Evaluation of Compressive Strength for Recycled Aggregate Concrete Reinforced with Polypropylene Fibers

تقييم مقاومة الانضغاط للخرسانة المعاد تدويرها والمدعومة بألياف البولي بروبلين

by

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Abstract

The compressive strength of recycled aggregate concrete reinforced with polypropylene fibers was investigated. The possibility of using polypropylene fibers (PPF) in the recycled aggregate concrete (RCA) was extensively studied. Moreover, the mixes experimented were using different RCA replacement ratios and different PPF content. The results present the compressive strength behavior of Recycled Aggregate Concrete (RAC) with and without addition of Polypropylene (PP) fibers. The normal coarse aggregate was replaced by recycle aggregate in the percentage of 0, 25, and 50%. The polypropylene fibers (PP) were used in the recycle aggregate concrete by 0.2% and 0.35% by volume. The values of compressive strength of the natural aggregates concrete (NAC) were set as a control. 27 concrete cubes (150x150x150mm) for each RAC and NAC were casted making a total of 54 concrete cubes. Three cubes for each designed mix were also cured for 7 days and 28 days. The test results revealed that the incorporation of PP fibers did not considerably change the compressive strength and the density of concrete, but the compressive strength of RAC was satisfactory at the early ages until the later ages where NAC was higher than RAC. Therefore, use of recycled aggregate concrete showed tolerable performance with respect to compressive strength and will have a better employment at fast setting concrete where early strength is required. Furthermore, more studies are necessary to determine the effect on durability and enhancement to the workability.

Keywords: *concrete, recycled material, aggregate, polypropylene fiber, compressive strength.*

الملخص

تم فحص مقاومة الانضغاط للخرسانة المعاد تدويرها والمسلحة بألياف البولي بروبلين. تمت دراسة إمكانية استخدام ألياف البولي بروبلين (PPF) في الخرسانة المعاد تدويرها (RCA) على نطاق واسع. علاوة على ذلك، كانت الخلطات التي تم اختبارها تستخدم نسب استبدال RCA مختلفة ومحتوى PPF مختلف. توضح النتائج سلوك مقاومة الانضغاط للخرسانة المعاد تدويرها (RAC) مع وبدون إضافة ألياف البولي بروبلين (PP). تم استبدال الركام الخشن العادي بمواد إعادة التدوير بنسبة 0 و25 و50٪. تم استخدام ألياف البولي بروبلين (PP) في إعادة تدوير الخرسانة بنسبة 0.2٪ و0.35٪ من حيث الحجم. تم تحديد قيم مقاومة الانضغاط لخرسانة الركام الطبيعي (NAC) كعنصر تحكم. تم صب 27 مكعبًا خرسانيًا (150 × 150 × 150 ملم) لكل من RAC وNAC مما يجعل إجمالي 54 مكعبًا خرسانيًا. ثلاث مكعبات لكل مزيج مصمم تم معالجتها أيضًا لمدة 7 أيام و28 يومًا. كشفت نتائج الاختبار أن دمج ألياف PP لم يغير بشكل كبير من قوة الانضغاط وكثافة الخرسانة، ولكن قوة الانضغاط لـ RAC كانت مرضية في العصور المبكرة حتى العصور المتأخرة حيث كان NAC أعلى من RAC. لذلك، أظهر استخدام خرسانة الركام المعاد تدويرها أداءً مقبولاً فيما يتعلق بمقاومة الانضغاط وسيكون لها عمل أفضل في الخرسانة سريعة التثبيت حيث تكون القوة المبكرة مطلوبة. علاوة على ذلك، من الضروري إجراء المزيد من الدراسات لتحديد التأثير على المتانة وتحسين قابلية التشغيل.

الكلمات المفتاحية: *الخرسانة، المواد المعاد تدويرها، الركام، ألياف البولي بروبلين، مقاومة الانضغاط.*

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Chapter 1. Introduction

1.1 Research Background and Significance of the Research Problem

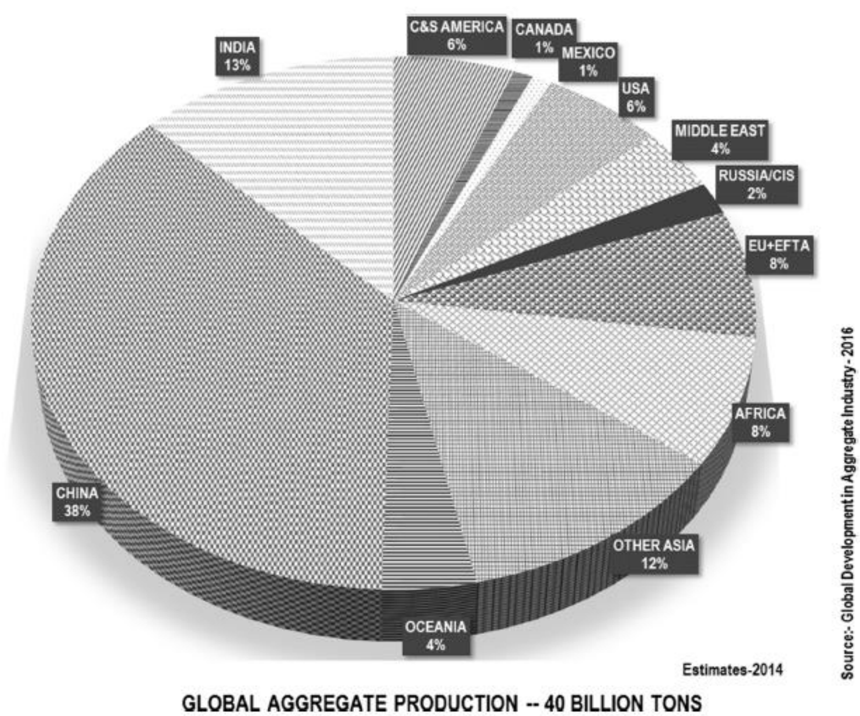
The massive increase in urbanization combined with the construction, demolition, and renovation has forced to create large amounts of construction waste worldwide. This is precisely accurate in the UAE, where it's one of the fastest growing economies in the world and the second largest in the Arab world. According to Aswan (2019), the GDP of UAE economy is predicted to grow around $425.00 Billion by the year 2020 when it was recorded at $382.58 Billion in 2017. The economy of UAE has grown by almost 231 times, since its independence in 1971.

In the UAE the demand has been slowly increasing since the 2008, and it is currently estimated to be around 19 million tons, however, the 12 cement factories in the UAE have a capacity of up to 39 million tons per year (Sabouni 2016).

The flourishing economy of UAE demands the need for building new houses and infrastructure and reinforced concrete is the most economical and suitable building construction material. But due to the continuous large scale of aggregate mining and extraction, the consumption of aggregates from natural resources has been a question with indefinite answer. The great awareness of environmental protection increased the demand to count on recycled aggregate from demolition waste and construction. A sustainable concrete or green concrete has become a leading term in the construction industry and its research. It can be noticed from the huge focus of almost all the research publications. Recycled Aggregate Concrete is the most common type which has been used in the industry for years. Construction and demolition waste are the main source for recycled aggregate (Ramadevi& Chitra, 2017).

The construction industry is a main consumer of natural resources and the worldwide aggregate production jumped from 21 billion tons in 2007 to 40 billion in 2014. Countless countries such as China, Indonesia, India, Malaysia, Thailand, Turkey, Russia, Brazil have noted a massive demand for waste recycling. Therefore, the gradual depletion of natural resources accompanied with the arise of waste management awareness, have given a huge attention to re-use and recycle C&D waste in civil engineering projects. As shown below in Figure 1 the aggregate production globally is a sign of the huge development of projects around the world. The annual demand of aggregate is increasing the importance to figure ways to reuse C&D waste. Its available, and cheap. However, extensive researches are highly needed in order to find alternative materials to produce concrete that contains recycled aggregate.

Figure 1*: Global Aggregate production (*Slattery, K.*, 2014)*



The Coarse aggregate is considered the main contributor to the performance and strength of concrete. It consists between 70-80% of concrete mixes by volume. Mainly, the production of coarse aggregate is done through mining, where rocks of mountains are crushed to the required size. This kind of process threatens the environment where the most obvious environmental impact of mining the aggregate is the transformation of the land use, converting an agricultural land use to a big hole in the ground. The previous impact is accompanied by noise, blasting affects, erosion, dust, sedimentation, and loss of habitat (Mulatu, 2013).

In UAE, Bee’ah which located in Sharjah is a waste management complex which has a construction and demolition waste (CDW) recycling facility. This facility with the use of special machines more than 7,000 tons of construction waste consists of concrete, wood, bricks, and asphalt are broken and processed into fine and coarse aggregates. As reported by Bee’ah Waste Management Complex, recycled aggregate was never used in structural elements, although it has been used in North America, Europe, and Australia for a long time (Leading Environmental Management Company in UAE (Bee'ah, 2015). In the Emirate of Abu Dhabi, Pearl Building Rating System (PBRS), a new system proposed and implemented to promote the development of sustainable buildings and enhance the quality of life. This was initiated by Estidama, a building design methodology used in construction and operating buildings. Estidama is considered as a key aspect of the “Abu Dhabi Vision 2030” to build the emirate following the innovative green standards. This framework ensures that sustainability is always addressed among the construction projects through four aspects: environmental, cultural, social, and economical (Pearl Rating System (Abu Dhabi) - Wikipedia, 2021).

1.2 Research Objectives

The main goal of this academic research paper is to study the compressive strength behavior of recycled aggregate concrete reinforced with polypropylene fiber. Also, the usage of recycle aggregate will give a clear destination of the usage limitations in the construction industry. To achieve this goal, the proposed experimental program consists of 54 cubes to be cast and tested at 7 & 28 days. 18 cubes will contain conventional normal weight aggregate and will be used as control. The balanced 36 cubes will have 25% and 50% of recycled aggregate, and 0.35 % and 0.20% of polypropylene fiber.

1.3 Expected Contributions of the Study

Concrete is the primer construction material across the world and the most extensively used in all the civil engineering works. Hence, there should be a major focus of research towards achieving a green concrete that will decrease the pollution issues around the world. Recycling the concrete offers sustainability in various ways. This will lead to reduction of material that must be landfilled. Also, using the recycled aggregate will reduce the need for normal weight aggregate. Therefore, this will decrease the environmental impact of aggregate mining process. However, transportation requirements for the project will be decreased if we remove the need for waste disposal and the need for new materials.

1.4 Organization of The Dissertation's Structure

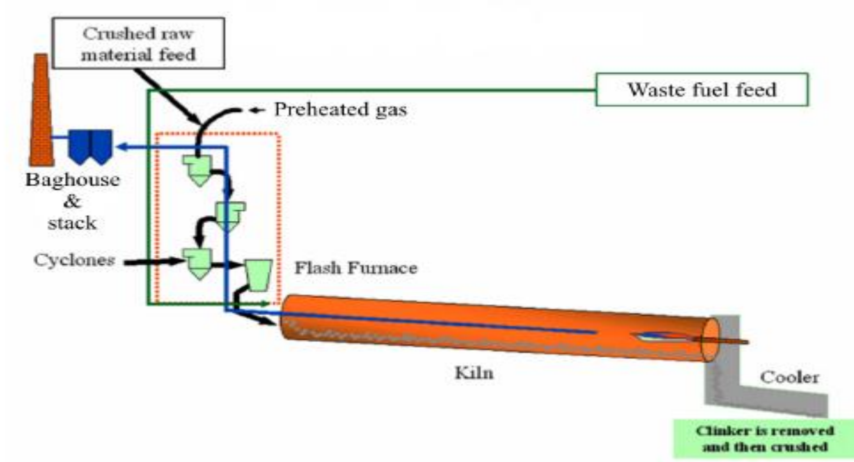
This dissertation is divided into 6 chapters. Chapter 1 introduces the background and the significance of this study, objectives, and the expected contribution of this study. Chapter 2 will show the environmental impact of concrete, recycled aggregate concrete, sustainability of recycled aggregate, effects of polypropylene fiber on NAC and RCA, and the compressive strength of recycled aggregate concrete. Chapter 3 demonstrates the experimental methodology to be used in this study, its experimental program and test setup. Chapter 4 introduces the observation outcomes and results acquired from the experimental stage.

Chapter 2. Literature Review

2.1Environmental Impact of Concrete

The increase in world population demands an increase in the facilities, which requires infinite number of natural resources. For this purpose, several industries, supported by the government are searching for ways of reusing old materials to manufacture new products. Concrete is the most extensively used material on earth. If we consider the cement industry to be a country, it would be the third largest emitter of carbon dioxide in the world after china and the US (Watts, 2019). The production of concrete yearly reaches 1.7 billion tons, and this accounts for about 8% of the global loading of carbon dioxide in the atmosphere. Moreover, the process of mining large amounts of raw materials such as limestone, clay, and coal for fuel repeatedly results in disforestation. Normal concrete consists about 12% cement and 80% aggregate by mass, this indicates that to make concrete we are using natural resources as crushing rocks, sand, and gravel at a rate of 10 to 11 billion tons every year. Also, considering the amounts of energy consumed during the mining, processing, and transport to produce this substance. Also, the concrete industry demands large amounts of fresh water, where the required amount of water for mixing is almost 1 trillion L every year. Other than the three primary components of concrete, that is, aggregate, cement, and water, several types of minerals and chemicals admixtures are involved in the concrete production and considered as energy intensive. Also, the mixing, batching, transport, placement, and finishing. All the previous procedures are energy intensive (Mehta, 2001).

Figure 2: Cement Kiln process



The cement kiln is considered the heart of this process. The kiln is a long cylinder sloped with zones that are used to heat the mixtures up to about 1,480^{O}C. The role of the kiln is to rotate slowly to mix the fine raw materials that is moving through it (Fig. 2). During the rotation, these materials experience complex physical and chemical changes in order to make them react together through hydration. This type of reaction occurs at very high temperatures to make the ingredient molts. When the new compound cool, and solid clinker is formed. Then the clinker is grounded to a fine powder with an addition of some gypsum, and the final product cement is bagged and shipped to the ready mix concrete plants (Babor,Plian, &Judele2009).

Concrete is a mixture of cement with coarse aggregate (gravel or crushed stone), fine aggregate (sand), water, and chemicals named as admixtures that are used to control the properties of the concrete such as the plasticity and the setting time. Hydration is a chemical reaction that hardens the concrete. It happens when water is added to cement; this forms a gel or slurry that fills the voids and coats the aggregate to form concrete in solid state (Babor,Plian, &Judele2009).

The manufacture of cement and concrete is one of the biggest environmental concerns as they are energy intensive. In particular, the cement industry is the most energy demanding of all industrial manufacturing process. It takes 1,760 kWh for every ton of cement. Coal is the reliable energy source for the cement industry, which it's also responsible for high emission levels of CO_2, nitrous oxide and sulphur, and other pollutants. The huge usage of energy in cement manufacture goes for running the rotary cement kilns. The Dry-process is more energy efficient than older wet process kilns, because there is no energy required to remove the moisture. Concrete production seems considerably better than cement production in terms of energy usage, because the ingredients for concrete such as sand, water, and crushed stone consume less energy (Babor,Plian, &Judele2009). The biggest concerns of all is the CO_2 Emissions. In the manufacture of cement, there are two sources of carbon dioxide emissions. The largest cause is coming from burning of fossil fuels to run the rotary kiln: almost ¾ ton of CO_2 per ton of cement. Also, the CO_2 produced from the chemical process of calcining limestone into lime in the cement kiln. These two sources, if we combine them there will be for every one ton of cement produced, a 1.25 ton of CO_2 is released to the atmosphere.

2.2Recycled Aggregate Concrete

2.2.1 Overview

The most widely used construction material is concrete. Principally consists of a binding agent and a mineral filler. Hydraulic cement is the binding agent which its strength is developed when mixed with water, by hydration, the loose powder changes to a brittle, hard, stone-like material. During the hydration part of the water is combined chemically with cement, and the other part remains to dry out, affecting the set of cement and causing to shrink. For this matter to reduce the shrinkage an inert filler is utilized. The filler, or aggregate, makes about 75% of the whole volume. Different materials can be used as aggregate, but the most used is gravel and sand. The principal concrete making components will be defined based on ASTM C125 (Standard Definition of Terms Relating to Concrete and Concrete Aggregates), and ACI Committee 116 (A Glossary of Terms in the Field of Cement and Concrete Technology):

Cement is a fine pulverized powder works as a binder but not necessarily an official binder. It just develops the binding property due to the hydration with water. The most known and commonly used cement is Portland cement, which essentially consists of hydraulic calcium silicates. Which are accountable for the adhesive characteristics. The Aggregate is a granulated material, such as gravel, crushed stone, and sand. We have the **coarse aggregate** that belongs to particles larger than 4.75 mm (No. 4 sieve), and the term **fine aggregate** is for particles smaller than 4.75 mm but larger than 75 mm (No. 200 sieve). The coarse aggregate which is resulted naturally from the abrasion of rock called **Gravel.** The term **Sand** is for the fine aggregate resulted from the abrasion of rock (Mehta & Monteiro, 2014).

The synthesis of this literature suggests that structures are frequently subjected to changes that leads to their deterioration, are affected by natural disasters, and demolished to meet up the changing demands of the city. The construction sector is responsible for generating massive amount of waste all over the world. In European Union alone, the sector is responsible for the generation of 850 million tons of waste (Kurda, de Brito and Silvestre, 2019). In the United States, the waste production by the demolition of structures is estimated to be 130 million tons per annum. In the global arena, the concrete waste generated primarily comes from the old structures, which are transported to landfills (Kurda, de Brito and Silvestre, 2019). However, the waste is considered to be hazardous and detrimental for the environment. As a result, researchers have emphasized on adopting the concept of sustainability to alleviate the problems caused by concrete wastes. As indicated in literature, waste from concrete can be recycled to adopt the concept of sustainability (Arulrajah et al, 2014, Andreu and Miren, 2014, Lima et al, 2013, Kurda, de Brito and Silvestre, 2019). Many of nations such as United States, United Kingdom, Canada, Australia, France, Germany, and China have adopted the use of concrete waste together with natural aggregates to create concrete for construction purposes (Ismail and Ramli, 2013, Andreu and Miren, 2014, Lima et al, 2013). In this domain, many researches have been conducted and therefore, majority of the researches have concluded the consumption of recycled concrete waste is acceptable environmentally, economically, and technically.

Aggregates are comprised of 70% of the concrete content in terms of volume. The majority of the aggregates comprise of coarse aggregates and therefore, its demand in the construction industry is high. As natural coarse aggregates (NCAs) are derived from natural resources, it is responsible for causing a disruption in the environment (Arulrajah et al, 2014). As a result, recycled concrete aggregates (RCA) has been recognized as an alternative of natural coarse aggregates (NCA) as it helps in reducing the environmental impact that occurs because of extraction of CA (Kurda, de Brito and Silvestre, 2019). Furthermore, generation of concrete waste and increasing costs associated with landfills have increase the demand for RCA to be used as substitute in concrete (Exteberria et al. 2007, Khalid et al, 2017, Dimitriou, Savva and Petrou, 2018, Kurda, de Brito and Silvestre, 2019) As indicated in literature, numerous studies have been done to study RCA’s properties and its impact on concrete as a substitute of CA. Since the last 3 decades, many investigations have been conducted out. This section of the literature review, offers a comprehensive and extensive review of RCA as a replacement of CA in concrete.

2.2.2 What is RCA?

The analysis of literature demonstrates that RCA's physical properties are responsible for affecting the overall properties of concrete as well as its mix proportion. According to Arulrajah et al (2014), the physical properties of RCA such as absorption capacity, pore volume, shape, texture, specific gravity, and bulk density are inferior as compared to the physical properties of normal CA. This is because RCA contains impurities along with residual cement mortar. According to Belin et al (2014), the RCA based concrete's compressive strength is low because of the existence of residual cement mortar (Elhakam, Mohamed and Awad, 2012, McNeil and Kang 2013). According to McNeil and Kang (2013), "residual cement paste or mortar is responsible for significantly affecting the overall physical properties of RCA including density, porosity, and water absorption capability".

Recycled concrete aggregate are identified as the aggregates that are retrieved through the recycle of concrete waste to be used as an alternate for the natural aggregate (NA) in concrete. According to the BS 8500-2 (British Standard), recycled aggregate used in concrete is known to have maximum 5% of fine content, 0.5% of lightweight material, and 1% foreign materials. Within the concrete, the replacement of RCA with NA should be less or equal to 100%. According to Khalid et al (2017), the utilization of fine RCA is uncommon. Çakır (2014) proposes that RCA material that is below the diameter of 2 mm requires massive amount of water, which is responsible for causing shrinkage in concrete. It is also responsible for reducing its strength. Fine RCA is also responsible for affecting the overall quality of concrete because of its high-water absorption capability.

2.2.3 Properties of RCA

2.2.3.1 Physical Properties

Table 1: *Overview of Properties of RCA and NCA Compared (Anderson, Uhlmeyer and Russell, 2009)*

Property	Virgin Aggregate	RCA
Shape and Texture	Well rounded, smooth (gravels) to angular and rough (crushed rock).	Angular with rough surface.
Absorption Capacity	0.8 – 3.7 percent	3.7 – 8.7 percent
Specific Gravity	2.4 – 2.9	2.1 – 2.4
L. A. Abrasion Test Mass Loss	15 – 30 percent	20 – 45 percent
Sodium Sulfate Soundness Test Mass Loss	7 – 21 percent	18 – 59 percent
Magnesium Sulfate Soundness Mass Loss	4 – 7 percent	1 – 9 percent
Chloride Content	0 – 1.2 kg/m^3	0.6 – 7.1 kg/m^3

2.2.3.1.1 Size and Texture of RCA

RCA texture is known to be rough and angular because it is derived from the concrete waste that is subjected to recycling and also because of the existence of previous hardened cement paste. According to Kim, Kim and Yang (2016), the percentage of previous cement paste in RCA particle varies from 30% to 60% and is dependent on the size of the aggregate. According to Dimitriou, Savva and Petrou (2018), the texture of RCA is rough, and irregular as compared to NCA because it derived from old concrete.

2.2.3.1.2 Specific Gravity

As compared to NA, RCA's specific gravity is low. This is because the previous cement paste is existed. This cement paste is responsible for increasing the density of the RCA. Under saturated dry surface conditions, the specific gravity of RCA is in between the ranges of 2.1 to 2.5. This value is lower than NA. A study by Limbachiya, Leelawat and Dhir (2000) revealed that the relative density of RCA (in the saturated surface dry state) is nearly 7–9 % smaller than that of NA.

2.2.3.1.3 Bulk Density

In terms of bulk density, NA has higher value as compared to RCA. In Sagoe-Crentsil, Brown and Taylor (2001), the researchers reported that the bulk densities of RCA and NA varied by 17%. They also reported that this difference was primarily because of previous residual cement mortar that caused the RCA to have a lower density as compared to NCA. In a study conducted by Yong and Teo (2009), it was reported that the bulk density of RCA was significantly lower than that of CA. The researchers concluded that this was because of the occurrence of residual cement paste that increases the porosity of RCA significantly. In a study conducted by Limbachiya et al (2000), it was revealed that the density of RCA under surface dry conditions was lower than NA by 7 to 9 percent.

2.2.3.1.4 Pore Volume

As indicated in literature, the pore volume of RCA is higher as compared to NCA and this is also attributed to residual cement paste presence (Tam et al, 2008). As RCA has a higher pore volume, it is considerably “weak and less dense” as compared to NCA (González-Taboada et al, 2017). It is reported that RCA’s pore volume ranges between 3% to 12% as compared to NCA, which is between 0.5% to 2% (Belin et al, 2014, Gómez-Soberón, 2002, Katz, 2003, Xiao, Li, and Jhang, 2005, Evanelista, 2007).

2.2.3.1.5 Water Absorption

The water absorption property of RCA is known to be greater than NCA as it is extremely porous in nature. As a result, it has a higher tendency of retaining water in its pores as compared to NCA. In Belin et al (2014), higher absorption capacity of RCA is responsible for affecting the overall mechanical and micro properties of concrete. In a study performed by Etxeberria et al (2007), it was reported that water absorption of RCA is responsible for affecting the concrete's workability and mechanical properties in negative manner. Water absorption values for RCA is in between the range 4% to 5.2% as compared to NCA that is between the range of 0.5% to 2.5% (Sagoe-Crentsil, Brown and Taylor, 2001, Cui et al, 2015). In Dimitriou, Savva and Petrou (2018), it has been reported that RCA's water absorption capacity varies from 3% to 15%.

2.2.3.2 Mechanical Properties of RCA

The mechanical properties of concrete are significantly dependent on the mechanical properties of aggregates that are used in it (Zheng et al, 2018,Atmajayanti and Haryanto, 2018, Singh and Singh, 2020). As indicated in literature, the mechanical properties of RCA are lower as compared to NCA. This is also mainly because of the presence of residual cement mortar (Zhou and Chen, 2017, Yang and Lee, 2017, Elansary, Ashmawy and Abdalla, 2020, Adessina et al, 2019).

2.2.3.2.1 Aggregate Abrasion Value

It has been reported by various studies are that RCA's aggregate abrasion value is higher for RCA as compared to NCA. The aggregate abrasion value (AAV) is defined as the measure of resistance for a given aggregate. When this value increases, the material loss increases significantly. As reported by Zhou and Chen (2017), the abrasion values of RCA is in between the range of 20% to 45%. Generally, the AAV value of RCA below 50% is acceptable.

2.2.3.2.2 Aggregate Impact Value

The aggregate impact value (AIV) is defined as the measure of strength of the aggregate that is affected by the impact. AIV measures the ability of the aggregate to show resistance to non-stationary load (Zhou and Chen, 2017, Yang and Lee, 2017). The value of AIV for RCA as indicated in literature varies from 20% from 25%, which is a higher value as compared to NCA (Zhou and Chen, 2017). This value is greater because of residual cement, which affects its strength significantly.

2.2.3.2.3 Aggregate Crushing Value

The aggregate crushing value (ACV) is defined as the ability of the aggregate to resist the crushing action after the application of compressive load in a gradual manner (Elansary, Ashmawy and Abdalla, 2020, Elansary, Ashmawy and Abdalla, 2020, Adessina et al, 2019). For RCA, this value is in between the range of 20% to 30% and is higher than the value of NCA (Zheng et al, 2018, Atmajayanti and Haryanto, 2018).

2.2.3.3 Chemical Properties

The RCA is also responsible for affecting the overall properties of the concrete through its chemical properties. According to Saberian and Li (2018) , RCA may have presence of chemicals such as chlorides, sulphates, and akalis that can overall affect the concrete's properties made up from RCA.

2.2.3.3.1 Soundness

The capability of the aggregate to resist to environmental conditions is known as soundness. For evaluation of an aggregate's soundness, a sodium sulphate and magnesium sulphate tests are conducted. As reportedSaberian and Li (2018) , RCA normally fails when it comes to sodium sulphate soundness test. However, in terms of magnesium sulphate tests, it passes. Based on the experimental investigation conducted by Poon and Chan (2007), the soundness test based on magnesium sulphate soundness test values for RCA was found to be 2.5% to 3.7%. In the study conducted by Tabsh and Abdelfatah (2009), the sodium sulphate soundness test was used. The soundness value for RCA came to be 12%. The soundness properties are affected by the pore size's distribution of the aggregate.

2.2.3.3.2 Alkali-Aggregate Reactivity

Alkali-aggregate reactivity (AAR) is responsible for the expansion and cracking of concrete because of their ability to react with alkalis over a period of given time (Adessina et al, 2019). It is reported in literature that RCA can increase the AAR if the previous aggregates used in it were vulnerable to react with alkalis (Adessina et al, 2019, McNeil and Kang, 2013, Ho et al, 2013). Additionally, presence of cement paste also contains some alkali content that can make the RCA based concrete more vulnerable to AAR.

2.2.3.3.3 Sulphate Content

The analysis of literature demonstrates that RCA has a higher level of sulphates as compared to NCA (Koushkbaghi et al, 2019). Poon and Chan (2007) state that high sulphate content of RCA is responsible for causing the cracking, expansion, and loss of strength in concrete. Poon and Chan (2007) studied the sulphate content in NCA and RCA and reported that the high amount of sulphate in RCA is because of the residual cement mortar.

2.2.3.3.4 Chloride Content

Another significant chemical property of RCA is associated with the chloride content, which is found to be higher in RCA as compared to NCA (Anderson, Uhlmeyer and Russell, 2009, Koushkbaghi et al, 2019). Because of this, the overall durability of the concrete is affected. They increase the possibility of corrosion in steel that is used for reinforcement within the concrete. Furthermore, it has been stated that concrete made from RCA can fail at initial level because of excessive steel corrosion(Anderson, Uhlmeyer and Russell, 2009).

2.2.3.3.5 Organic Matter

The presence of polymeric materials such as rubber, plastics, seals, and other materials such as wood, paper, and fabrics can be found in RCA (Ho et al, 2013). Under hot or cold weather, these materials become highly unstable. For RCA based concrete, the presence of organic matter should be less or equal to 0.15% (Andal, Shehata and Zacarias, 2016, Spaeth and Tegguer, 2013).

2.2.4 Recycled Concrete Aggregate based Concrete Properties

2.2.4.1 Fresh Properties

The use of RCA is responsible for affecting the overall properties of fresh concrete significantly because of its physical properties such as rough surface angular structure, high water absorption capacity, and higher pore volume (Aned, Nemes and Tayeh, 2020, Belagraa et al, 2020, Ali, Zidan and Ahmed, 2020). The influence of RCA properties on concrete is well documented.

2.2.4.1 Workability

The workability of the fresh concrete decreases because of angular shape and rough surface of the RCA particles (Bai et al, 2017). This is responsible for affecting the finish of the concrete. The decreased workability of the concrete increases substantially with the higher percentage of RCA used in the formation of the concrete. Furthermore, extra water is required to get the workability of the concrete. While it is stated that concrete mixes using RCA pass the slump requirements during the initial stages where the concrete is fresh, RCA has a higher absorption rate that leads to decreased workability (Bidabadi, Akbari and Panahi, 2020) Thus, this restricts the time required for the placement and finishing of the concrete. To address the problem associated with workability in RCA based concrete, it is essential to modify and control the moisture content.

2.2.4.2 Stability

As compared to NCA based concrete, RCA concrete has a lower rate of bleeding. Because of the presence of residual mortar in RCA, it mixes with the RCA based concrete mix and provided extra fine particles to the concrete (Hossain et al, 2019). These particles reduce bleeding in the concrete through the adsorption of the water from the mix. The presence of fine particles improves the overall cohesion of the concrete mixture at a relative lower water level. Furthermore, the angular and rough surface provider further cohesiveness in concrete, thus, increasing the overall stability of the concrete (Batham and Akhtar, 2019).

2.2.4.3 Wet Density

The analysis of literature demonstrates that the RCA concrete has a lower wet density as compared to ordinary concrete composed of NCA (Kazmi et al, 2020,Fortova and Pavlu, 2019). The RCA concrete's wet density is about 5 to 15 times lower than NCA concrete because of the presence of residual cement mortar (Berredjem, Arabi and Molez, 2020).

2.2.4.4 Air Content

In concrete, the air content is dependent on the volume of the mortar. RCA with non-entrained air and low residual cement mortar with the use of air-entraining admixtures can result in low performance concrete (Dilbas, Çakır and Atiş, 2019). At the same time, RCA from air-entrained concrete will also affect the overall properties of RCA based concrete because of its high pore volumes and lower density (Guo et al, 2018, Yehia et al, 2015). When an air-entrained RCA is used to make concrete, it will be unable to withstand the freezing and thawing actions in cold-weather.

2.2.5 Hardened Properties

The influence of RCA on the properties of concrete in its hardened state can vary based on its physical properties, its content level, its source, and its type (Guo et al, 2018, Yehia et al, 2015, Zhu et al, 2015, Jin et al, 2018). While generally it is revealed in studies that the RCA concrete properties decline when RCA is used as a substitute of NCA. The replacement level used is responsible for affecting the hardened properties of the concrete. generally, RCA can be replaced by NCA by 30% on basis of weight to ensure that the hardened properties of concrete are not affected in negative manner.

2.2.5.1 Dry Density

The RCA concrete's dry density is lower than NCA concrete by 5% to 15% because of the presence of residual mortar that is already present in the RCA (Bui, Satomi and Takahashi, 2017). Jin et al (2018) asserts that the residual cement mortar presence in RCA is found within the range of 30% to 60%, which is responsible for affecting the density of the RCA concrete.

2.2.5.2 Compressive Strength

One of the fundamental objectives of this research is to investigate the compressive strength of concrete using polypropylene fibre as reinforcement. This section will only discuss the compressive strength of RCA briefly. Many of the research has revealed that RCA concrete has lower compressive strength as compared to NCA concrete. The difference is in the range of 5% to 10% (Pacheco et al, 2019). However, the compressive strength is also dependent on the quality of RCA used. Compressive strength of RCA is also affected by higher air content, replacement level of RCA used to create the concrete, higher quantity of residual cement mortar and the use of fine RCA particles (Zhu et al, 2015, Jin et al, 2018).

2.2.5.3 Splitting Tensile Strength

Tamayo et al (2020)quotes that the research conducted by Nelson (2004) and asserts that the tensile strength of RCA concrete is lower as compared to NCA concrete and its value is lower than NCA concrete by 0% to 10%.

2.3 Sustainability of RCA

2.3.1The Need for Sustainability and Sustainable Materials in Construction Sector

Building structures are frequently subjected to changes that leads to their deterioration, are affected by natural disasters, and demolished to meet up the changing demands of the city. Sustainability from environmental perspective means the preservation and conservation of natural resources and protection of the flora and fauna in the ecosystem (Sivakrishna et al, 2020, Younis et al, 2020). It has been identified as the protection of the environment to fulfil the needs of the existing generation, while at the same time, ensuring that the natural resources are preserved for the future generation (Sivakrishna et al, 2020). It considered to be the precautionary approach that ensures that natural environment is not deteriorated by the human activities. It has also been adopted by the construction sector as it is responsible for generation of the massive amount of greenhouse emissions that contribute to global warming, increasing sea-levels, ozone layer depletion, and climate change conditions (Sneha and Senthamarai, 2018, Xuan, Poon and Zheng, 2018).

As landfills space are becoming costly and construction waste is being generated at a massive scale, researchers, academics, and industry professionals are calling for the adoption of sustainability to be adopted within the construction sector(Sivakrishna et al, 2020)(Younis et al, 2020, Gua et al, 2020, Ali et al, 2020, Makul, 2020). Other reasons for this call include preservation of natural resources that are being depleted at an alarming rate. Therefore, alternative construction materials are being explored (Arulrajah et al, 2014, Andreu and Miren, 2014, Lima et al, 2013, Kurda, de Brito and Silvestre, 2019).Many of the developed nations such as United States, France, United Kingdom, Australia, Germany, Canada, and China have adopted the use of concrete waste together with natural aggregates to create concrete for construction purposes (Ismail and Ramli, 2013, Andreu and Miren, 2014, Lima et al, 2013). In this domain, many researches have been conducted and therefore, majority of the researches have concluded the usage of recycled concrete waste is acceptable environmentally, technically, and economically.

2.3.2 The Need and Development of Recycled Concrete Aggregate

The construction sector primarily relies on NCA to form concrete. The global demand for NCA has increased significantly in recent years. In 2010, the global demand for NCA was found to be 25 billion tons (Sivakrishna et al, 2020). This demand increased to 60 billion in 2017 (Sivakrishna et al, 2020). The usage of NCA is common in South American, South-East Asian, and Middle Eastern countries such as Brazil, Mexico, Malaysia, China, Thailand, Saudi Arabia, United Arab Emirates (UAE), and Qatar (Sivakrishna et al, 2020,Younis et al, 2020). These economies have an active construction sector and as a result, depletion of natural resources is inevitable. In countries such as United States, United Kingdom, Germany, Sweden, France, and Canada have explored the use of RCA in construction, it still under development phase (Sivakrishna et al, 2020,Majhi, Nayak and Mukharjee, 2018, Damdelen, 2018, Sneha and Senthamarai, 2018, Xuan, Poon and Zheng, 2018). This is because of lack of standards and regulations associated with RCA and lack of expertise.

In terms of global warming, recycled concrete is considered to be an essential discipline of research and has gained attention of researchers. The usage of recycled concrete and other materials started during the 1940s in Europe after the end of World War II (Xuan, Poon and Zheng, 2018). The construction wastes and debris that was product of war and bombardments was successfully used as reconstruction material. As the most affected countries of World War II were United Kingdom and Germany, the usage of debris as a reconstruction material was popular. The debris used comprised of variety of materials such as bricks, natural stone, rubbers, and plastics along with hydraulic concrete.

The use of recycled concrete was first explored after the end of the World War II by former Soviet Union. P. Gluzhge explored and reported its usage in 1946 (Damdelen, 2018). After this, the use of recycled hydraulic concrete was conducted in United States as a material for roads and pavements and building homes (Majhi, Nayak and Mukharjee, 2018). The initial researches reported that the recycled concrete based roads and buildings were subjected to sulphate contamination because of the use of semi-hydrated calcium sulphate as plaster for these structures (Rashid et al, 2017). Consequently, the recycled concrete was damaged with the increase of corrosion in its steel reinforcement. While these initiatives were taken, the use of RCA was still at its nascent stage.

It was not until the 1980s when initiatives were introduced by European Union Countries to promote the recycling and reuse of concrete waste in the construction sector. The first country to adopt this initiative was Germany, which established the foundation of Federal Quality Association for Recycled Building Materials that was located in Berlin. This initiative was undertaken in 1984 (Silva et al, 2019). The goal of this association was to support recycling and reuse of construction waste. In 2006, the European Quality Association for Recycling was launched, which also emphasized on protection of the environment, adoption of sustainable construction practices, and management of concrete waste through recycle and reuse procedures

(Verian, Ashraf and Cao, 2018). The concept of recycling and reuse of concrete waste has also been supported by the USA government, Australian government, and New Zealand's government (Senaratne et al, 2017, Arulrajah et al, 2020, Silva et al, 2019, Shaban et al, 2019). In United States, the use of RCA is only limited to filler material for the base of roads. In Canada, RCA's usage in construction sector is only 3% (Shaban et al, 2019).

Within the European Union, the Waste Framework has been revised that mandates that all member states must recover 70% of the concrete waste to recycle and reuse it for building and construction sites (Arulrajah et al, 2020, Silva et al, 2019). The European Aggregate Association's foundation was laid out in 1987. The objective was to adoptive sustainable practices in terms of demand and supply of aggregates and to support the usage of RCA. By 2014, production of RCA increased in European by 8.6% (Shaban et al, 2019).

Within Australia, RCA development is done at governmental level. Between 2016 to 2018, a total of 86.34 tons of waste was produced in Australia (Arulrajah et al, 2020). Within this waste, 42% of the waste was concrete waste (Senaratne et al, 2017, Arulrajah et al, 2020). In China, 40% of the waste in the form of concrete waste. 100 million tons of waste comes from the new construction, whereas demolition of construction produces 200 million tons of waste (Ding, Xiao and Tam, 2016, Ma et al, 2019). In Hong Kong, 28% of the concrete waste comes from various construction activities such as clearance of site, demolition activities, site renovation and restoration, and road infrastructure development (Hossain, Xuan and Poon, 2017). In Hong Kong, some of the concrete waste is recycled and reused as RCA but the percentage of its usage is relatively very low (Hossain, Xuan and Poon, 2017). In Japan, the law of recycling concrete waste was introduced during the 1990s (Verian, Ashraf and Cao, 2018). Through this initiative, around 48% to 96% of the RCA is used as a base material for roads in Japan (Shaban et ,2019).

To create a sustainable concrete product with the use of RCA, it is essential that it meets the following criteria:

- The objective is to reuse the concrete waste with the objective of decreasing its presence in the environment.
- The product design and innovation are sustainable and environmentally friendly.
- Protection of natural aggregates, protection of the local flora and fauna, protection of the landscape, and conservation of mineral resources.
- Developing a material that reduces greenhouse emissions.

Table 2: *Current Status of RCA in Different Countries (Shaban et al, 2019)*

Country/Standard	Classification	Maximum replacement ratio of NA		Applications	Maximum strength
		Fine	coarse		
Germany, DIN 4226-100	RCA	0%	20-35%	Structural concrete, prestressed concrete not allowed	C30/37 (20% replacement), C25/30 (35% replacement)
	RMA & RA	-	-	Non-structural concrete	-
UK, BS 8500:2	RCA	0%	20%	Structural concrete	C40/50
	RA	0%	-	Non-structural concrete	-
HK, WBTC No.12/2002	RCA	0%	100%	Less demanding applications	20 MPa
			20%	structural concrete,	35 MPA
Japan, BCSJ	MRA	100%	100%	Foundations and less demanding situations	18 MPa
Japan, JIS A5021	MRA - Class H	-	-	No limitations	45 MPa
Japan, JIS A5022	MRA – Class M	-	-	Members not subjected to draying or freezing and thawing action	-
Japan JIS A5023	MRA – Class L	-	-	Backfill concrete, blinding concrete, leveling concrete	-
USA, ACI 555R-01	BA	0%	50%	Non-structural concrete	-
	RCA	50%	50%	Non-structural concrete	-

RCA: recycled concrete aggregate; RMA: recycled masonry aggregate; MRA: mixed concrete and masonry recycled aggregate; MRA - Class H: high-quality recycled aggregate; MRA - Class M: medium-quality recycled aggregate; MRA - Class L: low-quality recycled aggregate; BA: blending aggregate.

2.3.3 Benefits of RCA

Recycled concrete offers many potential benefits. These include reducing the requirement of natural resources needed to create the new concrete through the adoption of sustainable building materials and practices, reduction of costs associated with production and transportation of concrete's raw materials, and the use of the waste that would otherwise only become part of the waste in landfills (Sneha and Senthamarai, 2018, Xuan, Poon and Zheng, 2018). According to Damdelen (2018), recycled concrete aggregates is also responsible for helping the preservation of the environment as improper disposals techniques can be harmful. These benefits are discussed in detail.

2.3.4 RCA Saves Cost and Time

The use of RCA is proven to be beneficial as the extraction of the natural aggregates is lengthy, time consuming process, and requires a massive amount of efforts (Majhi, Nayak and Mukharjee, 2018). The NCAs are collected from the site and are transported to the construction sites, which can be affected by delays. Such delays are responsible for increasing the cost associated with the transportation and overall extraction of the NCAs. At the same time, demolition sites comprise of large amount of concrete wastes that is not recycled and is wasted (Rashid et al, 2017). This concrete can be crushed to overall reduce time, efforts, and cost associated with the NCA's extraction process. Reusing the waste can further enhance in developing sustainable concrete that would be economically viable.

2.3.5 Landfills Management

The construction sector produces large number of wastes worldwide. In European Union alone, the sector is responsible for the generation of 850 million tons of waste (Kurda, de Brito and Silvestre, 2019). In the United States, the waste production by the demolition of structures has reached 123 million tonnes on a yearly basis. In the global arena, the concrete waste generated primarily comes from the old structures, which are transported to landfills (Kurda, de Brito and Silvestre, 2019). With increasing problem associated with space and costs associated with landfills, the management of massive amount of concrete waste is considered to be problematic and difficult (de Brito and Kurda, 2020). Consequently, recycling construction waste and concrete can help in solid waste management, while at the same time, reducing the number of landfills required.

2.3.6 Reduction in Carbon and Greenhouse Emissions

As indicated in literature, RCA is efficient in terms of reducing carbon emissions and greenhouse emissions that are primary responsible for environmental problems such as global warming, increasing sea levels, climate change, and ozone layer depletion. According to Kisku et al (2017), RCA is beneficial since it acts as a substitute of NCA, thus supporting the conservation of natural resources, helps in reducing the cost associated with mining and quarrying of NCA, and overall reduces the greenhouse emissions associated with the entire production of concrete. In Australia, it has been reported that using RCA is effective in reducing carbon dioxide emissions by 22% to 46%, which is considered to be lower value as compared to carbon dioxide emissions produced by quarrying of NCA (Ahmed and Lim, 2020). In another research, it has been revealed that RCA reduced carbon dioxide emission by 22% to 28% (Ali et al, 2020). Studies conducted in United States have reported that RCA reduces carbon emissions by 30% (Makul, 2020, Dosho, 2020,Chan et al, 2019). Hossain et al (2016) study revealed that the use of RCA instead of NCA can be beneficial in reducing greenhouse emissions by 65%. Similar findings have been reported by Serres, Braymand and Feugeas (2016) and Wijayasundara, Crawford and Mendis, (2017).

2.3.2.4 Construction Material

The use of RCA as an alternate of concrete offers variety of applications in the construction field as a building material (Gua et al, 2020). Studies have revealed that common applications of RCA in the constructions sector including road infrastructure, concrete pavements, commercial, residential, and industrial building structures, and in retaining walls

(Senaratne et al, 2017, Arulrajah et al, 2020, Silva et al, 2019, Shaban et al, 2019, Sivakrishna et al, 2020, Younis et al, 2020, Gua et al, 2020). Studies have demonstrated that RCA can be replaced by NCA in the construction of road infrastructures for the base layers(Silva et al, 2019, Shaban et al, 2019) This is because the physical properties and geo-mechanical performance is similar to that of NCA. Consequently, researchers have reported that RCA is economically viable and environmentally friendly alternate of NCA (Senaratne et al, 2017, Shaban et al, 2019)

2.3.3 Disadvantages of RCA

The disadvantages of RCA are associated with its weak properties. The weak properties of RCA have already been discussed extensively in the previous section of the literature review and therefore, it will be discussed briefly here. Because of previous residual cement mortar presence and the existence of interfacial transition zone (ITZ), RCA is considered to have weak properties as compared to NCA. Weak properties affected by these two factors include high porosity, lower density, increased water absorption capacity, and decreasing workability (Limbachiya, Leelawat and Dhir 2000, Sagoe-Crentsil, Brown and Taylor, 2001, Cui et al, 2015, Belin et al, 2014, Gómez-Soberón, 2002, Katz, 2003, Xiao, Li, and Jhang, 2005, Evanelista, 2007). As a result, these properties affect the RCA's mechanical properties and durability (Zhou and Chen, 2017, Yang and Lee, 2017, Elansary, Ashmawy and Abdalla, 2020, Adessina et al, 2019, Bai et al, 2017).

2.4 Effects of Polypropylene Fiber on NAC and RCA

After water, concrete is the second most used material in the world. It is the most broadly utilized construction material. However, with the development in research and technology, different modifications have been implemented on the traditional concrete to acquire better quality cement and satisfy today's durability and mechanical necessities. Concrete recycling into recycled aggregates has been recognized as a possible source of construction aggregates. (Oikonomou, 2005)

Construction, demolition, and excavation waste have risen significantly as concrete engineering has advanced. It may be used to replace natural aggregate as a recycled aggregate, which not only reduces air emissions and construction-related wastage but also conserves natural resources. The mechanical strength and longevity of Recycled Aggregates Concrete (RAC) are, overall, inferior to those of normal concrete. To boost the mechanical properties and toughness of RAC, various fiber or mineral resources are commonly used. Polypropylene (PP) fiber is perhaps the most widely used fiber material in RAC, and it can enhance the strength and durability of the material while also compensating for several of the flaws. Recycling has become an important part of the construction industry while the idea to use sustainable building materials as well as creating "green concrete" has evolved.

This study investigates the previous literature on the impact of polypropylene fibers upon natural coarse aggregate (NCA) including recycled coarse aggregate (RCA) (RCA). Polypropylene fiber is used in the construction industry as an additive to enhance the properties of concrete. This alleviates the pressure of extracting existing scarce natural resources. Furthermore, by using RCA, environmental pollution resulting from waste disposal can be lowered.

2.4.1 Polypropylene fiber reinforced concrete

Gahleitner and Paulik, (2017) define Polypropylene fiber as an engineered fiber, transformed from 85 percent propylene, and utilized in various applications. Polypropylene fiber is utilized in various industries. It is the first stereoregular polymer that is valuable in the industrial sector as well. Moreover, PP fiber is a thermoplastic, which means that it gets moldable or pliable at a specific temperature and solidifies after cooling.

Though concrete has many benefits in terms of mechanical properties or economic factors of constructing, the material's brittle behaviors continue to be a major disadvantage for earthquakes and many other purposes wherever versatile behavior is crucial. However, the advancement of polypropylene fiber-reinforced concrete (PFRC) had given a technological foundation for addressing these shortcomings. Also, because fibers addition in concrete increases the hardness, split tensile, flexural strength, and effect resilience along with the mode of failure of concrete, thus the usage of PP fibers in structure construction had recently expanded significantly. Polypropylene fibers bind the concrete mix collectively. This lowers the rate of bleeding by slowing the settling of coarse aggregate. (Madhavi, Raju & Mathur, 2014)

In solidified concrete, PP fibers are used as crack arresters. Just like other secondary reinforcements, these fibers are used to prevent cracks from proliferating by holding the solid together so that cracks don't grow longer or spread wider. Anyhow, since PP fibers are circulated all through the concrete, these are effective at the areas where cracks initiate at the aggregate-paste interface.

In this way, the inclusion of Polypropylene fiber in RCA is a promising method for keeping intact the durability and strength properties of concrete, as these fibers keep up the concrete integrity by limiting the development of shrinkage and cracks. PP fiber being the most well-known polymer fiber category and effectively accessible is utilized for the replacement of natural coarse aggregate by recycled coarse aggregate. The replacement of natural coarse aggregate by recycled coarse aggregate causes a decline in durability and strength of concrete however these properties are enhanced by the expansion of PP fiber. It is due to the property of polypropylene fiber to keep up the concrete integrity and impart concrete strength. (Gahleitner&Paulik, 2017))

2.4.2 Effects of polypropylene fibers on a natural coarse aggregate and recycled coarse aggregate.

Previous literature has mentioned the advantages of concrete waste recycling. These advantages include their benefits in managing the over-release of demolition and construction wastes that in any case would have been released into landfills, diminishes the reliance of the construction sector on the natural aggregates, in this way saving the natural resources, yields various alternate sources for urban zones confronting lack of natural aggregates, and provide savings from waste disposal treatment. (Ismail, Hoe & Ramli, 2013)

According to recent research, the properties of Recycled Coarse Aggregate are inferior when contrasted with Natural Coarse Aggregate, therefore, the utilization of recycled coarse aggregate has been restricted to the development of non-primary applications and non-load bearing constructions. The study did not find any major negative impact on strength properties of concrete up to 30 percent substitution of natural coarse aggregate by recycled coarse aggregate; however, there is a steady decrease in strength with expansion in recycled coarse aggregate content beyond 30 percent. Subsequently, steps should be taken to hold the strength of concrete even after high rate substitution of natural coarse aggregate by recycled coarse aggregate. (Limbachiya, Leelawat, &Dhir, 2000)

Song et al. (2005) included Polypropylene fiber in concrete at rates of 0%, 0.25%, 0.5%, 0.75%, 1% & 1.5% and presumed that Polypropylene fiber builds the compressive strength, split flexural strength and tensile strength of cement up to 1.5% fiber expansion.

The impact of Polypropylene fibers relies on a few parameters, including size, type, surface properties, tensile strength stiffness, fiber-matrix bond, volume fraction, geometry, and aspect ratio. (Self-Compacting Concrete European Project Group, 2005)

Polypropylene fiber is used by Ju et al. (2018) in the reactive powder concrete and found that a volume fracture of between 0.3 and 0.9 percent PP fiber improved surface performance with mechanical properties.

When 50 percent to 100 percent of the natural aggregates (NA) are substituted for RCA, the strength properties of concrete decrease by 5% to 25%, while no noticeable effects of RCA are detected whenever the ratio of aggregate substitution stays below 30%. The separating, tensile, and flexural strengths of concrete are also affected by RCA additions. Increased RCA substitution ratios resulted in a reduction in tensile strength, as shown in the references. (Choi & Yuan, 2005)

In specific, Thomas et al (2013) discovered that perhaps the strength of RAC comprising 20%, 50%, and 100% RCA are 90%, 85%, and 80% of the strength of comparable NAC, collectively. Flexural strength losses because of RCA integration were also noted in another research (Topcu&Şengel, 2004). For example, they reported 13 percent to 30 percent declines in flexural strength for RCA rates up to 100 percent.

Another previous research (Rahal, 2007) noted a substantial decrease in the elastic modulus of concrete from rising RCA content; this is observed that RCA improvements would decrease the Young's modulus by up to 3%, 15%, and 20%, typically. Moreover, Thomas et al (2013) discovered that even the effect of RCA at elastic modulus could be substantially greater than those on compressive strength. Indeed, Xiao et al.(2005) affirmed so for a 100 percent RCA substitution ratio, the modulus of elasticity would decline significantly up to 45 percent.

In the related literature, the impact of RCA upon Poisson's ratio of concrete isn't yet adequately measured. Having said that, earlier research has discovered a great decline in Poisson's ratio by increasing the RCA substitution ratio. (Corinaldesi, 2010)

Fibers are also used to enhance the properties of concrete. In fact, when opposed to unreinforced concrete, fiber-reinforced concrete has higher crack resistance, flexural strength, ultimate tensile, bearing capacity, durability, and hardness. The fiber's presence also causes concrete to become more relatively homogenous, isotropic, even tensile. (Ashour, Hasanain, &Wafa, 1992)

Polypropylene fibers (PPF) in particular are commonly used within structural concrete to improve its consistency, power, and durability. (Akça, Çakır&İpek, 2015) The most significant advantage of fiber-reinforced concrete is its ability to withstand bigger displacements preceding the outbreak of the very first crack; the fibers will usually remain unbreakable when cracks appear, and then those fibers trying to bridge the crack would restrict against further openings. The major disadvantage of increasing the fiber content of concrete is that it loses flowability. (Corinaldesi, 2010)

For example, Bayasi and Zeng (1993) previously suggested that PPF enhancements with such a volume concentration greater than 0.5 percent resulted in a reduction in slump values, whereas PPF has no effects on flowability whenever the volume fraction is less or equivalent to 0.3 percent. Moreover, Alsadey and Salem (2016) discovered that whenever the volume fraction of PPF surpassed 1% and 2%, simultaneously, concrete stiffened as well as presented significant positioning or even compaction problems. The compressive strength of concrete is hampered by fiber blending and indeed the resulting rise in friction force. (Alsadey& Salem, 2016)

Xiao et al. (2005) discovered that even by replacing 50 percent or more of RA (coarse or fine) by NA, mechanical properties can be decreased; additionally, while using 100 percent substitution of RA, high storage density can be used to achieve adequate ductility and toughness.

Moreover, Polypropylene fibers have been added to recycled coarse aggregate to diminish its consistence. According to research conducted by Matar and Assaad [58], when polypropylene fibers (having 150 aspect ratio and 12 mm long) were utilized with a recycled coarse aggregate, the descending pattern of the 150 aspect ratio diminishes with expanding polypropylene fiber content. This might be because of adhesive boundary between the polypropylene fibers and the matrix; the little pores enhanced the water absorption of matrix. In this case, the surface area of the polypropylene fibers was coated using mortar that helped reduce the matrix fluidity. As a result, the researchers found a great decrease within the slump of the matrix.

Though PPF additions have no effect on compressive strength, they do greatly enhance flexural s well as split tensile strengths. (Bayasi& Zeng, 1993) Nevertheless, Mohod (2015) indicated that for PPF ratios up to 0.5 percent, the improvement in splitting tensile strength and flexural strength was observed, where after such strengths declined. The PPF effect on the modulus of elasticity and Poisson's ratio of concrete still has not been studied extensively. Nonetheless, previous research indicates that PPF additions reduce both the modulus of elasticity and also Poisson's ratio of concrete. (Akça, Çakır&İpek, 2015).

2.4.3 Comparison of effects of polypropylene fibers on a natural coarse aggregate and recycled coarse aggregate.

The mechanical and physical properties of RCA vary markedly from those of natural aggregates. Natural aggregates as well as a special portion of hardened concrete that covers the actual aggregate particles make up RCA. In particular, the RCA is composed of 65 to 70 percent natural aggregates and 30 to 35 percent rigidly adhere concrete. The prevalence of adhering mortars to recycled aggregate is the primary reason for the low quality in comparison to natural aggregates since the rigidly adhere mortar is translucent and has countless microcracks. (Poon, Shui & Lam, 2004) As an outcome, when compared to pure aggregate, RCA characteristics have a smaller footprint, greater water holding capacity, with low permeability.

Poor recycled aggregate characteristics, that have a significant impact upon concrete performance, are becoming a dilemma, and the consequences have restricted the extensive commercial usage of recycled aggregate in concrete manufacturing. Therefore, in order to realize wide commercial usage of RAC throughout the construction sector, especially in engineering material, the detrimental impacts associated with RCA's innate poor quality should be reduced. (Padmini, Ramamurthy & Mathews, 2009).

As a reaction, while using RCA throughout the development of new concrete, such aggregate features could have a negative impact on the strength and durability properties of concrete. Table 1 shows an overview of the properties of natural aggregate concrete compared with recycled aggregate concrete as identified by various researchers.

Prior literature, as evidenced by the researchers (Ismail & Ramli, 2014) has suggested substrate methods of treatment with the ability to minimize the negative impacts of RCA. The substrate of coarse RCA was amended in this study by covering this with wollastonite (calcium metasilicate) particles prior to inserting it into the RAC mixture. These studies have shown that the impact of this therapy will increase the interfacial bonding among both RCA and the fresh cement paste in new concrete, thus enhancing concrete workability. Nevertheless, when making new concrete, concentrating solely on enhancing RCA structures with surface treatments without considering certain ongoing residual mortar is deemed inadequate.

Table 3: *Comparison of RAC properties with NAC (Wan Muhammad, Sallehan Ismail & Wan Abdullah Wan Alwi, 2016).*

RAC Properties	Comparison of RAC with NAC	References
Modulus of elasticity	Reduced more than 20 percent	(Kou, Poon, &Agrela, 2011)
Compressive strength	Reduced up to 20 percent	(Poon, Shui & Lam, 2004), (*Yang & Han, 2006*)
Workability	Increased slump loss	(Poon, Shui & Lam, 2004), (Rao et al., 2007)
Splitting & flexural tensile strength	Reduced more than 10 percent	(Tabsh&Abdelfatah, 2009), (Gómez-Soberón, 2002)
Chloride penetration	Increased or lower resistance	(Ann, Moon, Kim &Ryou, 2008)
Water absorption	Increased up to 40 percent	(Grdic, Toplicic-Curcic, Despotovic&Ristic, 2010)
Drying shrinkage	Increased more than 30 percent	(Gómez-Soberón, 2002)

The results reported that the influence of surface treatment method will only affect the enhancement of RAC property through to a certain degree, with either the effect of surface treatment often being helpful for enhancing the interfaces bonding among aggregate-new mortar and aggregate-old, adhered mortar bonds. The existence of adhered mortar on RCA can affect the RAC to become a heterogeneous and brittle material characteristic than that of normal concrete. (Poon, Shui & Lam, 2004).

Consequently, in addition to the stages that enhance RCA qualities by surface treatment, studies offer insight into the advantages of using fiber reinforcement systems in increasing RAC properties. According to previous research, when short discrete fibers are arbitrarily scattered in the concrete matrix, the tactile is reinforced and the slipperiness of the concrete reduces. The fibers addition to concrete will improve cracking strength by bridging the gap within the metal surface of current microcracks, delaying crack initiation, and limiting crack propagation. (Şahin&Köksal, 2011) Additionally, the well-distributed fiber improves the inner structure of concrete, thereby increasing its longevity. As a result, the current experimental investigation explores the implications of using polypropylene fiber at different volume concentrations mostly on mechanical and permeability characteristics of RAC containing processed rough RCA.

The mechanical properties, flexural strength, and ultrasonic wave velocity of modified RAC specimens consisting of processed coarse RCA and corresponding fiber at different content specimens were subjected. Furthermore, the permeability of adjusted RAC is evaluated by measuring the absorption of water and performing a total porosity test. The findings are compared to typical RAC (unmodified) specimens, that serve as controls. With the proper analysis of the findings, it is possible to calculate the most acceptable and optimal fiber percentage which contributes to a significant improvement of the performance of modifying RAC produce. (Peled, Jones & Shah, 2005)

RAs do have a porous structure, a bigger circular impact, greater gaps, excessive water absorption, lower apparent concentrations, as well as a maximum corrosion capacity when contrast to NAs. Therefore, RCAs have an effect on concrete consistency. The downturn of self-compacting concrete (SCC) reduced by 13.4 percent if the water/binder (w/b) ratio was 0.4 and also the RCA contents varied between 0 to 100 percent. (Sun, Chen, Xiao & Liu, 2020)

RAs are distinguished from NAs by their higher water emission. higher flowability, low stiffness and toughness, greater shrinkage, and decreased evident pressure due to the presence of weak particles like old mortar blocks. (Yang & Han, 2006).

Although their performance is superior to that of NAs, RAs are environmentally friendly construction materials with significant application valuation. Whenever the percentage of RA replacing NA is 30%, the substitution seems to have no effect on certain concrete properties like compressive properties, flexural modulus, chloride-ion corrosion, or tartness. Nevertheless, as the RA content increases, the matrix's compressive strength decreases. (Limbachiya, Meddah&Ouchagour, 2012).

Cakir et al. (2015) analyzed various combinations of polypropylene fiber and recycled coarse aggregate in the concrete mix and contrasted it with natural concrete mix. The researcher figured out that the ideal blend for flexural strength, compressive strength, and split tensile strength was different. At the point where compressive strength accomplished its most extreme value at 1 percent fiber content, flexural strength and split tensile strength kept on expanding even beyond 1 percent.

Once the aggregate in the matrix is entirely substituted by RA, the matrix tensile strength decreased thrice as much when its RA contents are 50% [16]. Under the same circumstance, the matrix ductility tensile strength drops by 10–13% compared with the reference concrete. (Ajdukiewicz&Kliszczewicz, 2002) This could be owing to an old mortar associated with RA. The old mortar has several cracks and faults, that increase the matrix's consumption of water. Nonetheless, Rao et al. (2007) indicated that the ratio of RA in the matrix does not affect the matrix's bending and tensile strength. The stress–strain curve and maximum level of stress underneath the lateral force of recycled coarse aggregate (RCA) concrete are comparable to that of natural aggregate concrete (NAC). The strain increases as the RA content increases and the modulus of elasticity and compressive strength are less than those in NAC. (Limbachiya, Meddah&Ouchagour, 2012).

As in the range of temperatures of 25–800 C, Gowda et al. (2017) revealed that perhaps the compressive strength and stiffness of RCA concrete are comparable to that of normal concrete. Gales et al. (2016) stated that since the matrix was placed in a 500 C environment and indeed the RA contents enhanced, the matrix's remnant strength and modulus of elasticity unsteadily declined. It also suggests that RAC is more resistant to high temperatures than NAC.

All things considered, different researchers studied the effects of polypropylene fibers on NCA and RCA. It can be concluded that these investigations presented by the researchers about the impact of PP fiber on NCA and RCA depend on the basis of different parameters such as modulus of elasticity, split tensile strength, flexural strength, and compressive strength. Moreover, the effects of polypropylene fibers on a natural coarse aggregate and recycled coarse aggregate can further be examined to gain more understanding of the influence of PP fibers on NCA and RCA.

2.5 Compressive Strength of Recycled Aggregate Concrete Reinforced with Polypropylene Fibers

Concerning the influence of polypropylene fibers on the compressive strength of concrete, conflicting arguments have been made. The aim of this paper is to explore the influences of various dosages of monofilament polypropylene fibers on compressive strength when it is used in concrete. Since compressive strength is commonly used as a key measure of concrete construction, it must be determined precisely.

The results of different polypropylene fiber dosages in low/medium and medium/high strength concrete on compressive strength are contrasted to analyze the compressive strength of recycled aggregate concrete reinforced with polypropylene fibers. The paper includes analysis of previous literature including various tests and their results to measure compressive strength.

According to the Building Research Establishment, "performance testing on specimens revealed that the cube tensile strength of concrete comprising polypropylene fibers was substantially decreased due to the resulting lower density" (This must be included in the construction, but compressive strength and reliability are not always specifically connected). This argument contradicts the findings of Alhozaimy et al. (1996), who say that polypropylene fibers have no statistically meaningful impact on compressive power. The points above were major considerations in shaping this document. According to Aulia (2002), using certain fiber volumes in concrete did not have a negative impact on the core mechanical properties of higher strength concretes.

The research towards the use of polypropylene fibers in high strength concrete indicates that perhaps the effect of fibers in low concrete strength behave differently than that of high strength concrete, and this feature is studied throughout this study. Warner (1995) conducted compressive and flexural strength tests on several concrete samples containing different forms of fibrillated polypropylene fiber and glass fiber additions between 1 and 28 days after batch processing. Warner's concrete had a compressive strength of about 45 N/mm2 with a cement substitution of pulverized fuel ash of 27% as well as water to cement ratio of 0.45. Fibermesh provided 6,130 collated fibrillated 100 percent polypropylene fibers in lengths of 19 mm, 38 mm, and 50 mm at a dosage of 0.9 kg/m3.

The fiberglass concrete samples were overlooked for this study because the similarities included as in the study only relates to polypropylene fiber used in concrete. Compressive intensity testing followed BS 1:4:1: Part 116: 1983. When the efficiency of the concrete with varying fiber addition was compared to those of normal or basic concrete, substantial results were found. During 3-, 7-, 14-, and 28-day cycles, the fibers of 19 nun length outperform the fiber of 38 mm and 50 mm. Table 2 indicates the percentage shifts. The final strength comparison after 28 days revealed a 5% improvement in compressive strength, which is statistically negligible considering the dynamic existence of concrete.

As previously mentioned, it is proposed that the compressive strength of polypropylene fiber reinforced concrete is slightly diminished. While Gold (2000) has mentioned a potential explanation for lower compressive strength and density if using polypropylene monofilament fibers. This is because "Fibres naturally entrain small quantities of air as a result of the surface treatment they undergo during the production process," providing a possible explanation for the lesser frequency and resulting compressive power. But, in the author's view, owing to the many factors found inside the concrete, this is not a definitive description and deserves further investigation. If air entrainment was caused by concrete with a monofilament fiber attachment. Thus, monofilament polypropylene fiber concrete can act similarly to air compressed concrete in that "at regular water cementing material levels, changes in the air would substantially minimize intensity".Every other percentage of entrained air decrease strength property by around 2% to 9% in medium concrete strength. (Çakır, 2014) The true strength differs and is determined either by the nature of the cementing components, admixtures, and other concrete additives.

According to Alhozaimy (1996, p. 85), separate authors have registered conflicting test findings of the impact of polypropylene fibers mostly on flexural strength and compressive strength of concrete materials. The disparities in performance may be attributed to differences in a matrix structure, polypropylene volume fraction and fiber form, and institutional frameworks. A work comparison by Mindness and Vondran (1988) and Hughes and Fattuhi (1976) shows a discrepancy in empirical test results, with Mindness and Vondran claiming a 25% rise in compressive strength and Hughes and Fattuhi claiming a 25% decrease in compressive strength.

The complexity and variability of findings allow a strong argument for further experimental research to gain a deeper insight into the effect of polypropylene fibers throughout the concrete matrix.

The following benefits are claimed for concrete with monofilament polypropylene fiber additions: Young age break repression; lesser water demand; quality of blend; long durability; improved pressure to failings; improved cure caused by water preservation; removal of the need for structural support for controlling crack (particularly while using crimped/structural fibers) in some situations; A performance benefit against steel reinforcing fibers; a finer crack-free complete; better resistance to water; improved durability; and an improvement in reliability and reduced life - cycle cost, including environmental and financial. An aspect that is rarely discussed is the loss of strength properties while polypropylene fibers are being used in concrete.

The variation of compressive strength and toughness among plain concrete and fiber additive concrete around the continuum of low/medium concrete strength and medium/high concrete strength indicates how polypropylene fibers, often used as concrete reinforcement, can influence an array of concrete strengths in concrete compressive strength as contrasted to a certain simple concrete mix. The decreased compressive strength was believed to be caused either by the presence of the fibers within the cement matrix of concrete, that, due to their poor bearing capacity, formed splits in the CSH bond among the cement and the underlying aggregate (Richardson, 2005). The integration of monofilament polypropylene fibers within cement is significant since nearly half a million fibers per cubic meter would include 30 million splits in the cement-aggregate bonding, yet this insertion reflects a wide contact area of materials breaching the cement bond with a substantially reduced weight presence.

The decreased density cannot even be justified adequately by the entrapped air or indeed the low density of fiber addition. During the slump experiments, rising water persistence (low bleed) was found, which was believed to provide better hydration of the cement, resulting in a larger amount of cement paste with resultant evaporation pockets, resulting in reduced density. The measured lowered density could be explained by the fact that "fibers made a contribution to the difficulties of compressing the lower density" (Büyüköztürk, 2006). When clarifying concrete to fiber inclusion, the producer should modify the mix design to sustain compressive strength.

When 50 percent to 100 percent of the natural aggregates (NA) are substituted with RCA, the strength properties of concrete reduce by 5% to 25%, whereas no potential impacts of RCA are found when the aggregate substitution level stays below 30%. (Dilbas, Şimşek&Çakır, 2014)

The workability of concrete is hindered by fiber bunching and the resultant rise in inner friction. (Monteiro, Paulini&Nanukuttan, 2016) This dilemma, though, can be mitigated to some degree by the inclusion of an appropriate additive capable of providing a uniformity of fibers distribution in the concrete mixture. Though PPF improvements have little effect on tensile strength (Bayasi& Zeng, 1993), they do substantially increase split-ting toughness and flexural strengths. However, Mohod (2015) indicated that for PPF ratios up to 0.5 percent, the enhancements in splitting tensile strength and flexural strength were observed, then these strengths declined. Nonetheless, previous research indicates that PPF additions reduce both modulus of elasticity and Poisson's proportion of concrete. (Akça, Çakır&İpek, 2015).

2.5.1 Mechanical properties of compressive strength of RCA

As the polypropylene fiber content rises from 0% to 2, the compressive strength of RAC also increases. (Hanumesh, Harish & Ramana, 2018) According to a recent study by Zahid-

Hossein et al. (2019), the compressive strength with 10 percent recycled coast aggregate in the matrix was better than that with 30 percent of RCA. This outcome is almost comparable to the research investigation by Choi and Yun (2012) and might be because of the great capacity of water-absorption of RCA compared with NCA that makes the inner hydration response of the substrate more comprehensive. Adding 30 percent of recycled coast aggregates helps improve the porosity of concrete and diminishes the compressive strength. The polypropylene fibers are used as bridges in the cement paste, deferring the break spread and improving the strength of concrete. As mentioned in Figure 3 (a) and (b) given below, the impact of RCA on the compressive strength of recycled coarse aggregate is more noteworthy than that of polypropylene fibers. Moreover, the ideal measure of polypropylene fivers varies for various substrates. Along these lines, the measure of RAC added to concrete is ≤30 percent, and the suitable measure of polypropylene fiber added to the framework can improve the compressive strength matrix.

Figure 3 (a): *Impact of PPF on the compressive strength of Recycled Aggregate Concrete with w/c ratio of 0.55 (Zhang, Yang, Wang, Jiao & Ling, 2020)*

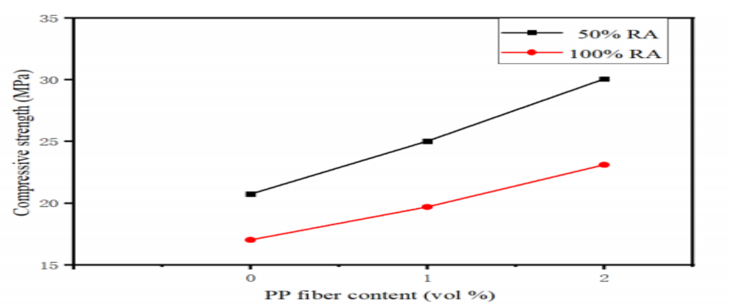
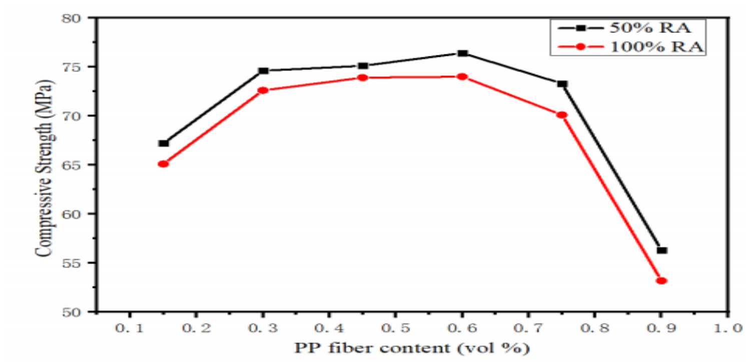


Figure 3 (b): *Impact of PPF on the compressive strength of Recycled Aggregate Concrete with w/c ratio of 0.22–0.2 (Zhang, Yang, Wang, Jiao & Ling, 2020)*



(b)

2.5.2 Effect of Recycled Coarse Aggregate on compressive strength

This study shows the drop in compressive strength, however, the compressive strength of RCA can be believed comparable to the compressive strength of NCA. Therefore, we can assume that the new interfacial transition zone is somewhat vulnerable than the old interfacial transition zone and it relates to the primary parameter overseeing the performance of concrete strength. (Otsuki, Miyazato &Yodsudjai, 2003) The compressive strengths of NCA and RCA are related to the presence of this new ITZ, with generally comparable properties in the two sorts of concrete. Katz (2003) also proposed a similar idea who presumed that more concrete (both non-hydrated and hydrated) linked to RCA increases the aggregate sum of concrete in the concrete mixture.

2.5.3 Effect of PPF on the compressive strength

The different deviations of compressive strength with increased polyethylene fiber content showed comparable patterns in both NAC and RAC. Overall, the compressive strength expanded with the consolidation of polyethylene fiber, however, this increment was not critical, and the noticed estimations of compressive strength stayed inside the normal reach for repeatability. For instance, the 28-day f'c of the RAC25 blend didn't change essentially with increased polyethylene fiber content; the recorded qualities were 31.92, 31.47, and 32.19 MPa for polyethylene fiber substance of 0.15%, 0%, and 0.3%. It would thus be able to be affirmed that polyethylene fiber has an insignificant effect on the compressive strength of concrete.

These outcomes are in concurrence with different investigations (Mohod, M.V., 2015; Akça, Çakır&İpek, 2015) which concludes that there is no huge improvement of compressive strength brought about by the expansion of polyethylene fiber. Moreover, Akça et al (2015)] found that the compressive strength was contrarily influenced by 1 percent and 1.5 percent polyethylene fiber increments. Another researcher Kayali et al. (2003) noticed a limited positive outcome of little positive amounts on the compressive strength of lightweight total solid, such as 0% and 4.6% improvement relating to 0.28% and 0.56% PPF expansion rates, individually. They additionally reported a huge 10.8 percent drop in compressive strength upon the addition of a large amount of polyethylene fiber. The test outcomes acquired in this study are reliable with other relevant research studies discussed above that show that aggregate type has the biggest impact on compressive strength when contrasted with the inclusion of polyethylene fiber.

All things considered, the findings from various previous studies discussed in this paper show that the incorporation of short discrete PP fibers at various proportions can improve the compressive strength of recycled coast aggregate. The outcomes show that the maximum value of compressive strength is acquired when RAC specimens were added with PPF at 0.6% of fiber content.

Chapter 3. Experimental Investigation

3.1 **Experimental Program**

The main objective to achieve in this paper is to evaluate the compressive strength of recycled aggregate concrete reinforced with polypropylene fibers. A standard size of 54 cubes with M30 grade concrete were casted to find the compressive strength at different ages. The mix design was designed as per the British Standard for concrete design BS 8500. In this experiment nine mixes were performed with 0%, 25%, 50% of RAC, and for each mix the PP fibers were added at 0, 0.20% and 0.35% by volume of specimen. NAC which has 0% of RAC samples were taken as a control specimen for comparison purpose. Moreover, 3 samples of each mix were cast and tested then the average of the three samples will be the considered result of each mix. Table 4 summarizes the mixing plan of this experiment.

Table 4*: Mixing Plan of Experiment*

Mix #	**Code**	**Type of Aggregate**	**PP Fiber Content**	**Cubes QTY**	
				7 Days	**28 Days**
1	RCA0/PPF0	Normal Weight Aggregate	0%	3	3
2	RCA0/PPF0.2		0.2%	3	3
3	RCA0/PPF0.35		0.35%	3	3
4	RCA25/PPF0	Recycled Coarse Aggregate	0%	3	3
5	RCA25/PPF0.2		0.2%	3	3
6	RCA25/PPF0.35		0.35%	3	3
7	RCA50/PPF0		0%	3	3
8	RCA50/PPF0.2		0.2%	3	3
9	RCA50/PPF0.35		0.35%	3	3

3.2 Materials

3.2.1 Aggregate properties.

The normal aggregates were basalt aggregate mined from a local quarry, and the natural sand was mined from a local pit. The recycled coarse aggregate utilized in this experiment was obtained from Bee'ah, and samples were gathered to evaluate the physical and mechanical properties of the recycled aggregate. The aggregates particle size were between 4.75mm and 19mm for coarse aggregate, and below than 4.75mm for natural sand and fine aggregates. Their properties were calculated by using test methods described in international standards.

Table 5: Aggregate properties.

Property	Standard	Normal aggregates		Recycled aggregates	
		Coarse	Fine	Coarse	Fine
		12.5/19 mm	4.75/12.5 mm	12.5/19 mm	4.75/12.5 mm
Bulk dry specific gravity	ASTM C128	2.76	2.74	2.39	2.4
Bulk saturated surface dry (SSD) specific gravity	ASTM C128	2.79	2.77	2.51	2.53
Apparent specific gravity	ASTM C128	2.73	2.71	2.68	2.69
Water absorption/%	B.S 812-103	0.61	0.85	3.61	3.63
Fineness modulus	ASTM C128	0.5	10.4	0.81	0.85
Crushing value/%	BS 812-110	27.1	N/A	30.1	N/A

Impact value/%	BS 812-112	4.1	N/A	5.4	N/A
Bulk density (dry roddedunit weight)/(kg·m^{-3})	ASTMC29	1,653	1,673	1,501	1,517

Figure 4: (a) recycled aggregate **(b)** 4.75/12.5 aggregate **(c)** 12.5/19mm aggregate

(a) **(b)** **(c)**

3.2.1.1 Absorption.

The water absorption for recycled aggregate and normal weight aggregate were evaluated according to BS 812: PART 2: 1995 CLS. 5.5in the Sharjah municipality materials laboratory. The results indicated that the recycled aggregate has greater absorption capacity than the normal weight aggregate, this is anticipated with the high porosity. The challenging part here is to prepare a mix that will not have any probability of shrinkage of getting dry after the final set of concrete.

3.2.1.2 Relative Density.

The relative density of the normal weight aggregate and the four recycled aggregate batches were determined in accordance to BS 812: PART 2: 1995 CLS. 5.5

Table 6: *relative density of the Normal Weight Aggregate & Recycled Aggregate.*

	NWA		RCA
	10mm	20mm	
Apparent Relative Density	2.77	2.78	2.71-2.73
Relative Density on Oven Dried	2.72	2.74	2.29-2.34
Relative Density on (S.S.D)	2.74	2.75	2.47-2.50

3.2.2 Cement:

The cement was used Ordinary Portland cement of 43 grade confirming to BS EN 196-1:2005 standards was used to cast the cubes. The specific gravity of cement was noticed as 3.1.

3.3Polypropylene (PP) Fibers.

Eco-Fiber PP is a micro reinforcement manufactured of 100% polypropylene fibers designed for all cementitious mixes. The use of this fiber within a concrete mix will control shrinkage cracks. It has a high flexural strength resistance, high post cracking control. Ecofiber PP is widely used in bridge, road, underground waterproof projects, wall, roof. The PP Fibers were purchased from Envirocon Construction Products Factory, Abu-Dhabi. The physical properties for these fibers are shown in table 7.

Table 7: *Physical properties of pp fiber*

Specification	EcoFiber PP (Polypropylene)
Identical Diameter	35±5 µm
Density (g/cm^3)	0.91 – 0.93
Length (mm)	Ava. In 3, 6, 12, and 19 mm
Tensile strength (Mpa)	≥500 MPa
Modulus of Elasticity	≥3500 Mpa

Melting Point(^{O}C)	160 – 180 ^{O}C
Elongation at Break	≥15%
Codes	AST C1116 / ANSI-SDI C-1.0

Figure 5: Polypropylene fibers.

3.3 Mixing Stage

The 54 cubes were casted and tested. 6 cubes were cast as a control containing normal weight aggregate. 12 cubes are prepared with normal weight aggregate and polypropylene fiber percentages of 0.20%, and 0.35%. Remaining 54 cubes were casted with recycled aggregate with percentages of 25%, and 50% along with polypropylene fibers.

3.4 Admixture

In order to achieve the target slump, a water reducer Spectra 212EB a new generation polycarboxylate blend high performance superplasticizer. It is formulated from blend of polycarboxylate polymers using state-of-the-art technologies to produce a superplasticizer for promoting high early and ultimate strength with high slump values concrete. Spectra 212EB conforms to the requirements of ASTM C494 Type G and EN 934-2. The specific gravity of Spectra 212EB is 1.10 ± 0.02.

3.4 Testing

The proposed 54 cubes were prepared, casted and tested. 6 cubes were used as a control including normal weight aggregate. 12 cubes are prepared with normal weight aggregate and polypropylene fiber percentages of 0.20%, and 0.35%. Remaining 54 cubes were casted with recycled aggregate with percentages of 25%, and 50% along with polypropylene fibers.

3.4.1 Compressive Strength

The compressive strength of concrete was determined at 7 and 28 days according to BS 1881-108: 1983. Tests were executed concrete cubes of standard dimensions, i e, 150x150x150mm. The chosen specimens exposed to a compression tests are demonstrated in Figure 6.

Figure 6: Concrete cubes subjected to compression tests: (a) RCA0/PPF0; (b) RCA0/PPF0.20; (c) RCA0/PPF0.35; (d) RCA25/PPF0; (e) RCA25/PPF0.20; (f) RCA25/PPF0.35; (g) RCA50/PPF0; (h) RCA50/PPF0.20; (i) RCA50/PPF0.35

(a)

(b)

(c)

(h)

(d)

(e)

(f)

(g)

(h)

(i)

Table 8: concrete mix proportions

Weight, kg per 1 m3 of concrete										
Mix	Cement	Natural crushed aggregates		Natural Sand	Recycled aggregates		Water	SP	PPF	Bulk density (kg·m^{-3})
		4.75/19 mm	< 4.75 mm	< 4.75 mm	4.75/19 mm	< 4.75 mm				
RCA0 /PPF0	370	928	620	325	0	0	175	2	0	2,420
RCA0/PPF0.20	370	928	620	325	0	0	175	2.5	0.20%	2,424
RCA0/PPF0.35	370	928	620	325	0	0	175	2.95	0.35%	2,426
RCA25/PPF0	370	687	465	320	241	155	185	1.5	0	2,425
RCA25/PPF0.20	370	687	465	320	241	155	185	2.2	0.20%	2,427
RCA25/PPF0.35	370	687	465	320	241	155	185	3.5	0.35%	2,430
RCA50/PPF0	370	350	230	320	350	235	195	1.2	0	2,051
RCA50/PPF0.20	370	350	230	320	350	235	234	1.7	0.20%	2,092
RCA50/PPF0.35	370	350	230	320	350	235	234	2.1	0.35%	2,094

Chapter 4. Results

In this chapter, the compressive strength of the cubes from the experimental results is presented in Table 9. According to the review of the literature, the usage of PPF in natural aggregate concrete (NAC) is reasonably well known. Fortunately, further research towards the usage of PPF in recycled aggregate concrete (RAC) is required. This paper is conducted to evaluate the impact of PPF on the compressive strength of RAC. It looks at how PPF influences compressive intensity. Three different series of concrete mixes were formulated for this reason, with RCA ratios contributing to 0%, 25%, and 50%. In each sequence, three PPF volume fractions of 0%, 0.20 %, and 0.35 % also were preserved.

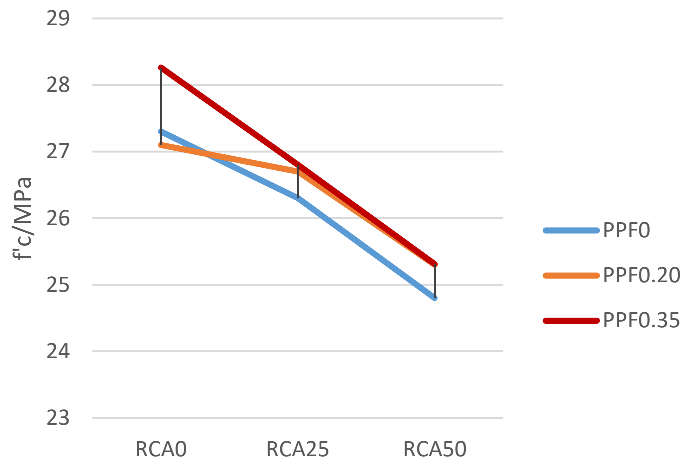
Table 9: Compressive Strength test results at 7 & 28 days.

Mix	*Avg.* f'_c /MPa		% difference
	7 Days	28 Days	
RCA0/PPF0	27.30	34.32	-
RCA0/PPF0.20	27.10	35.44	3.26%
RCA0/PPF0.35	28.26	36.30	5.70%
RCA25/PPF0	26.30	33.10	3.68%
RCA25/PPF0.20	26.70	34.70	2.13%
RCA25/PPF0.35	26.80	34.90	4.01%
RCA50/PPF0	24.80	31.90	7.59%
RCA50/PPF0.20	25.30	32.40	9.38%
RCA50/PPF0.35	25.31	32.90	10.33%

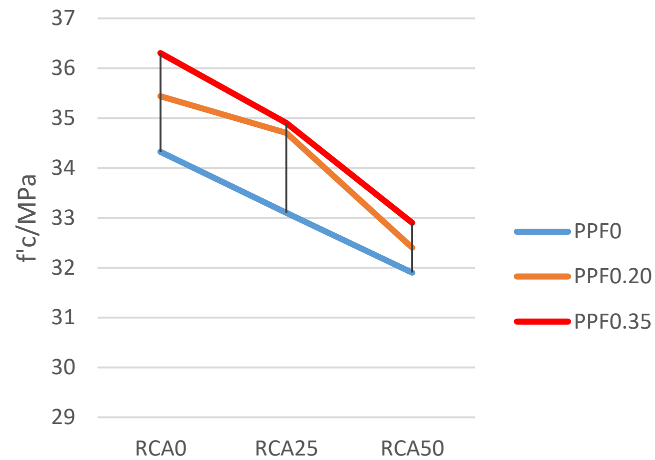
The compressive strength marginally reduced to the replacement of 25% and 50% of the NWA with RCA. Moreover, the reduction in the 28- day for the 25% RCA replacement is very small, i e, 4.01%, 2.13%, and 3.68% in the mixes with 0%, 0.20%, and 0.35% PPF mixes, respectively, and to some extent higher for 50% RCA replacement, i e, 10.33%, 9.38%, and 7.59% for the 0%, 0.20%, and 0.35% PPF addition, respectively. For instance, f'c of the control mix RCA0 at 28 days went down from 34.32 MPa to 33.10MPa and 31.90Mpa in the mixes containing 25% and 50% of RCA, respectively. Generally, the usage of polypropylene fiber increased the compressive strength, though this increase was not significant. The addition of PPF increased the compressive strength, but with a minimal influence. For instance, the 28 day f'c of RAC25 mix did not change considerably with an addition of PPF; the noted values were 33.10 MPa, 34.70 MPa, and 34.90 MPa for PPF percentages of 0%, 0.20%, and 0.35%, respectively.

Multiple studies have proven declines in compressive intensity with increasing RCA content (Evangelista & Brito, 2007), ((Akça, Çakır&İpek, 2015)), but these decreases were not greater than 12%. Specifically, Xiao, Li J, and Zhang C (2005) reported 6%, 12%, 10%, and 12% falls in intensity, comparable to RCA replacement levels of 30%, 50%, 70%, and 100%, respectively. Rahal (2007) observed a 6–12% reduction in strength after replacing all existing coarse aggregates with RCA in five separate concrete groups. The results evaluated in Table 6 are illustrated in Figure 7.

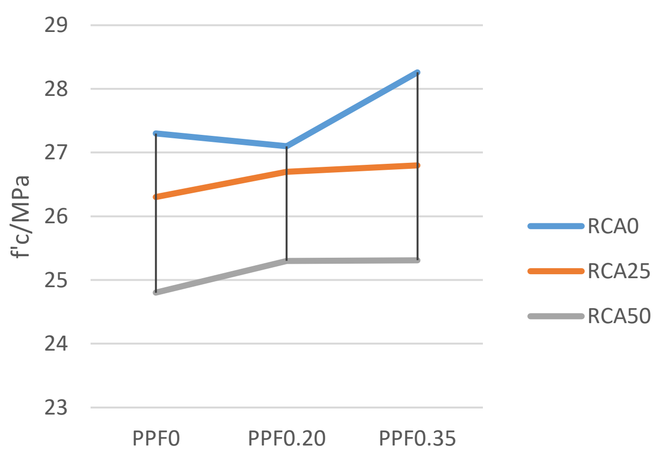
Figure 7: Effect of RCA and PPF on the compressive strength



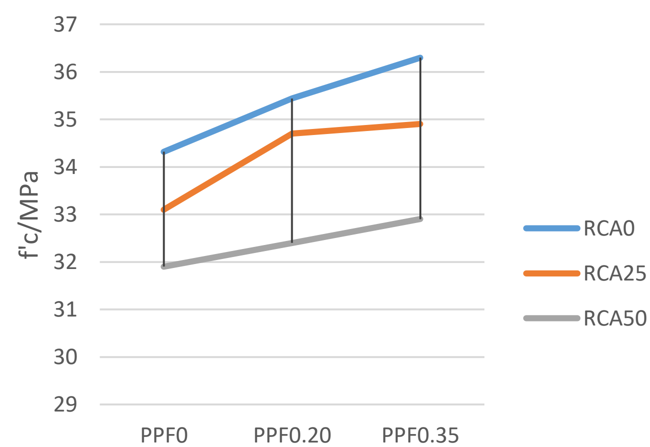
(a) Effect of RCA on the compressive strength at 7 days



(b) Effect of RCA on the compressive strength at 28 days



(c) Effect of RCA on the compressive strength at 7 days



(d) Effect of RCA on the compressive strength at 28 days

Chapter 5. Conclusion and Recommendations

Dumping of construction and demolition wastes is becoming a major problem in many developing countries and have serious effects on the environment, and economy. In this paper, an investigation was held on the usability of aggregates extracted from C&D to prepare mixes with addition of PPF. To reach to a conclusion 54 cubes were prepared, casted and tested. 6 cubes were cast as a control containing normal weight aggregate. 12 cubes are prepared with normal weight aggregate and polypropylene fiber percentages of 0.20%, and 0.35%. Remaining 36 cubes were casted with recycled aggregate with percentages of 25%, and 50% along with polypropylene fibers. Tests were done on two periods: 7 & 28 days. In general, the recycled aggregate concrete needs more water to attain the same workability of normal concrete. The density and compressive strength are lower for recycled aggregate concrete than normal concrete. The test results presented a reduction in the 28- day for the 25% RCA replacement is very small, i e, 4.01%, 2.13%, and 3.68% in the mixes with 0%, 0.20%, and 0.35% respectively, and to some extent higher for 50% RCA substitution, i e, 10.33%, 9.38%, and 7.59% for the 0%, 0.20%, and 0.35% PPF addition, respectively. The workability of concrete decreases due do the high tendency of water absorption for recycled aggregates. Especially, the incorporation of PPF in the mixes negatively affected the gradation, which it led to some changes on the compressive strength parameters. Also, PPF mixes revealed a higher demand of water to reduce the clumping of fiber. The addition of a high-range water reducer superplasticizer admixture will attain the desirable workability. The test results held from the investigation in this study presented that the compressive strength decreases with RCA replacement. The RCA mixes without fiber reinforcement showed a minor reduction in the mechanical properties, specifically the compressive strength. This reduction is considered due to the higher absorption capacity of RCA to absorb water this will lead to a more porous concrete. Moreover, an increase in water absorption was not only witnessed in normal weight aggregate mixes but also in the recycled aggregate mixes due to the addition of fibers. Which will increase the possibility of having a greater number of voids that will demand a huge need of water to be filled in. In this investigation, a clear approach shows that it is possible to an extent to produce structural concrete with RCA derived from construction and demolition waste. Still, a proper usage of RCA depends on the material quality of the demolished structure. It is recommended to use RCA at fields which have low structural risk factor such as road concretes.

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