SHEAR BEHAVIOR OF CONCRETE BEAM WITH RECYCLED AND POLYPROPYLENE AGGREGATES

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M. Engineering Thesis

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DECLARATION

I hereby declare that this thesis is our original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis. The thesis has not been submitted for any degree or diploma in any university or institute previously.

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ABSTRACT

SHEAR BEHAVIOR OF CONCRETE BEAM WITH RECYCLED AND POLYPROPYLENE AGGREGATES

The disposal of recycled concrete and plastic waste is an environmental concern. Hence, using this recycled aggregate (RA) and waste polypropylene (PP) aggregate in new concrete can provide a workable solution for disposal. Incorporating these waste or recycled materials in concrete will introduce more inhomogeneity, voids, and weaker interfacial transition zones (ITZs). Therefore, the replacement percentages of recycled aggregate (RA) and PP aggregate, and the shear-span-to-depth ratio of the reinforced concrete beams have been examined in this study. A total of 24 longitudinally reinforced concrete beams with 1100 mm length, 100 mm width and variable depth (150 mm, 200 mm, and 300 mm) are made. Additionally, waste polypropylene (PP) is acquired through a procedure and incorporated into the concrete as a partial replacement of coarse aggregate. Four distinct polypropylene aggregate (PPA) replacement percentages 0%, 5%, 10%, and 15%, with natural aggregate (NA) and RA are considered. The beam specimens are subjected to a four-point bending test at 56 days. The peak load and corresponding deflection, shear capacity at first crack, ductility, toughness of the beam, and strain in the steel and concrete are all measured in this test.

According to the test results, adding 5% of PPA with NA concrete increases shear capacity by 8.1% to 9.8%. Except for one case with a 200 mm depth beam, RA concrete also shows a rise in shear capacity for 5% PPA. A similar trend is also observed for the peak load. Peak load up to 24.3% and 22.6% is observed with 5% PPA in NA and RA concrete. Yet, if more PPA is added, the shear capacity and peak load decrease. The application of RA in concrete reduces the shear capacity and peak load. Polypropylene and recycled aggregate show an increase in the ductility of the beam, especially with 5% PPA. Based on the test results, it is concluded that up to 5% PPA can be adopted in concrete with NA and RA.

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SHEAR BEHAVIOR OF CONCRETE BEAM WITH RECYCLED AND POLYPROPYLENE AGGREGATES`

পুনর্ব্যবহৃত কংক্রিট এবং প্লাস্টিক বর্জ্য নিষ্পত্তি একটি পরিবেশগত সমস্যা। তাই, নতুন কংক্রিটে এই পুনর্ব্যবহৃত সমষ্টি (RA) এবং পরিত্যক্ত পলিপ্রোপিলিন (PP) সমষ্টি ব্যবহার করা বর্জ্য নিষ্পত্তির জন্য একটি কার্যকর সমাধান হতে পারে। কংক্রিটে এই বর্জ্য বা পুনর্ব্যবহৃত উপকরণগুলিকে অন্তর্ভুক্ত করলে কংক্রিট আরও অভারসাম্যতা, বায়ু শূন্যতা এবং দুর্বল ইন্টারফেসিয়াল ট্রানজিশন জোন (ITZs) প্রবর্তন করবে। অতএব, পুনর্ব্যবহৃত সমষ্টি (RA) এবং পিপি সমষ্টির প্রতিস্থাপন শতাংশ এবং চাঙ্গা কংক্রিট বিমের শিয়ার-স্প্যান-টু-গভীরতার অনুপাত এই গবেষণায় পরীক্ষা করা হয়েছে। ১১০০ মিমি দৈর্ঘ্য, ১০০ মিমি প্রস্থ এবং পরিবর্তনশীল গভীরতা (১৫০ মিমি, ২০০ মিমি এবং ৩০০ মিমি) সহ মোট ২৪টি অনুদৈর্ঘ্যভাবে চাঙ্গা কংক্রিট বিম তৈরি করা হয়েছে। উপরন্তু, বর্জ্য পলিপ্রোপিলিন (PP) একটি পদ্ধতির মাধ্যমে অর্জিত হয় এবং মোটা সমষ্টির আংশিক প্রতিস্থাপন হিসাবে কংক্রিটে অন্তর্ভুক্ত করা হয়। প্রাকৃতিক সমষ্টি (NA) এবং RA সহ চারটি স্বতন্ত্র পলিপ্রোপিলিন এগ্রিগেট (PPA) প্রতিস্থাপন শতাংশ ০%, ৫%, ১০% এবং ১৫% বিবেচনা করা হয়। মরীচির নমুনাগুলি ৫৬ দিনে একটি চার-পয়েন্ট নমন পরীক্ষা করা হয়। সর্বোচ্চ লোড এবং সংশ্লিষ্ট আকৃতির বিকৃতি, প্রথম ফাটলে শিয়ার ক্ষমতা, নমনীয়তা, মরীচির বলিষ্ঠতা এবং স্টিল এবং কংক্রিটের স্ট্রেন এই পরীক্ষায় পরিমাপ করা হয়।

পরীক্ষার ফলাফল অনুসারে, NA কংক্রিটের সাথে ৫% PPA যোগ করলে শিয়ার ক্ষমতা ৮.১% থেকে ৯.৮% বৃদ্ধি পায়। একটি ২০০ মিমি গভীরতার রশ্মি সহ একটি কেস বাদে, RA কংক্রিট ৫% PPA-এর জন্য শিয়ার ক্ষমতা বৃদ্ধি দেখায়। সর্বোচ্চ লোডের জন্যও একই ধরনের প্রবণতা পরিলক্ষিত হয়। NA এবং RA কংক্রিটে ৫% PPA সহ ২৪.৩% এবং ২২.৬% পর্যন্ত সর্বোচ্চ লোড পরিলক্ষিত হয়। তবুও, যদি আরও PPA যোগ করা হয়, শিয়ার ক্ষমতা এবং সর্বোচ্চ লোড হ্রাস পায়। কংক্রিটে RA এর প্রয়োগ শিয়ার ক্ষমতা এবং সর্বোচ্চ লোড হ্রাস করে। পলিপ্রোপিলিন এবং পুনর্ব্যবহৃত সমষ্টি রশ্মির নমনীয়তা বৃদ্ধি দেখায়, বিশেষত ৫% পিপিএ সহ। পরীক্ষার ফলাফলের উপর ভিত্তি করে, এটি উপসংহারে পৌঁছানো যায় যে NA এবং RA এর সাথে কংক্রিটে ৫% পর্যন্ত PPA গ্রহণ করা যেতে পারে।

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Symbols	**Description**
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACV	Aggregate Crushing Value
AIV	Aggregate Impact Value
ASTM	American Society for Testing Materials
CDW	Constructed and Demolition Waste
DCC	Dhaka City Corporation
EVA	Ethylene Vinyl Acetate
LWC	Light Weight Concrete
OPC	Ordinary Portland Cement
PA	Plastic Aggregate
PP	Polypropylene
PS	Polystyrene
PPA	Polypropylene Aggregate
RA	Recycled Aggregate
RAC	Recycled Aggregate Concrete
NA	Natural Aggregate
NAC	Natural Aggregate Concrete

CHAPTER 1

INTRODUCTION

1.1 General

With the growth and development of civilization, plastics have become part of our daily consumption habits. It has become more requisite but a prime matter of concern. Plastic waste affects the whole earth, including humankind, wildlife, and aquatic life. It is spreading like a disease that has no cure. The predicamental issue with plastic is that it is not biodegradable (Abdel-Shafy and Mansour, 2018). Plastic-based waste products are occupying the landfill spaces. They are not getting rot. The presence of such sort of waste is highly threatening to the environment. It impedes the infiltration of water through soil and decreases soil fertility. It hinders the growth of plant roots. One of the most discussed issues in today’s Bangladesh is the water drainage problem. This problem occurs due to the clotting of plastic trash blocking the drainage system.

The conventional construction material of today’s world is concrete. The use of concrete is augmenting on a larger scale. A recent article shows that the global consumption of concrete is around 25 billion tons per year (Akhtar and Sarmah, 2018). The predominant part of concrete is coarse aggregate, and the primary source of this aggregate is natural resources. The estimated usage of coarse aggregate is more than 3.9 billion tons (Akhtar and Sarmah, 2018). Hence, the construction industries bear a deleterious impact on the environment.

The primary purpose of this study is to identify possibilities and practical applications of polypropylene aggregate (PPA) from waste plastic disposals with recycled aggregate (RA) and natural aggregate (NA) in various ratios to investigate the material strengths. For this study, a total of 24 beams were prepared in two groups. The first group was made of NA and PPA, and the second group was made of RA and PPA. The depth of those beams was 300 mm, 200 mm, and 150 mm. The replacement ratio of PPA with RA and NA was 0%, 5%, 10%, and 15%. Then shear strength was studied experimentally by measuring the first crack load, ultimate failure load, and deflections and monitoring the crack patterns until failure for each beam.

1.2 Background

Concrete is one of the most widely used materials in the world. Each year, 13.12 billion natural aggregates are required for concrete construction (Mohammed et al., 2014). The use of potential plastic waste and recycled aggregate in concrete can reduce the dependence on natural aggregate.

Plastic is the most widely used office and household item in the last century because of its low cost, lighter weight, durability, and ease of manufacturing and fabrication. The consumption of plastic materials was raised from 5 million tons to 368 million tons between 1950 and 2016 (Statista Research Department, 2023). Almost 35.7 million tons of plastic waste in the USA were produced in 2018 (Banerjee et al., 2014). These PP plastic wastes are non-biodegradable, and improper dumping turns into a great threat to the soil and the environment. Several studies have been conducted while incorporating PP as a partial replacement of course aggregate in concrete.

Recycled aggregate (RA) can produce concrete with equivalent strength compared to natural aggregate (NA) (Ajdukiewicz and Kliszczewicz, 2002, KS F 2573-2014, 2014). Most of the plastic wastes are non-biodegradable, and their improper dumping becomes a great threat to soil and the environment (Frigione, 2010, Islam and Shahjalal, 2021). Therefore, the application of recycled aggregate and PP aggregate in concrete provides ecological benefits by reducing the disposal load on landfill sites and conserving natural rock resources that are currently being depleted to produce NA. Very few studies have been reported on the shear behavior of reinforced concrete beams while incorporating varying percentages of PP as a replacement for natural or recycled coarse aggregates. Therefore, it is essential to study the effect of the shear behavior of reinforced concrete beams with PP aggregate as a partial replacement of natural and recycled coarse aggregates.

1.3 Research Objective

The study aims to:

i. Determine the shear behavior of reinforced natural aggregate concrete (NC) beams.
ii. Investigate the shear behavior of reinforced recycled aggregate concrete (RC) beams.

1.4 Research outcome

Sustainable construction is an important social issue. The researchers have been working for a long time to find more reliable, cheaper, load-bearing construction materials. In this circumstance, the researcher considered using recycled aggregates to reduce concrete waste and polypropylene to reduce plastic waste. This process will preserve natural resources and significantly influence human health and the environment. Recycled aggregates and polypropylene (PP) can help the environment from becoming polluted and save natural resources, creating new opportunities for sustainable construction by recycling plastic waste, and recycled aggregates. A 5% PP content with NA and RA exhibited comparatively better ultimate strength than the control concrete. The increase of polypropylene with NA and RA decreased the crack angle which influenced the failure of the beam early. Furthermore, 5% polypropylene content with natural aggregate (NA) showed a higher value of toughness compared to 0% PP. 5% Polypropylene with NA and 15% with RA obtained the maximum value of ductility respectively.

1.5 Methodology

In this study, natural aggregate (NA) and recycled aggregate (RA) are replaced with 0%, 5%, 10% and 15% PPA. Three different sizes of beams will be prepared to evaluate the shear behavior of concrete beams. That is 1100 mm x 100 mm x 150 mm, 1100 mm x 100 mm x 200 mm, and 1100 mm x 100 mm x 300 mm. The beam will be prepared with only flexural reinforcements with varying specifications. No shear reinforcement will be provided. These beams will be tested with a four-point bending test. Concrete cylinders with 100 mm x 200 mm sizes will also be prepared to evaluate concrete's compression and splitting tensile strength.

1.6 Organization of research

Chapter 1 presents the background of the research. It also highlights the significance and objective of the study.

Chapter 2 discusses a detailed literature review on concrete with natural and recycled plastic based on previous studies and publications.

Chapter 3 describes the properties of the material research methodology and test setup used in the experiment.

Chapter 4 discusses the experimental results of the test and analyzes the results.

Chapter 5 summarizes the research work, conclusion, and recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The demand for concrete is increasing day by day. And the dependence of engineers for this concrete is natural resources. However, it is recognized that construction industries adversely impact the environment. So, one prominent focus of the modern industry is using recycled aggregates (RA). Using recycled aggregate will reduce concrete waste and minimize the dependence of concrete materials on nature. Previous studies showed the behavior and benefits of using recycled aggregate in new reinforced concrete. Some researchers reported that concrete's structural strength using recycled coarse aggregates is lower than that using natural coarse aggregates. So, researchers focused on replacement ratios with natural aggregate (NA) to emphasize quality control, cost, ease of manufacture, and structural strength. Analyzing the recent test result, the researchers suggested that RA concrete can be used in practice and achieve structural performance.

2.2 Shear Behavior of Recycled Aggregate Concrete (RAC) Beam

Arezoumandi et al. (2015) performed a study on the effect of recycled concrete aggregate replacement level on the shear strength of reinforced concrete beams. That study tested the beams with three different longitudinal reinforcement ratios (1.3%, 2.0%, and 2.7%) and RA (coarse aggregates) replacement ratios of 0%, 50%, and 100%. The concrete strength value was 35 MPa. It was found that the RA with 100% RA beams has a lower shear capacity than the NA and 50% RA concrete beams. No significant difference was observed between the 50% RA and NA concrete beams' shear capacity.

Choi et al. (2010) performed an experimental study on the shear strength of recycled aggregate concrete beams. In the study, it was evaluated that the shear strength of 20 reinforced concrete beams with different span-depth ratios (1.5, 2.5, and 3.25), longitudinal reinforcement ratios (0.53%, 0.83%, and 1.61%), and RA (coarse aggregates) replacement ratios (0%, 30%, 50% and 100%). The study showed that the higher RA replacement ratio led to lower shear strength.

Al Mahmoud et al. (2020) shared a study about the shear behavior of reinforced concrete beams cast with recycled coarse aggregate. He studied the effect of different parameters on the structural behavior of simply supported RC beams made from RA (coarse aggregates), with different proportions of RA, compared with beams made from NA concrete. The result was that the shear capacity increases as the RA ratio increases up to 50%. Again, the 75% RA replacement ratio displayed the smallest ultimate load. It indicates that a greater than 50% replacement ratio reduces the beam’s shear capacity.

Fonteboa and Abella (2007) performed a study about the shear strength of recycled concrete beams. They produced controlled and 50% RA by volume concrete beams. The NA and RA concrete had similar compressive strength values (40 MPa). Each variety of concrete was utilized to create longitudinally reinforced concrete beams with four different shear reinforcement ratios. The beams failed in shear. Results of their study showed that in terms of deflection and ultimate shear strength, RA and NA concrete beams showed no discernible differences.

Schubert et al. (2012) shared a study regarding the experimental shear resistance of slabs without shear reinforcement. The study shows the behavior of fourteen slabs with 100% RA and reported that the same design equations used for NA concrete could also be used to construct RA concrete slabs.

Faithifzl et al. (2011) shared a study about the shear capacity evaluation of steel-reinforced recycled concrete (RRC) beams. He proposed an Equivalent Mortar Volume (EMV) method that provides a special mix design to construct RA (coarse aggregates) beams. The results showed that the shear capacity of RA concrete beams is equivalent to NA concrete beams.

Ajdukiewicz & Kliszczewicz (2007) studied comparative tests of beams and columns made of recycled and natural aggregate concrete while using NA and RA concrete batches with concrete strength values of 36 MPa and 32 MPa, respectively. Three sets of beams with various longitudinal reinforcement ratios for each type of concrete were made to fail in shear in a four-point bending arrangement due to diagonal cracking. Testing the beams revealed that the RA concrete beams had a lower shear capacity than the control beams.

2.3 Shear Behavior of Natural Aggregate Concrete Beam (NAC).

Al-Ahmed & Al-Gasham (2011) proposed an equation for finding the shear strength of reinforced concrete beams without stirrups. It has been documented that those 334 examples of beams without web reinforcement failed under shear stress, and all of these data sets have been obtained from previous research. They had a compressive strength in the range of (12.2 MPa $\leq f_c' \geq$ 69 MPa), the shear span to depth ratio, *a/d*, ranged from (2 to 8.67), and tensile reinforcement ratio (ρ_w) ranged from 0.35 to 6.64%.

Sudheer et al. (2010) shared a study regarding the shear resistance of high-strength concrete beams (70 MPa) with different shear span-to-depth ratios without web reinforcement and compared the test results with the available shear models. Five shear models were compared. Those models are ACI 318 (2014), Canadian Standard, CEB-FIP Model (2010), Zsutty Equation, and Bazant Equation. Zhang et al. (2016) studied the effects of stirrup corrosion on the shear behavior of reinforced concrete beams. The damage to concrete cross-section, loss of cross-sectional area, and decrease of yielding strength of corroded stirrups are considered in the study. A minor effect on cracking load is seen due to stirrup corrosion. When beams are cracked by shear loading, the stirrup stress in high-corrosiongrade beams increases rapidly with increasing loading, and a significant decrease in ultimate shear strength and ductility is observed. As the concrete's strength decreases, the stirrups' contribution to the beam's total shear strength increases. Stirrup corrosion, therefore, has a more definite effect on beam shear behavior. The portion of the overall shear strength of a beam provided by stirrups increases with the increase of stirrup ratio and shear-span ratio, and stirrup corrosion significantly affects the shear behavior of RCC beams.

Another study looked at how RC beam behavior affects the fire exposure period and concrete cover thickness when exposed to fire in a shear zone and cooled by water {Gao, 2017 #16}. Eight reinforced concrete beams (800 x 200 x 120 mm) were investigated. The day after being exposed to fire, the non-destructive compressive strength of the beams' concrete was tested. The beams were divided into two groups. Each group was subjected to a fire of 650°C for different periods, i.e., 0, 30, and 60 minutes, assessed using a hammer. Two transverse loads were incrementally applied to the beams during testing. Strains and deformations were measured at each load increment. Crack loads, crack propagation, and ultimate loads were recorded for each beam. The fire exposure duration and cover thickness changes significantly impact the behavior of beams exposed to fire in the shear zone.

2.4 Polypropylene Aggregate concrete

This study used polypropylene (PP) to replace coarse aggregate partially. Waste plastics were collected, sorted into various types, and then prewashed. Prewashed plastic was then moved to a shredder, transforming into smaller particles. Small plastic particles were melted into an oven and poured into a mold to cool down. Finally, cooled samples were crushed with a crushing machine. PP aggregates have different surface characteristics. Polyethylene terephthalate aggregate (PTA) has a smoother surface, whereas polypropylene aggregate (PPA) has a relatively rougher surface (Haque et al., 2019, Haque et al., 2018, Islam, 2022, Islam and Shahjalal, 2021, Islam et al., 2022). Physical tests, such as specific gravity, water absorption capacity, and unit weight, have been conducted according to ASTM C 128 and ASTM C 29 for PPA and PTA. The test results show that PPA has a relatively lower specific gravity of 0.85 compared to PTA (1.18). Furthermore, PPA has a higher number of voids in them; thus, it has the lowest unit weight of 510 kg/$m^{3,}$ {Islam, 2022 #59}.

The use of various forms of plastic as fine and coarse aggregate in concrete has been extensively studied over the last few decades. It is used in concrete due to its durability, strength-to-weight ratio, corrosion resistance, and low unit weight. Several kinds of research showed that plastic aggregate concrete exhibits lower mechanical properties because of weaker plastic-to-cement mortar bonds. However, a lower water-to-cement (w/c) ratio, such as a w/c ratio of 0.50 or lower, may help overcome this reduction (Haque et al., 2018). Shiuly et al. (2022) replaced NAC with polyethylene (PE) and polyethylene terephthalate (PET) based aggregate and concluded that 30% aggregate replacement did not affect the concrete strength. Islam and Shahjalal (2021) disclosed that 10% polypropylene aggregate (PPA) replaced concrete demonstrated higher compressive strength, splitting tensile strength, and rupture modulus than the reference concrete. Ozbakkaloglu et al. (2017) observed that concrete with 10% PPA underwent a minor loss in compressive strength and elastic modulus, whereas 0-20% incorporation of PPA showed the least amount of loss in the flexural and splitting tensile strength. They compared PPA mixed concrete to control concrete at elevated temperatures up to 200°C, where concrete with PPA exhibited very significant compressive strength losses. This difference got more prominent as PPA% was increased. Islam et al. (2022) witnessed a similar outcome when PPA was incorporated by 10% and 20% by volume. They noted that at 100°C and 200°C, respectively, compressive strength dropped by up to 10.8% and 34%. Haque et al. (2019) found that 20% PPA replaced concrete after being exposed to 200°C reduced compressive strength by 21% but still possessed more than 25 MPa strength. Pawar et al. (2022) investigated various properties of concrete by using different percentages of recycled plastic aggregate at 600°C to 800°C ambient temperature. They reported that the optimum level of compressive strength, split tensile strength, and flexural strength was achieved when plastic aggregate was substituted for 30% of the aggregate.

2.5 Conclusion

The target of the literature review is to figure out the applicability of polypropylene and recycled aggregate as primary materials for improving the performance of concrete, keeping the shear capacity in mind. But notably, applying polypropylene along with recycled aggregate for the shear behavior of a concrete structure requires more study and experimental results to write down a competitive remark. Major findings from this review can be briefly described as follows:

i. Regardless of the shear span-to-depth ratio, recycled aggregates weaken the shear strength of beams compared to beams made of natural aggregates.

ii. In terms of both deflection and ultimate shear strength, RA and NA concrete beams showed no discernible differences.

iii. With an increase in stirrup ratio and shear-span ratio, a greater proportion of a beam's overall shear strength is provided by stirrups, and stirrup corrosion has a substantial impact on the shear behavior of RC beams.

iv. The fire exposure duration and cover thickness change significantly impact the behavior of beams exposed to fire in the shear zone.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Introduction

Concrete is a versatile building material widely used in construction due to its strength and durability. When used in the construction of beams, concrete provides a strong and stable foundation that can support heavy loads. The curing process of concrete is essential in ensuring its strength, as it allows the material to reach its full potential over time. This chapter will describe the preparation for investigating polypropylene aggregate (PPA) and recycled aggregate (RA) properties.

It is necessary to adopt quality ingredients to achieve good quality concrete. Therefore, materials for concrete, such as cement, crushed stone, recycled aggregates, sand, and PP, were collected from the best possible local sources. Furthermore, all the materials were tested according to the respective ASTM standards. Based on the properties of the material, concrete mix proportions were prepared, and concrete samples were prepared for testing. This chapter elaborates on study planning, materials properties, mix designs, sample preparation, and casting procedures.

3.2 Materials

In this study, cement (as binding material), river sand (as fine aggregate), and coarse aggregates, such as crushed stone, recycled aggregate, and waste plastic aggregate from PP, were used as the ingredients for concrete. Several tests were conducted for these materials to identify their properties and perform efficient mix proportions for concrete.

3.2.1 Cement

Portland composite cement, also known as CEM type-II/A-M (S-V-L) 32.5 N following BS EN 197-1: 2000, was the cement used in this research. Because it is widely used for numerous building projects in Bangladesh and is easily available on the market, it complies with standard BS EN 197-1: 2000. The cement required 124 minutes for the initial setting time and 210 minutes for the final setting time. The specific gravity and fineness of cement (using the Blaine apparatus) were 2.9 and 308 m^2/kg, respectively. The mortar underwent a compressive strength test following ASTM C109-13, and the findings at 3, 7, and 28 days were 22.3 MPa, 29.8 MPa, and 39.2 MPa, respectively.

3.2.2 Course Aggregate

This study used three kinds of coarse aggregates: recycled aggregate (RA), waste polypropylene (PP) aggregate, and natural aggregate (NA). Since the aggregates were used as a replacement, all the aggregates have similar gradation, fineness modulus value, and maximum aggregate size.

3.2.2.1 Natural Aggregate (NA)

A stone quarry in Pakur, India, with an angular form and 100% three or more fractured faces provided the crushed stone aggregate, as shown in Fig. 3.1. For concrete to be strong, there must be an interaction between the aggregates and cement mortar matrix. The aggregate's angular shape and rough surface have a high chance of strengthening the bond through mechanical interlocking. Due to the crushing of the aggregate during the preparation stage, the aggregate had a rough surface and an angular shape. As observed from Table 3.1, the NA has a specific gravity of 2.87 and a unit weight of 1620 kg/m^3. The Los Angeles abrasion value of NA is 17.3, which indicates a good-quality aggregate. The NA has a maximum aggregate size of 19 mm and fineness modulus of 7.03. Similar values were used for other coarse aggregates too.

Table 3.1: Physical properties of FA, NAC, RAC, and PPA

Description	Unit	FA	NAC	RAC	PPA
Maximum aggregate size	mm	2.37	19	19	19
Fineness Modulus	-	2.48	7.03	7.03	7.03
Specific gravity (SSD)	-	2.60	2.87	2.61	0.85
Absorption capacity	%	1.30	1.05	4.58	0.80
Unit weight	kg/m^3	1600	1620	1430	-
Void content	%	35.1	41.1	42.6	-
Abrasion value	%	-	17.3	31.6	-

Fig 3.1: Natural Aggregate (NA).

3.2.2.2 Recycled Aggregate

For this study, recycled aggregate (RA) was collected from a twenty-year-old two-storied reinforced concrete building’s slab. The building was demolished to free space for a new structure. The processing of recycling concrete is a relatively simple process. It involves breaking, removing, and crushing existing concrete into a specified size and quality material. Samples of the RA are shown in Fig. 3.2. ACI 555 (2001) provides detailed information on processing old concrete into recycled aggregates. The quality of concrete with RA depends on the quality of the recycled material used. Reinforcing steel and other embedded items, if any, must be removed, and care must be taken to prevent contamination by other materials that can be troublesome.

RA is lighter and has 4.36 times higher water absorption capacity than NA. Furthermore, RA has a more rounded, spherical shape which seems to improve workability. The residual mortar on RA can smooth out the hard edges of the original aggregate. This allows the new mortar to flow better around the aggregate. The compressive strength of RA also improved with age. Since the aggregate can store more water, this water can be released into the new mortar over time to continue to feed the cement for a longer time, which improves strength.

Fig 3.2: Recycled Aggregate (RA).

3.2.2.3 Polypropylene Aggregate

Polypropylene (PP) is a synthetic resin built up by the polymerization of propylene. Plastic recycling has a long and exciting history. It has expanded rapidly over the past few decades. Consumers now can find a wide range of products made with recycled plastics, from furniture to clothing to kitchen gadgets, which gives new life to these valuable materials by closing the recycling loop.

In this study, the used polypropylene (PP) aggregate was used. The following processes were taken to prepare the waste PP aggregate: collection, sorting, washing, shredding, melting, cooling, and lastly, crushing into the required size. The light, angular, porous PP material had a rough surface, as shown in Fig. 3.3. It has a specific gravity of 0.85 and an absorption capacity of 0.8%.

Fig 3.3: Polypropylene (PP).

3.2.3 Sand

The natural siliceous sand was used in the concrete mix as a fine aggregate, as observed in Fig. 3.4. The sand was first sieved using a 4.75 mm sieve and then washed in a tub to remove unwanted elements. According to ASTM C128 (2015), ASTM C29 (2017), and ASTM C136 (2019), the sand was examined for various physical characteristics, including specific gravity, water absorption capacity, unit weight, and fineness modulus. The material is especially coarser, according to the sand's grading size distribution and fineness modulus analysis. The properties of fine aggregate (FA) are tabulated in Table 3.1. This study used FA with a specific gravity of 2.60 and a 1600 kg/m3 unit weight. The absorption capacity of FA is 1.30%, which is greater than the absorption capacity of NA and PPA.

Fig 3.4: Sand.

3.2.4 Reinforcement

2-10mmϕ, 2-12mmϕ bars for beams of 150 mm and 200 mm depth and 2-10mmϕ, 3-12mmϕ bars for beams of 300mm depth were used in this study. All bars were of 60 grades. ASTM A370 standard was followed during the test procedure for determining the tensile strength of reinforcement bars. A 300 mm length of rebar was used as a test sample. The specimen in the testing machine was aligned so that the axis of the specimen was parallel to the direction of the applied load. Test results from the test are presented in Table 3.2. The stress-strain curve for the test samples is shown in Fig. 3.5. The reinforcements have an average yield strength of 454 MPa and an average ultimate strength of 617 MPa.

Table 3.2: Reinforcement Properties

Sample	**Yield Stress f_y (MPa)**	**Average Yield Stress f_y (MPa)**	**Ultimate Stress f_u (MPa)**	**Average Ultimate Stress f_u (MPa)**
1	453.57	454	668.95	617
2	486.07		640.81	
3	421.70		540.48	

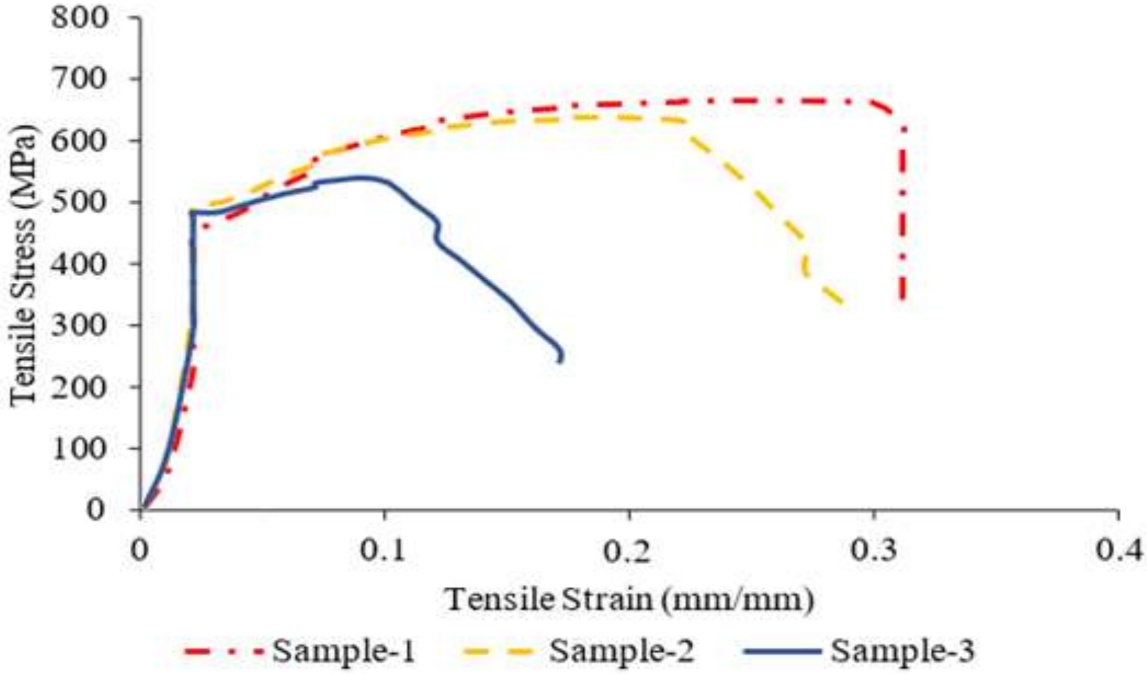


Fig 3.5: Stress-strain curve comparison between reinforcement samples.

3.3 Concrete Mix Design

The process of determining the proportions of the constituents in a concrete mixture is a concrete mix design. Eight alternative mix designs for cylinders and beams were prepared for this study. The water-cement (w/c) ratio has been considered fixed (0.45) throughout the mix design so that the samples can only be affected by variations in the RA and PPA. PPA has been replaced by 0%, 5%, 10%, and 15% on a volume basis. All the aggregates have been used in the SSD condition while preparing the concrete mix. The concrete's intended strength, durability, and workability were considered while developing a substantial variety. Slump flow is used to assess workability. In the concrete mix design, finesse modulus, unit weight, and water absorption capacity of coarse and fine aggregates all play a role. In the present study, eight combinations of concrete were prepared: four for natural aggregate concrete with PPA and four for recycled aggregate concrete with PPA. PPA was replaced in four percentages (0%, 5%, 10%, and 15%). Table 3.3 shows the mix proportions for all different concrete combinations. A sample collection of the mix design is shown in Annex A.

Table 3.3: Mix design for 1 cum of concrete

Designation	**Cement (kg)**	**Water (kg)**	**Sand (kg)**	**NAC (kg)**	**RAC (kg)**	**PP (kg)**
NP0	456	205	639.72	1056.24	-	0
NP5	456	205	640.55	1003.43	-	20.25
NP10	456	205	641.37	950.62	-	40.49
NP15	456	205	642.19	897.8	-	60.73
RP0	456	205	639.72	-	932.36	0
RP5	456	205	640.55	-	847.7	20.25
RP10	456	205	641.37	-	803.09	40.49
RP15	456	205	642.19	-	758.47	60.73

Note – N = natural aggregate, R = recycle aggregate, P = polypropylene aggregate

3.4 Sample Preparation

The most crucial part of research is sample preparation. The sample material processing directly impacts the accuracy of the outcome. The components for the sample preparation were meticulously measured. Recycled aggregates, sand, cement, and PP were calculated independently for each mix design. The digital weight measuring meter was used to determine the weight of the stone, sand, cement, and PP, as indicated in Figure 3.6.

3.5 Methodology

A total of 96 concrete cylinder samples of 100 mm x 200 mm and beams of different dimensions 1100mm x 100mm x 150mm, 1100mm x 100mm x 200mm, and 1100mm x 100mm x 300mm were prepared as per the requirement of the test methods following ASTM C 192. After 24 hours of humidity curing, the samples were water-cured for 28 days. To achieve the fresh, hardened, and durability properties of concrete, the following tests will be conducted:

i. Workability immediately after mixing concrete ingredients.

ii. The dry density of concrete.

iii. For cylinders, compressive strength test following ASTM C39 at 28 and 56 days and tensile strength test following ASTM C496 at 28 and 56 days.

iv. Shear behavior test of different beams.

All the obtained results are analyzed and represented in graphical forms for comparison.

3.6 Testing and Data Acquisition

3.6.1 Casting and Sampling

The components for concrete mixers were combined for different concrete combinations using a concrete mixing machine, as shown in Fig. 3.6 (a). Fig. 3.6 (a) shows that freshly mixed concrete is poured on a dry surface. The freshly mixed concrete was tested for slump value and recorded, as shown in Fig. 3.6 (b & c). The concrete was then poured into a 100 mm x 200 mm cylinder and beams 1100mm x 100mm, where the depth was 300 mm, 200 mm, and 150 mm. For an excellent compaction, an internal vibrator was used.

Fig 3.6 (a) Mixing

Fig 3.6 (b) Slump test

(c) Slump value taking

(d) Unit weight test

(e) Casting of beams (f) Cylinder and beam casting

Fig 3.6: Casting Procedure.

3.6.2 Compressive Strength Test of Concrete

The compressive strength of hardened concrete is an essential property. It is determinedby a compression test of a 100 mm x 200 mm concrete cylinder. The samples were prepared and then stored in moist air for 24 hours before being removed from the molds and maintained in submerged condition for 28 days. After hardening, the specimen was tested at 28 days and 56 days. The compression testing machine was used to test cylinder specimens up to failure, as shown in Figure 3.7.

Fig 3.7: Compressive Strength Test.

Fig 3.8: Split Tensile Strength Test.

3.6.3 Tensile Strength Test of Concrete

Tensile strength is essential for concrete structures because they are highly vulnerable to tensile forces, which cause concrete to crack. On the other hand, the tensile strength of concrete is much lower than the compressive strength. Because determining tensile strengthdirectly is difficult, using two approaches, tensile strength is determined indirectly. It is a standard test for concrete tensile strength that is performed indirectly. The test procedure isASTM C496 compliant. A standard sample(100mm x 200mm) was employed horizontallybetween the loading phases of the compressivetesting equipment. The basic laboratory setup for the split tensile test of concrete is shown in Figure 3.8.

3.6.4 Shear Test of RC Beam

The shear tests of the beams are the primary objective of this study. The length of the beam was 1100 mm. The beam is simply supported, and the distance between the supports is 750 mm. A long section of the beam is shown in Figure 3.9. A four-point loading system was used in this study. The loading span was 250 mm. In total, three LVDTs were used in this study. One was placed in the middle, and two others at a distance of 225 mm from the beam edges, as shown in Figure 3.10

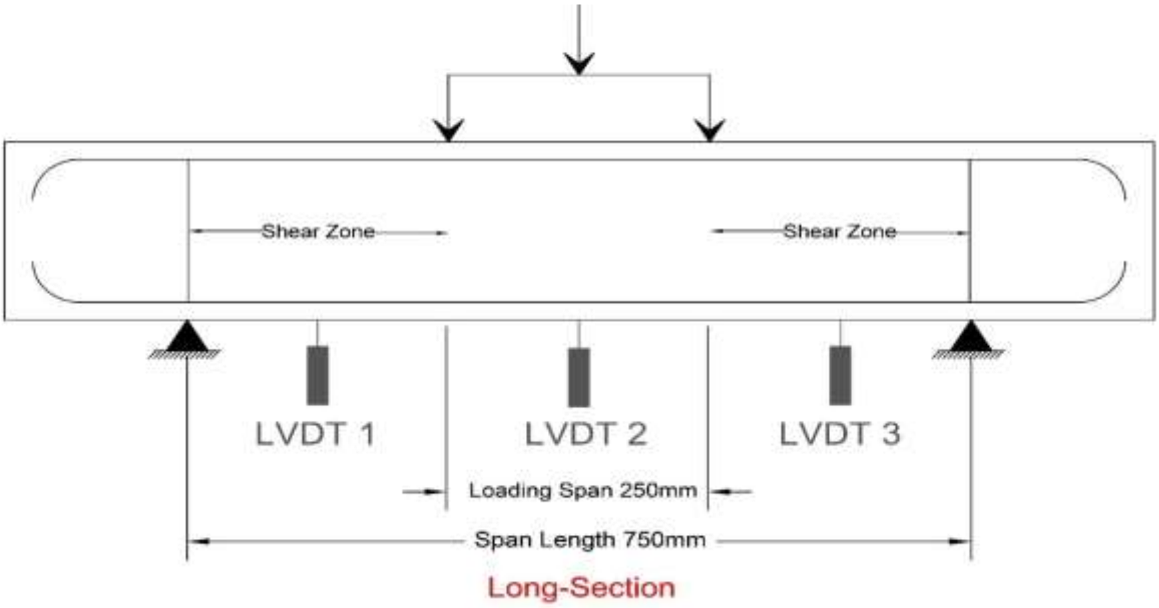


Fig 3.9: Reinforcement and strain gauge detailing of shear test RC beams.

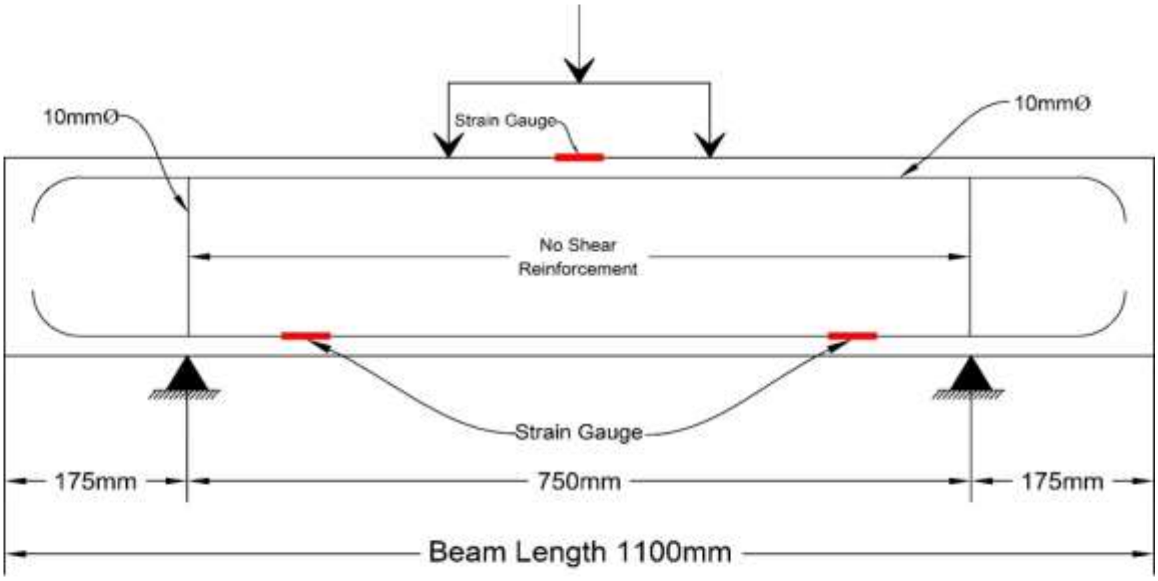


Fig 3.10: Shear test setup of RC beam setup.

The reinforcement details of the beam are shown in Figures 3.10 and 3.11. The beams were reinforced with 2-12mmφ (in 100 mm × 150 mm) and 3-12mmφ (in 100 mm × 300 mm beams) mild steel rebar as the main reinforcement at the bottom. Besides, 2- 10mmφ rebars were used at the top of the beams to hold the stirrups. Though no shear reinforcement has been provided, 2-10mmφ stirrups were provided at the supports with a spacing of 750 mm for better fabrication of reinforcement cages, as shown in Figure 3.10.

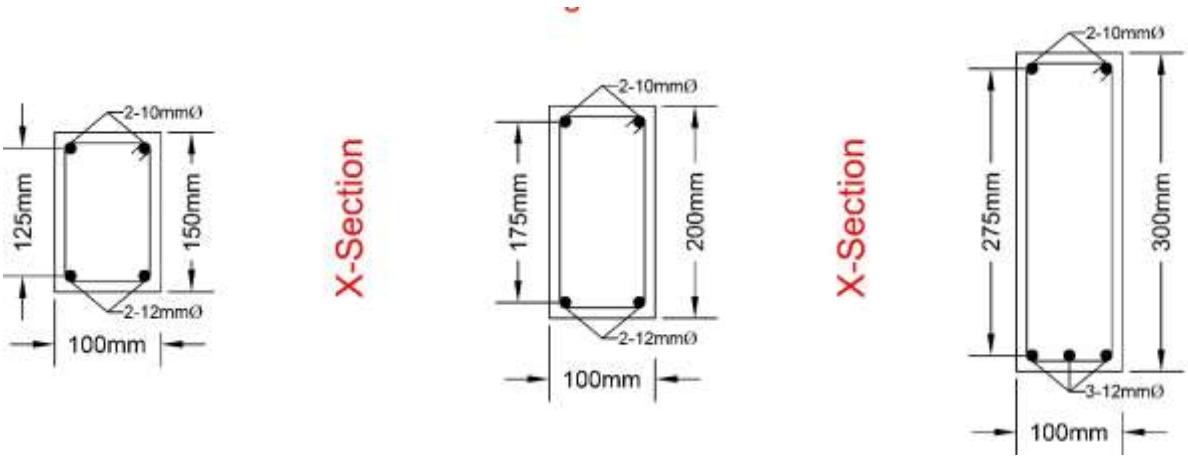


Fig 3.11: Cross-Section of RC beam.

To estimate the lengths of the cracks, the beams were bleached, and the surfaces were griddled with tiny square boxes. At 28 days after casting, all the beams were put through a four-point static bending test utilizing a Universal Testing Machine (UTM) with a 1000 KN capability. The beams test employed a displacement loading rate of 0.15 mm/min. The beam continued to be loaded after it failed. To track the deflections of the beams at various sections, three linear variable displacement transducers (LVDT) were installed with the UTM at the mid-points of two shear zones and one at the midspan. To measure the reinforcement's strains at the mid-point of the two shear zones, two electrical resistance steel strain gauges were placed into the bottom reinforcement of beams. A concrete strain gauge was also positioned in the middle of the beams' tops. Extra attention was taken when mounting the beams in the center of the UTM machine to achieve a concentric loading. The UTM machine recorded the applied load and the related movement of the beam. Additionally, steel and concrete strain gauges used automated data loggers to record the strain of reinforcement and concrete automatically. The first crack's initiation and the associated loading were meticulously documented. A high-resolution camera was used to record the failure pattern. The total arrangement of the instruments is presented in Figure 3.12.

Fig 3.12: RC beam test setup and data acquisition.

3.7 Conclusion

This study aims to investigate the shear behavior of reinforced concrete beams with natural, recycled, and PP aggregates. Hence, in this chapter, the properties of the materials, especially coarse aggregate properties, are meticulously described. Furthermore, concrete mix proportions, sample preparation, reinforcement details, test setup, and data acquisition process are discussed in detail.

CHAPTER -4

RESULT AND DISCUSSION

4.1 Introduction

The beams were whitewashed and the surfaces were grided with small square boxes (50 mm x 50 mm) to identify the crack locations under four-point loading. The beam specimens were examined with three different shear spans to depth ratios, two different aggregate types such as natural aggregate (NA) and recycled aggregate (RA), containing (0%, 5%, 10%, and 15%) of polypropylene (PP). To track concrete strain, one strain gauge was mounted in the middle of the beam. Two additional strain gauges were placed in the reinforcements of the beam's two shear zones to measure the steel's strain in response to the loading. At 56 days after casting, all the beams were put through a four-point static bending test utilizing a Universal Testing Machine (UTM) with a 1000 KN capacity. The beam test employed a 0.15 mm/min displacement loading rate. The outcomes are discussed in terms of the load-deflection response, the method of failure, the strain in the steel and concrete, the shear capacity, the peak load, and the impact of polypropylene on shear strength. A total 18 beams were used for result analysis.

4.2 Fresh Properties

4.2.1 Workability

Workability is a property of raw or fresh concrete mixture. In simple words, workability means ease of placement, and workable concrete means the concrete that can be placed and compacted easily without any segregation. The slump test is a standard procedure for determining the workability of fresh concrete. In this study, it was performed according to the ASTM C143 standard. A cone-shaped metal mold with a base diameter of 200 mm, a top diameter of 100 mm, and a height of 300 mm was used to conduct the test.

Figure 4.1 shows slump (mm) variation for different combinations of concrete. As shown in the figure, the slump value decreases with the increase in polypropylene content for natural aggregate concrete (NAC). When the 5% polypropylene was mixed with natural aggregate, the value of the slump test decreased by 12.5%. When the mix ratio of polypropylene was increased by 10% and 15%, the value of the slump test gradually decreased by 30% and 40.63%, respectively. This is due to the fact that PP aggregates have more voids and relatively rougher surfaces compared to the NAC. Hence, the slump values decrease with the increase in PP content.

On the other hand, with the increase of polypropylene with RA content, the slump value increased. For the 5%, 10%, and 15% mix ratio of polypropylene with RA, an increase in slump value was seen by 7.69%, 53.85%, and 115.38%, respectively, compared to the concrete made of only RA. Recycle aggregate (RA) has a higher water absorption capacity than the NA and PP aggregates. Because of that, recycled aggregate concrete (RAC) showed lower workability compared to the NAC. Furthermore, with the increase in PP content, RAC showed more workability.

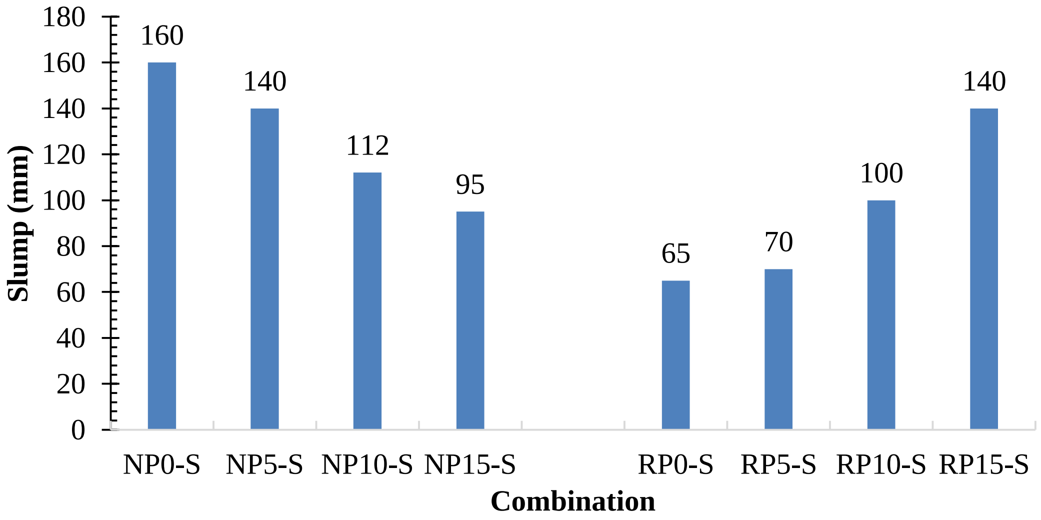


Fig 4.1: Change of slump value with combination.

4.2.2 Hardened Density

The Hardened density of concrete is critical as it influences hardened concrete's strength and durability. Lower density implies higher void content, which can weaken the final product. Higher density implies a lower amount of voids and can increase the strength and durability of the hardened concrete. Figure 4.2 shows the hardened density of various concrete combinations. From the figure, it can be said that the inclusion of polypropylene with natural aggregate decreases the concrete density. Adding polypropylene leads to a reduction in the density of the mixture, as polypropylene is often lighter than natural aggregates. When natural aggregate was replaced with polypropylene by 5%, 10%, and 15%, the density was noticed to be decreased by 1%, 2.3%, and 5.12%, respectively. Again, when polypropylene was mixed with RA, concrete density decreased slightly. RA is much lighter than NA. So, the density of concrete made with RA will be lesser than that of NA concrete. When the concrete made of RA was replaced with polypropylene by 5%, 10%, and 15%, the decrease in density was seen by 0.3%, 1.64%, and 3.27%, respectively.

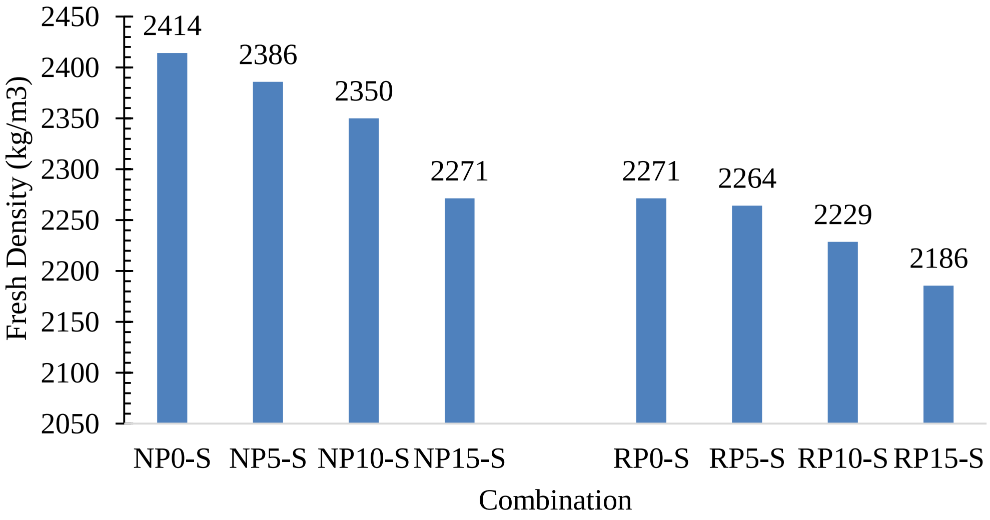


Fig 4.2: Change of fresh density with combination.

4.3 Mechanical Properties of Concrete

The compressive strength of concrete was determined following ASTM C39-18 using a compression machine of 2000 KN capacity. Before testing, both the top and bottom of the cylinder were grinded to make the surface smooth to minimize the eccentricity of loading. A customized fixture was prepared to hold the specimens in a UTM machine for the direct tensile strength test of concrete. For the tensile test, a displacement rate of 0.05mm/min was used.

4.3.1 Compressive Strength

Based on the data presented in Figure 4.3, it is apparent that the compressive strength for 28 days of the NA concrete decreased by 31%, with an increase of polypropylene content of 5%, and decreased by 27% and 26%, with an increase of polypropylene content 10% and 15%, respectively. Because of the artificial nature of PP aggregate, it showed a weak interfacial transition zone (ITZ), hence the reduction in compressive strength compared to NAC. Similar observation is also made in previous studies (Islam and Shahjalal, 2021, Islam et al., 2022). Polypropylene containing 0%, 5%, 10%, and 15% with RA, it is apparent that the compressive strength for 28 days of the RA concrete initially increases by 1.93% for concrete with polypropylene content of 5%. Because of the high absorption capacity of RA, ITZ is weaker than NA. At lower PP content, the effect of ITZ is not that significant. However, the compressive strength decreased by 11%, 10%, and 34.67%, with the polypropylene content of 5%, 10%, and 15%. A similar pattern is also observed at 56 days for NA and RA concrete.

4.3.2 Tensile Strength

According to Fig. 4.4, tensile strength for 28 days of the NA concrete decreased by 7.5% and 1%, with an increase of polypropylene content of 5% and 10%, respectively, and increased by 11% with a rise in polypropylene content 15%, respectively. The tensile strength for 28 days of the RA concrete decreased by 1.2 % and 11% for concrete with 5% and 15% polypropylene content, respectively. But the tensile strength increased by 20%, with a polypropylene content of 10%. However, at 56 days, tensile strength showed a different pattern. NA concrete without any PP showed the maximum tensile strength. Furthermore, RAC with increased PP content showed a declining trend.

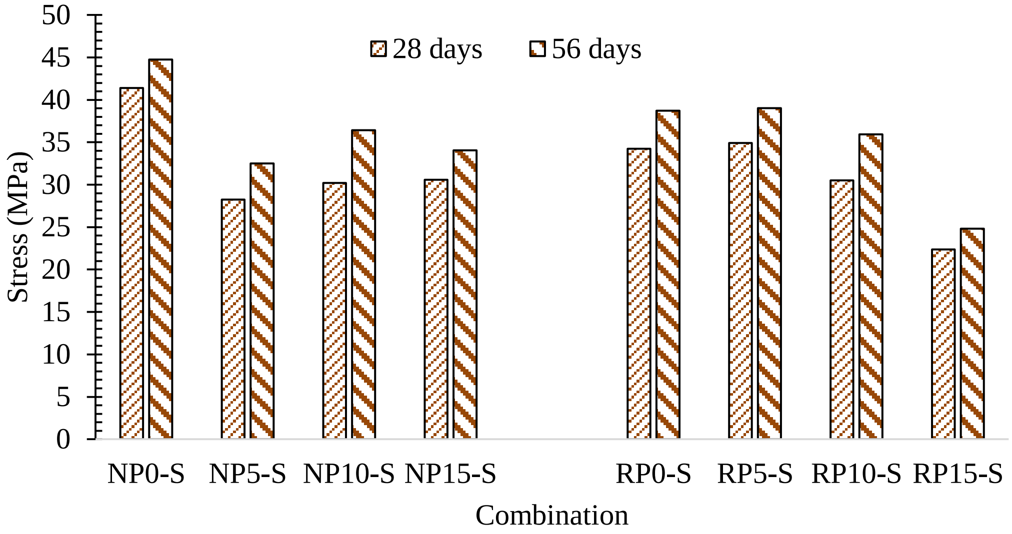


Fig 4.3: Variation of compressive strength with combinations.

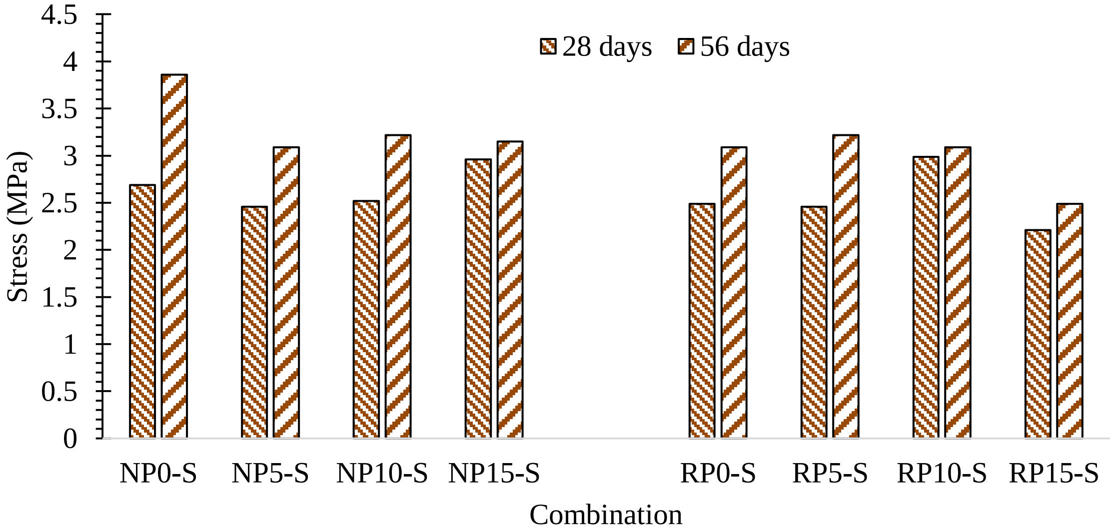


Fig 4.4: Variation of tensile strength with combinations.

While loading, fine vertical flexural cracks have formed within the non-shear zone and afterward, cracks developed in the shear zone with the increment of the load shown in

Figure 4.5. Inclined shear cracks were initially created near the supports. Then, it developed and propagated toward the loading point with the load increment. At the same time, a number of flexural and shear cracks have developed in the beam. Though a shear crack was visible on both sides of the beams near the supports, a crack on one side led to the failure of the beam. Figure 4.5 shows the crack developed in the beams while the beams were introduced to load. As observed from the figure, number of flexural cracks and shear crack angle increased with the rise in beam depths.


(a) NP0-S 150


NP0-S 200


NP0-S 300

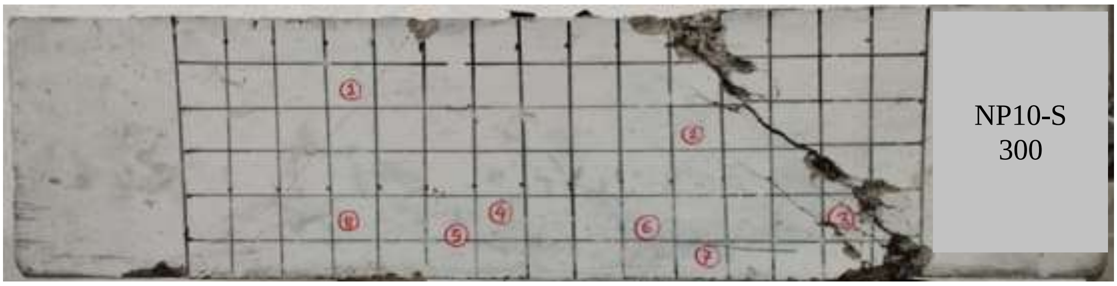

NP5-S 150

NP5-S 200


NP5-S 300


NP10-S
150


NP10-S
200

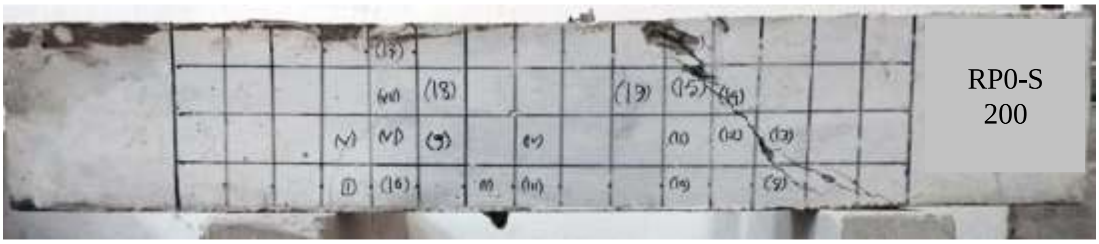

NP10-S
300

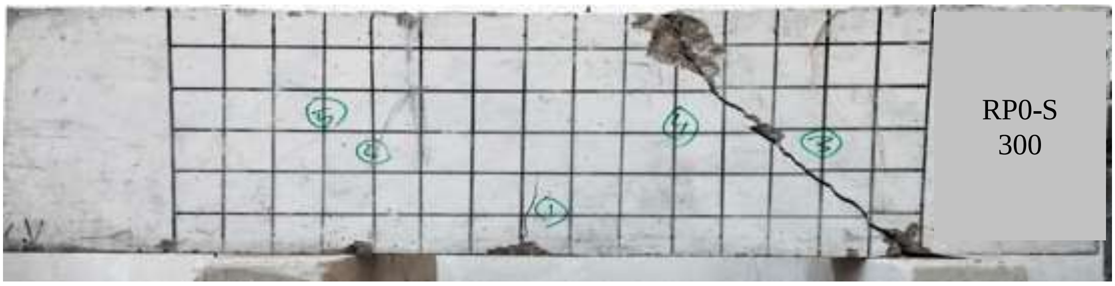

NP15-S
150

NP15-S
200


NP15-S
300


RP0-S
150

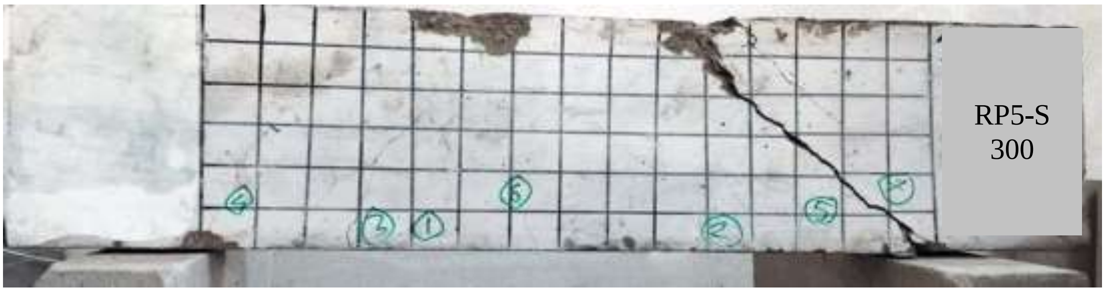

RP0-S
200


RP0-S
300


RP5-S
150

RP5-S
200


RP5-S-200


RP5-S
300


RP10-S
150


RP10-S
200


RP10-S
300


RP15-S
150

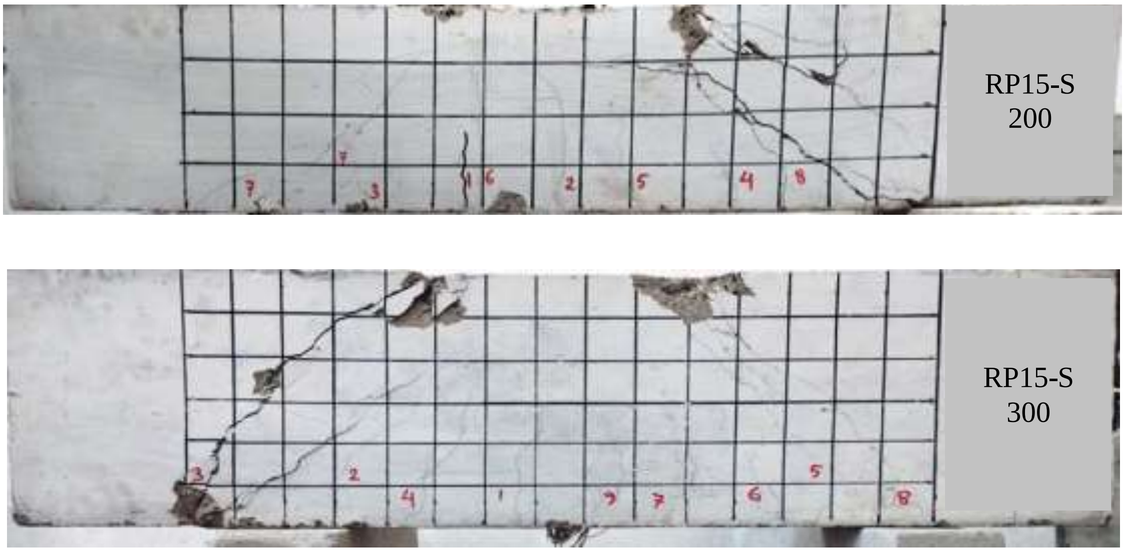


Fig 4.5: Failure pattern of different beams under shear load in 56 days.

4.4.2 Crack Widths and Angles

Table 4.1 shows all twenty-four beams' crack widths and diagonal crack angles. As observed from Table 4.1, the width of the crack for which the beam has failed ranges between 2 mm and 3 mm for the 150 mm deep beam. For the 200 mm deep beam, the width of the failure crack is between 2.5 mm and 3.5 mm. and For the 300 mm deep beam, the width of the failure crack is between 3 mm and 4 mm. Furthermore, from Figures 4.5, it can be seen that the crack width increases with the increase of polypropylene ratio with both NAC and RAC.

A minimal variation in the crack width is noticed over the shear-span-to-depth ratios. Table 4.1 compares crack angles with a variation of polypropylene percentage with RAC and NAC. As the data shows, the crack angle for the beams of 150 mm depth is less than 45°. In contrast, it is more than 48° for a 300 mm beam depth. Shear capacity increases when the crack angle varies from 45° as the crack path rises. Furthermore, it is found that the increase of RA in concrete increases crack angle for both 150 mm and 300 mm deep beams. Table

4.1 shows RA's effect in crack angle variation for 150 mm, 200 mm, and 300 mm depth, respectively. As shown in Table 4.1, for the 150 mm deep beams, the crack angle increases up to 29% for an increase of mixture ratio of polypropylene with NAC where a minimum crack angle of 24° with 0% polypropylene was seen. Up to 28% increment of crack angle value was seen to increase the ratio of PP with RA. Again, the effect of (0%, 5%, 10%, and 15%) PP mixture with NA and RA in crack angle variation for 200 mm depth, respectively. For the beam with 300 mm depth, a similar pattern is found. A minimum crack was found for the ratio of 0% PP with NA. Here, for up to a 15% increment of PP with RA, the shear crack angle increases up to 19%. So, with the increment of PP in concrete made of both NA and RA, the shear crack angle increases in all three beam variations. However, an exception was seen for the beam of depth 200mm, in which polypropylene shows a decrease in the crack.

4.4.3 Shear Load and Peak Load

Figures 4.6 and 4.7 describe the shear load at the first crack and peak load under the four-point bending load of the beams with three different depths. The shear load at the first crack was measured through visual inspection and load-deflection plots. As observed in Figure 4.6, the shear capacity of the beams with 5% PP increased compared to the NAC, and it was up to 9.8%. However, with further increment of PP content, shear load decreased by up to 32.4%. These results are consistent with compressive strength data from this study and from the literature (Islam and Shahjalal, 2021, Islam et al., 2022). RAC also observed a similar pattern with PP. When compared with the NAC, RAC showed a lower shear capacity. It was more prominent with 200 mm depth beams where up to 26.5% drop in shear capacity was observed.

The inclusion of PP in concrete increased peak load for the beams. As seen from Figure 4.7, peak load increases with PP content in NAC for the 150 mm depth beam, and it was maximum at 15% PP concrete. However, for the 300 mm depth beam, the peak load was maximum for 5% PP conc, declining for 10% and 15% PPA concrete. For RAC with PP, peak load behavior is a little inconsistent. Although RAC with 5% PPA showed a rise in peak load compared to the control specimen, it did not consistently rise or fall for 10% and 15% PPA content. This inconsistency is due to the random nature of the adhered mortar in the RA. Compared to the NAC, RAC showed a decreased peak load capacity. It was consistently high for the 150 mm depth beam, and up to 28.3% drop in peak load was observed.

Table 4.1: Result of shear test of RC beams

Comb-beam size (mm)	**$V_{F\text{-}Crack}$ (KN)**	**V_{peak} (KN)**	**$\Delta_{F\text{-}Crack}$ (mm)**	**Δ_{Peak} (mm)**	**$\frac{V_{peak}}{V_{F\text{-}Crack}}$**	**Crack width (mm)**	**Diagonal Crack angle (^{o})**	**Ductility Δ_{Peak}**	**Toughness (KN-mm)**
NP0 150	18.08	98.34	0.48	4.51	5.44	2.0	24	9.40	253.87
NP0 200	29.18	133.94	0.42	4.90	4.59	2.5	38	11.67	475.18
NP0 300	32.07	265.28	0.70	5.12	8.27	3.0	43	7.31	894.41
NP5 150	19.54	116.85	0.48	6.54	5.98	3.0	25	13.63	646.88
NP5 200	31.46	166.52	0.37	6.65	5.29	3.5	36	16.35	1340.92
NP5 300	35.22	271.69	0.55	4.67	7.72	4.0	42	8.49	1618.15
NP10 150	17.60	109.06	0.77	7.20	6.20	3.0	30	9.35	559.23
NP10 200	19.73	114.96	0.27	3.69	5.83	3.3	37	13.67	193.68
NP10 300	32.16	237.94	1.78	5.14	7.40	4.0	40	2.89	321.25
NP15 150	13.42	119.42	2.45	6.59	8.90	2.0	31	2.69	260.58
NP15 200	24.81	136.19	1.57	5.91	5.49	2.5	28	3.76	249.87
NP15 300	29.26	231.10	3.03	6.08	7.90	2.8	46	2.01	461.66
RP0 150	16.39	85.25	0.60	4.46	5.20	2.8	21	7.43	334.67
RP0 200	25.51	135.65	0.35	4.54	5.32	3.0	25	12.97	447.57
RP0 300	30.94	241.18	0.30	4.42	7.79	3.5	41	14.98	674.22
RP5 150	18.00	95.50	0.67	4.79	5.14	2.5	23	7.15	288.81
RP5 200	23.12	165.97	0.30	6.68	7.18	3.5	28	22.27	748.87
RP5 300	31.29	256.40	0.73	5.90	8.19	4.0	40	8.08	971.53
RP10 150	19.07	78.26	0.86	5.48	4.10	2.5	24	6.37	263.11
RP10 200	18.46	114.02	0.09	3.78	6.18	2.8	25	42.00	294.46
RP10 300	29.94	254.25	0.57	6.80	9.10	3.2	39	11.93	1132.09

Comb-beam size (mm)	**$V_{F\text{-}Crack}$ (KN)**	**V_{peak} (KN)**	**$\Delta_{F\text{-}Crack}$ (mm)**	**Δ_{Peak} (mm)**	**$\frac{V_{peak}}{V_{F\text{-}Crack}}$**	**Crack width (mm)**	**Diagonal Crack angle (°)**	**Ductility Δ_{Peak}**	**Toughness (KN-mm)**
RP15 150	13.23	87.14	0.47	6.22	6.59	2.5	27	13.23	406.95
RP15 200	19.48	135.27	0.68	8.09	6.94	2.8	42	11.90	831.80
RP15 300	26.18	231.00	0.14	6.08	8.83	3.0	49	43.43	1072.01

Note: V_{peak} = Peak Shear Load, $V_{F-Crack}$ = Shear Load at First Crack, $\Delta_{F-Crack}$ = Deflection corresponding to First Crack, Δ_{Peak} = Deflection corresponding to Peak Shear Force.

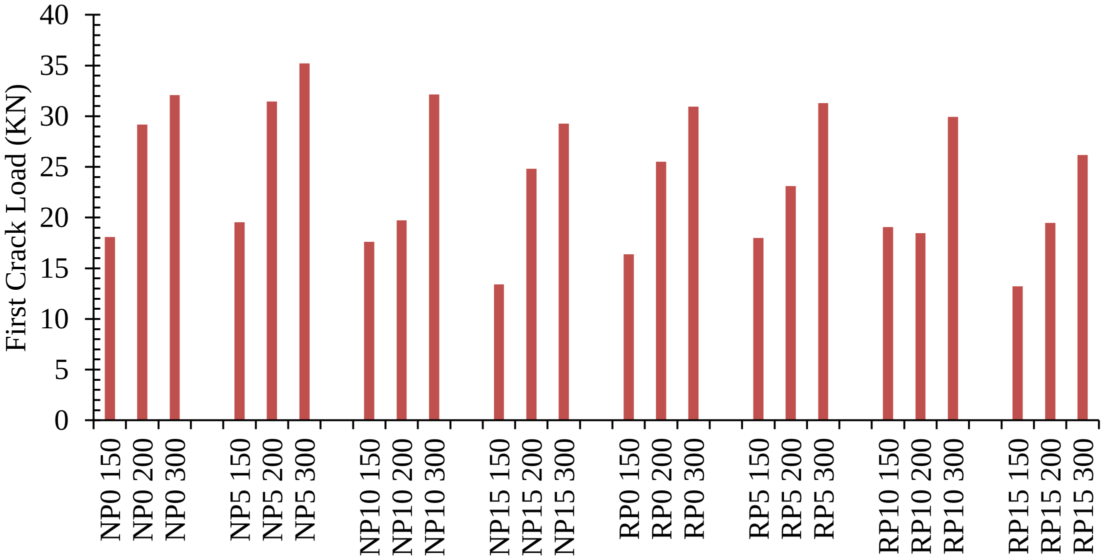


Fig 4.6: Shear force at first crack according to beam size.

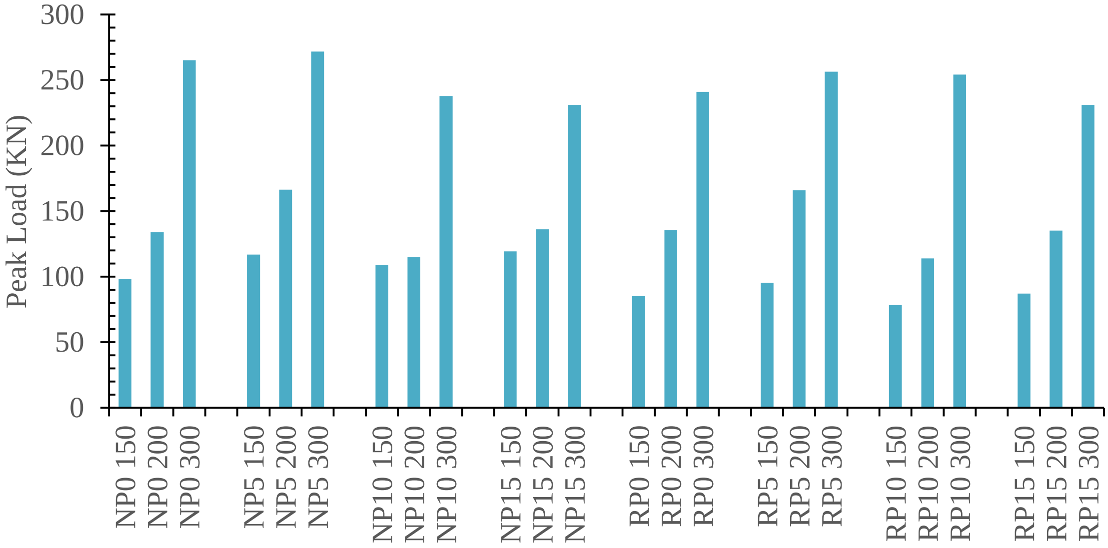


Fig 4.7: Variations of peak load according to beam size.

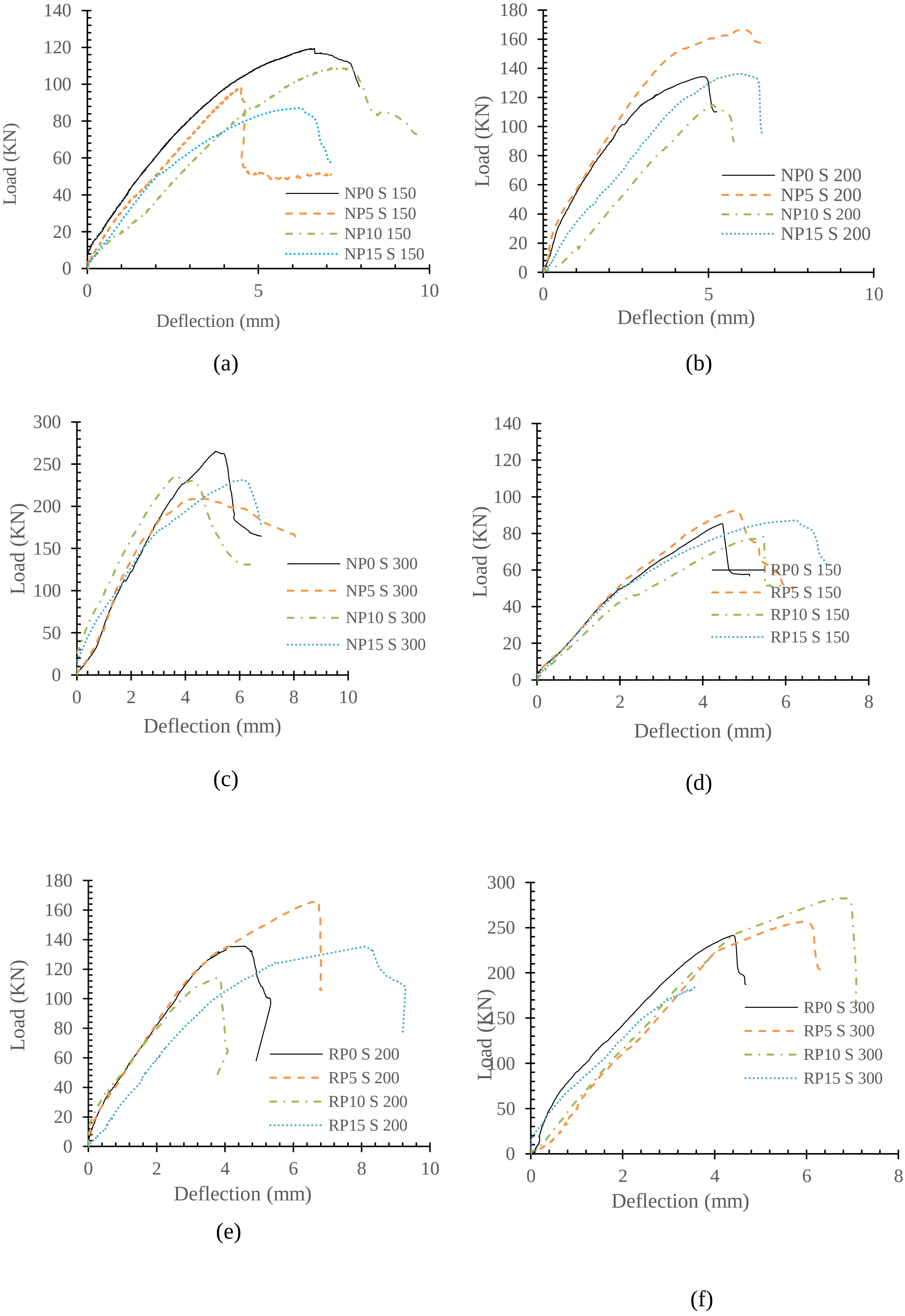
4.4.4 Load-Deflection Relationship

Deflection at the middle of the beam was recorded during the test and used to find the relationship between load and deflection in the beam. Figures 4.8(a), 4.8(b), and 4.8(c) show the load-deflection plots while considering the effect of PP and NA percentages. Figures 4.8(d), 4.8(e), and 4.8(f) show the load-deflection plots while considering the effect of PP and RA percentages. The load-deflection curve can be divided into three segments. The first segment is up to the peak load, then the rapid drop part, and finally, the part up to the failure of the beam.

As shown in Figures 4.8(a) and 4.8(d), among the beams of 150 mm when 0%, 5%, 10%, and 15% PP was mixed with NA and RA, respectively, the maximum peak load was seen for the combination of 0% PP with NA and 5% PP with RA. But the scenario was different for deflection. Deflection is the degree to which a part of a structural element is displaced under a load (because it deforms). Analyzing Figures 4.8(a) and 4.8(d), it was determined that the combination of 10% PP with NA and 15% PP with RA has maximum deflection. The increment of PP by 10% with NA improves deflection by 20%, and 15% PP with RA improves deflection by 35% compared to the control samples.

Again, from Figures 4.8(b) and 4.8(e), for the beams of 200 mm depth and a mixture of PP (0%, 5%, 10%, and 15%) with NA and RA, respectively, 5% PP with NA and 10% PP with RA has maximum deflection. The increment of PP by 5% with NA improves deflection by 19%, and 15% PP with RA improves deflection by 87%.

As shown in Figures 4.8(c) and 4.8(f), for the beams of 300 mm depth and a mixture of PP (0%, 5%, 10%, and 15%) with NA and RA, respectively, the maximum peak load is seen for 0% PP with NA and 5% PP with RA. But the scenario is different for deflection. Like the beam of depth 200 mm, the combination of 5% PP with NA and 15% PP with RA has maximum deflection.



(a)

(b)

(c)

(d)

(e)

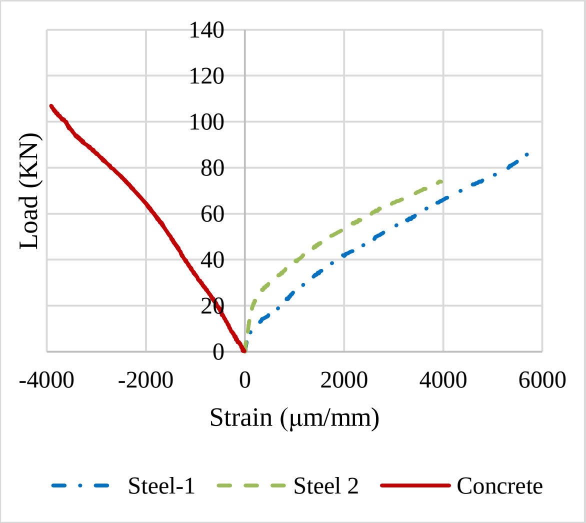
(f)

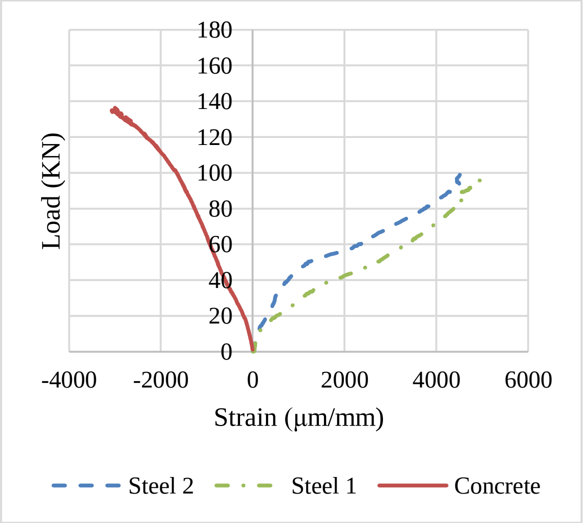
Fig 4.8: Load-deflection curve.

4.4.5 Load-Strain Behavior

Figure 4.9 below show the relationship between load and concrete's and steel's strains for NAC and RAC the replacement of NA and RA with PP (in ratios of 0%, 5%, and 10%, respectively). The value of the stain increases with the increase of beam depth. It's a common phenomenon for the beams made of RA as well. The peak load increases with the increase of beam depth. But the peak load is lower compared to the peak load of beams made of NA. But a slight variation was found for the value of stain in the beams made of RA. The value of strain was found to be highest in beam of 200 mm depth, and the value was found to be minimum for 150 mm depth.

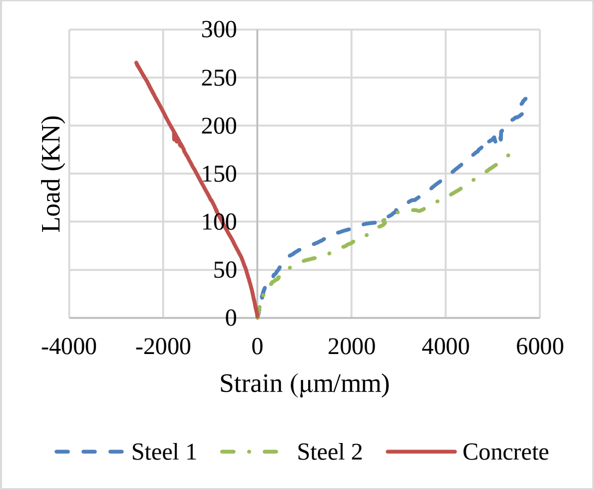
When the NA was replaced with PP, some variations were seen. When the PP replacement was 5%, a decrease in the peak load and an increase in the value of strain was found compared to beam made of only NA. But when the PP replacement was 10%, the maximum peak load was found, which was 108 KN and the minimum strain was found of 7893 µm/mm. When RA was replaced with PP, the maximum load was seen for a beam with 5% PP. But it was found that the strain value decreased with the increase of PP replacement with RA.

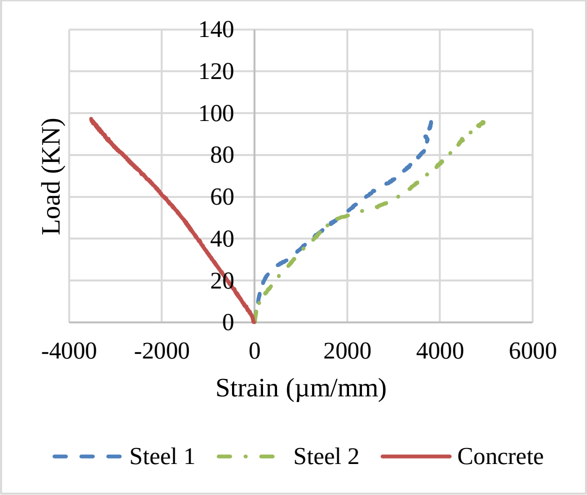




(a) NP0-150

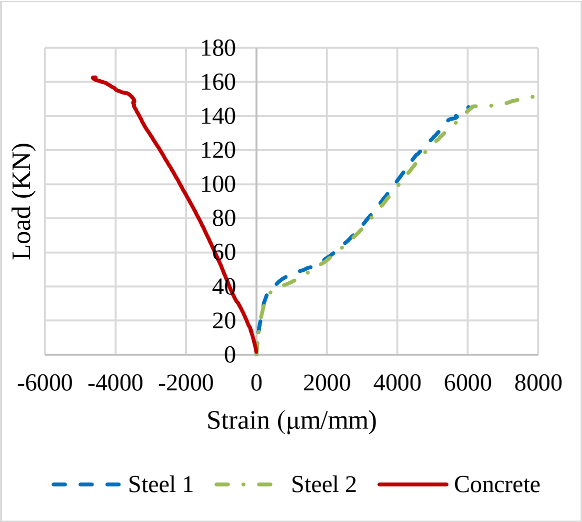
(b) NP0-200

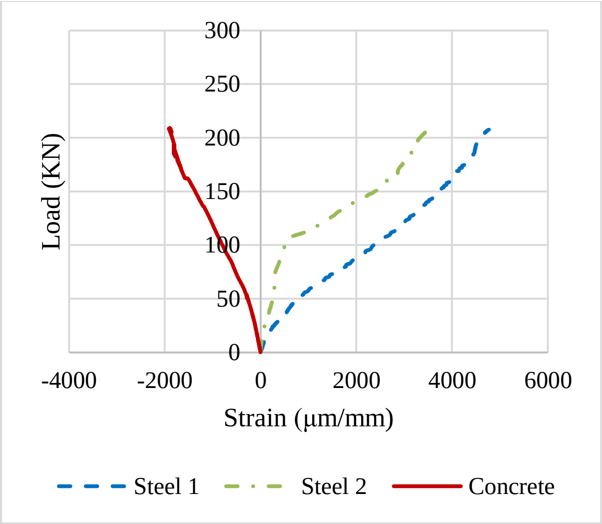




(c) NP0-300

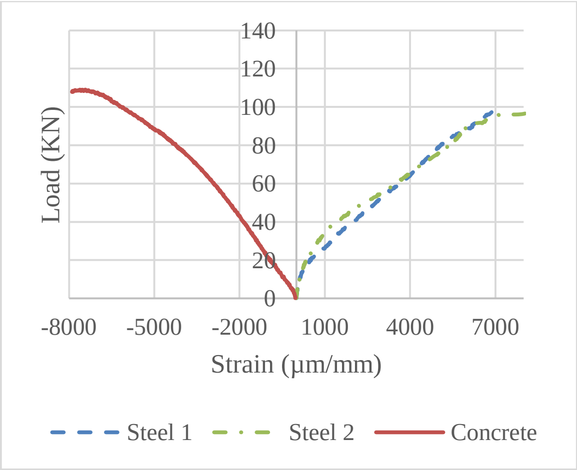
(d) NP5-150

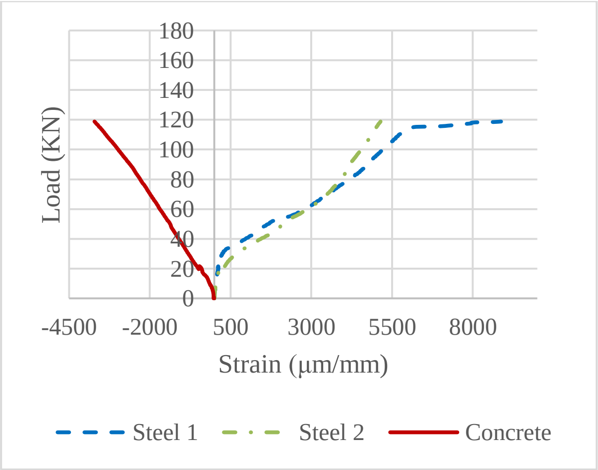




(e) NP5-200

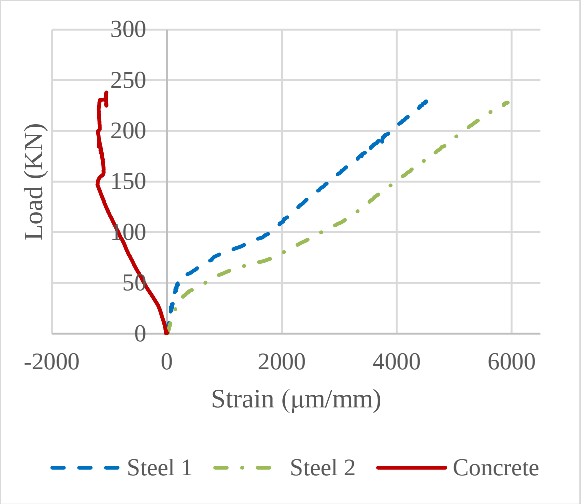
(f) NP5-300

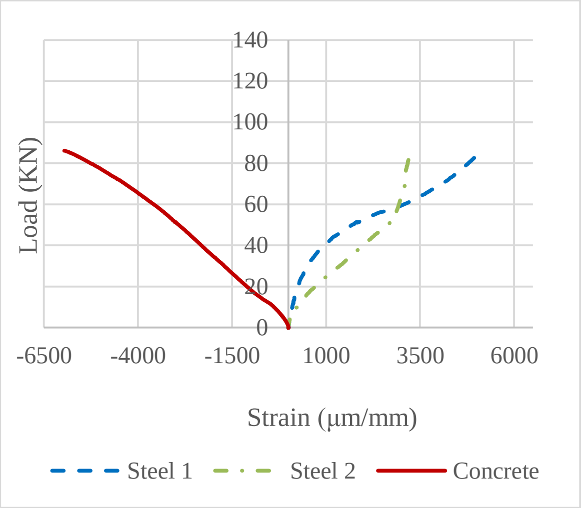




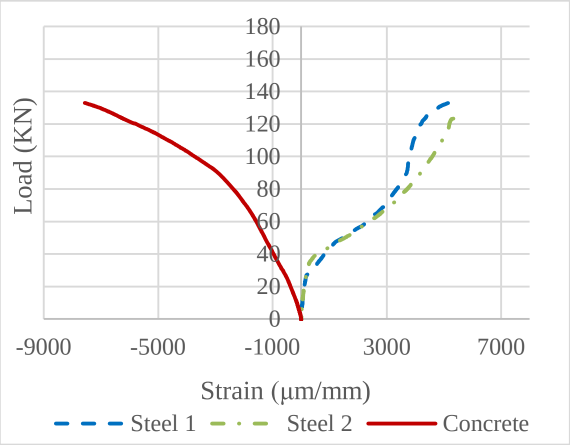
(g) NP10-150

(h) NP10-200



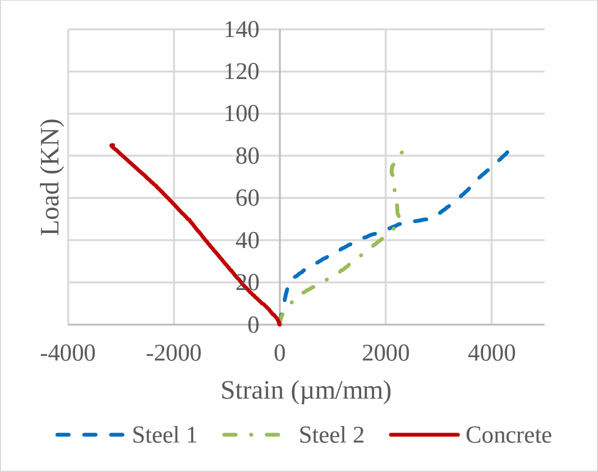


(j) NP15-150

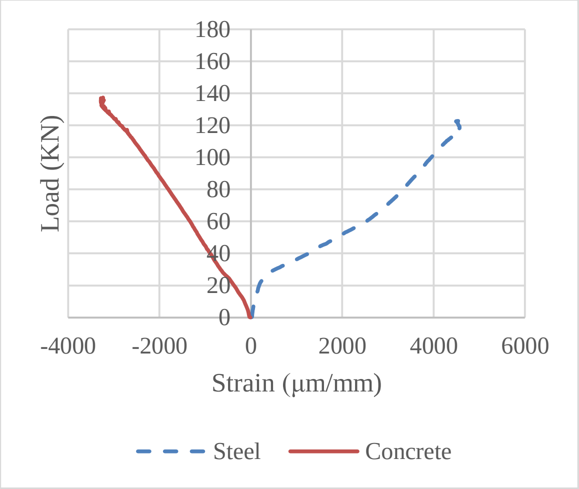


(i) NP10-300

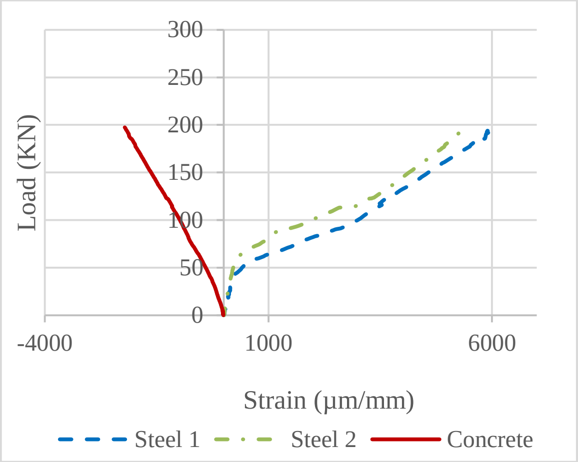
(k) NP15-200



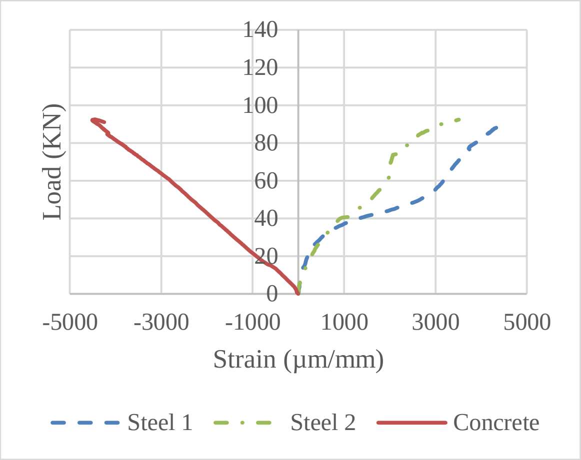
(m) RP0-150



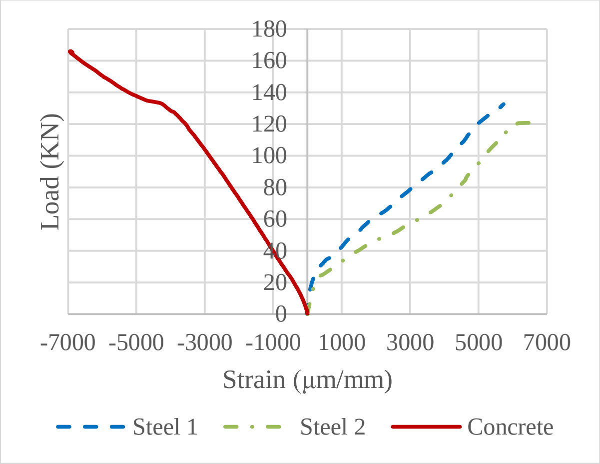
(n) RP0-200



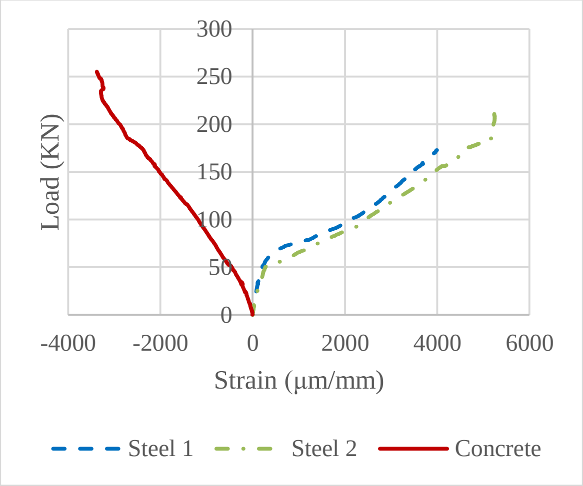
(o) RP0-300



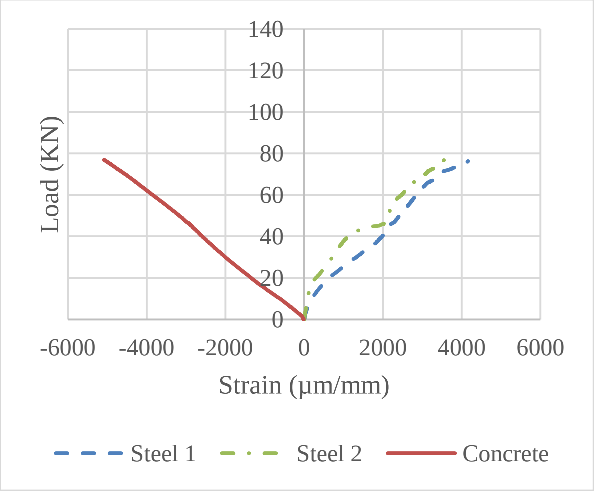
(p) RP5-150



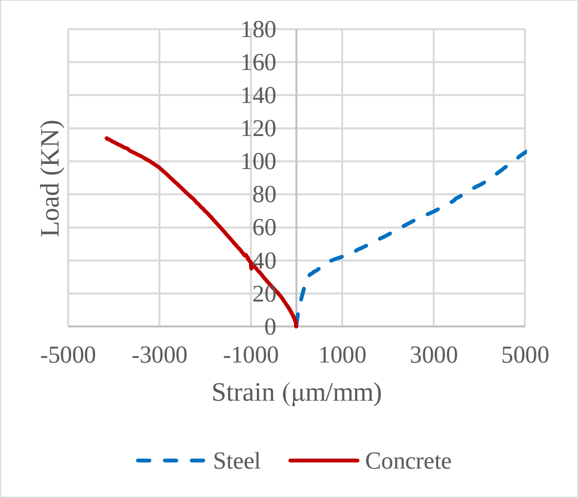
(q) RP5-200



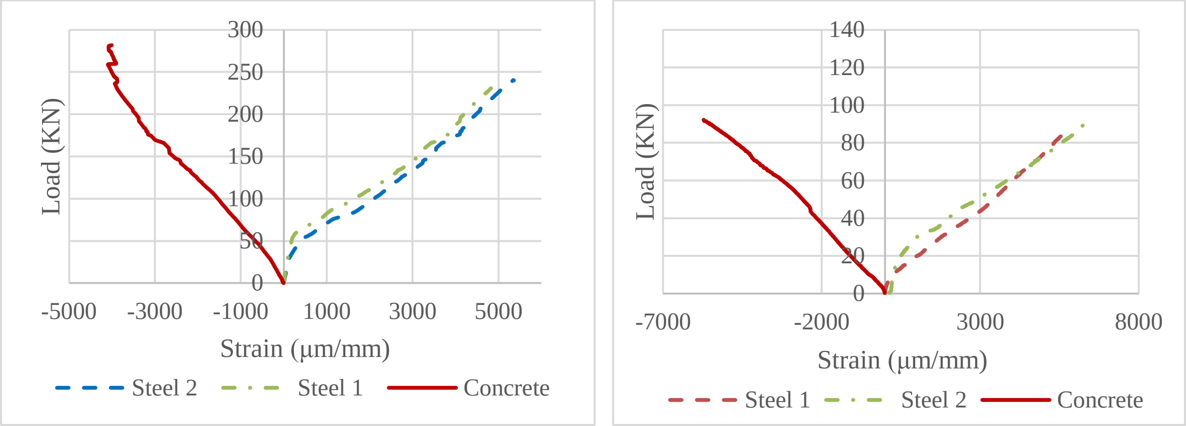
(r) RP5-300



(s) RP10-150

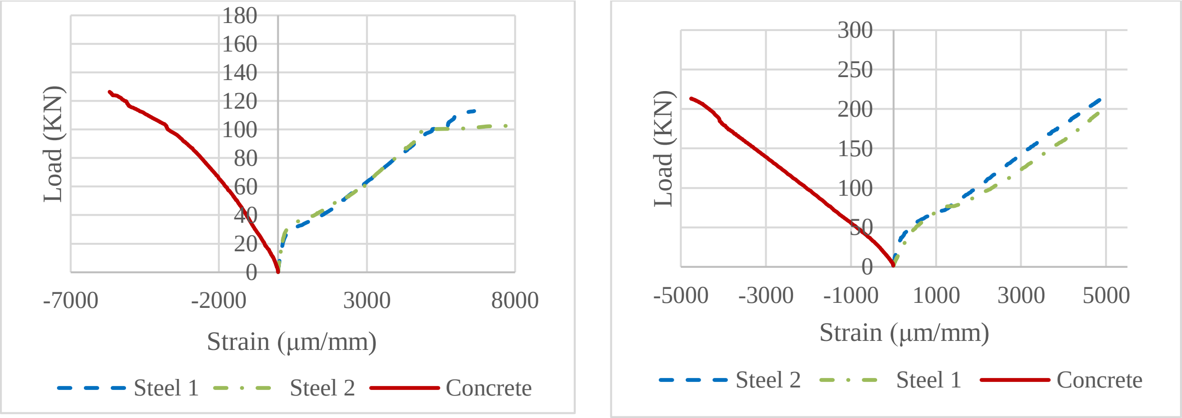


(t) RP10-200



(u) RP10-300

(v) RP15-150



(w) RP15-200

(x) RP15-300

Fig 4.9: Load-strain (steel and concrete) plots.

4.4.6 Ductility

Ductility is a measure of the ability of a material to deform plastically before fracture. For this study, ductility measures the ratio of deformation pick load/ deformation first crack load. For a 150 mm depth beam, the ductility of the beam with 5% PP content was higher than that of 0%, 10%, and 15% PP with NAC. Ductility was increased by 45% when 5% PP replaced NA. However, a 0.5% decrease in ductility was observed for replacing 10% PP. Similarly, when 15% PP was used, a decrement of 71% ductility was found. For a 200 mm depth beam, ductility was increased by 40% and 17% when 5% and 10% PP were used with NA. However, a decrement of 70% ductility was found to replace 15% PP. For a 300 mm depth beam, ductility increased by 16% when 5% PP was used. A decrease of 4.42% and

72% in ductility was found for 10% and 15% replacement of PP with NAC. Therefore, 5% PP with natural aggregate improved the ductility of the beam with depths of 150 mm, 200 mm, and 300 mm.

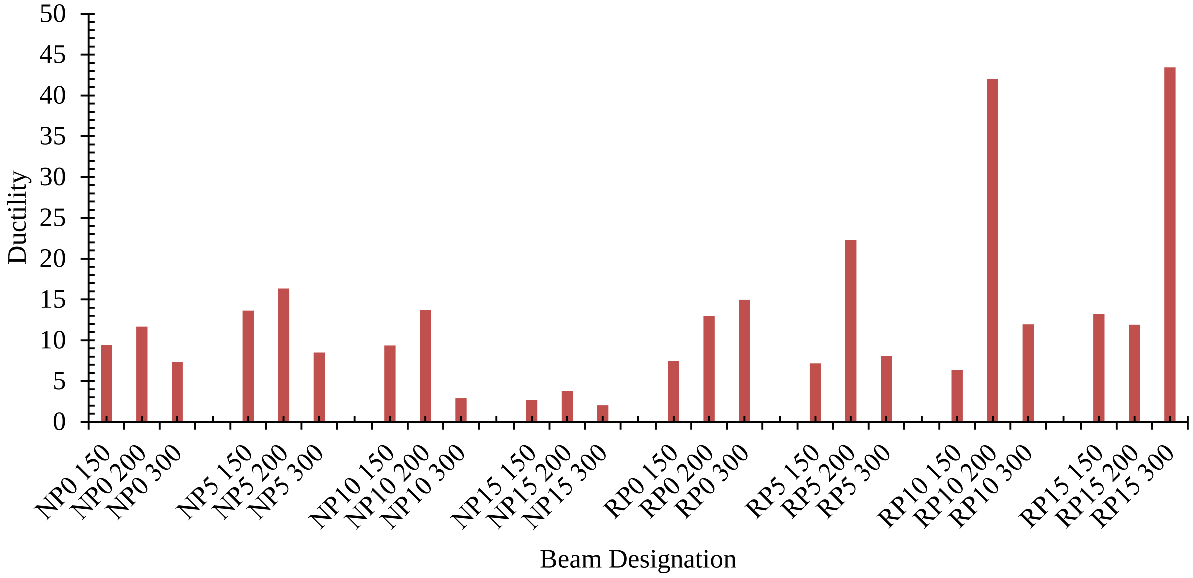


Fig 4.10: Ductility of RC beams according to size.

For a 150 mm depth beam, ductility decreased by 3.77% and 14.27% when RA was replaced by 5% and 10% PP. However, a 78% decrease in ductility was observed for replacing 15% PP. For a 200 mm depth beam, ductility is increased by 71.7% and 223.8% compared to the beam made of only RA when 5% and 10% PP were used with RA. However, a decrement of ductility by 8.25% was found to replace 15% PP. For the 300 mm depth beam, ductility decreased by 46.06% and 20% when 5% and 10% PP were used, respectively. The increment of ductility by 289.92% was found for the 15% replacement of PP with RA. The maximum ductility was found for a 300 mm depth beam made of 15% PP with RA. Hence, 5% PP with NAC improves the ductility of the beam when 150 mm, 200 mm, and 300 mm depth were used.

4.4.7 Toughness

Toughness indicates how much energy can be absorbed before failure. Figure 4.11 shows the beam's toughness variation for the PP and recycled aggregate effect. For a 150 mm depth beam, toughness was increased by 159%, 120%, and 3% when NA was replaced by 5%, 10%, and 15% PP, respectively. For a 200 mm depth beam, toughness was increased by 182% when 5% PP was used with NA. But, a decrement of 59% and 47% toughness was found to replace 10% and 15% PP, respectively. For a 300 mm depth beam, toughness is increased by 80% when 5% PP is used. A 64% and 48% decrease in toughness was found for 10% and 15% replacement of PP with NA.

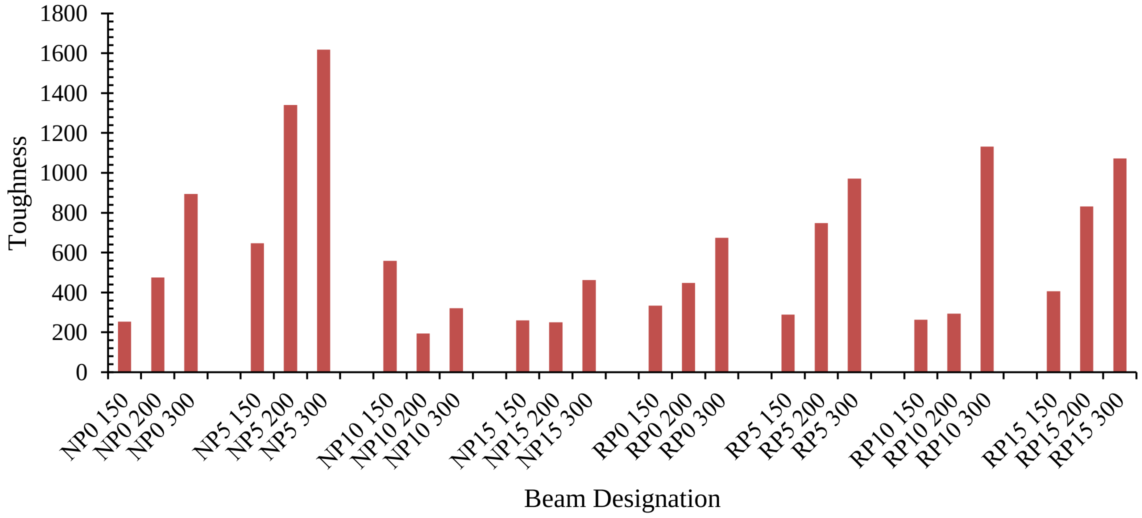


Fig 4.11: Toughness of RC beams according to size.

The maximum toughness was found for a 300 mm depth beam made of 5% propylene with NA. For a 150 mm depth beam, toughness decreased by 14% and 21% when RA was replaced by 5% and 10% PP, respectively. However, a 21% increase in toughness is observed for the replacement of 15% PP. For a 200 mm depth beam, toughness is increased by 67% when 5% and 15% PP were used with RA, respectively. However, a decrement of toughness by 34% was found for the replacement of 10% PP. For the 300 mm depth beam, toughness was increased by 44%, 67%, and 59% when 5%, 10%, and 15% PP were used with RA. The maximum toughness was found for the 300 mm depth beam made of 10% propylene with RA. This analysis shows that 5% PP with NA exhibited maximum toughness for beam depths of 150 mm, 200 mm, and 300 mm.

4.5 Conclusion

This study has been conducted to determine the effect of aggregate (NA and RA), the effect of the replacement of PP with NA and RA, and the span-to-depth ratio in the beam's shear capacity. Here, three beams of depth 150 mm, 200 mm, and 300 mm were used, and they were made of some variations of replacement of PP (i.e., 0%, 5%, 10%, and 15%) with NA and RA.

Firstly, for beams made of NA, the crack angle of the beam increased with the increase of beam depth; for beams made of RA, the crack angle of the beam increased with the increase of beam depth. Again, with the rise of the replacement ratio of NA with PP and RA with PP, the decrement of crack angle was found for replacement up to 10%. When a replacement was made by 15%, the increment of crack angle was found again for both beam categories.

Similarly, the crack width increased with the increase in beam depth for the beams made of NA and PP. The same result was found for the beams made of RA and PP. But with the rise of replacement of RA and NA with PP, respectively, the crack width increases for up to 10% replacement. However, the crack width decreases to replace 15% PP with NA and RA.

Again, for beams made of NA that are replaced by 5% PP, the ductility of the beam increases, but when replaced by 10% and 15% PP, the ductility value gradually decreases. When RA was replaced by 5% and 10% PP, the ductility value decreased, but an increment was found for the 15% replacement of PP.

Similarly, for beams made of NA replaced by 5% PP, the toughness of the beam increased, but when replaced by 10% and 15% PP, the toughness value gradually decreased. When RA was replaced by 5% and 10% PP, the value of ductility decreased, but an increment was found for the 15% replacement of PP with RA.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

The effect of mixing PP (PP) with natural aggregate and recycled aggregate to prepare concrete and the shear span-to-depth ratio has been considered to find the shear capacity of the beam in this study. Four variations of PP content (0%, 5%, 10%, and 15%) with both natural and recycled aggregate and three beam depths (150 mm, 200 mm, and 300 mm) have been used in this study. There has been a four-point bending stress applied to the beam. As a result, it experiences a variable moment and a constant share from both supports within the span's first third. Zero shear and constant moment will characterize the middle portion of the span. The beams don't have any shear reinforcement, either. The results have been compared with controlled specimens to determine the impact of PP with natural and recycled aggregate and the depth of the beam.

5.2 Conclusions

Several conclusions about concrete with PP can be drawn from the examination of the test results:

i. The slump value decreased to 40.6% when PP was added to NAC, whereas it increased to 115.6% when PP was used in RAC. PP aggregate has a rougher surface compared to NA, which caused a reduction in slump value. On the contrary, RA has a significantly higher water absorption capacity, which lowers the slump values. However, when RA is replaced with PP, slump values increase.

ii. The compressive strength decreases as the fraction of PP increases. When 5%, 10%, and

15% NA were replaced by PP, the compressive strength decreased by 32%, 27%, and 26% at 28 days. Again, when 5% RA was replaced by PP, the compressive strength at 28 days increased by 2% and decreased by 11% and 35% for 10% and 15% replacement of PP with RA. The variation was again found for a 5% replacement of PP with RA. A similar pattern was also found at 56 days.

iii. The tensile strength decreases similarly as the fraction of PP increases. When 5%, 10%, and 15% PP replaced NA, the tensile strength decreased by 27%, 18%, and 23%. Again, when PP replaced 5% RA, the tensile strength increased by 0.8% and decreased by 7% and 35% for 10% and 15% replacement of PP with RA.

iv. The shear capacity of the beams with 5% PP increased compared to the NAC, and it was up to 9.8%. However, with further increment of PP content, shear load decreased by up to 32.4%. RAC also observed a similar pattern with PP. When compared with the NAC, RAC showed a lower shear capacity.

v. The inclusion of PP in concrete increased peak load for the beams. The peak load increases with PP content in NAC for the 150 mm depth beam, and it was maximum at 15% PP concrete. However, for the 300 mm depth beam, the peak load was maximum for 5% PP concrete, declining for 10% and 15% PPA concrete. Although RAC with 5% PPA showed a rise in peak load compared to the control specimen, it did not consistently rise or fall for 10% and 15% PPA content. Compared to the NAC, RAC showed a decreased peak load capacity.

vi. The ductility of the NAC beam improves initially for the addition of PP until 5%. But further addition of PP causes a reduction in the ductility of the beam. On the other hand, the ductility of the RAC beam decreases initially to add PP until 5%. But further addition of PP causes an increase in the ductility of the beam.

The compressive, tensile, and shear strength tests on the PP-replaced concrete demonstrate that PP may be used for structural concrete. The building's materials consist of PP, weighing less per unit than regular concrete, making it lighter. Additionally, it has been found that PP concrete has a more ductile behavior than regular concrete by analyzing the load-strain curves.

5.3 Recommendation for Future Research

Polypropylene is readily available in our country. Again, resulting waste from the concrete structure is becoming an environmental issue daily. So, using PP and recycled aggregate in concrete structures will help save the environment and cost. Therefore, researchers may include the following points in their future studies on PP and recycled aggregate:

i. Only one w/c ratio has been used in this study. The performance of the concrete can be evaluated using several w/c ratios.

ii. Three variations in the depth of the beam have been used in this study. Further addition in the variation of depth of the beam can be used to find the effect on various mechanical and physical studies.

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ANNEX-A

Mix Design for NP0

Lab test data

Material	Specific gravity	Unit weight	Fineness Modulus
Cement	2.95		
Sand	2.55	1600	2.48
CA(Stone)	2.82	1620	7.03
CA(PPA)	1.1	621	6.17

Water/Cement Ratio= 0.45

Water= 205kg [Table 5.3.3; ACI 211.1-22]

$$\mathbf{Cement} = \frac{\mathbf{Water}}{\mathbf{Ratio}} = \frac{\mathbf{205}}{\mathbf{0.45}} = \mathbf{456g}$$

CA Volume= 0.652 m^3/m^3

$$\mathbf{CA\ mass\ 0.625 \times 1620 = 1056.24\ kg}$$

$$\text{Water volume} = \frac{205}{1000} = 0.205$$

$$\text{Cement Volume} = \frac{456^2}{2.95 \times 1000} = 0.1546$$

$$\text{CA Volume} = \frac{1056.24}{2.82 \times 1000} = 0.3746$$

$$= 1.5\% = 0.015$$

$$\text{FA Volume} = 1 - \text{Vw} - \text{Vc} - \text{VCA} - \text{Vair}$$

$$= 1 - 0.205 - 0.1546 - 0.3746 - 0.015$$

$$\boldsymbol{FA\ mass = 0.251 \times 2.55 \times 1000 = 639.72\ kg}$$

Mix Design for NP5

Lab test data

Material	Specific gravity	Unit weight	Fineness Modulus
Cement	2.95		
Sand	2.55	1600	2.48
CA(Stone)	2.82	1620	7.03
CA(PPA)	1.1	621	6.17

Water/Cement Ratio= 0.45

CA mass-

CA-95%

CA(pp)-5%

CA Volume= 0.652 m^3/m^3

Water= 205kg [Table 5.3.3; ACI 211.1-22]

$$\mathbf{Cement = \frac{Water}{Ratio} = \frac{205}{0.45} = 456g}$$

CA Volume= 0.652 m^3/m^3

CA mass= 0.95 x 0.652 x 1620 =1003.43kg

CA (pp) mass= 0.05 x 0.652 x 621 =20.25 kg

$$\text{Water volume} = \frac{205}{1000} = 0.205$$

$$\text{Cement Volume} = \frac{456^2}{2.95 \times 1000} = 0.1546$$

$$\text{CA Volume} = \frac{1003.43}{2.82 \times 1000} = 0.36$$

CA (pp) Volume= $\frac{20.25}{1.1 \times 1000} = 0.018$

$= 1.5\% = 0.015$

$$\text{FA Volume} = 1 - \text{Vw} - \text{Vc} - \text{VCA} - \text{Vca(pp)} - \text{Vair}$$

$$= 1 - 0.205 - 0.1546 - 0.36 - 0.018 - 0.015 = 0.248$$

$$\boldsymbol{FA\ mass = 0.248 \times 2.55 \times 1000 = 640.55\ kg}$$

Mix Design for RP0

Lab test data

Material	Specific gravity	Unit weight	Fineness Modulus
Cement	2.95		
Sand	2.55	1600	2.48
RAC(Stone)	2.61	1430	7.03
CA(PPA)	1.1	621	6.17

Water/Cement Ratio= 0.45

Water= 205kg [Table 5.3.3; ACI 211.1-22]

$$\mathbf{Cement} = \frac{\mathbf{Water}}{\mathbf{Ratio}} = \frac{\mathbf{205}}{\mathbf{0.45}} = \mathbf{456g}$$

CA Volume= 0.652 m^3/m^3

$$\mathbf{CA\ mass\ 0.652 \times 1430 = 932.32\ kg}$$

$$\text{Water volume} = \frac{205}{1000} = 0.205$$

$$\text{Cement Volume} = \frac{456}{2.95 \times 1000} = 0.1546$$

$$\text{CA Volume} = \frac{932.30}{2.82 \times 1000} = 0.316$$

$$= 1.5\% = 0.015$$

$$\text{FA Volume} = 1 - \text{Vw} - \text{Vc} - \text{VCA} - \text{Vair}$$

$$= 1 - 0.205 - 0.1546 - 0.316 - 0.015 = 0.3094$$

$$\boldsymbol{FA\ mass = 0.3094 \times 2.55 \times 1000 = 639.72\ kg}$$