MECHANICAL PROPERTIES OF RECYCLED AGGREGATE CONCRETE INCORPORATED WITH RICE HUSK ASH & NYLON FIBER

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ABSTRACT

Bangladesh aspires to establish a sustainable environment and economy; as a result, recycled aggregate concrete (RAC) is receiving more attention than ever before as a possible replacement for natural aggregate concrete. To improve RAC's credibility, its performance in terms of strength and durability must be optimized. Rice husk ash (RHA) is a waste material, and nylon fiber (NF) is a non-biodegradable material that is commonly accessible materials in this country. Incorporating these two materials into concrete is a way of recycling and saving the environment. The objective of the research is to develop a unique technique for improving the mechanical behavior of recycled aggregate concrete (RAC) by the joint integration of RHA and NF.

The experiment is carried out by adding 10% RHA as a supplementary cementitious material (SCM) and incorporating different dosages of NF (0.1%, 0.2%, and 0.35%) in RAC. The RAC is made with 100% replacement of recycled coarse aggregate with natural coarse aggregate. The fiber length is 20 mm, the w/c ratio is 0.45, and the mix ratio of the components in the concrete mix is 1:1.5:3 (Cement: Fine Aggregate: Coarse Aggregate). Compressive strength test, split tensile strength test, and flexural strength (three-point loading) test are done to observe the combined effect of RHA and NF on the mechanical properties of RAC. The current research revealed that the combined effect of RHA and fiber has a positive effect on recycled concrete. The maximum increment is 16.9% in compressive strength, 5.21% in tensile strength, and 12.8% in flexural strength. Based on the experimental results, the optimal fiber content is 0.2%. From the outcome of the study, it can be said that using recycled aggregate concrete incorporated with RHA and NF can be used to replace conventional concrete. It will help preserve the natural materials from being overly used in construction which will be one step close to achieving sustainability.

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LIST OF ABBREVIATION

ASTM	American Society for Testing and Materials
CDW	Construction and Demolition Waste
FA	Fly Ash
FE-SEM	Field Emission Scanning Electron Microscopy
GGBS	Ground Granulated Blast-furnace Slag
ITZ	Interfacial Transition Zone
NF	Nylon Fiber
NAC	Natural Aggregate Concrete
NCA	Natural Coarse Aggregate
PP	Polypropylene
RAC	Recycled Aggregate Concrete
RCA	Recycled Coarse Aggregate
RHA	Rice Husk Ash
SCM	Supplementary Cementitious Material
SF	Silica Fume

CHAPTER 1: INTRODUCTION

1.1 General

Concrete is a crucial and widely utilized material in Bangladesh's rapidly expanding construction industry. It is the only building material that can provide benefits like weather resistance and hardness while remaining inexpensive, making it increasingly popular. Portland cement, water, fine aggregates, and coarse aggregate are the main components of concrete. Concrete has two primary flaws: (a) it is prone to cracks due to its low tensile strength, and (b) cement is a major component of concrete that functions as a binder. Portland cement manufacture is energy demanding, emitting about a kilogram of carbon dioxide (CO_2) for every kilogram of cement produced, and increasing concrete use will increase carbon emissions and energy consumption. (Snyder et al. 2013) Various technologies like adding fibers and admixtures in concrete mix and different supplementary cementing materials (SCMs) in different combinations have been adopted over the years to minimize the problems.

1.2 Problem Statement

Concrete is the most utilized substance today, second only to water, with three tones used per person per year. Concrete is utilized in construction twice as much as all other building materials combined. Concrete will almost certainly continue to be used as a construction material in the future.(Gagg 2014) But stone chips which are the coarse aggregate, are not readily available material in Bangladesh. Importing it from neighboring countries costs a lot of money every year. Also, as a developing country, Bangladesh continues to develop and urbanize rapidly; we are faced with the moral challenge of preserving the present ecosystem. Every year, smaller structures are demolished to make room for newer, larger construction to achieve this urban sprawl rate. As a consequence, there is a growing strain on landfill capacity, as well as on building sites to divert garbage from landfills. Previously, leftover aggregate from demolition and construction projects would have ended up in landfills, but it is now seen to be helpful for a variety of reasons. The term "recycled aggregates" refers to materials that have been reprocessed and previously utilized in buildings. Crushing, mixing, and grading aggregate to fulfill the needed standards are all examples of reprocessing. Recycled aggregates are generally less expensive than normal coarse aggregates.

Since concrete has a low tensile strength, various fiber reinforcements such as steel, polypropylene, nylon, and jute are employed to reduce cracks in the tensile area and improve other attributes. Fiber-reinforced concrete is a composite material made up of conformist concrete that has been randomly reinforced with short, discontinuous, and discrete tiny fibers. In Bangladesh's context, nylon is a commonly accessible micro synthetic fiber that can be utilized to prevent concrete cracking in the tensile zone. With its strong, elastic, and quick-drying properties, numerous studies have been conducted to determine the situations in which nylon can be used—utilizing nylon results in an improved concrete condition with an optimal percentage. Additionally, several chemical admixtures are necessary to achieve the desired qualities of concrete. Still, a small amount of nylon fiber with a longer length can enhance the properties of concrete.(Martínez-Barrera et al. 2006a)

Cement is a significant component of concrete as a binder. It is manufactured using limestone that has been burnt to a temperature of 1400˚C. Carbon dioxide (CO_2) emissions from cement manufacture are the highest. To mitigate these effects, it is required to develop cement composite materials made from waste material, which will minimize the amount of cement used in concrete manufacturing and trash. Typically, waste material used to substitute cement is a by-product of industry. Rice husk is a by-product of rice milling. (Ekaputri et al. 2015) RHA is an exciting pozzolanic substance that can be combined with Portland cement to produce durable concrete. It is also a value-added technology.

1.3 Research Objectives

The overall objectives of the research are to evaluate the mechanical properties of concrete by-

- ✓ Observing the effect of using RHA as 10% partial replacement of cement by weight when the coarse aggregate is replaced 100% with RCA;

- ✓ Evaluating the influence of the addition of nylon fiber in various dosages on the mechanical properties of concrete;
- ✓ Assessing the combined effect of RHA and NF on the mechanical properties of concrete.

The mechanical properties that needed to be determined are-

1. Compressive Strength
2. Split Tensile Strength
3. Flexural Strength

1.4 Scope of Research

The research has been conducted to determine the combined influence of rice husk ash, and nylon fiber on the mechanical properties of concrete made using recycled concrete aggregate. Recycled concrete is naturally inferior to regular concrete. But previous researches have proved that rice husk ash and nylon fiber can enhance the compressive strength and tensile strength of concrete individually. Rice husk ash and nylon fiber are both locally available materials in Bangladesh. For a fixed w/c ratio and constant percentage of rice husk ash, the effects of different amounts of nylon fiber in recycled concrete have been determined. The curing period for tensile and flexural strength is 28 days and 28 days, and 90 days for compressive strength. A comprehensive comparison of mechanical performances of different mixes has been clearly represented in graphs in this study.

1.5 Outline of Methodology

There are three parts to the research- 1) Preparation of the materials, 2) Determination of properties of materials, and 3) Testing.

1.5.1 Preparation of the Materials

The raw materials were not suitable to use them in the experiment directly. Certain procedures had to be taken before testing their suitability and using them to prepare the concrete mix.

1.5.1.1 Rice Husk Ask

The rice husk was burnt to get the ash from it and later ground into finer particles.

1.5.1.2 Nylon Fiber

The nylon fibers were in the form of ropes. So, they had to be cut into specific lengths before mixing in the concrete.

1.5.2 Determination of Properties

The standard tests were done to determine the properties of the materials all according to the ASTM standards.

1.5.2.1 Fine Aggregate and Coarse Aggregate

All the standard tests (sieve analysis, unit weight, specific gravity) were done according to ASTM standards.

1.5.2.2 Recycled Aggregate

The impact Value test and Crushing Value test were done according to BS standards, and Los Angles Absorption test was done according to ASTM standards.

1.5.2.3 Rice Husk Ash

The XRF (X-ray fluorescence) analysis was done to find the chemical composition of rice husk ash. Sieve analysis and hydrometer analysis were done to determine the particle size.

1.5.3 Testing

Compressive strength and split tensile strength were done according to ASTM standards, and two-point flexural loading was done according to BS standards.

CHAPTER 2: LITERATURE REVIEW

2.1 General

Rapid urbanization, which includes rapid industrialization, necessitates new constructions, renovations of existing structures, and the demolition of numerous older structures, resulting in massive volumes of construction and demolition debris worldwide. Simultaneously, the construction sector is facing significant constraints in obtaining natural coarse aggregates due to natural resource depletion. These factors significantly complicate the sustainability of buildings. As a result, recycled coarse aggregate obtained from the construction and demolition wastes (CDWs) is a viable alternative to natural aggregate for concrete that eliminates waste and conserves natural resources and the environment. Numerous researchers have examined the mechanical and durability features of recycled coarse aggregate concrete and their relationship to the properties of recycled coarse aggregate concrete (RAC). Using RAC has several disadvantages in terms of mechanical and durability performance compared to conventional concrete. The high porosity of RA is the primary reason for its lower strength and durability compared to natural aggregate concrete (NAC).(Ali and Qureshi 2019; Nawaz et al. 2020) Researchers have demonstrated that supplementary materials, such as SCMs and fibers (steel fiber, polypropylene fiber, nylon fiber) can improve the performance of RAC.(Ali and Qureshi 2019; Lee 2019; Martínez-Barrera et al. 2006b; Nayel et al. 2018) This chapter will primarily discuss the available research on the various mechanical properties of concrete composed of 100% recycled coarse aggregate reinforced with various SCMs and fibers.

2.2 Recycled Concrete Aggregate

Recycled concrete aggregate (RCA) is made from broken used concrete. After destructed concrete is crushed, pollutants such as reinforcement, paper, wood, plastics, and gypsum are screened and removed. The concrete produced using such RCA is referred to as recycled concrete. RCA has a worse quality than the natural aggregate (NA) due to the presence of mortar between the stone particles in RCA.(Bidabadi et al. 2020) RCA has the following properties in comparison to NA: increased water absorption (Evangelista and de Brito 2007; Rahal 2007), decreased bulk density (Hansen 2014; RILEM n.d.), decreased relative density (Hansen 2014), increased abrasion loss (Hansen 2014; López-Gayarre et al. 2009), increased crushability, increased amount of dust particles, increased amount of organic impurities due to possible earth mixing with concrete following building destruction, and some amount of harmful chemicals released by workers extracting the recycled aggregates (Hansen 2014). Despite the RCA's shortcomings, the un-hydrated cement from the original concrete contained in the RCA may contribute to its application in structural concrete. Additionally, when RCA is used, the specific surface area of the aggregates is increased, resulting in an improved binder/recycled aggregate interaction (Khatib 2005).

Evangelista and Brito (Evangelista and de Brito 2007) investigated the mechanical properties of recycled fine aggregate concrete. The results indicated that up to 30% RCA had a negligible effect on the mechanical properties of concrete. Silva et al. (Silva et al. 2014) conducted research on the physical qualities and content of RCA intended for application in concrete. The RCA obtained from the crushing of waste concrete were categorized based on their qualities in this study. Cakir (Çakır 2014) investigated the effect of a 100 percent RCA replacement on the compressive strength of concrete. The compressive strength of concrete composed entirely of RCA was found to be roughly 24 percent lower than that of concrete made entirely of NA.

Leite and Santana (Leite and Santana 2019) produced concrete using fine recycled aggregate. They demonstrated that the compressive strength, splitting tensile strength, and modulus of elasticity of recycled concrete decrease with increasing flowability due to the low aggregate/cement ratio and increase with increasing RCA content. It is widely assumed that as the proportion of recycled concrete replaced grows (Evangelista and de Brito 2010), the compressive strength of concrete falls, which may be attributed to the old mortar in fine RCA, which makes concrete more porous and less dense (Wang et al. 2019).

2.3 Supplementary Cementitious Materials

Different type of SCMs have been used to in concrete over the years in different percentages to investigate their effects on recycled aggregate concrete to find the optimum percentage.

2.3.1 Silica Fume (SF)

SF is ultrafine silica (SiO_2), a byproduct of silicon and ferrosilicon alloy manufacturing. SF contains a high proportion of amorphous silica, which aids in the rapid consumption of portlandite (CH) in pozzolanic processes and contributes to the strength of cement paste. RAC's mechanical and durability properties have been evaluated utilizing SF as the SCM(Qureshi et al. 2020). According to Dilbas (Dilbas et al. 2014), RAC demonstrated compressive strength comparable to that of standard natural aggregate concrete when including 5–10% SF. Kou (Kou et al. 2011) observed that RAC composed of 50% RA and 10% SF exhibited mechanical properties comparable to natural aggregate concrete. In terms of mechanical properties, SF has been shown to be superior to other SCMs such as FA, GGBS, and metakaolin(Kou et al. 2011). Additionally, SF is quite good at extending the life of RAC.(Sasanipour et al. 2019)

2.3.2 Ground Granulated Blast Furnace Slag (GGBS)

GGBS is a finely ground powder composed of stone-like industrial waste generated during the refining (or smelting) ores (iron, copper, nickel, etc.). GGBS is composed primarily of silica (SiO_2), calcium oxide (CaO), and alumina (Al_2O_3) and has excellent pozzolanicity.(Qureshi et al. 2020) The effect of GGBS on RAC has been examined. According to Wang et al. (Wang et al. 2013), RAC composed of 50% RA and 10% GGBS exhibited greater compressive strength than natural aggregate concrete. Additionally, 10% GGBS-RAC had lower permeability than natural aggregate concrete. Another study (Anastasiou et al. 2014) found that GGBS enhanced the interfacial transition zone between the binder matrix and the RA, restoring some of the strength and durability that had been lost. Kou(Kou et al. 2011) investigated the effect of high-volume GGBS integration (up to 55% by volume) on the mechanical and durability properties of RAC. It was demonstrated that RAC containing 55% GGBS had a considerable reduction in mechanical performance when compared to RAC or natural aggregate concrete prepared without GGBS. Despite its reduced mechanical performance, GGBS was the most effective in preventing chloride ion penetration of all SCMs tested (FA, SF, and metakaolin)(Kou et al. 2011)

2.3.3 Fly Ash (FA)

FA is a byproduct of coal-fired power plants and possesses pozzolanic qualities. RAC has been investigated at various FA concentrations in terms of mechanical and durability performance.(Qureshi et al. 2020) FA decreased the early age strength of RAC but increased its later age strength features (Kurad et al. 2017; Nawaz et al. 2021). FA enhanced the rheological characteristics of RAC and decreased the requirement for water-reducing admixtures to obtain the desired workability (Nawaz et al. 2020). Kou et al. (Cong et al. 2007) showed that, despite decreased early-age strength properties, FA was significantly beneficial in improving the durability of RAC at both early and late ages. Additionally, researchers (Cong et al. 2007; Kurad et al. 2017),(Kou et al. 2011) have shown that RAC has a more favorable environment for pozzolanicity than NAC; thus, FA contributes more to RAC's strength and durability qualities.

2.3.4 Rice Husk Ash (RHA)

RHA is produced by burning rice hulls or husks (the rice grain's strong outer shell) at temperatures considerably below 780˚C. RHA is high in SiO_2 and has pozzolanic characteristics. One study report showed that RHA did not show any effect on early age mechanical properties but it contributed to later age strength.(Madandoust et al. 2011)

Padhi and Mukherjee(Padhi and Mukharjee 2017) worked to determine the influence of RHA of various percentages on recycled concrete. Eight concrete mixes including 100% natural aggregates (control mix) and eight recycled aggregate mixes containing increasing percentages of rice husk ash (0, 5%, 10%, 15%, 20%, 25%, 30%, and 35%) were prepared. Compressive, split tensile, and flexural strengths of the aforementioned mixtures were determined after 28 days to determine the effect of RHA and RAC. It had been observed that the slump value and the mechanical properties gradually decreased with the increasing percentage of RHA. However, concrete with 10% RHA and 100% RCA may be helpful for use in the construction industry.

In another study, RHA was used to replace up to 10% of the cement by weight. A total of 135 concrete specimens were made, cured, and tested in the Universal Testing Machine for experimental purposes (UTM). Finally, laboratory results for compressive and splitting tensile strength using natural and recycled coarse aggregates were compared. All specimens were made at a 1:1.5:3 ratio with a 0.50 w/c ratio and tested at curing ages of 7, 14, 21, 28, and 56 days. Experimental investigation indicates that fresh normal concrete has a workability of 7% and 10% more than recycled aggregates concrete blended with 10% RHA and pure recycled aggregates concrete without RHA, respectively. Compressive strength increases by up to 6%, while splitting tensile strength increases by 4% after 56 days of curing when 10% of the cement is replaced by RHA. Additionally, it is established that when more than 10% RHA is replaced with cement, compressive strength drops.(Bheel et al. 2018)

2.4 Fibers

2.4.1 Steel Fiber

Steel fibers (SF) have received much attention in recent years due to their ability to improve recycled material's flexural and split tensile strengths. Carneiro et al. (Carneiro et al. 2014) evaluated the effect of SFs (hooked end) with a length of 35 mm and an aspect ratio of 65 on the stress-strain behavior, split tensile strength, and flexural strength of concrete prepared with recycled coarse and fine aggregate at a volume fraction of 0 and 25%. It was observed that the incorporation of SFs into recycled concrete improved stress-strain control upon post crack. The addition of SFs increased the toughness of recycled aggregate concrete mixes, i.e., the slope of the descending region of the stress-strain curve was increased, and so the compression behavior of recycled aggregate concrete is similar to that of natural concrete with SFs. Additionally, the use of SFs and recovered aggregates improved the mechanical qualities of concrete.

Gao and Zhang (Gao and Zhang 2018) investigated the flexural performance of recycled coarse aggregate concrete with varying amounts of SF. Regardless of the percentage of recycled coarse aggregate, it was discovered that the flexural behavior of SF reinforced recycled aggregate concrete was nearly identical prior to the crack. However, the deflection increases significantly in conjunction with the marginal increase in flexural strength and toughness. Flexural performance of SF reinforced recycled coarse aggregate concrete was not apparent until the fiber volume fraction reached 0.5 percent; however, when the fiber volume fraction was between 0.5 and 1%, the flexural behavior of recycled aggregate concrete with SFs significantly improved; however, the growth trend became horizontal when the fiber volume fraction exceeded 2%. When a 1% volume fraction of double hooked end SF was added to recycled aggregate concrete at 28 days of curing age, the split tensile and flexural strengths increased by 60% and 88 percent, respectively.(Afroughsabet et al. 2017)

2.4.2 Polypropylene fiber

Due to their low weight, high efficiency, low thermal conductivity, and resilience to acid and alkali attacks polypropylene fibers have significant benefits over other commercially available synthetic fibers. As a result, polypropylene fibers are gaining favor in field concrete these days. The addition of 0.5%, 0.75%, and 1% polypropylene fibers to natural aggregate concrete (NAC) and recycled aggregate concrete (RAC) was investigated experimentally. The recycled aggregate concrete was prepared by completely substituting natural coarse aggregates for recycled coarse aggregates. It was observed that the density of RAC is lower than that of NAC, and this density drops more when the amount of polypropylene fibers incorporated increases. This is because fibers have lower specific gravity than concrete.

The investigation's experimental results showed that the compressive strength values for RAC were similar to those for NAC. Both NAC and RAC exhibit an initial gain in compressive strength when fiber content is increased to 0.5% but then falls as fiber content is increased further. This is because the stress concentration over the length of the fiber is not constant in a dispersed fiber cement matrix, and stresses are more significant near the fiber ends. Given the short length of the fibers investigated in this study (12 mm), there may be a greater number of critical sites that become prone to breaking.

As with compressive strength, a similar trend is evident with variation in fiber content for split tensile and flexure strength. The amount of fiber in a material has a minor effect on compressive strength. However, the fibers contribute significantly to the split tensile and flexural strength of concrete. On the basis of the results from each series, it can be concluded that the optimal fiber content is 0.5%. Both NAC and RAC exhibit the same pattern of stress-strain behavior. Additionally, it can be deduced that the influence of fibers on strain augmentation is more pronounced in the case of NAC than in the case of RAC. However, the peak strain for RAC is more significant in all cases except those containing 1% PP, which is attributable to early cracking.(Das et al. 2018a)

2.4.3 Nylon Fiber

Nylon is resistant to a large variety of materials, is heat stable, hydrophilic, reasonably inert, and relatively inert. It is especially excellent at imparting impact resistance and flexural toughness to concrete, as well as sustaining and increasing its load carrying capacity following the initial crack. Lee(Lee 2019) studied the effect of nylon fiber addition on the performance of recycled aggregate concrete. Concrete was made by adding NF at concentrations of 0, 0.6, and 1.2 kg/m3 and curing it in water for a set period. Compressive and split tensile strengths, ultrasonic pulse velocity, and total charge passed through concrete were all measured. The resulting test results were compared to those of crushed stone aggregate-containing concrete (CA). Due to the glued mortars in recycled coarse aggregate concrete (RAC), the test findings suggested that it performed less well than crushed stone aggregate concrete (CAC). However, it was clear that adding NF to RAC mixes significantly improved the performance of the concretes due to the crack bridging action of NF. In particular, a high NF level (1.2 kg/m3) had a beneficial influence on the mechanical characteristics and permeability of concrete compared to a low NF content (0.6 kg/m3), particularly for RAC mixes.

2.5 Combined Influence on mechanical properties of Recycled Aggregate Concrete

Previous researches have proved that the benefits of combining fibers and SCMs are significantly greater than the benefits of incorporating fibers and SCMs separately. SCMs contribute more to the development of RAC's durability features, whilst fibers contribute more to the development of its mechanical properties. The type of fibers and SCMs used in the mix, as well as their volume proportion in the mix, have a considerable effect on the concrete's qualities.(Koushkbaghi et al. 2019a)

2.5.1 Combined Effect of SCMs and Steel Fiber on RAC

A recent research has demonstrated the combined effect of supplementary cementitious materials (silica fume, GGBS, fly ash, and rice husk ash) and steel fiber on the mechanical and durability properties of recycled aggregate concrete. Four distinct SCMs (silica fume (SF), ground granulated blast furnace slag (GGBS), fly ash (FA), and rice husk ash (RHA)) were used in this investigation in combination with 0% and 1% HSF, respectively. SF, GGBS, FA, and RHA were employed in mass replacement of regular Portland cement at a rate of 10%, 30%, 20%, and 15%, respectively.

The addition of SCMs and HSF increased the compressive strength of RAC after 28 and 90 days, respectively. The use of 15% RHA and 10% SF was more effective at increasing the compressive strength of RAC (7–19%) than the use of 20% FA and 30%

GGBS. The addition of 1% HSF enhanced the compressive strength of RAC by (5.5–7%). The compressive strength of RAC was increased by 22–25 percent and 18–24 percent, respectively, when 1% HSF + 10% SF and 1% HSF + 15% RHA were added.

The addition of 1% HSF enhanced the tensile strength of RAC by 28%. Additionally, SCM integration resulted in improvements of 7–14 percent. The coupling of 1% HSF and 10% SF enhanced the splitting tensile strength by 41–44%. Additionally, the coupling effect of fibers and other SCMs increased the tensile strength by more than 39% after 90 days.(Qureshi et al. 2020) In this study, 10% SF + 1% HSF and 15% RHA + 1% HSF aided in the manufacture of RAC with higher mechanical and durability capabilities when compared to plain RAC.

In another study, 20% of RHA was taken as the optimum percentage of cement replacement and

2.5.2 Combined Effect of SCMs and Nylon Fiber

There are only a few studies on the influence of nylon fiber (NF) on RAC and even fewer studies on the combined effect of SCMs and NF on RAC. Recently Ahmad at el.(Ahmad et al. 2022) has done an experimental research on mechanical properties of nylon fiber reinforced recycled aggregate concrete with silica fume. In both RAC and NAC, silica fume was used at a 20% volume ratio as a cement substitute. To reinforce concrete mixtures, nylon fibers were added at a rate of 0.5%. Nylon fiber enhanced the mechanical performance of NAC and RCA mixtures by up to 26%. In comparison to compressive strength, nylon fiber was advantageous for flexural and split tensile strength. Silica fume reinforced concrete samples with nylon fiber reinforcement demonstrated a more significant increase in mechanical strength than mixes without silica fume. Nylon fibers played a significant role in concrete as crack arrestors, lowering the permeability, reducing crack dispersion, and increasing the concrete's strength. The optimal mix composition for RCA concrete in terms of mechanical behavior, durability, and sustainability was 50% RCA, 0.5% nylon fibers, and 20% silica fume was obtained from this study.

2.6 Research Significance

The previous literatures revealed that RAC degrades the mechanical properties and durability of concrete because of its porous nature. As a result, it is essential to incorporate waste mineral additive (such as Rice Husk Ash) into RAC to compensate for its porous character by filling voids and enhancing the inter transition zone due to the pozzolanic reaction, which improves the binding property of concrete. Although the mechanical performance and durability characteristics of RAC were significantly improved through the addition of supplementary cementitious materials, the concrete retained a low tensile capacity, which can result in brittle failure without warning and thus requires reinforcement to increase its tensile strength. As a result, concrete required tensile reinforcements to increase its tensile strength and compensate for unwanted brittle fractures. Fibers are a widely used method of increasing the tensile strength of concrete. Additionally, fiber boosts tensile capacity more effectively than compressive strength, according to studies. Nylon fibers affect the environment, and recycling them will help to mitigate this impact. Nylon is resistant to a large variety of materials, is heat stable, hydrophilic, moderately passive, and relatively inert. Nylon is particularly effective at increasing the impact resistance and flexural toughness of concrete, as well as sustaining the enhanced load-bearing capacity after the initial crack. The use of nylon fiber as a component of cement concrete is promising since it gives an alternative method of disposing of fibers while also enhancing the strength and longevity of the concrete. Also, in Bangladesh, Rice Husk Ash (RHA) is a waste material which can be found in abundance. About 34.0 million tons of rice is produced and almost 7 million tons are RH. (FAOStat, 2014). Incorporating RHA can help to dispose of vast quantities of materials that might otherwise damage land, water, and air. But there are no significant researches where both RHA and Nylon fibers are used to observe the properties of recycled aggregate concrete (RAC). This study will mainly focus on the mechanical properties (compressive strength, split tensile strength, flexural strength) made with 100% recycled aggregate and RHA with different dosages of nylon fiber.

CHAPTER 3: EXPERIMENTAL PROCEDURES

3.1 General

This chapter is devoted to a comprehensive illustration of the various materials utilized in this investigation to prepare test samples. This chapter also includes the mix design and the testing procedures of determining the mechanical properties of the concrete specimens.

3.2 Collection of Material

Ordinary Portland Cement was used as the cementitious material for all the concrete mixes (Fig. 3.1). The cement was bought from the Bengal Cement Ltd. and was stored in the Concrete Laboratory, Bangladesh University of Engineering and Technology (BUET) before the casting took place. Sylhet Sand was used as the fine aggregate and it was provided by the concrete laboratory storage of Civil Engineering Department of BUET (Fig. 3.2). Stone chips which were used as coarse aggregate in controlled concrete were bought from Shitalakkhya river bank stone crushing yard, Demra, Dhaka (Fig. 3.3). Then they were transferred by truck from the site to BUET. The recycled aggregates were from a demolished concrete building. Rubbles were gathered mostly from column, beam, and grade beam locations - sections of the structure subjected to significant loads throughout its service life (Fig 3.4). The nylon fiber was provided by the author's supervisor- Dr. Rupak Mudsuddy, Assistant Professor, Department of Civil Engineering, BUET. Rice Husk Ash was collected from Bishwash Auto Rice Mill, Pabna (Fig. 3.5). The plasticizer was supplied by the concrete lab.

(a) OPC Cement

(b) Sylhet Sand Sample

(c) Stone Chips

(d) Recycled Aggregate

(e) Rice Husk Ask (RHA)

Fig. 3.1: Raw Materials used in the Experiment

3.3 Preparation of Materials for Determining Various Mechanical Properties

The materials were sieved, oven dried, kept in the open air and submerged in water for various testing of the properties.

3.3.1 Sieve Analysis of Fine Aggregate and Coarse Aggregate

The sieve analysis for both fine aggregate and coarse aggregate were done according to ASTM specification C136(ASTM C136 / C136M-14 (2014)). In sieve analysis, a known-mass sample of dry aggregate was passed through a succession of sieves with progressively smaller apertures to determine particle size distribution. For fine aggregate, the sieve sizes used were 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm and 0.075mm. For natural coarse aggregate (NCA), the nominal size was 19mm and the sieve sizes were 19mm, 12.5mm, 9.5mm, 4.75mm and 2.36mm. And for recycled coarse aggregate, the sieves sizes were 19mm, 12.5mm, 9.5mm, 4.75mm, 2.36mm and 1.18mm. After sieving, the samples retained in each sieve were collected individually and their weight was determined.

3.3.2 Fineness Modulus of Fine Aggregate and Coarse Aggregate

To characterize the aggregate's overall coarseness or fineness, the concept of fineness modulus is established. The Fineness Modulus is defined as the empirical factor produced by combining the cumulative percentages of aggregates retained on each ASTM standard sieve and then arbitrarily dividing this total by 100. ASTM standard requirements of specification C136/C136M-14(ASTM C136 / C136M-14 (2014)) was followed here.

$$\text{FM} = \frac{\sum cumulative\ \%\ retained\ on\ all\ standard\ sieves\ upto\ no.100}{100} \qquad (3.1)$$

3.3.3 Specific Gravity and Absorption Capacity

Specific Gravity is defined as the ratio of the mass of aggregate to the mass of water in an equal volume. The specific gravity of an aggregate is considered a measure of the material's strength or quality. Again, aggregates comprise the majority of the volume in concrete. Size, distribution, shape, and texture of aggregate particles influence the amount of water required in concrete. Therefore, aggregates have the biggest impact on the quantity of water required for a given concrete's workability. The specific gravity and absorption of coarse and fine aggregate are determined according to the specification ASTM C128-01(ASTM C128 (2009)) (for fine aggregate and rice husk ash) and ASTM C127- 01(ASTM C127 (2007))(for coarse aggregate).

3.3.4 Unit Weight

Unit weight values of aggregates are necessary for selecting proportions for concrete mixtures. The unit weight of the aggregates is measured in accordance to ASTM specification C29(ASTM C29 (2009)). The unit weight in terms of saturated surface dry (SSD) condition was determined and used for further calculations.

$$M_{SSD} = \left(1 + \frac{A}{100}\right) M \quad (3.2)$$

Where:

M= unit weight of aggregate in OD condition, lb./ft^3 (kg/m^3)

M_{SSD} = unit weight of aggregate in SSD condition, lb./ft^3 (kg/m^3)

A = absorption capacity in aggregate (%)

3.3.5 Aggregate Impact Value

The test method conforms to the BS: 812: 1975 (PART 1, 2, 3). The aggregate impact value gives a relative measure of the resistance of an aggregate to “sudden shock or impact”. If the value is above 30, then the sample should be discarded. The aggregates were in SSD condition. Samples were weighted up to 305g. The aggregate of 14mm-10mm was filled up in the cylindrical measure in 3 strata folded using a tamping rod 25 times. Perpendicular edge was used as the level of the surface tamping rod. The cylindrical measure was transferred to the brass plate. The Trigger was escaped to flop down on the aggregate and gave 15 blows were subjected to a total of the given test. Samples were sieved in a 2.36mm sieve after being removed from the cup. Weights of retaining ad passing were measured.

3.3.6 Aggregate Crushing Value

The aggregate crushing value is a relative measure of an aggregate's resistance to crushing when subjected to a gradually applied compressive load. The test was done with accordance to the BS: 812: 1975 (PART 1, 2, 3). The test is similar to the Aggregate Impact Value test.

3.3.7 Resistance to Degradation of small-size Coarse aggregate by abrasion and impact in Los Angeles Machine

The test method conforms to the ASTM standard requirements of specification C131/C131M-14(ASTM C131 (2003)). The grading of the aggregate sample was B. So, 2500 gm of aggregate passing ¾ in IS sieve and retained on ½ in IS sieve and another 2500 gm of aggregate passing ½ in IS sieve and retained on 3/8 in IS sieve was required as specified by the code.

3.3.8 Rice Husk Ask (RHA)

The obtained rice husk ash was coarse material. So, in order to use it as a SCM, it had to be grinded into finer particles which was quite a challenge. A grinder machine was bought from New Market, Dhaka and was used for the grinding. 1gm of the sample was sent to the Glass & Ceramic Engineering Department, BUET to obtain the chemical properties.

The hydrometer analysis is performed to determine the distribution of the finer particles (usually passing #200 sieve). There is no particular standard for hydrometer analysis of RHA. So, standard test method for particle-size distribution (gradation) of fine-grained soils (ASTM-D7928) was followed for RHA also.

(a) (b)

Fig. 3.2: Rice Husk Ash (a) Before Grinding and (b) After Grinding

3.3.9 Nylon Fiber (NF)

The supplied nylon fiber was in a form of rope. It was straightened and cut into length of 20mm.

3.4 Properties of Aggregates

The calculation to determine the properties of aggregates is shown in Appendix A.1.

3.4.1 Cement

The cement is Ordinary Portland Cement, CEM 1. The unit weight is taken as 1440 kg/m^3.

3.4.2 Fine Aggregate

The properties are shown in table 3.1.

Table 3.1: Properties of Fine Aggregate

Unit Weight (kg/m^3)	**Specific Gravity (SSD Basis)**	**Fineness Modulus**	**Water Absorption (%)**
1623.39	3.23	3.08	1.13

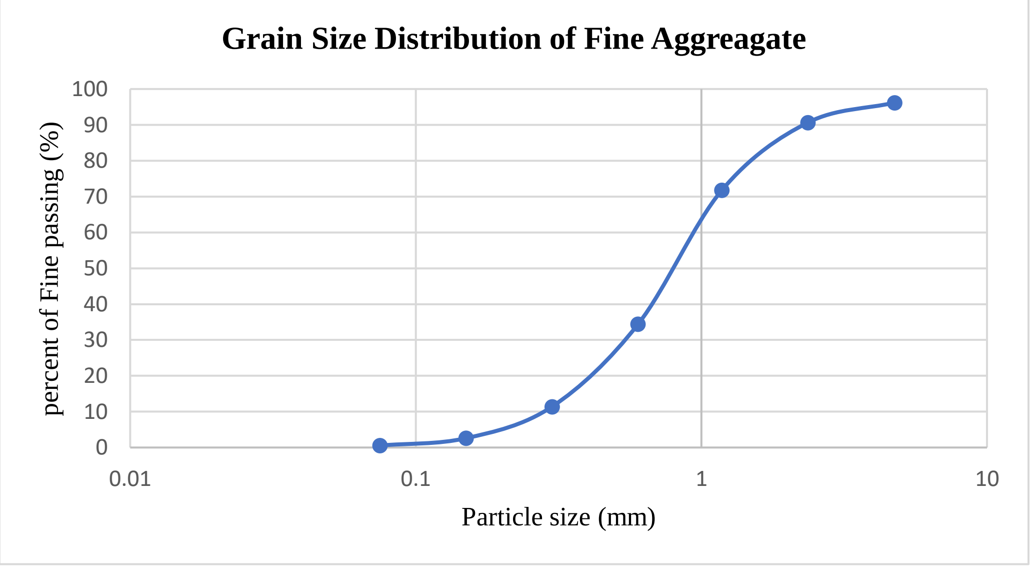


Fig. 3.3: Gradation Curve for Sylhet sand sample used in the study

3.4.3 Coarse Aggregate

The physical properties of coarse aggregates (Natural Coarse Aggregate and Recycled Coarse Aggregate) are shown below.

Table 3.2: The physical properties of coarse aggregates

Materials	**Unit Weight (kg/m^3)**	**Fineness Modulus**	**Apparent Specific Gravity**	**Specific Gravity (O-D Basis)**	**Specific Gravity (SSD Basis)**	**Water Absorption (%)**
NCA	1519.56	7.55	2.72	2.64	2.67	1.16
RCA	1435.2	7.36	2.71	2.31	2.45	6.38

Table 3.3: Properties of Recycled Coarse Aggregate

Tests	**Limit**	**Test Value**
Impact Value (%)	30	29.2
Crushing Value (%)	30	26.2
Los Angeles Abrasion Resistance (%)	-------	32

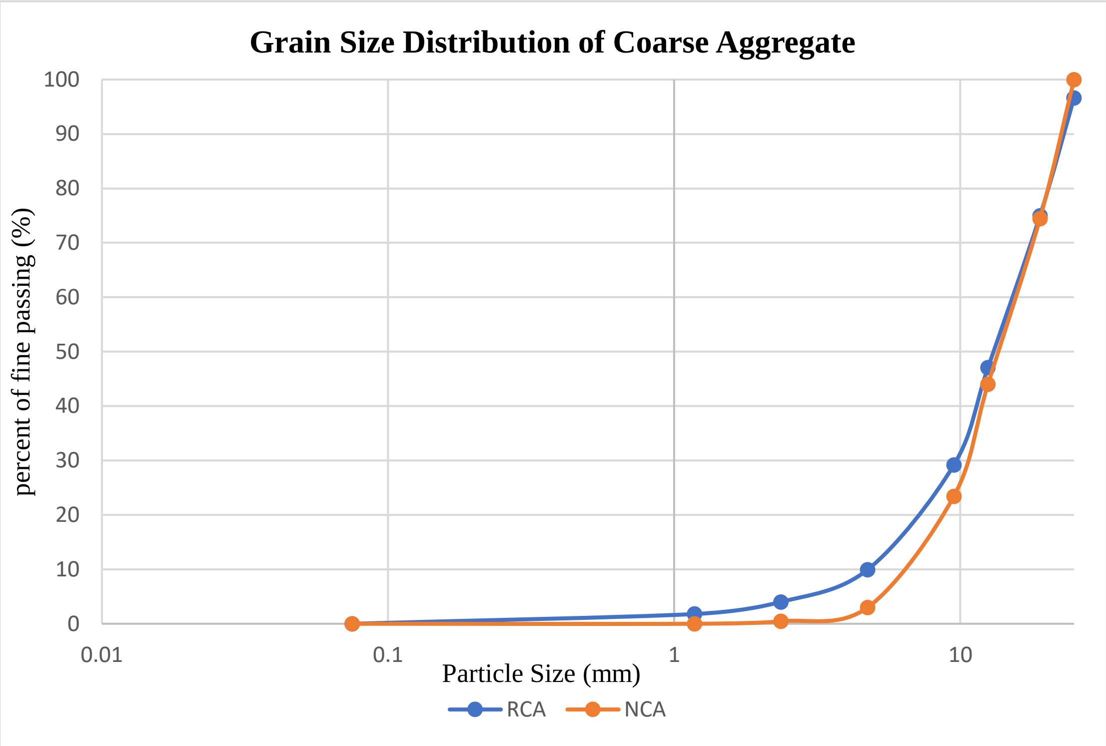


Fig. 3.4: Gradation Curve for NAC and RAC used in the study

3.4.4 Rice Husk Ash (RHA)

The physical properties and chemical properties of RHA are shown in table 3.4 and table 3.5 sequentially.

Table 3.4: Physical Properties of RHA

Unit Weight (kg/m^3)	**Specific Gravity**
1377.28	2.02

Table 3.5: Chemical Composition of RHA

Chemical Composition	Percentage (%)
Silicon dioxide (SiO_2)	92.2498
Potassium oxide (K_2O)	2.2149
Phosphorus pentoxide (P_2O_5)	1.8806
Calcium oxide (CaO)	1.0715
Magnesium oxide (MgO)	0.7916
Sulfur trioxide (SO_3)	0.6679
Iron oxide (Fe_2O_3)	0.3022
Calcium (Cl)	0.2518
Aluminum oxide (Al_2O_3)	0.2416
Sodium oxide (Na_2O)	0.1401
Manganese oxide (MnO)	0.097
Titanium oxide (TiO_2)	0.0417
Chromium oxide (Cr_2O_3)	0.0369
Zinc oxide (ZnO)	0.0095
Zirconium oxide (ZrO_2)	0.003

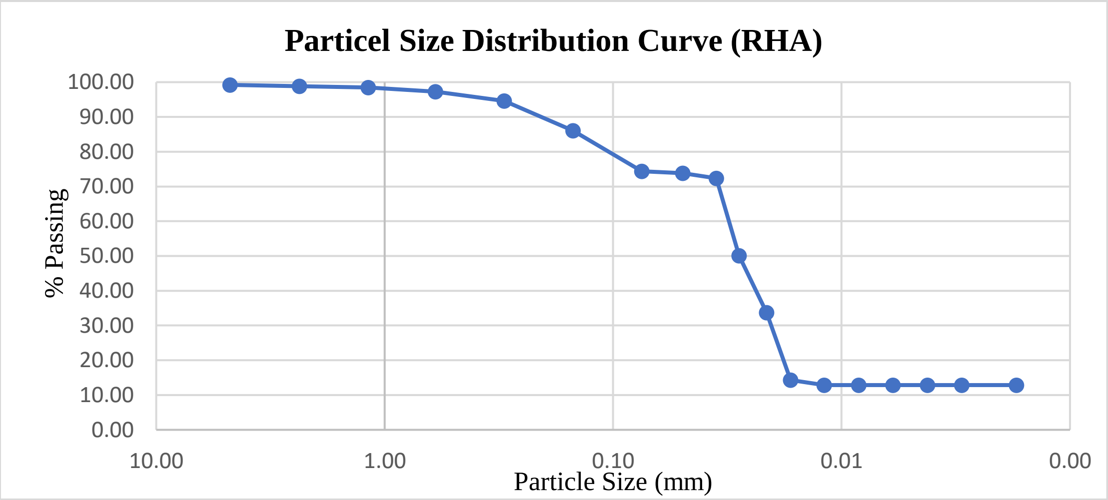


Fig. 3.5: Gradation Curve for RHA used in the study

From the table 3.5, it is seen that the RHA used in this study, has high silica content (92.25%) which is necessary for pozzolanic reactions to take place and it makes RHA an adequate cement replacement.

3.4.5 Nylon Fiber (NF)

The unit weight of nylon fiber is 750 kg/m^3.

3.4.6 Super plasticizer

Addition of fibers reduce workability of concrete. To prevent that, a super plasticizer was used. It was Conplast SP337. The rate of addition should be in the range of 500ml to 1.5 liters /100 kg cement for high workability concrete.

3.4.7 Water

The water that was used to create the concrete was drinkable and free of oil and other organic contaminants. Throughout the mixing procedure, ordinary tap water was used as mixing water.

3.5 Mix Design

The mix ratio for this experimental plan was decided from previous literatures. A fix percentage of RHA was used as SCM. And it was considered as an optimum percentage from previous literatures. The water/cement ratio was also constant. There are total 5 different concrete mixes made for this study. The nylon fibers were added in different dosages with incorporated RHA and recycled aggregates. The following tables summarizes the whole mix design plan. Cylindrical molds were used for compressive and tensile strength and prism was used as the casting mold for flexural strength.

Table 3.6: Mix Ratio

Cement	Fine Aggregate	Coarse Aggregate	w/c ratio
1	1.5	3	0.45

The amount of material needed for each mix is given in Appendix A.2.

Table 3.7: Mixture Type

Mixture	MIX ID	Cement Type	Coarse Aggregate	Rice Husk Ash (% weight)	Nylon Fiber (% volume)
1 (Controlled Concrete)	R0A0F0	Ordinary Portland Cement (OPC)	100% Stone Chips	0	0
2	R100A10F0	OPC	100% Recycled Concrete Aggregate	10	0
3	R100A10F0.1	OPC	100% Recycled Concrete Aggregate	10	0.1
4	R100A10F0.2	OPC	100% Recycled Concrete Aggregate	10	0.2
5	R100A10F0.35	OPC	100% Recycled Concrete Aggregate	10	0.35

Table 3.8: Tests and Specimen Numbers

MIX ID	**Tests**	**Specimen Size**	**Curing Period**	**Specimen**
R0A0F0	Compressive Strength Test	100mm×200mm	28 days	3
			90 days	3
	Tensile Strength test	100mm×200mm	28 days	3
	Flexural Strength Test	75mm×75mm×275mm	28	3
			Total	**12**
R100A10F0	Compressive Strength Test	100mm×200mm	28 days	3
			90 days	3
	Tensile Strength test	100mm×200mm	28 days	3
	Flexural Strength Test	75mm×75mm×275mm	28	3
			Total	**12**
R100A10F0.1	Compressive Strength Test	100mm×200mm	28 days	3
			90 days	3
	Tensile Strength test	100mm×200mm	28 days	3
	Flexural Strength Test	75mm×75mm×275mm	28	3
			Total	**12**
R100A10F0.2	Compressive Strength Test	100mm×200mm	28 days	3
			90 days	3
	Tensile Strength test	100mm×200mm	28 days	3
	Flexural Strength Test	75mm×75mm×275mm	28	3
			Total	**12**
R100A10F0.35	Compressive Strength Test	100mm×200mm	28 days	3
			90 days	3
	Tensile Strength test	100mm×200mm	28 days	3
	Flexural Strength Test	75mm×75mm×275mm	28	3
			Total	**12**
			Total	60

3.6 Casting and Sample Preparation

Initially, the needed amount of each ingredient in the first batch of every concrete mix was added to the automated concrete mixer and mixed for a specified amount of time to ensure a homogeneous concrete mix. A slump test has been done on the concrete mixture obtained in the batch. Plasticizer was applied to water in order to achieve slump value. After obtaining the concrete mixture, it was poured and tamped in two layers into standard-sized molds to manufacture concrete specimens.

(a)

(b)

(c)

Fig. 3.6: (a) Mixing of Concrete; (b) Compaction of Concrete and (c) casting of Concrete specimens

3.7 Curing of Concrete Specimen

In order to achieve appropriate hydration of the cement paste, the cylindrical concrete specimens were completely submerged in a lime water solution in a curing pond before further testing. Before being submerged in the pond, each specimen was labelled with the appropriate initials and casting date to facilitate future sample identification.

Fig. 3.7: Sample identification and curing of concrete cylinders in water

3.8 Slump Test on Fresh Concrete Mix

The slump test has been performed on fresh concrete paste in this research as per the standards of ASTM C 143 (2015)(ASTM C143 / C143M, (2015)) The main objective of performing the slump test was to infer the workability of the concrete mix and to ensure whether the target slump values in the mix design has been achieved or not. The apparatus for the test consists of a metallic mold in the shape of a cone frustum and an instrument for linear measurement, such as ruler. The frustum of the metal mold has a base and top diameter of 203 mm and 102 mm, respectively, along with a height of 305 mm. Having an open base and a top perpendicular to the cone axis, the frustum has also foot pieces and handles for easy maneuvering during the slump test. During the slump test, the frustum has been filled with four approximately equal layers of fresh concrete paste. Each concrete layer was then tamped uniformly for 25 evenly distributed strokes with the tamping rod in order to ensure a uniform compaction of the concrete mass. The mold was then lifted upwards slowly with an attempt of not disturbing the concrete mass in the frustum. The difference between the average of the deformed surface and the top of the resting mold was later measured with the ruler and has been denoted as the slump value of the concrete mix.

3.9 Testing of Concrete Specimens

All the tests of concrete were done in accordance with the ASTM standards.

3.9.1 Compressive Strength

In this study, the compressive strength test was conducted on concrete cylindrical specimens according to ASTM C39 requirements(ASTM C39 -14a (2014)). Three 100mm by 200mm concrete specimens were subjected to a compressive strength test to determine a more reliable average value. In the universal testing machine, cylindrical specimens are subjected to a compressive axial load at a rate of 2500 N/sec or 560 lb./sec until they are crushed. The specimen's compressive strength was determined by dividing the greatest load attained during the test by its cross-sectional area. Compressive strength was determined for 28 days and 90 days curing period. Typically, the results of this test serve as a basis for quality control of concrete proportioning, mixing, curing, and placement operations (ASTM C39, 2005). The equation used to determine compressive strength is given below.

$$f'c = P/A \tag{3.1}$$

$$A = \frac{\pi}{4} d^2 \tag{3.2}$$

Where,

f'_c= Compressive Strength (MPa)

P= Calibrated Load (KN)

A= Area of the specimen (mm^2)

d= Diameter of the specimen (mm)

(a) (b)

Fig. 3.8: Compressive Strength Failure (a) At 28 days curing period and (b) At 90 days curing period

The method of failure of the concrete examples was observed and recorded after their failure. In the vast majority of the concrete sample, combined shear failure was seen.

3.9.2 Tensile Strength Test on Concrete Specimens

The tests for tensile strength were conducted in accordance with ASTM C496(ASTM C496/C496M – 11. (2011)). Casting cylinders with a 100 mm diameter and 200 mm height. This test method assesses the tensile strength of cylindrical specimens of concrete, such as cast cylinders and cores drilled from the material. Cylinders were subjected to a compressive lateral load until they were crushed during the test. The specimen's tensile strength was determined by dividing the greatest load attained during the test by its cross-sectional area. The outcomes of this test serve as the basis for quality control of concrete proportioning, mixing, curing, and placement operations. The tensile strength was determined for five concrete mixes and for 28 days curing period. Three cylindrical molds were used for each reading, and the average tensile strength of the three specimens was taken as the tensile strength test result. The following equation was used to determine the tensile strength:

$$f_s = 2P/ \pi LD \tag{3.3}$$

Where,

f_s= Split Tensile Strength of Concrete Specimen (MPa)

P= Calibrated Applied Load (KN)

L= Height of the Specimen (mm)

D= Diameter of the Specimen (mm)

Fig. 3.9: Failure pattern after Tensile Strength Test (28 days)

3.11 Flexural Strength Test on Concrete Specimens

The flexural strength test specimen was a basic beam with dimensions of 75 mm×75 mm×275 mm. The test was conducted in accordance with ASTM C-78's standard test technique(ASTM C78/C78M-16. (2016)). Calculated results were presented as the modulus of rupture. As surface drying of the specimens would reduce the measured flexural strength, the specimens were tested as soon as they were removed from storage in a humid environment. The specimen was then loaded continuously and without stress. In flexure tests of concrete specimens, the third point loading method was employed to confirm that forces applied to the beams were perpendicular to the specimen's face and applied without eccentricity. In order to ascertain the dimensions of the specimen cross section for use in computing the modulus of rupture, measurements were taken across one of the shattered faces following the testing to determine the dimensions of the specimen cross section. For each dimension, one measurement was made at each edge and one at the cross-section’s center. Using the three measurements for each direction, the average width and depth were calculated. Every measurement was rounded to the nearest 0.05 inch.

Fig. 3.10: Three Point Loading of Flexural Strength

The following equation was used in determining the flexural strength:

$$f = 3Pa/bd^2 \quad (3.4)$$

Where,

f= Modulus of Rupture (MPa)

P= Calibrated Applied Load (KN)

a= average distance between line of fracture and the nearest support measured on the tension surface of the beam (mm)

b= average width of specimen (mm), at the fracture

d= average depth of specimen (mm), at the fracture

Fig 3.11: Failure by Flexural test (R100A10F0)

Fig 3.12: Failure by Flexural Test (R100A10F0.35)

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 General

This chapter contains a comprehensive summary of the results acquired from the various experiments conducted in the course of the research, as well as a discussion of any frequent patterns in the collected data. The numerical results are supported by appropriate graphs, and bar charts in order to deduce any existing patterns between them. The chapter is divided into various sections, and each section provides a concise summary of specific research findings. The primary objective of this study is to determine the effects of various dosages of nylon fiber on the mechanical properties of concrete. The effects of RHA and NF on concrete were compared in order to have a comprehensive understanding. The collected results are depicted in graphical representations and are thoroughly analyzed.

4.2 Slump Value Result

The slump values obtained while concrete casting is shown in table 4.1.

Table 4.1: Slump Values for Various Mixes

Mix ID	**Slump Value (mm)**
R0A0F0	57.2
R100A10F0	34
R100A10F0.1	22
R100A10F0.2	13
R100A10F0.35	7

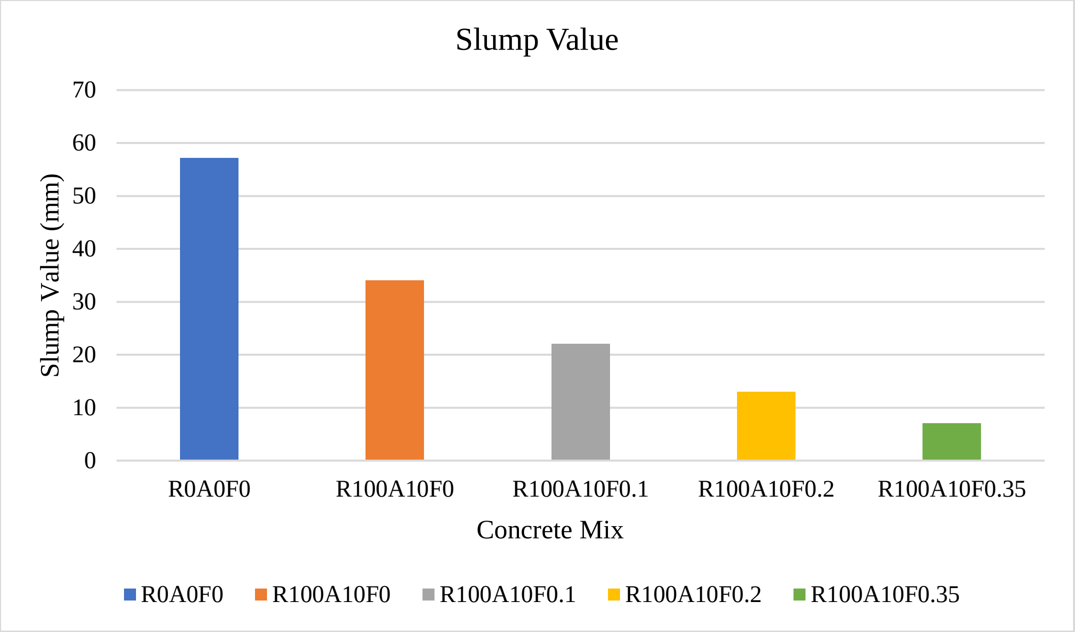


Fig. 4.1: Slump Value Test Results for Various Mixes

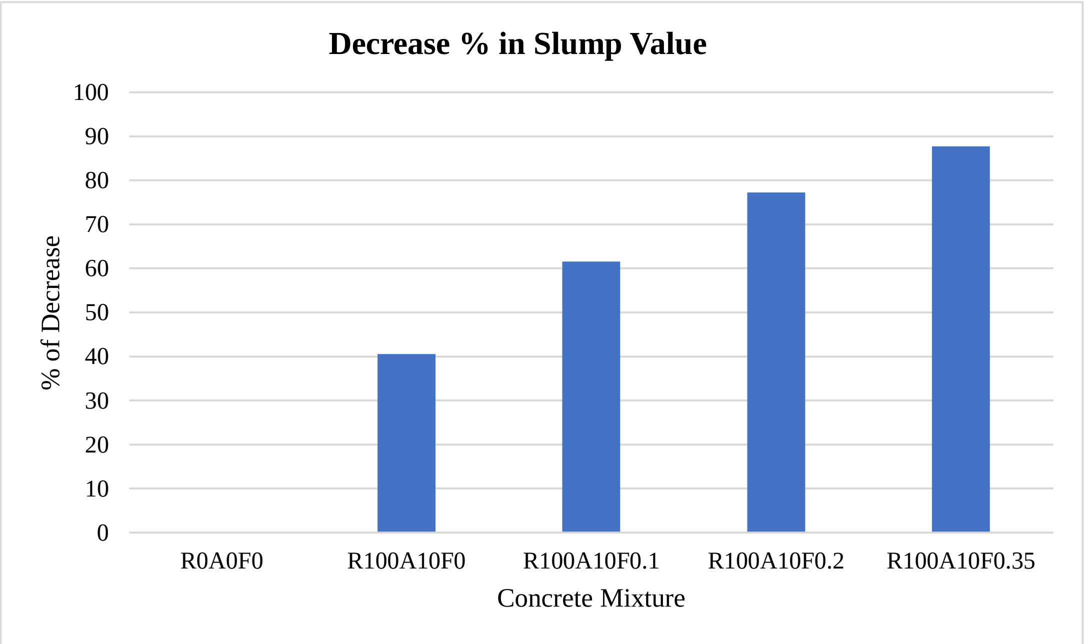


Fig 4.2: Decrease percentage of the concrete mixes compare to the controlled concrete

It has been noted that recycled aggregate concrete is less workable than natural aggregate concrete. This is due to the high water absorption capacity of recycled aggregate concrete (RAC) compared to plain concrete. In addition, it is observed that adding RHA and fiber affects the workability of concrete. The slump value decreases with the increasing amount of nylon fiber in the concrete mix. The factor to consider here is the surface area of the fiber. In addition to the coarse aggregate, the mortar (sand and cement) must also coat the fibers. If the mortar fraction is insufficient, then the effect on the slump and workability will be greater. For a fixed mix ratio, the surface area to be coated increases with the dosage, and as a consequence, the slump value decreases.(Figueiredo and Ceccato 2015)

4.3 Compressive Strength

The detailed calculation of compressive strength is shown in Appendix A.3. The summarized results of the compressive strength of the concrete mixes of 28 days curing period and 90 days curing period is in table 4.2.

Table 4.2.: Compressive Strength Test Results

Mix Type	Compressive Strength (MPa) (28 days)	Compressive Strength (MPa) (90 days)
R0A0F0	28.42	31.9
R100A10F0	27.95	32.60
R100A10F0.1	31.12	34.10
R100A10F0.2	33.24	37.20
R100A10F0.35	32.44	35.40

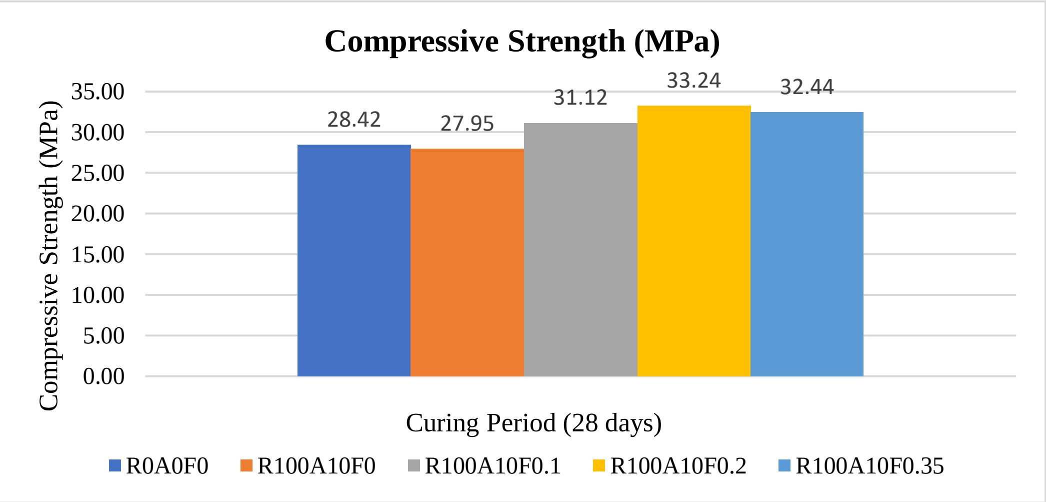


Fig. 4.3: Compressive Strength of Concrete Mixes for 28 days Curing Period

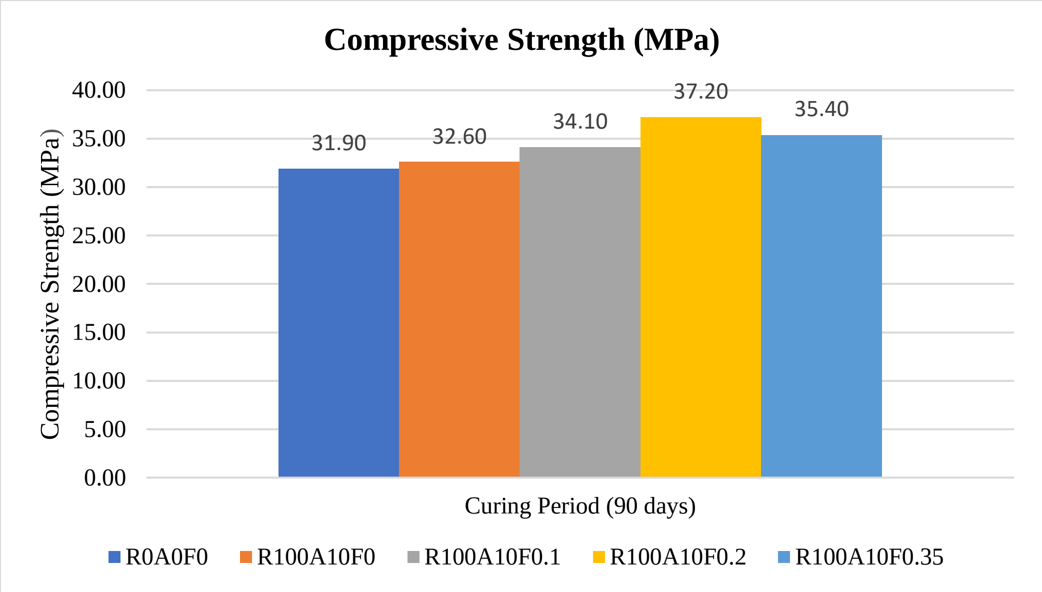


Fig. 4.4: Compressive Strength of Concrete Mixes for 90 days Curing Period

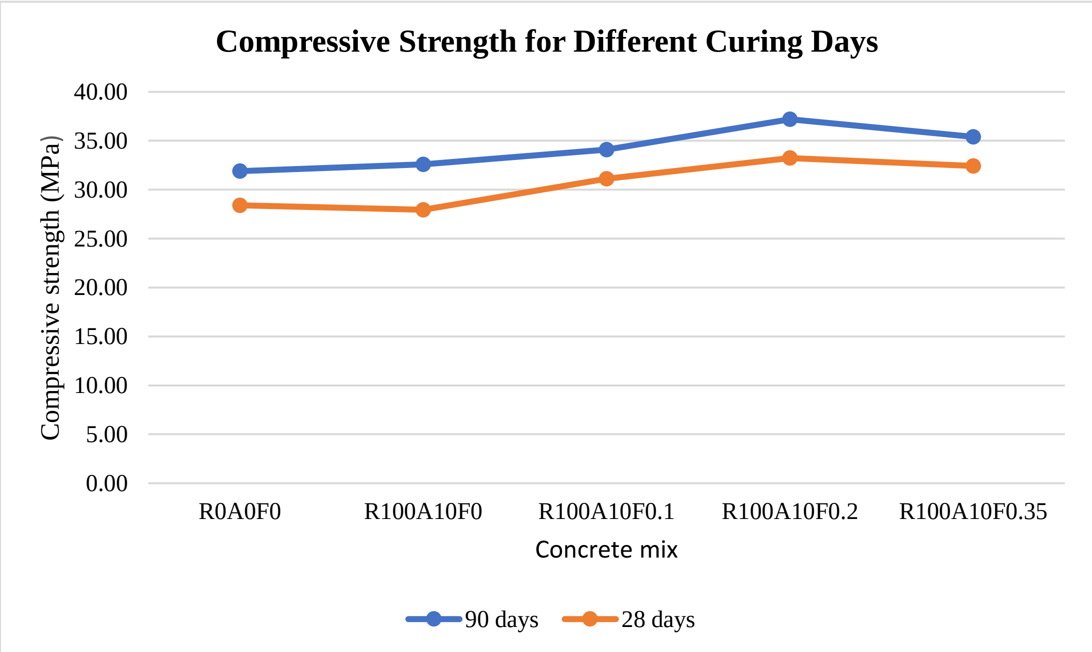


Fig. 4.5: Compressive Strength of Concrete Mixes for Different Curing Periods

Here the improvement of adding RHA and nylon fiber is shown in figure 4.3 and figure 4.4. When there is no fiber, the compressive strength is 1.65% less for a curing period of 28 days for the R100A10F0 concrete mix than the R0A0F0 (controlled) mix. That is because using 100% recycled aggregate instead of coarse aggregate lessen the compressive strength of concrete. There are three types of interfacial zones (ITZ) within RCA concrete: (a) the zone between aggregates and new cement mortar, (b) the zone between old and new cement mortar, and (c) the zone between old adhered mortar and recycled aggregate. Under compression, the presence of several ITZs can lead to the failure of early bonding in recycled aggregate concrete; as a result, the compressive strength of recycled aggregate concrete is much lower than that of conventional aggregate concrete.(Ali et al. 2019) The weakest of the three interfacial zones in RCA concrete is the transition zone between adhering mortar and aggregates. Due to the presence of microcracks in the transition zone, concrete with artificial aggregates has a lower strength than concrete with natural aggregates. Also, the loss in compressive strength is attributable to the porous nature of recycled aggregates, which results in a lower strength than natural aggregates.(Koushkbaghi et al. 2019b)

At 90 days curing period, the effect of RHA on concrete is noticeable as the compressive strength of the R100A10F0 is 2.19% higher than the R0A0F0 (controlled) mix. As the concrete ages, the compressive strength also increases because of the hydration process. At later ages, the incorporation of RHA increased the rate of hydration. RHA probably released water into the surrounding cement matrix as the concrete aged. With the partial replacement of cement with RHA, the rate of compressive strength increase over time was found to be enhanced.(Koushkbaghi et al. 2019b)

When nylon fiber was added, the compressive strength gradually increased to a certain amount and then decreased. It is true for both curing periods. The maximum increment is 16.96% at 29 days curing period and 16.6% at 90 days curing periods which is found in the R100A10F0.2 mix. This behavior can be due to the high fineness of the fibers, which form a network that functions as a bridge and stops the microfracture from propagating. However, when the proportion of nylon fibers in concrete is increased, the fibers are dispersed unevenly due to decreased workability and incorrect mixing. Consequently, these fiber masses are collected to form comparatively weaker places that behave as voids and are more prone to cracking, resulting in a decrease in compressive strength.(Das et al. 2018b)

4.4 Split Tensile Strength

For the construction of concrete structures, tensile strength is one of the most essential mechanical properties of concrete in terms of the initiation and development of cracks, shear, and anchorage of reinforcing steel. The splitting tensile test is typically conducted due to its ease of administration. The splitting tensile strength of the five distinct mixtures was tested at 28 days of age. For each concrete mix, average value of 3 concrete specimen was taken. The calculations are shown in Appendix A.4. The results obtained from the tensile test are in the following table and figure.

Table 4.3: Split Tensile Strength Test Results

Mix Type	Tensile Strength (MPa)
R0A0F0	2.45
R100A10F0	2.26
R100A10F0.1	2.53
R100A10F0.2	2.58
R100A10F0.35	2.22

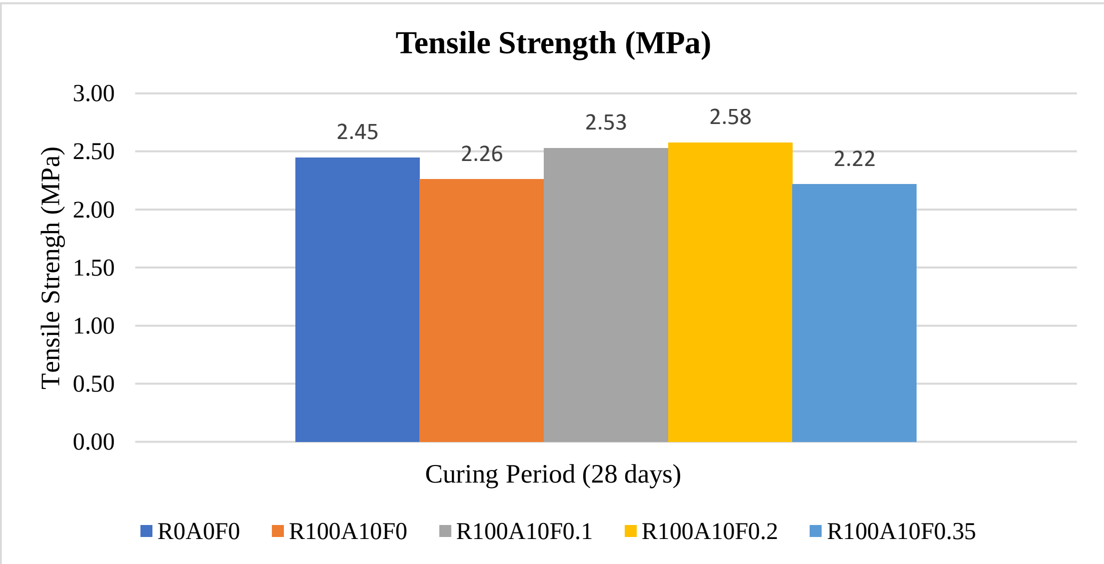


Fig. 4.6: Split Tensile Strength of Concrete Mixes for 28 days Curing Period

From the results, it can be said that adding nylon fiber improved the tensile strength of concrete. Adding fiber in tensile strength somehow follows a similar pattern as that of compressive strength. Initially, without fiber, the tensile strength of the R100A10F0 mix is 7.76% less than R0A0F0. After incorporating nylon fiber into the mix, the value increases maximum of 5.21% (for R100A10F0.2 mix), but further addition of fiber decreases the tensile strength 9.55% which is less that the value of non-fiber recycled concrete mix. Once the splitting process has occurred, the fibers operate as the bridge element, effectively transferring the load from the matrix to the fibers, absorbing the additional load, and increasing the split tensile values relative to unreinforced concrete. The increase in concrete's split tensile strength depends on the size and shape of the fibers. In a dispersed fiber cement matrix, stress concentrations do not remain constant along the length of the fiber. Stresses are more significant at the ends and in discontinuous fibers of shorter lengths; as a result, there will be a greater number of critical places where stresses are high, and failure is possible. This explains why split tensile values fall with increasing fiber composition.

4.5 Flexural Strength

Flexural strength measures the ability of concrete to resist breaking under load. The outcome helps to determine the material's application compatibility, durability, and user safety. At 28 days of age, the flexural strength of five different combinations was evaluated. For each concrete mixture, the average value of three concrete samples was determined. In Appendix A.5, the calculation of determining the flexural stress is given. The results of the flexural test are shown in the table and diagram below.

Table 4.4: Flexural Strength Test Results

Mix Type	Flexural Strength (MPa)
R0A0F0	5.3
R100A10F0	5.2
R100A10F0.1	5.7
R100A10F0.2	6.0
R100A10F0.35	5.7

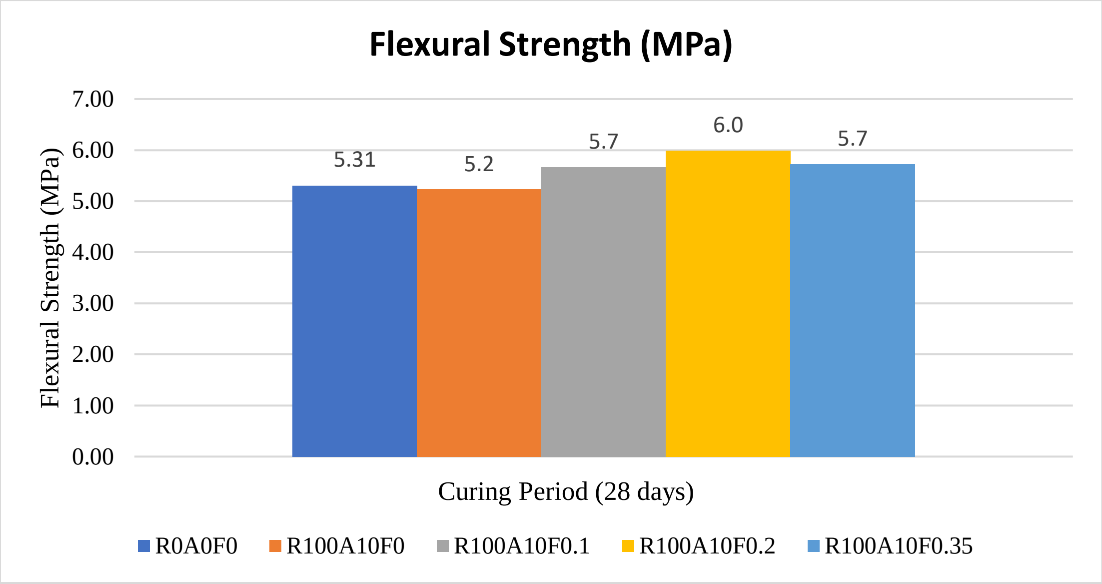


Fig. 4.7: Flexural Strength of Concrete Mixes for 28 days Curing Period

From previous studies, it was determined that adding fibers enhance the flexural strength of both NAC (natural aggregate concrete) and RAC (recycled aggregate concrete) significantly.(Koushkbaghi et al. 2019b),(Meesala 2019),(Ali et al. 2019),(Das et al. 2018b) However, in this present study, though adding fibers improves flexural strength, it is not noteworthy. Without fiber, the flexural strength decreases 1.5% with 100% replacement of coarse aggregate by RCA. After adding 0.1% and 0.2% fiber, the value increases 6.67% and 12.8% sequentially against normal concrete. The addition of nylon fibers to concrete increases its capacity to withstand cracking caused by external tensile load since unreinforced concrete is susceptible to breaking under tension. Nylon fiber can effectively withstand tensile stresses during the secondary and primary loading stages.

With additional increasement of percentage of fiber, the flexural strength value starts to lessen. This behavior can be explained by the fact that voids increase in the matrix with the increase in nylon fibers.

4.5.1 Flexural Crack Behavior

Following the flexural strength test, the cracking patterns of the specimen of nylon fiber-reinforced concrete were observed, and it was determined that nylon fiber held the specimen's components together. In the absence of fiber, samples were separated into two distinct portions.

Fig. 4.8: Flexural failure of R100A10F0 concrete mix


Fig. 4.9: Flexural failure of R100A10F0.2 concrete mix

4.6 Comparison of Improvements of Mechanical Properties

Here is a figure to depict which mechanical property is benefitted most from the combined effect of RHA and NF.

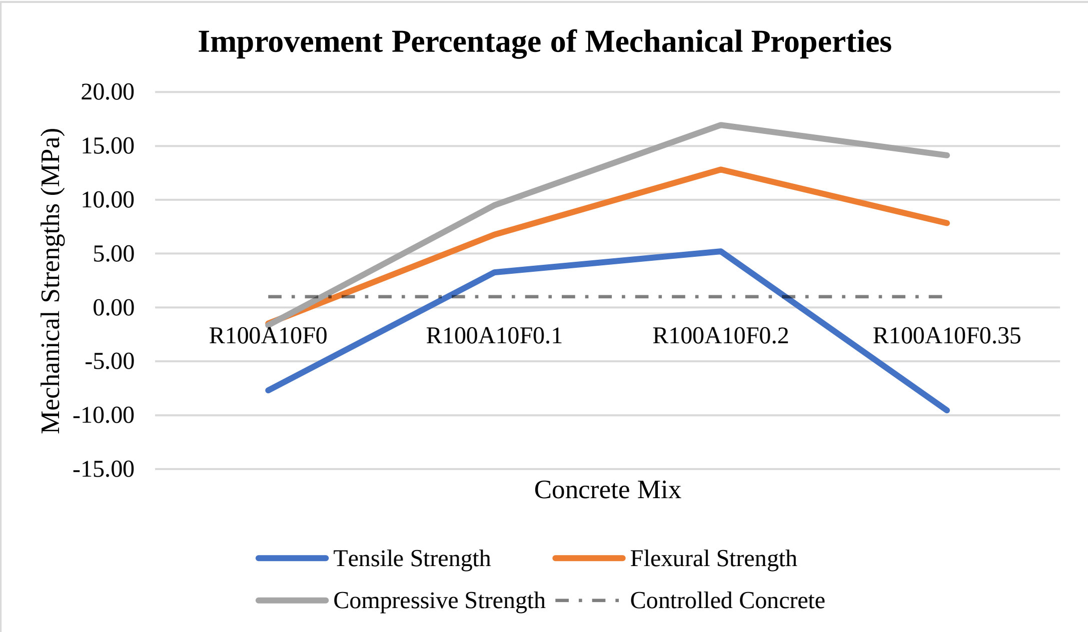


Fig. 4.10: Comparison of Improvement among the Mechanical Properties

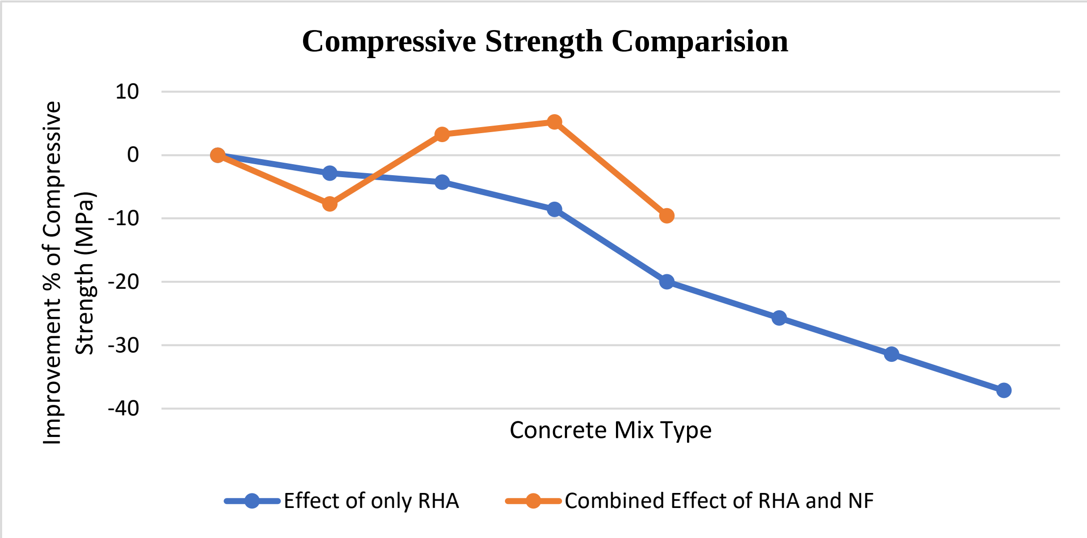
It is apparent from the above graph that nylon fiber improves the compressive strength more than other mechanical properties of concrete. This maybe because rice husk ash (RHA) generally enhance the compressive strength more than the other properties of concrete. So, the influence of combined effect of RHA and fiber is evident here.

4.7 Comparison of Effects of SCMs and Fibers on Mechanical Properties of Concrete with Previous Studies

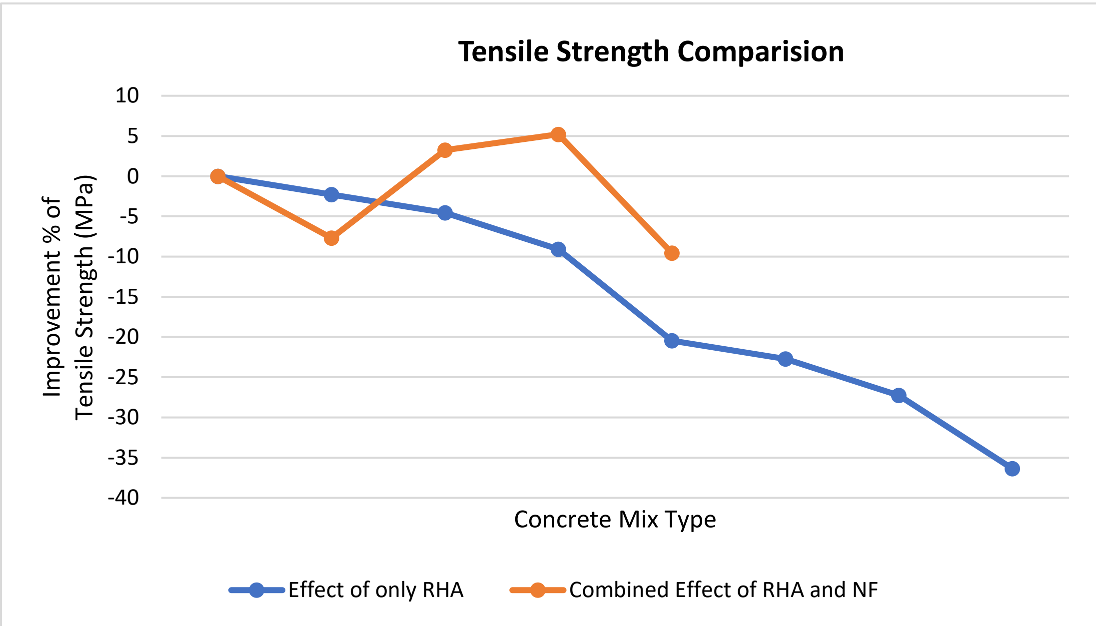
The percentage of improvement of the mechanical properties in the present study have been compared with the previous studies values in graphical representation to observe the benefits of choosing RHA and NF combination over other materials.

4.7.1 Comparison Between Combined Effect of RHA and NF and Different Percentage of RHA on 100% Recycled Aggregate Concrete

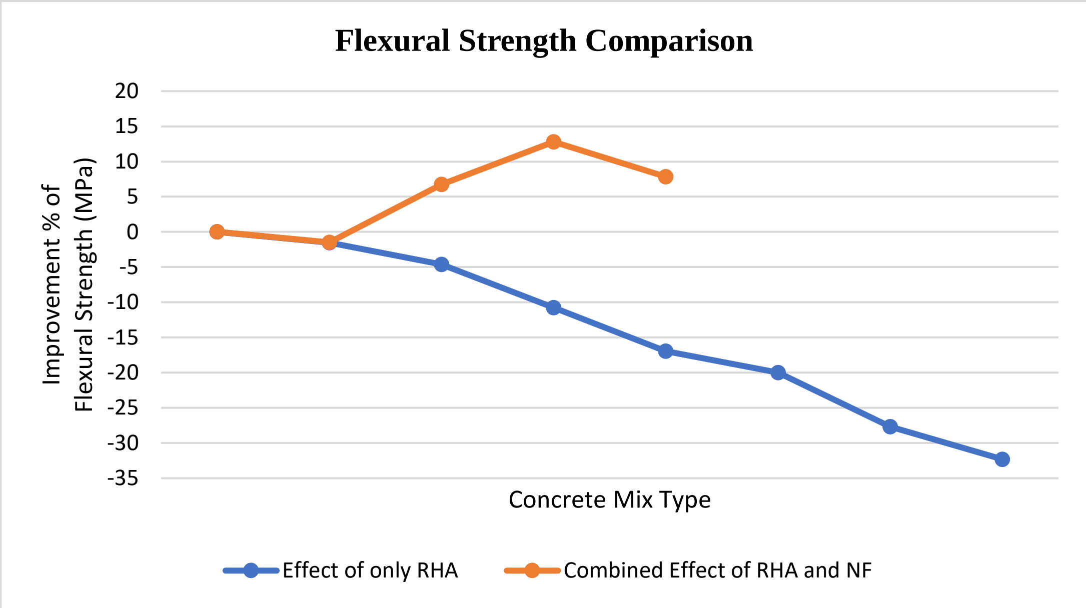
Padhi at el. investigated the influence of various percentages of RHA on 100% RAC. The cement was replaced by 0%, 5%, 10%, 15%, 20%, 25%, 30% and 35% RHA by weight.(Padhi et al. 2018). The comparison effects on concrete's compressive strength, tensile strength, and flexural strength is depicted in the figures below. From the figures it is clearly visible that combined effect of RHA and NF is better than only RHA.



(a) Compressive Strength Comparison



(b) Split Tensile Strength Comparison

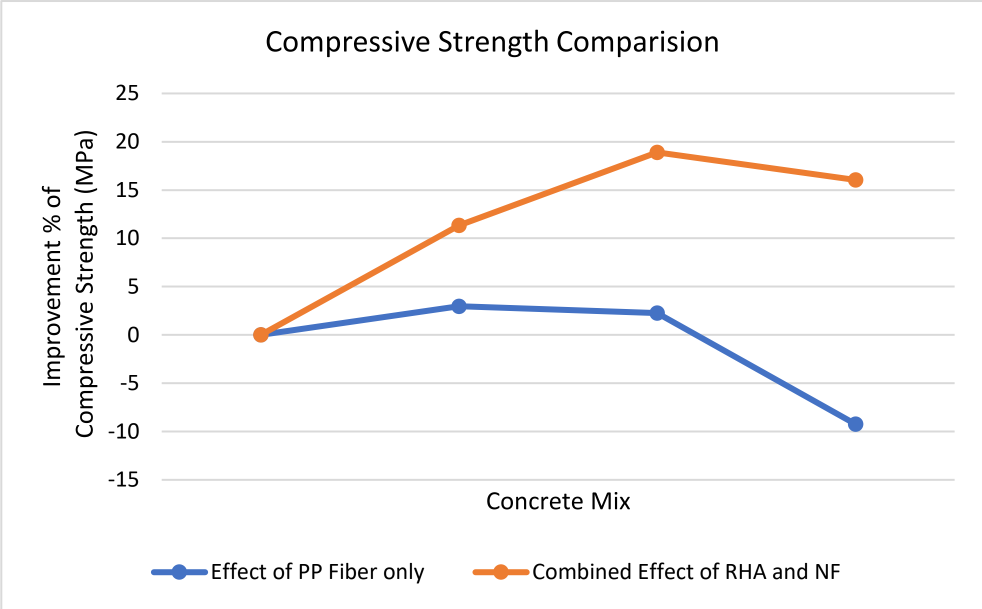


(c) Flexural Strength Comparison

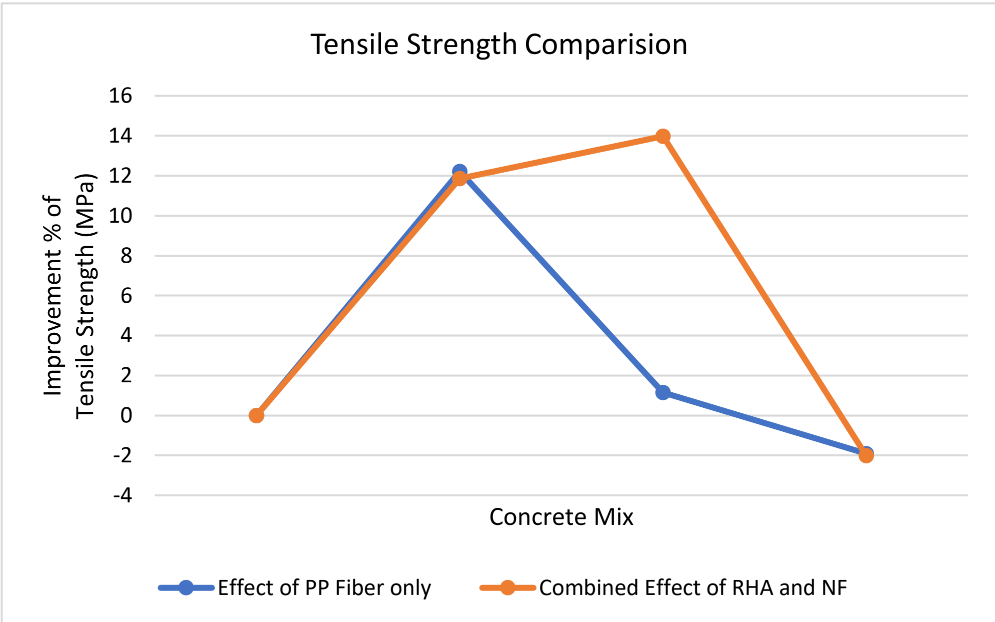
Fig. 4.11: Comparison of Mechanical Properties Between Combined Effect of RHA and NF and Different Percentage of RHA on 100% Recycled Aggregate Concrete

4.7.2 Comparison Between Combined Effect of 10% RHA-NF and only Polypropylene (PP) Fiber on 100% Recycled Aggregate Concrete

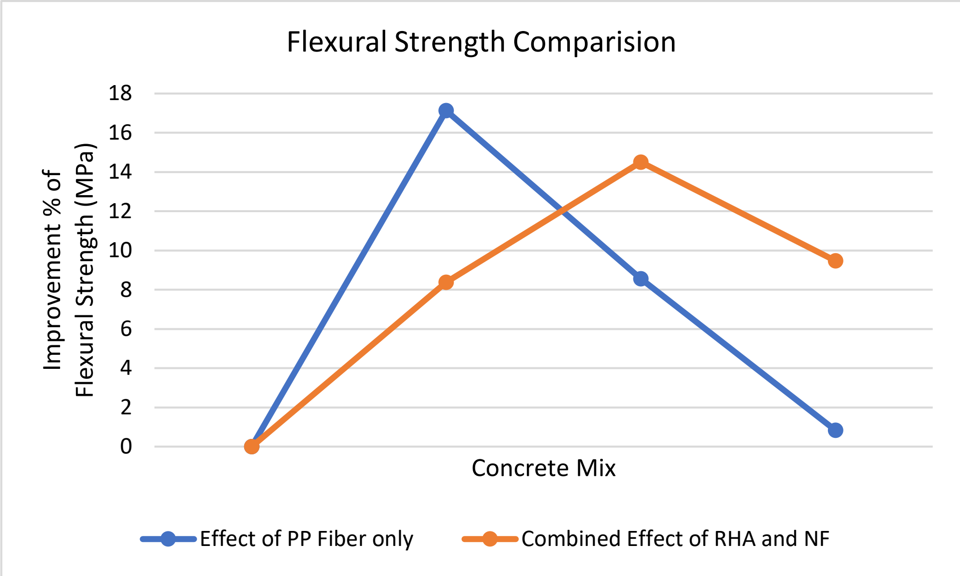
Das et al. evaluated the impact of incorporating microfilament-type polypropylene fibers into low-strength recycled aggregate concrete based on a variety of criteria, including compressive strength, split tensile strength, and flexural strength. Experiments are conducted using recycled aggregate concrete containing 0.5 percent, 0.75 percent, and 1 percent polypropylene fibers (RAC). The recovered coarse aggregates entirely replace the natural coarse aggregates in the recycled aggregate concrete. The curing period is 28 das. (Das et al. 2018c) The comparison graphs are shown in Figure 4.12.



(a) Compressive Strength Comparison



(b) Tensile Strength Comparison



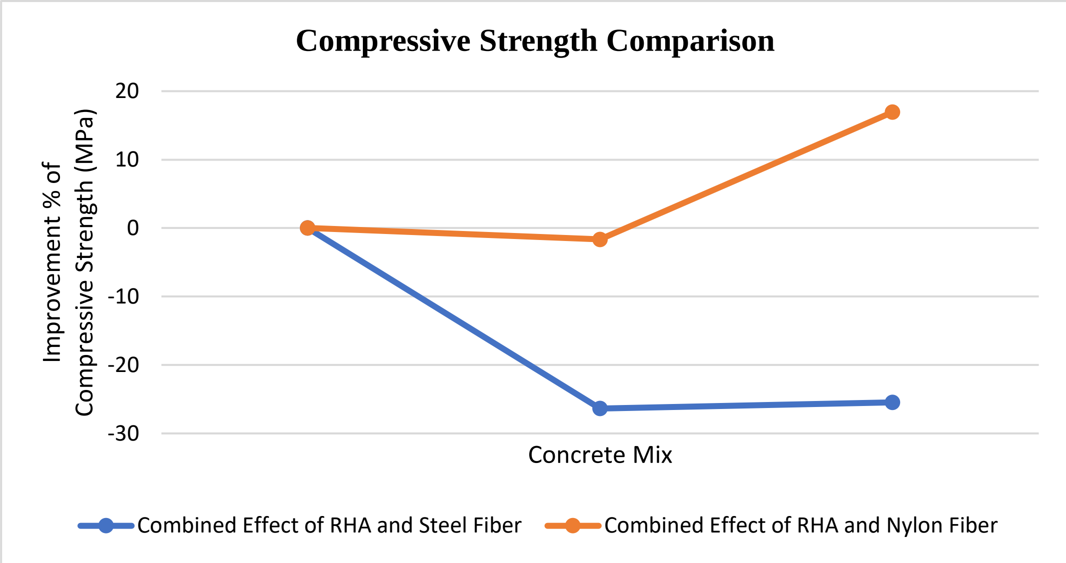
(c) Flexural Strength Comparison

Fig. 4.12: Comparison of Mechanical Properties Between Combined Effect of RHA and NF and Different Percentage of PP Fiber on 100% Recycled Aggregate Concrete

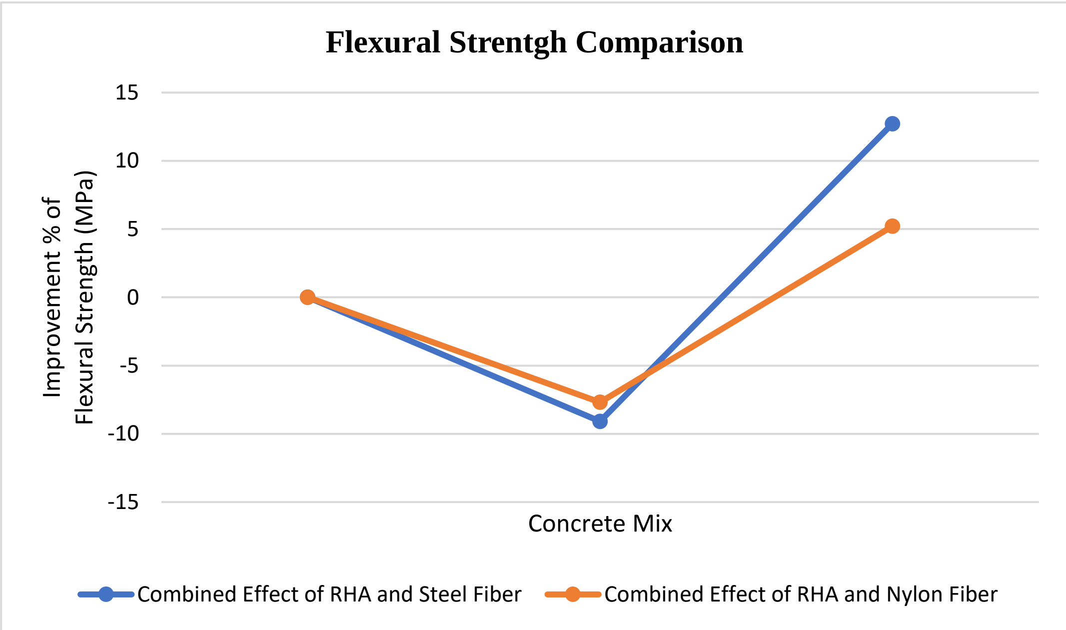
From the comparison figure, it is observed that Polypropylene fiber does not enhance compressive much, whereas the combined effect of RHA and nylon fiber is significant here. For tensile strength, 0.5% is the optimum amount for PP fiber as it increases the strength by 12.2% more than the non-fiber concrete. But the combined effect of RHA and NF gives a higher value of increment of 13.98%, and the optimum nylon fiber content is 0.2%. PP fiber gives better results in flexural strength. But considering overall performance, the combination of RHA and NF is better than using polypropylene fiber in a concrete mix.

4.7.3 Comparison of Combined Effect Between 10% RHA-NF and 20% RHA-1% Steel Fiber on 100% Recycled Aggregate Concrete

Koushkbaghi at el.(Koushkbaghi et al. 2019c) investigated the combined influence of rice husk ash and steel fiber both on natural coarse aggregate and recycled coarse aggregate in details. Mechanical features like as compressive strength and splitting tensile strength are investigated in this study. In addition, fibrous and non-fibrous concrete were produced in order to examine the effects of RHA and RCA. The test results taken to be compared are of 28 days curing period. The comparison result figure is in the following figure.



(a) Compressive Strength Comparison



(b) Flexural Strength Comparison

Fig. 4.13: Comparison of Combined Effect of Mechanical Properties Between 10% RHA-NF and 20% RHA-1% Steel Fiber on 100% Recycled Aggregate Concrete

It is evident that at 28 days curing period, the combined effect of RHA and Steel Fiber does not improve compressive strength at all. In comparison, the 10% RHA-0.2% Nylon Fiber combination improves the controlled concrete's compressive strength by 16.94%. On the other hand, this 10% RHA-0.2% NF combination does not significantly affect tensile strength. However, the effect of RHA and Steel Fiber combination on tensile strength is twice the other one.

CHAPTER 5: CONCLUSION

5.1 General

The primary objective of the research was to observe if rice husk ash (RHA) and nylon fiber can improve the mechanical properties (compressive strength, split tensile strength, flexural strength) of concrete if the coarse aggregate is 100% replaced by recycled coarse aggregate (RCA) and how different dosages of nylon fiber affect these properties. By reusing waste materials like rice husk ash and nylon fiber in concrete, it provides a positive impact on the environment by lowering pollution. Using RHA as cement replacement also reduce the production and waste of Portland cement. This chapter contains a summary of the major findings taken from the observed effects in the results, and it has also been utilized as a reference for suggesting future recommendations.

5.2 Research Findings

In this study, for a fixed percentage of RHA (10% replacement of cement by weight) different dosages of nylon fiber (0.1%, 0.2% and 0.35% volume fraction of concrete) were added into recycled aggregate concrete. The following conclusions can be derived from the experimental results:

a) RAC has less workability than NAC. The workability further decreases with the incorporation of RHA and increasing dosages of nylon fiber.
b) Because of the adhered mortar in the recycled aggregate, replacing natural aggregate with RCA has a negative effect on the mechanical properties of concrete. The compressive strength, splitting tensile strength, and flexural strength decreased. The inclusion of SCM (rice husk ash) did not significantly improve the properties.
c) The incorporation of nylon fiber (NF) improved the compressive strength of the concrete notably at both 28 days and 90 days. At 28 days, addition of 0.1%, 0.2% and 0.35% of fiber in the concrete mix increased the strength by 9.5%,

16.9% and 14.1% respectively. At 90 days, the increased percentage of the strength is 6.9%, 16.6%, and 10.97%, respectively.

d) At 28 days curing period, the compressive strength of non-fibrous RAC incorporated with RHA was 1.65% less than the NAC. But at 90 days, the compressive strength value of RAC is 2.2% more than that of NAC. It is due to the fact that RHA accelerated the rate of hydration of concrete as its age increased.
e) The tensile strength of concrete decreased by 7.69% when the coarse aggregate was replaced by recycled aggregate. It increased by 3.2% and 5.2% with addition of 0.1% and 0.2% fiber respectively. But further addition of fiber decreased the strength significantly by 9.5% of the controlled concrete strength.
f) Adding fiber to the concrete had positive effect on the flexural strength of RAC. The value is increased by 6.76%, 12.8%, 7.84% of the controlled concrete strength by adding 0.1%,0.2% and 0.35% fiber respectively.
g) All the mechanical properties of RAC follow the same behavior pattern. The strengths increase with the increasing dosage of fiber percentage up to a certain value. Then the value starts to decrease. In this study, the optimum value of fiber which gives the highest values of the mechanical properties, is 0.35%.
h) R100A10F0.2 concrete mix is the optimum concrete mix which is a viable replacement of conventional concrete.

5.3 Limitations of the Present Study

There were few limitations due to time and facility constraints.

a) Rice Husk Ash could have been finer. Having an automatic grinding machine could have made the process more efficient and less time consuming.
b) The tensile strength and flexural strength of specimens could have been observed for longer curing period (56 days/90 days).

5.4 Scope for Future Study

There are many kinds of research where the incorporation of different SCMs and fibers into low strength recycled aggregate concrete to observe if there is any enhancement on the properties has been conducted. But very little research has been done with nylon fiber, and none has been done so far where the SCM is rice husk ash, and nylon fiber is the fiber. This opens up vast prospects for further research and advancement in this industry. In addition, validation of the acquired results necessitates the execution of identical tasks on a large sample pool to achieve a better level of dependability. Therefore, the following suggestions are recommended as future scopes for conducting additional studies in this area:

a) In this study, only the basic mechanical tests (compressive strength test, split tensile strength test and flexural strength test) were performed on concrete. There is a scope to conduct other tests like modulus of elasticity, stress-strain behavior, porosity and density test, shrinkage tests to observe the effect of SCM and fiber on these properties.
b) The durability tests of concrete i.e. water absorption test, rapid chloride ion penetration test (RCPT), acid attack resistance (AAR) can be done. Also, the relation between the mechanical properties and the durability properties of concrete can be investigated.
c) The FE-SEM analysis can be conducted to investigate the microstructure of concrete with the addition of RHA and increasing dosages of NF.
d) The w/c ratio, percentage of RHA added and the length of the nylon fiber were fixed parameters. For further studies, concrete mixes with variation in these parameters can be made and tested to find the optimum value of these parameters.

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APPENDIX

A.1 PROPERTIES of AGGREGATES

Sieve Analysis is done to obtain the fineness modulus and gradation chart.

Table A.1.1: Sieve Analysis Test Calculation of Fine Aggregate

Sieve No	Sieve Diameter	Amount Retained	% Retained	Cumulative % Retained	% Passing
	mm	kg			
#4	4.75	19	3.8	3.8	96.2
#8	2.36	27.8	5.56	9.36	90.64
#16	1.18	94.2	18.84	28.2	71.8
#30	0.6	187	37.4	65.6	34.4
#50	0.3	115	23	88.6	11.4
#100	0.15	44	8.8	97.4	2.6
#200	0.075	10.2	2.04	99.44	0.56
PAN	0	2.8	0.56	100	0

Table A.1.2: Sieve Analysis Test Calculation of Natural Coarse Aggregate

Sieve No	Sieve Diameter	Amount Retained	% Retained	Cumulative % Retained	% Passing
	mm	kg			
1"	25	0	0	0	100
3/4"	19	2.554	25.54	25.54	74.46
1/2"	12.5	3.047	30.47	56.01	43.99
3/8"	9.5	2.056	20.56	76.57	23.43
#4	4.75	2.042	20.42	96.99	3.01
#8	2.36	0.256	2.56	99.55	0.45
PAN	0	0.045	0.45	100	0

Table A.1.3: Sieve Analysis Test Calculation of Recycled Coarse Aggregate

Sieve No	Sieve Diameter	Amount Retained	% Retained	Cumulative % Retained	% Passing
	mm	kg			
1"	25	0.337	3.37	3.37	96.63
3/4"	19	2.167	21.67	25.04	74.96
1/2"	12.5	2.791	27.91	52.95	47.05
3/8"	9.5	1.787	17.87	70.82	29.18
#4	4.75	1.922	19.22	90.04	9.96
#8	2.36	0.595	5.95	95.99	4.01
#16	1.18	0.222	2.22	98.21	1.79
PAN	0	0.179	1.79	100	0

A.2 MIX PROPORTION OF THE CONCRETE MIXES

Table A.2.1: Amount of Materials in Controlled Concrete Mix

Mixture ID	Cement	Fine Aggregate	Natural Coarse Aggregate	Water	Super Plasticizer
	(kg)	(kg)	(kg)	(kg)	(ml)
R0A0F0	10.8	18.3	40.6	4.9	130

Table A.2.2: Amount of Materials in Recycled Aggregate Concrete

Mixture ID	Cement	Fine Aggregate	Recycled Aggregate	Rice Husk Ash	Nylon Fiber	Water	Super Plasticizer
	(kg)	(kg)	(kg)	(kg)	(gm)	(kg)	(ml)
R100A10F0	9.7	18.3	32.3	1.08	0	4.9	130
R100A10F0.1	9.7	18.3	32.3	1.08	20.71	4.9	130
R100A10F0.2	9.7	18.3	32.3	1.08	41.43	4.9	130
R100A10F0.35	9.7	18.3	32.3	1.08	72.79	4.9	130

A.3 COMPRESSIVE STRENGTH TEST CALCULATION

Curing period for compressive strengths were 28 days and 90 days.

Table A.3.1: Compressive Strength Test Calculation for 28 days

MIX ID	**Compressive Strength**					
	Dia	**Average**	**Area**	**Calibrated Load**	**Average Value**	**Compressive Strength**
Unit	**mm**	**mm**	**mm^2**	**KN**	**KN**	**KN/mm^2 (MPa)**
Formula			**π/4*(dia)^2**			**Load/Area**
R0A0F0	101	101	8010.34	218.68	227.66	28.42
	101			262.43		
	101			201.87		
R100A10F0	102	102	8169.74	232.8	228.37	27.95
	102			224		
	102			228.3		
R100A10F0.1	101.5	101.67	8116.43	256	252.60	31.12
	102			251.9		
	101.5			249.9		
R100A10F0.2	102	101.5	8089.84	274.9	268.87	33.24
	101.5			272.9		
	101			258.8		
R100A10F0.35	101	101.5	8089.84	267.4	262.40	32.44
	101.5			258.2		
	102			261.6		

Table A.3.2: Compressive Strength Test Calculation for 90 days

MIX ID	Compressive Strength					
	Dia	Average	Area	Calibrated Load	Average	Compressive Strength
Unit	mm	mm	mm^2	KN	KN	KN/mm^2 (MPa)
Formula			π/4*(dia)^2			Load/Area
R0A0F0	101	101	8010.34	252.06	255.4	31.9
	101			266.02		
	101			248.07		
R100A10F0	101	101.17	8036.79	277.99	262.0	32.6
	101.5			244.09		
	101			264.03		
R100A10F0.1	101	101.33	8063.30	283.97	275.3	34.1
	102			266.02		
	101			276.00		
R100A10F0.2	101.5	101.17	8036.79	295.94	298.6	37.2
	101			295.94		
	101			303.92		
R100A10F0.35	102	101.67	8116.43	305.91	287.3	35.4
	102			285.97		
	101			270.01		

A.4 SPLIT TENSILE STRENGTH TEST CALCULATION

The curing period is 28 days.

Table A.4.1: Tensile Strength Test Calculation

MIX ID	Tensile Strength					
	Dia	Average	Length	Calibrated Load	Average	Tensile Strength
Unit	mm	mm	mm	KN	KN	MPa
Formula						2P/π*L*D
R0A0F0	101	101.333	200	62	78	2.450142737
	102			72		
	101			100		
R100A10F0	102	101.333		62	72	2.261670218
	101			78		
	101			76		
R100A10F0.1	101	101.5		82	80.6667	2.529747531
	101.5			98		
	102			62		
R100A10F0.2	101.5	101.667		82	82.3333	2.577782231
	102			75		
	101.5			90		
R100A10F0.35	101.5	101.5		56	70.6667	2.216142465
	101.5			72		
	101.5			84		

A.5 FLEXURAL STRENGTH TEST CALCULATION

The curing period is 28 days.

Table A.5.1: Flexural Strength Test Calculation

MIX ID	Flexural strength				
	Load	d	a	Flexural Strength	Average Value
Unit	KN	mm	mm	MPa	MPa
Formula		75		$3Pa/bd^2$	
R0A0F0	9.1		85	5.50	5.31
	8.67		83	5.12	
	0		0	0.00	
R100A10F0	10.1		85	6.10	5.71
	9		83	5.31	
	0		0	0.00	
R100A10F0.1	6.8		101	4.88	5.67
	7.9		95	5.34	
	9.26		103	6.78	
R100A10F0.2	8.44		81	4.86	5.99
	9.26		103	6.78	
	8.89		100	6.32	
R100A10F0.35	9.26		88	5.79	5.73
	8.67		93	5.73	
	7.71		103	5.65	