WASTE ALUMINIUM WIRE INCORPORATED RECYCLED AGGREGATE CONCRETE

FINAL YEAR PROJECT UG-2019

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DEDICATION

CREDIT GOES TO OUR FAMILY AND TEACHERS, WHO HELPED AND INSPIRED US THROUGHOUT OUR LIFE.

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All praises be to ALMIGHTY ALLAH who made everything possible and easy for us to achieve in our amazing journey of NUST. We are extremely grateful to our parents who sacrificed and prayed for us to make progress in our course and research work.

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ABSTRACT

Recycled Aggregate Concrete (RAC) has emerged as an environment-friendly alternative to normal concrete, recycling concrete and using it as aggregate. Large-scale application of RAC is possible by incorporating a suitable amount of fibers. Aluminum wires are recyclable and exhibit tendencies to increase the strength of concrete. In this study, normal aggregate concrete (NAC) and recycled aggregate concrete (RAC) were both incorporated with waste aluminum. Results from fresh properties and mechanical testing showed that waste aluminum wires enhance strength by replacement. Lifecycle assessments showed that waste aluminum wire incorporated in recycled aggregate concrete (WAWIRAC) reduced greenhouse gas emissions by 16%. This means that WAWIRAC can be an eco-friendly alternative to NAC.

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Chapter 1

Introduction

The most widely used material for construction in the world is concrete[1]. According to the UN Report, the emissions of the building sector have increased and represent 28% of global energy-related CO2 emissions[2]. The construction industry is second to the power industry in terms of CO_2 contribution. Producing one ton of Ordinary Portland Cement (OPC) produces one ton of CO_2[3]. In Pakistan, 24 manufacturing units operate with a capacity of 49.4 million tons, which is expected to increase to 72.8 million[4].

Aggregate is an important material in the making of concrete. Aggregates are controlled by geology. There are areas where it is abundant and areas where it is absent. Extraction of aggregate has various environmental impacts, such as destruction of habitat, erosion, and landslides. To reduce the environmental impact of concrete on the environment, one way is to introduce recycled materials into concrete. One such method is the introduction of recycled aggregate as a replacement for normal aggregate.[5]

Recycled Aggregate Concrete (RAC) is formed by replacing the normal aggregate with the Recycled Aggregate. Recycled aggregate can be derived from sources such as demolished concrete, masonry, and asphalt[6]. This offers an alternative to the use of conventional aggregate and helps conserve natural resources and reduces waste material. However, the mechanical properties of RAC are inferior to those of conventional concrete because of impurities. This is because RAC uses used concrete and its properties depend on the concrete and the mix design of concrete it was derived from. It is seen that a reduction in strength of about 10-15% occurs when using recycled aggregate in concrete[7].

In recent years, researchers have focused on improving the strength of RAC to make it a viable competitor to conventional concrete. Various techniques are being developed such as supplementary cementitious materials, admixtures, and fiber reinforcements such as carbon and steel[8,9]. One such reinforcement is the incorporation of Waste Aluminum wires, which have excellent mechanical properties, corrosion resistance, and a lightweight nature[10,11,12].

Aluminum wires have been extensively used because of their high weight-to-strength ratio and the fact that they are corrosion resistant. Aluminum is added to the concrete as small wires and may have hooked ends to help with bonding. It can improve the overall tensile and flexural strength of concrete and provides resistance to crack propagation and spalling[13]. The weight of concrete is decreased as a result of the lightweight qualities of aluminum Incorporating aluminum wire or fibers into concrete can supply various benefits, such as amplified mechanical characteristics, improved durability, and reduced carbon footprint. Additionally, using aluminum wire or fibers in concrete can contribute to the recycling of this material, as aluminum scrap can produce this reinforcements[14].

This study will explore the use of Waste Aluminum wires in concrete and how it interacts with the concrete. We will also explore the effect of Waste Aluminum wires on the mechanical performance of Recycled Aggregate Concrete and compare it with that of OPC concrete. In addition to discussing the mechanical properties of aluminum and its interactions with concrete, we will also explore the environmental impact of using aluminum in construction. We will examine the sustainability of using aluminum as a building material and discuss ways to reduce its environmental footprint[15,16].

Overall, this report aims to provide a comprehensive overview of the use of aluminum in concrete structures and to assess its potential benefits and drawbacks. By examining both the technical aspects and environmental impact of using aluminum in construction, we hope to provide a balanced perspective on this emerging technology.

Chapter 2

Literature Review

A sustainable alternative to concrete has been the focus of researchers in the past years. One such material is Recycled Aggregate Concrete. Recycled aggregate concrete (RAC) is a sustainable material that reduces environmental degradation and waste management issues. RAC is sustainable and helps in the recycling of concrete but considering the drop in strength because of the presence of impurities and weaker bonds between RAC and Cement, its use in construction is limited. To compensate for these disadvantages, several studies have been conducted to study the impact of incorporating fibers of varied materials, and supplementary cementitious materials.

2.1 Recycled Aggregate Concrete:

Using recycled concrete aggregate reduces environmental pollution and saves natural resources. However, the mechanical properties of RAC are lower than those of OPC or conventional concrete due to the weakness of interfacial transition zones (ITZ) [17]. The drop is seen in properties such as compressive strength, tensile and flexural strength[18].

2.1.1 Compressive Strength:

The compressive strength, often called the cube strength of recycled concrete, is lower than that of conventional concrete. Work done by Gulzhge(R) in Russia in 1946 concluded that compressive strengths are less if the concrete is used as aggregate[19]. Khaldoun Rahal(R) in his paper concluded that the cube and cylinder compressive strength and the indirect shear strength of RAC were about 90% of that of a NAC with similar mix proportions and slump[20].

2.1.2 Flexural Strength:

Flexural strength is the property of concrete, which is a measure of its ability to resist bending and cracking under loads. Studies have shown that the flexural strength of RAC is generally less than that of conventional concrete. Sonwane et al. concluded that the flexural strength of RAC varies from 3 to 16% depending on the percentage of replacement of normal aggregate with recycled aggregate. Chen HJ et al. (2003) state that when the water/cement ratio is high, resulting in a lower strength of mortar, the compressive strength of recycled concrete is comparable to that of normal concrete[22]. However, at lower water/cement ratios, where the mortar has a higher strength, the compressive strength of recycled concrete is significantly lower than that of normal concrete. Although high-strength recycled concrete can be obtained by increasing the cement content in the mortar, this mixture proportion is not cost-effective.

2.1.3 Split Tensile Strength:

Tensile strength is another important mechanical property of concrete, especially in applications where the concrete is subjected to bending or tensile stresses. However, the tensile strength of concrete is generally much lower than its compressive strength. This is because concrete is a brittle material, and its strength is mainly derived from its compressive strength. R.V. Silva et al. (2015) concluded when using recycled aggregate (RA) in concrete, the expected decrease in tensile strength can be controlled by selecting the RA carefully. The relative loss in tensile strength between recycled aggregate concrete (RAC) and normal aggregate concrete (NAC) is influenced by factors such as the type, quality, size, and quantity of the RA used. So, the selection process for RA should consider these factors to mitigate the decrease in tensile strength as the RA content in concrete increases[23].

However, the strength can be increased by incorporating various reinforcements, such as fibers. Many researchers have studied the effect of adding fibers to RAC. According to Ramesh et al.

(2019), incorporating steel fibers (SF) in RAC containing 100% recycled coarse aggregate (RCA) can increase the splitting tensile strength by up to 93%, with the best results achieved with a volume fraction of 0.7% SF[24]. Similar findings were reported by Chandar et al. (2017) and GHORPADE VG, SUDARSANA RH, who found that increasing the volume content of SF from 1% to 1.25% resulted in a 29.65% to 50.96% increase in splitting tensile strength, and increasing the volume content to 1.5% produced an improvement of 34.48% [25,26]. However, a minor drop in splitting tensile strength was seen with increasing percentage replacements of RCA for the same volume fractions of SF. For example, RAC containing 0.5% volume content of SF showed a slight reduction in strength from 54.54% to 49% when the RCA content was increased from 30% to 50% (Ramesh et al., 2019). These findings suggest that SF dosage in the range of 0-1.5% (by volume) can effectively enhance the splitting tensile strength capacity of RAC.

2.2 Fiber Reinforcement of Concrete:

Incorporating fibers in recycled aggregate concrete has been a major focus of researchers and is considered an important source of improving the mechanical properties of RAC. Akça K, Çakir Ö et al. in their paper concluded that the use of RCA in concrete has been shown to result in a decrease in both flexural and splitting tensile strengths. However, adding fibers has been found to improve both mechanical properties in all tested series. In the study, the optimal fiber content for enhancing flexural and splitting tensile strengths was 1%. Increasing the replacement of RCA and fiber content has been found to decrease the modulus of elasticity in concrete. However, it was found that the use of RCA is the primary factor contributing to the reduction in the modulus of elasticity, rather than the fiber content.

Afroughsabet et al. (2015) found that the mechanical properties of concrete are improved by increasing the fiber content in both PP and steel fiber-reinforced concrete[28]. This improvement can be attributed to the fibers' ability to limit crack extension, reduce stress concentration at the crack tip, and delay the rate of crack growth. Shi Yin, Rabin Tuladhar et al. concluded the addition of macro plastic fibers to concrete does not significantly affect its compressive and flexural strength, as these properties are primarily determined by the concrete matrix. However, using macro plastic fibers can improve the ductility and flexural toughness of concrete in the post-crack region. This results in excellent post-crack performance and high energy absorption capacity. Additionally, macro plastic fibers are effective in controlling cracks caused by dry shrinkage. To enhance the bonding strength between the fibers and concrete, the plastic fibers are often designed with various shapes and indents[29].

T. Simoes, H. Costa et al. observed in their research the addition of fibers to fiber reinforced concrete matrix increases its compressive strength. The amount of this increase is directly proportional to the tensile strength and stiffness of the fiber, with steel fibers resulting in a greater increase than polypropylene fibers. In terms of the flexural behavior of the FRCM matrix, ductile behavior is seen when the fibers themselves exhibit ductile behavior, such as in polypropylene and steel fibers. Conversely, fragile behavior is seen when the fibers themselves exhibit fragile behavior, as with glass fibres[30].

K. Holschemacher et al. (2010) in their paper on steel fibers in high-strength concrete, concluded that fibers are crucial for achieving a definite load-bearing capacity after matrix fracture, with the post-cracking load depending on fiber content. High-strength fibers show better ductile behavior and higher load levels in the post-cracking range than normal-strength fibers. The load-bearing capacity of bar-reinforced beams can be improved with corrugated fibers, while a longitudinal reinforcement ratio of 1% is recommended for fiber contents of 40 kg/m3[31].

Neves, R. D. et al. (2005) conducted a study and found that Young's modulus decreases slightly with increased fiber content in concrete. Fiber influence on maximum compressive strength depends on the characteristics of the matrix and fibers used. Additionally, the study shows that strain at peak stress increases with concrete strength and that toughness in higher-strength concrete is more sensitive to fiber reinforcement [32]. Researchers concluded that the stress-strain relationship model presented by Vipulanandam and Paul[33] is useful in modeling the compressive behavior of tested steel fiber reinforced concrete. They also proposed equations to model steel fiber-reinforced concrete behavior in uniaxial compression. However, the validity of the proposed model needs to be verified under different experimental conditions.

2.3 Aluminum Wires:

In recent years, aluminum wires have been widely considered as a substitute for copper wires as they are lightweight, have high conductivity, and are inexpensive. Various studies have analyzed the characteristics and uses of aluminum wires in areas like electrical engineering, the automotive industry, and aerospace [35,36,37].

Aluminum wires possess an advantageous high conductivity that is approximately 61% of that of copper wires. Aluminum wires' attributes make them well-suited for industries such as aerospace and automotive, where weight is a major factor. Various research has demonstrated that aluminum wires can offer comparable electrical results compared to copper wires when properly configured and put in place.

Despite its benefits, aluminum wires also have certain drawbacks that should be examined. A major issue is the formation of an oxide layer on the surface, which leads to higher resistance and lower conductivity. Electrical circuits may experience overheating, causing a fire hazard. Several studies have been performed to assess the application of surface treatment and coatings to hinder the creation of the oxide layer, thereby increasing the durability and dependability of the wire.

Another issue with aluminum wires is their mechanical properties, particularly their tensile strength, and ductility. Aluminum wires are generally less ductile than copper wires, which can lead to cracking and breakage during installation and operation. Studies have shown that alloying aluminum with other metals, such as magnesium or silicon, can improve the wire's mechanical properties and reduce its tendency to break [40].

In addition to electrical and mechanical properties, the corrosion resistance of aluminum wires is also an important consideration. Aluminum wires are susceptible to corrosion in certain environments, particularly in the presence of moisture and salts. Studies have investigated the use of coatings and alloys to enhance the corrosion resistance of aluminum wires[41].

Overall, using Waste Aluminum wires has shown promise as a cost-effective and lightweight alternative to copper wires in various applications. However, their properties and performance need to be carefully considered and optimized for specific applications to ensure their durability, reliability, and safety. Further research is needed to address the challenges associated with aluminum wires and to explore new applications and opportunities for this material.

2.4 Aluminum Wires in Concrete:

There have been many studies regarding the properties of aluminum wires and the incorporation of fibers in concrete. However, studies done on the effect of aluminum fibers in concrete are few and so their addition in RAC is even rarer.

Studies have shown that the addition of Waste Aluminum wires in concrete increases the strength of concrete, especially the split tensile strength. A study published in 2021 by Y.K. Sabapathy et. al[42] concluded that adding aluminum fibers had a positive impact on concrete strength. The article summarizes the outcomes of tests conducted on concrete specimens reinforced with aluminum fibers at varying volume fractions and different grades of concrete. The research findings indicate that adding aluminum fibers to concrete improves its compressive and splitting tensile strength. The optimal volume concentration of fibers to achieve maximum strength properties is 0.77% of V_f. The equations proposed for predicting the compressive and splitting tensile strengths of reinforced concrete are accurate to a considerable extent, but further research is required for validation. Using aluminum scrap in concrete is an effective and sustainable approach that can enhance its strength properties.

Chapter 3

Methodology

3.1 Introduction:

Aluminum wire-incorporated concrete is a relatively newer area of research, as it improves the properties of concrete by adding Waste Aluminum wires as fibers. However, there is limited research available on the impact of aluminum fibers on the behavior of concrete. There is even less research done regarding its behavior on RAC.

This chapter discusses the research methodology and steps taken to investigate the properties of aluminum wire incorporated in RAC. The research aims to evaluate the feasibility and effectiveness of aluminum wire as reinforcement in concrete and to determine the optimal amount and size of aluminum wire for achieving desirable properties.

The experimental program includes material selection, specimen preparation, testing, life cycle analysis, and data analysis. The program includes resting specimens of both conventional and recycled aggregate concrete containing different proportions of Waste Aluminum wires. These proportions include replacement by volume. The percentage replacements are 0%,0.3%,0.4%,0.5%,0.6%, and 0.7% in both conventional and recycled concrete.

3.2 Research Design:

The research design is based on a quasi-experimental design[43]. The dependent variables or the variable to be studied are the compressive, flexural, and tensile strength and the independent variable is the percentage of Waste Aluminum wires incorporated into the specimen. The study will compare concrete specimens with varying volumes of Waste Aluminum wires (ranging from 0.3% to 0.7%) with control specimens (without Waste Aluminum wires) of the same grade of concrete (M30). The study will use a between-subjects design, where each group of specimens will have a different volume fraction of Waste Aluminum wires.

3.3 Methodology:

3.3.1 Sample Selection:

The samples for this study consist of concrete samples with different fractions of Waste Aluminum wires and control specimens. The specimens are created according to the ASTM C192/C192M standard for making and curing concrete specimens[44].

3.3.2 Material Characterization:

3.3.2.1 Workability:

The slump values for both NAC and RAC are shown in . It is seen that increasing the replacement percentages causes a decrease in workability. The increase in replacement percentages causes a decrease in slump value for NAC from 5 to 3.9 and from 4.7 to 3.5 for RAC.

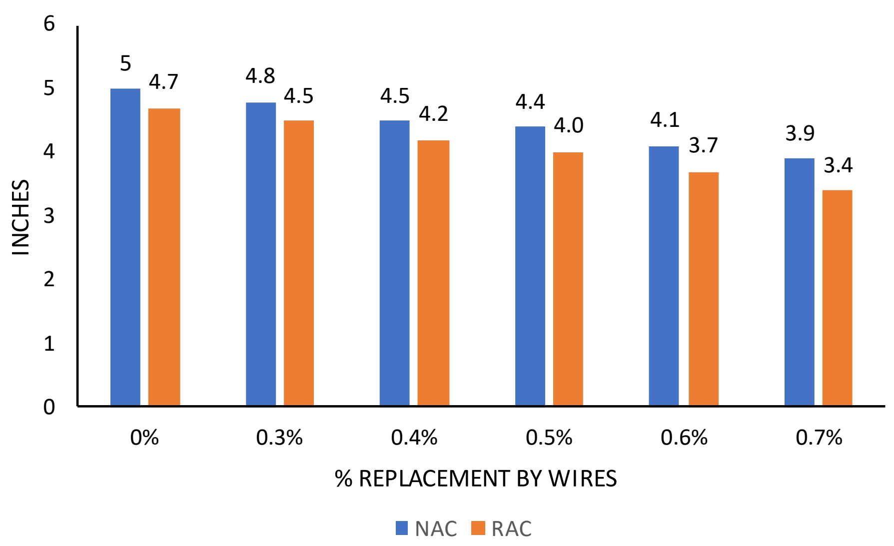


Figure 1 Slump values on NAC and RAC

3.3.2.2 Aggregate:

Grading of both coarse and fine aggregate was done. 3/8 in sieve kept aggregate was used and the maximum aggregate size was kept 1/2in[45,46].

3.3.2.3 Tensile Strength Tests:

The obtained Waste Aluminum wires were tested for tensile strength using Ultimate Testing Machine (UTM) at the School of Chemical and Material Engineering, NUST[47].

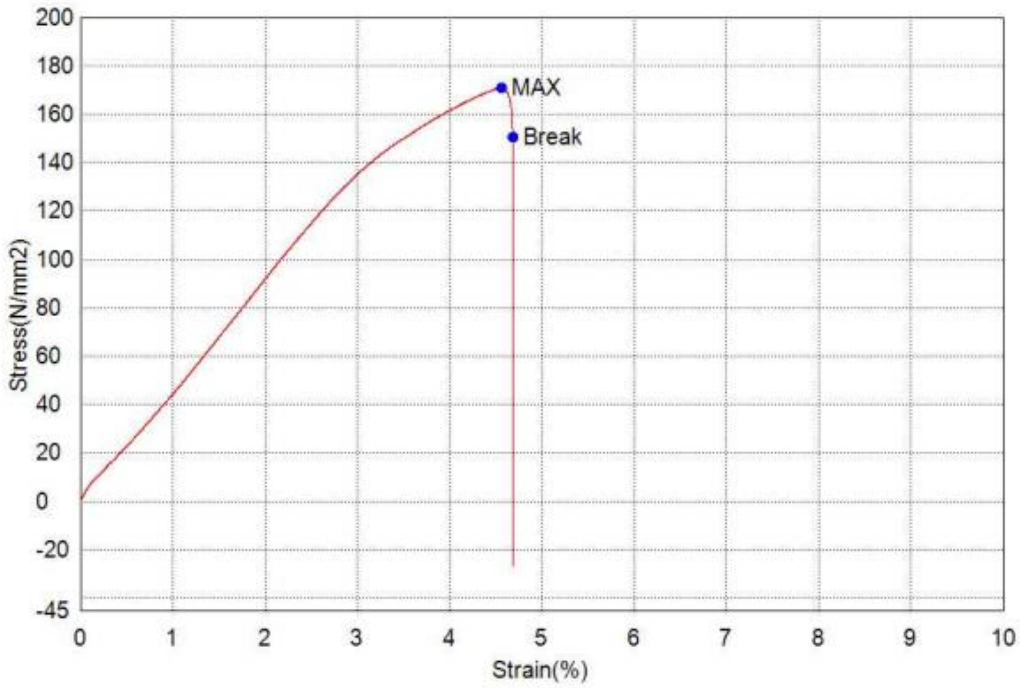


Figure 2 Stress-Strain Curve of Waste Aluminum Wires

3.3.2.4 Material Procurement.

3/8 in sieve kept aggregate was used and the maximum aggregate size was kept 1/2in for both NAC and RAC. The cement used was Bestway Company's during the casting and it was obtained right before the mixing.

3.3.3 Casting:

For the testing of the impact Waste Aluminum wires have on Concrete, 3 types of samples were cast. Specimens for Compressive strength, Flexure, and Split tensile Tests were cast according to the ASTM standards C39[48], C293[49], and C49650, respectively.

3.3.3.1 Cubes For Compressive Strength:

- Cubes of 150mm x 150mm x150mm dimensions
  - 2 control samples with 0% replacement of NAC
  - 2 control samples with 0% replacement of NAC
  - 10 samples with Waste Aluminum wires. 2 for each percentage replacement (0.3%,0.4%,0.5%,0.6%,0.7%)

Figure 3 Cubes (150 x 150 x 150) during the casting

3.3.3.2 Beams for Flexure Strength:

- Beams having dimensions 400mm x 100mm x 100mm were cast for testing compressive strength
    - 2 control beams for both NAC and RAC.
    - 10 with fiber content. 2 for each replacement, as in the case of cubes.

Figure 4 400mm beams casting.

3.3.3.3 Cylinders for split tensile strength:

- Cylinders with 200 mm in height and 100 mm in diameter
    - 3 cylinders for each replacement percentage
    - 6 control samples. 3 for NAC and 3 for RAC
- Total cylinder cast 36. 18 for NAC and 18 for RAC

Figure 5 Cylinders during casting

3.3.3.4 Waste Aluminum wires:

The Waste Aluminum wires used for casting were all cut to be of the same size ranging from 1.5-2.5in. the wires had a diameter of 0.052in. All the wires were twisted from the center to form loops. The loops range from 0.2-0.3 inches in radius. The advantage of looping the wires was to improve the anchorage and provide better tensile strength. Other advantages of Waste Aluminum wires are that looped wires provide an increased grip and prevent the propagation of cracks.

Figure 6 Waste Aluminum wires

3.3.3.5 Concrete mix:

The mix design was used of M30 for both NAC and RAC. The water to cement ratio was kept at 0.45. Cement, sand and coarse aggregate were kept at 400 kg/m^3, 690 kg/m^3 and 1200 kg/m^3 respectively. The wire replacement was done by volume.

3.3.3.6 Curing Period:

To ensure the concrete specimens achieve their maximum strength, a curing period of 27±3 days was set for both the beams and cylinders. The curing process involved regularly watering the specimens to have a moist environment. This is a crucial step in the concrete production process as it helps in enhancing the strength and durability of the concrete by allowing enough time for the chemical reactions to occur and for the concrete to reach its desired strength.

Figure 7 Curing of samples

Chapter 4

Experimental Setup

4.1 Compressive strength:

The cubes were tested for compressive strength at the NUST Institute of Civil Engineering (NICE). The tests were performed according to ASTM C39. The cubes were removed from curing and placed in the Sun for 24hrs before testing.

Figure 8 Compression testing apparatus

4.2 Flexure Strength:

The flexure strength was measured according to ASTM C293. The 400mm beams were tested using center point loading. The beams were simply supported. All beams were tested for 28-day strength.

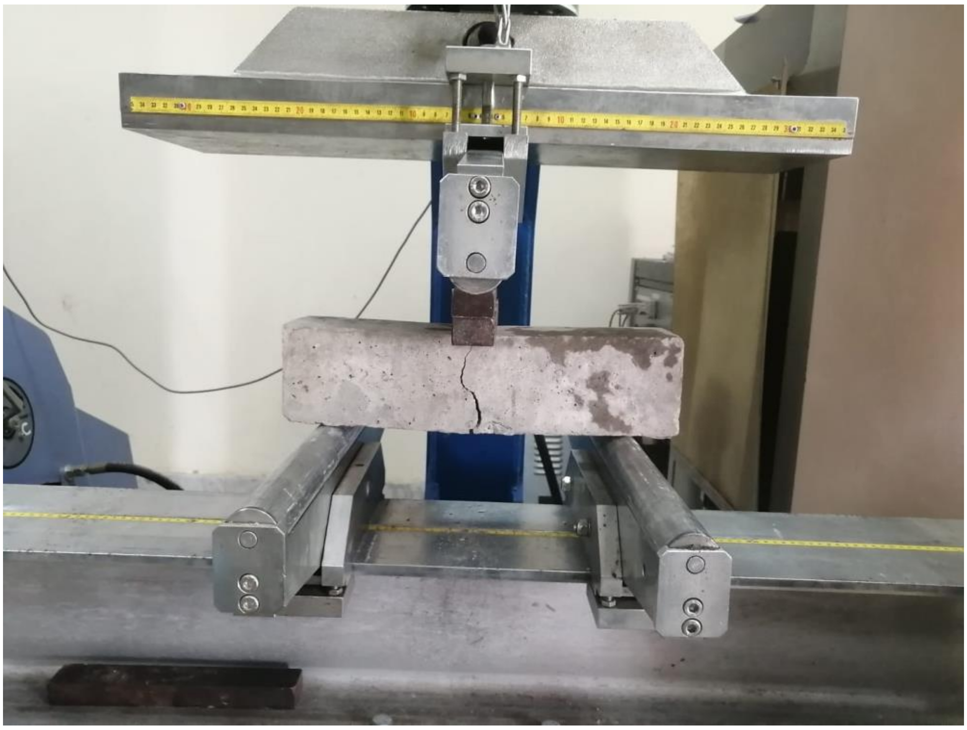


Figure 9 Center Point Loading for Flexure Testing

4.3 Split Tensile.

Cylinders of both NAC and RAC were tested for tensile strength according to ASTM C496. This was done at the NUST Institute of Civil Engineering. The cylinders were also tested for 28-day strength.

Figure 10 Cylinder Test (Split Tensile Test)

Chapter 5

Results and Analysis

5.1 Compressive strength:

Shows the compressive strength test results for all tested specimens. The compressive strength of the control sample of Conventional Concrete was 30.5 MPa. For the mix design with a replacement ratio of 0.3% an increase in strength of 3.61% was seen. Similarly, for 0.4%, an increase of 6.55% was seen. The peak is achieved at 0.5% with a strength of 33.4 MPa, an increase of 9.5%. The specimen of 0.6% and 0.7% show a decrease in strength at 2.6% and 5.9% as compared to conventional concrete.

The compressive strength of the Recycled Aggregate control sample was 26.4 MPa. Like the case of conventional concrete, 0.3 and 0.4% replacement specimens showed an increase in strength of about 1.89% and 6.06% respectively. An increase in the strength of Recycled Aggregate Concrete was seen when the replacement percentage was increased to 0.5%. It showed an increase of 10.6% in compressive strength. The 0.6% and 0.7% samples showed a decrease of 2.39% and 9.9% respectively from the 0.5% sample and an increase of 7.9% and 0.3% from the control sample.

Figure 10 illustrates the effect of the incorporation of aluminum fibers in concrete. An increase in strength is recorded from 0.3% to 0.5%. The peak strength is seen at 0.5%. The strength then shows a decreasing trend after 0.5% till 0.7%. There are two main reasons for the improvement of the compressive strength of concrete:

- By bridging cracks: When a concrete structure is loaded, it can develop cracks. Fibers can help to bridge these cracks and prevent them from propagating. This increases the load-bearing capacity of the structure.

- By confining the concrete matrix, fibers can help to confine the concrete matrix, which makes it more resistant to deformation. This also increases the load-bearing capacity of the structure.

As the fiber dosage in concrete increases, the confining property of the fiber matrix (concrete) also increases, resulting in reduced transversal deformations and an increase in the compressive strength of the concrete. However, this effect is only seen up to a certain threshold limit of fiber dosage.

The results show a peak strength of 0.5%. Beyond this limit, adding fibers harms the compaction of the concrete. At higher fiber dosages, the workability of the concrete is significantly reduced, making it difficult to properly mix and place the concrete. Even with the addition of admixtures, the damage to the workability of the concrete may not be rectified.

Workability is influenced by several factors, including cement fineness, aggregate properties, water-cement ratio, and the fiber-reinforcing index. The formation of honeycombs and voids due to poor compaction and reduced workability hurts the compressive strength of the concrete at higher fiber dosages. So, it is crucial to carefully consider the dosage and aspect ratio of fibers when incorporating them into concrete to ensure the desired improvements in strength without compromising the workability and compaction of the material.

A similar trend is shown by RAC due to similar reasons. Some have observed that the addition of aluminum fibers makes the strength of RAC comparable to that of conventional concrete. With 0.5% replacement of RAC showing an increased strength of 2.3% as compared to conventional concrete with no replacement.

Table 1 Compressive Strength of All Samples

Sample Type	% Replacement by Wires	Compressive Strength MPa
NAW	0	30.5
	0.3	31.6
	0.4	32.5
	0.5	33.4
	0.6	31.5
	0.7	30.8
RAW	0	26.4
	0.3	26.9
	0.4	28.0
	0.5	29.2
	0.6	28.5
	0.7	26.3

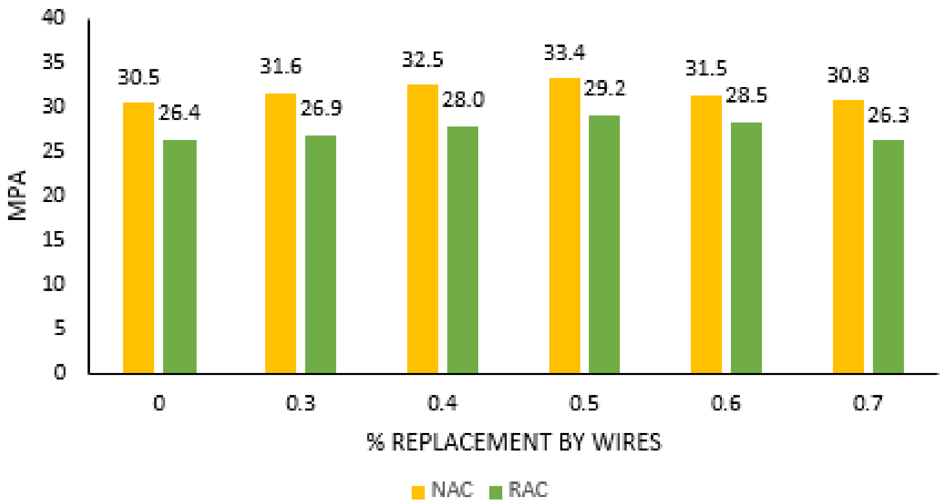


Figure 10 Compressive strength of Natural Aggregate Concrete and Recycled Aggregate Concrete

5.2 Stress-Strain Relationship:

To determine the stress-strain curves of NAC and RAC, displacement-controlled testing of samples was conducted shown in. In this study, displacement-controlled testing of the sample was used to assess the stress-strain relation between recycled aggregate concrete (RAC) and normal aggregate concrete (NAC). Plotting the load versus displacement and the stress versus strain, respectively, yielded the stress-strain curves for NAC and RAC. The strength, stiffness, and ductility of concrete can be determined by looking at the stress-strain curve, which is a crucial parameter in understanding the mechanical behavior of concrete. The data obtained can be used to optimize the usage of recycled aggregates in the manufacturing of concrete and to help design structures using NAC and RAC.

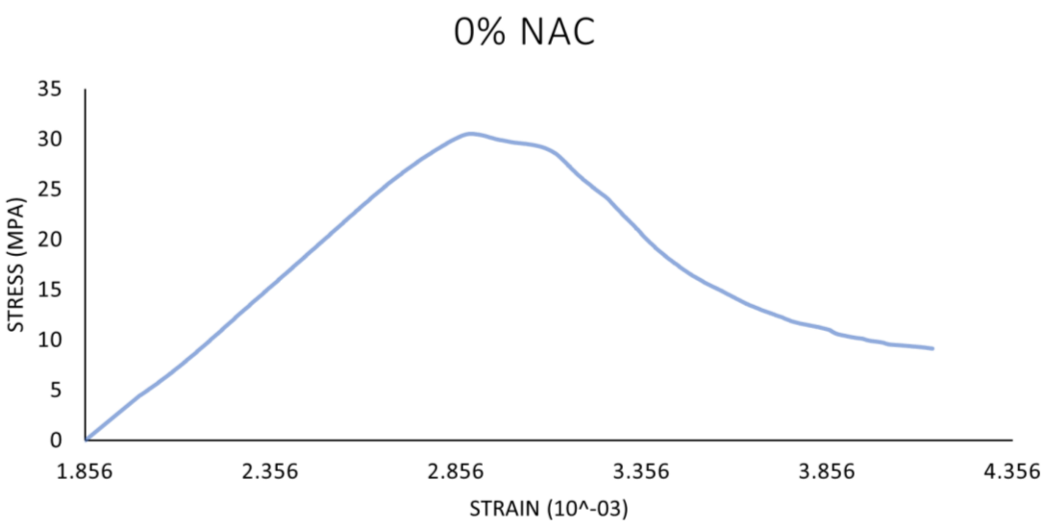


Figure 11 Stress-Strain Relationship for 0% replacement NAC

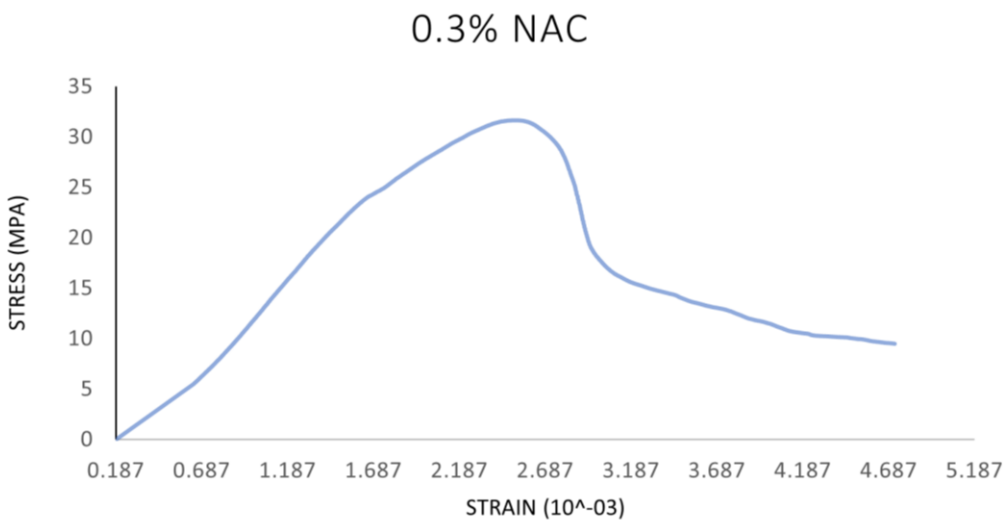


Figure 12 Stress-Strain Relationship for 0.3% replacement NAC

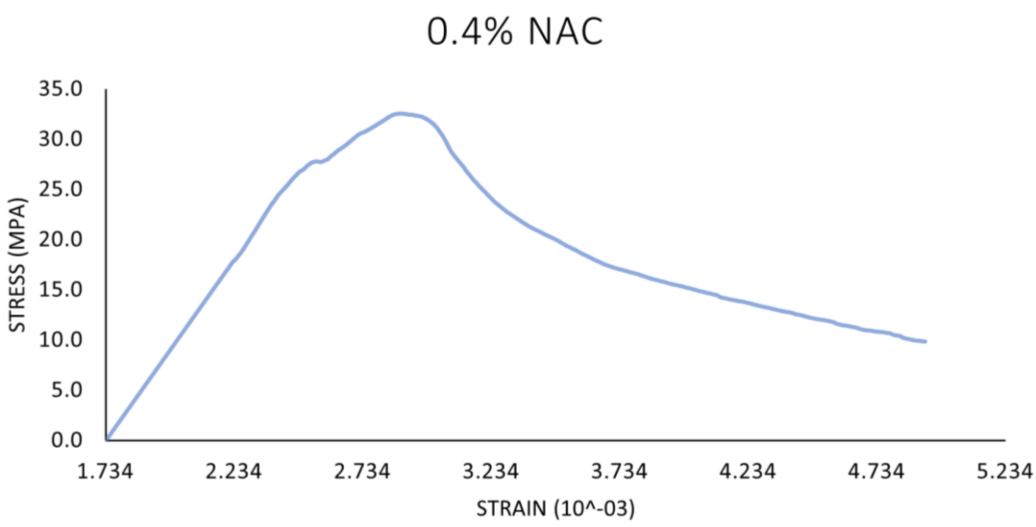


Figure 13 Stress-Strain Relationship for 0.4% replacement |NAC

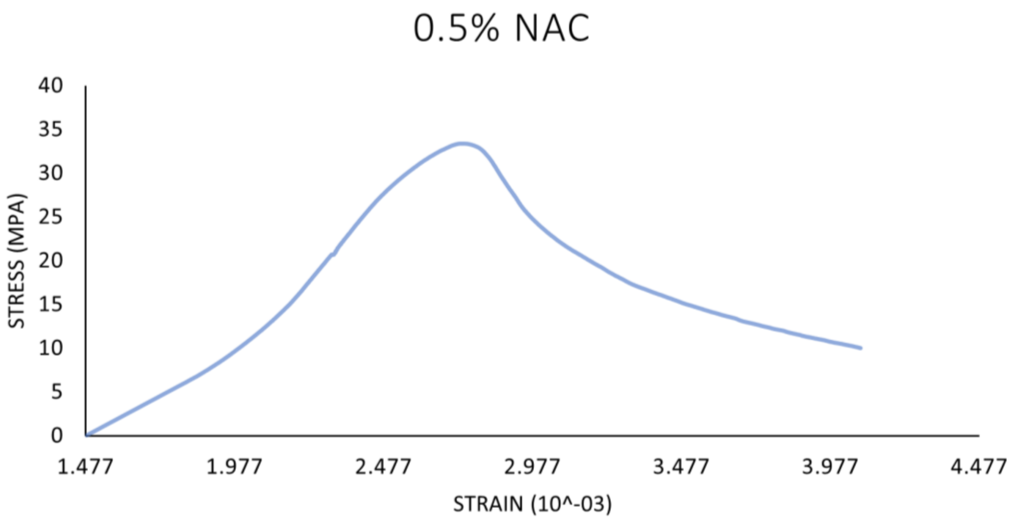


Figure 14 Stress-Strain Relationship for 0.5% replacement NAC

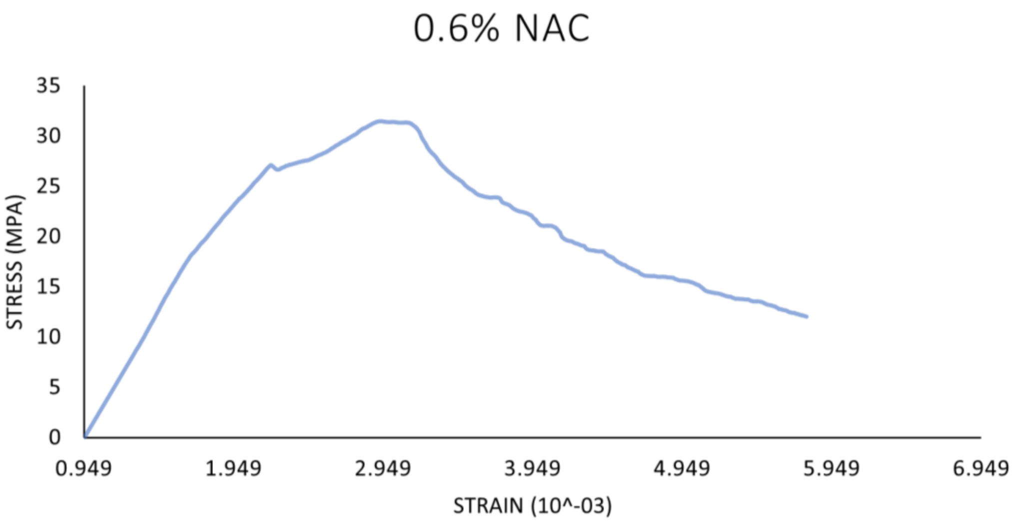


Figure 15 Stress-Strain Relationship for 0.6% replacement NAC

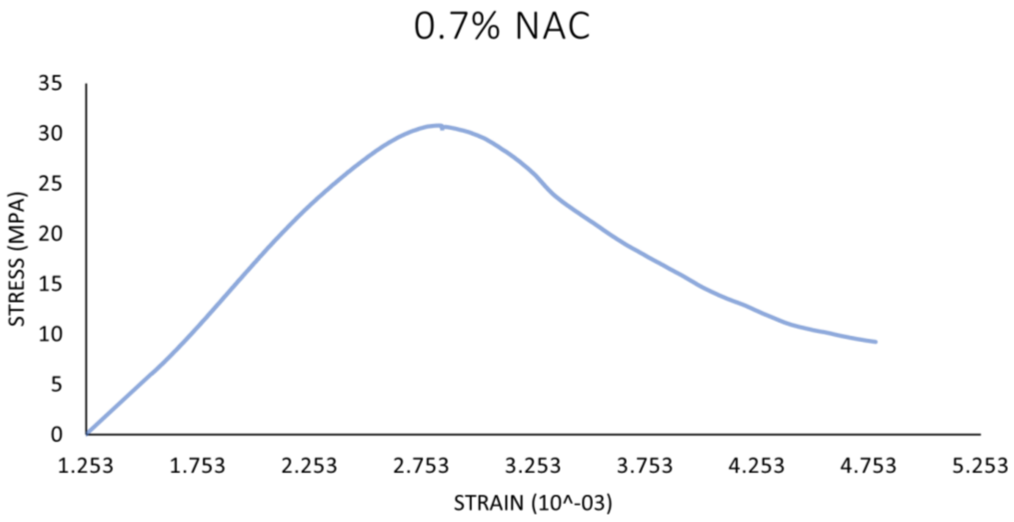


Figure 16 Stress-Strain Relationship for 0.7% replacement NAC

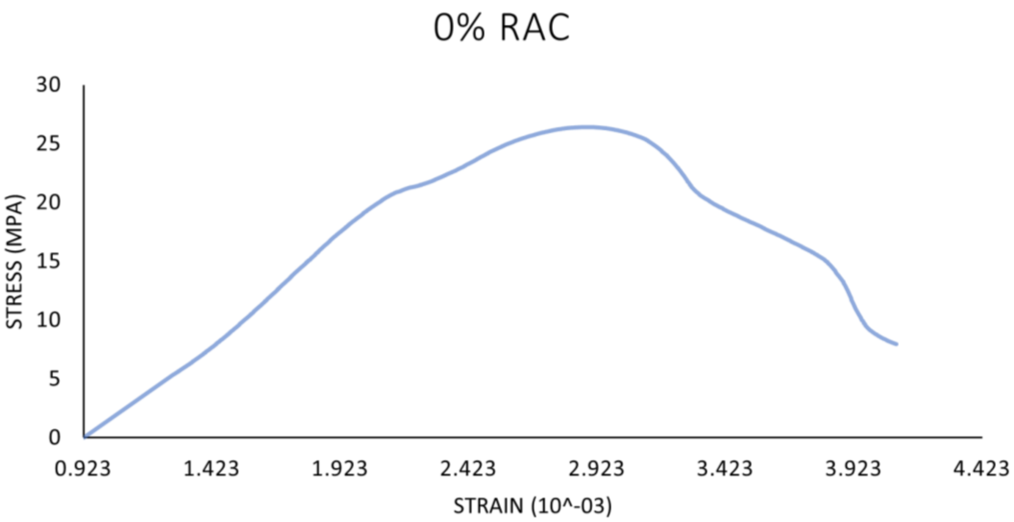


Figure 17 Stress-Strain Relationship for 0% replacement RAC

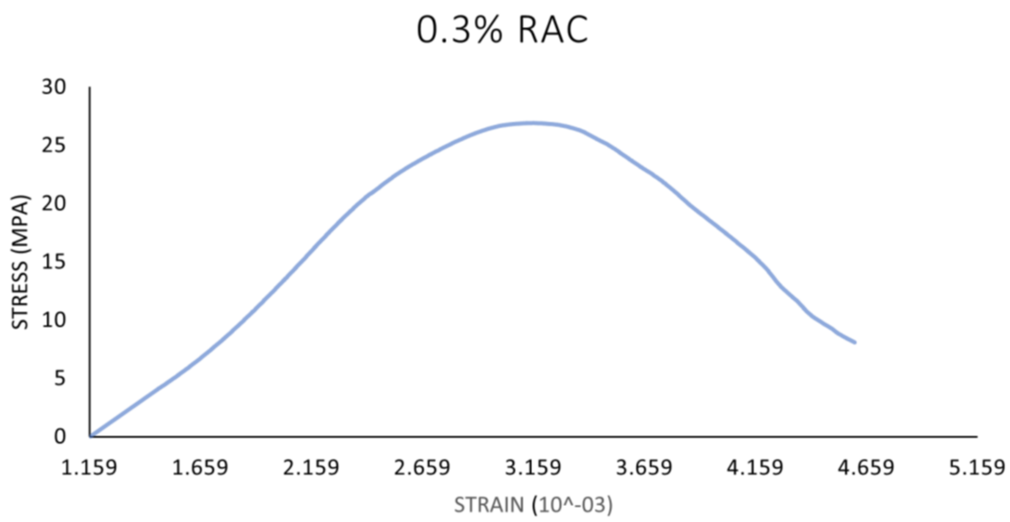


Figure 18 Stress-Strain Relationship for 0.3% replacement RAC

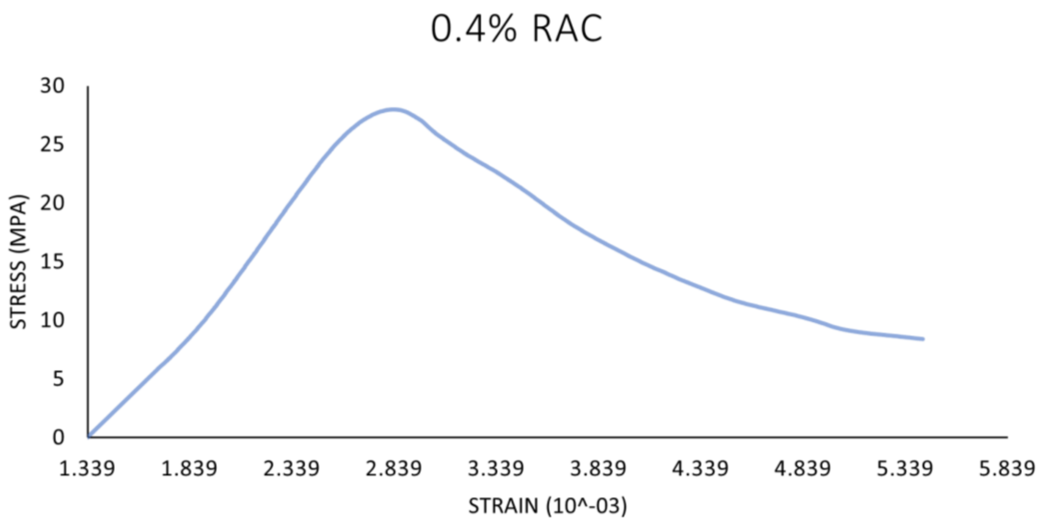


Figure 19 Stress-Strain Relationship for 0.4% replacement RAC

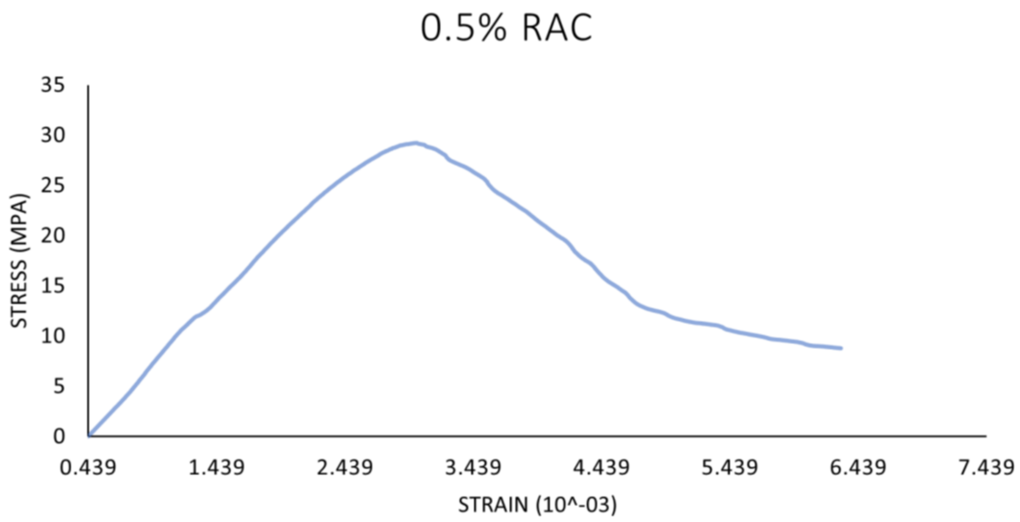


Figure 20 Stress-Strain Relationship for 0.5% replacement RAC

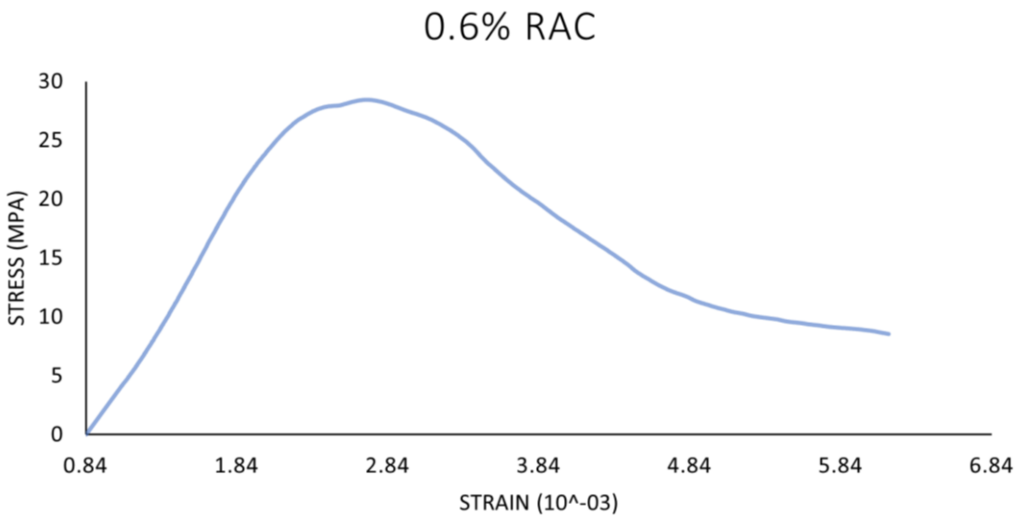


Figure 21 Stress-Strain Relationship for 0.6% replacement RAC

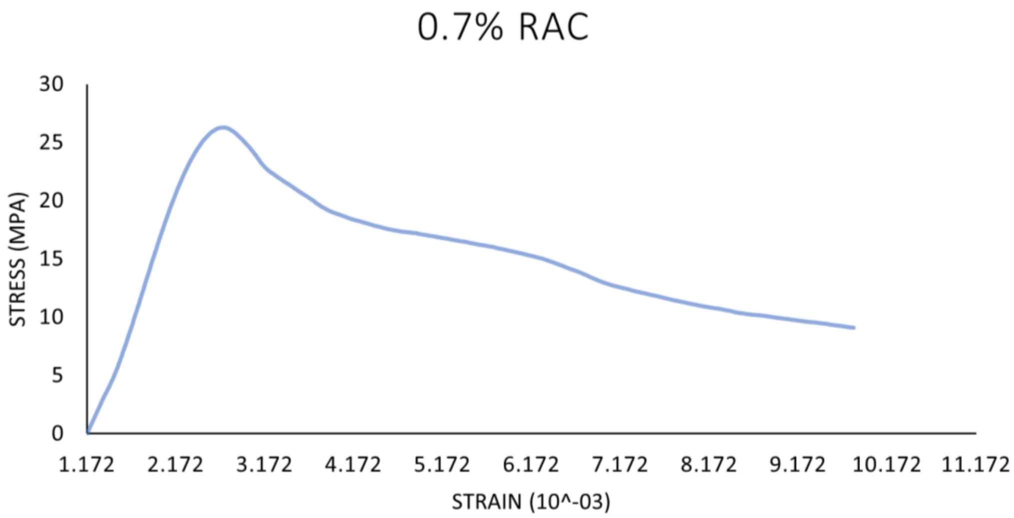


Figure 22 Stress-Strain Relationship for 0.7% replacement RAC

5.3 Flexural Strength:

The flexural strength of all mixes is presented in **Table 2.** The flexural strength of the control sample is 10.7 MPa. The flexural strength recorded at 0.5% shows an increase of 21.5%. The 0.7% replacement shows an increase in strength of 35.5% as compared to a 28.9% increase in 0.6% replacement. The 0.4% concrete shows an increase in flexural strength of 10.2% as compared to an increase of 1.87% of 0.3% replacement.

The recycled aggregate concrete shows a similar trend, with strength increasing from 0% RAC (control sample) to 0.7%. The 0.5% shows 10.8 MPa strength, a 33.3% increase as compared to the control sample, which showed a flexural strength of 8.1 MPa. Using a replacement ratio of 0.3% by volume shows an increase in strength of 7.4%. Similarly, 0.4% and 0.6% show an increased strength of 18.5% and 40.7% respectively. The 0.7% RAC shows an increase of about 48.1%.

The flexural strength is seen to increase throughout the specimens. This trend is seen both in the case of conventional concrete and recycled aggregate concrete. The increase in the flexural strength of reinforced concrete incorporating Waste Aluminum wires can be attributed to the confining effect of the wires on the concrete matrix.

When Waste Aluminum wires are incorporated into concrete, they act as a confining agent that limits the development and propagation of cracks in the concrete matrix. As a result, the flexural strength of the reinforced concrete increases.

Moreover, adding Waste Aluminum wires to the concrete mix increases the volume of reinforcing material, which improves the load-bearing capacity of the reinforced concrete. The Waste Aluminum wires also have a higher tensile strength than the concrete, so they can bear more load than the surrounding concrete. This further enhances the flexural strength of the reinforced concrete.

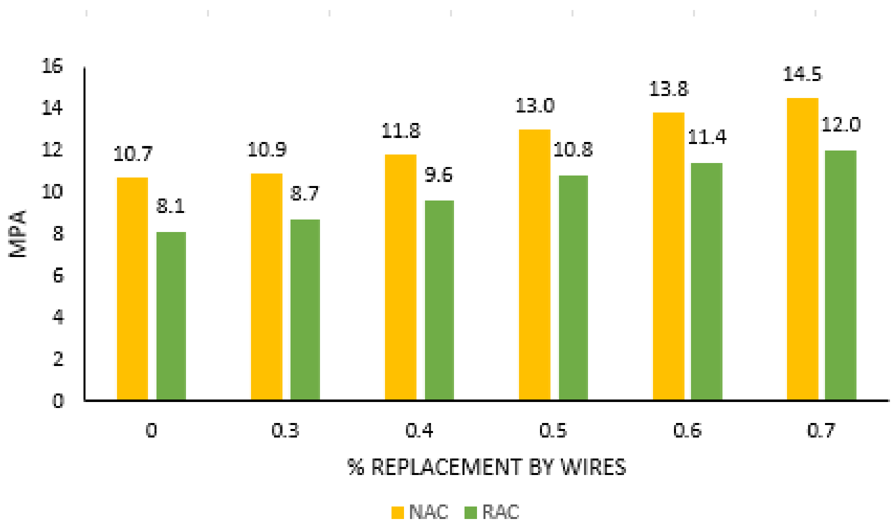


Figure 23 Flexural Strength trend of NAC and RAC

Table 2 Flexure Strength

Sample Type	% Replacement by Wires	Flexural Strength (MPa)
NAW	0	10.7
	0.3	10.9
	0.4	11.8
	0.4	12.2
	0.5	13.0
	0.6	13.8
	0.7	14.5
RAW	0	8.1
	0.3	8.7
	0.4	9.6
	0.5	10.8
	0.6	11.4
	0.7	12

5.4 Split Tensile Strength.

The split tensile strength results obtained for different percentages of aluminum wire incorporation are presented in **Table 3**. The control sample of conventional concrete showed a split tensile strength of 3.7 MPa. The replacement of Waste Aluminum wires at 0.3% resulted in an increase in the split tensile strength to 3.9 MPa, which is an increase of 5.4%. Similarly, an increase in split tensile strength was seen for replacement ratios of 0.4% and 0.5%, with values of 4.2 MPa and 4.8 MPa, respectively. Samples with replacement ratios of 0.6% and 0.7% showed an increase in split tensile strength by 29.7% and 48.6%, respectively.

The results showed a significant effect of the replacement percentage on the split tensile strength of RAC. The split tensile strength of the control sample of RAC was 3.1 MPa. For the mix design with a replacement ratio of 0.3%, an increase in strength of 6.4% was seen. Similarly, for 0.4% and 0.5% replacement ratios, increases in strength of 16.2% and 29.03%, respectively, were seen. The specimens of 0.6% and 0.7% showed an increase in strength of 41.9% and 58.06%, respectively, as compared to the control sample.

Split tensile strength is the measure of the tensile strength of concrete across the diameter of a cylinder or a prism specimen. In the case of RAC, the split tensile strength increased with the increase in the percentage of replacement of natural aggregate with recycled aggregate. This can be attributed to the improved interlocking between the recycled aggregates and the cement paste due to the wires. After conducting tests on the cylinder specimens, the observation revealed that the looped ends of the fibers were securely embedded within the concrete matrix. This indicated that the randomly oriented looped end fibers had an ample pull-out resistance to effectively impede any propagation of cracks, thus resulting in an improvement in the ductility of the traditionally brittle NC matrix.

Table 3 Split Tensile Strength of samples.

Sample Type	% Replacement by Wires	Split Tensile Strength MPa
NAW	0	3.7
	0.3	3.9
	0.4	4.2
	0.4	4.3
	0.5	4.8
	0.6	5.0
	0.7	5.5
RAW	0	3.1
	0.3	3.3
	0.4	3.7
	0.5	4.0
	0.6	4.4
	0.7	4.9

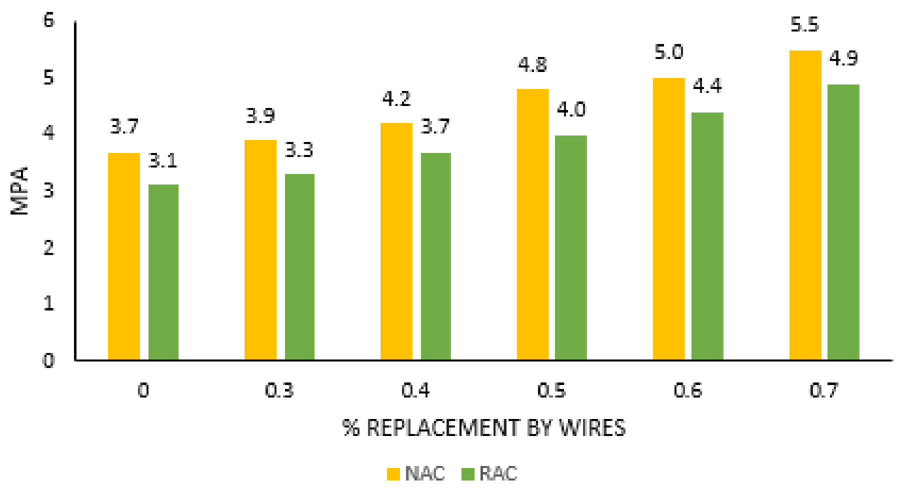


Figure 24 Split Tensile strength of NAC and RAC

Chapter 6

Finite Element Analysis

6.1 Introduction:

The performance of waste aluminum incorporated RAC was calculated using non-linear modeling on ETABS. In engineering and research, nonlinear analysis is a computational technique used to address nonlinear behavior-related issues. One of the complex mathematical techniques used in nonlinear analysis to simulate a system's response under varied conditions is finite element analysis (FEA). This technique forecasts the system's behavior under stresses that surpass its elastic limit, including plastic deformation and eventual failure.

6.2 Methodology:

- Stress-Strain curves of samples were obtained using displacement-controlled compression testing.
- They were provided to ETABS as a material property.
- A simple 2 story moment resisting frame structure was modeled for specimens containing 0% and 0.5% replacement ratios for both NAC and RAC.
- Response target spectrum function was defined having an S_s value of 1.15 and S_1 value of 0.51.
- The building was assumed to be in site class B.
- For this ASCE 7-16 was used.
- After that, the time history function was defined in both x and y direction. Spectral matching was done in time domain. For this ALTADENA function was used in both x and y direction.

- Later the frequency-domain spectral matching was done for both the response spectrum and time history function in g units.
- The load patterns were defined with centricity for both wind loading and seismic loading in ±x and ±y direction. Time history case was set to run.
- After that, the mass source was defined with a dead load multiplier of 1 and live load multiplier of 0.25.
- The built-in load combination for ordinary moment resisting frame were defined.
- Dead and live loads per floor were assigned as 0.295psf and 0.313psf respectively, and the analysis was run.

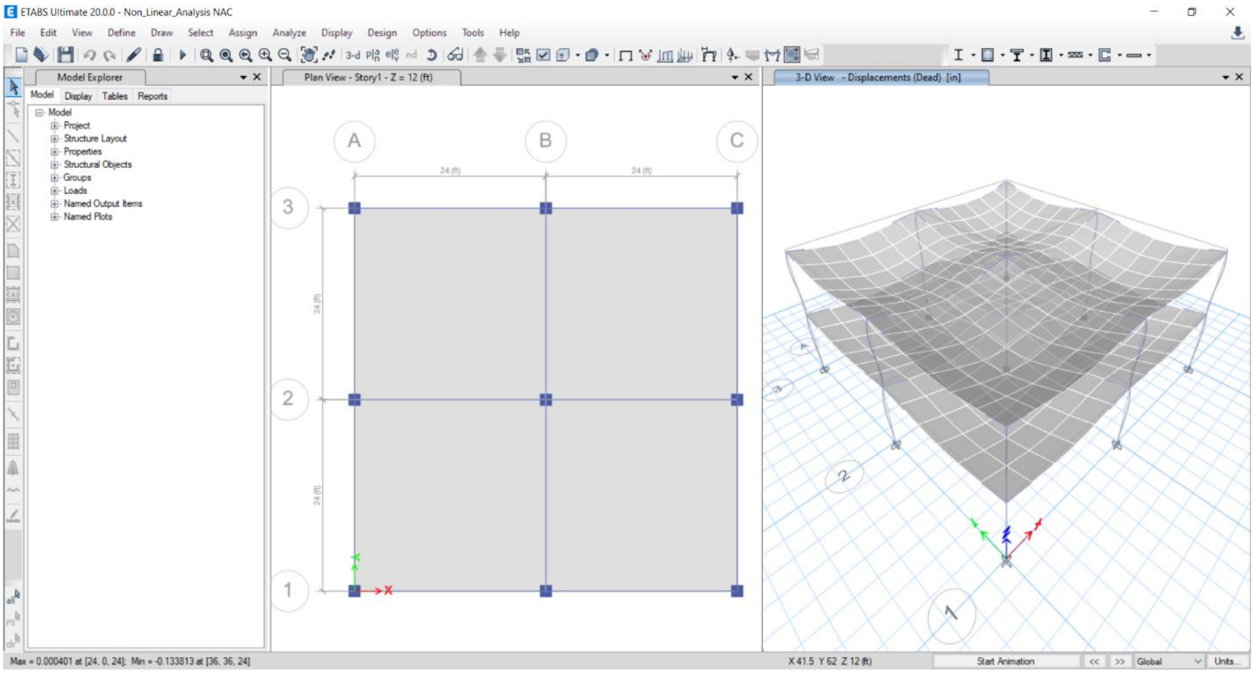


Figure 25 ETABS Model

6.3 Results and Discussion:

After the analysis, the story response plots, combined story response plots, plot functions and response spectrum curves data were obtained.

6.3.1 Normal Aggregate Concrete (NAC):

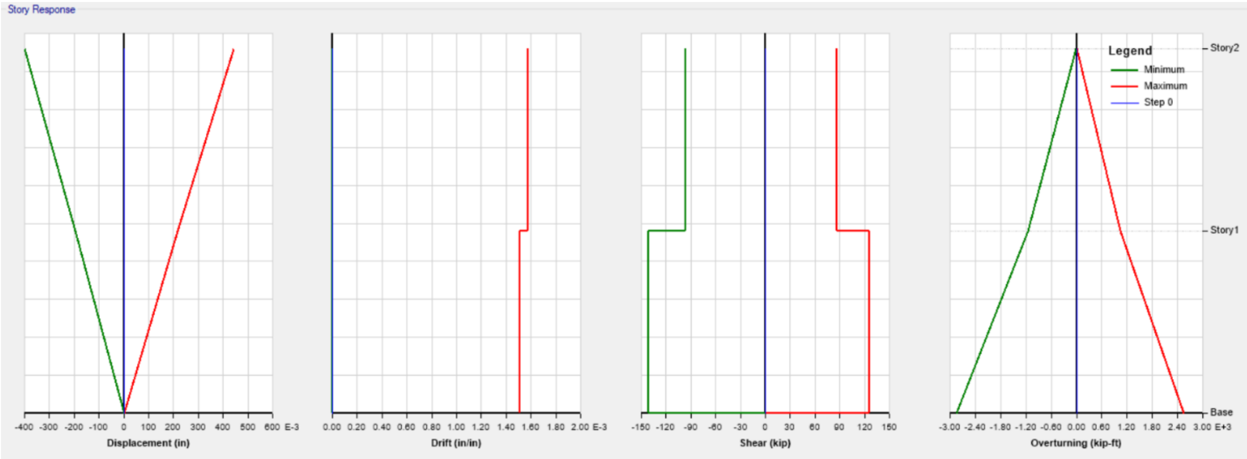


Figure 26 Combined Story Response Plot for NAC

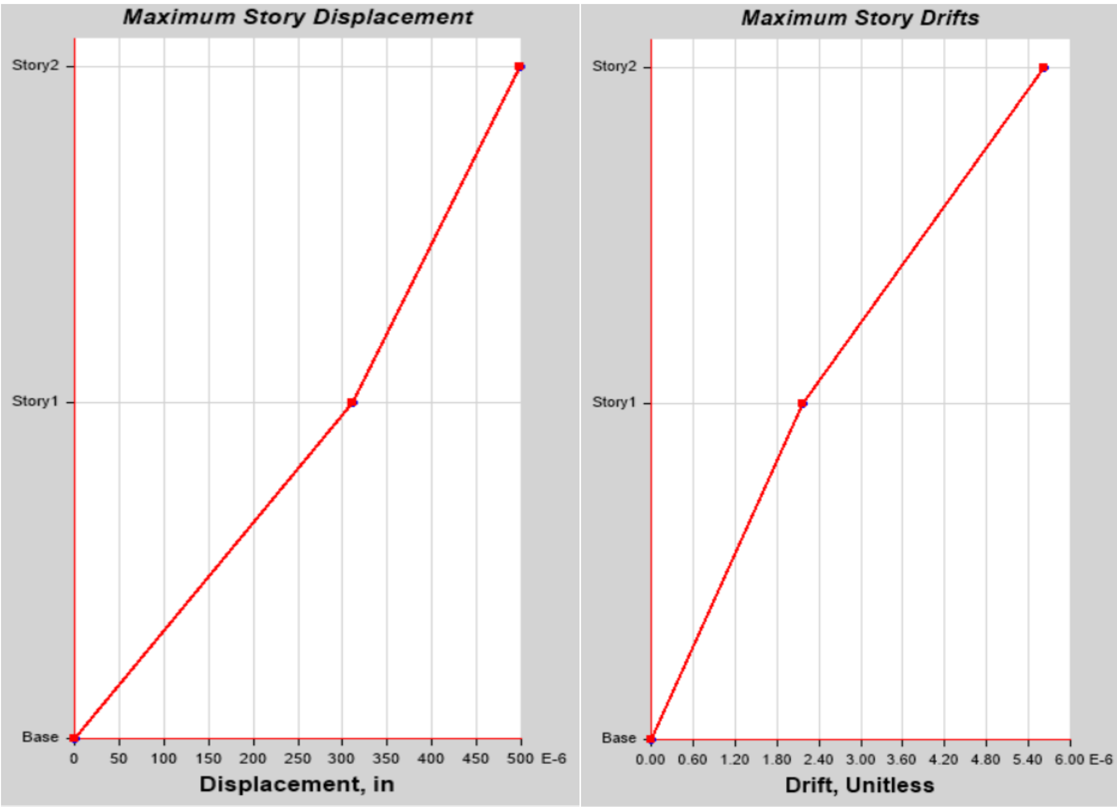


Figure 27 Maximum Story Displacement and drift for NAC

6.3.2 0.5% NAC:

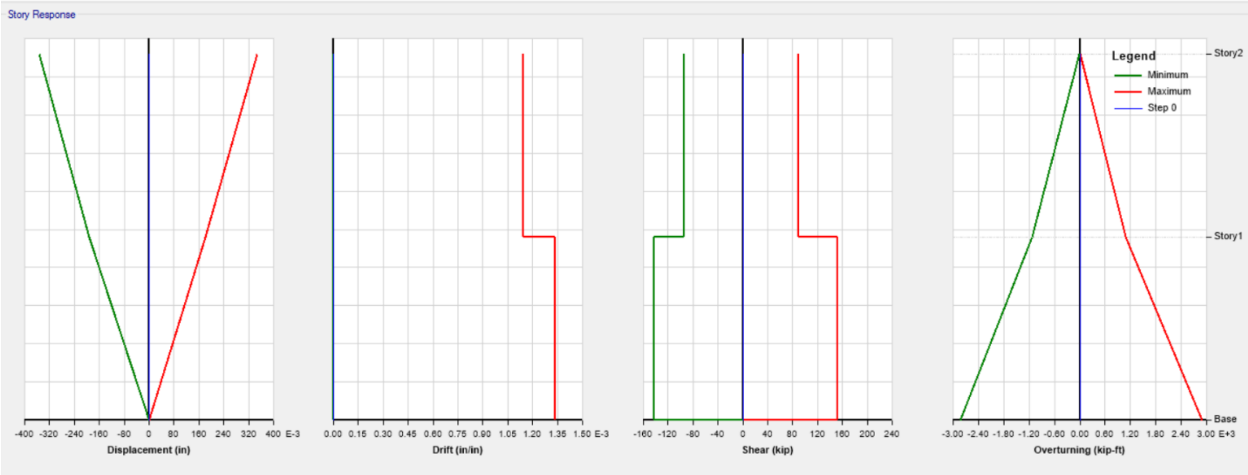


Figure 28 Combined Story Response Plot for 0.5% NAC

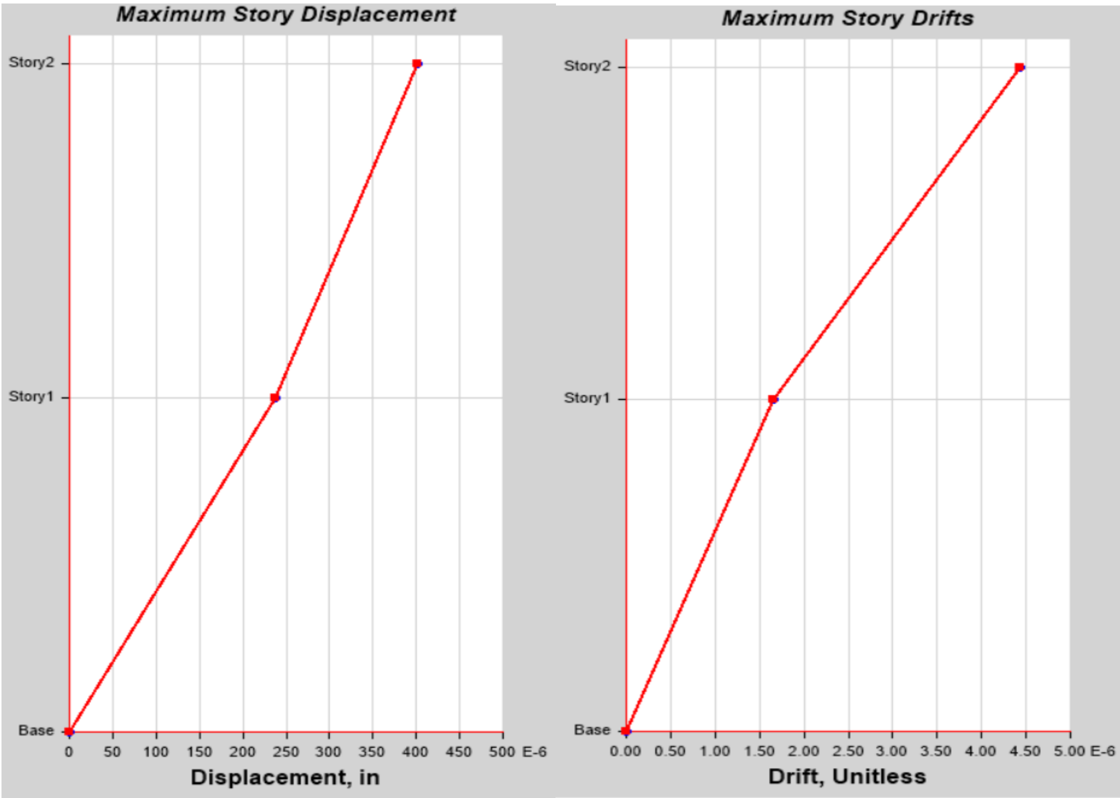


Figure 29 Maximum Story Displacement and drift for 0.5% NAC

6.3.3 RAC:

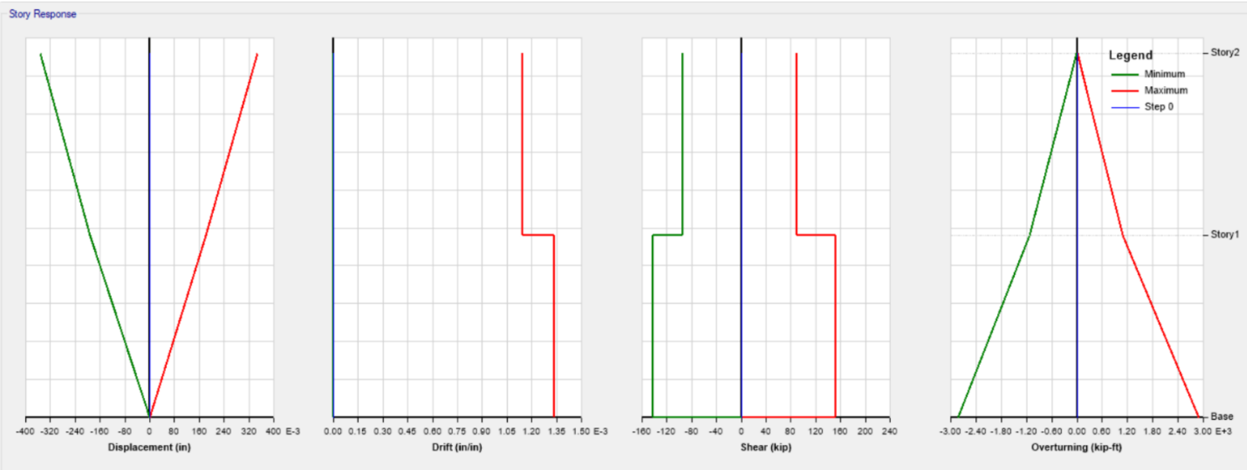


Figure 30 Combined Story Response Plot for RAC

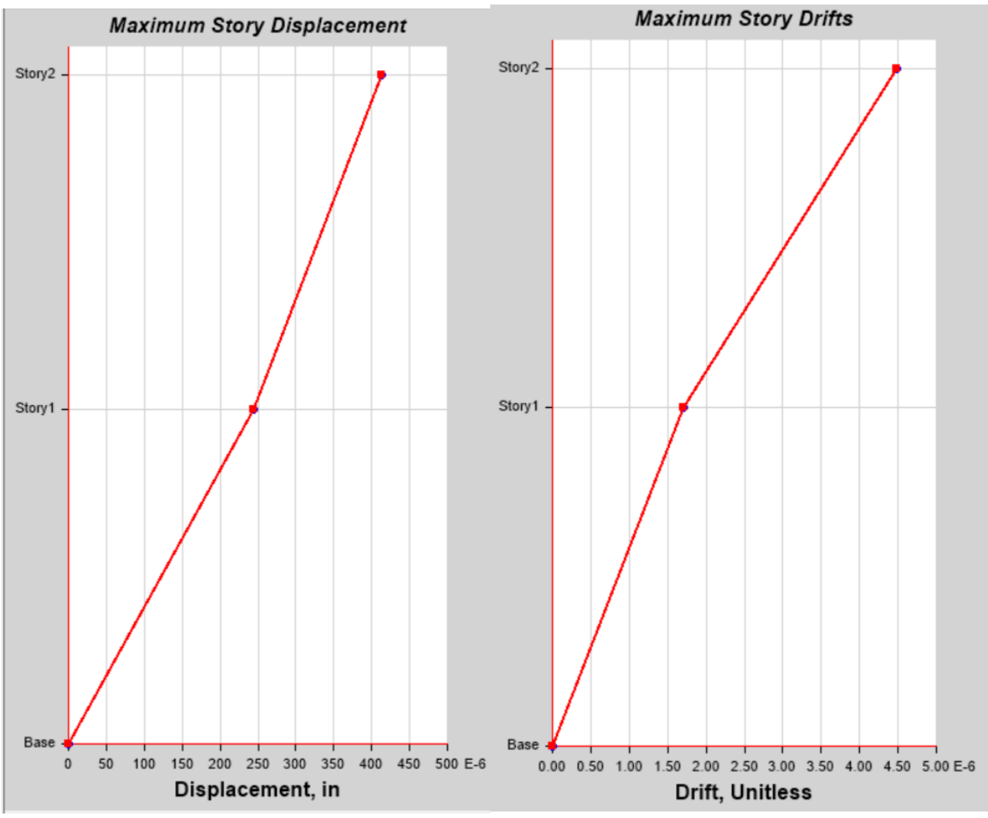


Figure 31 Maximum Story Displacement and drift for RAC

6.3.4 0.5% RAC:

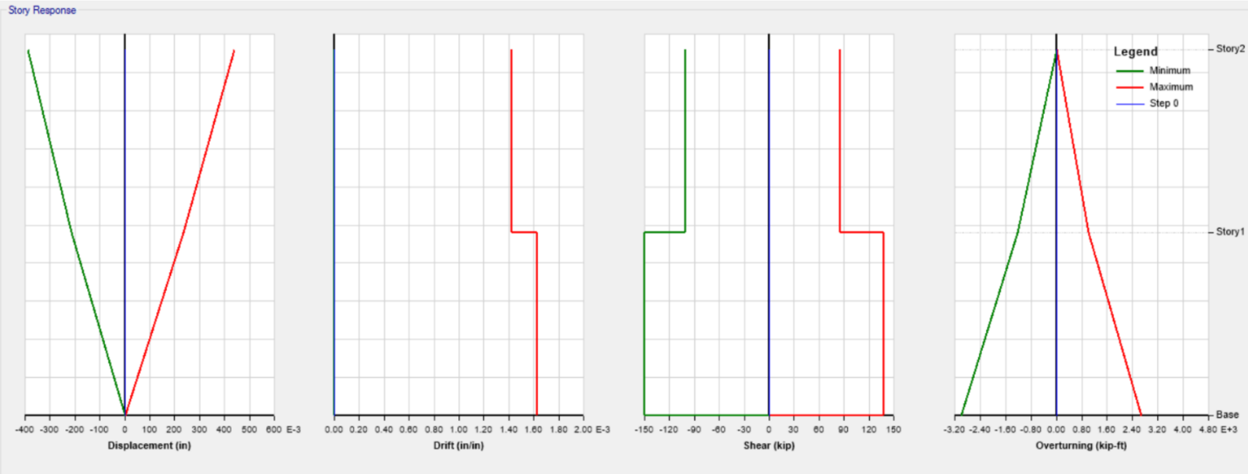


Figure 32 Combined Story Response Plot for 0.5% RAC

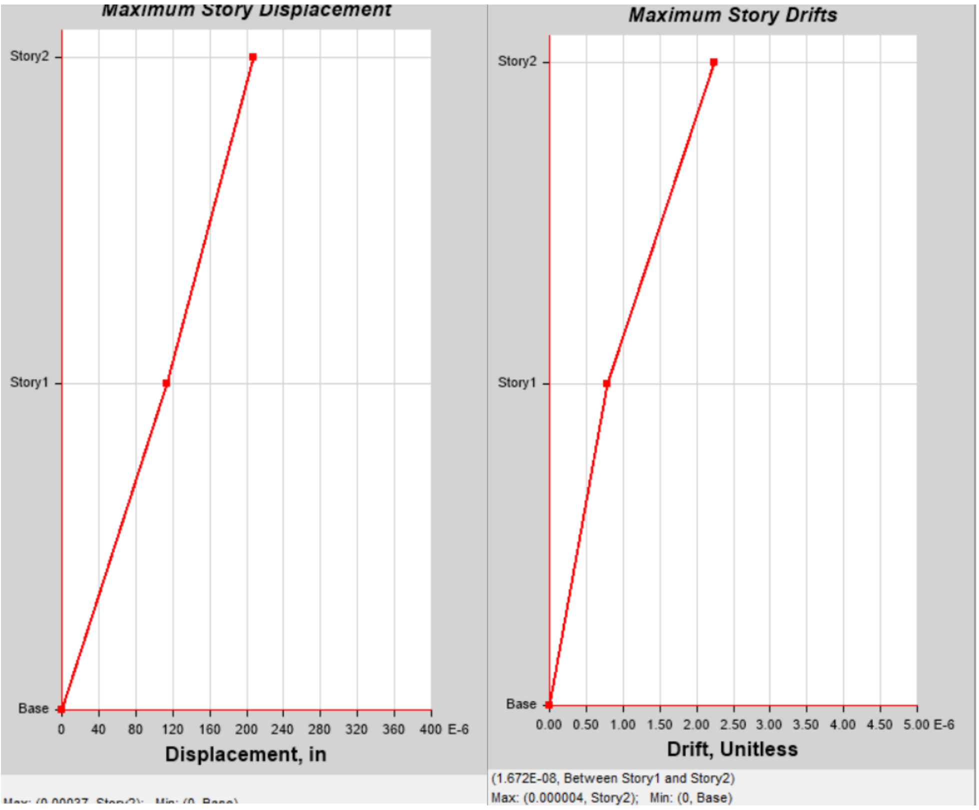


Figure 33 Maximum Story Displacement and drift for 0.5%RAC

6.4 Finite Element Analysis Conclusion:

So, the conclusion that we arrived at was that waste aluminum wire incorporated concrete at 0.5% replacement RAC proved to be 10.6% in compression, 33.3% in flexure and 29.03% in split tensile. These experimental findings manifested themselves in the non-linear model.

The Performance of 0.5% replacement RAC proved to improve the maximum story displacement by 25.8% and maximum story drift by 33.3%. Similarly, the performance of 0.5% replacement NAC proved to improve the maximum story displacement by 19.6% and maximum story drift by 25%.

Chapter 7

Life Cycle Assessment

7.1 Introduction:

The construction industry is one of the biggest contributors to environmental degradation. According to the Global Alliance for Buildings and Construction's (Global ABC) 2020 Global Status Report for Buildings and Construction, while worldwide building energy consumption was stable year over year in 2019, energy-related CO2 emissions rose to 9.95 GtCO2 in 2019. This increase was brought about by a switch away from using coal, oil, and traditional biomass directly for electricity, which had a higher carbon content because so many fossil fuels were used to generate it. The sector was responsible for 38% of all global energy-related CO2 emissions when building construction emissions are added to operational emissions[51]. This high ranking is due to its high consumption of natural resources and energy. The main material used in construction is concrete and 3 out of 4 parts of concrete are natural resources i.e., aggregate, sand, and water. The 4th is cement which requires a high amount of heat and energy to be produced. It has been estimated that per 1kg of cement produced, 0.5-0.9kg of CO2[52] emissions are evolved, and this equates to about 3.24 billion tons of CO2/year for 3.6 billion tons of cement produced annually[53]. In recent years there has been an increase in developing sustainable construction practices, which reduce the carbon footprint of the industry.

Life Cycle Assessment also known as Life Cycle Analysis (LCA) is a useful tool for assessing and evaluating the impact of a material or service on the environment. Depending on the analysis LCA considers all stages of the life cycle of the product, including raw material extraction, transportation, and refining to production use and disposal of the product. Each step considers the impact of the product on the environment during that stage.

According to standards in ISO 14040 and 14044[54,55] there are four phases of LCA. Goal and Scope, Life Cycle Inventory, Impact Analysis, and Interpretation. Each stag has a distinct role in assessing the impact of a product on the environment. This chapter presents the results of an LCA study conducted on concrete incorporating aluminum wire as a sustainable alternative to conventional steel reinforcement.

7.2 Methodology:

The assessment was made according to ISO 14040 and 14044 standards. The method was cradle-to-gate.

There are various software and databases for Life Cycle Assessment.

7.2.1 SimaPro:

SimaPro is a widely used software for LCA studies. It offers a user-friendly interface and a comprehensive database of materials and processes.

7.2.2 GaBi:

GaBi is another popular software for LCA studies. It offers a range of features and tools for conducting detailed LCA studies.

7.2.3 OpenLCA:

OpenLCA is a free and open-source software for LCA studies. It offers a user-friendly interface and a range of features for conducting detailed LCA studies.

7.2.4 Ecoinvent:

Ecoinvent is a widely used database for LCA studies. It has a comprehensive database of materials, processes, and emissions.

7.2.5 PE International's GaBi:

PE International's GaBi is another widely used database for LCA studies. It has a range of data on materials, processes, and emissions.

7.2.6 ELCD:

The European Life Cycle Database (ELCD) is a database created by the European Commission for LCA studies. It has a comprehensive database of materials, processes, and emissions.

7.2.7 US LCI Database:

The US LCI Database is a database created by the US Environmental Protection Agency (EPA) for LCA studies. It has a range of data on materials, processes, and emissions.

7.2.8 LCA databases by Thinkstep:

Thinkstep provides a range of LCA databases, such as the Gabi, GaBi Environment, GaBi Packaging, and PRé's SimaPro. They also provide customized LCA databases according to specific industrial sectors or geographic locations.

For this study, the software used was Open LCA and the database used is Ecoinvent.

7.3 Goal and Scope:

The goal of this Life Cycle Assessment is to analyze and study the impact of Waste Aluminum wire incorporated RAC(WAWIRAC) on the environment. The aim is to assess the impact that it has throughout its life from raw materials to production. The study will also compare the environmental performance of the aluminum wire-incorporated concrete with that of traditional concrete with no replacement of coarse aggregate.

7.3.1 System Boundaries:

The system boundaries will cover the life cycle of the RAC and conventional concrete from raw material extraction to production. It includes extraction of raw materials, manufacturing, production, and transportation. The study will assess the environmental impact of RAC throughout all the processes involved in concrete production and will also consider the energy used during the process of production.

7.3.2 Impact Categories:

The study will consider the impact of WAWIRAC in these categories:

7.3.2.1 Acidification:

Acidification is the process of making something more acidic. This can be caused by the release of acidic compounds into the environment, such as sulfur dioxide and nitrogen oxides. Acidification can harm plants and animals, and it can also damage buildings and infrastructure.

7.3.2.2 Climate Change:

Climate change is the long-term change in the Earth's climate. This is caused by the release of greenhouse gases into the atmosphere, such as carbon dioxide and methane. Climate change is causing the Earth's temperature to rise, which is leading to several problems, such as more extreme weather events, sea level rise, and habitat loss.

7.3.2.3 Freshwater ecotoxicity:

Freshwater ecotoxicity is the harm caused to freshwater ecosystems by toxic substances. These substances can come from a variety of sources, such as agricultural runoff, industrial waste, and sewage. Freshwater ecotoxicity can lead to the death of fish and other aquatic life, and it can also make the water unsafe for drinking and swimming.

7.3.2.4 Land use:

Land use is the amount of land used for a particular purpose, such as agriculture, industry, or housing. Land use can have several environmental impacts, such as deforestation, habitat loss, and water pollution.

7.3.2.5 Marine eutrophication:

Marine eutrophication is the excessive growth of algae and other aquatic plants in marine ecosystems. This can be caused by nutrient pollution from agriculture, industry, and sewage. Marine eutrophication can deplete the oxygen in the water, which can kill fish and other aquatic life.

7.3.2.6 Ozone depletion:

Ozone depletion is the thinning of the ozone layer in the Earth's atmosphere. This is caused by the release of ozone-depleting substances, such as chlorofluorocarbons (CFCs). Ozone depletion can increase the amount of ultraviolet radiation that reaches the Earth's surface, which can cause several problems, such as skin cancer, eye damage, and crop damage.

7.3.2.7 Particulate matter:

Particulate matter is tiny particles suspended in the air. These particles can come from a variety of sources, such as construction sites, power plants, and cars. Particulate matter can cause respiratory problems, heart disease, and cancer.

7.3.3 Data Sources:

The data was collected from various sources. The data sources were databases and a literature review. The database used for LCA was Ecoinvent and the consequential cutoff model.

7.4 Inventory Analysis:

7.4.1 Inventory Analysis

Inventory analysis, also known as the inventory assessment, is the second phase of life cycle assessment (LCA). It is a comprehensive and detailed study of the inputs and outputs of a product system throughout its entire life cycle, including the production, use, and end-of-life stages.

In aluminum wire incorporated concrete, the inventory analysis tries to identify and measure all the inputs and outputs of the production process, as well as their environmental impacts.

7.4.1.1 Inputs

The inputs of the production process of aluminum wire-incorporated concrete include:

- Cement
- Aggregates
- Water
- Aluminum wire
- Energy for mixing and transportation

7.4.1.2 Environmental Impacts

The environmental impacts associated with these inputs and outputs can be measured in terms of various impact categories, such as:

- Energy consumption
- Greenhouse gas emissions
- Water consumption
- Waste generation

7.5 Impact Assessment:

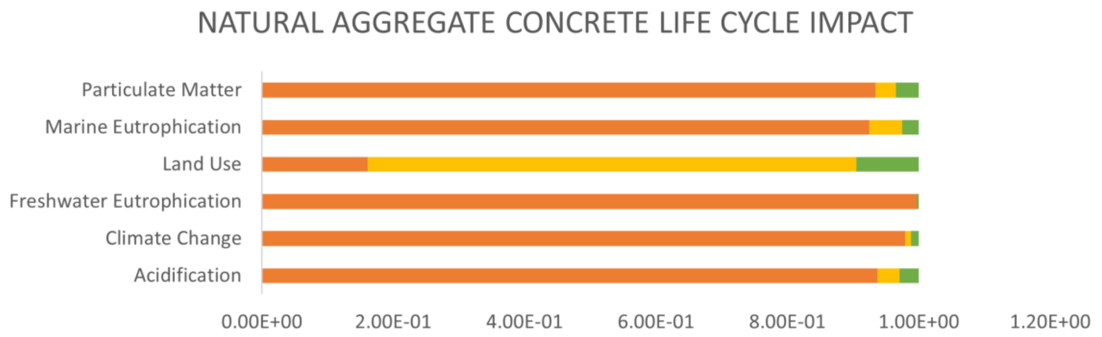
Impact assessment of aluminum wire concrete identifies acidification, climate change, and freshwater eutrophication as the most significant environmental impacts. These impacts are mainly due to the use of cement in the production process. Using recycled aggregate can help to reduce some of these impacts and aluminum helps by improving the strength and durability of concrete, which can reduce the need for natural aggregate. Overall, using recycled aggregate in concrete can help to reduce the environmental impacts of concrete production.

7.6 Interpretation:

The results for the Life Cycle Assessment of Waste Aluminum incorporated recycled aggregate concrete containing recycled Waste Aluminum wires, and normal concrete of comparable strength were determined in this section. The results are illustrated in **Figure 34, Figure 35, Figure 36, Figure 37, Figure 38, Figure 39, Figure 40, and Figure 41**

Relative results of LCA of normal concrete and WAWIRAC are shown in **Figure 34** and **Figure 35**. It is seen that RAC with Waste Aluminum wires reduces greenhouse gas by 16%. Freshwater eutrophication was reduced by 0.3%, but emissions of particulate matter in the atmosphere were also reduced by 2%. A decrease of 10% in marine eutrophication. Land use was reduced by 10% and 39.9% lesser terrestrial acidification was also seen.

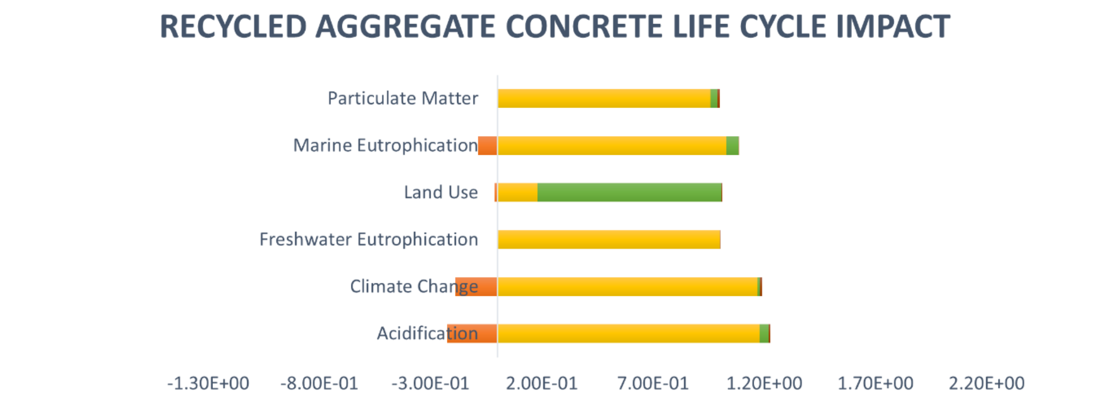
The process contribution, presented in Figure shows the contribution of each process for six impact categories. It is seen that the addition of recycled aggregate reduces the impact of concrete on the environment. Incorporating aluminum wire also increased the strength making it comparable to the strength of conventional concrete.



	Acidification	Climate Change	Freshwater Eutrophication	Land Use	Marine Eutrophication	Particulate Matter
Cement	9.37E-01	9.79E-01	9.97E-01	1.61E-01	9.25E-01	9.34E-01
Sand	3.34E-02	9.06E-03	3.02E-04	7.44E-01	4.98E-02	3.06E-02
Natural Aggregate	2.93E-02	1.16E-02	3.13E-03	9.50E-02	2.52E-02	3.49E-02

Cement Sand Natural Aggregate

Figure 34 Process contribution in NAC



	Acidification	Climate Change	Freshwater Eutrophication	Land Use	Marine Eutrophication	Particulate Matter
Aluminum Wires	-2.26E-01	-1.89E-01	2.09E-04	-1.20E-02	-8.70E-02	2.76E-03
Cement	1.18E+00	1.17E+00	9.99E-01	1.79E-01	1.03E+00	9.56E-01
Sand	4.19E-02	1.08E-02	3.03E-04	8.27E-01	5.53E-02	3.12E-02
Recycled Aggregate	5.36E-03	8.68E-03	8.42E-05	5.33E-03	3.01E-03	1.04E-02

Aluminum Wires Cement Sand Recycled Aggregate

Figure 35 Process contribution of RAC

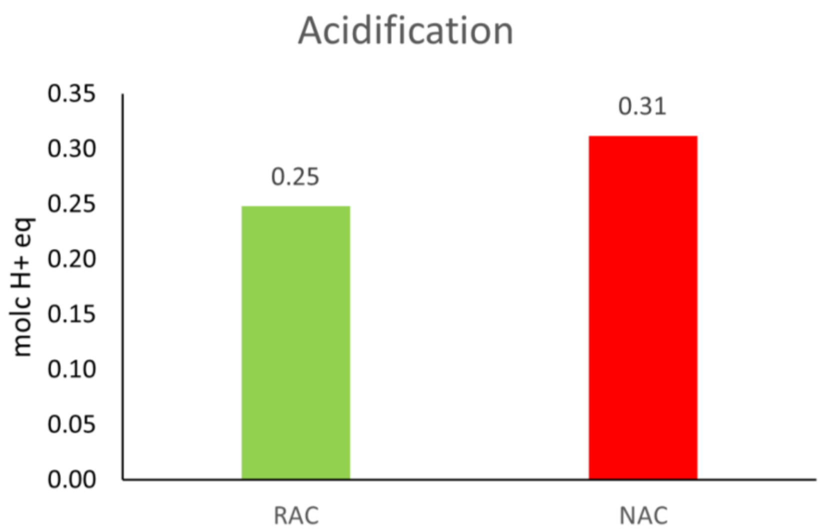


Figure 36 Comparison of acidification impact of NAC and RAC

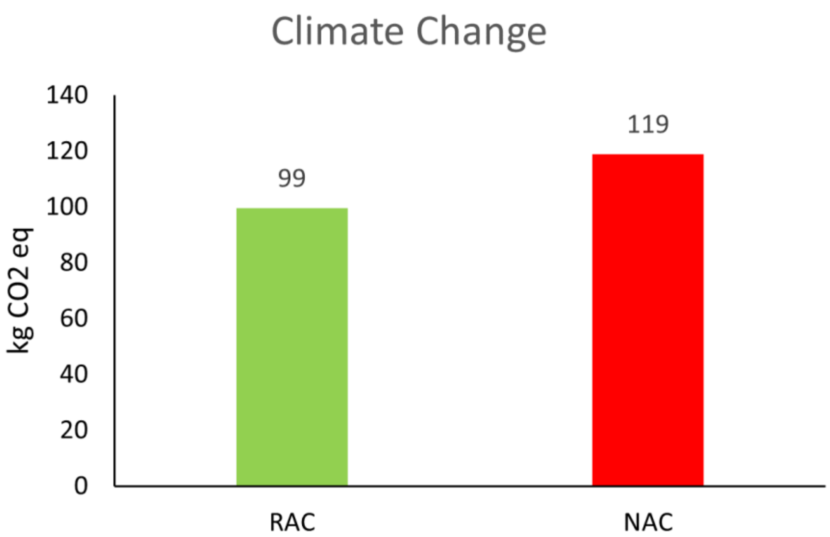


Figure 37 Comparison of the environmental impact of NAC and RAC

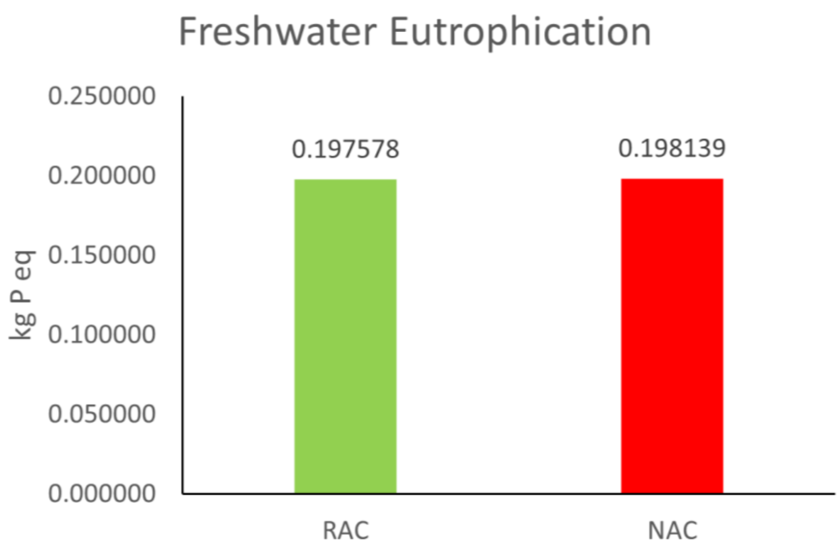


Figure 38 Comparison of freshwater eutrophication of NAC and RAC

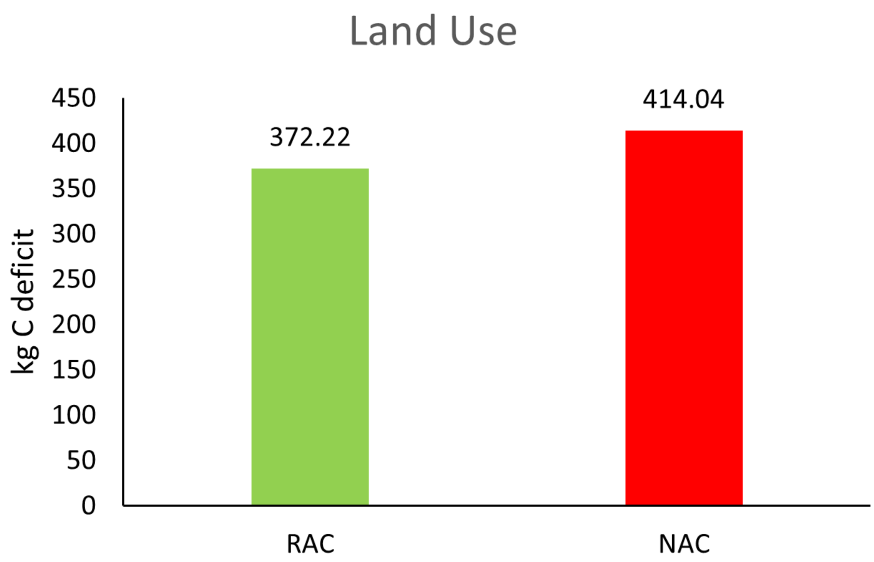


Figure 39 Comparison of land use impact of NAC and RAC

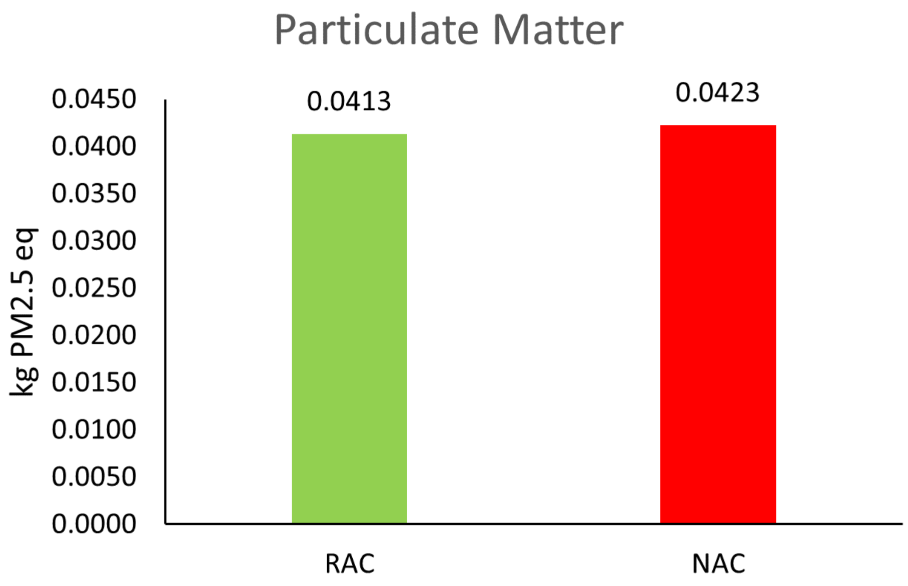


Figure 40 Comparison of particulate matter emission of NAC and RAC

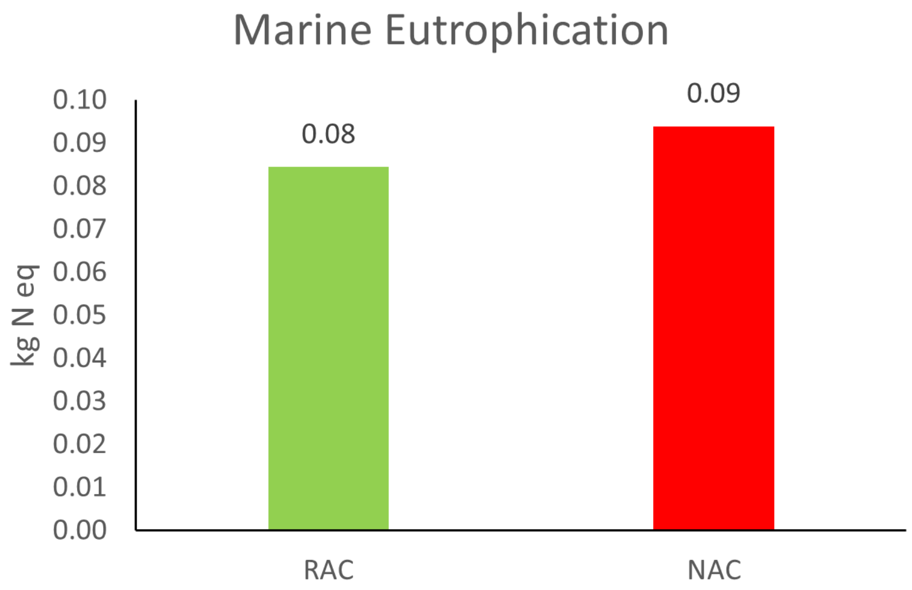


Figure 41 Comparison of marine eutrophication of NAC and RAC

Chapter 8

Cost Analysis

8.1 Introduction:

Aluminum wire-incorporated concrete has several advantages over conventional concrete including less environmental impact and comparable strength to that of conventional concrete. Analyzing the cost of WAWIRAC is crucial to assess the feasibility of the concrete.

8.2 Raw Material:

The cost of raw materials required for making and producing WAWIRAC is the main cost of production. These include the extraction of sand and aggregate from quarries, the production of cement, and Waste Aluminum wires.

8.3 Cost Comparison:

The cost of production of conventional concrete with Waste Aluminum wires and without incorporation of wires. The cost of Recycled Aggregate concrete with wires incorporated is also calculated and both Costs are compared to access the feasibility of WAWIRAC.

Table 4 and **Figure** 42 show the comparison of the price of both concretes.

Table 4 Comparison of Cost of NAC and RAC

Cost Analysis								
Parameter	Ingredients	Amount	Unit	Amount	Unit	Cost	Unit	Total Cost (PKR)
Raw Materials	Cement	400	Kg	8	Bag	1100	PKR/Bag	8800
	Fine Aggregate	690	Kg	13.8	Bag	250	PKR/Bag	3450
	Coarse Aggregate	1200	Kg	24	Bag	300	PKR/Bag	7200
	Recycled Aggregate	1200	Kg	24	Bag	100	PKR/Bag	2400
% Replacement by Wires	0.3	2673	m	8.13	Kg	400	PKR/Kg	3252
	0.4	3555	m	10.81	Kg	400	PKR/Kg	4326
	0.5	4455	m	13.55	Kg	400	PKR/Kg	5420
	0.6	5346	m	16.26	Kg	400	PKR/Kg	6504
	0.7	6237	m	18.97	Kg	400	PKR/Kg	7588

Table 5 Cost of NAC as per Replacement percentage.

Natural Aggregate Concrete	Cost (Rs)
0%	19450
0.3%	22702
0.4%	23776
0.5%	24870
0.6%	25954
0.7%	27038

Table 6 Cost of RAC as per replacement percentages

Recycled Aggregate Concrete	Cost (Rs)
0%	14650
0.3%	17902
0.4%	18976
0.5%	20070
0.6%	21154
0.7%	22238

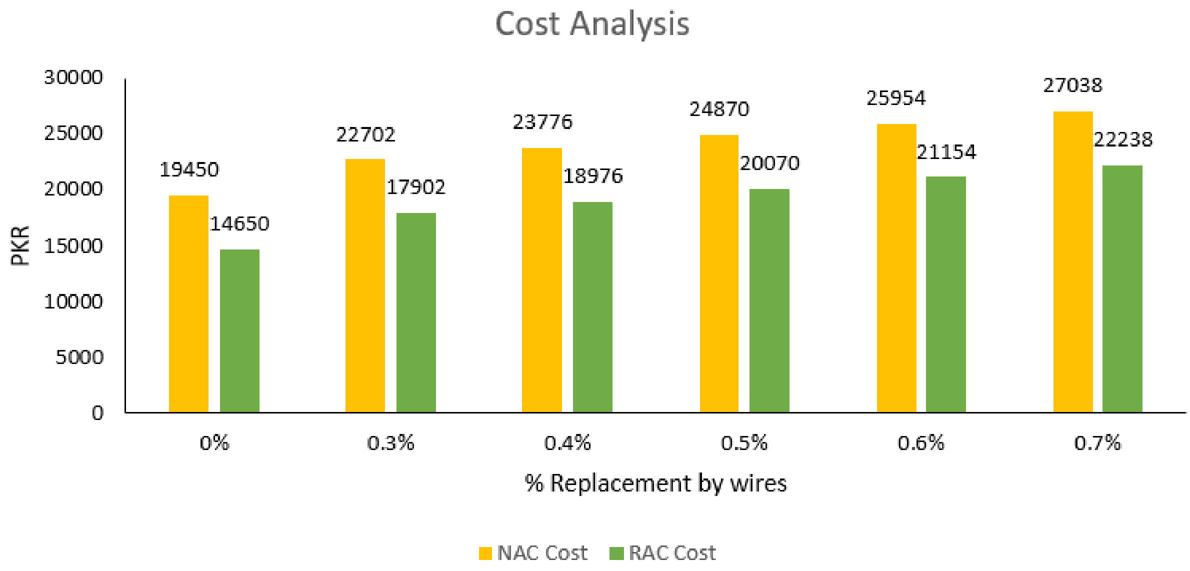


Figure 42 Cost Comparison of different Replacement percentages of Concrete

Chapter 9

Conclusion

In this study scrap Waste Aluminum wires were added to conventional and recycled aggregate concrete to study its impact on the properties of Concrete. Following conclusions were drawn,

- The compressive strength of conventional concrete increased from 3.6-9.5%. Recycled aggregate concrete also showed an increase in strength from 1.8%-10.6%. Both NAC and RAC display an increase in strength till the replacement ratio of 0.5%. The peak of WAWIRAC was at 95% that of 0% replacement of conventional concrete.
- The addition of aluminum to RAC showed an increase in strength from 1.87%-35.5%. NAC showed an increase in strength from 7.4%-48.1%. The peak of RAC was seen at 35.5%. RAC reaches 90% strength of NAC.
- Incorporating Aluminum increases the strength of RAC from 6.4%-58.06%, while the strength of NAC increases from 5.4%-48.6%. Adding aluminum lets RAC reach 32% above the Control sample of NAC.
- Increasing the percentage of wire in concrete decreases the workability of concrete.
- Life Cycle Assessment shows RAC with Waste Aluminum wires reduces greenhouse gas by 16%. Freshwater eutrophication was reduced by 0.3%, emissions of particulate matter in the atmosphere were also reduced by 2%. A decrease of 10% in marine eutrophication. Land use was reduced by 10% and 39.9% lesser terrestrial acidification was also seen.
- A cost analysis indicates that RAC costs less than NAC. The replacement of 0.5% Waste Aluminum wires costs Rs.500 more per 1m^3 or 3.19%.

Based on the test results, incorporating Waste Aluminum wires in RAC shows increased strength in compressive, flexural, and split tensile strength. The RAC with replacement ratio 0.5% shows the highest compressive strength with it reaching 90% of that of NAC. In flexure and split tensile tests, 0.7% shows the highest strength, but compressive strength decreases after 0.5%. This implies that 0.5% is the best replacement percentage.

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