Experimental Investigation on Effect of SMA Fibers on the Strength Properties of Recycled Fine Aggregate Concrete with Electromagnetic Water

Submitted in partial fulfilment of the requirements

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Master of Engineering

in

Civil Engineering

(With Structural Engineering Subjects)

Submitted By

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CERTIFICATE

This is to certify that the project entitled **"Experimental Investigation on Effect of SMA Fibers on the Strength Properties of Recycled Fine Aggregate Concrete with Electromagnetic Water"** is a bonafide work of **"Riya Jamil Athanikar"** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of **"Master of Engineering in Civil Engineering (With Structural Engineering Subjects)"**.

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Examiners

1. --

2. --

Date:

Place: Navi Mumbai

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Abstract

Shape Memory Alloy (SMA) is a widely used smart material in various fields such as civil, biomedical, electrical, mechanical, etc. in various forms. Present research is focused to check the feasibility of nickel based SMA fibers as an alternative to conventional steel fibers for enhancement of strength as well as re-centering ability to reduce the crack developed in the concrete respectively. Another aspect is the utilization of recycled material in concrete. The waste materials are a major problem, which is also a threat to the environment and hence can be used in concrete by replacement of natural aggregates. Also, the water available at the site is not in good conditions and affects the strength properties of concrete, so to overcome this problem and enhance the strength of concrete, electromagnetized water is used in concrete for comparison with normal water in concrete. In particular, various types of concrete mix have been compared with reference mix concrete to study the effect of recycled fine aggregate on normal water concrete, effect of electromagnetic water concrete and effect of SMA fibers on normal as well as electromagnetic water concrete. The dimension of SMA fibers is used as 0.60 mm diameter and 30 mm in length and they are used by 1% of the volume of concrete. The natural fine aggregates are replaced by recycled fine aggregates (RFA) by 35%, 50% and 65% respectively. Slump test is used to measure the workability of fresh concrete and compressive test and split tensile test after 7 and 28 days in is used to measure strength of hardened concrete. Flexural strength is calculated in co-relation with compressive strength as per IS 456: 2000 and crack width closing ability is calculated using Vernier Caliper. Overall results show that the partial use of recycled fine aggregate increased the strength of the concrete up to 35% replacement of NFA with RFA and up to 50% replacement of NFA with RFA in some cases. The use of electromagnetic water instead of normal water significantly helped in increasing the strength of concrete. SMA fibers helped in increasing the tensile strength and re-centering ability of concrete as well as the overall strength of the concrete.

Keywords: *shape memory alloy [SMA], fiber reinforced concrete [FRC], SMA fiber, recycled fine aggregate [RFA], natural fine aggregate [NFA], electromagnetic water.*

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Chapter 1

Introduction

1.1 General

Durability of concrete most importantly depends upon its strength and resistance to cracking. Strength involves compressive, tensile and flexural strength. Tensile and flexural capacities of Fiber Reinforced Concrete (FRC) are greatly enhanced compared to unreinforced concrete [5]. Moreover, addition of fibers significantly improves concrete post-cracking behaviour [5] and hence, FRC is a fast-growing field in the civil engineering industry. FRC also displays increased resistance to cracking, greater control of crack size and its propagation [15]. Whereas, the conventional reinforcement deals with large permanent plastic strain; weak re-centering capability; low resistance against corrosion; and low resistance against fatigue.

To overcome this deficiency, intensive research was carried out in the field of structural engineering over the past decade to develop alternative reinforcement. As a result, advanced materials in the form of superelastic (SE) shape memory alloy (SMA) has been developed, which can undergo large inelastic deformations and recover its original shape by stress removal, thus diminishing the problem of permanent deformation [11]. Materials having one or more properties which can be changed by a controlled external stimulus such as moisture, stress, pH, temperature, magnetic or electric fields are called as smart materials. Shape memory alloy [SMAs] is a smart material which is a group of alloys that can return to their initial shape and size when they subjected to a restoration process between two phases under the effect of a change in temperature. This phenomenon is named “Shape Memory”. They also have high strength, high energy absorption, high damping, good fatigue resistance, good corrosion resistance and excellent re-centering ability. They can be formed into various shapes like bars, plates, wires and ring thus serving various functions.

Simultaneously, the construction field faces a major problem of where the demolished concrete waste can be utilized. For new concrete production, an excellent source of aggregates can be concrete demolition waste. It is believed that the greater water absorption of these recycled aggregates can threaten the final results; there are no thorough similar studies. The use of recycled aggregate as coarse aggregates can decrease the strength of concrete due to high water absorption as compared to recycled fine aggregates [23]. Hence, it can be expected that partial replacement of natural fine aggregates with recycled fine aggregates might not decrease the strength to a larger extent.

To overcome above problems with recycled aggregates concrete, now a day’s electromagnetic water is used to manufacture the concrete by some researchers. Electro-magnetic water concrete has been recently developed by using electromagnetically treated water instead of potable water in concrete. Based on the literature survey, it is observed that, electro-magnetized water is found to increase compressive strength of concrete by 20% to 30% [26].

Based on the above scenario and literature study, present study is focused on the experimental investigation to check the effect of recycled fine aggregate on concrete, comparison of normal water concrete and electromagnetic water concrete and effect of SMA fibers in concrete. Ultimately, it is expected that the use of shape memory alloy fibers will help to increase the strength of concrete and enhance the re-centering ability of concrete. Recycled fine aggregates will be used for re-using the demolished waste. While, electromagnetic water will helpful for enhancing workability and strength properties of concrete.

1.2 Shape Memory Alloy

1.2.1 History of Memory Metal

Shape Memory Alloys (also known as memory metal) are materials capable of undergoing large recoverable strains of the 8% order while producing hysteresis. It is a metal that “remembers” its initial geometry during transformations. The four main types of shape memory alloys are the copper-zinc, aluminium-nickel, copper-aluminium-nickel and nickel-titanium (NiTi) alloys, but SMAs can also be created by alloying zinc, copper, gold, and iron. Shape memory alloy was first discovered by Arne Olande in 1938. He observed the shape and recovery ability of a gold-cadmium alloy (Au-Cd). W.J. Buehler and Wang at the US Naval Ordinance Laboratory in 1963 observed the shape memory effect (SME) in a nickel and titanium alloy, today known as NITINOL (NIckel TItanium Naval Ordinance Lab). It was the most commonly used SMA until 1982, when the SME was observed in Fe–Mn– Si alloy

1.2.2 Properties of Shape Memory Alloy

It exists in two different temperature dependent crystal structures, known as martensite at lower temperature and austenite at higher temperature or parent phase. In austenite phase, i.e. at higher temperature, SMAs is stronger and stable and in martensite phase i.e. at lower temperature it is weaker. These two phases differ in their crystal structures. The austenite has a body-centered cubic crystal structure, while the martensite has a parallelogram asymmetric structure having up to twenty-four variations. When, SMA in martensite phase is subjected to external stress, it deformed through a detwinning mechanism and transforms different crystal structure variations to a particular one variation which can accommodate maximum elongation. Due to parallelogram structure, the martensite phase is weak and can be easily deformed. In austenite phase, the high temperature causes the atoms to arrange themselves into the most compact and regular pattern possible, resulting in a rigid cubic arrangement and have relatively stronger resistance to external stress. The special property that allows shape memory alloys to revert to their original shape on increase in temperature is that their crystal transformation is fully reversible. Simplified two-dimensional representation of the materials crystalline arrangement is shown in Fig. 1.1.

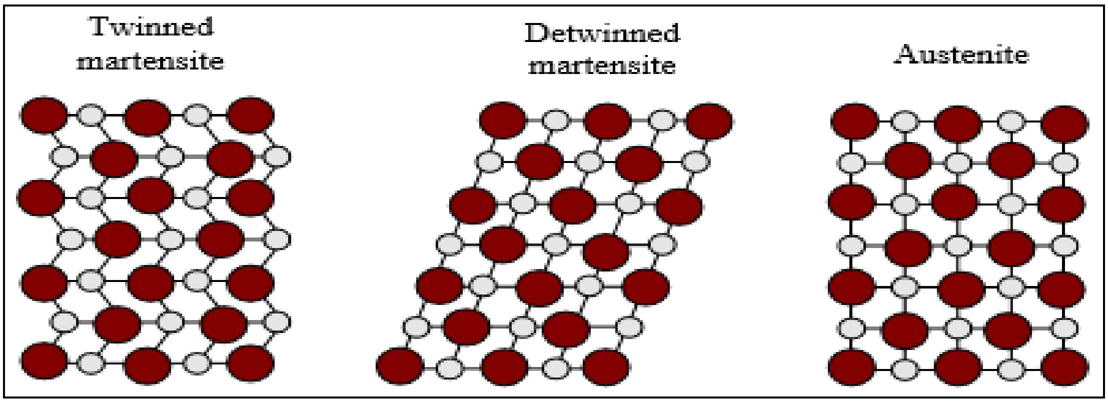


Fig 1.1 Different phases of shape memory alloys [Ozbulut, 2011]

1.2.3 Applications of Shape Memory Alloy in Civil Structures

Shape memory alloy (SMA)is a functional material and has found increasing applications in mechanical, medical, aerospace field. Recently, research efforts have been extended to use SMA for control of civil structures due to their high-power density, high corrosion resistivity, solid state actuation, high damping capacity, durability and fatigue resistance. When integrated with civil structures, SMAs can be passive, semi-active, or active components to reduce damage caused by environmental impacts or earthquakes. The history of SMAs has already gone through 20-years. However, the practical applications of these alloys have just been started. The background of SMAs applications in civil structure is introduced in this section.

- **Damping in Bridge Systems**–Both superelastic and martensite SMAs can be used as damper elements for bridges. A stay-cable bridge was used to study theoretically the vibration mitigation of a combined cable–SMA damper system, shown in Fig. 1.2. The dynamic responses of the SMA damped cable were simulated as it vibrated at its first mode or at its first few modes respectively. In both cases, the authors used the results to propose the ability of superelastic SMA dampers to suppress the cable's vibration (Li et al., 2004).

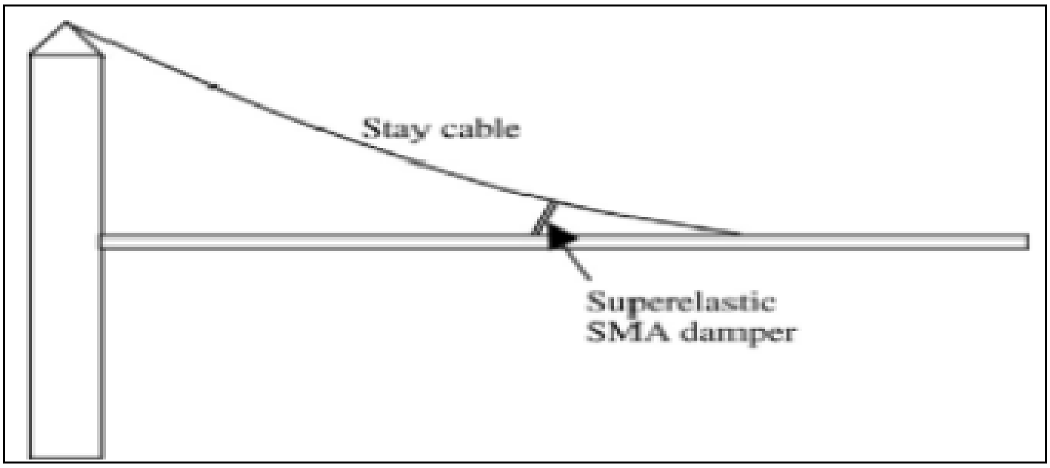


Fig. 1.2 Stay-cable bridge (Li et al., 2004)

- **Application of SMAs for Structural Self-Rehabilitation** -Structural self-rehabilitation using SMAs comes under active structural control. The concept of Intelligent Reinforced Concrete (IRC) was proposed using the actuation property of SMA wires (Song, 2003). Its intelligence is based on the ability to sense and self-rehabilitate. Fig. 1.3 IRC with stranded martensite SMA wires for posttensioning. The electric resistance change of the shape memory alloy wires can be monitored to exhibit the strain distribution inside the concrete. Occurrence of macro sized cracks from earthquakes can be reduced by electrically heating the SMA wire strands, causing them to contract and hence, minimize the cracks.

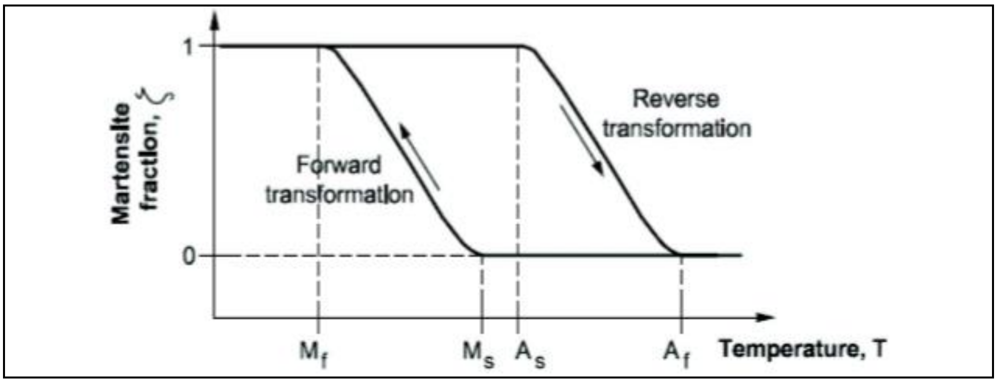
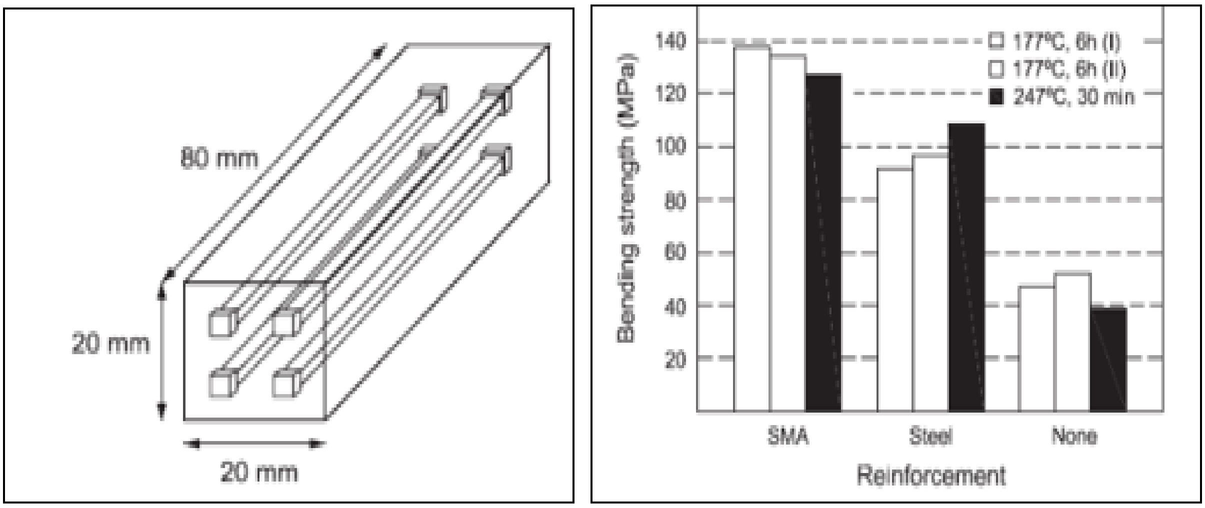


Fig. 1.3 Schematic of intelligent reinforced concrete specimen (Song, 2003)

- **Shape Memory Effect in Structural Applications -** Small mortar prisms were reinforced with square Fe–28Mn– 6Si–5Cr–1(NbC) bars by Sawaguchi et al. as shown in Fig. 3.3. The mechanical properties of the mortar increased with the 177 ºC curing, but they worsened for the 247 ºC treatment, except for the surprising results they got from prisms strengthened with steel subjected to the high temperature curing as per Fig. 1.4. The authors concluded that the iron-based SMAs were usable for producing prestress in the mortar because the bending strength increased significantly in the specimens with the SMA respect to the specimens reinforced with steel or the non-reinforced specimens. Sawaguchi et al. also highlighted that further strengthening could be achieved by lowering the reverse transformation temperatures of the SMAs, thus avoiding significant thermal damage to the mortar matrix.



(a) (b)

Fig. 1.4 (a) Specimens tested by Sawaguchi et al., 2006 (b) Bending strength of mortar specimens with SMA, steel and without reinforcement

1.2.4 Nickel based Shape Memory Alloy

Nickel based shape memory alloy fibers demonstrate two unique properties namely shape memory effect and super elasticity. The ability of the alloy to undergo deformation at one temperature and then recover its original non-deformed shape upon heating above its transformation temperature is called as shape memory effect. The capability of the alloy to cause non-deformed shape to recover without heating and occurs at a narrow temperature range just above its transformation temperature is called as super elasticity. The material exhibits enormous elasticity, sometimes 10 times more than that of ordinary metal.

Nickel based shape memory alloy helps in increasing the tensile strength of concrete. The most unique property of nickel based SMA is that after deformation, it partially regains its in original shape and size even after deformation. This helps in partial crack closing after deformation. The percentage of fibers to be used should be in between 0.01-3.0% by the total volume of concrete where its optimum up to 1% whereas it causes flocculation if used more than 2.5% [9].

Fig 1.5 Nickel based shape memory alloy in wire form [Special Metals Ltd.]

Table 1.1 Chemical Composition of selected Nickel based Shape Memory Alloy (Austenitic) [Special Metals Ltd.]

Chemical Composition- Percent							**Nearest Equivalent Specification**
C max	**Mn max**	**P max**	**S max**	**Si max**	**Cr**	**Ni**	
0.03	2	0.045	0.03	1	18.0/20.0	8.0/12.0	02Cr18Ni11

1.3 Electro-Magnetic Water

1.3.1 Timeline of Electro-Magnetic Water

Electromagnetic water is the water that passes through an electromagnetic device for a particular period of time until it's physical properties are changed. When the water passes through a certain electromagnetic field it becomes electromagnetic water. It is found that an increase of about 10% in strength when the water is electromagnetized does not change any of its mechanical properties it only changes the trajectory of the charged particles movement [5].

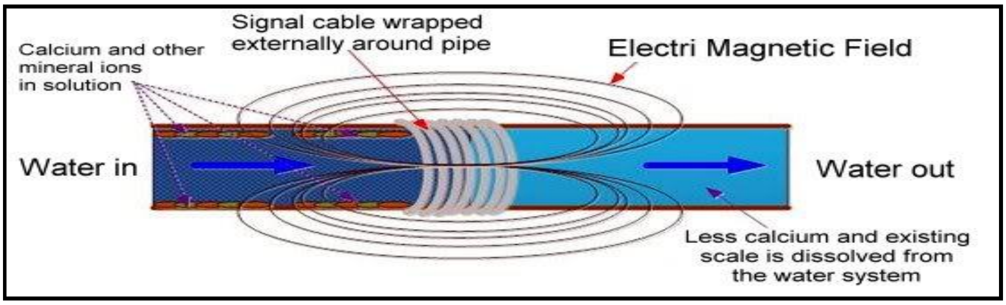


Fig 1.6 Electromagnetic water mechanism [Autofill Systems Pvt Ltd.]

1.3.2 Electro-Magnetic Device

The electromagnetic device which consists of two components namely electronic water conditioner and magnetic water conditioner. The electromagnetic device generates a strong sweeping frequency magnetic frequency on the pipeline which carries the water flow. The electronic water conditioner uses a series of controlled complex modulating high frequency waveform. This field effectively agitates different size molecules likely to form scale and to break the bonds between molecules and water. The magnetic water conditioner consists of one or more permanent magnets affixed either to interior or exterior of the pipe carrying water. The two components are joined to a terminal and this terminal is then connected to a power supply.

1.3.3 Electro-Magnetic Water Mechanism

The Electro-Magnetic Machine is properly set up and is connected to a power source. The water is allowed to pass through the machine at a flow rate of about 200ml/min. The water is made to pass through the machine at this rate for at least three times in succession. This ensures complete electro-magnetizing of the water. A small pump is used for the circulation of water through the machine. Hence, the water coming out of the machine by following the above procedure is electromagnetized and is called as electromagnetic water. It requires 24 hours for complete electromagnetizing of the water which may help in increasing the strength of the concrete.

1.4 Recycled Fine Aggregates

1.4.1 History of Demolished Concrete Waste

One of the things, builders, developers and contractors must consider during construction, renovation or demolition is where to put all the debris. Studies and experiments are being done to find solution considering the present situation, preservation of the environment and economic purposes. Since, there is an increasing environmental problem regarding the waste disposal to landfills, it is necessary to think of possible ways on how to avoid these problems with safety and convenience at the same time, and that is, to recycle. When structures made of concrete are to be demolished, concrete recycling is an increasingly common method of disposing of the rubble. Concrete debris was once routinely shipped to landfills for disposal, but recycling has a number of benefits that has made it more attractive option in this age of greater environmental awareness, more environmental laws, and the desire to keep construction costs down. It is beneficial in two ways: it reduces the inputs (energy and raw materials) to a production system and reduces the amount of water produced for disposal.

Fig 1.7 Demolished waste collected from site

1.4.2 Replacement of Natural Fine Aggregates [NFA] with Recycled Fine Aggregates [RFA]

There are several extraneous matters in the demolished waste obtained from a structure such as various types of dirt, steel, lumber, finishes, hardware's, cladding materials, plastics, woods, etc. Mechanical devices such an impact crusher, jaw crushers, swing hammer crushers, etc are used in the process of removal of impurities and crushing of rubble into suitable and desirable aggregate particle size can be carried out in a continuous and sequential manner. Dry, wet and thermal are three processes for processing demolished waste. Based on the literature survey, it is observed that recycled aggregates can be used by replacing natural fine aggregates in concrete from 10-65% [20].

Fig 1.8 Jaw crusher to crush the demolished waste

1.5 Scope of Work

Nickel based shape memory alloys (SMAs) have attracted much attention in the research community. The problem of large amount of demolished waste also arises which leads us to the usage of recycled aggregates in concrete. In order to overcome the problem of decrease in strength of concrete due to recycled aggregates as per studies, electromagnetic water can be used in concrete which is said to be increasing the overall strength of concrete. In the present research, experimental investigation is carried out on various types of concrete mix to study the effect of recycled fine aggregate in concrete, to study the comparison of normal water concrete and electromagnetic water concrete and to show the structural performance of SMA fibers reinforced concrete.

The mechanical properties of nickel based SMA fiber reinforced concrete are compared with reference mix of M35 grade concrete. Here, natural fine aggregates are replaced with recycled fine aggregate as 35%, 50% and 65% respectively. Also recycled fine aggregate concrete with 1% SMA fibers is studied and results are compared with reference mix along with 1% SMA fibers with normal as well as electromagnetic water respectively. All types of concrete mix are tested for workability, compressive strength, tensile and flexural strength as well as crack width closing ability due to SMA fiber reinforcement.

1.6 Problem Statement

1. Exploring the effect of replacement of 35%, 505 and 65% natural fine aggregate by recycled fine aggregate on the strength properties of concrete with normal water.
2. Examining effects of electro-magnetic water as compared to normal water and the increase in concrete strength properties as well as workability with all types of concrete mix.
3. Experimental investigation and comparison of performance of Nickel based SMA fibers (0.6mm diameter and 30mm length) with natural fine aggregates partially replaced by recycled fine aggregates with normal as well as electromagnetic water.

4. Investigating the 7 and 28 days results comparison between concrete mix types of eight types viz plain concrete reference mix, 1% SMA fibers in plain concrete reference mix, concrete with replacement of natural fine aggregates with 35% recycled fine aggregates, 1% SMA fibers in concrete with replacement of natural fine aggregates with 35% recycled fine aggregates, concrete with replacement of natural fine aggregates with 50% recycled fine aggregates, 1% SMA fibers in concrete with replacement of natural fine aggregates with 50% recycled fine aggregates, concrete with replacement of natural fine aggregates with 65% recycled fine aggregates, 1% SMA fibers in concrete with replacement of natural fine aggregates with 65% recycled fine aggregates.

Table 1.2 Design input data

Description	Design Data
Grade of concrete	M35
SMA fibers	Grade AISI 304L Nickel based SMA of 0.6mm diameter and 30 mm length
Water set up	Electromagnetic device consisting two parts i.e Electronic water conditioner and Magnetic water conditioner.
Recycled fine aggregates	Crushed Demolished Waste
Code standard	IS: 10262-2009, IS: 2720(Part 4)-1985, IS: 7320-1959, IS: 526-1959, IS: 456-2000
Compression test	CTM
Split Tensile test	CTM
Cube size	150 mm x 150 mm x 150 mm
Cylinder size	150 mm diameter and 300 mm height

1.7 Aim and Objectives

The primary aim of the present study is to investigate the effect of SMA fibers on the strength properties of concrete with partial replacement of natural fine aggregates with recycled fine aggregates along with normal as well as electro-magnetic water. Based on present literature review following objectives are drawn:

1. To study various literatures and find out the best combination of alloys to manufacture SMA fibers that can help in retaining the strength of the concrete when natural fine aggregates are partially replaced with recycled fine aggregates.
2. To analyze various literature studies to decide the aspect ratio of the SMA fibers, percentage of reinforcement of SMA fibers and conventional placement of SMA fibers in the specimen sections which will enhance the strength of the concrete.
3. To study the mechanical properties of the concrete with recycled fine aggregates as partial replacement with natural fine aggregates.
4. To study the effects of electromagnetic water on the properties of recycled aggregate concrete and to inhibit in the concrete mix in order to enhance the strength.
5. To study the effect of SMA fibers on the compressive strength, split tensile strength and crack closing ability of recycled aggregate concrete and compare the results with reference mix concrete.
6. To calculate relative flexural strength based on experimental compressive strength with reference to IS 456:2000.
7. To carry out the cost analysis of SMA fibers with various other types of fibers which can be used.
8. To suggest the optimum percentage of replacement of natural fine aggregate with recycled fine aggregate in concrete with and without electromagnetic water respectively.

1.7 Dissertation Outline

This dissertation contains six chapters. The complete study is presented in the following chapter wise manner:

Chapter 1: This chapter consists of introduction of shape memory alloy, electromagnetic water, recycled aggregates, history, advantages, scope of work, problem statement, aim and objectives.

Chapter 2: This chapter covers review of literature on development and application of SMA in RC structures in brief, which are useful to understand the advantages of nickel-based shape memory alloy in comparison with conventional reinforcement and FRC, use of recycled fine aggregates and effects of electromagnetized water on the properties of concrete.

Chapter 3: This chapter gives details about materials required and the concrete mix deign.

Chapter 4: This chapter gives details about experimental program involving experimental setup.

Chapter 5: In this chapter, comparison of workability, compressive strength, tensile strength, flexural strength and crack width closing ability of various mix proportions with and without electromagnetic water are summarized with graphs.

Chapter 6: This chapter covers conclusions made from obtained results as well as future scope.

Chapter 2

Literature Review

2.1 General

This chapter reviews the previous work done related to the shape memory alloy, electromagnetic water and partial replacement of recycled aggregates as fine aggregates in concrete. The literature survey carried out to serve three purposes, firstly, it was meant for obtaining a complete picture of various material combinations for shape memory alloy and their performance, experimental analysis, numerical analysis, vibration control for various applications and its optimizations. Secondly, to obtain a brief information regarding the use of electromagnetic water, its uses, its applications and workability. Thirdly, the study of why recycled aggregates must be used, its research and related information was found out. It was observed that, nickel based shape memory alloy is best for using as fibers in concrete in order to enhance the tensile strength and the re-centering ability of concrete. Also, it is figured out that electromagnetic water helps in increasing the compressive strength of concrete. Recycled aggregates can be partially replaced by fine aggregates up to 65 percent respectively.

2.2 Literature Review

Fukuta et al. (2004) carried out an experimental study on stress-strain property of shape memory alloy and its application to self-restoration of structural members. The mortar beam with SMA wires was examined to verify the potential self-restoration capacity. The test results revealed that the beam with SMA wires almost recovered after incurring an extremely large deformation, in comparison with that of the beam with steel wires. This result suggests that the SMA Rebars is added self-restoration capacity to concrete beams.

Li (2007) carried out a study on reinforced concrete beams strengthened using shape memory alloy wires in combination with carbon-fiber-reinforced polymer plates. The results indicate that recovery forces of SMA wires can decrease deflections and even close cracks in the concrete. The recovery rate of deflection of the beam increases with increasing the ratio of SMA wires. The effectiveness of this strengthening method for RC beams is verified by experimental and numerical results.

Yazici et al. (2007) studied the effect of aspect ratio and volume fraction of steel fibers on the mechanical properties of concrete which includes compressive strength, tensile strength and flexural strength. The authors found that increase in aspect ratio and volume fraction reduced the workability of concrete. The optimum aspect ratio for steel fibers was found between 50 and 100 and the volume fraction was found in between 0.5% and 1.5%. The steel fibers were found to significantly increase the strength properties of concrete.

Ahmed (2009) studied the effect of magnetic water on engineering properties of concrete. Results showed that the strength of concrete prepared with magnetized water increased by 10 to 20%, the use of magnetic water increased workability and strength, it’s a good phenomenon, since conventional increase in workability by adding water leads to a decrease in strength of concrete.

Orvis (2009) carried out the prestressing concrete with shape memory alloy fibers. It was found that without the prestraining, the prestressing force in the wire would be about 25 percent less and it would cost half to a third as much. A larger number of smaller diameter fibers is better than a low number of larger ones. The bondage between the Nitinol and the concrete can be improved. While prestressing concrete with steel cables went very smoothly, prestressing concrete with Nitinol had a number of challenges. It is possible to prestress concrete using Nitinol wires and fibers, but more research is needed.

Shajil et al. (2009) investigated the pseudo elastic behaviour of a Cu-Al-Mn based and compare it with that of Cu-Al-Be and Ti-Ni alloys. Results revealed that a typical Cu-Al-Mn-Ni based pseudo elastic alloy has been shown to exhibit better pseudo elastic behaviour over a large number of cycles as compared to a conventional Cu-Al-Be alloy. Dissipation energies of the order of 1 to 1.7 MJ/m3/cycle are realizable over a number of cycles > 200 at large strain amplitudes in these alloys. Ti-Ni wire shows ideal pseudo elastic behaviour with well-defined upper and plateaus that persist over a large number of cycles.

Karam and Al-Shamali (2010) studied the effect of using magnetized water on concrete properties. Test results concluded that the strength of concrete prepared with MW increased by 10 to 15 %, other mechanical properties such as tensile strength and flexural increased by 7 to 28 %, workability of concrete increased that eventually led to enhanced quality of concrete without adding water and the enhancement of concrete quality is an evidence of the effect of using MW in preparing concrete.

Mirzaee et al. (2010) carried out the experimental Investigation of compressive concrete elements confined with shape memory Ni-Ti wires. Results showed that applying the confining pressure using the Ni-Ti SMA wires improved compressive strength and ultimate strain of the concrete cylinders by 200% and 1500% respectively.

Shin and Andrawes (2010) carried out experimental investigation of actively confined concrete using shape memory alloys. The results of the study show that SMA spirals exhibit stable recovery stress under monotonic and cyclic loading. The compression test results indicate that the SMA spirals are effective in applying large and reliable active confining pressure on the tested concrete specimens. Additionally, the concrete cylinders confined with the SMA spirals show significantly higher ultimate strain and slightly higher strength compared to those of the GFRP passively confined cylinders.

Gholizadeh and Arabshahi (2011) studied the effect of magnetic water on strength parameters of concrete. Based on their research, magnetic water that caused the average compressive strength of samples has 23% more than that of samples made by ordinary water. The experimental results have also shown the advantages of magnetic samples in concrete industry because of increase in plasticity, efficiency and resistant in comparison with non-magnetic samples.

Numa (2011) studied the strength and toughness of HDPE fiber reinforced recycled aggregate concrete as a sustainable aggregate material. Given adequate curing time, Recycled Aggregate Concrete (RAC) with 10 % cement and 10% fly ash exhibited greater compressive and split tensile strengths than RAC with 20% cement and no fly ash. The inclusion of HDPE fiber reinforcements can increase strain capacity and improve overall toughness of the composite. It also was found that a Fiber Factor of 6 produced the highest toughness results.

Park et al. (2011) compared the cyclic behavior of concrete cylinders confined by shape memory alloy wire or steel jackets. This study showed the cyclic behavior of an SMA wire during a cyclic test. The SMA wire showed a hysteretic loop for each cyclic loading, and the stress of the wire increased overall with increasing circumferential strain.

Alam et al. (2012) investigated the seismic performance of concrete frame structures reinforced with superelastic shape memory alloys. It was observed that he SMA-RC joints performed better in terms of recovering post-elastic rotations. The unique feature of such SMA-RC joints makes it very attractive in highly seismic regions where it is not only able to dissipate energy, but also remain functional even after strong earthquakes.

Lei (2012) investigated the simulation and analysis of shape memory alloy fiber reinforced composite based on cohesive zone model. It was found that to better utilize the superelastic effect of SMA, a reasonable fiber ratio and perfect interface in research model is necessary. It can be easily introduced into the finite element method which would be useful for strength evaluation and design of composites structures. Furthermore, the results obtained from tests and stimulation will be helpful to SMA smart structure composite design.

Abdulridha et al. (2013) studied the behaviour and modelling of super elastic shape memory alloy reinforced concrete beams. The experimental results demonstrated the superior capacity of the SMA beams to recover inelastic displacements. The SMA beams sustained displacement ductility and strength capacity comparable to conventional beams. Crack widths and crack spacing were larger in SMA beams; however, upon removal of load, the crack openings were recovered. Energy dissipation was lower in SMA beams especially when subjected to reverse cyclic loading. The constitutive model based on a tri-linear backbone envelope response and linear unloading and reloading rules provided satisfactory results.

Shajil et al. (2013) investigated the load-deformation characteristics of NiTi SMA fiber reinforced cement mortar beams under cyclic loading to assess the self-centering mechanism. The study involved experiments on a beam structure and related analysis for the prediction of self-centering. Results showed that shape memory alloy reinforced cement mortar has very good self-centering properties that may be crucial in bringing back the functionality of a structure and prevention of permanent secondary deformations that may lead to catastrophic failure in some structures.

Czaderski et al. (2014) investigated the feasibility of iron-based shape memory alloy strips for prestressed strengthening of concrete structures. The study demonstrated the general feasibility of Fe-SMA strips in prestressed NSMR. The recovery stresses were in the range of 250–300 MPa. A sufficient bond behaviour was observed. Concrete bars could be successfully prestressed with a centrally embedded Fe-SMA strip.

Naghashia et al. (2014) carried out actuation curvature limits for a composite beam with embedded shape memory alloy wires. It was observed that the limiting stress in the SMA wires defines an upper actuation temperature, which falls in the range of composite glass transition temperatures. Which of these two factors become limiting will depend on the system. The SMA actuation strain will only become limiting for the most compliant of composite hosts.

Reddy (2014) studied the influence of magnetic water on strength properties of concrete. Test results show that the compressive strength of magnetized water concrete is more than that of nwc by 55%, the tensile strength of concrete was improved by 18% when magnetic water was used instead of normal water for preparing concrete and the flexural strength of magnetized water concrete is more than that of nwc by 25%. Also magnetized water concrete cylindrical specimens are found to be 59 % stiffer than normal water concrete cylindrical specimens.

Shin and Andrawes (2014) carried out a parametric study of seismically retrofitted bridge RC columns using Shape Memory Alloys. The parametric study results showed that for the range of values considered in this study, the effect of confinement is more prominent on the displacement ductility of columns with: 1) axial load less than or equal to 20% of the column’s gross section nominal capacity, and 2) slenderness ratio smaller than 6:1. In conclusion, this study helped in shedding the light on important design aspects of the innovative active confinement technique using thermally prestressed SMA spirals.

Behera et al. (2014) discussed the concerns arising from the large-scale use of natural resources in the construction industry. The authors had given a brief status on the recycled aggregate concrete from recycled aggregate. An attempt had been made to summarize and analyze the important findings on the subject in the past few years. According to the authors there was no significant reduction in compressive strength of concrete up to 30% replacement of natural aggregates by recycled aggregates.

Khakimova et al. (2015) carried out the experimental investigations on shape memory alloy fiber reinforced concrete by using randomly distributed SMA fibers in concrete. Test results were analysed in terms of tensile strength capacity, mid-span deflection, and crack width for each specimen. Both splitting tensile tests and cyclic flexural tests were conducted. The tensile test results showed that increasing the SMA fiber percentage decreases the tensile strength. Flexural test results indicate that SMA fibers reduce the crack width and development.

El-Tahan et al. (2015) carried out the development of a self-stressing NiTiNb shape memory alloy (SMA)/fiber reinforced polymer (FRP) patch. The paper concludes with an experimental study that evaluates the patch response during activation subsequent monotonic tensile loading. The results demonstrate that the self-stressing patch with NiTiNb SMA is capable of generating a significant prestressing force with minimal tool and labor requirements.

Gordon (2015) highlighted on the shape memory alloy fiber-reinforced mortar. In this study, the flexural strength and self-centering properties of NiTi fiber-reinforced mortar were tested at varying lengths and volume fractions. The 30 mm fibers were significantly more effective at self-centering than the 20 mm fibers. The 0.5% volume fraction specimens decreased in strength compared to the 0.3%, 30 mm specimens, but had better residual deformation values. The 1.0% volume fraction specimens maintained the highest strength and should be tested further to explore their self-centering properties.

Mishra and Ravindra (2015) explained a comparison of conventional and iron-based shape memory alloys and their potential in structural applications. Conclusion showed that the potential for iron-based SMAs seems to be vast, and are bound to overtake their Nitinol counterparts, since they show similar, if not better properties under the same conditions and are cost effective as well. SMAs may not be suitable as the sole reinforcement component, if used in conjunction with steel and a certain balance be achieved, it can serve to not only lower costs, but also optimize performance of said structures. SMAs can aid the reparation process, but structures reinforced with them have been capable of withstanding further damage as well.

Billah and Alam (2016) investigated the bond behavior of smooth and sand-coated shape memory alloy (SMA) rebar in concrete. The test results are explored to evaluate the influence of concrete strength, bar diameter, embedment length, and surface condition. Surface modification using sand coating notably improved the bond strength of SMA rebar. Finally, empirical equation based on statistical analyses is presented to predict the maximum average bond strength. The proposed equation reasonably calculates the average bond strength of SMA reinforcing bars in concrete.

Chavan et al. (2016) highlighted enhancing the properties of concrete using electromagnetic water. From the experimental work, it can be concluded that electromagnetic water can be used in construction if there is shortage of water, it increases the strength of concrete so it can help in reducing the dosage of cement, it increases the workability which helps in reducing the use of water and it also helps in preventing the scaling caused by salts and minerals.

Choi et al. (2016) investigated new SMA Short Fibers for Cement Composites Manufactured by Cold Drawing. This study illustrates that diameter bulging of prestrained SMA fibers in mortar due to heating generated additional confining pressure around the fibers and increased the pullout force by increasing frictional resistance. Finally, this study introduced an example applying SMA fibers to close and cure cracks developed in concrete beams including an experimental result.

Daghash and Ozbulut (2016) studied the superelastic shape memory alloy fiber-reinforced polymer composites. The results of the tests are assessed in terms of ultimate strength, ultimate strain, residual strain, and failure modes of the composites. It was found that compared to the other SMA/CFRP, SMA/GFRP, or SMA/epoxy composites, the fabricated SMA-FRP composite showed a comparable tensile strength and ability to recover strains, with the use of only 4.9% SMAs. The overall behavior of the composite can be further enhanced by using higher volume fraction of SMA wires with larger wires' diameter to eliminate the possibility of having a condensed coupon.

Daghash and Ozbulut (2016) carried out the characterization of superelastic shape memory alloy fiber-reinforced polymer composites under tensile cyclic loading. Results revealed that the SMA-FRP composites can recover relatively high strains upon unloading and exhibit very high failure strains. In general, tests results, failure modes and SEM images confirmed the composite action between the SMA wires and the epoxy matrix. Embedding SMA fibers into epoxy composites can provide increased damping, ductility, re-centring capability and large ultimate strains.

Monish et al. **(2016)** studied utilization of demolished waste as fine aggregate in concrete. Its objective was to utilize demolished waste as 10%, 20% and 30% fine aggregate and increase the strength of concrete. Test results showed the compressive strength of recycled concrete with 10% fine aggregate replacement by demolished waste at the end of 28 d has been found to be marginally lower than that of conventional concrete.

Kim (2016) studied direct tensile behaviour of shape-memory-alloy fiber-reinforced cement composites. It was found that the shape memory effects, activated by heat treatment, of short dog bone shaped SMA fibers embedded in a mortar mix clearly developed pre-stressing effects on the tensile behavior of SMA-FRCC's. It was concluded that further study is needed to investigate the temperature of SMA fiber embedded in a mortar matrix and to develop an effective method for activating the shape memory effects.

Shahverdi et al. (2016) highlighted the strengthening of RC beams by iron-based shape memory alloy bars embedded in a shotcrete layer. The results showed that the application of ribbed Fe-SMA bars embedded in a newly applied shotcrete layer on the bottom side of RC beams was successful and the strengthening technique worked well.

Suhail et al. (2016) carried out heat activated prestressing of shape memory alloys for active confinement of concrete sections. The results from this study demonstrate that the chemical composition of NiTiNb along with level of pre-strain and the corresponding transformation temperature range significantly affects the HAP, which in turn can affect the efficacy of the retrofitting strategy in which NiTiNb is used as a means to apply active confinement.

Phonde et al. (2017) carried out the experimental Investigation of effect of sulphates and chlorides on durability of normal and electromagnetic water M40 grade concrete. The results showed that the compressive strength of cubes with electromagnetic water was found to be more than that of normal water with Fly Ash as substitute in all the cases. And is optimum for M40+30% Fly Ash, which shows 13.13% increase in strength compared to that of normal water concrete.

2.3 Critical Appraisal

According to the research papers:

1. It has been reviewed that the use of of SMA materials is used more in the fields of aerospace, automotive, biomedical and construction. SMA materials like Nitinol have also been used in construction field but it had not been proved more effective as per the factors like low alarming, more cost and such other factors. Among the existing group of SMAs, NiTiNb has been found to be the most suitable SMA for active confinement. Further, many different compositions of NiTiNb has been studied in the past and has been found that they can have significantly different behaviour. Iron-based shape memory alloys (Fe-SMA) and their potential in structural applications showed that the potential for iron-based SMAs seems to be vast, and are bound to overtake their Nitinol counterparts, since they show similar, if not better properties under the same conditions and are cost effective as well. Load-deformation characteristics of NiTi SMA fiber reinforced cement mortar beams under cyclic loading to assess the self-centering mechanism. The Cu-Al-Mn-Ni based pseudo elastic alloy has been shown to exhibit better pseudo elastic behaviour as compared to a conventional Cu-Al-Be alloy.
2. The use of electromagnetic water by replacing potable water in concrete significantly increases the compressive strength of the concrete as well as tensile and flexural capacities to some extent. Electromagnetic water can be used in construction as it increases the compressive strength and the workability of which helps in reducing the use of water.
3. There are many studies that prove that concrete made with this type of fine aggregates can have mechanical properties similar to those of conventional concretes and even high-strength concrete is nowadays a possible goal for this environmentally sound practice. It was found that the strength of concretes using recycled fine aggregates with partial replacement with natural fine aggregates completely depends on the quality and characteristics of recycled aggregates.

Hence, on using SMA fibers of best combination of alloys reinforcement in concrete and replacing the conventional potable water by electromagnetic water in concrete might enhance the properties of concrete including tensile, compressive and flexural strength as well as re-centering ability of concrete. Recycled aggregates can be used for the utilization of demolished waste.

Chapter 3

Materials and Concrete Mix Design

3.1 Material Mix

In this part, a concise description on the materials used, methods used to acquire them and tests conducted on them to determine their physical and chemical properties are discussed.

3.1.1 Cement

The cement used in this experimental work is 53 Grade Cement. 53 grade cement was an Ordinary Portland Cement which surpasses the requirements of IS 12269-1987 for 53 grade. It is produced from high quality clinker ground with high purity gypsum. It provides high strength and durability to structures because of its optimum particle size distribution, superior crystalline structure and balanced phase composition. Table 3.1 shows the physical properties of cement and table 3.2 shows the chemical properties of the cement.

Table 3.1 Physical Properties of Cement [ACC Ltd.]

Particulars	**OPC Grade 53 IS 12269 – 1987**
Compressive strength	
a) 3 days	27 (Min)
b) 7 days	37 (Min)
c) 28 days	53 (Min)
Fineness (m^2 / kg)	225 (Min)
Setting Time (Minutes)	
Initial Setting Time	30 (Min)
Final Setting Time	600 (Max)
Soundness	
a) Autoclave (%)	0.8 (Max)
b) Le-Chatelier (mm)	10 (Max)

Table 3.2 Chemical Properties of Cement [ACC Ltd.]

Sr. No.	**Particulars**	**Unit**	**OPC Grade 53 IS 12269 – 1987**
1	Loss on Ignition	%	4.0 (Max)
2	Sulphuric Anhydride (By Mass)	%	3.0 (max)
3	MgO (By Mass)	%	6.0 (By Mass)
4	Insoluble Residue (By Mass)	%	3 (Max)
5	Chloride Content (By Mass)	%	0.1 (Max)
6	Lime Saturation Factor	Ratio	0.80 Min and 1.02 Max
7	Alumina Ratio	Ratio	0.66 (Max)

3.1.2 Fly Ash

TATA fly ash Class C of specific gravity 2.2 is used in the mix confirming to IS:3812 Part1-2013. In the presence of water, Class C fly ash hardens and gets stronger over time. It generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) are generally higher in Class C fly ash.

3.1 3 Coarse Aggregate

Two types of aggregates are used for this investigation viz. 20 mm and 10 mm. The various types of tests were performed on the coarse aggregates as per IS 2386:1977-Methods of tests for aggregate of concrete. Sieve analysis was performed according to IS 383:1970-specification for coarse aggregate and fine aggregate. The average results of the various tests of three samples of the coarse aggregate used are shown in the table 3.3.

Table 3.3 Coarse aggregate test results

Type of Coarse Aggregate	Type of Test			
	Specific Gravity	**Water Absorption**	**Moisture content**	**Fineness Modulus**
20 mm	2.82	1.62%	0.12%	6.5
10 mm	2.79	1.83%	0.80%	5.7

3.1.4 Natural Fine Aggregate [NFA]

The crushed rock fine [CRF] aggregates are used which is conforming to zone II and maximum size was 4.75 mm. The testing of crushed rock fine aggregate was done as per IS: 383-1970. The average test results of three samples of the natural fine aggregate used are shown in table 3.4.

Table 3.4 Natural fine aggregate test results

Type of Fine Aggregate	Type of Test				
	Specific Gravity	Water Absorption	Moisture content	Fineness Modulus	Zone
Crushed Rock Fine	2.53	4.52%	1.10%	2.3	II

3.1.5 Recycled Fine Aggregate [RFA]

Construction waste collected from a site located at Kalina, Santa Cruz, Mumbai, Maharashtra, India. The structure was about 10 years old and the concrete debris was separated from brickwork and other wastes. The demolished waste was collected from the beams and columns. The demolished waste was crushed to a consistency of fine aggregates as it had to be partially replaced by fine aggregates. The recycled fine aggregates collected was later sieve analyzed according to IS 383:1970-specification for coarse aggregates and fine aggregates and tests were conducted on aggregates as per IS 2386:1977-Methods of tests for aggregate of concrete. The RFA is of coarse fine conformed to zone II. The average test results of three samples of the recycled fine aggregate used are shown in table 3.5.

Fig 3.1 Crushing of demolished waste in a crusher

Table 3.5 Recycled fine aggregate test results

Type of Fine Aggregate	Type of Test				
	Specific Gravity	**Water Absorption**	**Moisture content**	**Fineness Modulus**	**Zone**
Recycled Fine Aggregate	2.27	10.37%	0.40%	3.1	II

3.1.6 Nickel based Shape Memory Alloy Fibers

The selected shape memory alloy [SMA] fibers are of grade nickel based. The aspect ratio selected was 50, where the diameter of fiber is 0.6 mm and the length of fiber is 30 mm. Initially the fibers were received in the form of wires of 0.6 mm diameter. The wires were later cut by a standard cutter into 30 mm sections. It was taken care that the tolerance in the size of fiber was not more than 10%. Table 3.6 shows the chemical composition of the selected nickel based shape memory alloy.

Table 3.6 Mechanical Composition of selected Nickel based Shape Memory Alloy (Austenitic) [Special Metals Ltd.]

Tensile Strength (MPa) Min	Yield Strength (MPa) Min	Percentage Age Elongation in 50mm Gauge Length Min	Hardness (Max)	
485	170	40	201	92

Fig 3.2 Nickel based shape memory alloy fibers

3.1.7 Water

Concrete mix with M35 grade concrete is manufactured with normal or electromagnetic water. Electromagnetic water is extracted after passing normal water through the electromagnetic device for 24 hours and then immediately it is use in concrete manufacturing. The TDS test of the water was done. TDS is Total Dissolved Solids which comprise of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates). After the TDS test, the results of the normal water used were 1250mg/l which is in poor condition.

3.1.8 Admixture

The admixture used is TP Build Tech Aqualoc TP350. This admixture is Polycarboxylate Ether (PCE) dispersed polymer. This is a low-cost admixture which is a new generation super-plasticizer based on polycarboxylate technology. This product is designed to provide medium to high water reduction, while providing excellent flow ability during placement and excellent slump retention without affecting initial setting time. This product was designed to produce super high-strength, flowable and self-consolidating concrete in a variety of applications. The properties of the admixture are as given in the table 3.7.

Table 3.7 Properties of Admixture Aqualoc TP350 [ACC Ltd.]

Sr. No.	Characteristics	Requirements	Test Results
1	Appearance	Pale Straw Liquid	Pale Straw Liquid
2	Specific Gravity	Within ±0.02 of DV	1.104
3	pH at 27°C	Min 6	6.64
4	Dry Material content in %	Within 5% of DV	31.45
5	Cl	Nil-0.2 Max	NIL
6	Ash Content in %	Within ± 5% of DV	2.85

3.2 Mix Design

Concrete mix design is a step by step procedure to work out the various proportions of the ingredients which go to make concrete. The purpose of mix design is to find the approximate design and to achieve exact design for safety and economy for instant use. Minimum cement content, environmental exposure condition, maximum aggregate size, standard deviation, constant value of ‘t’, water cement ratio and grading limits of fine aggregates are taken from IS: 10262-2009 and is substituted in the fixed values used in the steps to get approximate mix design. Table 3.8 shows final batch weight in Kg/m^3 for M35 grade of concrete. The workability is kept as 170 mm as in actual practice; the concrete retention should be minimum of 3 hours.

Concrete Mix Design for M35 Grade Reference Mix

A) Design Stipulations

1. Characteristic Compressive Strength at 28 Days Field : 35 N/mm^2
2. Tolerance “t” : 1.65 (1 in 20)

3. Standard Deviation "SD"	: 5 (IS 456-2000)
4. Minimum Fineness	: 225 m^2/Kg
5. Standard Consistency	: 30.5%
6. Initial Setting Time	: 30 minutes
7. Final Setting Time	: 600 minutes
8. Specific Gravity	: 3.15
9. Degree of Quality Control	: "Very Good"
10. Workability of concrete at the pouring point	: 170 mm at site
11. Exposure	: Severe
12. Design method adopted in the mix	: IS 10262-2009
13. Aggregates confirmed to	: IS 2386-1963, IS 383-2016

B) Raw Materials Testing Data for the Design

1. Type of Cement	: OPC-53
2. Specific Gravity of Cement (Standard)	: 3.15
3. Brand of Fly-Ash	: TATA FLY-ASH
4. Grade of Fly-Ash	: Type C
5. Specific Gravity of Fly-Ash	: 2.2
6. Type of Aggregates	: Coarse Aggregates and Crushed Rock Fine Aggregates

Specific Gravity of Coarse Aggregate

1. 20mm	: 2.82
2. 10mm	: 2.77

Specific Gravity of Fine Aggregate

1. Crushed Rock Fine	: 2.52

Water Absorption

1. 20mm	: 1.62 %
2. 10mm	: 1.83%
3. Crushed Rock Fine	: 4.52%

Free Moisture Content

1. 20mm	: 0.12 %
2. 10mm	: 0.80%
3. Crushed Rock Fine	: 1.10%

C) Determination of Design Strength of Concrete

$F_{ck} = f_{ck} + t \times S_d$: 43.25 N/mm^2

Where, F_{ck} – Design Strength of Concrete,

f_{ck}– Characteristic Strength of Concrete,

t – Tolerance, S_d – Standard Deviation of Concrete

$F_{ck} = 35 + 1.65 \times 5$

D) Determination of Water-Cement Ratio

1. Maximum free water-cement ratio	: 0.45 (As per IS 456-2000)
2. Adapted free water-cement ratio	: 0.41 (based on experience)

E) Determination of Water Content in the Mix

Water content for MSA 20mm	: 186 litre
For 170mm slump, water content	: 214 litre
23% reduction in water content due to use of superplasticizer	: 165 litre

F) Determination of Cement Content in the Mix

1. Minimum Cement Content : 320 Kg/m^3

2. Adapted Cement Content : 440 Kg/m^3

$$\frac{165}{0.41} \times 1.10$$

3. Pozzolanic Fly Ash (PFA) Replacement : 22%

4. Pozzolanic Fly Ash (PFA) Content in the Mix : 100 Kg

5. Cement Content in the Mix : 340 Kg

G) Determination of aggregate volume in the Mix (for pumpable concrete)

Volume of coarse aggregate : 0.56

Volume of fine aggregate : 0.44

H) Mix Calculations per unit volume of concrete.

a) Total Volume of Concrete : 1 m^3

b) Volume of Cement

$$\frac{\text{Mass of Cement}}{\text{Specific gravity of cement}} \text{X} \frac{1}{1000}$$: 0.107 m^3

$$\frac{340}{3.15} \text{X} \frac{1}{1000}$$

c) Volume of Fly Ash

$$\frac{\text{Mass of Fly Ash}}{\text{Specific gravity of Fly Ash}} \text{X} \frac{1}{1000}$$: 0.045 m^3

$$\frac{100}{2.2} \text{X} \frac{1}{1000}$$

d) Volume of Water : 0.165 m^3

$$\frac{\text{Mass of Water}}{\text{Specific gravity of Water}} \times \frac{1}{1000}$$

$$\frac{165}{1} \times \frac{1}{1000}$$

e) Volume of Superplasticizer (0.8% by mass

of cementatious material)

$$\frac{\text{Mass of Admixture}}{\text{Specific gravity of Admixture}} \times \frac{1}{1000}$$: 0.0032 m^3

$$\frac{3.52}{1.1} \times \frac{1}{1000}$$

f) Volume of all in Aggregate

[a – (b + c + d + e)] : 0.680 m^3

g) Mass of Coarse Aggregate

(f x Volume of Coarse Aggregate x Specific : 1055 Kg

Gravity of Coarse Aggregate x 1000)

h) Mass of Fine Aggregate

(f x Volume of Fine Aggregate x Specific Gravity : 750 Kg

of Fine Aggregate x 1000)

Therefore,

Adopted 20mm in the mix : 655 Kg

Adopted 10mm in the mix : 400 Kg

Adopted CRF in the mix : 750Kg

Table 3.8 Final Batch weight in Kg/m^3 of M35 grade plain concrete

Cement (Kg/m^3)	**Fly Ash (Kg/m^3)**	**CFA-CRF (Kg/m^3)**	**CA-20mm (Kg/m^3)**	**CA-10mm (Kg/m^3)**	**Water (Kg/m^3)**	**Admixture (Kg/m^3)**
340	100	750	650	405	165	3.52

The mix proportion of reference mix for M35 grade of concrete of cement, fine aggregates, coarse aggregates and water as per IS 10262:2009 is 1:1.64:2.37:0.4.

Table 3.9 shows the mix proportions of various concrete mix types such as, reference mix which is plain concrete, 1% SMA reference mix is plain concrete with 1% SMA fibers replaced by the total volume of concrete, 35% RFA is concrete with natural fine aggregates replaced with 35% recycled fine aggregates, 1% SMA 35% RFA is 1% SMA fibers replaced by the total volume of concrete and natural fine aggregates replaced with 35% recycled fine aggregates, 50% RFA is concrete natural fine aggregates replaced with 35% recycled fine aggregates, 1% SMA 50% RFA is 1% SMA fibers replaced by the total volume of concrete and natural fine aggregates replaced with 50% recycled fine aggregates, 65% RFA is concrete with natural fine aggregates replaced with 65% recycled fine aggregates, 1% SMA 65% RFA is 1% SMA fibers replaced by the total volume of concrete and natural fine aggregates replaced with 65% recycled fine aggregates respectively.

Table 3.9 Final batch weight in kg/m^3 of M35 grade for all types of concrete mix

Component	**Cement**	**Fly Ash**	**Coarse Aggregate**		**Fine Aggregate**		**Fibers**	**Water**	**Admixture**
			10 mm	**20 mm**	**NFA**	**RFA**			
Reference Mix	340	100	645	396	724	-	-	205	3.52
1% SMA Reference Mix	340	100	645	396	724	-	10	205	3.52
35% RFA	340	100	645	396	470	237	-	222	3.52
1% SMA 35% RFA	340	100	645	396	470	237	10	222	3.52
50% RFA	340	100	645	396	314	293	-	222	3.52
1% SMA 50% RFA	340	100	645	396	314	293	10	222	3.52
65% RFA	340	100	645	396	254	438	-	236	3.52
1% SMA 65% RFA	340	100	645	396	254	438	10	236	3.52

Chapter 4

Experimental Program

4.1 Experimental Setup

This section deals with total experimental set up including the tests carried out on the aggregates, fresh concrete and hardened concrete. Fig 4.1 shows the flow chart on the tests carried on the coarse and fine aggregates. Fig 4.2 shows the tests carried out after the mix was prepared.

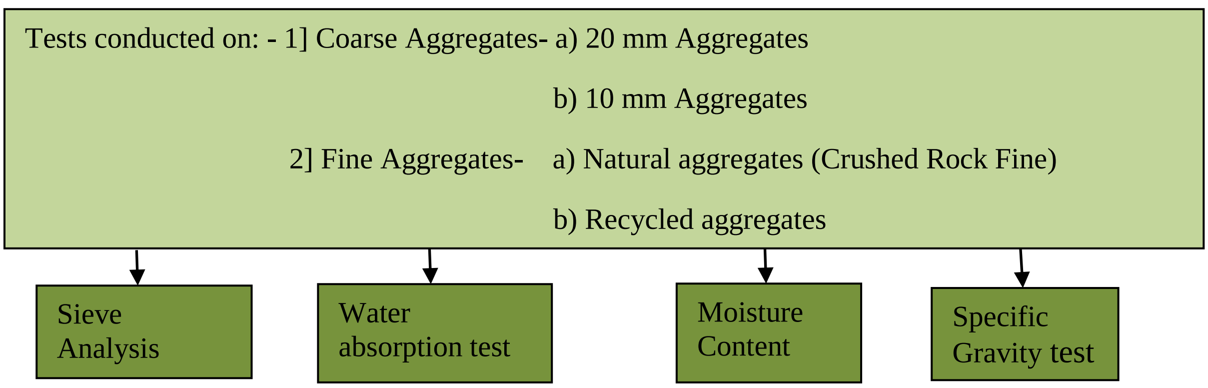


Fig 4.1 Flow chart showing the tests carried out on coarse and fine aggregates

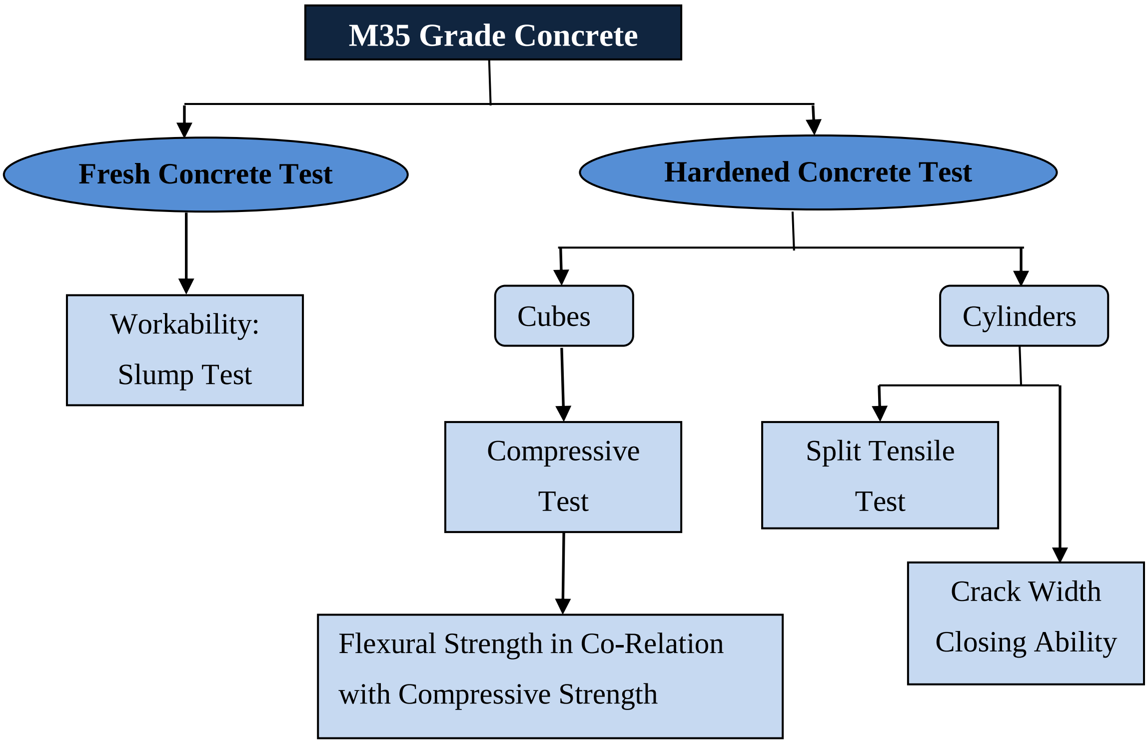


Fig 4.2 Flow chart showing the tests carried out after the mix was prepared

4.2 Experimental Procedure

The experimental procedure consists of the following:

1. Properties and tests of the materials: The properties of cement, fly ash, aggregates, water and admixture is obtained by using Indian standard methods of testing and obtained results are considered for designing concrete mix. Tests like water absorption, moisture content, specific gravity and sieve analysis to find out to fineness modulus conforming to IS: 2720(Part 4)-1985 were conducted.
2. Preparation of electromagnetic water: Circulating normal water from the electromagnetic device for 24 hours to turn the normal water into electromagnetic water which is to be used for comparison with the normal water.

Fig 4.3 Electromagnetic water setup

3. Batching: Placing the weighted mix into the mixer and adding the required percentage of fibers, percentage of recycled fine aggregate if required and normal or electromagnetic water.
4. Mixing: Combining all the concrete ingredients in two big flat drum mixers, one with normal water and the other with the water circulated for 24 hours which is the electromagnetic water. Fig. 4.4 shows the pan mixer.

Fig 4.4 Pan mixer

5. Fresh concrete test: In order to test the workability of the concrete, slump of concrete paste of both the mixes before the casting of samples were taken with a slump cone and a tamping rod conforming to IS: 7320-1974. Fig.4.5 shows the slump cone test.

Fig 4.5 Slump cone test

6. Placing of concrete: The oiled cube and cylinder moulds were filled with concrete by adapting the tamping method. Total of 6 cubes and 6 cylinders are casted; 3 cubes and 3 cylinders from normal water and 3 cubes and 3 cylinders from electromagnetized water.
7. Curing: The concrete and cylinder specimens from taken out from the moulds the next day and placed it in the curing tank for 7 and 28 days respectively.
8. Hardened concrete tests: Compressive strength and split tensile strength is measured by a compressive testing machine. The compressive strength and split tensile strength is the average of the three samples for each percentage. A compressive and split tensile test of different samples is done for 7 and 28 days respectively and results are compiled. The crack width closure was checked immediately after split tensile test, after 2 hours and then after four hours. The flexural test was done by co-relating the values of compressive strength as per the formula given in the IS 456:2000.
9. This procedure was repeated for each of the eight mix proportions.

4.3 Types of Tests

4.3.1 Compression Test

A cube compression test on 150 mm x 150 mm x 150 mm cubes was performed on CTM conforming to IS: 526-1959. The pace was set as 5.1 kN/sec. The compressive strength is carried out on minimum three samples of each type for 7 and 28 days respectively. Results of each tests were displayed on Enhanced Digital Indicator-MuCTM. Then by taking the average of the three, the final compressive strength was determined.

4.3.2 Split Tensile Test

A split tensile test is carried out on the cylinder of standard size 150 mm diameter and 300 mm height was performed on CTM conforming to IS: 526-1959. The pace was set as 1.4 kN/sec as per IS Code. Results of each tests were displayed on Enhanced Digital Indicator-MuCTM. The split tensile strength is carried out on minimum three sample of each type for 7 and 28 days respectively. The tensile strength of the specimen was calculated by using the formula:

$$\text{Tensile Strength } \sigma_{ct} = 2 \text{ x Peak Load} / \pi dl \ (N/mm^2)$$

4.3.3 Flexural Test

Flexural strength is determining by performing the flexural test on a concrete beam specimen. But in this study, it was determined in co- relation with the compressive strength.

According to IS 456: 2000 (Clause no. 6.2.2), in order to estimate the flexural strength from the compressive strength, the formula may be used:

$$\text{Flexural strength } f_{cr} = 0.7\sqrt{fck}\ (N/mm^2)$$

Where f_{ck} is the characteristic cube compressive strength of the concrete in N/mm^2.

4.3.4 Crack Width Closing Ability

Concrete frequently cracks no matter how well the job is done. There are various tests conducted to check the crack width of concrete such as Scanning Electron Microscopy (SEM), X-Ray Diffraction method (XRD) and test by using a Vernier Caliper. Scanning Electron Microscopy captures images from the cross sections of the concrete specimens and the images are then used to study the generation and interaction of the stress induced microcracks. X-Ray Diffraction method is a technique used to determine the crystalline phases present in concrete which helps in determining the cracks. Vernier Caliper is a simple method used in determining the crack width and does not require any set up. In this study, the crack width closing ability was checked with the help of a Vernier Caliper of an accuracy of 0.001. Crack width was measured immediately after the split tensile test, after 2 hours and then after 4 hours respectively. The crack closing width was then observed. Fig. 4.9 show the checking the crack width using Vernier Caliper.

Fig 4.4 Checking of crack closing width using Vernier Caliper

Chapter 5

Results and Discussions

5.1 General

Present study is focused on the effect of SMA fibers, effect of RFA and effect of electromagnetic water on various types of concrete mix in comparison with reference mix concrete. Slump cone test for workability, compression test on 96 concrete cube specimens and split tensile test on 96 concrete cylinder specimens is carried out in CTM after 7 and 28 days of casting respectively. Flexural strength is calculated in co-relation with compressive and crack closing ability is observed by using a Vernier Caliper. The results of compression, split tensile and flexural strengths of various types of concrete mix are analysed. The effect of replacement of 35%, 50% and 65% NFA by RFA on the strength and durability properties of concrete mixes has been investigated. The effect of electromagnetic water concrete on workability and strength properties of all types of concrete mix in comparison with normal water concrete is studied. The effect of SMA fibers added by volume of concrete by 1% on strength and durability properties is also investigated. The overall optimized comparative study is presented in following sections.

5.2 Workability

A concrete is said to be workable if it is easily transported, placed, compacted and finished without any segregation. The workability of concrete can be tested with the help of slump cone test or a flow table test. In this study, slump cone test was carried out and the target slump was kept as 170 mm in 60 mins as the retention period. Fig. 5.1 shows the workability of all the types of concrete mix with and without electromagnetic water. Table 5.1 shows the workability tests results of all the types of concrete mix. Results show that, overall workability is increased when electromagnetic water is used instead of normal water.

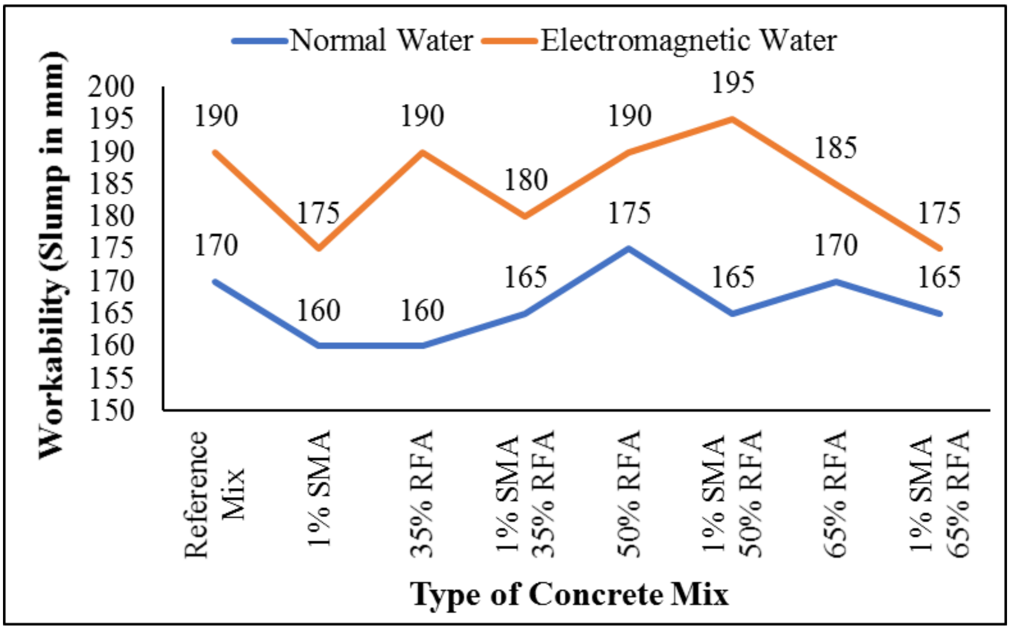


Fig. 5.1 Comparison of workability of normal and electromagnetic water of all types of concrete mix

Table 5.1 Workability test results of all types of concrete mix

Type of Concrete Mix	**Reference Mix**	**1% SMA Reference Mix**	**35% RFA**	**1% SMA 35% RFA**	**50% RFA**	**1% SMA 50% RFA**	**65% RFA**	**1% SMA 65% RFA**
Percentage Increase	10.52%	8.57%	15.78%	8.33%	7.89%	15.38%	8.10%	5.71%

5.3 Compressive Strength

Compressive strength is one of the most important properties of building materials. This section presents the results of the compressive strength after 7 days and 28 days of curing. Results are presented and respective comparison is made between them.

5.3.1 Effect of Recycled Fine Aggregates in Normal Water Concrete on Compressive Strength

Present results show the achieved strength is within the limit of target strength as per mix design calculations. The RFA helped in retaining as well as increasing the compressive strength of concrete as compared to the reference mix. Fig. 5.2 and table 5.2 show the 7 days compressive strength results for effect of replacement of NFA by 35%, 50% and 65% respectively with RFA.

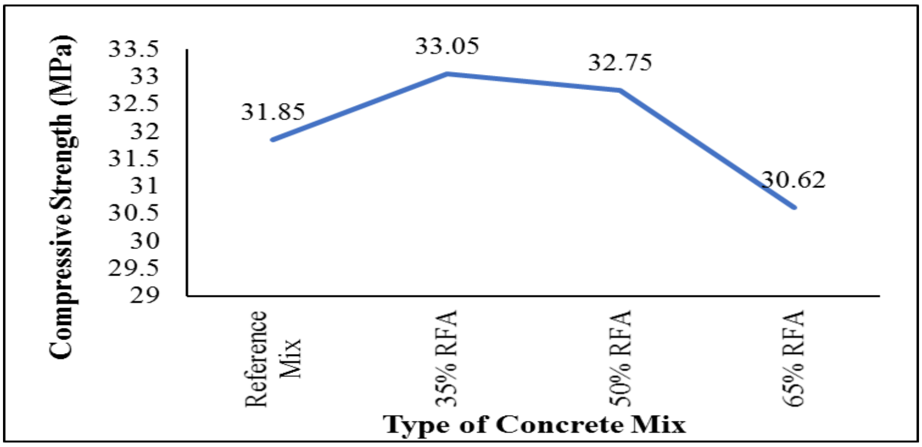


Fig 5.2 Comparison of effect of RFA on the compressive strength in 7 days

Table 5.2 Effect of RFA on 7 days compressive strength of all types of concrete mix

Type of Concrete Mix	Reference Mix	35% RFA	50% RFA	65% RFA
Percentage with Normal Water	-	3.63% Increase	2.75% Increase	4.02% Decrease

Further 28 days results also show the achieved strength is within the limit of target strength as per mix design calculations. Also, the RFA helped in retaining as well as increasing the compressive strength of concrete as compared to the reference mix. Fig. 5.3 and table 5.3 show the 28 days compressive strength results for effect of replacement of NFA by 35%, 50% and 65% respectively with RFA.

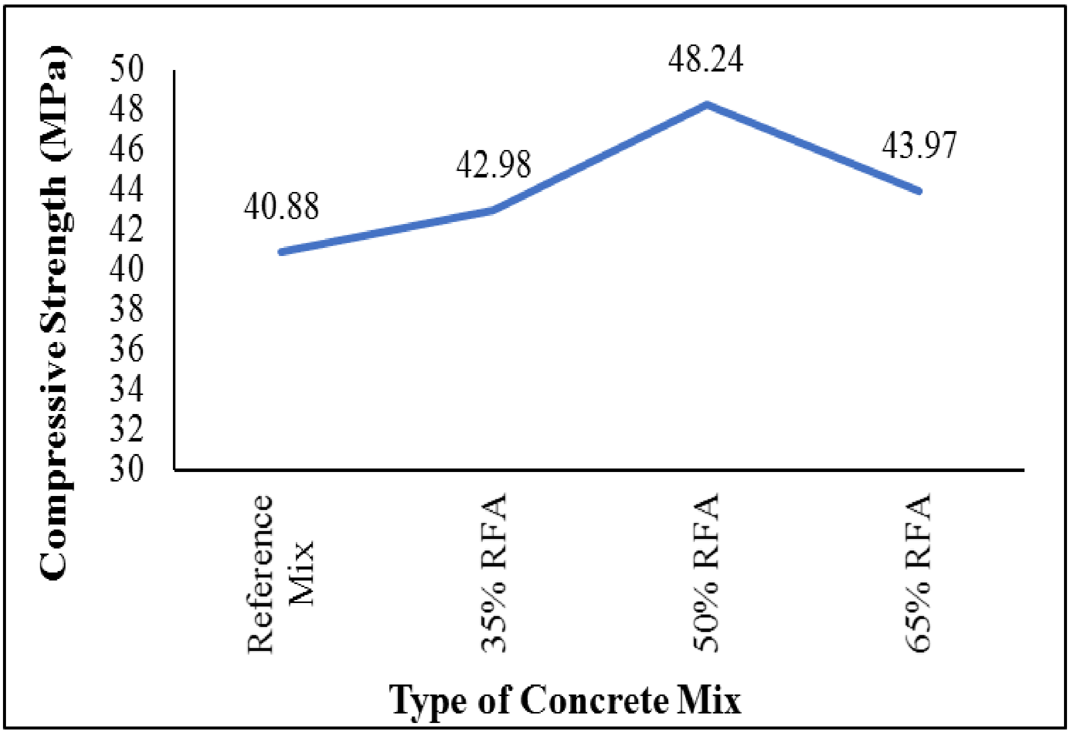


Fig 5.3 Comparison of effect of RFA on the compressive strength in 28 days

Table 5.3 Effect of RFA on 28 days compressive strength of all types of concrete mix

Concrete Mix Proportion	Percentage with Normal Water
Reference Mix	-
35% RFA	4.89% Increase
50% RFA	15.26% Increase
65% RFA	7.03% Decrease

5.3.2 Effect of Electromagnetic Water on Compressive Strength

Comparison was done for all the types of concrete mix with normal water and all the types of concrete mix with electromagnetic water i.e. water electromagnetized for 24 hours with an electromagnetic device. Fig. 5.4 and table 5.4 show the compressive strength of cubes with normal and electromagnetic water with all types of concrete mixes for 7 days. The overall results show that the compressive strength of concrete increased by 10% to 16% on using electromagnetic water in the concrete mix as compared to that of normal water.

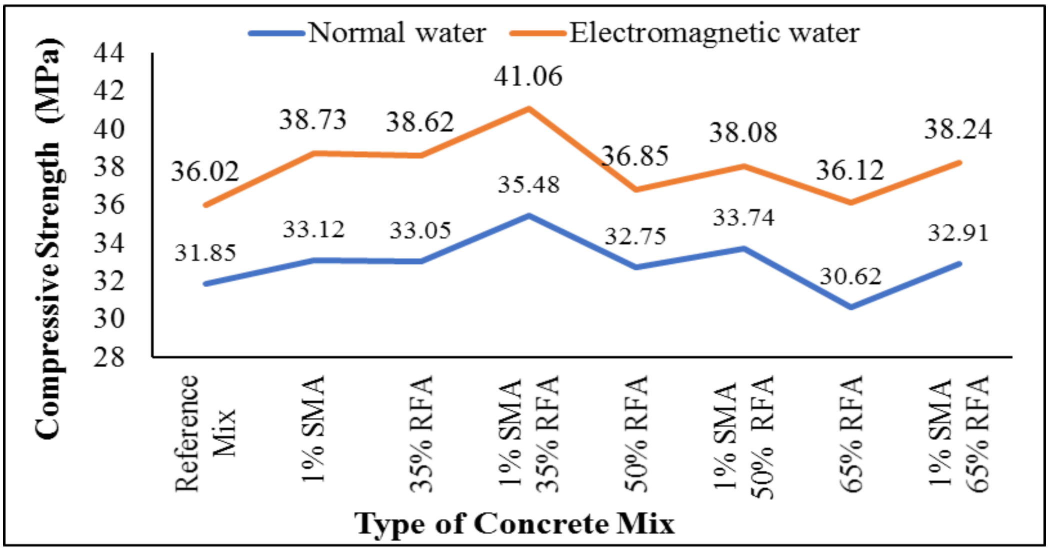


Fig.5.4 Compressive strength of concrete mix with normal and electromagnetic water after 7 days

Table 5.4 Effect of electromagnetic water on 7 days compressive strength of all types of concrete mix

Type of Concrete Mix Proportion	**Reference Mix**	**1% SMA Reference Mix**	**35% RFA**	**1% SMA 35% RFA**	**50% RFA**	**1% SMA 50% RFA**	**65% RFA**	**1% SMA 65% RFA**
Percentage Increase	11.57%	14.48%	14.42%	13.58%	11.12%	11.39%	15.22%	13.93%

Fig 5.5 and table 5.5 show the effect of electromagnetic water on 28 days compressive strength of all types of concrete mix. The overall results show that the compressive strength of concrete increased by 13% to 17% on using electromagnetic water in the concrete mix as compared to that of normal water.

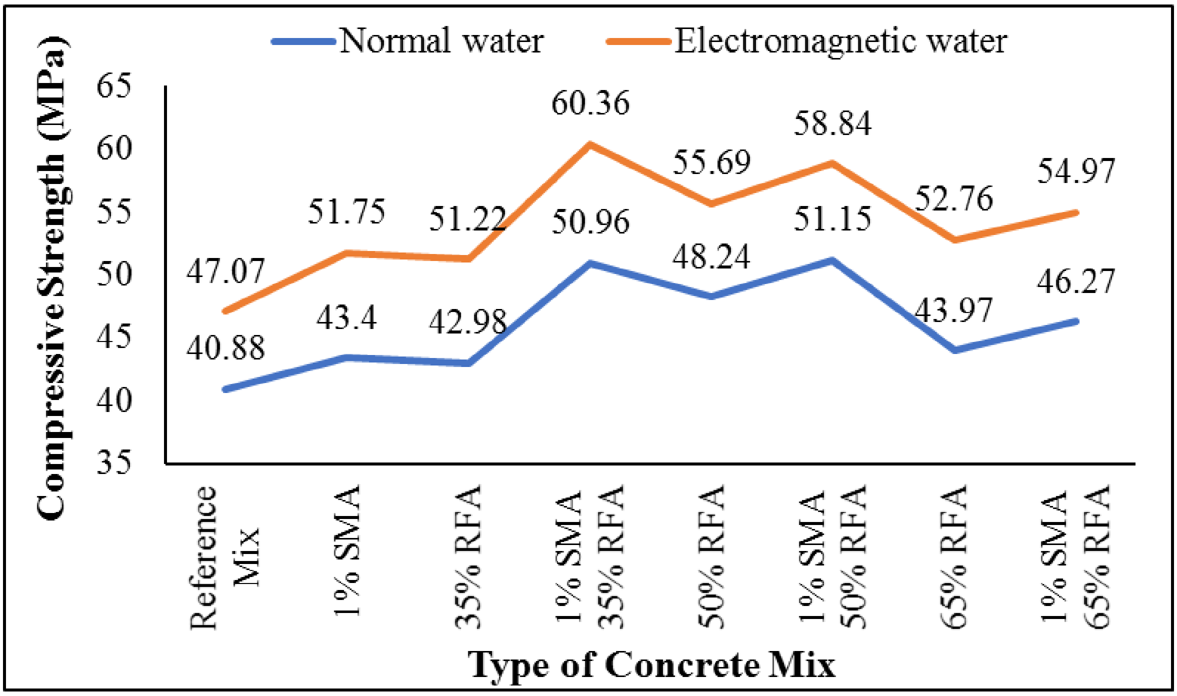


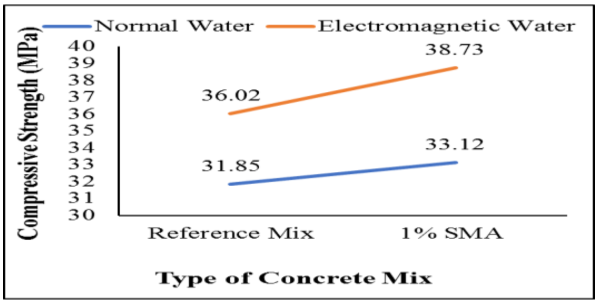
Fig.5.5 Compressive strength of concrete mix with normal and electromagnetic water after 28 days

Table 5.5 Effect of electromagnetic water on 28 days compressive strength of all types of concrete mix

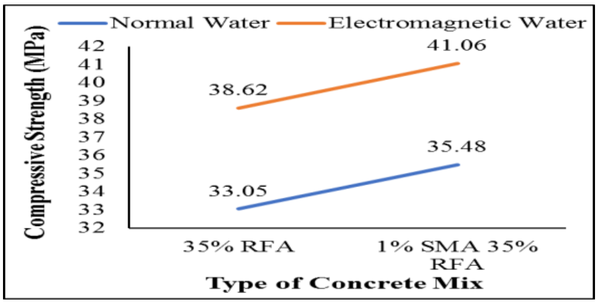
Type of Concrete Mix Proportion	**Reference Mix**	**1% SMA Reference Mix**	**35% RFA**	**1% SMA 35% RFA**	**50% RFA**	**1% SMA 50% RFA**	**65% RFA**	**1% SMA 65% RFA**
Percentage Increase	13.15%	16.13%	16.08%	15.57%	13.37%	13.36%	16.66%	15.82%

5.3.3 Effect of SMA Fibers on Compressive Strength

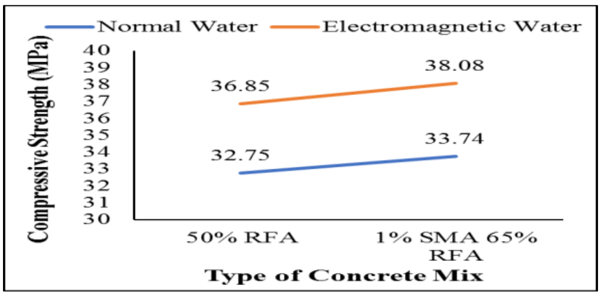
The compressive strength of concrete significantly increased on addition of SMA fibers in concrete. Fig 5.6 (a), (b), (c) and (d) and table 5.6 show the comparison of effect of SMA fibers on the compressive strength of normal water concrete and electromagnetic water concrete after 7 days curing respectively. The results show that SMA fibers effectively helped in increasing the compressive strength of concrete by 3-7% in case of both normal as well as electromagnetic water concrete.



(a)



(b)



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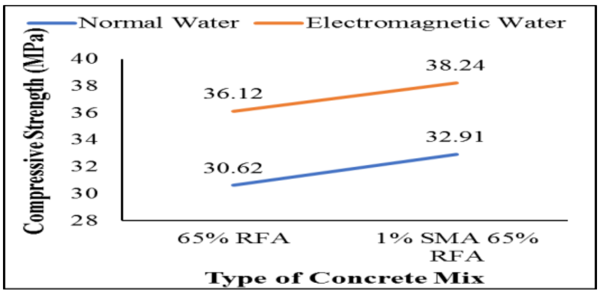


(d)

Fig. 5.6 Effect of 1% SMA fibers on compressive strength of concrete after 7 days (a) Reference Mix (b) 35% RFA (c) 50% RFA (d) 65% RFA

Table 5.6 Effect of SMA fibers on 7 days compressive strength of all types of concrete mix

Type of Concrete Mix Proportion	Percentage Increase on Addition of SMA Fibers with Normal Water	Percentage Increase on Addition of SMA Fibers with Electromagnetic Water
Reference Mix	3.83%	6.99%
35% RFA	3.84%	5.94%
50% RFA	2.93%	3.23%
65% RFA	6.95%	5.54%

Fig 5.7 (a), (b), (c) and (d) and table 5.7 show the comparison of effect of SMA fibers on the compressive strength of normal water concrete and electromagnetic water concrete after 28 days curing respectively. The results show that SMA fibers effectively helped in increasing the compressive strength of concrete by 4-15% in case of both normal and electromagnetic water concrete respectively.

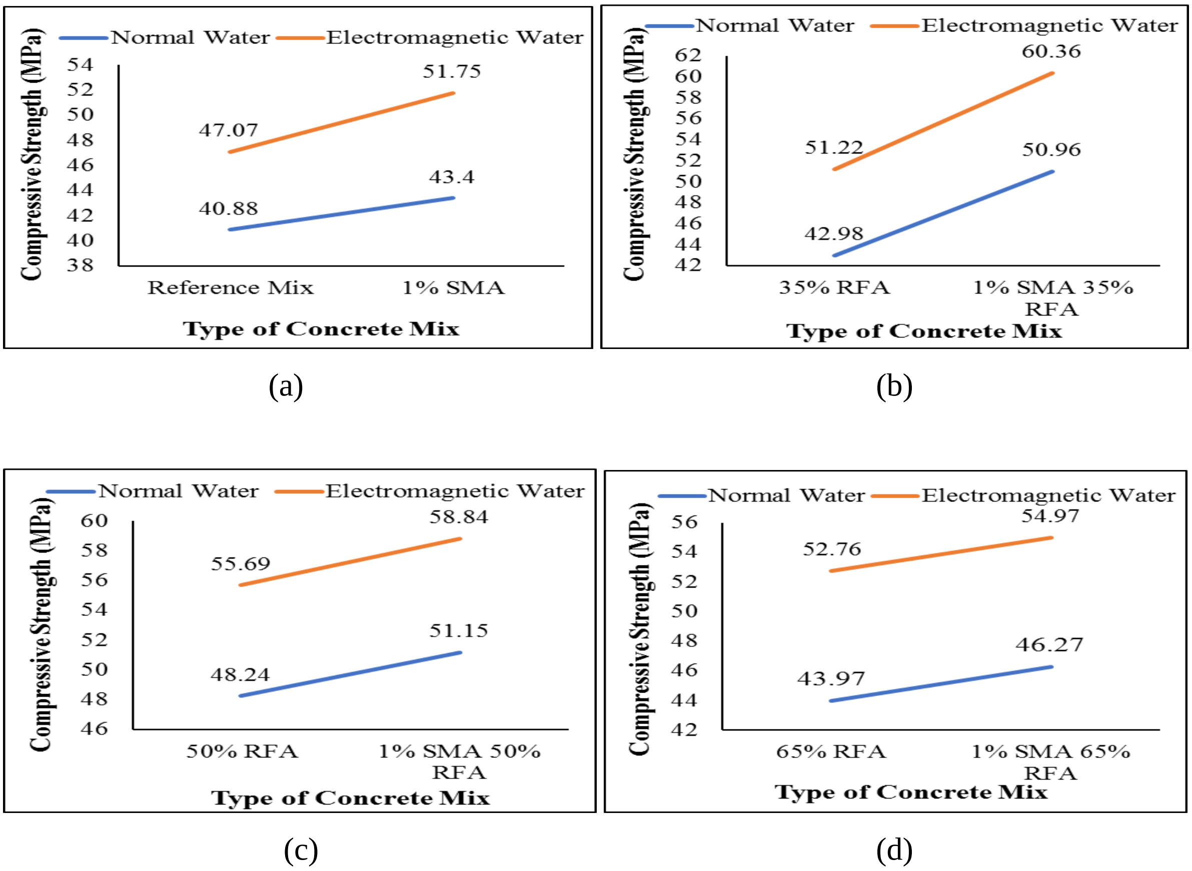


Fig 5.7 Effect of 1% SMA fibers on compressive strength of concrete after 28 days
(a) Reference Mix (b) 35% RFA (c) 50% RFA (d) 65% RFA

Table 5.7 Effect of SMA fibers on 28 days compressive strength of all types of concrete mix

Type of Concrete Mix Proportion	Percentage Increase on Addition of SMA Fibers with Normal Water	Percentage Increase on Addition of SMA Fibers with Electromagnetic Water
Reference Mix	5.80%	9.04%
35% RFA	15.65%	15.14%
50% RFA	5.68%	5.35%
65% RFA	4.97%	4.02%

5.4 Tensile Strength

Tensile strength is an important property of concrete because concrete structures are highly vulnerable to tensile cracking due to vulnerable kinds of effects and applied loading itself. The split tensile test is carried out after 7 and 28 days curing of all the types of concrete mix with normal water and electromagnetic water.

5.4.1 Effect of Recycled Fine Aggregates in Normal Water Concrete on Tensile Strength

The RFA helped in retaining and well as increasing the tensile strength of concrete as compared to the reference mix. Fig. 5.8 and table 5.8 show the 7 days tensile strength results for effect of replacement of NFA by 35%, 50% and 65% respectively with RFA.

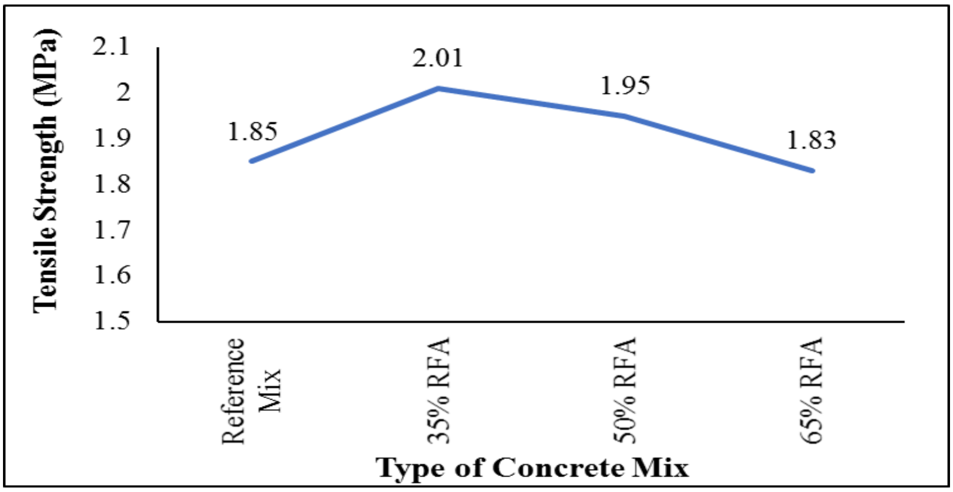


Fig 5.8 Comparison of effect of RFA on tensile strength in 7 days

Table 5.8 Effect of RFA on 7 days tensile strength of all types of concrete mix

Type of Concrete Mix	Reference Mix	35% RFA	50% RFA	65% RFA
Percentage with Normal Water	-	16.65% Increase	9.66% Increase	6.52% Decrease

Further 28 days results also show the achieved strength is within the limit of target strength as per mix design calculations. Also, the RFA helped in retaining as well as increasing the compressive strength of concrete as compared to the reference mix. Fig. 5.9 show the 28 days tensile strength results for effect of replacement of NFA by 35%, 50% and 65% respectively with RFA. Table 5.9 shows the effect of RFA on the 28 days tensile strength of all the types of concrete mix.

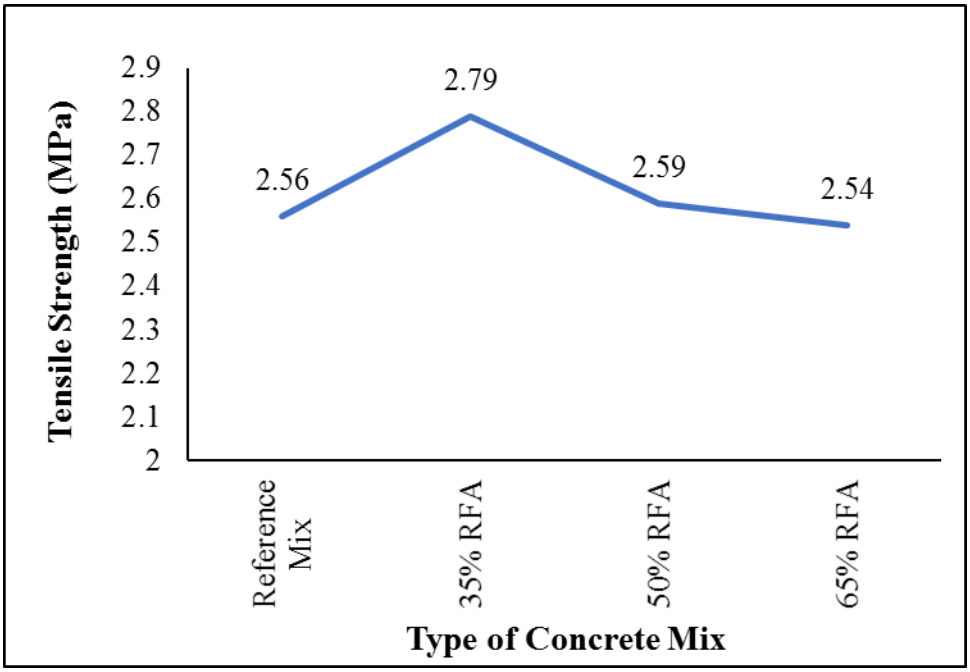


Fig 5.9 Comparison of effect of RFA on tensile strength in 28 days

Table 5.9 Effect of RFA on the 28 days tensile strength of all types concrete mix

Concrete Mix Proportion	**Percentage with Normal Water**
Reference Mix	-
35% RFA	9.94% Increase
50% RFA	3.35% Increase
65% RFA	3.65% Increase

5.4.2 Effect of Electromagnetic Water on Tensile Strength

Fig. 5.10 and table 5.10 shows the tensile strength of cubes with normal and electromagnetic water with all types of concrete mix for 7 days respectively. The overall results show that the tensile strength of concrete increased by 15% to 21% on using electromagnetic water in the concrete mix as compared to that of normal water. The trend of results of 7 days of all the types of concrete mix with electromagnetic water were same as that of concrete with normal water. But overall results show that the tensile strength is increased by using electromagnetic water.

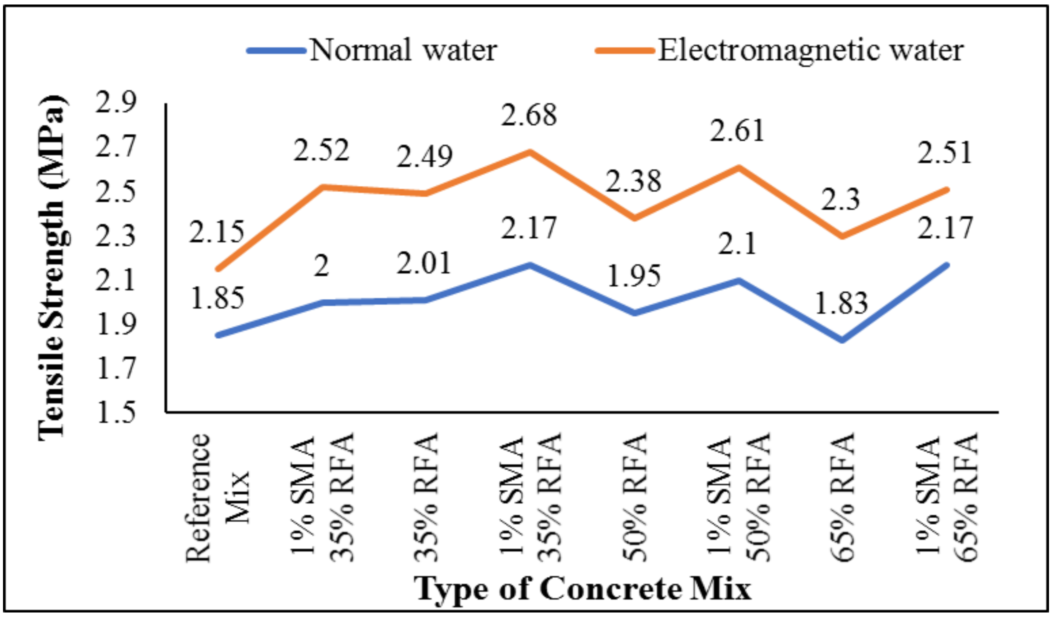


Fig. 5.10 Tensile strength of concrete mix with normal and electromagnetic water after 7 days

Table 5.10 Effect of electromagnetic water on 7 days tensile strength of all types of concrete mix

Type of Concrete Mix Proportion	Reference Mix	1% SMA Reference Mix	35% RFA	1% SMA 35% RFA	50% RFA	1% SMA 50% RFA	65% RFA	1% SMA 65% RFA
Percentage Increase	16.21%	20.63%	19.27%	19.02%	18.06%	19.54%	20.43%	15.89%

Fig. 5.11 shows the tensile strength of cubes with normal and electromagnetic water with all the types of concrete mix for 28 days Table 5.11 shows the effect of electromagnetic water on 28 days tensile strength of all types of concrete mix respectively. The overall results show that the tensile strength of concrete increased by 18% to 25% on using electromagnetic water in the concrete mix as compared to that of normal water. The trend of results of 28 days all the mix proportions of concrete with electromagnetic water were same as that of concrete with normal water. But overall results show that the tensile strength of 28 days is increased more than that of 7 days by using electromagnetic water.

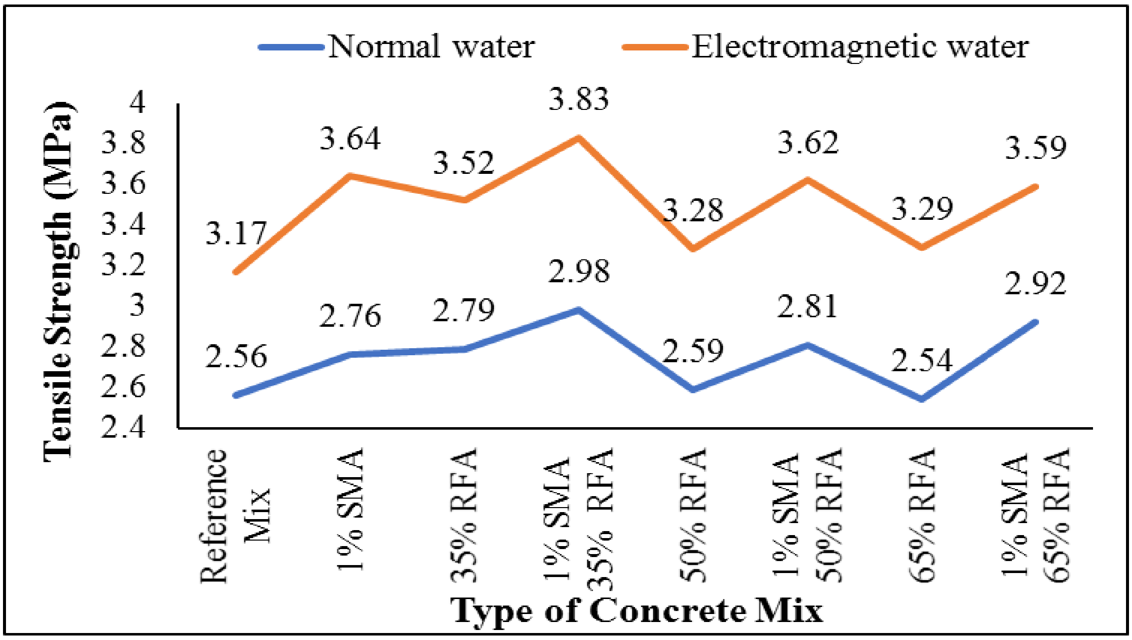


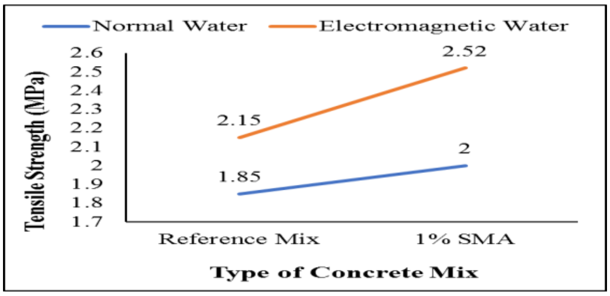
Fig. 5.11 Tensile strength of concrete mix with normal and electromagnetic water after 28 days

Table 5.11 Effect of electromagnetic water on 28 days tensile strength of all types concrete mix

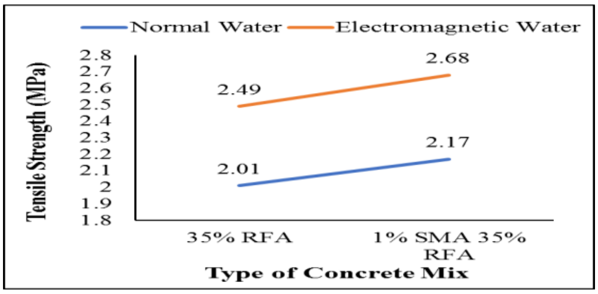
Type of Concrete Mix Proportion	**Reference Mix**	**1% SMA Reference Mix**	**35% RFA**	**1% SMA 35% RFA**	**50% RFA**	**1% SMA 50% RFA**	**65% RFA**	**1% SMA 65% RFA**
Percentage Increase	19.24%	24.17%	20.73%	22.19%	21.03%	22.37%	22.79%	18.66%

5.4.3 Effect of SMA Fibers on Tensile Strength

The increase in tensile strength of concrete due to SMA fibers was more as compared to compressive strength. Fig 5.12 (a), (b), (c) and (d) and table 5.12 show the comparison of effect of SMA fibers on the tensile strength of normal water concrete and electromagnetic water concrete after 7 days curing respectively. The results show that SMA fibers effectively helped in increasing the tensile strength by 7-16% in case of both normal and electromagnetic water concrete respectively.



(a)



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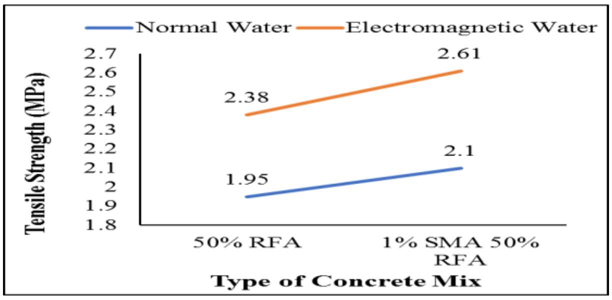

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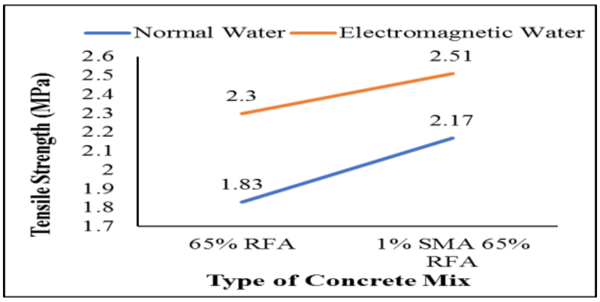


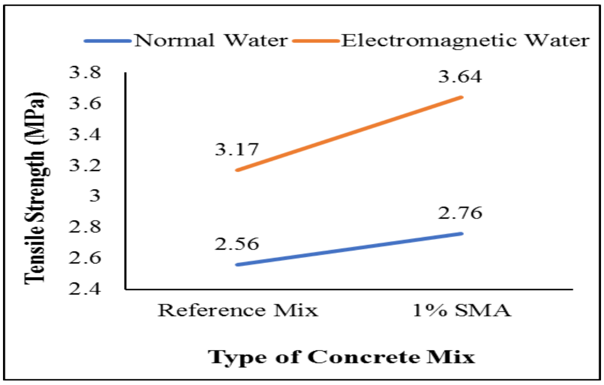
(d)

Fig. 5.12 Effect of 1% SMA fibers on tensile strength of concrete in 7 days
(a) Reference mix (b) 35% RFA (c) 50% RFA (d) 65% RFA

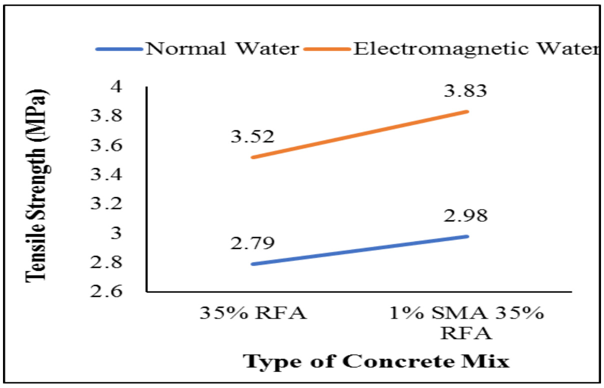
Table 5.12 Effect of SMA fibers on 7 days tensile strength for all types of concrete mix

Type of Concrete Mix Proportion	Percentage Increase on Addition of SMA Fibers with Normal Water	Percentage Increase on Addition of SMA Fibers with Electromagnetic Water
Reference Mix	7.50%	14.68%
35% RFA	7.37%	7.08%
50% RFA	7.14%	8.81%
65% RFA	15.66%	8.36%

Fig 5.13 (a), (b), (c) and (d) and table 5.13 show the comparison of effect of SMA fibers with tensile and without electromagnetic water on the tensile strength of concrete after 28 days curing respectively. The results show that SMA fibers effectively helped in increasing the compressive strength of concrete by 6-13% in case of both normal and electromagnetic water concrete respectively.



(a)



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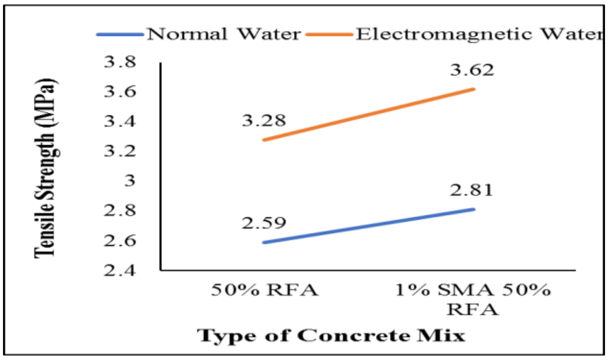

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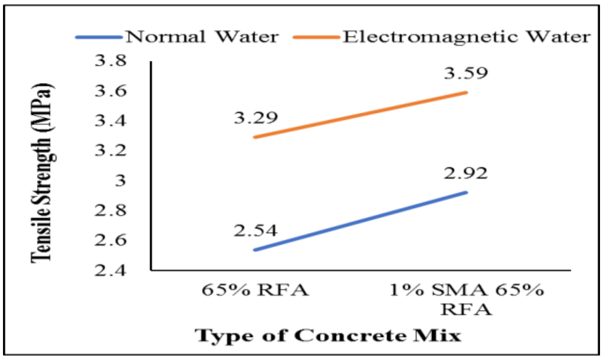


(d)

Fig. 5.13 Effect of 1% SMA fibers on tensile strength of concrete in 28 days

(a) Reference mix (b) 35% RFA (c) 50% RFA (d) 65% RFA

Table 5.13 Effect of SMA fibers on 28 days tensile strength for types concrete mixes

Type of Concrete Mix Proportion	**Percentage Increase on Addition of SMA Fibers with Normal Water**	**Percentage Increase on Addition of SMA Fibers with Electromagnetic Water**
Reference Mix	7.24%	6.37%
35% RFA	6.37%	8.09%
50% RFA	7.82%	9.39%
65% RFA	13.01%	8.35%

5.5 Flexural Strength

The flexural strength represents the highest stress experienced within the concrete at its moment of yield. It was calculated by using the formula as per IS 456: 2000 (Clause no. 6.2.2). The flexural strength graphs showed similar trend of results as that of compressive strength as it is co-related with the compressive strength.

5.5.1 Effect of Recycled Fine Aggregates on Normal Water Concrete on Flexural Strength

The natural fine aggregates were replaced by 35%, 50% and 65% recycled fine aggregates respectively and the effect of this replacement was similar to the compressive strength results. Fig. 5.14 and table 5.14 show the 7 days flexural strength results for effect of replacement of NFA by 35%, 50% and 65% respectively with RFA.

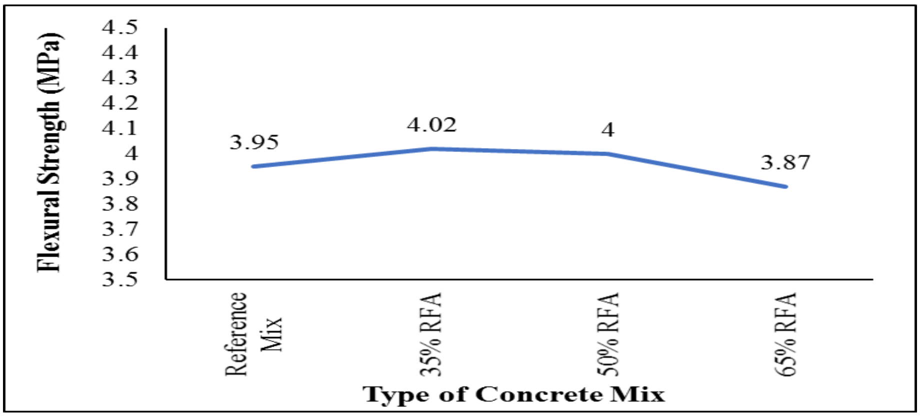


Fig 5.14 Comparison of effect of RFA on flexural strength in 7 days

Table 5.14 Effect of RFA on the 7 days flexural strength of all types of concrete mix

Type of Concrete Mix	**Reference Mix**	**35% RFA**	**50% RFA**	**65% RFA**
Percentage with Normal Water	-	3.67% Increase	1.18% Increase	0% Decrease

Table 5.15 shows the effect of RFA on the days flexural strength of all types of concrete mix. Fig. 5.15 shows the 28 days flexural strength results for effect of replacement of NFA by 35%, 50% and 65% respectively with RFA.

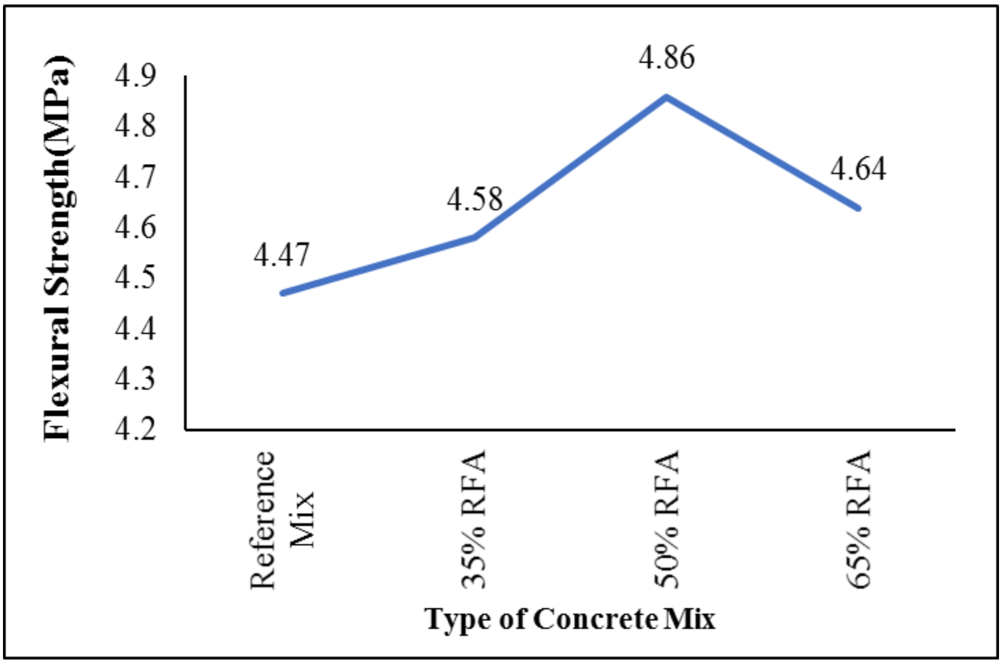


Fig 5.15 Comparison of effect of RFA on flexural strength in 28 days

Table 5.15 Effect of RFA on 28 days flexural strength of all types of concrete mix

Concrete Mix Proportion	Percentage with Normal Water
Reference Mix	-
35% RFA	3.63% Increase
50% RFA	2.75% Increase
65% RFA	4.02% Decrease

5.5.2 Effect of Electromagnetic water on Flexural Strength

The flexural strength of concrete with normal water and electromagnetic water with various types of concrete mix proportions was compared to compressive strength by using the formula given in IS 456:2000 (Clause no 6.2.2). Results show that, the overall flexural strength is increased while using electromagnetic water. Fig. 5.16 and table 5.16 show the flexural strength of cubes with normal and electromagnetic water with various types of concrete mix for 7 days respectively. The overall results show that the compressive strength of concrete increased by 5-8% on using electromagnetic water in the concrete mix as compared to that of normal water.

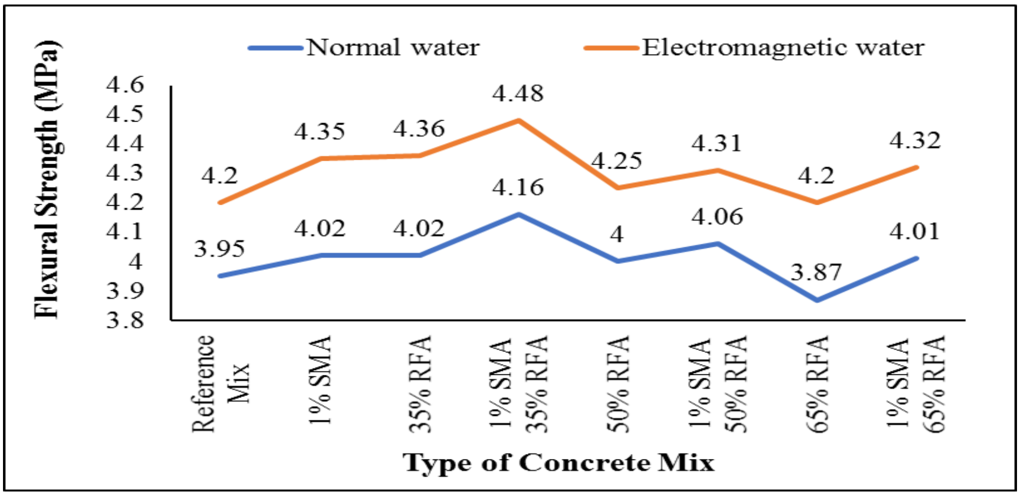


Fig.5.16 Flexural strength of concrete mix with normal and electromagnetic water after 7 days

Table 5.16 Effect of electromagnetic water on 7 days flexural strength of all types concrete mix

Type of Concrete Mix Proportion	**Reference Mix**	**1% SMA Reference Mix**	**35% RFA**	**1% SMA 35% RFA**	**50% RFA**	**1% SMA 50% RFA**	**65% RFA**	**1% SMA 65% RFA**
Percentage Increase	5.95%	7.73%	7.79%	7.26%	5.89%	5.88%	7.85%	7.17%

Table 5.17 shows the effect of electromagnetic water on 28 days compressive strength of all the concrete mixes and Fig. 5.17 shows the compressive strength of cubes with normal and electromagnetic water with all types of concrete mixes for 28 days respectively. The overall results show that the compressive strength of concrete increased by 6-9% on using electromagnetic water in the concrete mix as compared to that of normal water.

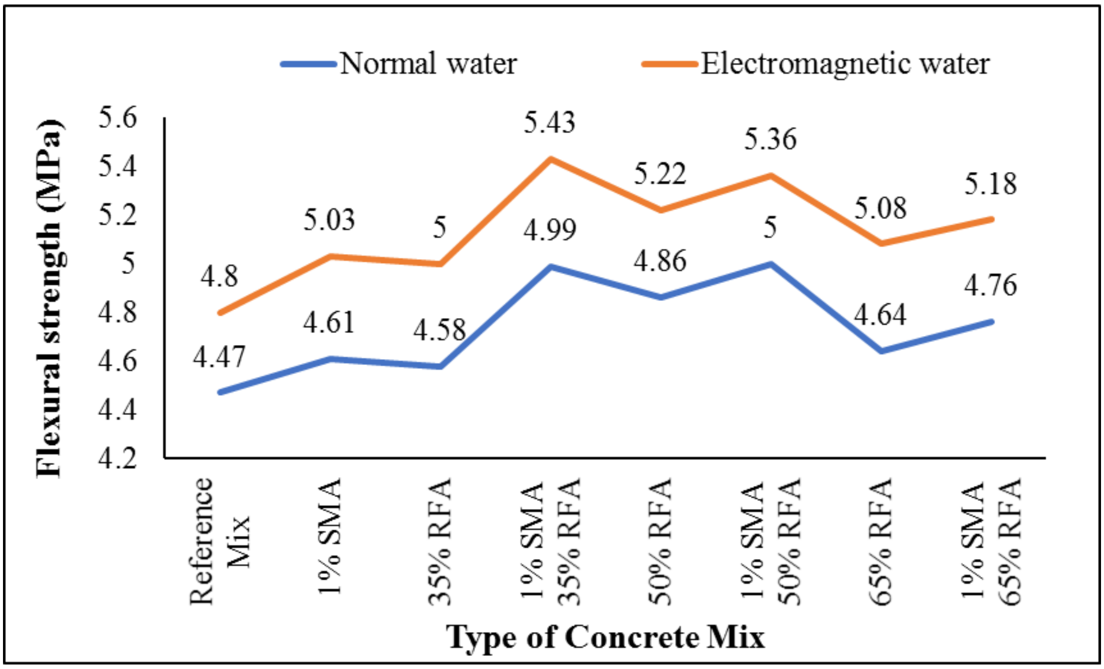


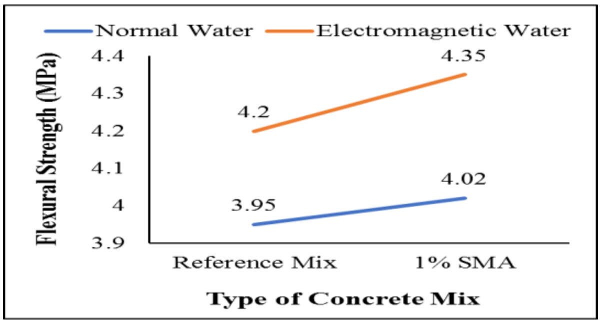
Fig.5.17 Flexural strength of concrete mix with normal and electromagnetic water after 28 days

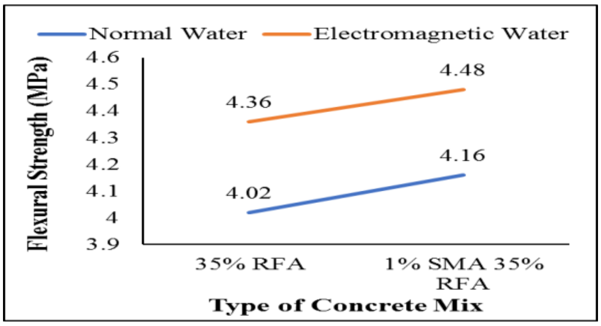
Table 5.17 Effect of electromagnetic water on 28 days flexural strength of all types concrete mix

Type of Concrete Mix Proportion	**Refere nce Mix**	**1% SMA Refere nce Mix**	**35% RFA**	**1% SMA 35% RFA**	**50% RFA**	**1% SMA 50% RFA**	**65% RFA**	**1% SMA 65% RFA**
Percentage Increase	6.87%	8.34%	8.40%	8.10%	6.89%	6.71%	8.66%	8.10%

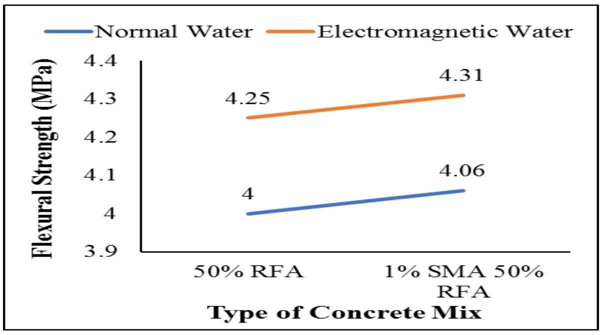
5.5.3 Effect of SMA Fibers on Flexural Strength

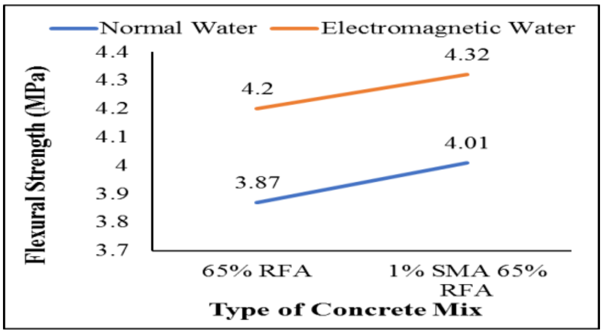
The comparison of effect of SMA fibers on flexural strength of normal water concrete and electromagnetic water concrete showed similar pattern of results as that of the compressive strength. Fig 5.18 (a), (b), (c) and (d) and table 5.18 show the comparison of effect of SMA fibers on flexural strength of normal water concrete and electromagnetic water concrete after 7 days curing respectively.





(a) (b)





(c) (d)

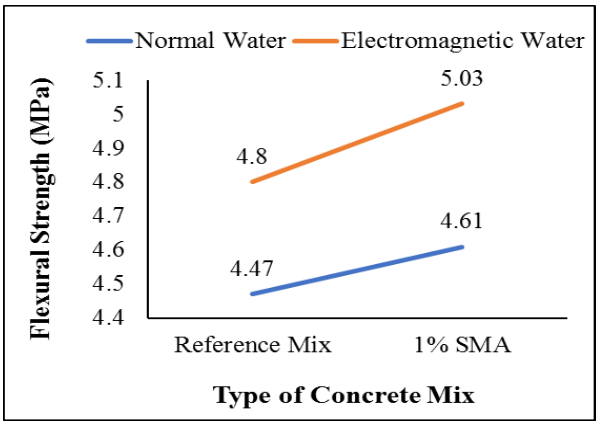
Fig. 5.18 Effect of 1% SMA fibers on flexural strength of concrete in 7 days

(a) Reference mix (b) 35% RFA (c) 50% RFA (d) 65% RFA

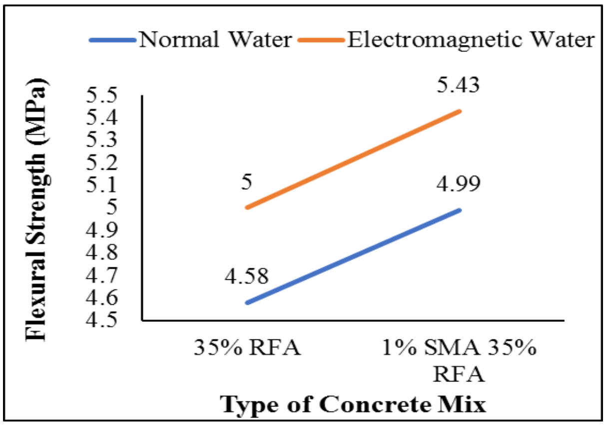
Table 5.18 Effect of SMA fibers on 7 days flexural strength for all types concrete mix

Type of Concrete Mix Proportion	Percentage Increase on Addition of SMA Fibers with Normal Water	Percentage Increase on Addition of SMA Fibers with Electromagnetic Water
Reference Mix	1.74%	3.44%
35% RFA	3.36%	2.67%
50% RFA	1.47%	1.39%
65% RFA	3.49%	2.77%

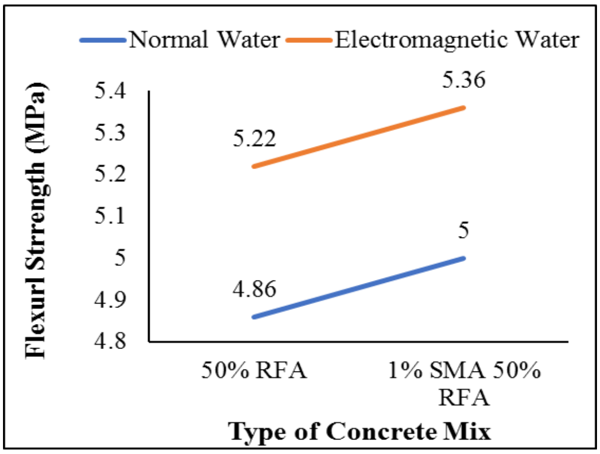
Fig 5.19 (a), (b), (c) and (d) and table 5.19 show the comparison of effect of SMA fibers on flexural strength of normal water concrete and electromagnetic water concrete after 28 days curing respectively. The results show that SMA fibers effectively helped in increasing the flexural strength of concrete by 1-9% in case of both normal and electromagnetic water concrete respectively.



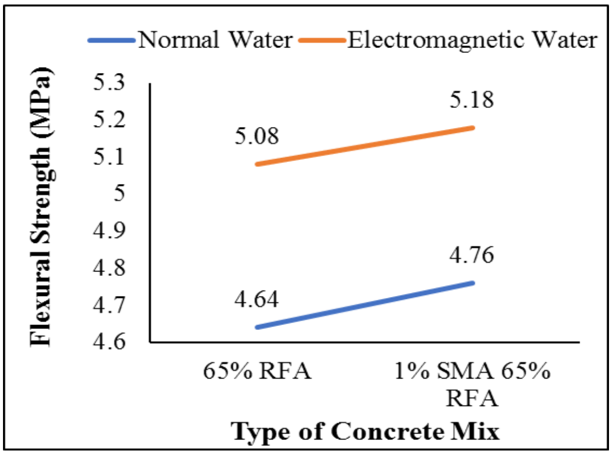
(a)



(b)



(c)



(d)

Fig. 5.19 Effect of 1% SMA fibers on flexural strength of concrete in 7 days

a) Reference mix (b) 35% RFA (c) 50% RFA (d) 65% RFA

Table 5.19 Effect of SMA fibers on 28 days flexural strength for all types concrete mix

Type of Concrete Mix Proportion	Percentage Increase on Addition of SMA Fibers with Normal Water	Percentage Increase on Addition of SMA Fibers with Electromagnetic Water
Reference Mix	3.03%	4.57%
35% RFA	8.21%	7.91%
50% RFA	2.80%	2.61%
65% RFA	2.52%	1.93%

5.6 Crack Width Closing Ability

The crack closing performance of the SMA fibers was evaluated with the help of a Vernier caliber immediately after the split tensile test of cylinders, after 2 hours of deformation and after 4 hours of deformation.

Fig 5.20 and table 5.20 show that SMA fibers significantly help in partially closing the crack width for all the specimens. It was observed that the involvement of SMA fibers increased the crack width. The specimens showed crack width closing ability in between 50-65%.

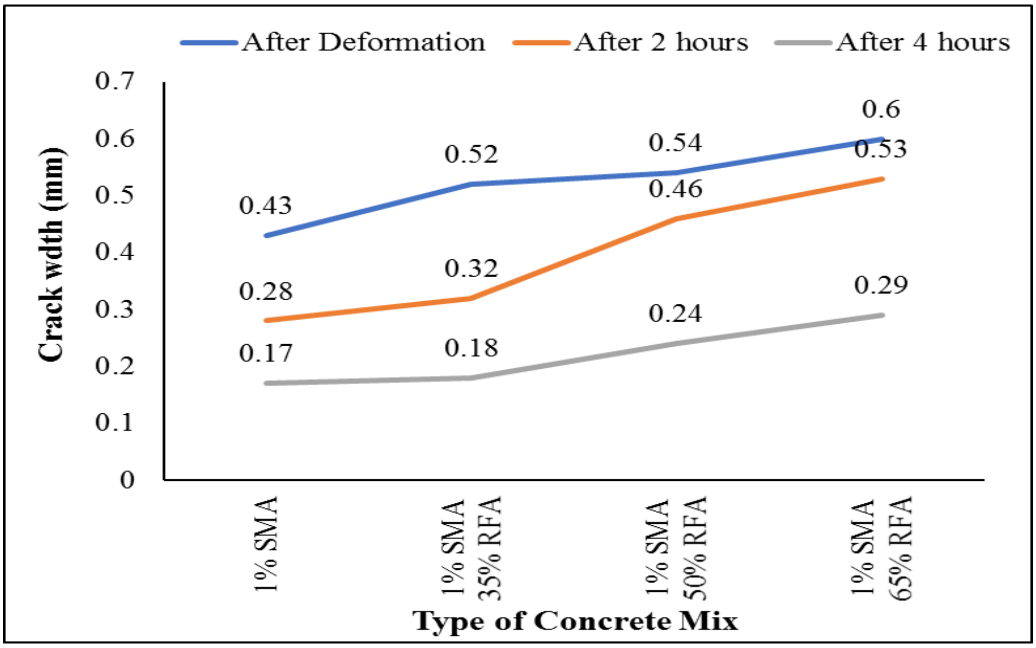


Fig 5.20 Crack width closing ability due to SMA fibers

Table 5.20 Crack width closing ability in percentage at all the time intervals

Type of Concrete Mix	After Immediate Deformation in Percentage	After 2 Hours of Deformation in Percentage	After 4 Hours of Deformation in Percentage
1% SMA Reference Mix	-	39.29%	60.47%
1% SMA 35% RFA	-	43.75%	65.38%
1% SMA 50% RFA	-	47.83%	55.56%
1% SMA 65% RFA	-	45.28%	51.67%

5.7 Cost Analysis

5.7.1 Comparison of SMA Fibers with Other Fibers

Cost analysis was carried out by comparing nickel based SMA fibers to iron based SMA fibers (Fe-SMA) and conventional stainless-steel fibers. Fig. 5.21 shows the graphical representation of the cost of various types of reinforcement. It was observed that nickel based SMA fibers are expensive than iron based SMA fibers and conventional stainless-steel fibers. This is because there is no awareness of nickel based SMA fibers in structural engineering which makes the demand of this material to be less than the conventional reinforcement fibers and iron based SMA fibers. As demand of this material will increase, automatically the cost will decrease. Even though nickel based SMA is costlier than iron based SMA and the conventional stainless steel, the re-centering ability and increase in tensile strength dur to nickel based SMA cannot be neglected.

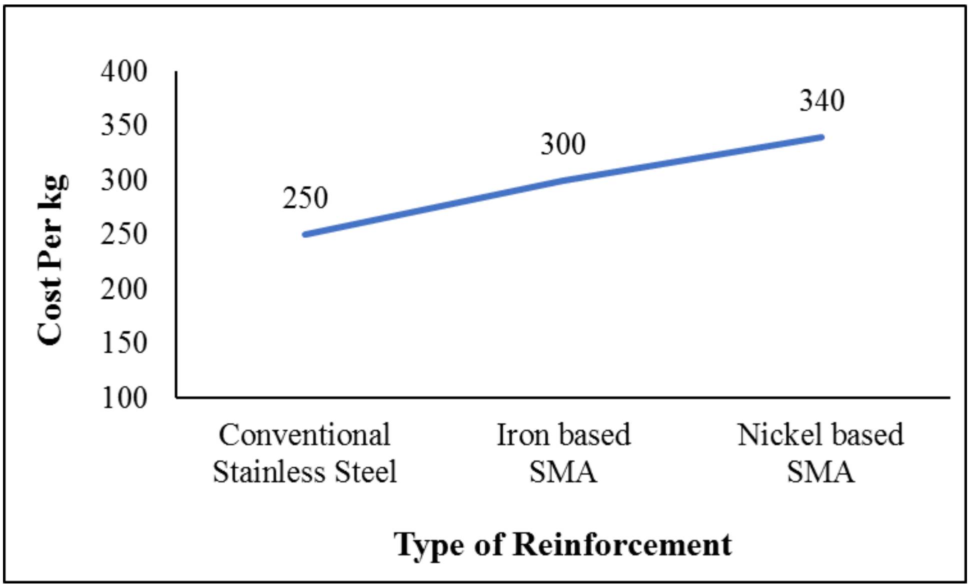


Fig 5.21 Cost analysis of nickel based SMA as compared to other types of reinforcement

Chapter 6

Conclusions

6.1 Conclusions

The present research has investigated the effect of partial replacement of recycled fine aggregates on normal water concrete. It has also focused on the effect of electromagnetic water on the properties of concrete and then further the role of nickel based SMA fibers in improving the strength properties and re-centering ability of concrete Conclusion from the above study has been drawn as follows: -

1. The SMA fibers worked well with the recycled fine aggregates. However, the fresh concrete mix had become harsh with increase in percentage of recycled fine aggregates.
2. It was observed that electromagnetic water concrete had more retention as compared to normal water concrete hence, electromagnetic water concrete had become more workable.
3. The compressive strength results showed:
    - In normal water concrete, on 35% replacement of NFA by RFA the 7 days compressive strength increased up to 3.63% and on further replacement of NFA by RFA, the compressive strength decreased. There was 4.89% increase in 28 days compressive

strength on 35% replacement of NFA by RFA and 16.66% increase on 50% replacement of NFA by RFA concrete and on further replacement of NFA by RFA, the compressive strength decreased.

- Electromagnetic water increased the compressive strength of concrete maximum up to 15.76% as compared to normal water.
- Nickel based SMA fibers helped in increasing the compressive strength of concrete.

4. Tensile strength results show:
   - In normal water concrete, on 35% replacement of NFA by RFA the 7 days tensile strength increased up to 16.65% and on further replacement of NFA by RFA, the tensile strength decreased. There was 9.94% increase in 28 days tensile strength on 35% replacement of NFA by RFA and on further replacement of NFA by RFA, the tensile strength decreased.
   - Electromagnetic water increased the compressive strength of concrete maximum up to 24.17% as compared to normal water.
   - Nickel based SMA fibers significantly helped in increasing tensile strength of concrete.
5. Flexural strength results were similar to that of the compressive strength results.
6. The SMA fibers significantly helped in crack width closing maximum up to 65.38% and showed its re-centering ability.
7. Nickel based SMA fibers are expensive as compared to iron based SMA fibers and stainless-steel fibers but there is no major difference in the cost. And also, they play a very important role in improving the strength properties of concrete and its re-centering ability.

6.2 Future Scope

This study can be further extended by considering the following:

1. Copper based and iron based SMAs can be used in the form of fibers in order to check the increase in tensile strength and the re-centering ability due to these types of SMAs.
2. Nickel based SMA material consisting of more percentage of nickel content can be used.
3. SMA in the form of rod, plate, spring or ring may also be used instead of fibers for reinforcement.

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List of Publications

Based on the present study, following paper is communicated in international journal and conference.

[1] Riya Athanikar and Roshni. John, "Experimental Investigation on Strengthening of Recycled Fine Aggregate with SMA Fibers and Electromagnetic Water", 52^{nd} Science Research Contest-2018. (Under Review)

[2] Riya J. Athanikar and Priyanka A. Jadhav, "Effect of SMA Fibers on Recycled Fine Aggregate Concrete and Electromagnetic Water", International Conference on Civil, Mechanical, Biological and Medical Engineering (ICMBME-2018), Pune, June 17^{th}, 2018.

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