate and ether groups. There are basically three types of "grafts" or "side chains" which are ether, ester and amide. Ester is common group among them. Super-plasticizers are responsible for lowering the porosity of cementitious systems in hardened state [19].

2.4.1 Mechanism of Super-Plasticizers:

Now-a-days super-plasticizers are used at large scale in concrete industry. Two major super-plasticizers that are being used are polynaphthalene sulphonate and polymelamine sulphonate formaldehyde condensates. These are polymers and both follow the same dispersing mechanism. The main polymers chains (sulphonate groups $–SO_3$-) get themselves absorbed onto the surface of cement particles; as a result of it cement particles get negative charge on them. Therefore, electrostatic repulsion takes place between the cement particles and they start repelling each other. These repulsion forces between the cement particles offset the inter-particle attractive forces. Poly-carboxylate super-plasticizers increase dispersion because of their better performance in dispersing cement particles. They easily disperse cement particles even at smaller dosages and maintain the concrete slump without prolonging setting times of concrete [19]. Electrostatic repulsion plays an important role in the dispersion mechanism of super-plasticizers.

Poly-carboxylate polymers contain –COO- groups instead of $–SO_3$ - groups in sulphonated condensate.

The plasticizer used in this research work is vescoCrete-20 HE.

2.4.2 ViscoCrete-20 HE:

ViscoCrete-20 HE is a third generation super-plasticizer used in the production of self-compacting concrete. It is an aqueous solution of modified polycarboxylate ether (PCE). It is optimized for high early strength in concrete and for excellent workability requirement. ViscoCrete-20 HE meets the requirements for super-plasticizers according to EN 934-2 and SIA 262 (2003)

Table 2-2: Properties of ViscoCrete-20 HE

Properties	Description
Physical Shape	Liquid
Colour	Cloudy
Density	1.1 kg/l
PH value	~7
Water reduction	Up to 30%
Chloride Content	Nil
Air Entrainment	Nil
Dosage Recommendation	0.5-1.5% by weight of cement

2.4.2.2 Advantages of ViscoCrete-20 HE:

- Concrete containing ViscoCrete-20 HE has the following advantages:
- High density and high strength
- Pronounced increase in early strength development resulting in early stripping times for precast and in situ concrete
- Reduced energy costs due to reduction in use of steam curing systems
- Reduced closure times for repairs of roads and runways.

2.5 Experimental Techniques

2.5.1 Calorimetry

Cement hydration is extremely exothermic reaction taking place in a series of steps. It has following stages (Young 1985):

1. Rapid Initial Process
2. Dormant Period
3. Acceleration Period
4. Retardation Period
5. Long-term reactions

Calorimetry is the best procedure to find all the stages of hydration process of cement [20]. Determination of heat of hydration is very important because it affects almost all the properties of concrete including workability, setting times, strength development rates and pore structure development. Heat of hydration affects the early age of concrete as well as the long term performance of concrete. Basically, Calorimetry is the technique used to measure the heat production of the cement paste with time and evaluate the hydration kinetics. Calorimetric curves produced during a specific interval of time form various peaks. At initial stages, hydrolysis take place and the Ca and OH ions releases from the surface of C_3S the PH rises above 12 and the solution becomes alkaline. Heat of hydration is high due to the fast hydration of aluminate phase, C3A, in this phase the main product formed is calcium aluminate hydrate. After the initial period, heat of hydration decreases to minimum within 2-3 hours. This phase of hydration reaction is called induction period or dormant period. During the dormant period the hydrolysis process continues slowly to achieve a minimum concentration of ions necessary for the pozzolonic reaction. This is known as nucleation control. This dormant period is then followed by pozzolanic reaction and mass precipitation of hydration products, mainly Calcium silicate hydrate (CSH) gel. Then the calorimetric curve rises to a second highest value of hydration process and this happens after 15-18 hours for self-compacting paste systems. After this the hydration process slows down and smaller peaks are formed in the process [21]. Super-plasticizer's presence in the cementitious systems delays the heap peaks produced during

Calorimetry of cement process [22]. Moreover, amount of heat evolved depends upon a variety of factors which include cement type, its content and water to cement ratio because super-plasticizer acts as retarder.

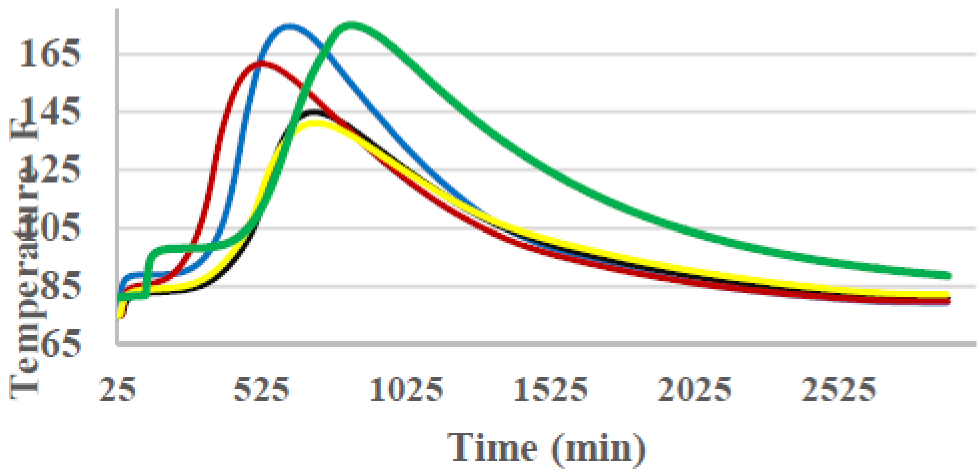


Figure 2-4 Typical Calorimetric Curves

2.5.2 Durability Study

A durable concrete has the property that it will satisfactorily withstand the service conditions to which it is subjected. Both external and internal factors are accountable for affecting the durability of concrete. External factors are the environment factors given in fig 5

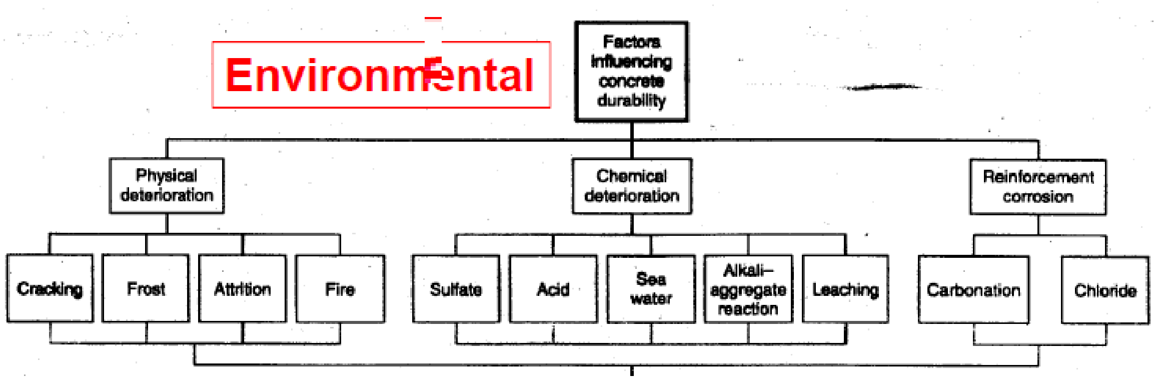


Figure 2-5 External factors influencing durability of concrete

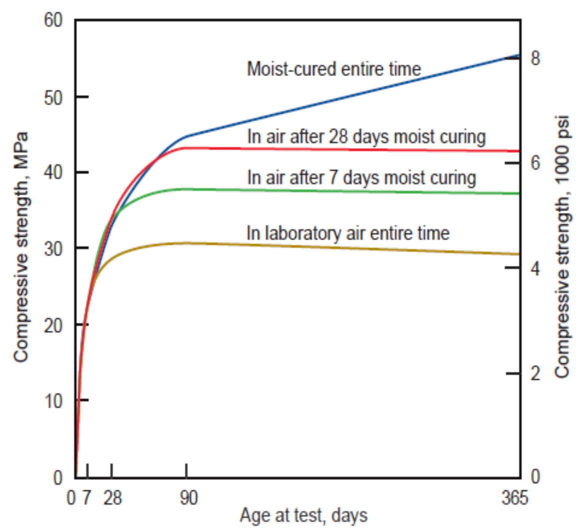
The study of this research is restricted to the chemical deterioration of Acid, salt and the effect of alkali on the both latex modified normal and latex modified self-compacting concrete.

Concrete is susceptible to the attack of acid because of its alkaline nature. Acid causes the deterioration of cement paste when it comes in contact with concrete. Acid attack deteriorates both the hydrated and unhydrated compounds of cement. The most prominent is the deterioration of calcium hydroxide, a cement paste product. The calcareous aggregate is more susceptible to the attack than siliceous aggregate [23]. Properly cured concrete with minimum content of calcium hydroxide may only slow the attack. The reason is that acid resistance of concrete depends on total content of calcium and not just on the calcium hydroxide content [24]. Primarily the attack on concrete depends on its permeability and water-cement ratio. Another cause of deterioration is the salts attack on concrete. Salts attack the concrete when they are in a solution. Solid salts don't react with concrete. The sulphate salts of potassium, magnesium and calcium are the most common. In the sulphate attack process the sulphate reacts with the hydrated paste of concrete causing the deterioration of concrete by weight reduction and softening, resulting in strength reduction and expansion of concrete [25]. One of the protections against sulphate attack is to lower the C_3A content of the cement. The deterioration of concrete by ammonium sulphate is the most aggressive type because only gypsum is formed which results in increased volume [26]. Both the salts and acids causes severe weight and strength loss in concrete [5]. Also these two greatly changes the PH level during hydration which is of pivotal role for the reform of additional CSH and fro the dissolution of pozolonic material. The decrease in PH level compromises the strength and durability of concrete. The alkali or lime shows different behaviour than acids and salts. As concrete is an alkaline medium, its strength and durability improves in an alkaline environment. The concrete in alkaline environment shows greater strength than those cured in normal water. In addition to this lime also plays an important role in curing and those specimens which are cured in lime water yields higher compressive strength. The CH formed during the hydration process accelerates the hydration rate in early stage and later it contributes to pozzolonic reaction. Concrete in alkaline environment have sufficient Ca^+ concentration and produces high pozzolonic reactivity, thus increase the compressive strength especially in early age. [27].

2.6 Curing Methods

Curing is the requirement of sufficient moisture for the satisfactory production of hydration product and maintaining a suitable temperature necessary for the optimum rate of hydration [28].

ASTM C192 specifies curing requirements in water but this must meet the ASTM C511 to provide a suitable and controlled temperature of curing. Curing in the laboratory is different than curing in the field. ASTM C192 provides specifications for laboratory curing and ASTM C31 is utilized for field samples. The curing environment plays an important role in the strength and durability of concrete. With suitable curing method used and enough moisture provided for hydration, concrete gains higher strength and becomes more resistant to abrasion, freeze and thaw, and stresses. Curing temperature is an important aspect in curing. When the curing temperature is low, the hydration proceeds at a slower rate and early strength gain is much lower because of low hydration products. A high curing temperature causes high early strength gain but it decreases the 28 days strength of concrete. Curing methods used in this research are water curing and air curing. Concrete yields higher strengths when cured in moist environment than air cured for the same period. It is because in moist environment sufficient moisture is available for hydration. In air cured concrete may also lose water causing shrinkage in concrete which results in low compressive strength [29]. Comparison of strengths for different curing methods is given in fig 6.



CHAPTER 3

MATERIALS

The following materials were used for this experimental program.

3.1Cement

Type 1 Ordinary Portland Cement (OPC) was used according to the ASTM C150 standards and was kept moisture free by storing it according to laboratory requirements. The properties of cement used are mentioned in Table A-1 of Annexure-A.XRF analysis of the cement was carried out with a view to determine its chemical composition and results are shown in Table 3.

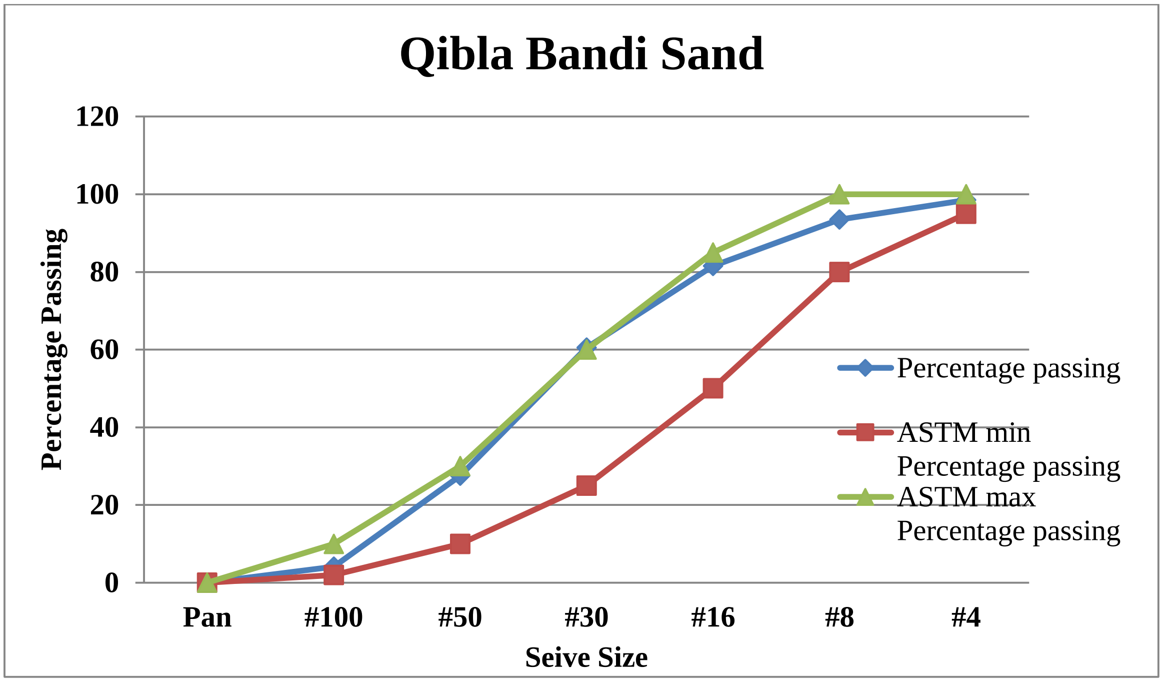
Table 3: Chemical composition of Cement Used

Sample Name	CEM E 880
SiO_2	19.19
TiO_2	0.29
Al_2O_3	4.97
Fe_2O_3	3.27
MnO	0.04
MgO	2.23
CaO	65.00
Na_2O	0.58
K_2O	0.51
P_2O_5	0.08
LOI	3.84

3.2 Fine Aggregate

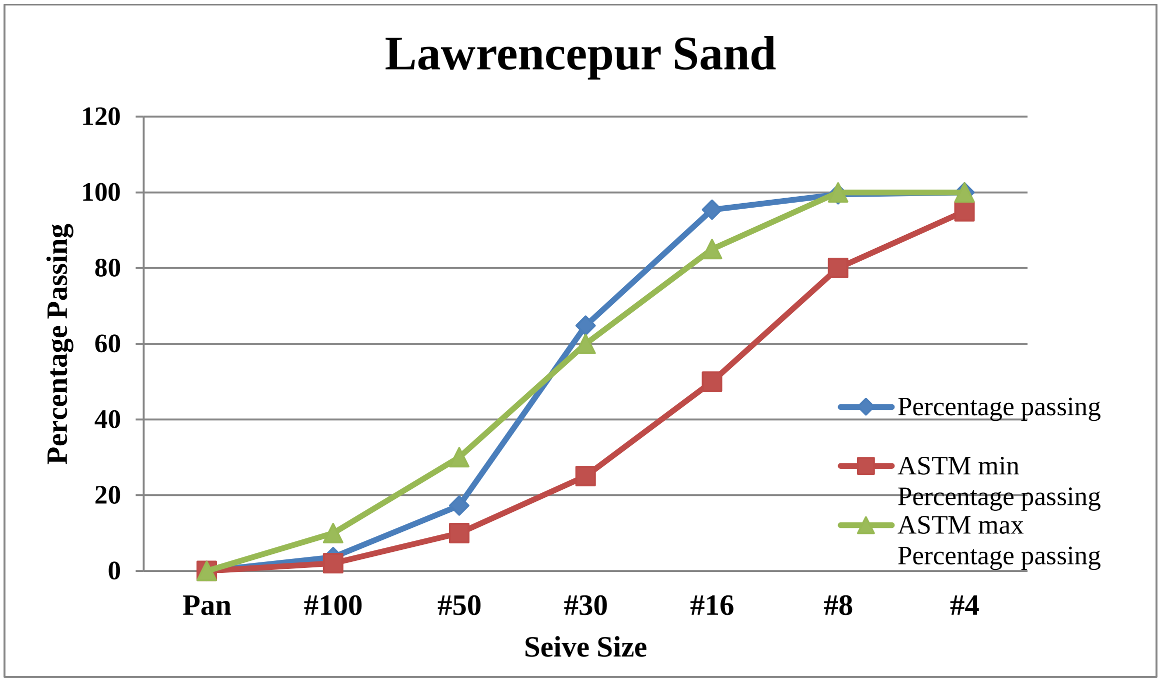
Natural sand from two quarry pits (Lawrencepur and Qibla Bandi) was used in making all samples. A mix of both sands was used which had an equal amount of each sand. Sieve Analysis was performed conforming to ASTM C136 and results are shown in the graphical form in figure while in tabular form in table of annexure.

Figure 6: ASTM Gradation of Qibla Bandi Sand



Fineness Modulus of Qibla Band Sand = 2.34

Figure 7: ASTM Gradation of Lawrencepur Sand

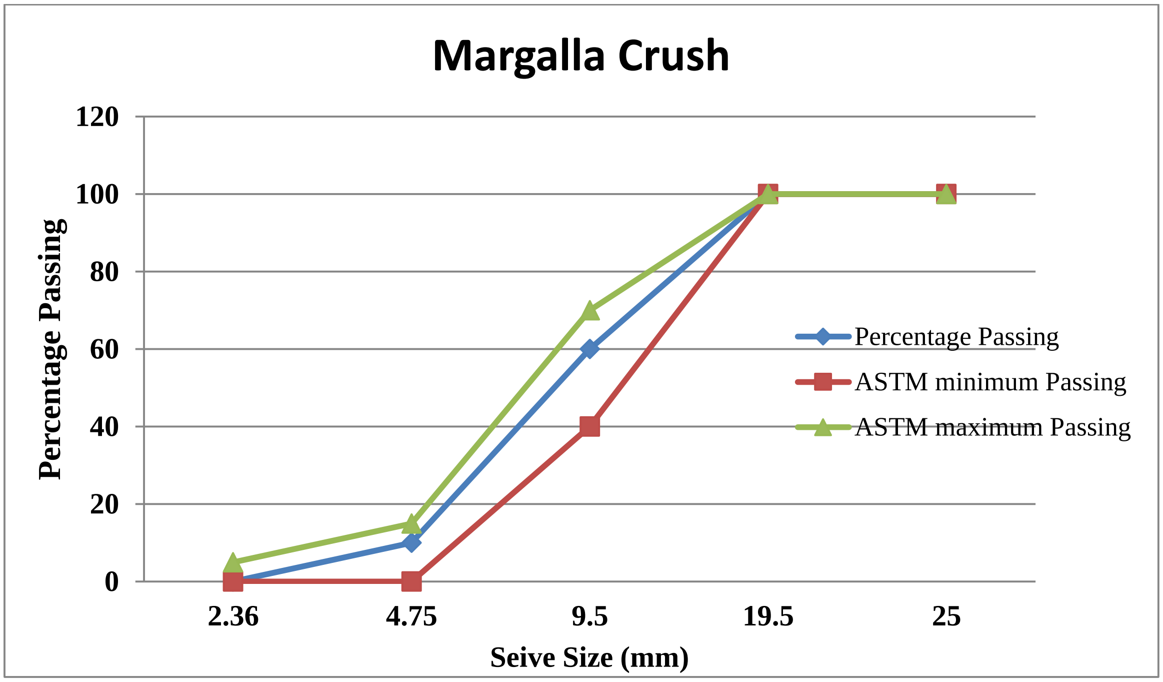


Fineness Modulus of Lawrencepur Sand = 2.19

3.3 Coarse Aggregate

Aggregates in the concrete are used specifically for a purpose. They provide the economic benefit by reducing the cost of the concrete. In addition to that it provides the volume stability to the concrete. The shrinkage in cement paste is more comparatively to the aggregates. So in order to reduce the shrinkage potential of concrete, aggregates are used. The shrinkage potential and cracking potential increase together. The coarse aggregate was collected from Margalla crush aggregate quarries near Islamabad. Sieve Analysis was performed and its gradation curve was plotted which was found to be in the limits specified by ASTM C 33. The aggregate brought had a market name ‘half inch down’ conforming to its size.

Figure 8: ASTM Gradation of Margalla Crush



Fineness Modulus of Coarse Aggregate = 6.45

3.4 Styrene-Butadiene Rubber Latex

Styrene Butadiene rubber (SBR) is a synthetic rubber emulsion. It is added to cement mortars and concrete where good adhesion is required. It is a milky white liquid which increases the workability of the concrete. It is also used in cold joints during construction. The gluing action of rubber latex ensures the stronger bonding of the old concrete with new concrete. Research has shown that by adding SBR, the freeze thaw resistance of the concrete is increased. The solid content of the SBR was verified by keeping 100 grams of SBR liquid in oven at 110℃ for 24 hours and noting the residual solid content weight. The properties of SBR latex are tabulated below.

Table 4: Properties of SBR Latex

Solid Content	38%
Weight	1 kg/litre
pH	10-11
Color	white
Styrene-Butadiene Ratio	1.5
Specific Gravity	1.01

3.5 Superplasticizer

The superplasticizer (SP) used to make self compacting concrete was Sika Viscocrete-20 HE. It is a third generation superplasticizer for concrete and mortar. As recommended by the manufacturer it is used for production of concrete mixes which require high early strength development, powerful water reduction and excellent flowability. It is an extremely powerful water reduction agent resulting in high density of concrete. The plasticizing effect of this SP is considerable. The mentioned properties make it suitable for self compacting concrete. The properties of Viscocrete-20 HE are listed below in table 5.

Table 5: Properties of VIscocrete-20 HE

Physical Form	Liquid
Color	Light Brownish liquid, clear to slightly cloudy
Shelf life	12 months
Density at 25°C	Approx. 1.08 kg/lt
Recommended Dosage	1-2% by weight of Cement
Solid Content	39%

3.6 Mixing Water

Ordinary tap water was used for all mixes; the temperature of the water was normally within 19-24°C.

CHAPTER 4

EXPERIMENTAL PROGRAM

4.1 Tests on Materials

The experiments which were conducted on materials are illustrated below.

4.1.1 Sieve Analysis

Sieve analysis is widely used in civil engineering. The test is used to assess the granular particle size of the material which determines how the material will perform in use. It is also called gradation test. The test is performed by using the set of sieves as recommended by ASTM C 136. The sieves are then mechanically shaken. The whole procedure mentioned in ASTM C 136 was followed.

4.2 Tests on Concrete Mixes

4.2.1 Mixing Proportion and Mixing Regime

After hit and trial method, the mixing proportion was determined for normal, latex modified and latex modified self compacting concrete.

The details are given below:

- Mix Proportion by weight 1:1.75:1.45
- Water/Cement ratio = 0.37
- The ratio of fine to coarse aggregate was 55:45
- The fine aggregate was of 0-2 mm size
- The coarse aggregate used was ½ inch down

For latex modified concrete, the amount of SBR used was 7% of weight of cement based on solid content of SBR. The liquid content of SBR was deducted from the mixing water in order to maintain the net water/cement ratio constant.

For latex modified self compacting concrete, the amount of SBR used was same as used for latex modified concrete. The liquid content of SBR was deducted in order to maintain the water/cement ratio constant. The amount of Superplasticizer used was 1.8% of weight of cement. The liquid content of SP was also deducted from mixing water in order to maintain the net water/cement ratio constant.

The ingredients were placed in concrete mixer. They were first dry mixed for 15-30 seconds. Then 70% of water was added along with SP. They were mixed for 90 seconds. The remaining water was added afterwards along with SBR and mixed for two minutes. The total mixing time was 4 minutes.

4.3 Tests on concrete's Fresh Properties

4.3.1 Slump Test

Concrete slump test is the criterion for measuring the workability of fresh concrete. The test measures the consistency in that specific batch. The test is carried out using a mould commonly known as slump cone or Abrams cone. The surface on which cone is placed should hard and non-absorbent. The cone is filled in three layers. Each layer is tamped 25 times using a tamping rod of standard dimensions. At the end of third stage, concrete is struck off flush to the top of the mould. The mould is lifted vertically with the twisting motion upwards with utmost care. The slump is then measured.

4.3.2 Slump Flow time

Slump flow test is used to measure the flow-ability and flow rate of self-compacting concrete. It assists us in measuring two flow spread and flow time T50 simultaneously. Flow spread specifies the free deformability without any restrain while flow time shows the rate of deformation within a specified flow stretch.

ASTM C1611 [7] standard offers two cone positioning choices, that is, upright and downside-up. In this experimentation, upright position of slump cone was adopted. After the completion of mixing, allow the sample in motionless stance for about 1 minute. By employing damp towel or sponge, dampen the slump cone's interior surface and the base plate's test surface, then put the cone on the 200 mm circle presenting the mid of base plate. Fill cone with the sample from the bucket barring any compacting effort, following a little pause (sparsely 30 seconds for cleaning and verification of dampness of test surface), remove the slump cone by lifting vertically upward, so as concrete flows out easily without hindrance of the cone, and set out the time piece the instant there is disconnection between the cone and base plate. Determine the time when concrete reaches 500 mm diameter (T50) and total spread time. Also determine the final slump flow of concrete when it has halted by measuring in two orthogonal directions. The concrete spread needs to be visually checked carefully for segregation, particularly at the edges. The slump flow apparatus is shown in Figure

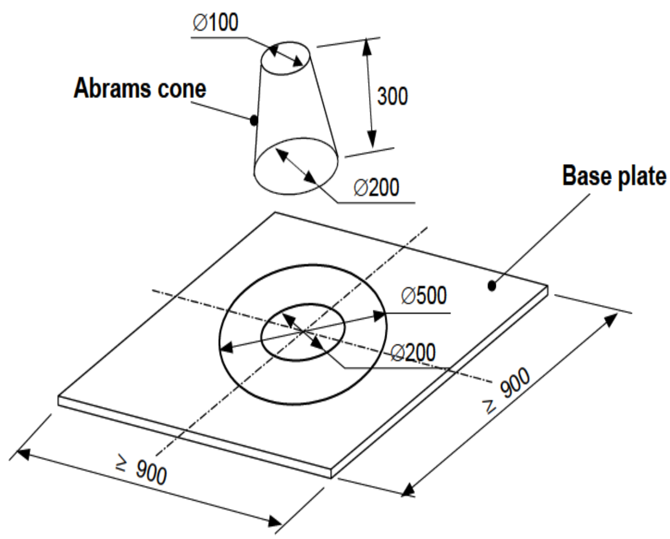


Figure 9: BASE PLATE & CONE APPARATUS (RIZWAN 2006)

4.4 Acceptance Criteria for SCC

For self compacting concrete with maximum aggregate size upto 20 mm some of the criteria are shown in table below

Table 6: Acceptance criteria for SCC

	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump flow by Abrams cone	Mm	650	800
2	T50 cm slump flow	Sec	2	5

4.5 Casting and Curing

After the tests for fresh concrete properties were completed, concrete was cast into moulds for each formulation. In order to check the compressive strength of concrete, cubes of 4”x4”x4” were casted (BS EN 12390-1). For conducting flexural strength tests, prisms of 4”x4”x16” were casted. The compressive strength was checked against 3 different ages. Two type of curing methods were used: water curing and air curing.

- The casting of samples for water curing was done at temperature 26.4°C while relative humidity measured was 35%. The mixing water temperature was noted to be 24.4°C.
- The casting of samples for air treatment was done at following atmospheric conditions: temperature=28.4°C, Relative Humidity= 39%, Mixing water temperature= 22.6°C.

For air curing, samples were kept in laboratory and were exposed to air. The temperature values for the days of curing are shown in the graph.

The samples were kept in water at room temperature for water curing.

4.6 Strength Evaluation

For testing the compressive strength of concrete, cubes of 4”x4”x4” were used. The loading rate was set to 0.25 N/mm^2. The compressive strength was checked against the ages of 3, 7 and 28 days. Tests were conducted separately for water and air curing. Prisms of 4”x4”x16” were used to check the flexural strength of concrete.

4.7 Calorimetry

F-CAL 8000 Field Calorimeter obtained by NICE through an international

Figure 10: F-CAL 8000 FIELD CALORIMETER

research project sponsored by DAAD was used for this investigation. Calorimetry is the technique used to measure the hydration kinetics of a cement based system with time. Better monitoring of concrete heat flow leads to an improved understanding of characteristics of concrete materials and mix proportions. With calorimetry, forecasting of setting time and required curing regime, prediction of strength gain, evaluation of thermal cracking risk and identification of materials incompatibility etc. can be made. Calorimetry was performed on normal, latex modified and latex modified self compacting concrete for 117 hours.

4.8 Tests on Durability of Concrete

The three types of concrete were checked for durability against the attack of acids, salts and alkalis. For this purpose, a cube of 4”x4”x4” size was cut into 2”x2”x2” eight cubes. The smaller cubes had three sides cut. These cubes were kept in 0.5 N solution of HCl, 0.5N solution of $Ca(OH)_2$ and 0.5 N solution of $(NH_4)_2SO_4$. A set of samples were cured for three days and were kept in all these solutions for three weeks. Another set of samples were cured for 7 days and kept in all these solutions for three weeks. The SSD weight of samples was noted daily. The solutions were replaced every week. The treated samples were checked for their compressive strength after

21 days immersion in respective solutions. Their strength was compared with the cubes that were cured for the same age.

CHAPTER 5

RESULTS AND DISCUSSION

The results acquired from the experiments are presented in this section. The discussion is also written along with the results to give possible reasoning of the obtained results. The effect of SBR on the strength properties of normal concrete was studied. Furthermore, the combined effect of SBR and superplasticizer was also studied. Calorimetry analysis was conducted on the samples. All the three forms of concrete were checked for durability.

5.1 Slump Test

The slump test was carried out for normal and latex modified concrete. The results obtained from these slump tests are given below in the table.

Table 7: Results of Workability Test

Test	Normal Concrete (mm)	Latex modified concrete (mm)
Slump Test	0	60

It was observed that the addition of SBR in normal concrete while keeping the net water/cement ratio constant increases the workability of the concrete. The addition of 7% SBR of weight of cement based on solid content of SBR increases the workability from 0mm slump to 60mm slump. It must be noted here that the liquid content of SBR was deducted from the mixing water. Therefore, it was not the liquid content of SBR that was responsible for increase in workability. The concrete has been classified into different categories depending upon its slump. The slump test not only tells workability of concrete but also the cohesion and stability index of the concrete can be observed by the slump test. The different categories of the slump according to the European standard EN 206-1:2000 are shown in the table 8.

Table 8: Categories of Slump

Slump	Slump in mm
S1	10-40
S2	50-90
S3	100-150
S4	160-210
S5	≥ 220

The results of slump flow test on self compacting concrete are shown in the table 9.

Table 9: Results of Slump Flow Test

	Method	Unit	Values	Typical Ranges of the values
1	Slump flow by Abrams cone	mm	680	650-800
2	T50 cm slump flow	Sec	3.2	2-5

5.2 Strength Evaluation

BS EN 12390-1 was used to evaluate the compressive strength of 4”x4”x4” cubes while EN 196 was used for evaluating flexural strength of prisms. The results of the compression test on air cured samples are shown in the figure 11.

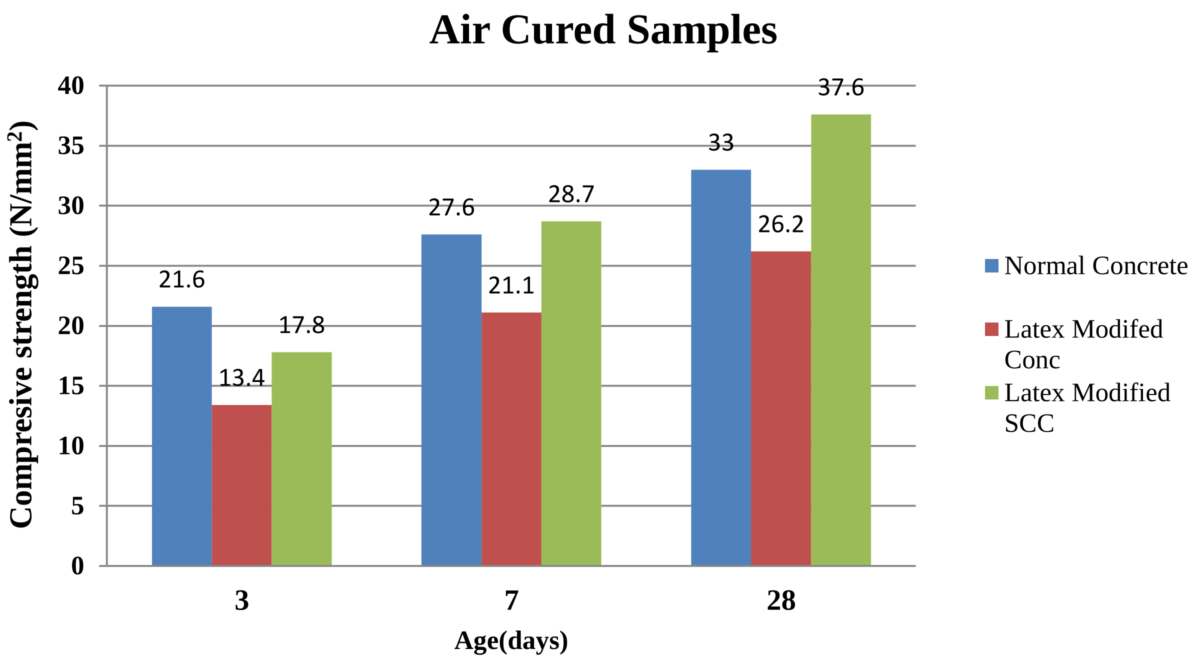


Figure 11: Compressive Strength of air cured samples

The compression test was carried for 3,7 and 28 days. The strength of normal concrete at age 3 days is more than latex modified conventional concrete and latex modified self compacting concrete. While at the age of 28 days the strength of latex modified concrete is highest among three. The reason that the strength of latex modified SCC is less than normal concrete that the start can be explained by the fact that the addition of superplasticizer retards the hydration process of the concrete. The argument will be complemented later in the calorimetry analysis. However, the general trend can be seen that by addition of SBR to normal concrete, the strength of the concrete decreases. The reason for the decrease of this strength can be explained by the fact that voids are generally created in the concrete by the polymer. The argument is supported by the literature as it has been mentioned in the research conducted by SA Rizwan.[]. However when the SP was added to the latex modified conventional concrete, there is an increase in the strength of concrete. The reason behind the gain in strength can be explained by the fact that the collective action of SP and SBR will result in the filling of voids.

The results of compressive strength for water cured samples are shown in the figure 12.

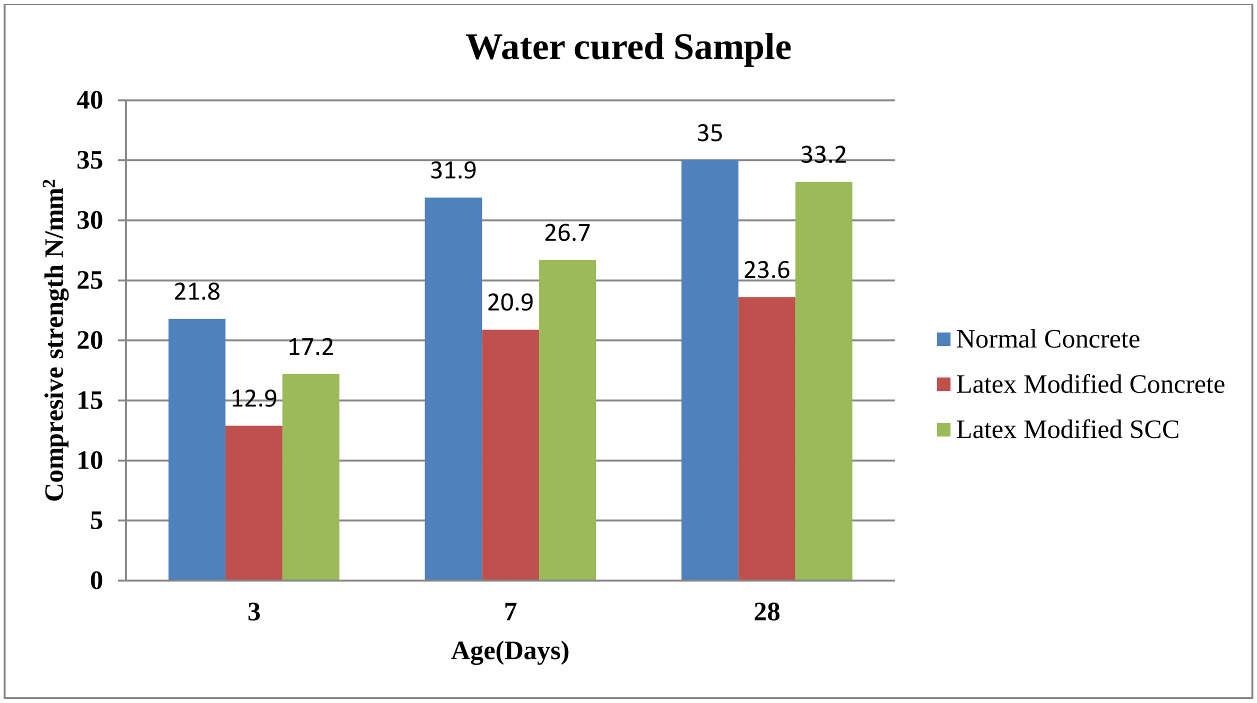


Figure 12: Compressive Strength of water cured samples

In the above presented graph, it can be noted that the strength of latex modified self compacting concrete is less than normal concrete at the age of 28 days. It can be further noted that previous research shows that the water curing results in higher strength of concrete than air curing. But the phenomenon is reverse for latex modified conventional and SCC. When SBR is added to the concrete, the strength of concrete is higher for air cured samples than water cured samples. This unique feature of SBR modified concrete will make this concrete to be used in the areas where water curing cannot be done easily. To avoid the loss of water, or construction in water scarce areas, or poor construction practices where water curing of concrete is not done properly, the latex modified concrete can be used conveniently. Moreover, it would yield good results against strength and durability. So it is highly recommended to use the latex modified SCC in the places where curing can’t be done and it is exposed to the air.

The figure 13 shows the strength in flexure. The tests were conducted according to the European Standards. The prism size was 4”x4”x16”. Their strength was checked against the age of 28 days, because the usual time in construction is 28 days.

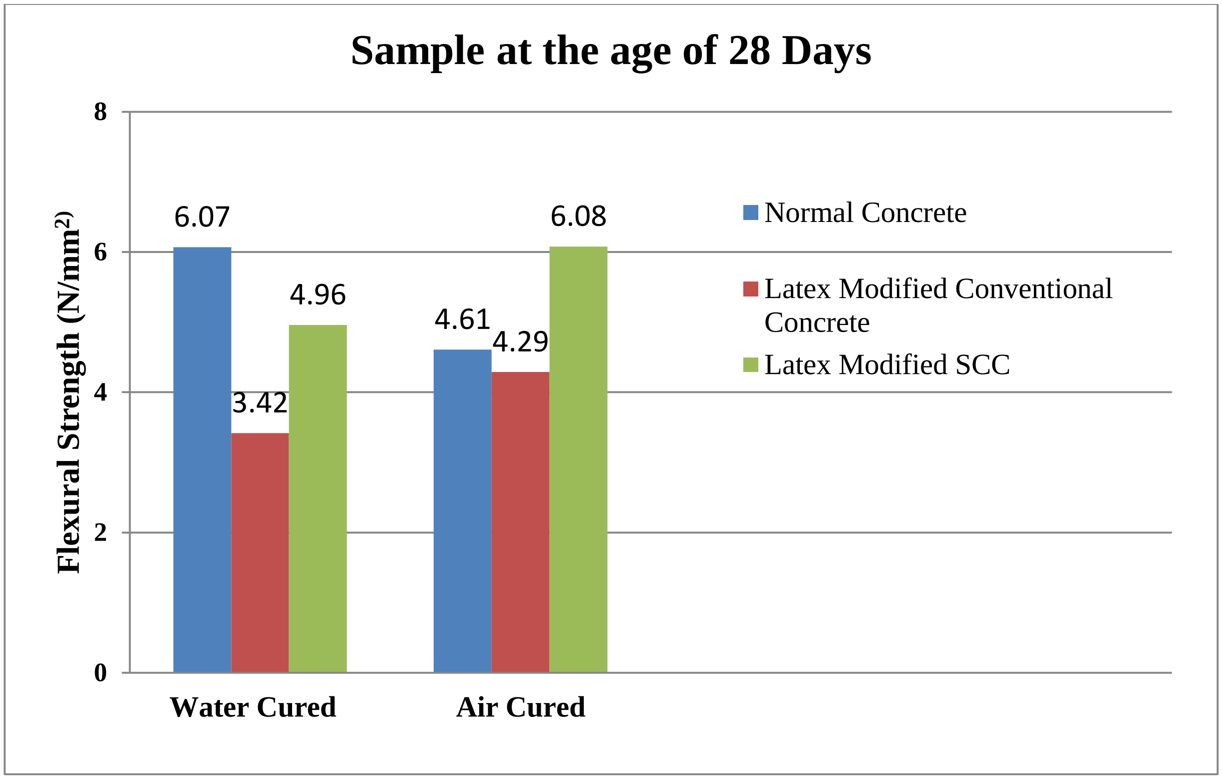


Figure 13: Flexural Strength at 28 days

the results for flexural strength again supports the previous results that the water cured samples of latex modified conventional and latex modified SCC show lesser strength than the air cured samples.

5.3 Durability Tests

The durability of the concrete was tested against the acids, salts and alkalis. From the literature, all the three types of chemicals were studied. The chemicals which had more corrosive attack on the concrete were picked up for the testing regime. The chemicals used were hydrochloric acid (HCl), calcium hydroxide ($Ca(OH)_2$) and ammonium sulphate. The cubes used were 2"x2"x2" of size with three sides cut. The cubes were cut from the 4"x4"x4" cubes. The purities of the chemicals were given and solution of 0.5 Normality was prepared. Their weights were checked regularly and the pH of solutions was also checked regularly. The samples were water cured for three days and then treated with the solutions. The reason for choosing the 3 day curing was because of the fact that the cubes were cut by a strong blade. So in order to avoid the breakage of the cubes, there were cured for enough time. They developed enough strength so that they may not break during the cutting of the cubes. The other samples were cured for 7 days. They were also treated in order to find the resistance that the concrete may develop over time against the acids, salts and alkalis. The results of reduction in weight of samples by treatment of the 0.5 normality solution is shown in the figure 14.

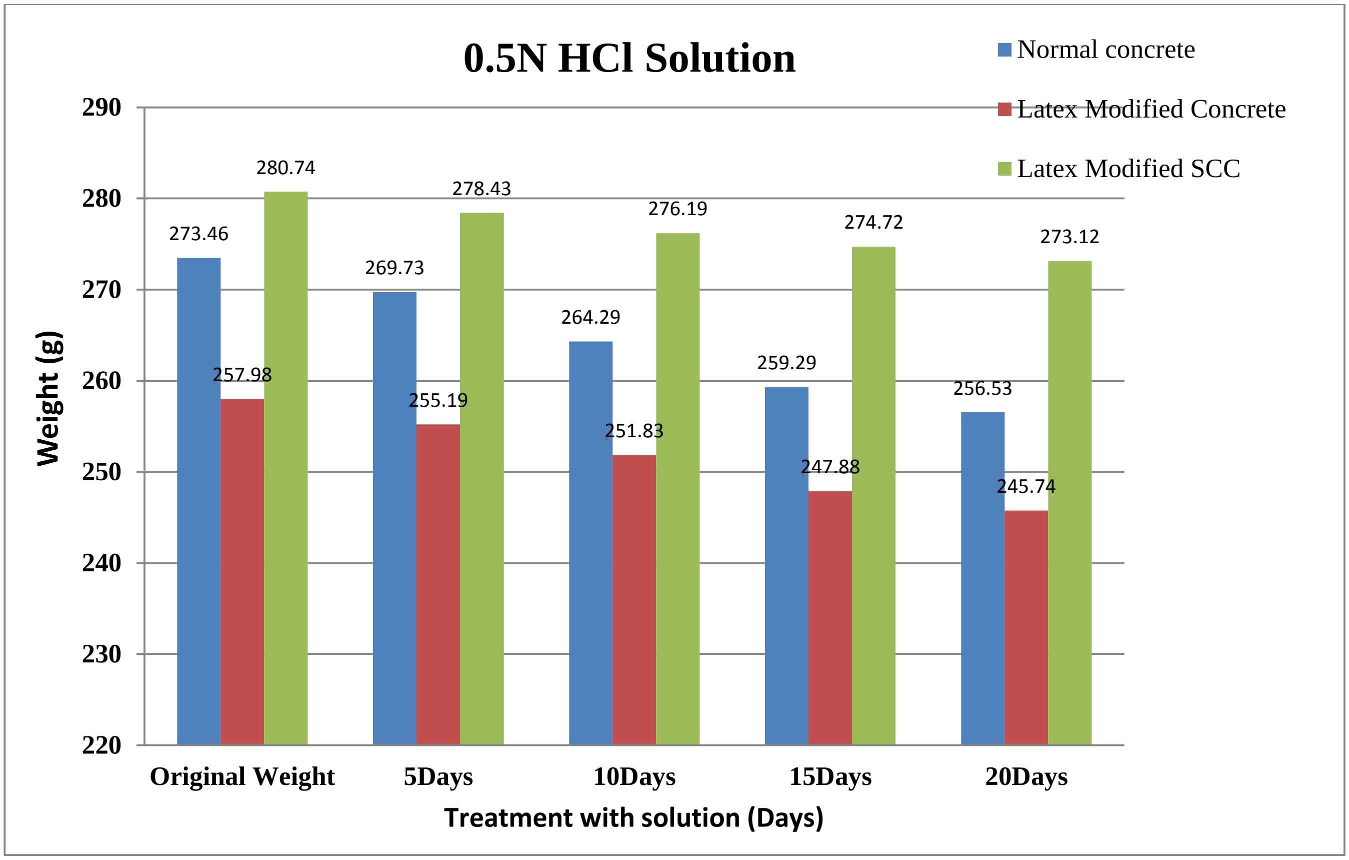


Figure 14: Reduction in weight by treatment of 0.5 HCl Solution (3 days water cured samples)

As it can be deduced from the above results, that hydrochloric acid has corrosive action against the concrete but the durability of the concrete has improved by the addition of the addition of SP to the Latex modified conventional concrete.

The results for the treatment against 0.5 HCl solution for 7 days water cured samples are shown in the figure 4-5

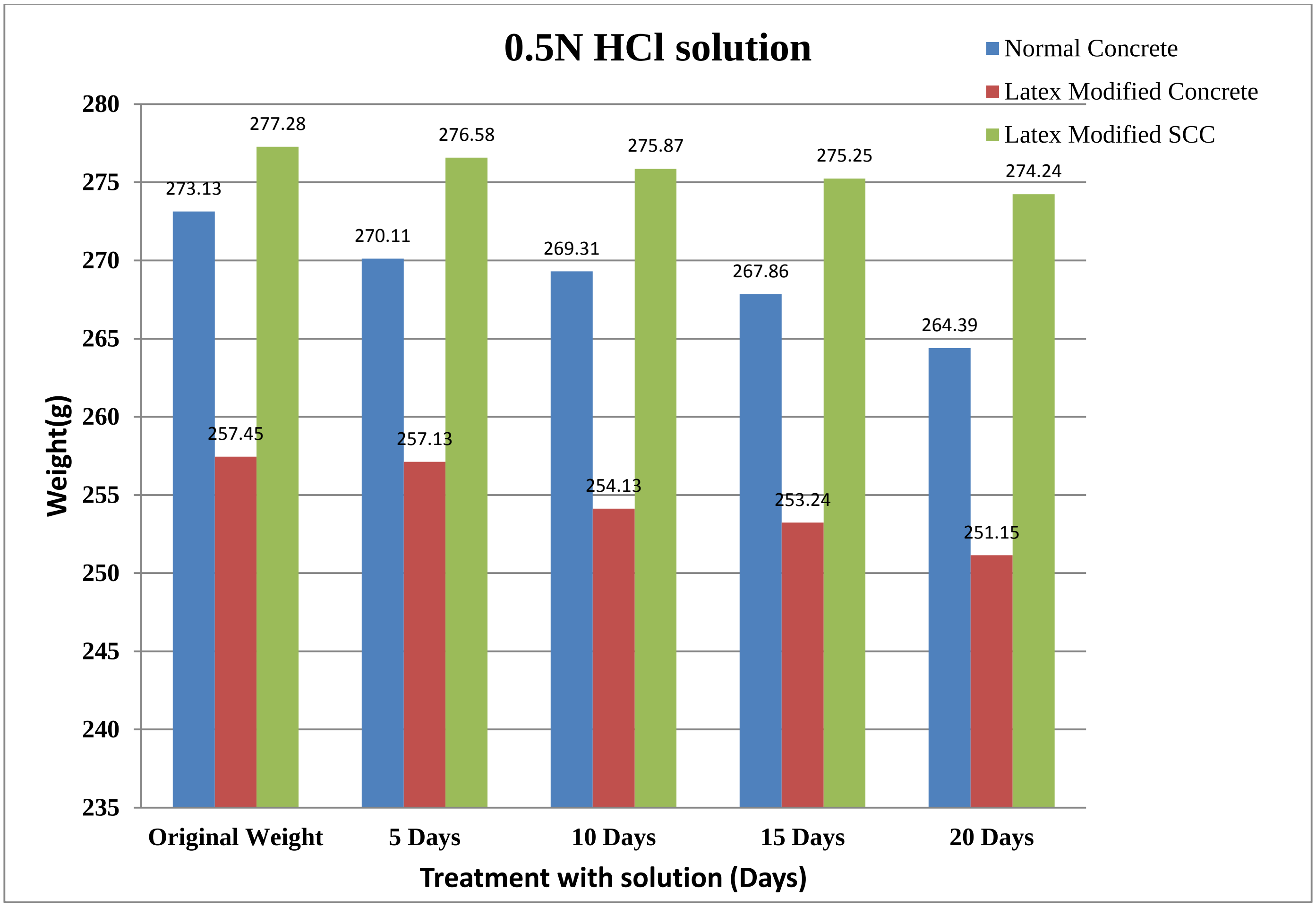


Figure 15: Reduction in weight by treatment of 0.5 HCl Solution (7 days water cured samples)

The comparison between the graphs of 3 days cured treated sample and 7 day cured treated samples show that as the concrete is cured for a longer period, it develops resistance against the acid attack. The acid attack on 7 days cured samples is weak as compared to 3 days cured samples.

The samples were treated against the alkali. The results of alkali treated three days water cured samples are given in the figure 16. It must be noted here that all the samples were treated for three weeks.

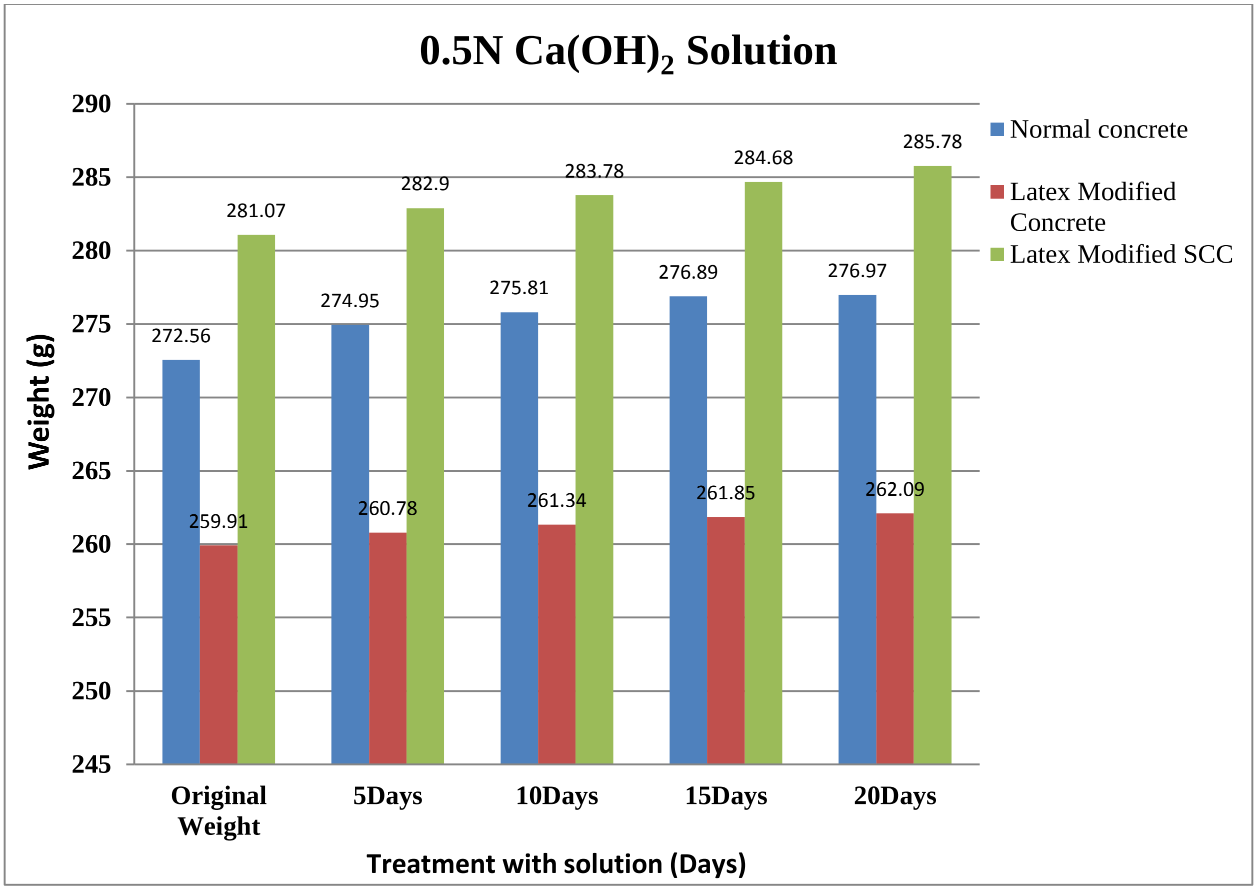


Figure 16: Gain in weight by treatment of 0.5 $Ca(OH)_2$ (3 days water cured)

The results of alkali treatment reveal that weight is gained by the samples. The calcium ions released by calcium hydroxide help in hydration process which results in the gain of the weight. The results of 7 days cured calcium hydroxide treated samples are shown in figure 17.

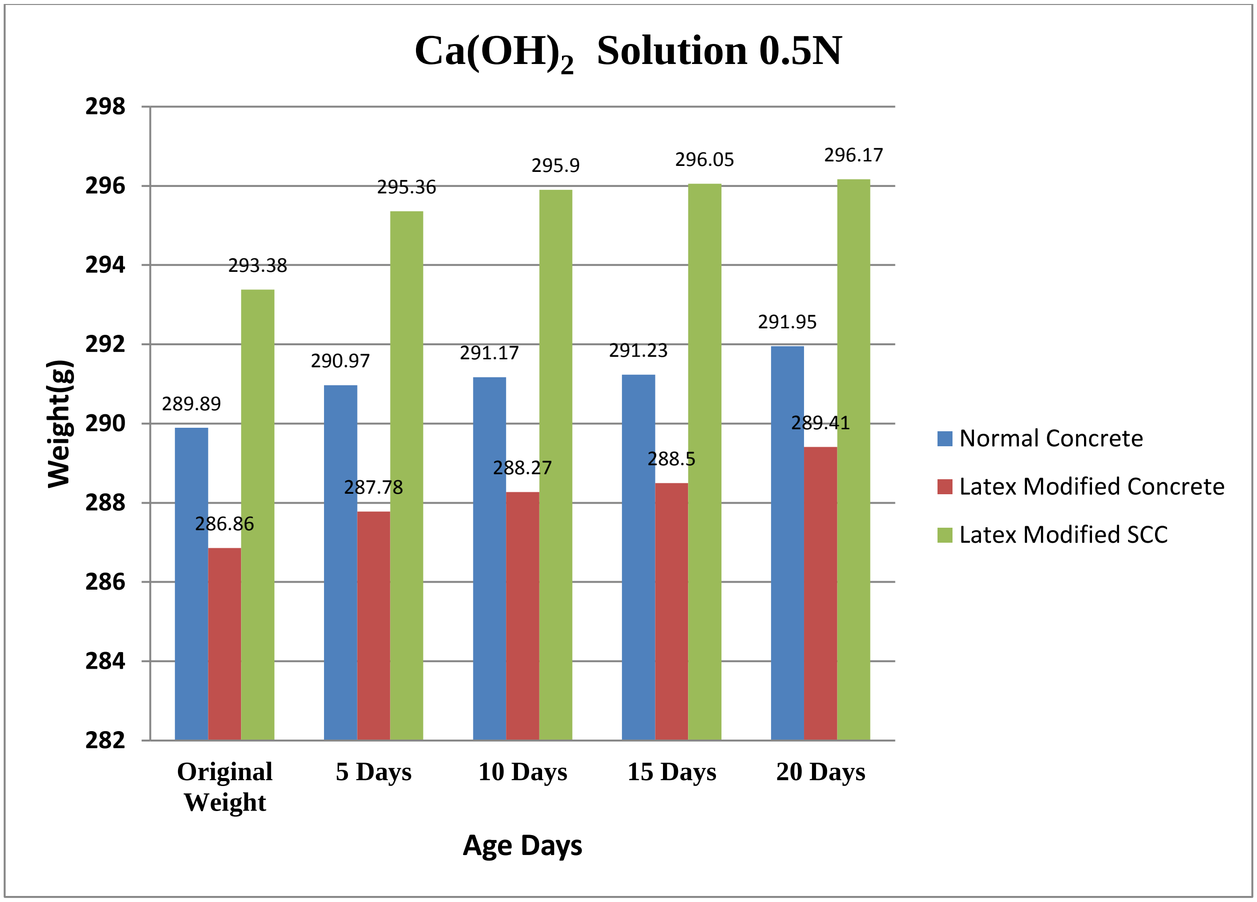


Figure 17: Gain in weight by treatment of 0.5 $Ca(OH)_2$ (7 days water cured)

The samples when treated with salts, it was shown by their graphs that they have reduced their weight. It implies that ammonium sulphate has corrosive action against the concrete. The weights of the samples are shown in the figure 18. These samples were water cured for three days.

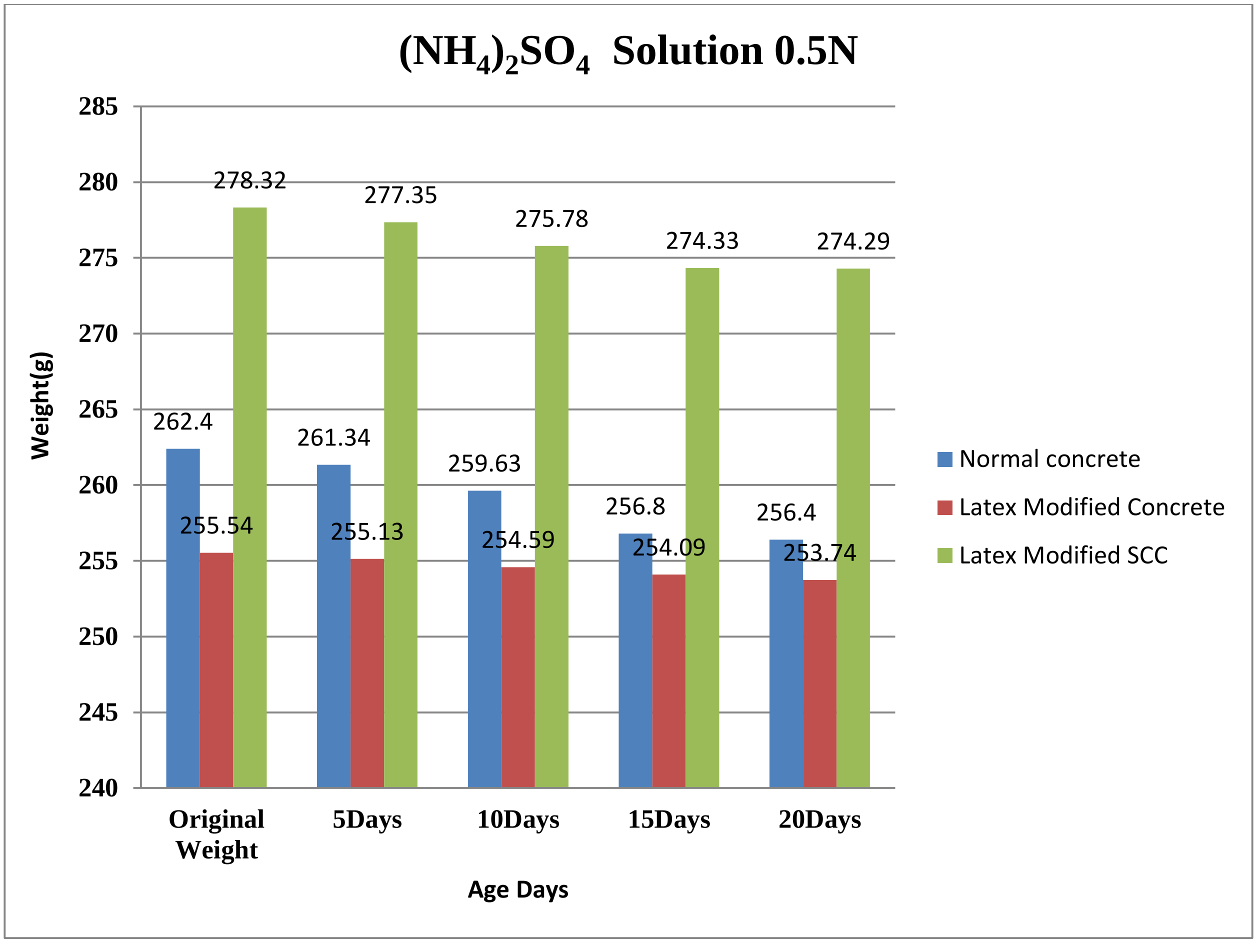


Figure 18: Loss in weight by treatment of 0.5 (NH4)2SO4 (3 days water cured)

The graphs show there is reduction in the weights of the samples. The trend is same for normal, latex modified conventional and latex modified self compacting concrete. The results of 7 days water cured samples are shown in figure 19.

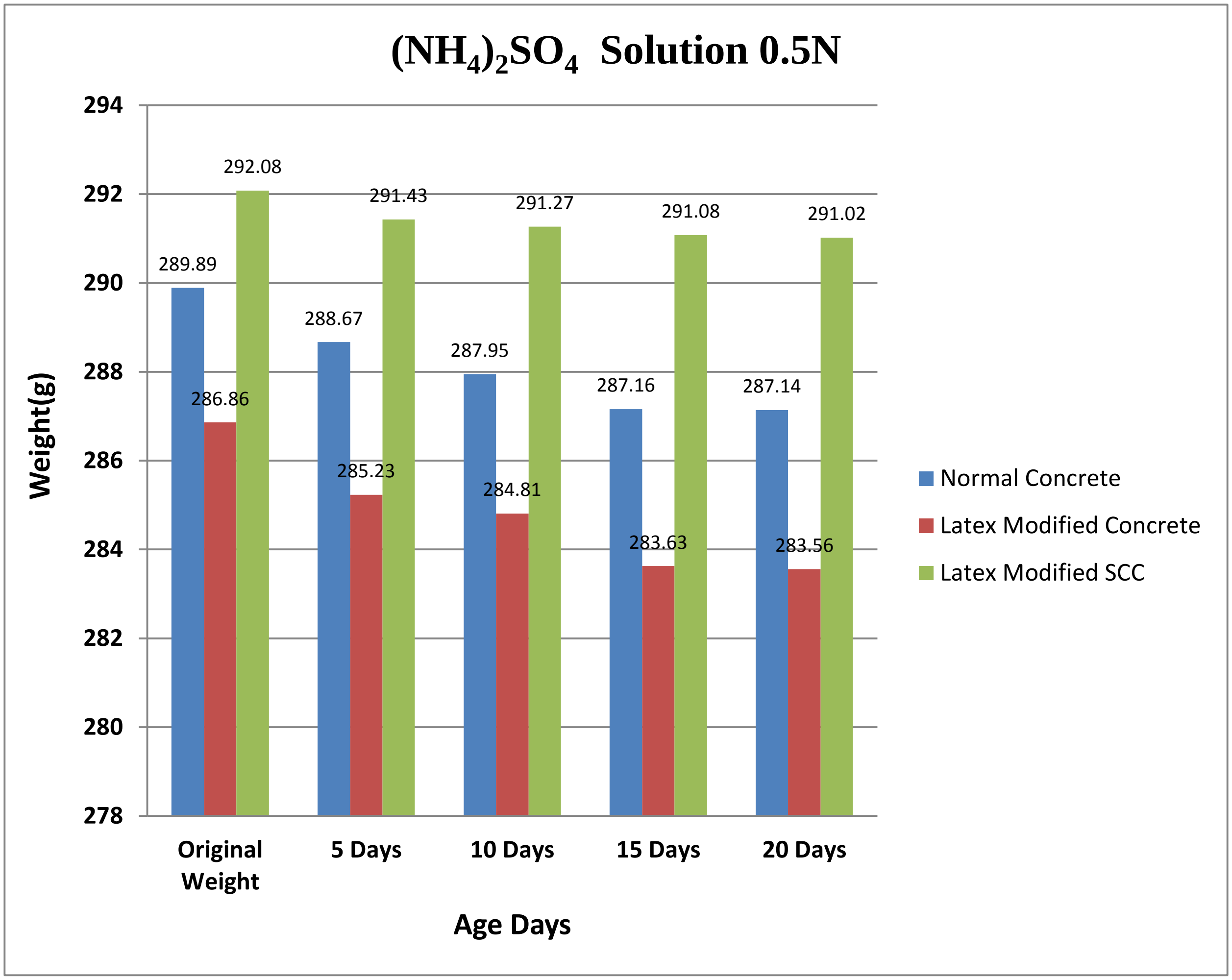


Figure 19: Loss in weight by treatment of 0.5 $(NH_4)_2SO_4$ (7 days water cured)

The treated samples were tested against the compressive strength and compared with the original samples that were kept for the curing. The results of these samples that were cured for 3 days are shown in the figure 4-9.

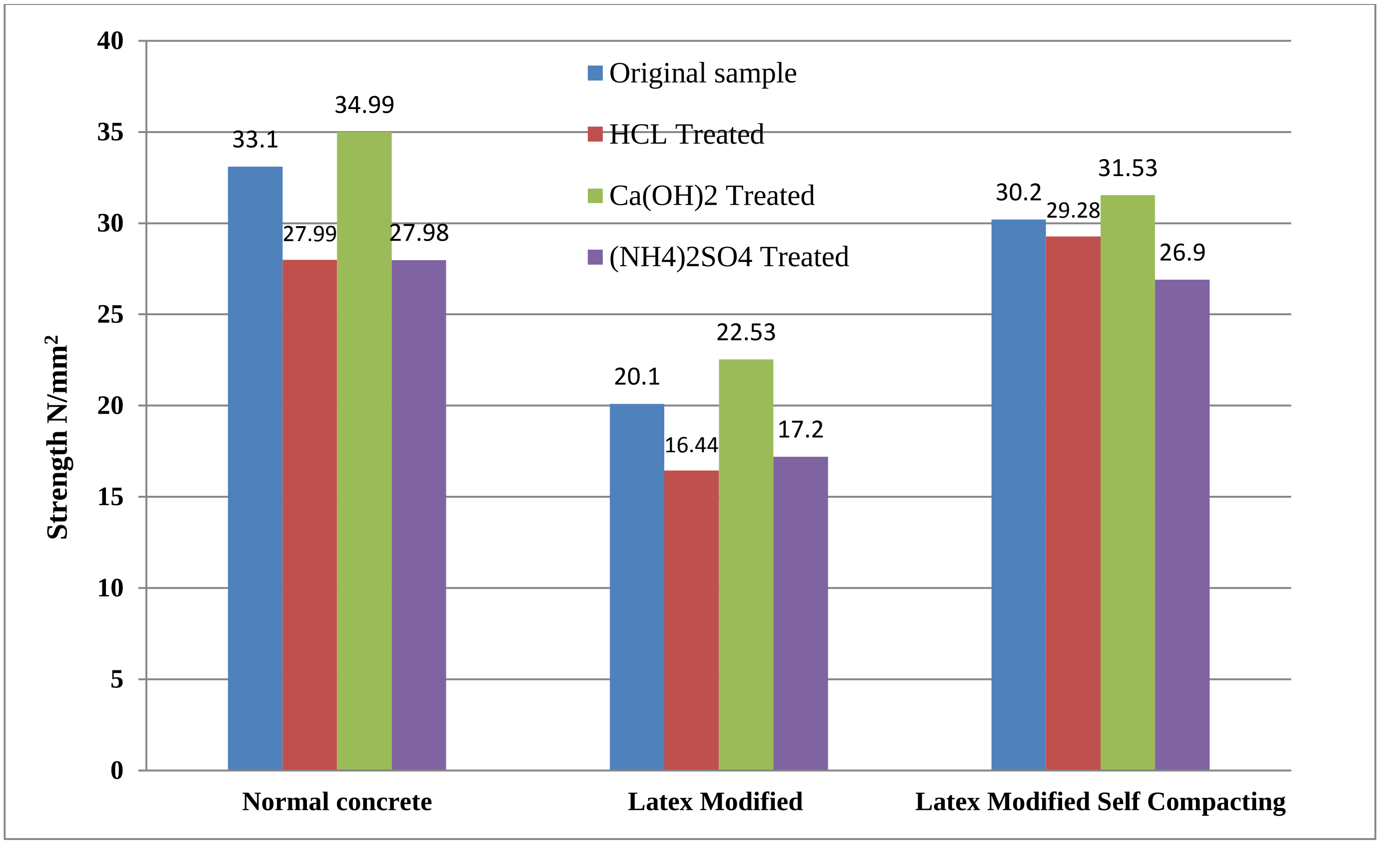


Figure 20: Durability Strength of 3 days water cured and 21 days chemically treated samples

The compressive strength of the samples that were cured for 7 days and treated for 21 days is shown in the figure 22.

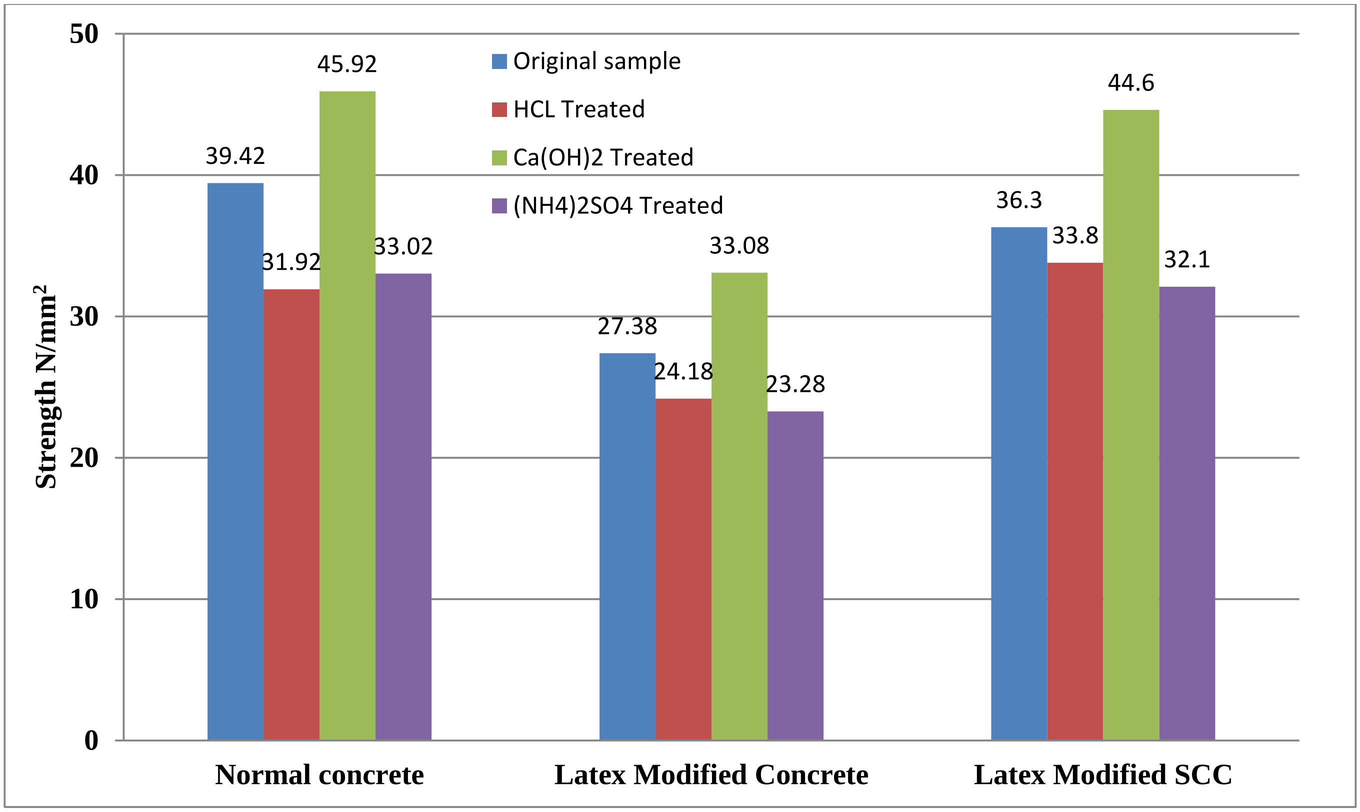
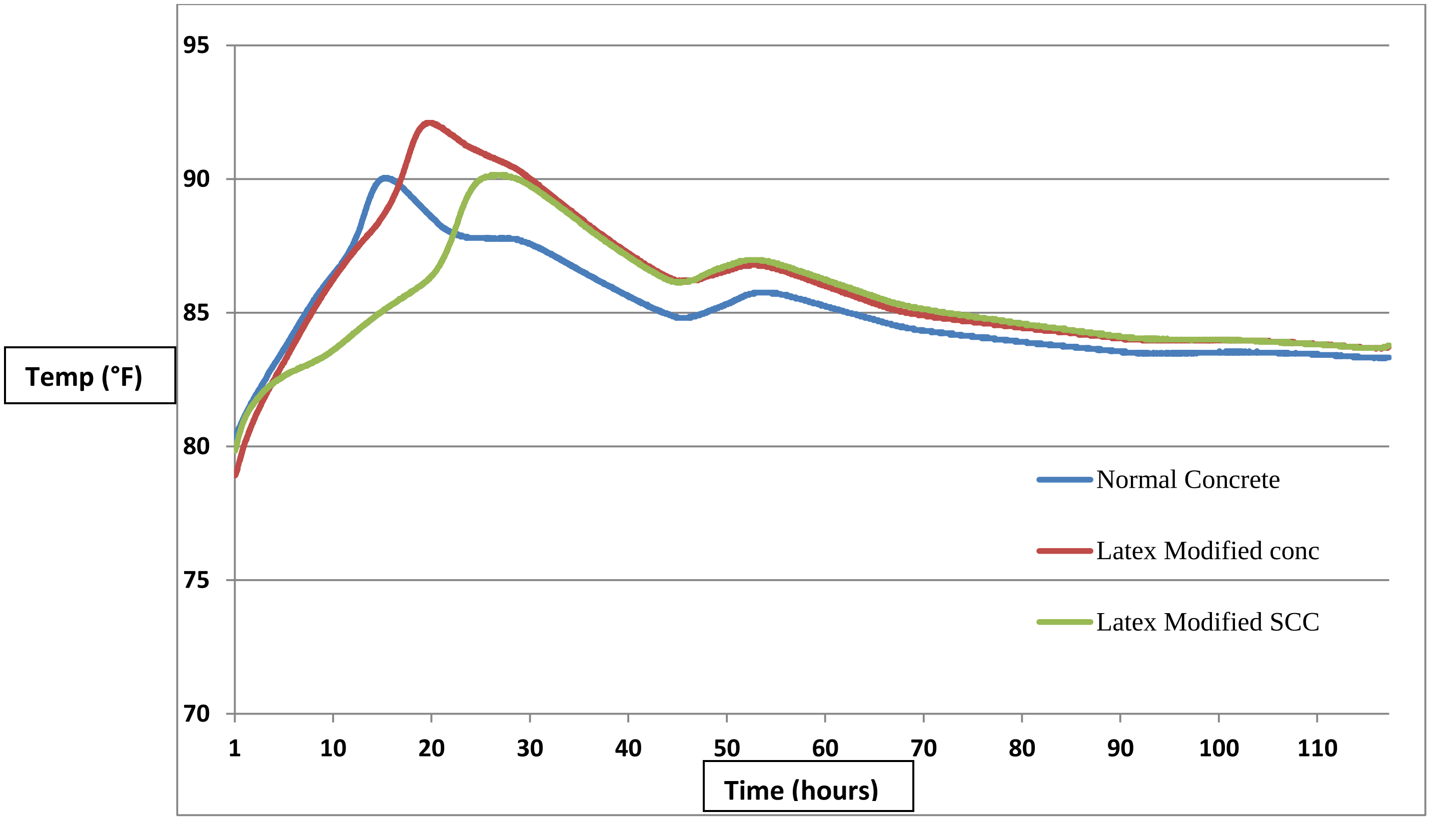


Figure 21: Durability Strength of 7 days water cured and 21 days chemically treated samples

The results of the durability show that by addition of SP to latex modified concrete, the chemical resistance of SCC is increased as compared to the normal and latex modified concrete. Therefore, in the areas like coastal areas where concrete is exposed to the salt attack, the addition of SP will improve its durability and strength. Likewise in the areas where acidic attack is possible, the addition of SP helps in the improvement of the durability of the concrete. The increased durability of the latex modified can be explained in the terms of density of concrete. The particles in latex modified SCC are densely packed by polymerization and hydration so penetration of ions released by acids and salts is less likely to happen as compared with the normal concrete.

5.4 Calorimetry

The calorimetry analysis was performed on the concrete samples. The results obtained from the experiment are shown in the figure 10



The graph is plotted between time (hours) on x-axis and temperature (°F) on y-axis. It can be observed by the graph that addition of SBR to the normal concrete delays the peak of hydration. However, the peak of latex modified concrete is higher than normal concrete while the strength measured of latex modified concrete is less than normal concrete. The higher peak may be because of the reason that enthalpy of polymerization is negative which implies that during polymerization heat is evolved. So the higher peak results because of the evolving of this heat. The addition of SP to latex modified conventional concrete further delays the hydration. The SP acts as a retarder and its open time is more than normal and latex modified concrete. The latex modified self compacting concrete maybe used where more open time is required.

CHAPTER 6

CONCLUSIONS

The following conclusions were drawn from the research conducted.

1. With the addition of SP to the latex modified conventional concrete, its resistance against acid and salt attack is increased.
2. Strength of Latex Modified concrete is less than normal Concrete's strength.
3. Strength of latex modified SCC is more than latex modified conventional concrete's strength due to improved microstructure.
4. Strength of air cured Latex modified concrete is more than the strength of water cured latex modified concrete. Same trend is followed for latex modified SCC.
5. Addition of SBR retards hydration of concrete while addition of SP to latex modified concrete further retards the hydration process.
6. SBR increases the workability of conventional concrete.

RECOMMENDATIONS

Keeping in the view of the research carried out and ongoing research in the field of concrete, the following recommendations are made.

1. To comprehend the behavior of SCC containing SBR thoroughly, its chemistry should be understood by investigating the hydration products by SEM
2. Secondary Raw Materials (SRMs) usually show good results when used in concrete. Further research should focus these areas

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ANNEXURE

Table 10: ASTM Gradation of Coarse Aggregate

Sieve Number	Sieve Size (mm)	Weight Retained (gm)	Percentage Retained	Cumulative Percentage Retained	Percentage Passing	ASTM minimum Passing	ASTM maximum Passing
# 8	2.36	100	10.00	100.00	0.00	0.00	5.00
# 4	4.75	400	40.00	90.00	10.00	0.00	15.00
$^{3}/_{8}$ inch	9.5	400	40.0	40.00	60.00	40.00	70.00
$^{3}/_{4}$ inch	19.5	0	0.00	0.00	100.00	100.00	100.00
1 inch	25	0	0.00	0.00	100.00	100.00	100.00
Total weight Retained		1000	100.00	-	-	-	-

Table 11: ASTM Gradation of Lawrencepur Sand

Sieve Number	Sieve size (mm)	Weight retained	Percentage retained	Cumulative Percentage Retained	Percentage passing	ASTM min Percentage passing	ASTM max Percentage passing
#4	4.75	0	0	0	100	95	100
#8	2.36	5.5	0.55	0.55	99.45	80	100
#16	1.18	40.5	4.05	4.60	95.4	50	85
#30	0.6	305.5	30.59	35.19	64.81	25	60
#50	0.3	475.5	47.60	82.79	17.21	10	30
#100	0.15	135.5	13.57	96.36	3.64	2	10
Pan	-	36.35	3.64	100	0	0	0
Total weight retained		998.9	F.M	2.19	-	-	-

Table 12: ASTM Gradation of Qibla Bandi Sand

Sieve Number	Sieve size (mm)	Weight retained	Percentage retained	Cumulative Percentage Retained	Percentage passing	ASTM min Percentage passing	ASTM max Percentage passing
#4	4.75	15	1.5	1.5	98.5	95	100
#8	2.36	50	5	6.5	93.5	80	100
#16	1.18	120	12	18.5	81.5	50	85
#30	0.6	210	21	39.5	60.5	25	60
#50	0.3	330	33	72.5	27.5	10	30
#100	0.15	261	26.1	95.9	4.1	2	10
Pan	-	41.35	4.1	100	0	0	0
Total weight retained		998.9	F.M	2.34	-	-	-

Table 13: Compressive Strength of 100mm x 100mm x 100mm cubes

Curing method	Time (days)	Normal concrete (N/mm^2)	Latex Modified concrete (N/mm^2)	Latex Modified self compacting concrete (N/mm^2)
Water Curing	3	21.8	12.9	17.2
	7	31.9	20.9	26.7
	28	35.0	23.6	33.2
Air Curing	3	21.6	13.4	17.8
	7	27.6	21.1	28.7
	28	33.0	26.2	37.6

Table 14: Flexure Strength of 100mm x 100mm x 500 mm prisms

Results of Modulus of rupture-28 days			
Curing Type	**Normal concrete (N/mm^2)**	**Latex Modified concrete (N/mm^2)**	**Latex Modified self compacting concrete (N/mm^2)**
Air curing	4.61	4.29	6.08
Water curing	6.07	3.42	4.96

Table 15: Weight of 3 day water cured samples treated with 0.5N HCl

Age of samples in solution (days)	Variation in Weight (grams)		
	Normal Concrete	Latex modified concrete sample	Latex modified self-compacting concrete
Pure Sample	273.46	257.98	280.74
1	271.03	256.17	279.33
4	270.68	255.87	278.91
5	269.73	255.19	278.43
6	268.94	254.93	278.14
7	268.32	254.56	277.99
8	265.59	252.97	276.43
11	264.29	251.83	276.19
12	263.33	250.99	275.89
13	262.52	250.32	275.57
14	261.96	248.98	274.39
15	259.29	247.88	274.72
18	258.17	246.91	273.87
19	257.33	246.33	273.53
20	256.53	245.74	273.12
Percentage reduction in weight	6.19%	4.7%	3.54%
Percentage reduction in strength	31.64%	38.05%	18.9%

Table 16: Weight of 3 day water cured samples treated with $Ca(OH)_2$

Age of samples in solution (Days)	Variation in Weight (grams)		
	Normal Concrete	Latex modified concrete sample	Latex modified self-compacting concrete
Pure Sample	272.56	259.91	281.07
1	274.65	260.99	282.27
4	274.7	260.76	282.87
5	274.95	260.78	282.9
6	274.9	260.81	283
7	274.91	260.79	283.2
8	275.69	261.33	283.45
11	275.81	261.34	283.78
12	275.73	261.3	284.09
13	275.84	261.25	284.37
14	276.89	261.85	284.68
15	276.95	261.98	284.91
18	276.94	262.03	285.1
19	276.95	262.1	285.45
20	276.97	262.09	285.78
Percentage Increase in weight	1.6%	0.83%	0.85%
Percentage increase in strength	11.76%	25.37%	27.58%

Table 17: Weight of 3 days water cured samples treated with Ammonium sulphate

Age of samples in solution (Days)	Variation in Weight (grams)		
	Normal Concrete	Latex modified concrete sample	Latex modified self-compacting concrete
Pure Sample	262.4	255.54	278.32
1	261.83	255.18	277.49
4	261.63	255.18	277.34
5	261.34	255.13	277.35
6	261.32	255.09	277.27
7	261.18	254.99	277.19
8	259.65	254.87	275.89
11	259.63	254.59	275.78
12	259.52	254.53	275.71
13	259.35	254.47	275.6
14	259.19	254.37	275.58
15	256.8	254.09	274.33
18	256.73	253.97	274.3
19	256.7	253.81	274.28
20	256.4	253.74	274.29
Percentage reduction in weight	2.28%	1.44%	0.78%
Percentage reduction in strength	31.76%	32.08%	68.27%

Table 18: Variation of pH in first week for 3 days water cured samples

Age (days)	HCL (0.5N)	(NH4)2SO4 (0.5N)	Ca(OH)2 (0.5N)
Pure solution	1.31	6.6	11.8
1	3.21	9.18	11.97
4	5.7	9.42	12.15
5	6.36	9.52	12.26
6	6.75	10	13.53
7	6.83	10.2	13.62

Table 19: Variation of pH in second week for 3 days water cured samples

Age (days)	HCL (0.5N)	(NH4)2SO4 (0.5N)	Ca(OH)2 (0.5N)
Pure solutions	0.3	7.83	13.40
1	1.99	9.31	13.42
4	4.68	9.50	13.54
5	6.01	9.55	13.60
6	6.28	9.62	13.63
7	7.62	9.65	13.65

Table 20: Variation of pH in second week for 3 days water cured samples

Age (days)	HCL (0.5N)	(NH4)2SO4 (0.5N)	Ca(OH)2 (0.5N)
Pure solutions	0.3	6.62	12
1	2.18	9.02	12.41
4	4.77	9.30	12.43
5	5.65	9.33	12.55
6	6.53	9.35	12.61
7	7.19	9.63	12.89

Table 21: Weight of 7 days water cured samples treated with 0.5 HCl

Age of samples in solution (days)	Variation in Weight (grams)		
	Normal Concrete	Latex modified concrete sample	Latex modified self-compacting concrete
Pure Sample	273.13	257.45	277.28
1	271.9	257.36	276.93
4	271.1	257.16	276.72
5	270.11	257.13	276.58
6	270.49	256.74	276.45
7	270.35	256.38	276.23
8	269.51	254.26	276.07
11	269.31	254.13	275.87
12	268.87	253.82	275.5
13	268.2	253.77	275.43
14	267.86	253.24	275.25
15	265.2	251.96	275.19
18	264.63	251.64	274.98
19	264.58	251.34	274.76
20	264.39	251.15	274.24
Percentage reduction in weight	3.19%	2.44%	1.41%
Percentage reduction in strength	35.71%	23.18%	34.24%

Table 22: Weight of 7 days water cured samples treated with 0.5 N $Ca(OH)_2$

Age of samples in solution (Days)	Variation in Weight (grams)		
	Normal Concrete	Latex modified concrete sample	Latex modified self-compacting concrete
Pure Sample	289.89	286.86	293.38
1	290.27	287.05	294.2
4	290.53	287.25	295.15
5	290.97	287.78	295.36
6	290.87	287.71	295.75
7	290.91	288.02	295.77
8	291.13	288.12	295.79
11	291.17	288.27	295.9
12	291.2	288.36	295.93
13	291.25	288.41	295.97
14	291.23	288.5	296.05
15	291.82	289.32	296.13
18	291.85	289.35	296.54
19	291.93	289.4	297
20	291.95	289.41	296.17
Percentage Increase in weight	0.88%	0.71%	1.17%
Percentage increase in strength	30.95%	41.30%	47.95%

Table 23: Weight of 7 days water cured samples treated with 0.5 N $(NH_4)_2SO_4$

Age of samples in solution (Days)	Variation in Weight (grams)		
	Normal Concrete	Latex modified concrete sample	Latex modified self-compacting concrete
Pure Sample	289.89	286.86	292.08
1	288.78	285.3	291.87
4	288.76	285.25	291.45
5	288.67	285.23	291.43
6	288.65	285.22	291.4
7	288.61	285.19	291.38
8	287.97	284.83	291.32
11	287.95	284.81	291.27
12	287.94	284.73	291.26
13	287.91	284.7	291.24
14	287.9	284.69	291.21
15	287.16	283.63	291.08
18	287.13	283.59	291.06
19	287.12	283.55	291.05
20	287.14	283.56	291.02
Percentage reduction in weight	1.15%	0.94%	0.45%
Percentage reduction in strength	30.47%	29.71%	57.53%

Table 24: Variation of pH in 7 days water cured samples after first week

Age (days)	HCL (0.5N)	(NH4)2SO4 (0.5N)	Ca(OH)2 (0.5N)
Pure solution	0.3	7.83	13.40
1	3.4	9.31	13.42
4	5.64	9.50	13.54
5	6.43	9.58	13.58
6	6.75	9.62	13.60
7	7.99	9.65	13.63

Table 25: Variation of pH in 7 days water cured samples after second week

Age (days)	HCL (0.5N)	(NH4)2SO4 (0.5N)	Ca(OH)2 (0.5N)
Pure solutions	0.3	7.83	13.40
1	2.16	9.31	13.42
4	5.75	9.50	13.54
5	6.15	9.55	13.60
6	6.04	9.62	13.63
7	6.23	9.65	13.65

Table 26: Variation of pH in 7 days water cured samples after second week

Age (days)	HCL (0.5N)	(NH4)2SO4 (0.5N)	Ca(OH)2 (0.5N)
Pure solutions	0.3	7.78	12.73
1	2.54	8.55	13.58
4	3.57	8.74	13.64
5	5.32	9.16	13.67
6	6.78	9.49	13.69
7	6.93	9.53	13.71