Chapter1

INTRODUCTION

1.1 GENERAL

Portland cement-based mortars and concretes are the most widely used structural materials in the world. Concrete has some serious drawbacks including low tensile and flexural strength, low strain capacity, brittleness, permeability, and long term durability. These should be overcome to obtain better concrete with enhanced properties.

These properties of cement-based concrete and mortars can be improved by the addition of Styrene-Butadiene Rubber (SBR). SBR is a kind of high-polymer dispersion emulsion made out of butadiene, styrene, and water and it can be successfully bonded to many materials. Synthetic polymeric additives for example; latexes, redispersible polymer powders, water-soluble polymers, and liquid resins have been added into the concrete mortar to get the polymer-modified mortars and concretes. The utilization of these materials for repair work, rebuilding, facade coatings, and tile adhesives, sealing coatings and decorative coating are used increasingly since the 1960 s; but the concrete could not maintain its compressive strength by addition of SBR latex. So, the compressive strength of concrete can be enhanced using different forms of SBR with admixtures. Hence, producing SBR modified mortars and concretes without loss in compressive strength is a big challenge.

1.2. OBJECTIVES

The utilization of polymers in concrete and mortars to enhance its properties has become a very common practice in the construction industry. The powder form of Styrene-butadiene rubber (SBR) along with admixtures is used to replace cement as a binder to enhance properties of concretes and mortars.

SBR Polymer is the most commonly utilized to modify the concretes and mortars. The addition of SBR latex in mortars and concretes enhance the mechanical properties i.e. tensile strength, corrosion resistance, reduced shrinkage, greater flexibility for crack bridging, excellent water resistance, improved chemical resistance, and it gives low adhesion of fresh concrete as compared to general concrete. But mortars and concretes could not maintain its compressive strength by the addition of SBR latex, due to entrained air.

Other forms of polymer, i.e. SBR in powder form along with admixtures have not been tried widely. So the admixtures will be utilized along with SBR in powder form in mortars to enhance the compressive strength of mortars and concrete. The basic objective of the study is to replace the cement content in the mortar by SBR powder and admixtures at various percentages to enhance compressive strength, while other properties of concrete are already enhanced due to SBR.

1.3. METHODOLOGY

Mortar cubes of 2”x2”x2” were prepared using cement: sand, 1:2.75 and w/c 0.48. And methodology and research procedure is shown below Figure 1.1.

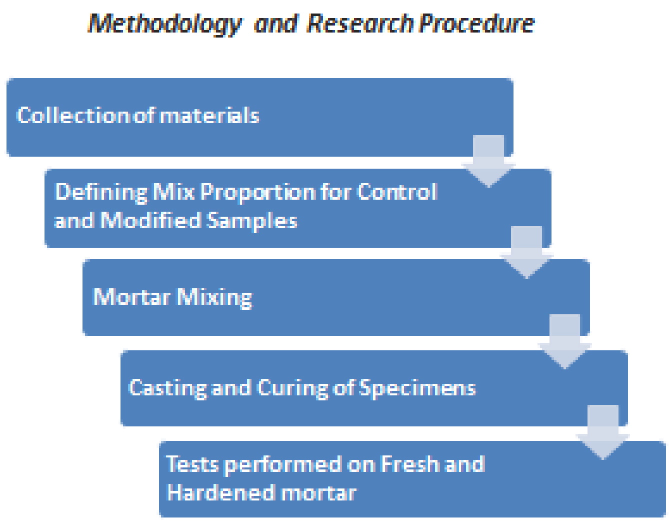

Figure 1.1: Methodology and research procedure

Mortar cubes were prepared at four phases shown in Figure 1.2.

i. SBR Latex modified mortar cubes

Preparation of polymer cement mortar using different percentages of SBR Latex i.e. mixes will be prepared using the SBR latex ratio of 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10% replacing the cement content respectively.

ii. SBR powder modified mortar cubes

Preparation of polymer cement mortar using different percentages of SBR powder i.e. mixes will be prepared using the SBR powder ratio of 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10% replacing the cement content respectively.

iii. Mortar cubes modified with SBR powder and nanomaterials and zinc stearate

Preparations of polymer cement mortars using different percentages of SBR powder

- SBR powder (0%, 3%, 5%, 7%, 10%) with 2% nano-silica
- SBR powder (0%, 3%, 5%, 7%, 10%) with 2% nano-titanium
- SBR powder (0%, 3%, 5%, 7%, 10%) with 0.5% zinc stearate

iv. Mortar cubes modified with SBR latex and nanomaterials and zinc stearate

Preparations of polymer cement mortars using different percentages of SBR powder

- SBR latex (0%, 5%, 10%) with 2% nano-silica
- SBR latex (0%, 5%, 10%) with 0.5% zinc stearate

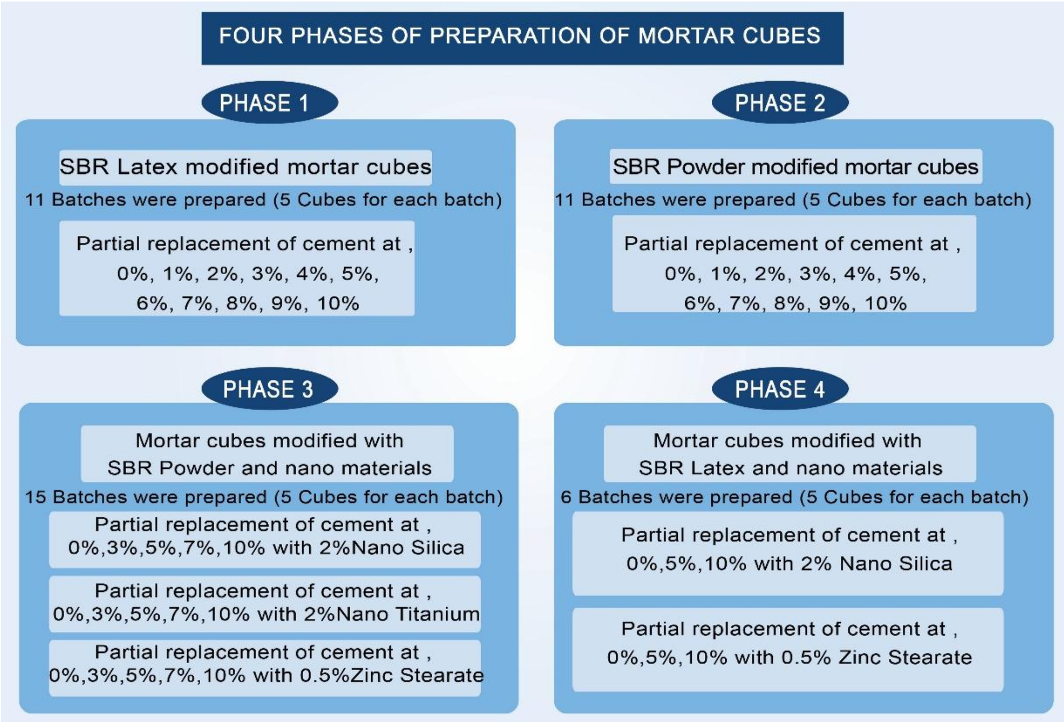

Figure 1.2: Four phases for preparation of Mortar cubes

Then tests performed were compressive strength, water absorption, flow table test and density of mortar Compressive strength test was performed at 28 days using the universal testing machine of mortar cube and results were evaluated and interpreted.

1.4. SCOPE OF RESEARCH

Nowadays, the study on cementitious based materials is focused on the consideration of additives and admixtures, to enhance certain physical and mechanical properties. Even though keeping its strength, low cost and ability to fill any shape. Adherence, permeability, ductility, flexural strength and compressive strength are primary research lines on cement matrix materials.

Polymeric admixtures are characterized as polymers used as the main ingredient for enhancing the cement-based material properties. Such a polymeric compound can be a polymer latex, re-dispersible polymer powder, water-solvent polymer or liquid polymer. Use of polymer, for example, SBR powder with admixtures has not been used broadly. So the admixtures will be utilized along with SBR powder in cement to enhance the compressive strength of mortar. Replacing cement with SBR powder also increases the lifespan of structures.

1.5. RESEARCH REVIEW

This research study comprises of five chapters. In chapter 1, the introduction of the topic, problem statement, objectives, methodology, and utilization of research are discussed. In chapter 2 the detailed literature review is described in which properties of SBR modified mortars and concretes are discussed. In chapter 3 “Methodology and research procedure” the detail of all batches and explanation of all tests performed on samples are given. Also, the method adopted for the preparation of mixes along with the method of curing is discussed in this chapter. Tests performed on mortar samples i.e. flow table test, density, water absorption, and compression test are also explained in this chapter. Results of all tests performed are on samples are given in chapter 4 “Results and Discussions”. In chapter 5 conclusions of the research are given and further research recommendations are discussed.

Chapter 2

LITERATURE REVIEW

2.1. USE OF POLYMERS IN MORTARS AND CONCRETES

Portland cement-based concretes are the most commonly utilized structural materials all over the world. There are many advantages like high rigidity and compressive strength, less cost, and easiness of fabrication. Nevertheless, they encountered with serious problems including low tensile and flexural strength, low strain capacity, brittleness, permeability, and long term durability, which need to be improved. Polymers are widely used to modify the physical and mechanical properties of mortars and concretes. Polymer modified mortars and concretes are made through adding polymers in forms of latex, redispersible powders, liquid resins, and monomers. Mortars and concretes made with Polymers have a co matrix where polymer matrix and cement gel matrix homogenized.

Polymers can be added in concretes and mortars by using polymers in re-dispersible powder or latex form in cement. When the polymer is used in latex form in mortars and concretes, hydration of cement started and the polymer layer is developed. As the polymer content increases the effect also increases and increases its tensile strength and fracture toughness. Discontinuous of the structure are caused due to excessive air entrainment due to which compressive strength is decreased through chemical reactions continuous as shown in fig. There is also an increase in water proofness due to the sealing effect of polymers layers in the structure. Other properties like resistance to chloride ion penetration, freeze-thaw durability, and moisture to carbonation are also improved using polymers. Such an effect is improved using a more polymer cement ratio.

Type of Polymer and the quantity of polymer cement ratio will affect the pore structure of polymer-modified mortars and concretes. With increase of polymer to cement ratio, the porosity will decrease. It will help to make it impermeable and to absorb less water.

2.2. PROPERTIES OF POLYMER MODIFIED MORTARS AND CONCRETES

Polymer modified mortars and concretes are made using hydraulic cement mixed with polymers which can be in re-dispersible powder form or latex form. A polymer is made up of small molecules joined into large molecules. The simple and small molecules are called monomers, and the process is called polymerization. The polymers are used available in three basic forms in the market: as latex form scattering in water; as redispersible powder form; and as a fluid that is dissolvable in water. These admixtures are known as polymer modifiers and are used in mortars and concrete for many years.

Many polymers are utilized in mortars and concretes along with cement such as polyvinyl acetate (PVA), styrene-butadiene rubber (SBR), acrylic polymers and copolymers (PAE) and vinyl acetate copolymers (VAC), etc. the choice of specific polymer for polymer-modified mortars and concretes relies upon the particular properties required for the application. The ideal polymer is the most affordable one that gives the required properties. S-B latexes are the polymers used where high bond strength and resistance to water are required because of cost and performance.

2.3. STYRENE BUTADIENE RUBBER (SBR)

The use of styrene butadiene latex in Portland cement started in the United States in the mid 1950s. Early uses of styrene butadiene were in floor leveling mixes, deck coatings, stucco and adhesives in construction after that it was used in concrete too. About 10000 bridge decks were made with styrene butadiene in United States till 1991.

2.4. PROPERTIES OF SBR MODIFIED MORTARS AND CONCRETES

Properties of Styrene-butadiene latex modified mortars and concretes are discussed;

When latex is blended into Portland cement excessive air can be entrained in it because of surfactants present in latex. Field experience has demonstrated that aggregate and cement composition can influence air content, that’s why care should be taken to check the mixture before use on site. Figure 2.1 demonstrates that with the increase in air content its compressive strength decreases.

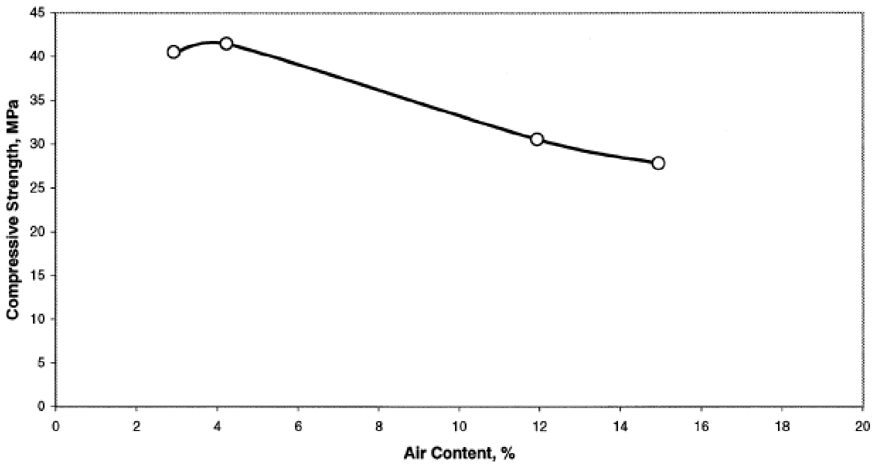

Figure 2.1:Air content verses compressive strength of SBR modified. Concrete

The workability of mortars and concretes also increases using styrene-butadiene rubber as compare to conventional mortars and concretes. The increase in workability is because of the dispersing effect of components of latex combined with water. Slump value increases using more water to cement ratio.

The curing is done for the first 24 to 48 hours by humidity and then air curing is done. Mortars and concretes modified with styrene-butadiene rubber have less compressive strength as compare to other mortars and concretes made from similar cement, sand, and aggregate. This is because during this air-curing extra water evaporates and allows the polymer membrane to fully form in internal structure. In unmodified concretes the larger sample sizes fail at less stress as compared to smaller ones this is because smaller size coarse aggregate will make a better composition with polymer particles and cement. Mortars and concretes modified with styrene-butadiene rubber have improved resistance to water absorption, resistance to freezing and thaw, resistance to chloride ion penetration and improved tensile bond strength as compare to unmodified mortars and concretes

Portland cement-based concretes are the most widely used structural materials in the world. They have many advantages such as high stiffness and compressive strength, low cost andrease of fabrication. Nevertheless, they encountered serious problems including low tensile and flexural strength, low strain capacity, brittleness, permeability, and long term durability, which need to be improved. Polymeric latexes are widely used to modify the physical and mechanical properties of cement-based mortars and concretes. Using polymer admixtures in all types caused a decrease in the compressive strength and modulus of elasticity of the specimens. Increasing polymer content caused also decrease in compressive strength due to the lubricant effect of the polymer particles in the cement matrix (Ohama, 1995).

M. J, H.R. and A.R. Pourkhorshidi (2014) have done a detailed study on the effect of polymer type and content. Two W/C ratios were used i.e. 0.35 and 0.45 to evaluate the best water to cement ratio for latex modified samples. The results show that mechanical properties i.e. compressive and tensile strength of latex modified samples decrease with the increase of the W/C ratio.

Different types of latex were utilized to study the mechanical properties of modified concrete. Compressive strength of latex modified concrete was studied and in all kinds of latex compressive strength decreases. Acrylic latex (CA) showedthe good compressive strength as compared to other latexes whereas SBR latex and PVA latex (FP) showed more reduction in compressive strength. The results are demonstrated in Figure 2.2.

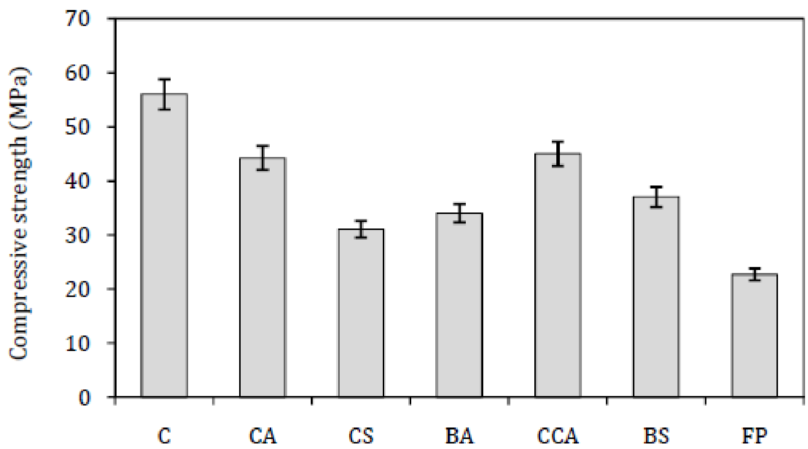

Figure 2.2: Effect of latex type on compressive strengthof modified concrete

The compressive strength of latex modified samples (Acrylic and its copolymers) is less with respect to control sample, and strength decreases with increase of latex (CA and CCA) amount as shown in Figure.2.3.

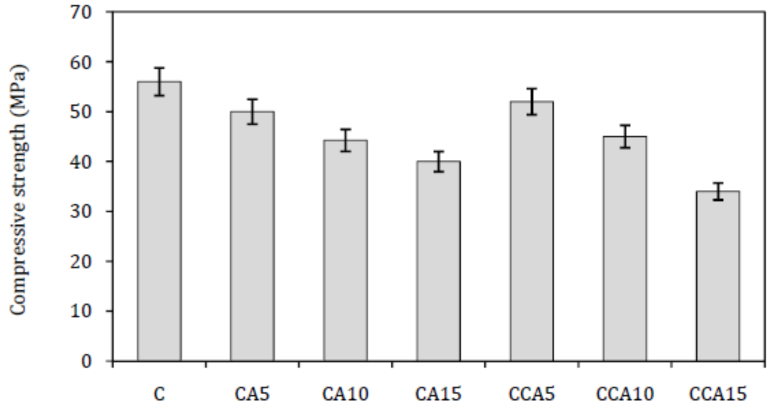

Figure 2.3:Compressive strength of concrete using different amounts of latexes

Flexural strength of latex modified concrete is better as compare to control specimen. Various latexes are used and CA and CCA exhibit the good flexural strength as compare to others latexes Figure2.4.

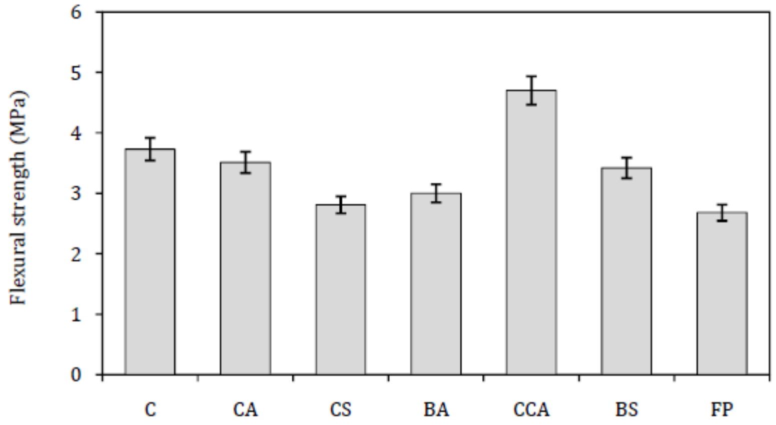

Figure 2.4: Effect of latex type on flexural strength of modified concrete

Tensile strength: Tensile strength results are similar to flexural strength i.e. CA and CCA have best results among all latexes shown in Figure. 2.5

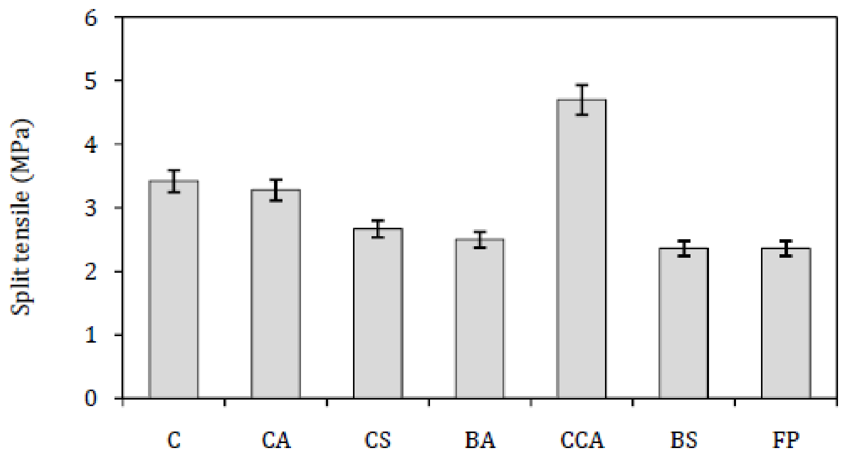

Figure 2.5: Effect of latex type on tensile strength of SBR modified concrete

Modulus of elasticity of different samples containing latexes is demonstrated in Figure. 2.6. There is reduction of modulus of elasticity using latexes in concrete.

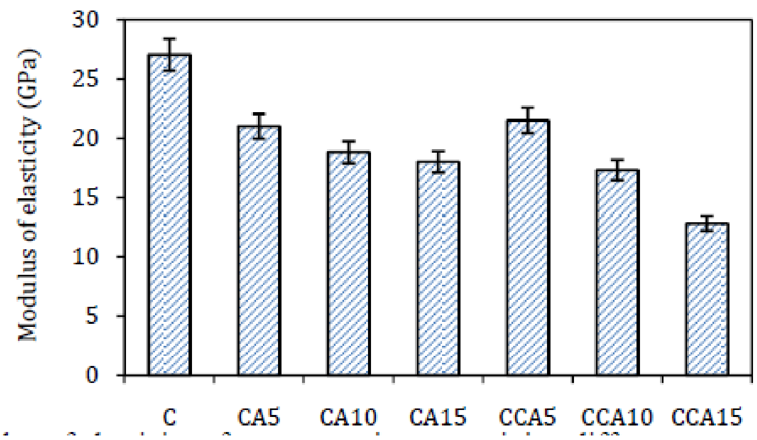

Figure 2.6: Modulus of elasticity of Latex modified concrete samples

Water absorption of latex modified concrete is shown in Figure 2.7. At 5 to 10 percent replacement of latex the water absorption decreases bur at 10 to 15 percent there is increase in water absorption. CA latex has better performance as compare to others (Jamshidi, Pakravan, & Pourkhorshidi, 2014) .

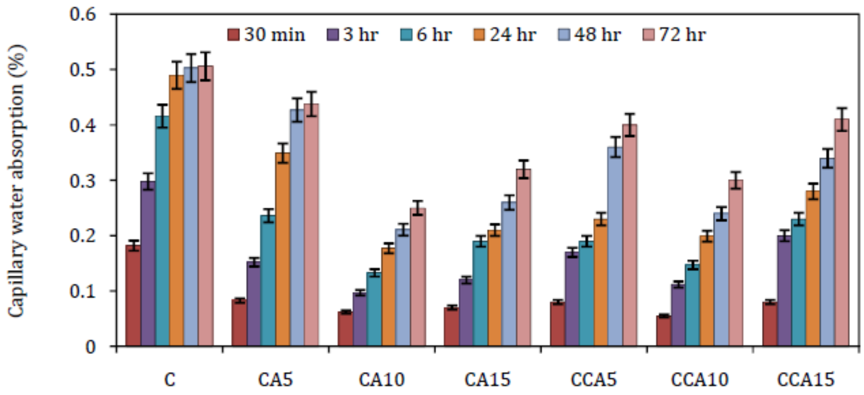

Figure 2.7: Capillary water absorption at different percentages of latex modified samples

Shuyih Yao and YongGe (2012) studied the effects of SBR latex on properties of concrete and found that the addition of SBR in concretes and mortars modify its mechanical properties and permeability. Using SBR in concrete will cause reduction in compressive strength, water absorption and elastic modulus; also there is an increase in flexural strength. The properties of paste, mortar, and concrete with SBR latex modify in the same manner. The ITZ zone of aggregate and paste has a great effect on the properties of modified concrete because it will cause a decrease in the compressive strength of mortar and paste. Effect of SBR latex on compressive strength is shown in Figure 2.8 and Figure 2.9.

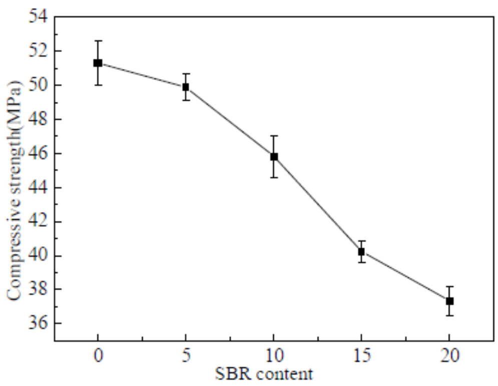

Figure 2.8: Effect of SBR Latex on 28 day compressive strength of concrete

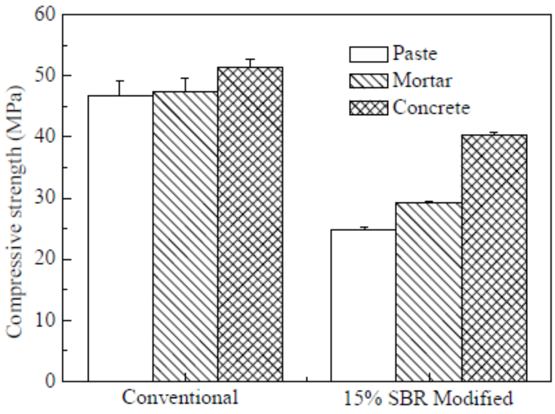

Figure 2.9: Compressive strength of mortar and concrete samples

Figure 2.10 demonstrates the effect of SBR on flexural strength of concrete. With increase of SBR quantity the flexural strength also increases gradually Figure 2.11 showed the flexural strength of the control specimen and SBR latex modified mortars and concretes. The increase in flexural strength of modified concrete is due to that SBR has better bond of paste aggregate of ITZ between cement past and aggregate.

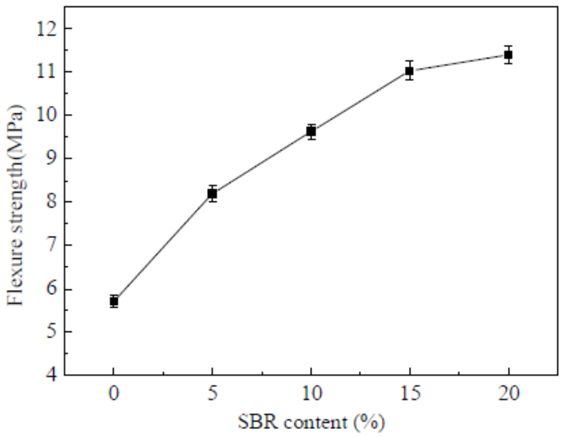

Figure 2.10: Effect of SBR Latex on 28 day flexural strength of concrete

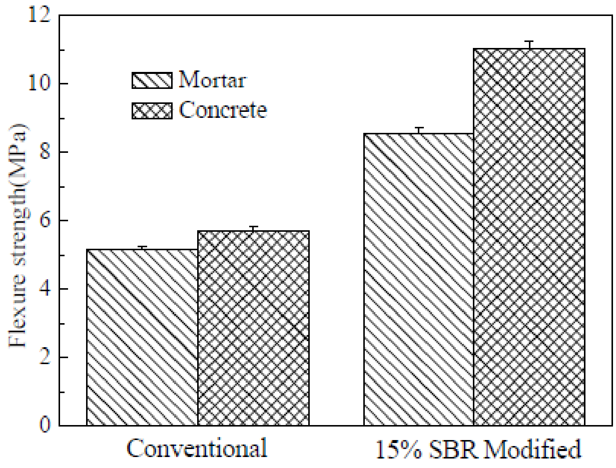

Figure 2. 11: Flexural strength of mortar and concrete samples

RCPT results of SBR modified concrete is demonstrated in Figure 2.12 and Figure 2.13. And it indicates that with increase of SBR quantity the anti-permeability of concrete will increase (Yao & Ge, 2012).

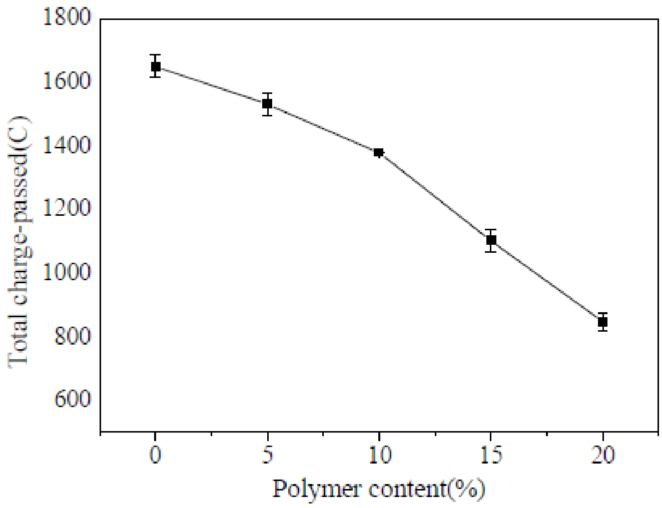

Figure 2.12: RCPT results of SBR latex modified concrete

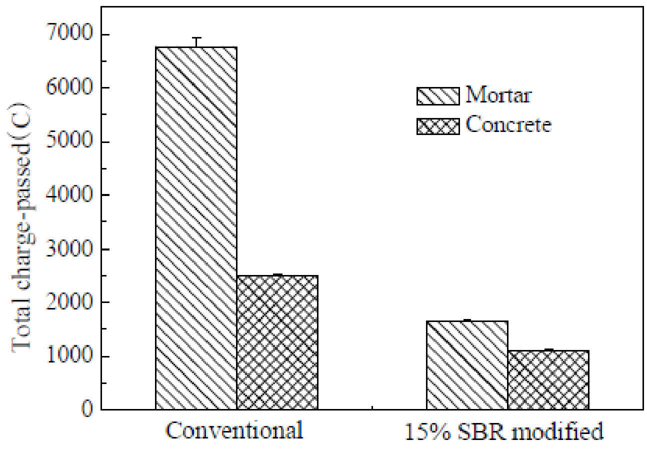

Figure 2.13: RCPT results of 15 percent replacement of SBR Latex with concrete

Using SBR latex with mortar will increase the chloride ion penetration resistance and leads to more developed microstructure of modified cement mortar. Mixing of SBR latex with mortar will change the microstructure of mortar in hardened form. A polymer membrane is created and it is more prominent when use more ratio of polymer in mortar. Using 10 percent of SBR latex in mortar was found to bind the sand particle (Yang, Shi, Creighton, & Marijean, 2009).

Lean concrete is having less cement and more aggregate and used in many construction works. Excellent mechanical properties of lean concrete are obtained using polymers such as SBR along with admixtures. Silica fumes can be used in concrete along with SBR to enhance its properties. Experimental results show that using 10 percent silica fumes and 10 percent SBR has excellent results of compressive strength, tensile4strength, and flexural strength. The increase in strength is because of the reaction of silica fumes and calcium hydroxide which release from cement hydration and create active gel which lessens the empty spaces in concrete and provides more strength (Alasadi, 2018).

The addition of scrap rubber as admixture to concretes or mortars considerably decreases the mechanical properties. By increase of rubber particles in concretes and mortars the mechanical strength decreases. By the addition of some other admixtures like silica fumes or by soaking rubber particles in sodium hydroxide the reduction of mechanical strength can be lessened. The addition of scrap rubber admixture to concretes or mortars have also other effects such as less density and workability and also increases concrete bleeding, setting time, abrasion resistance, shrinkage, freeze-thaw resistance and porosity (Corinaldesi & Donnini, 2018) .

Styrene-butadiene rubber can be used in Calcium aluminate cement mortar to modify its properties. SBR latex improves the workability of fresh mortar, but due to polymer coagulation process permeability, stiffnessand compressive strength decreases whereas flexural strength and adhesion strength to old concrete substrate increase with amount of added latex as shown in Figure. 2.14 and Figure2.15. The least compressive strength values are attained; because of transformation process in Calcium aluminate cement based materials those consequences in the increase of porosity (Ukrainczyk & Rogina, 2013).

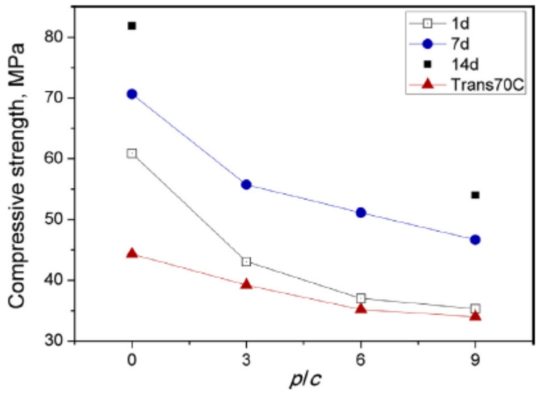

Figure 2.14: Effect of SBR percentage and curing on compressive strengthof mortar samples

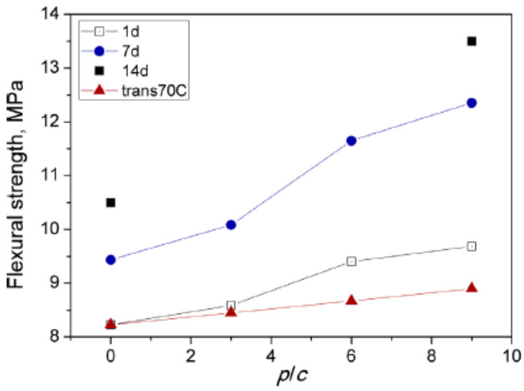

Figure 2.15: Effect of SBR percentage and curing on flexuralstrength of mortar samples

Ferrocement is a composite material that made up of cement mortar and layers of reinforcing mesh and is widely used in construction industry. Ferro cement has long life depending upon mortar composition, permeability and curing conditions etc. Different properties of modified ferrocements using styrene butadiene rubber (SBR), polyacrylic ester (PAE) and vinyl acetate ethylene (VAE) are evaluated. The compressive strength of polymer modified ferrocements also decreases because of continuous air exposure. The results indicated that the compressive strength of polymer modified ferrocements decreases. The reduction of compressive strength of is because of presence of voids around the aggregates, reducing the magnitude of applied compressive force at failure. Whereas the flexural strength of ferrocement increases using SBR because of presence of polymer membrane around and between cement particles linking and connecting these particles (Ramli & Tabassi, 2012).

In another research it is identified that mechanical properties of styrene butadiene rubber (SBR) latex modified cement pastes, using different percentages of SBR/binder ratio. Durability of SBR modified mortar is more than that of cement mortar because of flexible butadiene chains. SBR latex has brought down the strength compare withcement mortar. Different experiments evaluate that higher porosity is caused by the increase of polymer content, which will ultimately cause the reduction of compressive strength. The SBR latex large affects the compressive strength and a fairly low effect on the flexural strength (Wang & Lackner, 2011).

G. Barluengaa and F. Herna´ndez-Olivares has reviewed the effect of W/C ratio, and content of polymer on setting time, physical and mechanical properties of SBR modified mortar. The results showed that w/c ratio and quantity of SBR will affect the consistency of mortar. In fresh condition with increase of SBR latex the setting time will decrease. In hard form the density will decrease with increase of SBR quantity.

Using SBR in Latex form will increase its consistency because of ball bearing effect of SBR particles, entrained air and scatter effect of surfactants. Polymer content will affect the Mechanical properties of polymer modified mortar. There is visible improvement in flexural strength but no increase in compressive strength is observed as compare to conventional mortar shown in Figure 2.16 and Figure 2.17. Rather there is decrease of compressive strength with increase of SBR content for a fix WC ratio (Barluenga & Herna´ndez-Olivares, 2004)

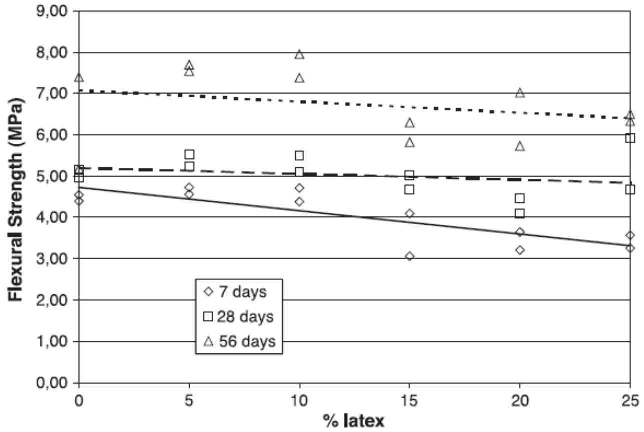

Figure 2.16: Flexural strength oflatex modified mortar

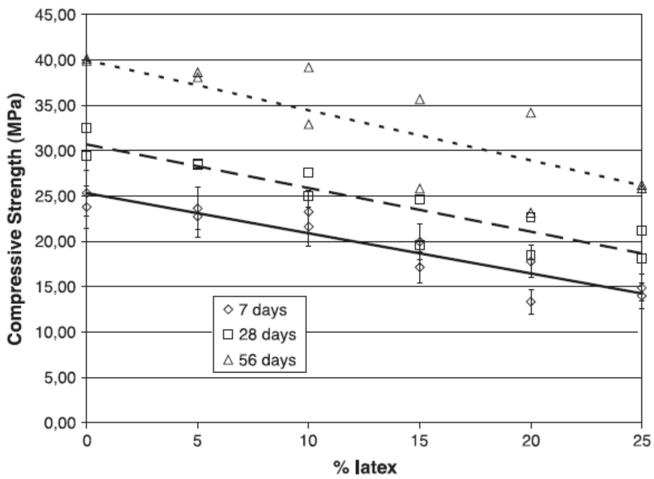

Figure 2.17: Compressive strengthof latex modified mortar

Benali Y and Ghomari F (2018) studied the effects of two latex types SBR latex and styrene-acrylic on mortar properties. And found that with the increase of latex content (BR and SA) the flexural strength will increase but no improvement in compressive strength. Polymers have negative effects on compressive strength because in the microstructure of mix two types of bonds are present, cement to cement bond and cement to polymer bond. Cement to cement bonds are stronger than cement to polymer bonds. With a higher content of polymer used, a polymer membrane cover up the hydrated cement and aggregate and many polymers to cement bonds are formed. This will cause a decrease in compressive strength. As compare to conventional mortar there is a clear decrease in the water absorption capacity of modified mortar. Bond strength of mortar to bricks and concrete will also increase using these polymers (Y & Ghomari, 2018).

The effect of addition of polymers (SBR) is studied with special attention to the microstructure and mechanical properties of polymer modified concrete. Setting time of cement and porosity of hardened materials will increase by addition of polymers in mortars. The mechanical properties of composite mortars will decrease with addition of polymer due to increase of porosity. The porosity of polymer modified mortars is greater than that of pure hydraulic mortars. These observations confirm the effect of air entrainment in composite mortars due to presence of polymers. With increase of polymer cement ratio the porosity will also increase whatever the polymer used. The higher porosity is due to air entraining effect of polymers (Marceau, Lespinasse, & Bellanger, 2012).

Reused glass powder (RGP) can be used with supplementary cementitious materials (SCMs), for example, fly ash and silica fumes as fractional substitutions of cement in mortar or concrete. Styrene butadiene rubber (SBR) can also be added in mortar mix with the end goal to enhance the physical and mechanical properties of hardened mortar. The bond between the SBR and cement matrix is significantly improved by the addition of fine (recycled glass powder)RGP, fly ash and silica fume, which ultimately leads to the increase in the compressive and flexural strengths. Alkali silica reaction expansions, water absorption, and permeability is also reduced by using of fine recycled glass powder, fly ash and silica fume. Recycled glass powder can be effectively used as a compelling mineral admixture in cement mortar with about 25% placement of cement (Parghi & Alam, 2016).

In another study compressive strength of concrete is studied along with styrene butadiene rubber (SBR) and silica fume. For this total thirty-two mixes were prepared using different water to binder ratio, different percentages of SBR and different amounts of silica fume as well. The results demonstrated that the compressive strength slightly rises with five percentage of SBR, but its compressive strength decreases with further increases the polymer ratio. For this purpose a numerical model was purposed in the study to evaluate the quantities of silica fume and styrene-butadiene rubber

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2.5. NANO PARTICLES IN CONSTRUCTION

Particles having one dimension 1 to 150 nm (10^{-9}m) are termed as nano particles. Properties of nanoparticles are totally changed for small scale (10^{-6}m) and larger scale (10^{-3}m). At present, the utilization of nano materials in the construction industry is decreased, primarily for the accompanying reasons: the absence of learning concerning the appropriate nano materials for use and their conduct; the absence of explicit principles for execution of the construction components utilizing nano materials and the absence of information in regards to the nanoparticles quantity. Since the particle size is a basic factor, at nano scales the properties of material critically vary as compared to larger scales. The utilization of nano materials in the construction industry is reasonable in four notable ways of improvement; structural monitoring, thermal insulation, coating, and painting. Numerous nano particles can be utilized in concrete to modify its properties i.e. carbon nanotubes, nano titanium particles, zirconium oxide nano particles, and nano alumina etc.

2.6. USE OF NANO PARTICLES IN MORTARS AND CONCRETES

The nano-titanium particles are added to cement to enhance its properties. The white colored particle can be utilized as a superb reflective covering, and on the other hand added to paints, concretes. By photocatalytic reactions, the titanium dioxide separates the organic pollutant and bacterial films when used in outdoor and lessens the air pollutants.

It gives the self cleaning properties to surface to which it is applied in concrete and maintains its white color.

Silicon Dioxide Nanoparticles (SiO_2) can be used in concrete with fly ash to enhance its compressive strength at early ages by filling the voids. It also lessens the setting time, segregation and bleeding of concrete. Aluminum dioxide nano particles can be utilized in concrete to enhance its tensile and flexural properties of concrete (OLAR, 2011).

These days, the use of nano materials has gotten various considerations to improve the concrete properties. Ultimately, the use of nano materials in concrete and mortars is to enhance its properties i.e. durability and strength. Nano material is characterized as material having size under 200 nm. The utilization of nano materials must be at least 500 nm in size for use in concrete. Using very fine nano particle will cause to lessen the cement quantity by replacement and will increase the bonding. It also act as a filler and assist to lessen the small pores, ultimately making it denser concretes and mortars and lessen pores which results in high strength. So nano particles can be used in mortars and concretes to increase its properties.

Nano-silica is formed from micro based silica and has been used in ultra-high-performance concrete for use of improvement of durability and strength. Using nano-silica in concrete will help to gain early strength, it will also increase the workability using with a super plasticizer. Further because of the very fine size it acts as filler in concrete and will fill the micro voids and will improve the microstructure of concrete and the improved strength of concrete is achieved.

Nano-silica and nano-alumina are two basic materials involved in cement hydration. In cement the silica will improve the strength and alumina will control the setting time. Titanium oxide is also used in UHPC and has self-cleaning effect in concrete; also it enhances the strength at an early age. For improvement in performance, titanium oxide makes a fiber reinforcement system that refines the hydration gel and helps to strength development and making it more durable (Norhasri & Hamidah, 2017).

In another research, the impact of nano-silica was used in concrete along with binder as cement and fly ash. Enhancement was seen in mechanical properties, refinement of pore structure, porosity and rapid chloride ion permeability. Nano-silica has a pozzolanic and filler effect to microstructure and also the content of nano-silica used is very important.

Trial results demonstrated that the properties of concrete are commonly improved by including nano-silica. At first, it was trusted that the enhancement in concrete properties is due to the filler effect and pozzolonic activity of nanoparticles. As of late, it has been accounted for that the small size of nano-silica gives a bigger surface area, which accelerates the rate of cement hydrationand pozzolanic (Said & Zeidan, 2012).

Nano titanium dioxide was used with concrete and the mechanical and electrical properties were studied. The results indicated that nano-titanium can improve the compressive strength of concrete having cement by increasing the degree of cement hydration and decreasing the porosity of the mixes. It is also suggested that the flexural and compressive strengths at 28 days was increased. And also improves the electrically conductivity property (Li, Han, & Yu, 2017).

The impact of using nano-titanium mortars and concretes was studied through experiments .By adding little content of nano-titanium powder the hydration process at early hydration stage was altogether upgraded. Nano-titanium was affirmed to be a non-reactive filler and had no pozzolanic action. The all out porosity of nano-titanium mixes was reduced and the decrease of pore volume essentially happened basically inside the pores. The smaller the nano TiO_2particles brought about higher water demand and less setting time and the compressive strength of the mortars was improved, for all intents and purposes at early ages (Chen & Kou, 2012).

Mahmoud Niliand Ahmad Ehsani in a research examined the microstructure of mortars and concrete samples using nano-silica and silica fumes and its effect on ITZ. Different percentages of nano-silica were used and 3 percent to 5 percent showed the excellent results for early age compressive strength for both mixes. A microstructure was examined to study the reasons for strength enhancement by XRD and SEM analysis. The microstructure investigation uncovered that alteration of the ITZ was accountable for this strength development (Nili & Ehsani, 2015).

ZhidanRong and Wei Sun (2014) in a research explore the impacts of nano-silica particleson the mechanical properties, hydration process and microstructure developme nt of concretes composites by various techniques. The outcomes demonstrated that the

compressive and flexural strength enhances with the use of the nano-silica quantity about 3% and mechanical properties reduces using more than 3 percent of nano-silica. The hydration procedure was quickened by using of nano-silica. The porosity and the pore size reduced using more nano-silica. The microstructure was progressively homogenous and thick for nano-silica samples when contrasted with the control sample. These enhancements could be mostly credited to the pozzolanic and filler impacts of nano-silica. It was likewise presumed that using nano silica can proficiently enhance the bond between the paste and aggregate. Using more than 5 percent of nano-silica had adverse effect on microstructure (Rong, Sun, & Xiao, 2015).

Ali Nazari andShadiRiahi investigated the compressive strength and workability of concrete with nano-alumina particles. The experimental results demonstrated that using up to 2 percent of nano-alumina will increase its strength and also the reduction of workability was observed with increase of nano-alumina particles (Nazari, 2010).

2.7. EFFECT OF ZINC STEARATE ON MORTATRS AND CONCRETES

Marcos Lanzón and Encarnación Martínez discussed the effects of zinc stearate in cementitious materials using 0.25 to 2 percent by weight. Durability and permeability were examined by different test methods and concluded that using zinc stearate has a slight effect on physical properties. It is very helpful for using fewer amounts i.e. 0.25 percent will have a positive effect on durability, water absorption, and acid rain attacks (Lanzón, Martínez, Mestre, & Madrid, 2017).

Abdal-Kareem M.A.Dawagreh has done a study on mechanical and flexural properties of concrete using polymer. EVA and hydroxyethyl cellulose were used in his research to study the mechanical properties of concrete. In addition to this zinc sulfate was also used at varying ratios by weight and it will help as a water reducer. He concluded that using these polymers in concrete samples will decrease its water absorption and enhance other properties like mechanical properties (flexural and compression) and the flow of concrete (ABDAL-KAREEM & DAWAGREH, 2018).

Chapter 3

METHODOLOGY AND RESEARCH PROCEDURE

3.1. INTRODUCTION

This chapter covers the detail of all procedures of experimental work. Mortar cubes of 50mm x50mmx50mm were prepared using 1%, 2%, 3%,4 % 5%, 6%,7%, 8%, 9%, 10% of SBR Latex and 1%, 2%, 3%,4 % 5%, 6%,7%, 8%, 9%, 10% SBR powder form then including nano-materials and zinc stearate at different percentages were added in these samples. The purpose of this study is to examine the effect of Styrene-butadiene rubber polymer in latex and powder form on compressive strength of mortar cubes and then with nano-materials and its effect on compressive strength. A total of 43 batches of mortar were prepared and each batch contains 5 cubes.

Concerning the (W/C) ratio, two different ways to prepare a latex-modified mortar were found in the related writing.

i. The first is to keep up the (W/C) ratio consistent to have a hydration level close to cement paste (usually a laboratory method).
ii. The second one is to keep constant the workability of the modified sample to that of the control sample, typically by changing the (W/C) ratio.

The first method is used in the present study that is usually used for the laboratory.

3.2. MATERIALS USED IN RESEARCH

Following materials are used in research.

- Ordinary Portland cement
- Sand
- Water

- Polymers
  - Styrene butadiene rubber (SBR) latex

- Styrene butadiene rubber (SBR) powder

- Nano Materials
  - Nano Silicon dioxide particles (SiO_2)
  - Nano Titanium dioxide particles (TiO_2)
- Zinc Stearate

- **Ordinary Portland cement**

OPC 43 Grade cement manufactured by pioneer cement factory was used as a binder in this research shown in Figure 3.1. Chemical analysis of cement is shown in Table 3.1.

Table 3.1: Chemical Analysis of Cement

Test	Results
%SiO_2	19.67
%Al_2O_3	4.90
%Fe_2O_3	3.46
%CaO	63.11
%MgO	1.85
%K_2O	0.96
%Na_2O	0.16
% SO_3	2.71
% Cl	0.012
LSFc	96.99
SIM	2.35
ALM	1.42
Blain, cm^2/gm	3078
Residue on 90 micron	2.66

Figure 3.1: Ordinary Portland cement

- **Sand**

Sieved Sand having fineness modulus 3.2 was used for experimentation work as shown in Figure 3.2.

Figure 3.2: Sand used in experimentation

- **Water**

Water used in research was drinking water and source is water supply in Laboratory shown in Figure 3.3.

Figure 3.3: Water used in research work

- **Polymers**

    - **Styrene butadiene rubber (SBR) latex**

Locally available material LIPATON SB 5843 was used as which is copolymer of Styrene butadiene rubber latex from Fast chemicals is used as a partial replacement to cement binder having 48.5% solid content.

Figure 3.4: Styrene butadiene rubber (SBR) latex

    - **Styrene butadiene rubber (SBR) powder**

Axilat ™ PSB 150 is a styrene butadiene rubber copolymer powder resin that is redispersible in water. Axilat PSB 150 redisperses to a particle size that is one-tenth of conventional latex powders, resulting in a very high binder power and enhanced adhesion for enduse formulations. SBR powder is shown in Figure 3.5.

Figure 3.5: Styrene butadiene rubber (SBR) powder

- **Zinc Stearate**

Zinc stearate is a polymer available in market white color powdered form and used as partial replacement of cement at different percentages shown in Figure 3.6.

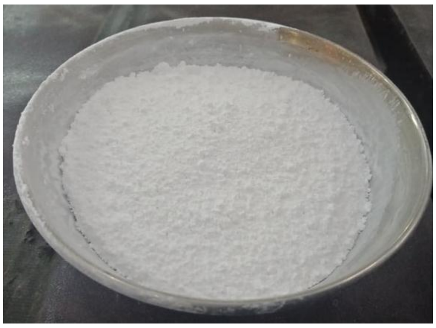

Figure 3.6: Zinc Stearate used in research work

- **Nano materials**

Nano Silicon dioxide particles (SiO_2) and Nano Titanium dioxide particles (TiO_2) having particles sizes 20-50 nanometers and 70-100 nanometers respectively were used in this research work shown in Figure 3.7 and Figure 3.8.

Figure 3.7: Nano-silica particles

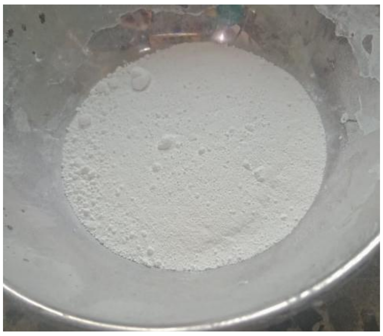

Figure 3.8: Nano- titanium particles

3.3. PREPARATION OF MORTAR SAMPLES

The SBR modified mortar cubes using nano materials were prepared with partial replacement of cement at different weight ratios. The replacement ratios were calculated using the total solid content in the latex. Then the samples were de-molded and placed in water for 3 days water curing then 4 days submerge curing is done. After 28 days compressive strength was determined. Five cubes of 50 mm x 50 mm x 50 mm were casted for each sample and then average of 3 cubes was taken to determine the compressive strength. Polymer modified cubes were made following ASTM C1439 – 13. Cubes were made using cement: sand ratio of 1:2.75 with W/C ratio 4.85 following ASTMC109/C109M – 16a.

Mortar cubes were prepared at four phases:

i. SBR Latex modified mortar cubes
ii. SBR Powder modified mortar cubes
iii. Mortar cubes modified with SBR powder and nano materials and zinc stearate
iv. Mortar cubes modified with SBR latex and nano materials and zinc stearate

3.3.1. Mix Proportion for Control and Modified Samples

i. SBR Latex modified mortar cubes

The SBR Latex modified mortar cubes were prepared with partial replacement of cement at different weight ratios, i.e. 0%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9% and 10%. The replacement ratios were calculated using the total solid content in the latex. Five samples for each percentage were prepared. Quantities are given in table 3.2.

Table 3.2 : Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm with SBR Latex

Sample Name	percentage of polymer	Solid content of SBR latex (g)	SBR latex (g)	Cement (g)	Sand (g)	Water (ml)
L0	0%	0	0	400	1100	194
L1	1%	4	8.33	396	1100	189.67
L2	2%	8	16.67	392	1100	185.33
L3	3%	12	25	388	1100	181.00
L4	4%	16	33.33	384	1100	176.67
L5	5%	20	41.67	380	1100	172.33
L6	6%	24	50	376	1100	168.00
L7	7%	28	58.33	372	1100	163.67
L8	8%	32	66.67	368	1100	159.33
L9	9%	36	75	364	1100	155.00
L10	10%	40	83.33	360	1100	150.67

ii. SBR powder modified mortar cubes

The SBR powder modified mortar cubes were prepared with partial replacement of cement at different weight ratios, i.e. 0%, 1%, 2%, 3%, 4% 5%, 6%, 7%, 8%, 9%, 10%. 5 samples for each percentage were prepared. Quantities are given in Table 3.3.

Table 3.3: Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm with SBR powder

Sample Name	polymer percentage	SBR Powder(g)	Cement (g)	Sand (g)	Water (ml)
S0	0%	0	400	1100	194
S1	1%	4	396	1100	194
S2	2%	8	392	1100	194
S3	3%	12	388	1100	194
S4	4%	16	384	1100	194
S5	5%	20	380	1100	194
S6	6%	24	376	1100	194
S7	7%	28	372	1100	194
S8	8%	32	368	1100	194
S9	9%	36	364	1100	194
S10	10%	40	360	1100	194

iii. Mortar cubes modified with SBR powder and Nano materials and Zinc Stearate

In the third phase, SBR powder modified mortar cubes were prepared using nano-silica, nano-titanium and zinc stearate. Quantities are given in table 3.4.

a. Using 2% of nanoSiO_2 with selected percentage of SBR Powder modified mortar cubes 0%, 3%, 5%, 7% ,10% were prepared. Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm nano-silica with SBR powder are given in Table 3.4 below.
b. Using 2% of nano-titanium with selected percentage of SBR Powder modified mortar cubes 0%, 3%, 5%, 7% ,10% were prepared. Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm nano-titanium with SBR powder are given in Table 3.5 below.
c. Using 0.5% of zinc stereate with selected percentage of SBR powder modified mortar cubes 0%, 3%, 5%, 7% ,10% were prepared. Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm zinc stearate with SBR powder are given in Table 3.6 below.

Table 3.4: Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm nano silica with SBR powder

Sample Name	SBR Powder percentage	Nano SiO_2 (percentage)	SBR Powder(g)	Nano SiO_2 (g)	Cement (g)	Sand (g)	Water (ml)
S0	0%	0%	0	0	400	1100	194
M0	0%	2%	0	8	392	1100	194
M3	3%	2%	12	8	380	1100	194
M5	5%	2%	20	8	372	1100	194
M7	7%	2%	28	8	364	1100	194
M10	10%	2%	40	8	352	1100	194

Table 3.5: Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm nanoTitanium with SBR powder

Sample Name	SBR Powder percentage	Nano TiO_2 (percentage)	SBR Powder(g)	Nano TiO_2 (g)	Cement (g)	Sand (g)	Water (ml)
S0	0%	0%	0	0	400	1100	194
T0	0%	2%	0	8	392	1100	194
T3	3%	2%	12	8	380	1100	194
T5	5%	2%	20	8	372	1100	194
T7	7%	2%	28	8	364	1100	194
T10	10%	2%	40	8	352	1100	194

Table 3.6:Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm Zinc Stearate with SBR powder

Sample Name	SBR Powder percentage	Zinc Stearate percentage	SBR Powder(g)	Zinc Stearate (g)	Cement (g)	Sand (g)	Water (ml)
S0	0%	0%	0	0	400	1100	194
Z0	0%	0.5%	0	2	398	1100	194
Z3	3%	0.5%	12	2	386	1100	194
Z5	5%	0.5%	20	2	378	1100	194
Z7	7%	0.5%	28	2	370	1100	194
Z10	10%	0.5%	40	2	358	1100	194

i. Mortar cubes modified with SBR Latex and Nano materials and Zinc Stearate

In the fourth phase, SBR latex modified mortar cubes were prepared using nano-silica and zinc stearate.

a. Using 2% of nano-silica with selected percentage of SBR powder modified mortar cubes 0%, 3%, 5%, 7% and 10% were prepared. Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm nano-silica with SBR powder are given in Table 3.7 below.
b. Using 0.5% of zinc stereate with selected percentage of SBR powder modified mortar cubes 0%, 3%, 5%, 7% and 10% were prepared. Quantities of materials for

5 cubes of 50 mm x 50 mm x 50 mm zinc stearate with SBR powder are given in Table 3.8 below.

Table 3.7: Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm nano silica with SBR powder

Sample Name	SBR Latexpercentage	Nano SiO2 (%)	Solid content of SBR Latex (g)	SBR Latex (g)	Nano SiO2 (g)	Cement (g)	Sand (g)	Water (ml)
L0	0%	0%	0	0	0	400	1100	194
LS0	0%	2%	0	0	8	392	1100	194
LS5	5%	2%	20	41.7	8	372	1100	172.4
LS10	10%	2%	40	83.3	8	352	1100	150.7

Table 3.8: Quantities of materials for 5 cubes of 50 mm x 50 mm x 50 mm Zinc Stearate with SBR powder

Sample Name	SBR Latex percentage	Zinc stearate (%)	Solid content of SBR Latex (g)	SBR Latex (g)	Zinc stearate (g)	Cement (g)	Sand (g)	Water (ml)
L0	0%	0	0	0	0	400	1100	194
ZS0	0%	0.5%	0	0	2	398	1100	194
ZS5	5%	0.5%	20	41.7	2	378	1100	172.4
ZS10	10%	0.5%	40	83.3	2	358	1100	150.7

3.3.2. Mortar Mixing

Mixing has very important role in mortar mixing. Therefore, proper mixing plays an important role in production of uniform mix. There are two methods of mortar mixing:

- Hand mixing
- Machine mixing

Hand mixing is used in this research. Procedure for mixing mortar is followed by ASTM C305 – 14**.**

i. Mixing steps of SBR Latex modified mortar cubes

Following steps were followed for preparation of SBR latex modified mortar:

1. A weighed amount of cement was placed in a dry bowl.
2. SBR latex was added in the water and mixed for 1 minute.
3. Then this blend of latex and water was added in cement and mixed for 2 minutes.
4. Then the weighed amount of sand was added into the mixture and mixed continuously for further 4 minutes with help of trowel until the mixture becomes homogeneous.
5. After mixing unit weight was measured in the cylinder and flow table test was performed.
6. Other batches were performed using the same procedure, except the control mix in which the second step is skipped and only water is added in cement. Steps of the mortar mixing procedure are shown in Figure 3.9.

(a) Weighing of materials

(b) Addition of SBR latex in water

(c) Adding SBR Latex mixture into cement

(d) Making it homogenous mixture

(e) Sand added into the mixture

(f) Final mixture

(g) Mortar mix poured in molds

(h)Prepared samples of mortar cubes

Figure 3.8: Steps of mortar mixing procedure for SBR latex modified mortar mix

ii. Mixing steps of SBR powder modified mortar cubes

Following steps were followed for preparation of SBR powder modified mortar:

1. Dry mixing of SBR powder and cement was properly done in a bowl.
2. Calculated amount of water was added in to mixture of cement and SBR powder. And then mixed for 3 minutes with help of trowel shown in Figure 3.10.
3. Then the weighed amount of sand was added into the mixer and mixed continuously for further 4 minutes with help of trowel until the mixture becomes homogeneous.
4. After mixing unit weight was measured in cylinder and flow table test was performed.

(a) Weighing of materials (b) Dry mixing of SBR powder and cement

(c)Adding water to dry mix

(d) Adding sand in mix

(e) Prepared mix of SBR powder modified mortar mix in molds

(f) Prepared mix in molds

(g) Prepared samples of SBR powder modified mortar mix

Figure 3.9: Steps for mortar mixing of SBR Powder modified mortar cubes

iii. Mixing steps of Mortar cubes modified with SBR powder and nano materials and Zinc Stearate

1. Following steps were followed for preparation of mortar cubes modified with SBR powder and nano materials and zinc stearate**:**

2. For the first phase, dry mixing of SBR powder, nano-silica, and cement was done in a bowl for SBR powder modified mortar cubes with nano-silica particles.
3. For the second phase, dry mixing of SBR powder, nano-titanium, and cement was done in a bowl for SBR powder modified mortar cubes with nano titanium particles.
4. For the third phase, dry mixing of SBR powder, nano-titanium, and cement was done in a bowl for SBR powder modified mortar cubes with zinc stearate.
5. The calculated amount of water was added into the mixture of each of the above mixture (step1, step2, step3) separately. Then continuously mixed for 3 minutes with the help of a trowel.
6. The weighed amount of sand was added into the mixer and mixed continuously for further 4 minutes with help of trowel until the mixture becomes homogeneous.

7. After mixing unit weight was measured in the cylinder and flow table test was performed.
8. Other batches were performed using the same procedure. Except for the control mix in which SBR powder is not added. Steps of the mortar mixing procedure are shown in Figure 3.10.
9.

(a)Weighing of materials

(b) Dry mixing of cement, SBR powder and Nano-particles

(c)Adding water to dry mix

(d) Adding sand in mix

(e) Final homogenous mixture prepared

(f) Prepared mix in molds

(g) Prepared samples of SBR powder modified with nano-titanium and zinc stearate

(h) Prepared samples of SBR powder modified with nano-particles and zinc stearate

Figure 3.10: Steps for mortar mixing of SBR powder modified with nano particles and Zinc Stearate

iv. Mixing steps of Mortar cubes modified with SBR Latex and nano materials and Zinc Stearate

1. For first phase, dry mixing of nano-silica and cement was done in a bowl for SBR latex modified mortar cubes with nano-silica particles.
2. For second phase, dry mixing of zinc stearate and cement was done in a bowl for SBR latex modified mortar cubes with zinc stearate.
3. SBR latex was added in the water and mixed for 1 minute.
4. Then this blend of latex and water was added in dry mix (step 1 and step 2 separately) and mixed for 2 minutes.
5. Then the weighed amount of sand was added into the mixture and mixed continuously for further 4 minutes with help of trowel until the mixture becomes homogeneous.
6. After mixing unit weight was measured in cylinder and flow table test was performed.

7. Other batches were performed using same procedure, except the control mix in which SBR latex was not added. Steps of mortar mixing procedure are shown in Figure 3.11.

(a)Weighing of materials

(b) Dry mixing of cement and nano materials

(c) Adding water to SBR Latex

(d) Mixing of cement and SBR mixture

(e) Adding sand to mix

(f) Final homogenous mixture prepared

(g) Prepared mix in molds

(h) Prepared samples of SBR latex modified with nano particles and Zinc Stearate

Figure 3.11: Steps for mortar mixing of SBR Latex with nano particles and Zinc Stearate

3.3.3. Casting of Specimens

A thin layer of oil was applied on all inner sides of molds. Molds were filled in two layers and consolidation was done by hand tamping. All Molds were filled about 1 inch (half depth of mold) with mortar and tamping was done for 32 times with uniform pressure. When tamping of one layer of all molds was completed then the remaining part of the mold was filled with mortar and 32 times tamped. After filling mold extra amount of mortar was removed with the flat surface of the trowel as shown in Figure 3.12. These mortar cubes were de-molded from molds after 24 hours. The whole procedure is followed by ASTM C109/C109M − 16a.

Figure 3.12: Prepared mortar mix filled in molds

3.3.4. Curing of Specimens

After de-molding, samples were curing was done as shown in Figure 3.6. 4 days submerged curing followed by 3 days wet curing was done for all mortar samples. Prepared samples for testing are shown in Figure 3.13.and prepared samples are shown in Figure 3.14.

Figure 3.13: Wet curing and submerge curing of mortar cubes

Figure 3.14: Prepared mortar samples for testing

3.4. TESTS ON FRESH MORTAR

Following tests were performed on fresh mortar.

3.4.1. Flow Table Test

After mixing the mortar flow table test was performed following the ASTM C1437-15. For this flow table and flow mold, confirming to the C230/C230M are required. Also, tamper confirming to C109/C109M and trowel is required. For this test mold was placed at the center of the flow table, a layer of mortar about 25mm thickness was placed and tamped for 20 times and tamping pressure should be uniform. Similarly, the second layer of mortar was placed and tamped as specified for the first layer. Then the edge of mortar is straightened with a trowel and extra mortar is removed from the table top and cleaned. After this the mold was removed slightly from mortar, immediately the table was dropped for 25 times within 15 seconds. And the diameter is measured along four sides of the table; flow is taken as an average of two readings. Flow table test apparatus and the cone are shown in Figure 3.15.

The flow is the increase in resulting average base diameter of mortar and expressed as a percent of original base diameter and determined by following formula,

$$\textbf{Flow} = (\text{Dia}_{\text{Average base}} - \text{Dia}_{\text{Original base}} / \text{Dia}_{\text{Original base}}) * 100$$

Where,

$\text{Dia}_{\text{Average base}}$ =Average base diameter

$\text{Dia}_{\text{Original base}}$ =Original base diameter

Figure 3.15: Flow table test apparatus

3.4.2.Bulk Density of Fresh Mortar

The bulk density of mortar was determined by calculated the mass of mortar in cylinder of known volume. The cylinder is filled with fresh mortar and weighed on weighing machine. The weight of mortar and cylinder is subtracted from weight of empty cylinder. Then this mass is divided by volume of cylinder and density is obtained. Bulk density of fresh mortar is determined in accordance with BS EN 1015-6.

The bulk density is determined by using the formula;

Bulk density = $(m_2 - m_1) / V$

Where,

m_2= mass of cylinder plus mortar

m_1= mass of empty cylinder

V= volume of cylinder

3.5. TESTS PERFORMED ON HARDENED MORTAR

Following tests were performed on mortar cubes.

3.5.1. Water Absorption

Water absorption test was performed by measuring the dry weight of mortar cube, then immersing mortar specimens in water for 24 hours and after that absorbed water was measured by weighing as shown in Figure 3.16. Water absorption percentage was determined by following formula,

Percentage Water Absorption = [(W-D) / D] ×100

Here,

D = Dry weight of mortar

W = Wet weight of mortar sample after immersion in water

Figure 3.16: Dry and wet weight of mortar sample for water absorption test

3.5.2. Compressive Strength

The compressive strength of mortar cubes was determined by following C109/C109M − 16a. Three cubes of each sample were tested and then the average value was taken as an accurate value. If one value differs more or less than 10% then that value was discarded and the average of the remaining two was considered. The compressive strength test was performed using a universal testing machine (UTM) as shown in Figure 3.17.

Load is applied in range of 200 to 400 lb/s confirming ASTM C109/C109M-16a. Compressive strength can be defined as that point where the material fails under uniaxial compressive stress.

Compressive strength can be calculated by formula given below,

Compressive strength = Load / Area

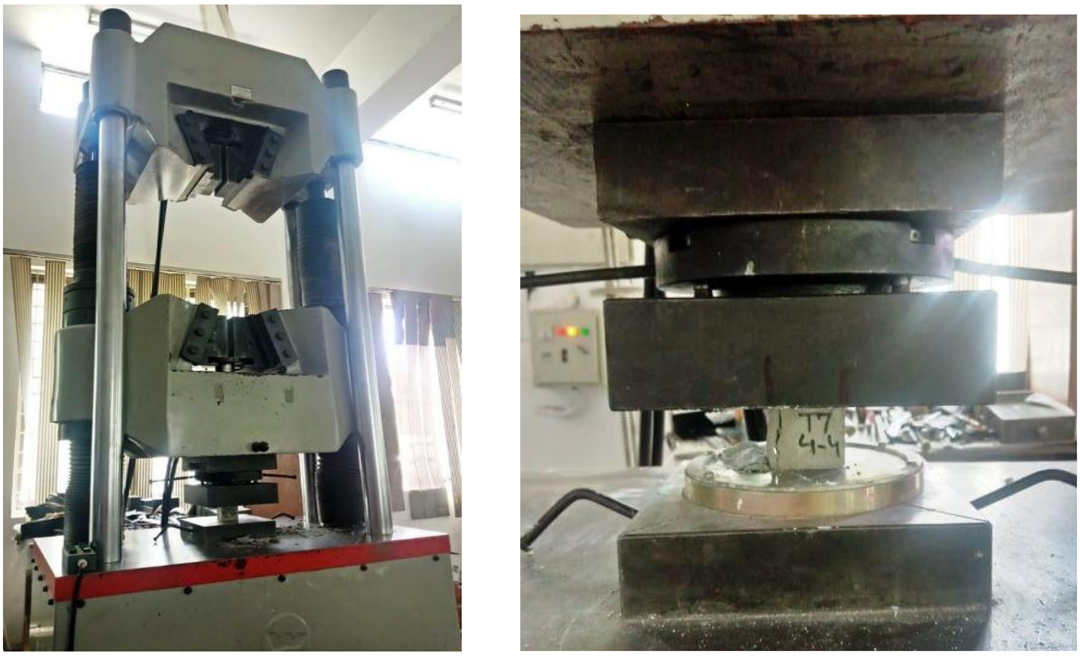

Figure 3.17: Universal Testing Machine for compressive strength test

Chapter 4

RESULTS AND DISCUSSIONS

This chapter describes all the results obtained from tests performed on mortar samples. The tests include flow table test and bulk density test on fresh mortar, and compression test and water absorption test on hardened mortar cubes.

4.1. TESTS ON FRESH MORTAR

4.1.1.Flow Table Test

To determine the workability of fresh mortar flow table test was performed. The flow is the increase in resulting average base diameter of mortar and expressed as a percent of original base diameter and determined by following formula,

Flow = $(Dia._{Average\ base} - Dia._{Original\ base} / Dia._{Original\ base}) * 100$

Where,

$Dia._{Average\ base}$=Average base diameter

$Dia._{Original\ base}$=Original base diameter

Results obtained are displayed below,

As Mortar cubes were prepared at four phases. Results of each phase are discussed below:

i. SBR Latex modified mortar cubes

The workability of mortar modified with SBR Latex is discussed below. From the table, it is clear that mortar having cement replacement with SBR Latex is more workable. The mix having a 10% replacement is more workable than all other mixes. The control mix having a 29% flow shows the least workability. As the content of SBR Latex increases the flow of mortar also increases shown in Table 4.1.

Table 4.1: Results of Flow percentage of SBR latex modified mortar cubes

Sample Name	Dia. 1 (cm)	Dia. 2 (cm)	Average Diameter(cm)	Original base diameter (cm)	Flow (Percentage)
L0	8.7	8.8	8.75	6.8	28.7
L1	9.5	9.7	9.60	6.8	41.2
L2	10.2	10	10.10	6.8	48.5
L3	11.3	11.6	11.45	6.8	68.4
L4	11.7	11.8	11.75	6.8	72.8
L5	11.8	12	11.90	6.8	75.0
L6	12.3	12.4	12.35	6.8	81.6
L7	12.9	12.7	12.80	6.8	88.2
L8	12.8	12.9	12.85	6.8	89.0
L9	13.4	13.2	13.30	6.8	95.6
L10	15.6	15.4	15.50	6.8	127.9

By increasing percentage of SBR Latex the flow percentage also increases. Increase in flow is shown in Figure 4.1.

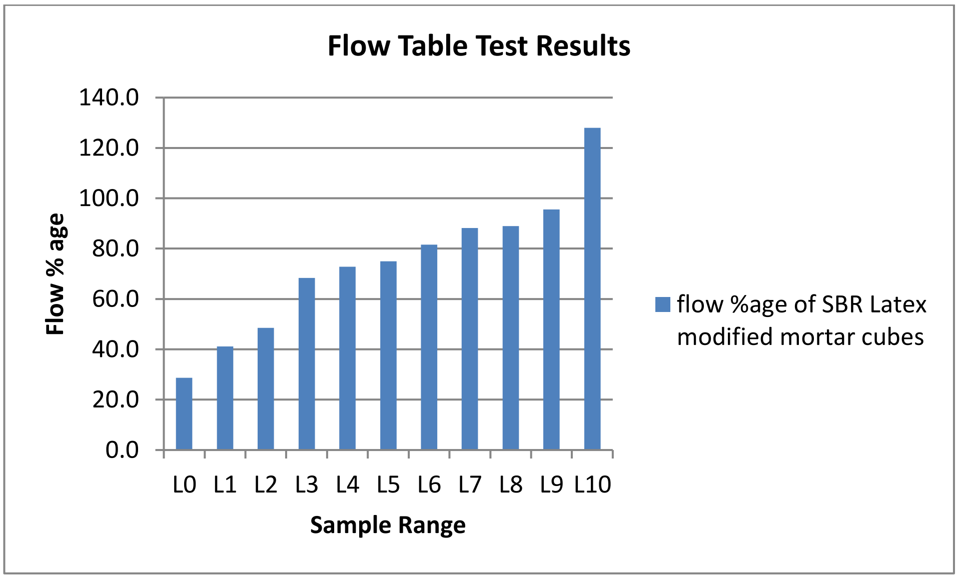

Figure 4.1: Graph of Flow percentage of SBR latex modified mortar cubes

ii. SBR powder modified mortar cubes

The workability of mortar modified with SBR Powder is discussed below. From the table, it is clear that mortar having cement replacement with SBR Powder is more workable. The mix having a 10% replacement is more workable than all other mixes. The control mix having a 29% flow shows the least workability. Results of SBR powder modified mortar samples are shown in Table 4.2.

Table 4.2: Results of SBR powder modified mortar samples

Sample Name	Dia. 1 (cm)	Dia. 2 (cm)	Average Diameter(cm)	Original base diameter (cm)	Flow (Percentage)
S0	8.7	8.9	8.80	6.8	29.4
S1	9.3	9.5	9.40	6.8	38.2
S2	10	10.1	10.05	6.8	47.8
S3	11.2	11.1	11.15	6.8	64.0
S4	11.8	11.7	11.75	6.8	72.8
S5	12	11.9	11.95	6.8	75.7
S6	12.2	12.4	12.30	6.8	80.9
S7	12.7	12.6	12.65	6.8	86.0
S8	13	12.7	12.85	6.8	89.0
S9	13.1	13	13.05	6.8	91.9
S10	13.2	13.3	13.25	6.8	94.9

As the content of SBR Powder increases the flow percentage of mortar also increases. Increase in slump is shown in Figure 4.2.

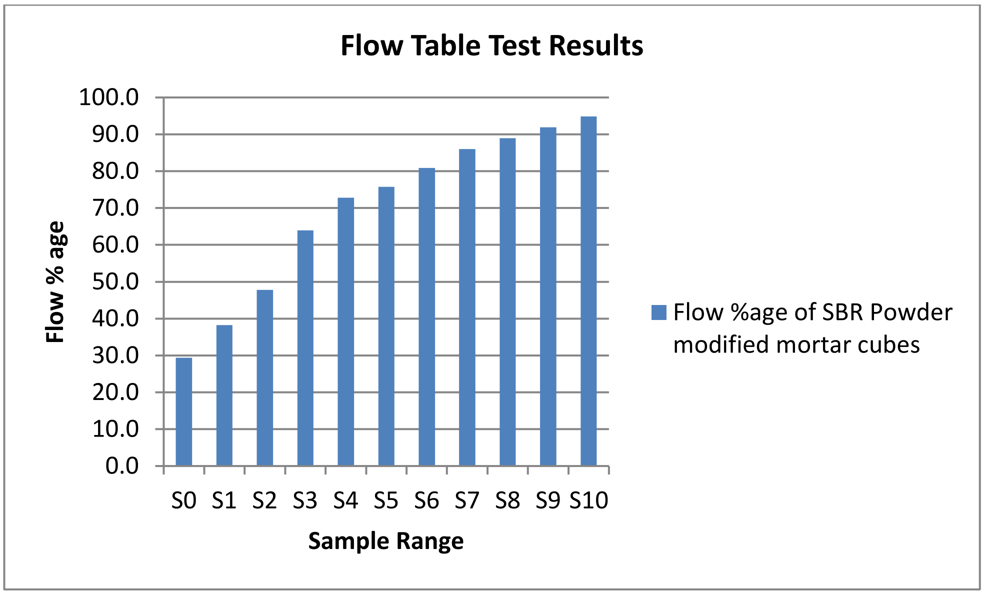

Figure 4.2: Graph of Flow percentage of SBR powder modified mortar cubes

iii. Mortar cubes modified with SBR powder and nano materials and Zinc Stearate

Workability of mortar modified with SBR Powder using nano-Silica, nano-titanium and zinc stearate is discussed below:

a. Mortar cubes modified with SBR powder and nano-silica

From the table, it is clear that mortar having cement replacement with SBR Powder is more workable. Since all mixes are having a 2% replacement with nano-silica and SBR Powder content increases for each mix. The mix having a 10% replacement with SBR and 2% replacement with nano-silica is more workable than all other mixes. The control mix having a 29% flow shows the least workability. The results are shown in Table 4.3.

Table 4.3: Results of flow percentage of mortar cubes with SBR Powder and nano-silica

Sample Name	Dia. 1 (cm)	Dia. 2 (cm)	Average Diameter(cm)	Original base diameter (cm)	Flow (Percentage)
S0	8.7	8.9	8.8	6.8	29.4
M0	9.1	8.9	9.00	6.8	32.4
M3	10.2	10.1	10.15	6.8	49.3
M5	11.3	11.6	11.45	6.8	68.4
M7	11.9	11.8	11.85	6.8	74.3
M10	11.9	12.1	12.00	6.8	76.5

By increasing percentage of SBR Latex with nano-silica the flow percentage also increases. Increase in workability is shown in Figure 4.3.

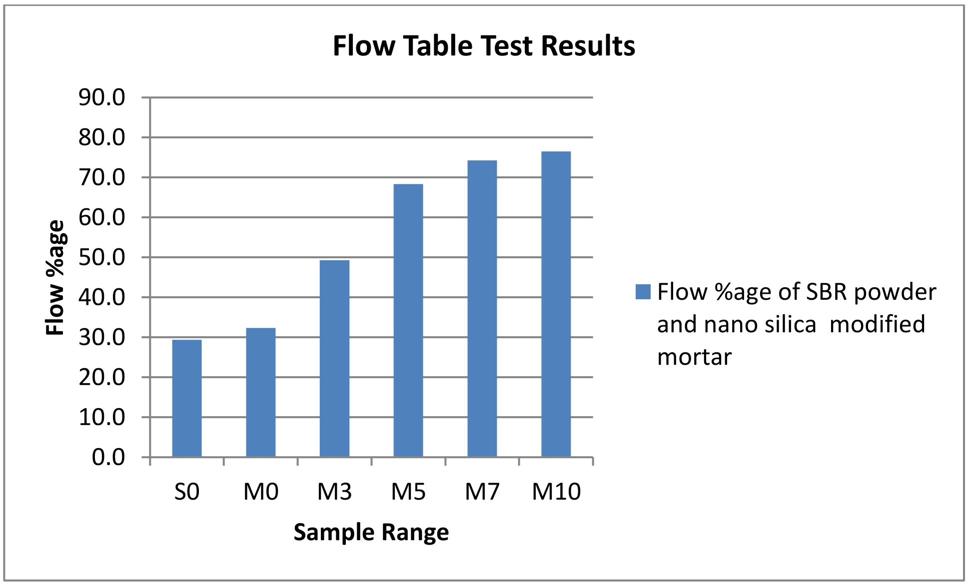

Figure 4.3: Graph of Flow percentage of mortar cubes with SBR Powder and nano silica

b. Mortar cubes modified with SBR powder and nano-titanium

From the table, it is clear that mortar having cement replacement with SBR Powder is more workable. Since all mixes are having a 2% replacement with nano-titanium and

SBR Powder content increases for each mix. The mix having a 10% replacement with SBR powder and a 2% replacement with nano-titanium is more workable than all other mixes. The control mix having a 29% flow shows the least workability. The results are shown in Table 4.4.

Table 4.4: Results of Flow percentage of mortar cubes with SBR powder and nano-titanium

Sample Name	Dia. 1 (cm)	Dia. 2 (cm)	Average Diameter(cm)	Original base diameter (cm)	Flow (percentage)
S0	8.7	8.9	8.8	6.8	29.4
T0	9	8.9	8.95	6.8	31.6
T3	10.5	10.6	10.55	6.8	55.1
T5	11.6	11.4	11.5	6.8	69.1
T7	11.9	11.7	11.8	6.8	73.5
T10	12	12.1	12.05	6.8	77.2

By increasing percentage of SBR Powder with nano-titanium the flow percentage also increases. Increase in slump is shown in Figure 4.4.

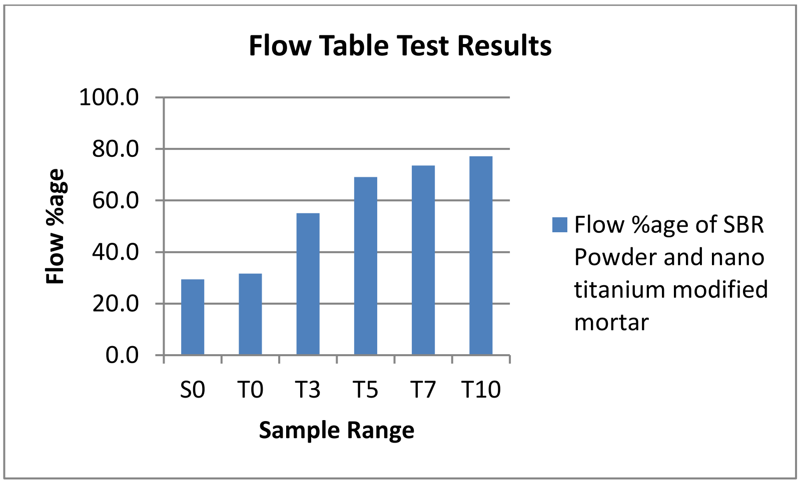

Figure 4.4: Graph of Flow percentage of mortar cubes with SBR Powder and nano-titanium

c. Mortar cubes modified with SBR powder and Zinc Stearate

From the table, it is clear that mortar having cement replacement with SBR Powder is more workable. Since all mixes are having a 0.5% replacement with zinc stearate and SBR Powder content increases for each mix. The mix having a 10% replacement with SBR and 0.5% replacement with zinc stearate is more workable than all other mixes. The control mix having a 29% flow shows the least workability. The results are shown in Table 4.5.

Table 4.5: Results of Flow percentage of mortar cubes with SBR powder and Zinc Stearate

Sample Name	Dia. 1 (cm)	Dia. 2 (cm)	Average Diameter(cm)	Original base diameter (cm)	Flow (percentage)
S0	8.7	8.9	8.8	6.8	29.4
Z0	8.9	8.9	8.9	6.8	30.9
Z3	9.5	9.3	9.4	6.8	38.2
Z5	10.8	10.9	10.85	6.8	59.6
Z7	11.6	11.8	11.7	6.8	72.1
Z10	12.2	12.3	12.25	6.8	80.1

By increasing percentage of SBR Powder with zinc stearate the flow percentage also increases. Increase in slump is shown in Figure 4.5.

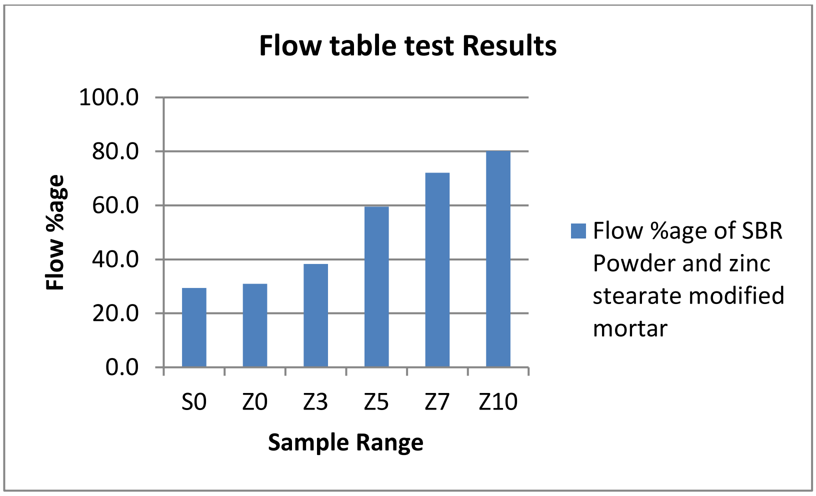

Figure 4.5: Graph of Flow percentage of mortar cubes with SBR Powder and zinc stearate

iv. Mortar cubes modified with SBR Latex and nano materials and Zinc Stearate

Workability of mortar modified with SBR Latex using nano materials is discussed below:

a. Mortar cubes modified with SBR Latex and nano-silica

From the table, it is clear that mortar having cement replacement with SBR Latex is more workable. Since all mixes are having a 2% replacement with nano-silica and SBR Latex content increases for each mix. By increasing the percentage of SBR Powder with nano-silica, the flow percentage also increases. Increase in flow is shown in Table 4.6.

Table 4.6: Results of Flow percentage of mortar cubes with SBR powder and nano-silica

Sample Name	Dia 1 (cm)	Dia 2 (cm)	Average Diameter(cm)	Original base Diameter (cm)	Flow (percentage)
L0	8.7	8.8	8.75	6.8	28.7
LS0	9.5	9.7	9.60	6.8	41.2
LS5	11.5	11.6	11.55	6.8	69.9
LS10	13.8	13.9	13.85	6.8	103.7

The increase in flow of mortar modified with SBR Latex and nano-silica is shown in Figure 4.6.

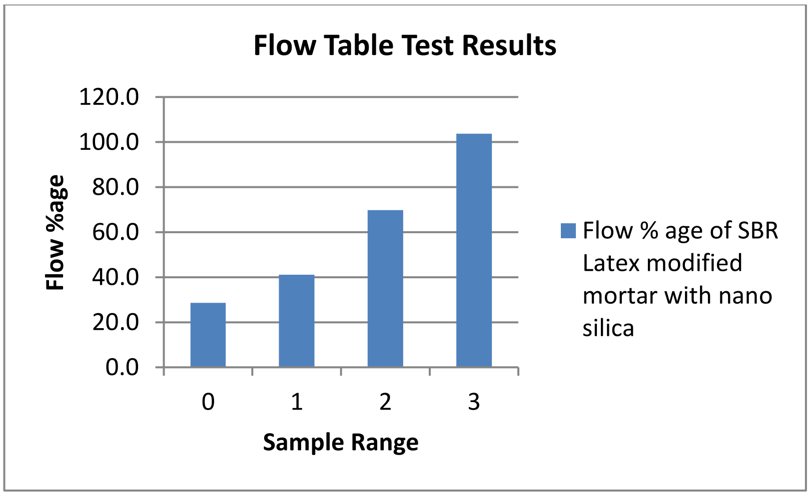

Figure 4.6: Graph of Flow percentage of mortar cubes with SBR powder and nano-silica

b. Mortar cubes modified with SBR Latex and Zinc Stearate

From the table, it is clear that mortar having cement replacement with SBR Latex is more workable. Since all mixes are having a 0.5% replacement with zinc stearate and SBR Latex content increases for each mix. By increasing the percentage of SBR Powder with nano-titanium the flow percentage also increases. The increase in workability is shown in Table 4.7.

Table 4.7: Results of Flow percentage of mortar cubes with SBR powder and zinc stearate

Sample Name	Dia 1 (cm)	Dia 2 (cm)	Average Diameter(cm)	Original base Diameter (cm)	Flow (percentage)
L0	8.7	8.8	8.75	6.8	28.7
ZS0	9.5	9.6	9.55	6.8	40.4
ZS5	11.6	11.7	11.65	6.8	71.3
ZS10	14.2	14.1	14.15	6.8	108.1

The increase in flow of mortar modified with SBR latex and zinc stearate is shown in Figure 4.7.

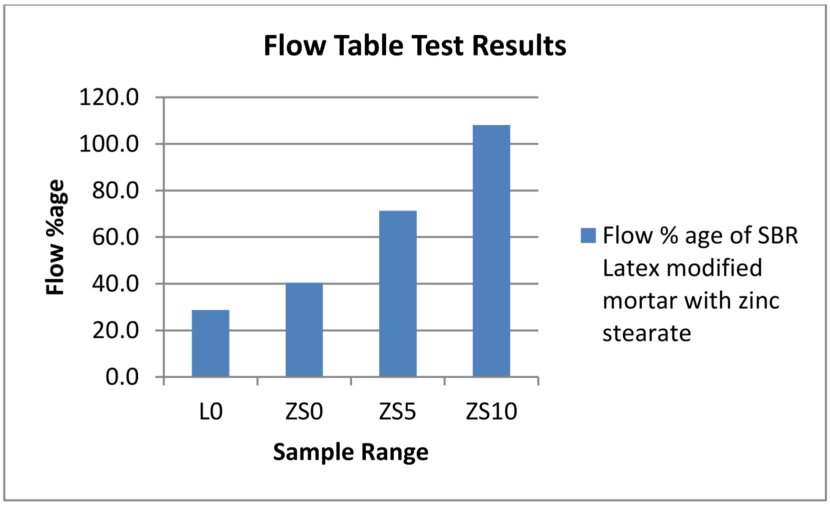

Figure 4.7: Graph of Flow percentage of mortar cubes with SBR powder and zinc stearate

4.1.2. Density

The Density of mortar was determined by calculating the mass of mortar in the cylinder of known volume. The cylinder is filled with fresh mortar and weighed on the weighing machine. The weight of the mortar and cylinder is subtracted from the weight of the empty cylinder. Then this mass is divided by volume of cylinder and density is obtained. Bulk density of fresh mortar is determined following BS EN 1015-6.

The bulk density is determined by using the formula;

Bulk density = $(m_2 - m_1) / V$

Where,

m_2= mass of cylinder plus mortar

m_1= mass of empty cylinder

V= volume of cylinder

i. SBR Latex modified mortar cubes

Unit weights of mortar mixes for each batch were calculated. For the control mix and partial replacement with SBR Latex were compared, the unit weight of SBR Latex modified mortar decreases with the increase of SBR Latex content i.e. 29% decrease in density for 10% replacement of SBR latex. This is due to entrapped air in mortar due to SBR latex. And also the density of fresh mortar also decreases and it is shown in Table 4.8.

Table 4.8: Results of Density of SBR Latex modified mortar cubes

Sample Name	Weight (g)	Volume of Cylinder (cm^3)	Density (g/cm^3)
L0	574	1174	0.489
L1	549	1174	0.468
L2	538	1174	0.458
L3	524	1174	0.446
L4	516	1174	0.440
L5	480	1174	0.409
L6	450	1174	0.383
L7	430	1174	0.366
L8	417	1174	0.355
L9	412	1174	0.351
L10	408	1174	0.348

The decrease in density of mortar modified with SBR Latex is shown in Figure 4.8. It shows that there is gradual decrease in density of mortar with addition of SBR Latex content.

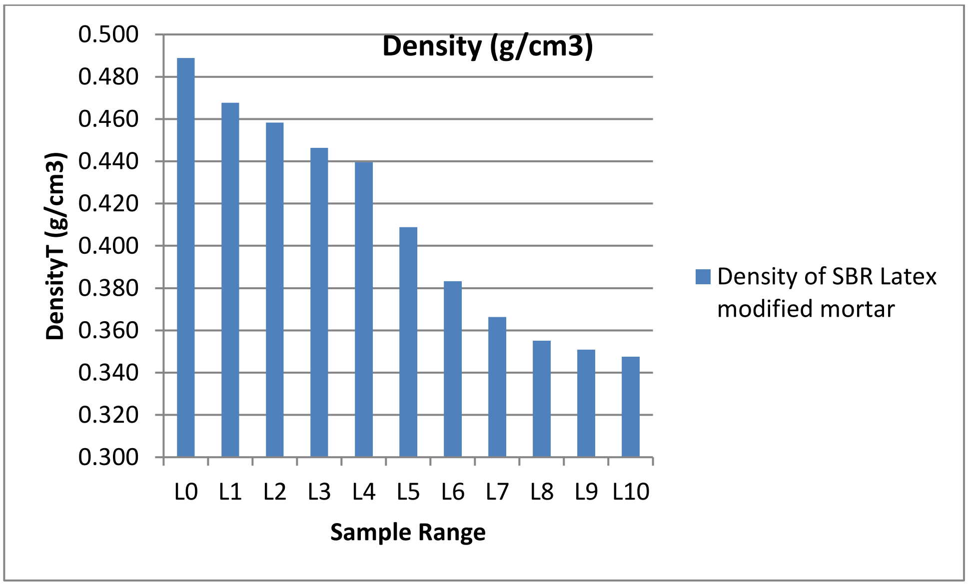

Figure 4.8: Graph of Density of SBR Latex modified mortar cubes

ii. SBR Powder modified mortar cubes

Unit weights of mortar mixes for each batch were calculated. For the control mix and partial replacement with SBR Powder were compared, the unit weight of SBR powder modified mortar decreases with an increase of SBR Latex content. The control mix is having 0.492 g/cm3 while for 10% replacement of SBR powder there is 13% decrease in density. The density of fresh mortar also decreases and it is shown in the table 4.9 below.

Table 4.9: Results of Density of SBR Powder modified mortar cubes

Sample Name	Weight (g)	Volume of Cylinder (cm3)	Density (g/cm3)
S0	578	1174	0.492
S1	568	1174	0.484
S2	560	1174	0.477
S3	555	1174	0.473
S4	551	1174	0.469
S5	545	1174	0.464
S6	538	1174	0.458
S7	531	1174	0.452
S8	525	1174	0.447
S9	520	1174	0.443
S10	505	1174	0.430

The decrease in density of mortar modified with SBR Powder is shown in Figure 4.9. The Graph shows that there is gradual decrease in density of mortar with addition of SBR Powder at different percentages.

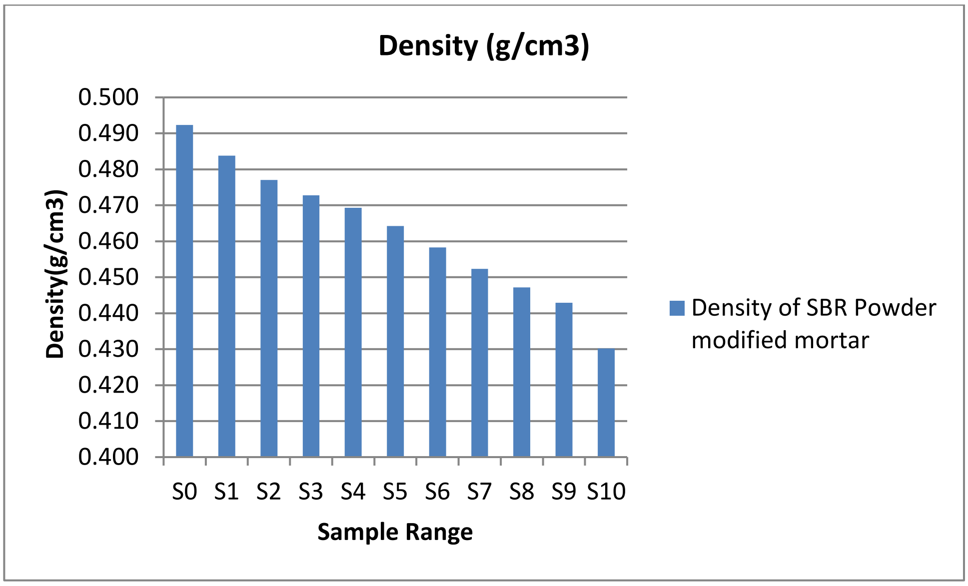

Figure 4.9: Graph of Density of SBR powder modified mortar cubes

iii. Mortar cubes modified with SBR powder and nano materials and Zinc Stearate

Density of mortar modified with SBR Powder using nano-silica, nano-titanium and zinc stearate is discussed below:

a. Mortar cubes modified with SBR powder and nano-silica

Since all mixes are having a 2% replacement with nano-silica and different percentages of SBR Powder. Unit weights of mortar mixes for each batch were calculated and results are shown in the table 4.10. The unit weight of SBR powder modified mortar with nano-silica decreases with the increase of SBR Powder content. The control mix with 0% SBR powder and 2% SiO2 is having 0.471 g/cm3 while mix with 10% replacement with SBR Powder and 2% replacement of nano-silica is having 12% decrease in density. By increasing the percentage of SBR Powder with nano Silica the density of fresh mortar decreases. The decrease in density is shown in Table 4.10.

Table 4.10: Results of Density of mortar cubes modified with SBR powder and nano-silica

Sample Name	Weight (g)	Volume of Cylinder (cm3)	Density (g/cm3)
M0	553	1174	0.471
M3	527	1174	0.449
M5	502	1174	0.428
M7	494	1174	0.421
M10	487	1174	0.415

The decrease in density of mortar modified with SBR Powder and nano-silica is shown in Figure 4.10. It shows that there is gradual decrease in density of mortar with addition of SBR Powder and nano-silica at different percentages.

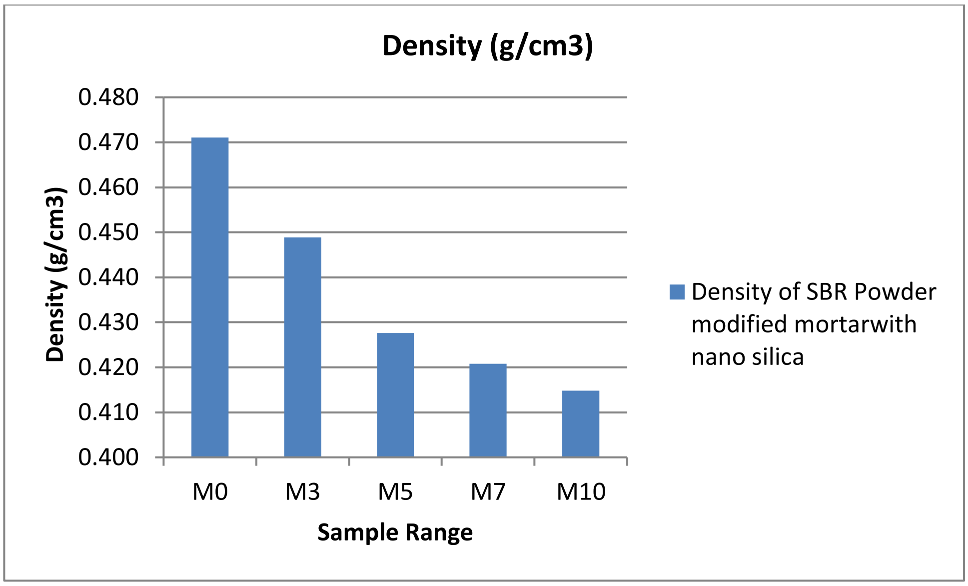

Figure 4.10: Graph of Density of mortar cubes modified with SBR powder and nano-silica

b. Mortar cubes modified with SBR powder and nano-titanium

Since all mixes are having 2% replacements with nano-titanium and different percentages of SBR Powder. The unit weight of SBR powder modified mortar with nano-titanium decreases with increase of SBR Powder content. The control mix with 0% SBR powder and 2% nano-titanium is having 0.475g/cm3 while mix with 10% replacement with SBR Powder and 2% replacement of nano-titanium has 9% decrease in bulk density. By increasing percentage of SBR Powder with nano-titanium the density of fresh mortar decreases. Decrease in density is shown in Table 4.11.

Table 4.11: Results of Density of mortar cubes with SBR powder and nano-titanium

Sample Name	Weight(g)	VolumeofCylinder (cm3)	Density (g/cm3)
T0	558	1174	0.475
T3	530	1174	0.451
T5	521	1174	0.444
T7	514	1174	0.438
T10	510	1174	0.434

The decrease in density of mortar modified with SBR Powder and nano-titanium is shown in Figure 4.11. It shows that there is gradual decrease in density of mortar with addition of SBR Powder and nano-titanium at different percentages.

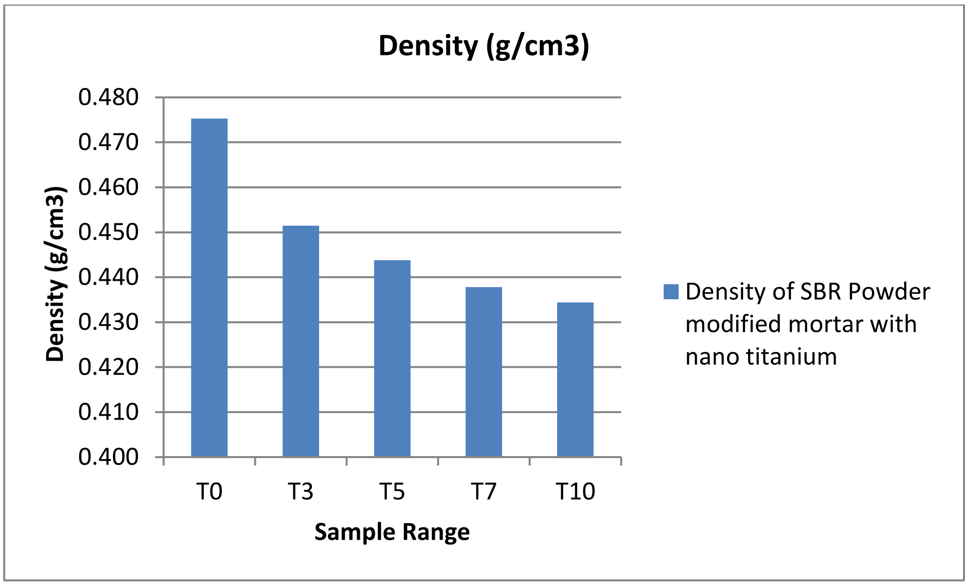

Figure 4.11: Graph of Density of mortar cubes modified with SBR powder and nano-titanium

c. Mortar cubes modified with SBR powder and Zinc Stearate

Since all mixes are having a 0.5% replacement with zinc stearate and different percentages of SBR Powder. The unit weight of SBR powder modified mortar with zinc stearate decreases with the increase of SBR Powder content. The control mix with 0% SBR powder and 0.5% zinc stearate is having 0.477 g/cm3 while mix with a 10% replacement with SBR Powder and 0.5% replacement of zinc stearate there is 9% decrease in density. By increasing the percentage of SBR Powder with zinc stearate the density of fresh mortar decreases. The decrease in density is shown in Table 4.12.

Table 4.12: Results of Density of mortar cubes with SBR powder and Zinc Stearate

Sample Name	Weight (g)	Volume of Cylinder (cm3)	Density (g/cm3)
Z0	560	1174	0.477
Z3	530	1174	0.451
Z5	522	1174	0.445
Z7	518	1174	0.441
Z10	512	1174	0.436

The decrease in density of mortar modified with SBR Powder and of zinc stearate is shown in Figure 4.12. It shows that there is gradual decrease in density of mortar with addition of SBR Powder and of zinc stearate at different percentages.

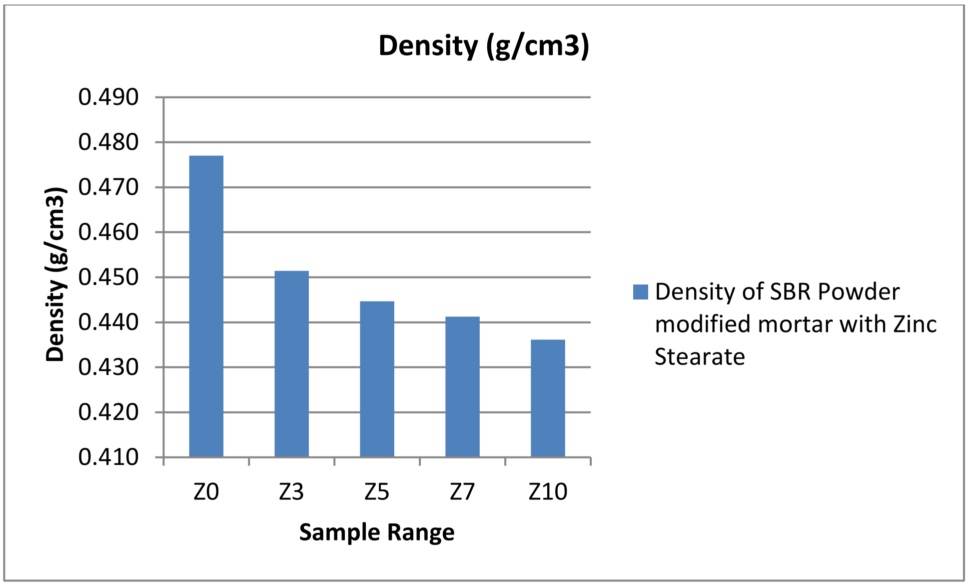

Figure 4.12: Graph of Density of mortar cubes modified with SBR powder and zinc stearate

iv. Mortar cubes modified with SBR latex and nano materials and Zinc Stearate

Density of mortar modified with SBR latex using nano materials and Zinc Stearate is discussed below:

a. Mortar cubes modified with SBR Latex and nano-silica

Since all mixes are having a 2% replacement with nano-silica and different percentages of SBR Latex. The unit weight of SBR Latex modified mortar with nano-silica decreases with the increase of SBR Latex content. By increasing the percentage of SBR Latex with nano-silica the density of fresh mortar decreases. The decrease in density is shown in Table 4.13.

Table 4.13: Results of Density of mortar cubes with SBR Latex and nano-silica

Sample Name	weight (g)	Volume of Cylinder (cm3)	Density (g/cm3)
L0	574	1174	0.489
LS0	540	1174	0.460
LS5	440	1174	0.375
LS10	423	1174	0.360

The decrease in density of mortar modified with SBR Latex and nano-silica is shown in Figure 4.13. The figure shows that there is gradual decrease in density of mortar with addition of SBR Latex and nano-silica at different percentages.

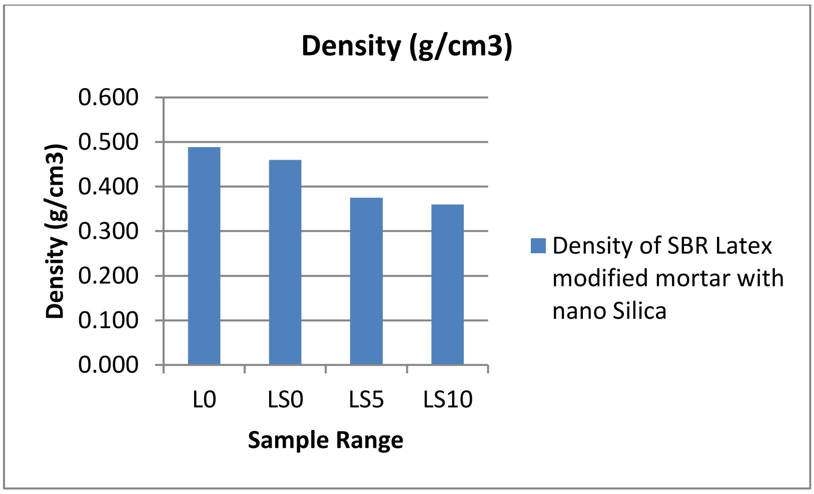

Figure 4.13: Graph of Density of mortar cubes modified with SBR Latex and nano-silica

b. Mortar cubes modified with SBR Latex and Zinc Stearate

Since all mixes are having a 0.5% replacement with zinc stearate and different percentages of SBR Latex. Unit weights of mortar mixes for each batch were calculated and results are shown in Table 4.14. By increasing the percentage of SBR latex with zinc stearate the density of fresh mortar decreases.

Table 4.14: Results of Density of mortar cubes with SBR Latex and Zinc Stearate

Sample Name	weight (g)	cylinder volume(cm3)	Density (g/cm3)
L0	574	1174	0.489
ZS0	542	1174	0.462
ZS5	437	1174	0.372
ZS10	416	1174	0.354

The decrease in density of mortar modified with SBR latex and zinc stearate is shown in Figure 4.14. The figure shows that there is gradual decrease in density of mortar with addition of SBR latex and zinc stearate at different percentages.

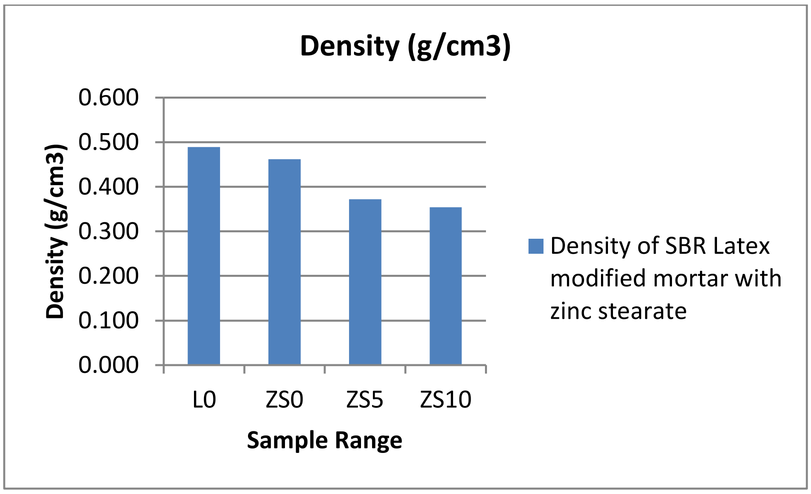

Figure 4.14: Graph of Density of mortar cubes modified with SBR Latex and zinc stearate

4.2. TESTS ON HARDENED MORTAR

4.2.1. Water Absorption Test

i. SBR Latex modified mortar cubes

The water absorption of mortar mixes for each batch was calculated. For control, mix water absorption is 8.10 % and the water absorption of SBR Latex modified mortar decreases with the increase of SBR Latex content i.e. for 10% replacement with SBR latex there is 40% decrease in water absorption. It is determined that SBR latex addition to mortar significantly decreased the water absorption ratio. The decrease in water absorption with SBR Latex is shown in Table 4.15.

Table 4.15: Results of Water Absorption of SBR Latex modified mortar cubes

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
L0	272	295	8.46	271	292	7.75	8.10
L1	267	287	7.49	271	293	8.12	7.80
L2	269	290	7.81	265	284	7.17	7.49
L3	256	275	7.42	260	279	7.31	7.36
L4	252	272	7.94	253	268	5.93	6.93
L5	255	271	6.27	254	269	5.91	6.09
L6	241	255	5.81	240	254	5.83	5.82
L7	255	270	5.88	251	265	5.58	5.73
L8	246	259	5.28	248	260	4.84	5.06
L9	243	255	4.94	246	258	4.88	4.91
L10	225	236	4.89	229	240	4.80	4.85

The decrease in water absorption of mortar modified with SBR latex is shown in Figure 4.15.

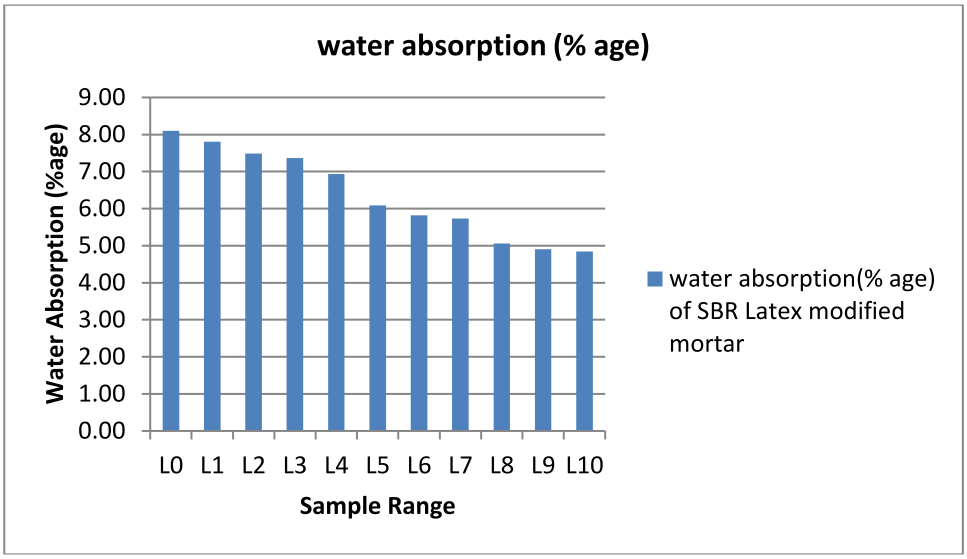

Figure 4.15: Graph of Water Absorption of SBR Latex modified mortar cubes

ii. SBR Powder modified mortar cubes

The water absorption of mortar mixes for each batch was calculated. For control, mix water absorption is 7.25 % and the water absorption of SBR powder modified mortar decreases with the increase of SBR powder content i.e. for 10% replacement with SBR powder there is 80% decrease in water absorption. It is determined that SBR powder addition to mortar significantly decreased the water absorption ratio. The decrease in water absorption with SBR powder is shown in Table 4.16 below

Table 4.16: Results of Water Absorption of SBR Powder modified mortar cubes

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
S0	270	289	7.04	268	288	7.46	7.25
S1	270	287	6.30	267	283	5.99	6.14
S2	261	274	4.98	259	272	5.02	5.00
S3	258	268	3.88	261	272	4.21	4.05
S4	256	263	2.73	260	273	5.00	3.87
S5	274	284	3.65	270	279	3.33	3.49
S6	266	274	3.01	262	271	3.44	3.22
S7	267	274	2.62	265	274	3.40	3.01
S8	270	275	1.85	271	279	2.95	2.40
S9	269	273	1.49	269	276	2.60	2.04
S10	269	272	1.12	266	271	1.88	1.50

The decrease in water absorption of mortar modified with SBR powder is shown in Figure 4.16.

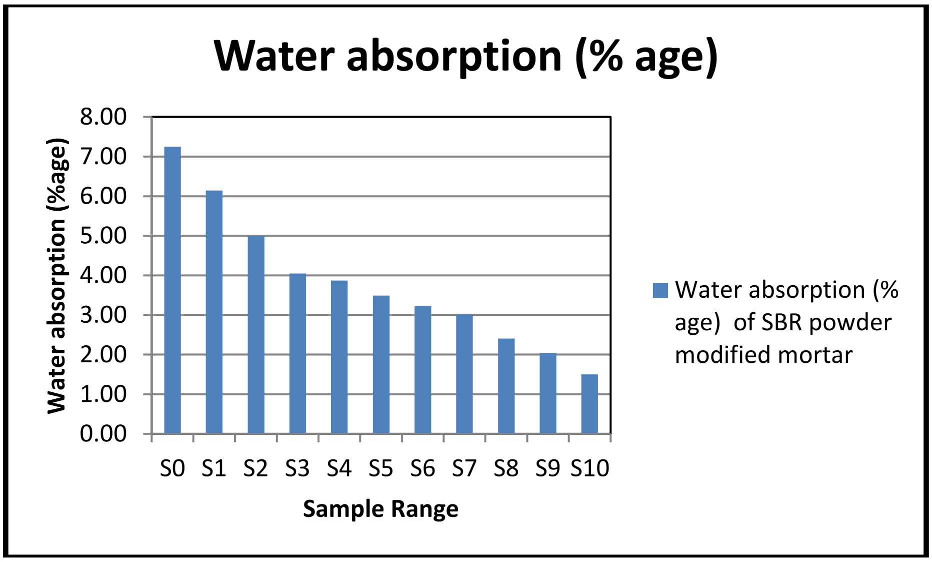

Figure 4.16: Graph of Water Absorption of SBR Powder modified mortar cubes

iii. Mortar cubes modified with SBR powder and nano materials and Zinc Stearate

Water Absorption of mortar modified with SBR Powder using nano materials and zinc stearate is discussed below:

a. Mortar cubes modified with SBR Powder and nano-silica

Since all mixes are having a 2% replacement with nano-silica and different percentages of SBR Powder. Water absorption of mortar mixes for each batch was calculated and results are shown in the Table 4.17. For control, mix water absorption is 7.25% and the water absorption of SBR powder modified mortar with nano-silica decreases with the increase of SBR powder content i.e. for 10% replacement with SBR powder with 2% replacement with nano-silica there is 60% decrease in water absorption. It is determined that SBR powder and nano-silica addition to mortar significantly decreased the water absorption ratio. The decrease in water absorption with SBR powder is shown in Table 4.17 below.

Table 4.17: Results of Water Absorption of mortar cubes with SBR Powder and nano-silica

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
S0	270	289	7.04	268	288	7.46	7.25
M0	278	296	6.47	278	293	5.40	5.94
M3	279	294	5.38	270	285	5.56	5.47
M5	272	284	4.41	278	290	4.32	4.36
M7	272	281	3.31	273	285	4.40	3.85
M10	270	278	2.96	279	287	2.87	2.8

The decrease in water absorption of mortar modified with SBR powder with nano-silica is shown in Figure 4.17.

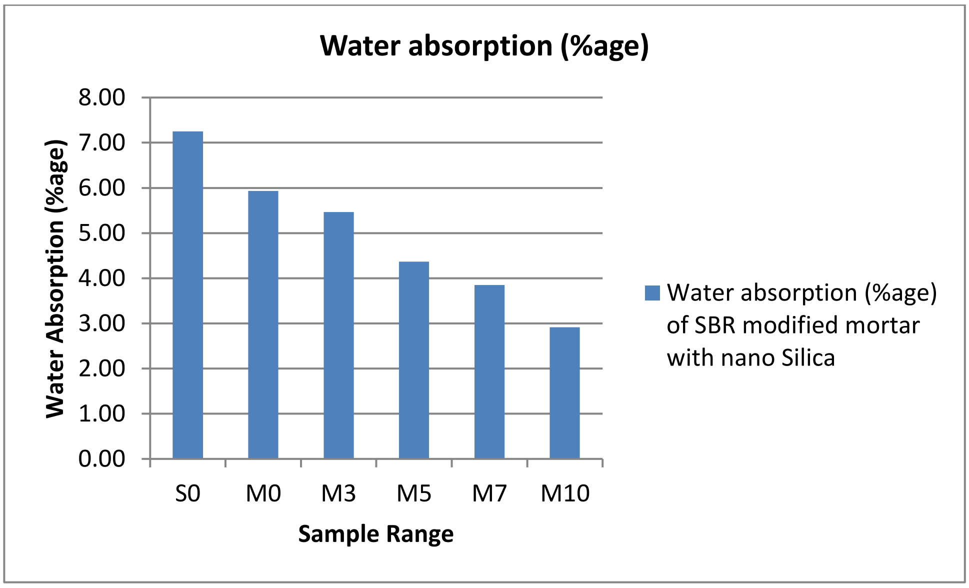

Figure 4.17: Graph of Water Absorption of mortar cubes modified with SBR Latex and nano-silica

b. Mortar cubes modified with SBR Powder and nano-titanium

Since all mixes are having a 2% replacement with nano-titanium and different percentages of SBR Powder. Water absorption of mortar mixes for each batch was calculated and results are shown in the table. For control, mix water absorption is 7.25% and the water absorption of SBR powder modified mortar with nano-titanium decreases with the increase of SBR powder content i.e. for 10% replacement with SBR powder and 2% replacement with nano-titanium there is 72% decrease in water absorption. It is determined that SBR powder and nano-titanium addition to mortar significantly decreased the water absorption ratio. The decrease in water absorption with SBR powder is shown in the table below 4.18.

Table 4.18: Results of Water Absorption of mortar cubes with SBR Powder and nano-titanium

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
S0	270	289	7.04	268	288	7.46	7.25
T0	279	292	4.66	280	294	5.00	4.83
T3	274	286	4.38	281	292	3.91	4.15
T5	282	291	3.19	284	292	2.82	3.00
T7	274	280	2.19	278	286	2.88	2.53
T10	268	272	1.49	270	277	2.59	2.04

The decrease in water absorption of mortar modified with SBR powder with nano-titanium is shown in Figure 4.18.

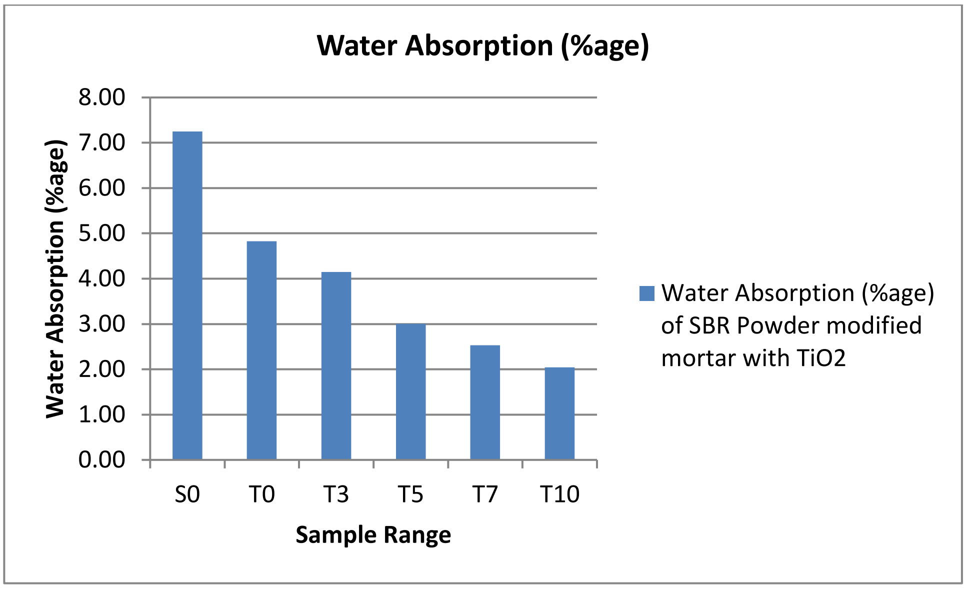

Figure 4.18: Graph of Water Absorption of mortar cubes modified with SBR Latex and nano-titanium

c. Mortar cubes modified with SBR Powder and Zinc Stearate

The water absorption of mortar mixes for each batch was calculated and results are shown in the table 4.19. For control mix water absorption is 7.25% and the water absorption of SBR powder modified mortar with zinc stearate decreases with the increase of SBR powder content i.e. for 10% replacement with SBR powder and 0.5% replacement with zinc stearate there is 82% decrease in water absoption. It is determined that SBR powder and zinc stearate addition to mortar significantly decreased the water absorption ratio. The decrease in water absorption with SBR powder is shown in Table 4.19.

Table 4.19: Results of Water Absorption of mortar cubes with SBR Powder and Zinc Stearate

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
S0	270	289	7.037	268	288	7.46	7.25
Z0	279	289	3.58	272	283	4.04	3.81
Z3	270	280	3.70	274	283	3.28	3.49
Z5	272	280	2.94	274	283	3.28	3.11
Z7	260	266	2.31	254	260	2.36	2.33
Z10	270	273	1.11	262	266	1.53	1.32

The decrease in water absorption of mortar modified with SBR powder with zinc stearate is shown in Figure 4.19.

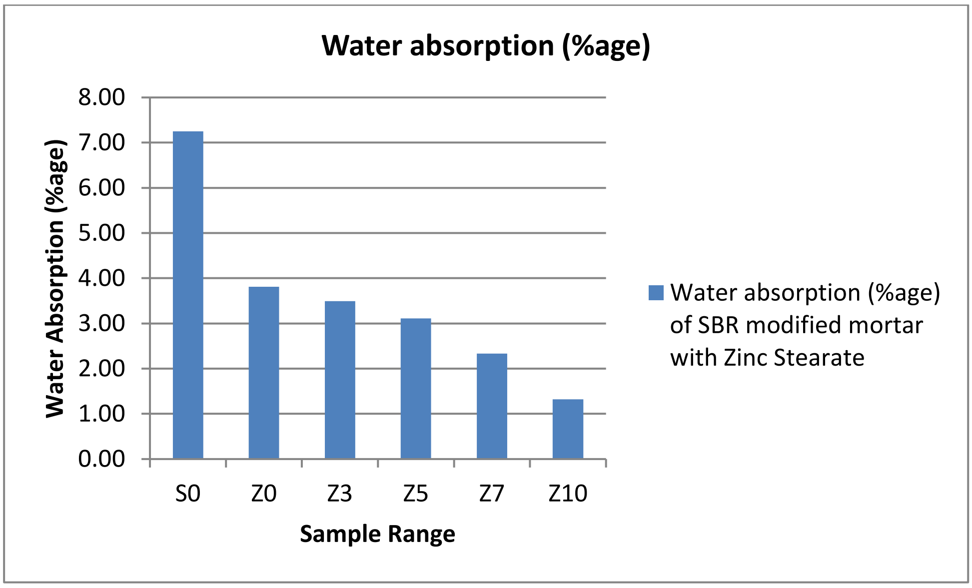

Figure 4.19: Graph of Water Absorption of mortar cubes modified with SBR Latex and zinc stearate

iv. Mortar cubes modified with SBR Latex and nano materials and zinc stearate

Water absorption of mortar modified with SBR Latex using nano materials and zinc stearate is discussed below:

a. Mortar cubes modified with SBR Latex and nano-silica

Since all mixes are having a 2% replacement with nano-silica and different percentages of SBR Latex. Water absorption of mortar mixes for each batch was calculated and results are shown in the table 4.20. For control mix water absorption is 8.1% and the decrease in water absorption of SBR powder modified mortar with 5% SBR latex with 2% nano-silica and 10% SBR latex and 2% nano-silica is 12% and 27% respectively. Water absorption with SBR Latex and zinc stearate is shown in Table 4.20 .

Table 4.20: Results of Water Absorption of mortar cubes with SBR Latex and nano-silica

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
L0	272	295	8.46	271	292	7.75	8.10
LS0	278	296	6.47	278	294	5.76	6.12
LS5	244	262	7.38	250	267	6.80	7.09
LS10	250	265	6.00	242	256	5.79	5.89

The water absorption of mortar modified with SBR Latex with nano-silica is shown in Figure 4.20.

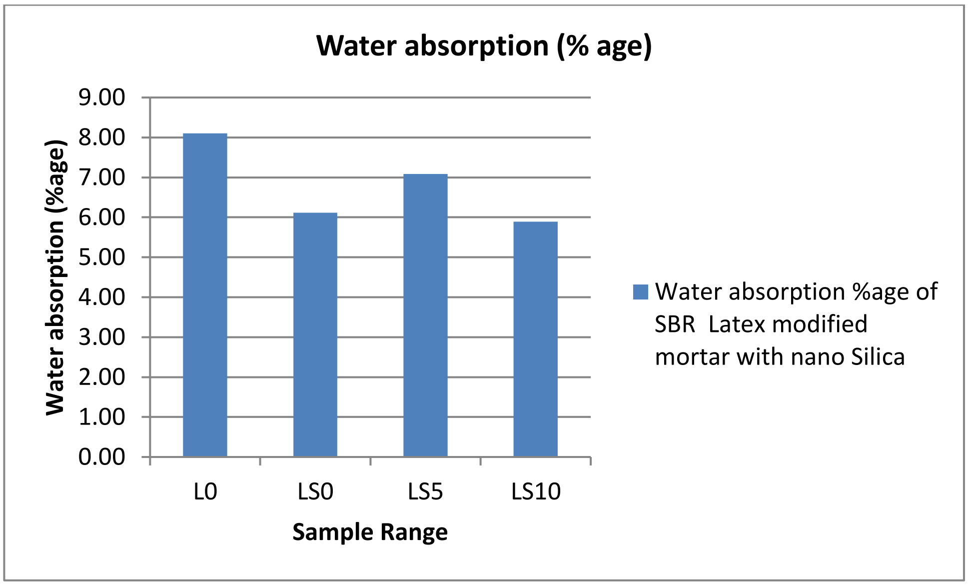

Figure 4.20: Graph of Water Absorption of mortar cubes modified with SBR Latex and nano-silica

b. Mortar cubes modified with SBR Latex and Zinc Stearate

Since all mixes are having a 0.5% replacement with zinc stearate and different percentages of SBR Latex. Water absorption of mortar mixes for each batch was calculated and results are shown in the table 4.21. For control, mix water absorption is

8.1% and the decrease in water absorption of SBR powder modified mortar with 5% SBR latex with 0.5% zinc stearate and 10% SBR latex with 0.5% zinc stearate is 45% and 53% respectively. Water absorption with SBR Latex and zinc stearate is shown in Table 4.21 below.

Table 4.21: Results of Water Absorption of mortar cubes with SBR Latex and Zinc Stearate

Sample Name	Dry weight (g)	Wet weight (g)	percentage of water absorption	Dry weight (g)	Wet weight (g)	percentage of water absorption	Avg. percentage of water absorption
L0	272	295	8.46	271	292	7.75	8.10
ZS0	279	290	3.94	272	283	4.04	3.99
ZS5	236	246	4.24	238	249	4.62	4.43
ZS10	250	260	4.00	253	262	3.56	3.78

The water absorption of mortar modified with SBR Latex with Zinc Stearateis shown in Figure 4.21.

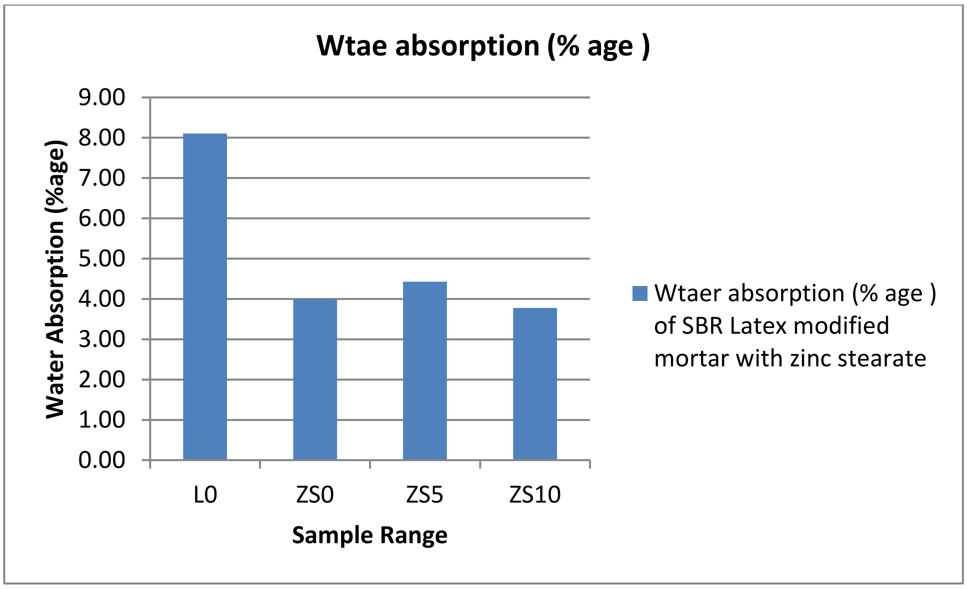

Figure 4.21: Graph of Water Absorption of mortar cubes modified with SBR Latex and zinc stearate

4.2.2. Compression Test Results

28 days Compressive strength of mortar cubes at four different phases was calculated by taking average of three cubes the compressive strength was determine by applying load through Universal Testing Machine by following ASTM C109/C109M-16a.

i. SBR Latex modified mortar cubes

Compressive strength at 28 days of mortar mixes for each batch was calculated and results are shown in table. For control mix with 0% replacement with SBR Latex the compressive strength is 21.2 MPa and with 1% there is slight increase in compressive strength, 2% to 4% partial replacement with SBR Latex there is no such effect on compressive strength and further 5% to 10% replacement with SBR Latex there is decrease in compressive strength of mortar cubes and at 10% replacement there is 47% decrease. This decrease in compressive strength is due to entrapped air in mortar due to SBR latex. And also 28 days compressive strength of 1 % to 10% replacement with SBR Latex is shown in Table 4.22 below.

Table 4.22: Results of Compressive strengths of SBR Latex modified mortar cubes

Sample Name	Average Load (KN)	Compressive Strength (MPa)
L0	54.72	21.21
L1	54.86	21.26
L2	54.77	21.23
L3	52.70	20.43
L4	53.20	20.62
L5	40.87	15.84
L6	32.80	12.71
L7	30.80	11.94
L8	30.65	11.88
L9	30.00	11.63
L10	29.10	11.28

The graph of compressive strength of SBR Latex modified mortar cubes at 1% to 10% replacement with SBR Latex is shown in Figure 4.22 below.

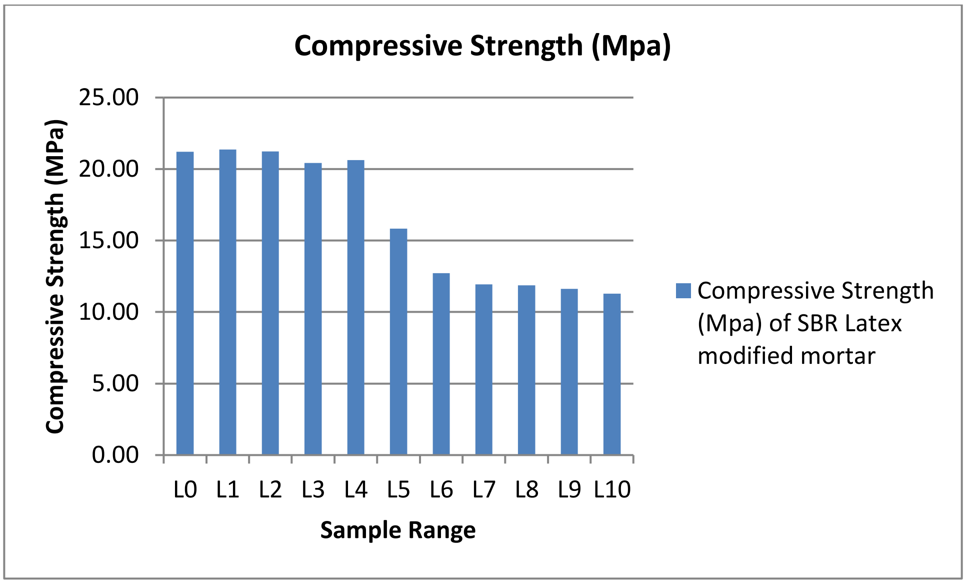

Figure 4.22: Graph of Compressive Strengths of SBR Latex modified mortar cubes

ii. SBR Latex modified mortar cubes

Compressive strength at 28 days of mortar mixes for each batch was calculated. For control mix with 0% replacement with SBR powder the compressive strength is 19.16MPa and with 1% to 10% replacement with SBR powder there is gradual increase in compressive strength i.e. 44% increase at 10% partial replacement with SBR powder gives the maximum strength. And also 28 days compressive strength of 1 % to 10% replacement with SBR powder is shown in Table 4.23 below.

Table 4.23: Results of Compressive strengths of SBR Powder modified mortar cubes

Sample Name	Average Load (KN)	Compressive Strength (MPa)
S0	49.42	19.16
S1	54.30	21.05
S2	54.97	21.30
S3	55.40	21.47
S4	56.58	21.93
S5	59.86	23.20
S6	61.37	23.79
S7	62.34	24.16
S8	68.63	26.60
S9	70.30	27.25
S10	71.00	27.52

The graph of compressive strength of SBR powder modified mortar cubes at 1% to 10% replacement with SBR powder is shown in Figure 4.23 below.

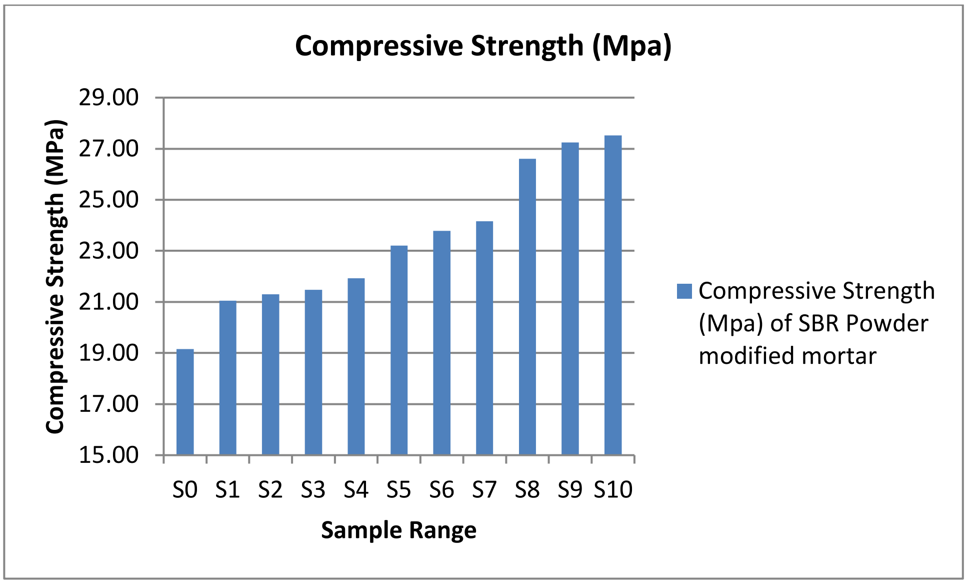

Figure 4.23: Graph of Compressive Strengths of SBR powder modified mortar cubes

iii. Mortar cubes modified with SBR powder and nano materials and Zinc Stearate

Compressive strength results of mortar modified with SBR Latex using nano materials and zinc stearate is discussed below:

a. Mortar cubes modified with SBR Powder and nano-silica

Since all mixes are having 2% replacements with nano-silica and different percentages of SBR Powder. Compressive strengths of mortar mixes for each batch were calculated. The compressive strength of SBR powder modified mortar with nano-silica increases with the increase of SBR Powder content. The control mix with 0% SBR powder has 19.03 MPa while mix with 10% replacement with SBR Powder and 2% replacement of nano-silica has highest strength i.e. 85% increase in compressive strength. By increasing the percentage of SBR Powder with nano-silica the compressive strength of mortar increases. Also, 28 days compressive strength of SBR Powder modified with 2% nano-silica is given in Table 4.24.

Table 4.24: Results of Compressive strengths of mortar cubes with SBR Powder and nano-silica

Sample Name	Average Load (KN)	Compressive strength (MPa)
S0	49.09	19.03
M0	63.9	24.8
M3	78.9	30.6
M5	80.1	31.0
M7	89.2	34.6
M10	90.9	35.2

The graph of compressive strengths of SBR powder modified mortar cubes along with 2 % nano-silica is shown Figure 4.24.

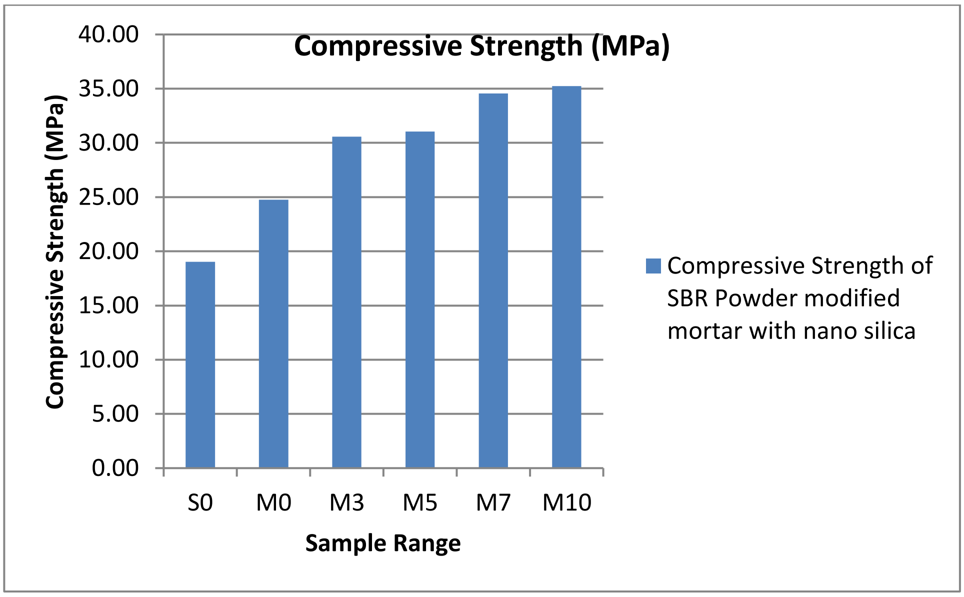

Figure 4.24: Graph of Compressive Strengths of mortar cubes modified with SBR Powder and nano-silica

b. Mortar cubes modified with SBR Powder and nano-titanium

Since all mixes are having a 2% replacement with nano-titanium and different percentages of SBR Powder. Compressive strengths of mortar mixes for each batch were calculated and results are shown in the table. The compressive strength of SBR powder modified mortar with nano-titanium increases with an increase of SBR Powder content at a particular level. The control mix with 0% SBR powder has 19.03 MPa while mix with 5% replacement with SBR Powder and 2% replacement of nano-titanium there is 96% increase in strength which is highest among all mixes. For 7% SBR Powder with 2% nano-titanium and 10% SBR powder with 2% nano-titanium the increase in compressive strength is 81% and 73% respectively. Also 28 days compressive strength of SBR Powder modified with 2% nano-titanium is given in Table 4.25 below:

Table 4.25: Results of Compressive strengths of mortar cubes with SBR Powder and nano-titanium

Sample Name	Average Load (KN)	Compressive Strength (MPa)
S0	49.09	19.03
T0	83.5	32.4
T3	95.2	36.9
T5	96.30	37.3
T7	88.9	34.5
T10	84.85	32.9

The graph of 28 days compressive strength of SBR powder modified mortar cubes cement replacement with SBR powder along with 2 % nano-titanium is shown in Figure 4.25.

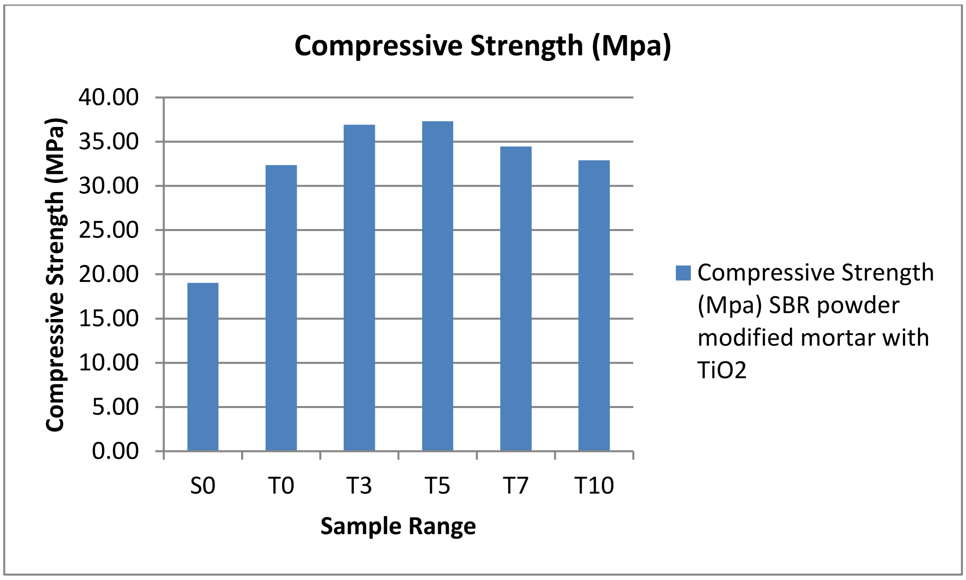

Figure 4.25: Graph of Compressive Strengths of mortar cubes modified with SBR Powder and nano-titanium

c. Mortar cubes modified with SBR Powder and Zinc Stearate

Since all mixes are having a 0.5% replacement with zinc stearate and different percentages of SBR Powder. Compressive strengths of mortar mixes for each batch were calculated. The control mix with 0% SBR powder has 19.03 MPa, the compressive strength of SBR powder modified mortar with zinc stearate increases with increase of SBR Powder content and gives highest compressive strength at 5 % replacement with SBR powder i.e. 64% increase in strength. For 7% SBR Powder with 0.5 % zinc stearate and 10% SBR powder with 0.5% zinc stearate the increase in compressive strength is 50% and 47% respectively. Also 28 days compressive strength of SBR Powder modified with 0.5% zinc stearate is given in Table 4.26 below:

Table 4.26: Results of Compressive strengths of mortar cubes with SBR Powder and Zinc Stearate

Sample Name	Average Load (KN)	Compressive Strength (MPa)
S0	49.09	19.03
Z0	63.5	24.6
Z3	69.2	26.8
Z5	80.6	31.2
Z7	73.8	28.6
Z10	72.3	28.0

The graph of 28 days compressive strength of SBR powder modified mortar cubes cement replacement with SBR powder along with 0.5 % zinc stearate is shown in Figure 4.26.

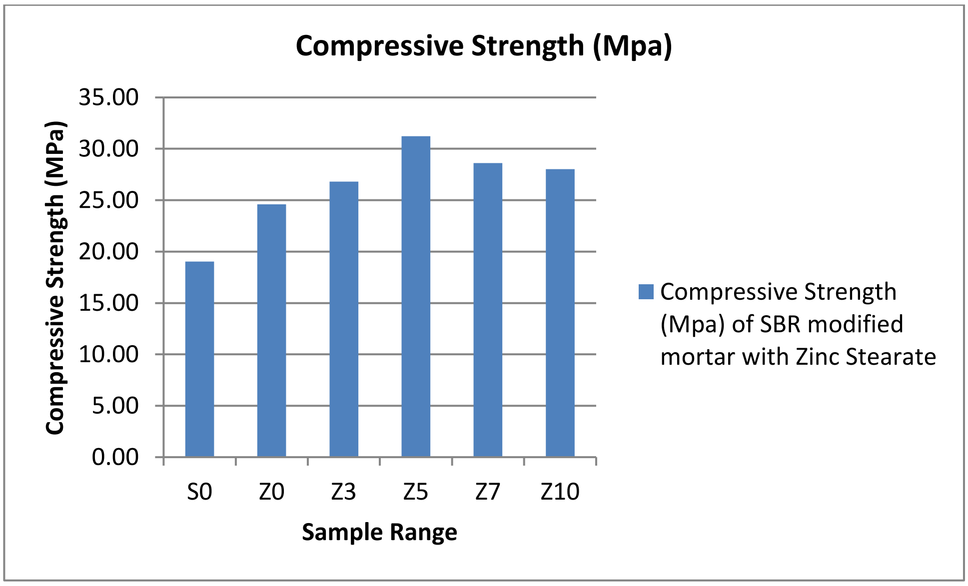

Figure 4.26: Graph of Compressive Strengths of mortar cubes modified with SBR Powder and Zinc Stearate

iv. Mortar cubes modified with SBR Latex and nano materials and Zinc Stearate

Compressive strength results of mortar modified with SBR Latex using nanomaterials and zinc stearate is discussed below:

a. Mortar cubes modified with SBR Latex and nano-silica

Since all mixes are having 2% replacements with nano-silica and different percentages of SBR Powder. The control mix is having 21.2 MPa compressive strength and mix with 0% SBR latex and 2% nano-silica is having 16% increase in strength while mix with 5% and 10% replacement with SBR latex and 2% replacement of nano-silica is having decrease in compressive strength 34% and 23% respectively. By increasing percentage of SBR Latex with nano-silica the compressive strength of mortar decreases. Also 28 days compressive strength of SBR latex modified with 2% nano-silica is given in Table 4.27 below:

Table 4.27: Results of Compressive strengths of mortar cubes with SBR Powder and nano-silica

Sample Name	Average Load (KN)	Compressive Strength (MPa)
L0	54.72	21.21
LS0	63.8	24.7
LS5	36.0	14.0
LS10	42	16.3

The graph of compressive strength of SBR Latex modified mortar cubes along with 2 % nano-silica is shown in Figure 4.27 below:

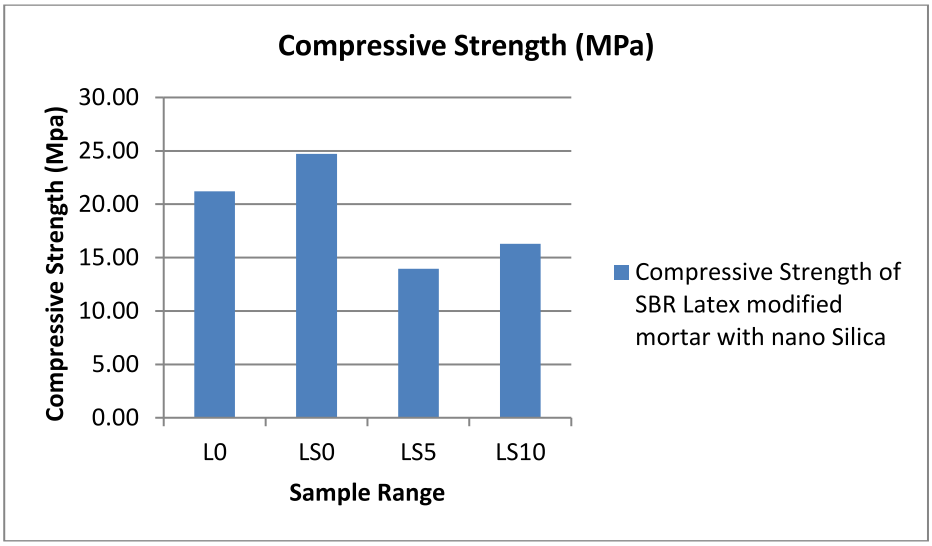

Figure 4.27: Graph of Compressive Strengths of mortar cubes modified with SBR Powder and nano-silica

b. Mortar cubes modified with SBR Latex and Zinc Stearate

Since all mixes are having 0.5% replacements with zinc stearate and different percentages of SBR Powder. The control mix is having 21.2 MPa compressive strength and mix with 0% SBR latex and 0.5% zinc stearate is having 16% increase in strength while mix with 5% and 10% replacement with SBR latex and 0.5% replacement of zinc stearate is having decrease in compressive strength 28% and 16% respectively. By increasing percentage of SBR Latex with zinc stearate the compressive strength of mortar decreases. Also 28 days compressive strength of SBR latex modified with 0.5% zinc stearate is given in Table 4.28 below:

Table 4.28: Results of Compressive strengths of mortar cubes with SBR Powder and Zinc Stearate

Sample Name	Average Load (KN)	Compressive Strength(MPa)
L0	54.72	21.21
ZS0	63.5	24.6
ZS5	39.0	15.1
ZS10	46	17.8

The graph of 28 days compressive strength of SBR Latex modified mortar cubes along with 0.5 % zinc stearate is shown below

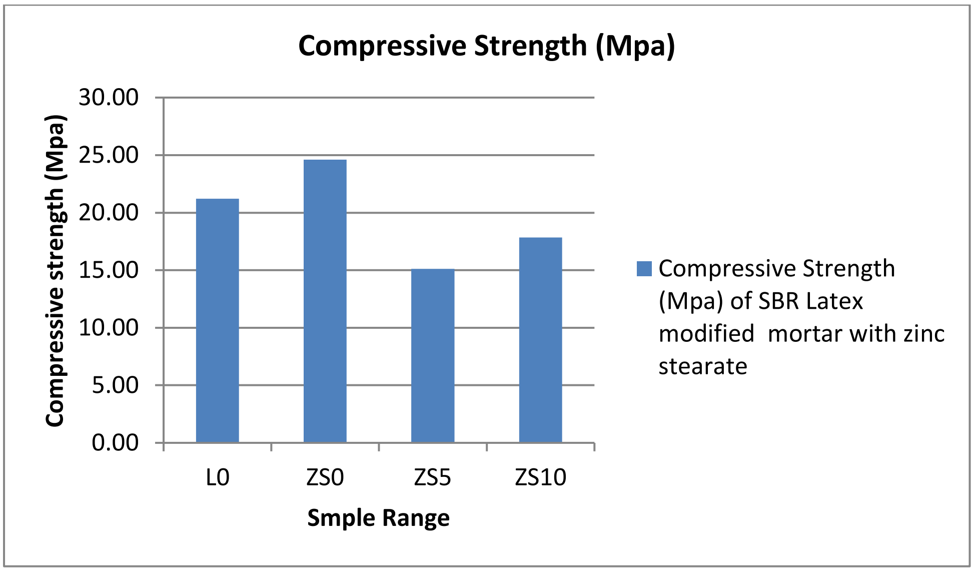

Figure 4.28: Graph of Compressive Strengths of mortar cubes modified with SBR Powder and zinc stearate

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter includes the conclusions made after the discussions of all experimental work performed. Assessment of results is carried by comparing the results with control mortar and recommendations for further study. After experimentation and analysis of results, the following conclusions are obtained.

5.1. WORKABILITY

- The workability of the mortar increases by increasing percentage of SBR Latex and SBR powder as compare to the control mix. At 10% replacement of SBR latex and powder, the maximum increase in workability is 127% and 94% respectively.
- The workability of mortar modified with SBR powder with 2% nano-silica, 2% nano-titanium and 0.5% zinc stearate also increases by increasing the percentage of SBR powder.
- SBR latex modified mortar with nanoparticles and zinc stearate is more workable than SBR powder modified mortar with nanoparticles and zinc stearate.
- The workability of mortar modified with SBR Latex with 2% nano-silica and 0.5% zinc stearate also increases by increasing the percentage of SBR latex. The mix with 10% SBR latex with nanoparticles and zinc stearate is more workable than all.

5.2. DENSITY

- By increasing the percentage of SBR Latex and SBR powder the density of fresh mortar decreases. There is 29% and 13% decrease in density with 10% replacement of SBR Latex and SBR powder respectively.
- The density of SBR powder modified with nanoparticles and zinc stearate decreases by increasing the percentage of SBR powder. There is 12%, 8% and 9%

decrease in density for mix with 10% replacement of SBR powder with 2% nano-silica, 2% nano-titanium and 0.5% zinc stearate respectively.

- The density of SBR latex modified mortar with nanoparticles and zinc stearate decreases by increasing the percentage of SBR latex. There is 26% and 28% decrease in density for mix with 10% replacement of SBR latex with 2% nano-silica and 0.5% zinc stearate respectively.

5.3. WATER ABSORPTION

- The water absorption of samples decreases for all samples. By comparing the water absorption of SBR powder and latex at 10% replacement, the SBR powder modified mortar has less water absorption than SBR latex modified mortar, i.e. the decrease in water absorption of SBR powder and SBR latex modified mortar is 80% and 10% respectively as compared to control sample. Latex may have higher void contents, which increase water absorption. In powders, voids themselves are reduced or filled by the fine powder.
- The maximum decrease in water absorption of mortar modified with 10% SBR powder with 2% nano-silica, 2% nano-titanium and 0.5% zinc stearate is 60%, 71% and 82% respectively.
- For mortar with SBR latex modified with nanoparticles and zinc stearate, 10% SBR latex with 2% nanosilica and 0.5% zinc stearate the maximum decrease in water absorption is 27% and 53% respectively.
- 10% SBR latex with 0.5% zinc stearate has least water absorption 82 % decrease in water absorption as compared to control sample, which is least among all. The zinc stearate (a soap or metallic salt) has hydrophobic characteristics, and it is a powerful friction retarder and reduces the number and size of voids. So it stops the water absorption.

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5.4. COMPRESSIVE STRENGTHS

- The 28 days compressive strength of mortar samples decreases with increase of SBR latex content. The decrease may be associated with the air-entraining effect of polymer latex, which leads to an increase in porosity or encapsulation. From 1% to 4% replacement of SBR latex there is slight decrease (upto 3%) in compressive strength, further 5% to 10% replacement there is 48% decrease in compressive strength as compared to control sample.
- On the other hand, the 28 days compressive strength of SBR powder modified mortar increases with the increasing percentage of SBR powder, i.e., 43% increase in strength for 10% replacement of cement. This increase in strength is attributed to the filler effect of SBR powder, which fills the pores and reduces the size of voids in mortar.
- There is a remarkable increase in compressive strength by introducing nanoparticles and zinc stearate in mortar. Increase in compressive strength using 2% nano-silica with 10% SBR powder, 2% nano-titanium with 5% SBR powder and 0.5% zinc stearate with 5% SBR powder is 85%, 96%, 64% respectively. Using 2% nano-titanium with 5% SBR powder gives maximum compressive strength, i.e., 96% increase in strength. The higher strength of mortar was observed because of the impermeable microstructure of mortar, which is the result of the filling effect of fine nanoparticles and zinc stearate.
- There is a gradual decrease in compressive strength of mortar samples modified with SBR latex with nanoparticles and zinc stearate. In mortar modified with SBR latex with nano-silica and zinc stearate the decrease in compressive strength is up to 34% and 28% respectively. Nanoparticles are not found compatible with latex.
- Based on the experimental results, SBR powder can be effectively used as cementitious materials in mortar. The results show that the combination of nano-silica, nano-titanium, zinc stearate, and SBR powder in mortars enhanced the compressive strength remarkably and reduced the water absorption.

5.5. RECOMMENDATIONS

- For further studies, it is recommended to study the tensile and flexural strength behavior of mortar cubes of all of the batches used in this research.
- It is also recommended to test all these polymers in concrete and check the tensile strength, flexural strength and compressive strength of concrete as well.

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