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FLEXURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS USING PVC PLASTIC PIPES WASTE PARTICLES AS SAND REPLACEMENT

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بسم الله الرحمن الرحيم

﴿نَرْفَعُ دَرَجَاتٍ مَّن نَّشَاءُ ۗ وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ﴾

سورة يوسف الآية 76

صدق الله العلي العظيم

DEDICATION

To my Allah

Thank you for the guidance, strength, power of mind, protection, and skills

To my parents

They have been my source of inspiration and gave me strength when I thought of giving up, who continually provide their moral, spiritual, emotional Support

To my brothers, sisters, friends, colleagues and teachers

Who shared their words of advice and encouragement to finish this study

All of these

I offer to you

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ABSTRACT

This study endeavors to measure the effect of using polyvinyl chloride (PVC) wastes as a partial substation of fine aggregate which investigated the study of mechanical and physical properties of concrete beside its impact on the flexural behavior of reinforced concrete beams.

The work was divided into two parts. The first part deal with the influence of partial replacement of sand with PVC wastes on the mechanical and physical properties of concrete. Five replacement percentages were used, namely 5%, 10%, 15%, 20% and 30%. The Mechanical tests at ages of 7, 14, and 28 days included the compressive strength, splitting tensile strength, flexural tensile strength, abrasion and modulus of elasticity, while the physical tests included the density, ultrasonic velocity and absorption. The results showed that the specimens which containing partial substitution ratios ranging within 5%–10% showed 15.86%–21.08%, 14.29%–21.43%, and 5%–6.67% increments in the compressive, tensile, and flexural strengths, respectively than the reference specimen. The optimum replacement percentage of PVC is 10% and the mechanical properties (compressive strength, splitting tensile strength, flexural strength) decreased when the PVC content exceeds 15%. The findings also revealed a decreasing in modulus of elasticity, abrasion,

density and ultrasonic pulse velocity of concrete while the absorption ratio increased when the percentages of PVC increased in concrete mixture.

The second part deal with the effect of using PVC waste as a partial replacement of sand on the flexural behavior of reinforced concrete beams. Five 150 * 300 * 2300 mm concrete beams with similar steel reinforcement (one beam for each PVC percentage) in addition to the reference concrete beam were investigated. Beams tested for ultimate load failure, ultimate deflection, energy absorption, stiffness, ductility index, and compression strain. Cracks investigation which including first crack load and crack pattern, then compare it with the reference beams to evaluate the effect of PVC wastes on its flexural behavior. The results showed that the increasing of PVC wastes content in the concrete beams led to increasing in the ultimate failure load at a rate ranging within 1.18%-3.73%, the ultimate deflection at a rate ranging within 4.64%-50.87% , ductility index at a rate ranging within 9.01%-151.44%, strain at a rate ranging within 1.94%-7.38% , energy absorption at a rate ranging within 8.31%-59.24% and the first crack load at a rate ranging within 16.67%-76.67% respectively. While a reduction in the initial and secant stiffness at a rate ranging within 9.09%-28.15% and 3.3%–34.9%, respectively.

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LIST OF SYMBOLES

ε_c Compression Strain

D.I Ductility Index

E Modulus of Elasticity in GPa

$fc`$ Cylinder concrete compressive strength in MPa

f_{cu} Cube Compressive Strength in MPa

fr Modulus of rupture in MPa

ft Tensile strength in MPa

fy Yield strength in MPa

ɣ Density in Kg/m^3

I.S Initial Stiffness in kN/mm

Pcr First Crack Load in kN

Pu Ultimate Load in kN

S.S Secant Stiffness in kN/mm

Δu Deflection in mm

LIST OF ABBREVIATIONS

Ab Absorption

ACI American Concrete Institute

ASTM American Society for Testing and Materials

BS British standard

HDPE High Density Polyethylene

LDPE Low-density polyethylene

PET Polyethylene Terephthalate

PP Polypropylene

PPVC Plasticized Polyvinyl Chloride

PS Polystyrene

PVC Polyvinyl chloride

RAC Recycled Aggregate Concrete

SP Superplasticizer

UPV Ultrasonic Pulse Velocity

UPVC Unplasticized Polyvinyl Chloride

w/c Water to cement ratio

CHAPTER ONE: INTRODUCTION

1.1 General

Concrete is the most widely used substance in the world after water. The main characteristics of concrete, such as quality, adaptability, accessibility, adequate compressive strength, and durability that have made concrete the most popular building material. That have come to accept the usage of concrete and led to its reputation as the most regularly was using construction material worldwide in many different uses, including as bridges, high-rise structures, highways, dams, and others. Also, the population of the world in the 21st century has surpassed eight billion people [1]. This has caused the demand for concrete to rise. Each year, more than 11.6 billion tons of concrete are produced globally, by 2050 that amount is anticipated to reach 18 billion tons [2]. The massive increase in construction activity and the population increases demand for construction materials This results in the depletion of the natural resources used to form concrete, particularly the aggregate, which represents almost three-quarters of the concrete's volume [3]. Thus, the use of alternative materials now is absolutely important. On the other hand, the quantity of solid waste increased significantly along with the rise in population capacity. The environmental and ecological systems are most at risk from these non-degradable wastes, which also increase pollution. Some of these wastes degrade over time, while others do not. The problem for most countries is how to handle this waste because there are various ways to do it without causing environmental destruction. The waste management hierarchy guidelines state that there are three basic ways to handle post-consumer plastic waste: landfilling, incineration, and recycling [4]. Landfilling now, has been regarded the final option for attempting to deal with waste plastic due to it takes up a lot of space and causes a lot of pollution. Due to the high content of polymers calorific and the fact that trash is fully eliminated, incineration is used in many nations. However, additionally to the harmful bottom and fly, a large quantity of carbon dioxide and toxic materials are published into the environment; that's also especially likely if the incineration procedures are not designed properly and governed. Most people agree that recycling the waste of plastic because it is the greatest strategy to lessen the environmental of consequences which include the using of natural resources, climate change, disposal of waste, pollution and the consumption of energy. Between all various recycling and control systems types, the waste reusability and recovered plastic in the construction process appears to being the most perfect option to reduce the waste of plastic because all material can used to replace natural resources of construction, typically little expensive [5].

1.2 Sustainability

The World Commission on Environment and Development defines sustainability as growth that meet current demands without compromising the ability of future generations to meet their own needs [6]. The ability to continue maintaining or sustaining a process over time is referred to as sustainability in its wide meaning. Stopping the natural resource depletion is the goal of sustainable development and ensure their long-term availability. One of the most important materials that can be sustainable is concrete. In addition to its durability and strength, it can be produced in environmentally friendly ways by recycling the waste materials found in nature, such as plastic, wood, rubber, fly ash, etc., and replacing them with one of the components of concrete (cement or aggregates). The concrete industry can provide a sustainable future for coming generations through sustainable concrete buildings and infrastructure. Additionally, because durable, environmentally friendly facilities often lead to better air quality and increase the productivity, these buildings frequently produce more. In conclusion, reducing the amount of water and cement used, as well as applying only high-quality, long-lasting materials and chemical additives, would help the cement and concrete industries remain sustainable.

1.3 Plastic Waste

Plastic is a versatile product that is used in a various application, including packaging, agriculture and construction. Since its invention for industrial use in 1920, plastics have become incredibly popular all over the world. The various advantages of plastics have led to an expansion in their production by plastics-related industries. Plastics are less expensive, stronger per unit of weight, more resistant to abrasion and damage (more durable), simple in the work, and have a lower density than other materials like glass and metal. In the 1960s, the manufacturing of plastics multiplied twenty times, and during the next 20 years, with the resulting million tons of plastic waste, it is anticipated to double once again [7]. The global production of plastic garbage is estimated to reach more than 300 million tons each year. [8]. Presently, recycling only plays a minimal part in how this plastic waste is disposed off, with the majority of it being burned or thrown into landfills Figure 1.1. In contrast, discarded plastics often endanger the environment. While it is impossible to stop the production of plastics in all their forms, recycling of plastic may be a way to lessen the environmental danger by plastic waste. In accordance with estimates from [9], just 9% of all plastics created between 1950 and 2015 were recycled. This recycled amount of plastic can be raised by recycling waste to materials appropriate for construction and building [10]. Figure 1.2 shows the total plastic waste quantity that produced and disposed of during 1950–2015, as well as the amount expected by 2050. Only 16% of the waste produced up to 2015 was recycled. Up to 33% of waste generated is expected to be recycled by 2050. Even if this forecast is correct, the amount of non-recycled waste will be unsatisfactory. [8].

Figure 1.1 Waste of Plastic in Landfills

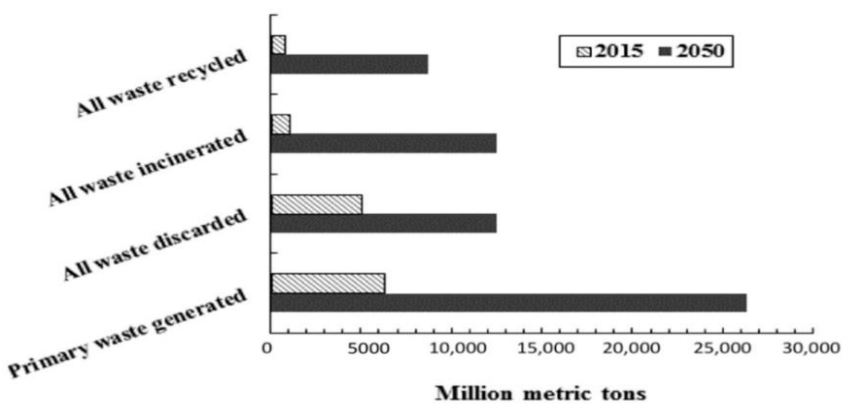


Figure 1.2 Production and Disposal of Plastic Wastes Cumulatively 2015-2050 [8].

1.3.1 Plastic Waste in Concrete

With a world concrete more than 5.3 billion cubic meters of production each year [9], there could be a significant opportunity to use recycled plastics in concrete. One possible option utilizes it as aggregate in concrete for many purposes. On the other hand, aggregates are the main component of concrete and continued mining has made aggregate availability which type of challenge in recent times. To solve this problem, some substitutes for aggregates must be found. When using the waste of plastic instead of the natural aggregate in concrete may assist in lowering the quantity of non-recycled waste of plastic even more. In concrete mixtures, plastic aggregate is used to partially replace either fine aggregate FA or coarse aggregate CA. plastic aggregates are widely employed in the manufacturing of lightweight concrete because its density lower than the natural aggregate [11].

1.3.2 Types of Plastic Waste Used in Concrete

As shown in Figure 1.3, many kinds of plastic waste can be incorporated into concrete mixtures in two ways: either plastic fiber or plastic aggregate. Can be listed briefly [12]:

- Polyethylene terephthalate PET: This kind of plastic is used in packaging, especially drink bottles, fibers, mineral water bottles, and food packaging., etc.
- High Density polyethylene HDPE: This kind of plastic used to make various containers, such as bottles of water, buckets, pipes, caps, mugs, garbage bags, and so on.
- Low-density polyethylene (LDPE): It is utilized in a variety of applications, including wire and cable insulation, milk packaging, miniature squeeze bottles, carrier bags, and heavy-duty bags.
- Polyvinyl chloride (PVC): PVC is versatile. There are two kinds of PVC: unplasticized polyvinyl chloride and plasticized polyvinyl chloride. Unplasticized Polyvinyl Chloride (UPVC) is rigid, tough, and transparent. These types of plastic are suitable for pipes used in sanitary and plumbing. Plasticized Polyvinyl Chloride (PPVC) is a transparent, elastic, and flexible material. It can be found in garden of the hoses, tubing, shoe bottoms, and bags of blood.
- Polypropylene (PP): it's used in Pipes, Bottles, sheets, furniture, household products, containers of ice cream, and other products are made of polypropylene.

- Polystyrene (PS): PS used in many applications such as Electrical and communication equipment such as plugs, sockets, switch plates, spacers, toys, wall tiles, baskets, dishes, mugs, and other items are made of polystyrene.

Figure 1.3 Types of Plastic Waste

1.4 PVC Plastic

Polyvinylchloride, or PVC, also known as vinyl, is a kind of thermoplastic polymer that is widely used in many fields of life for worldwide trends, including domestic and industrial uses. This substance, which is produced when the vinyl chloride monomer is polymerized, may be shaped into a variety of hard and soft objects. PVC has become a global polymer due to its intrinsic features, due to its low cost and great performance, combined with the wide variety of products that may be generated from different processing conditions and procedures [13]. Nonetheless, it can be turned into either short-life application, such as food and medical device packaging, or long-life applications, such as plumbing pipes, doors, windows, and roofing sheets [14]. According to estimates, 39.3 million tons of PVC were consumed globally in 2013.The demand for PVC is predicted to increase by around 3.2% year until 2021. [15]. Due to the PVC industry's explosive growth, PVC waste disposal has become a big topic in public discourse. Furthermore, even if long-life PVC products have a long service life they will ultimately degrade into trash because there is a significant time lag between PVC use and the buildup of PVC waste [16].

1.4.1 PVC Waste

As mentioned above, PVC products are available in a wide range today, and since this plastic is used so frequently. There is a significant amount of waste produced as a result. This waste poses a significant threat to water and land pollution, Figure 1.4. This type of polymer poses a greater risk than others, such as polyethylene terephthalate (PET) due to the presence of chlorine which makes up roughly 57% of its chemical composition. Thus, it is imperative to remove the waste of PVC products from the environment and eliminate any potential for further pollution [17]. One simple method of dealing with PVC waste, namely landfilling, has becoming more costly in many nations. Due to increased consumption, this form of disposal is no longer acceptable. Diminishing landfill space, and potential environmental risks linked to the polymer's chlorine concentration [13]. Recycling is a better option for recovering without posing any unique environmental risks. PVC recycling and recognition has expanded in recent years and it is now a topic of rising interest for various researchers. However, since the middle of the 1980s, as a result of the development of so many recycling activities, PVC recycling rates have been rising rapidly in the United States and Europe[18]. The amount of recycled PVC in Europe from 2003 to 2008 is shown in Figure 1.5. While Figure 1.6 compares the amount of recycled PVC by country in Europe in 2008 [19].

Figure 1.4 Types of PVC Waste in Landfills

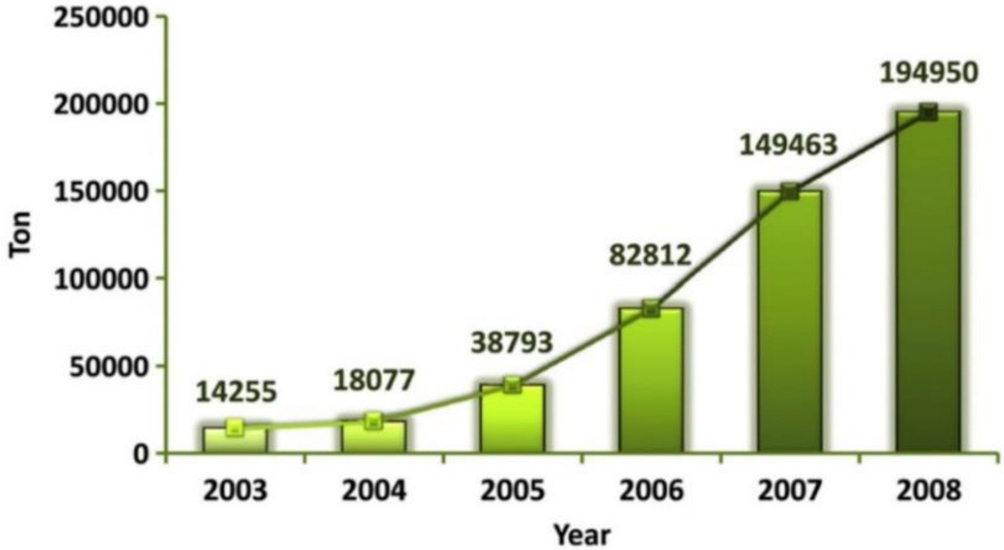


Figure 1.5 The Amount Of Recycled PVC In Europe 2003-2008 [19].

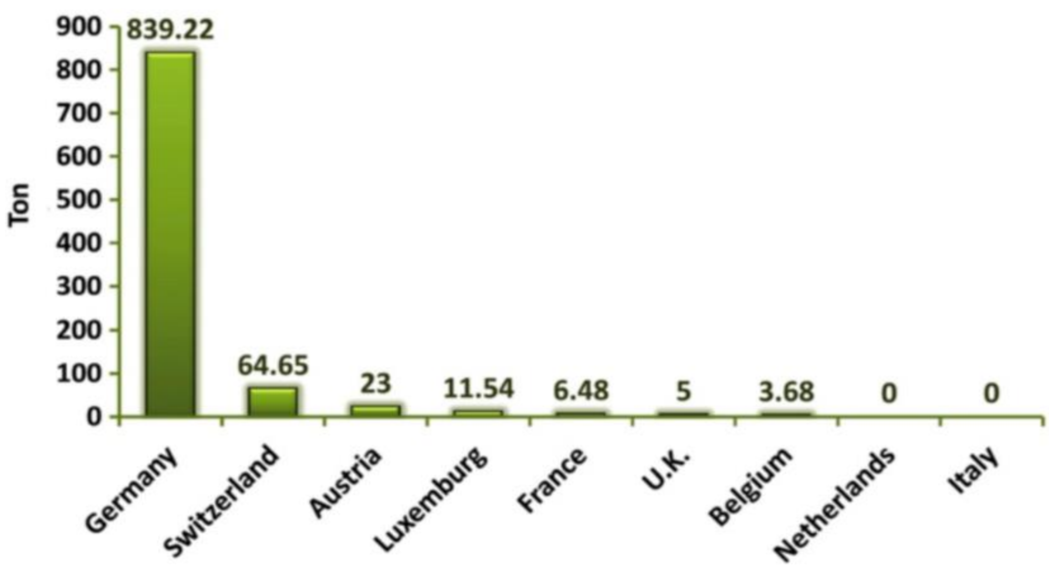


Figure 1.6 The Amount Of Recycled Roofing Materials By Country In Europe In 2008 [19].

1.4.2 Incorporation of PVC Plastic Waste in Concrete

PVC waste can still not be efficiently recycled in a practical manner. Large amounts of PVC waste will undoubtedly need to be disposed of as solid waste. Additionally, it is anticipated that construction and demolition projects will produce a substantial amount of PVC waste. Therefore, there is serious interest in the prospect of recycling this PVC waste. This social awareness has created a need for improved PVC waste recycling techniques. Given the high demand for concrete around the world particularly in developing economies like China and the recent lack of river sand. Recycling PVC waste to substitute it for the production of concrete can be one of the most environmentally sustainable ways. In this regard, it is possible to highlight the use of waste PVC in the production of concrete as a creative solution with favorable effects on the environment and the economy [20].

1.5 Research Objectives

The current study is concerned with the use of one type of plastic waste found in Misan province; polyvinyl chloride (PVC) scrapped pipes in the form of fine aggregate as sand replacement in concrete mixtures and beams. By incorporating these wastes, concrete's properties are improved. In addition, it has two advantages. The first advantage is an economic one, represented by the provision of a sustainable material that can substitute other concrete components, and the second is environmental, represented by the treatment of some problems associated with solid waste.

While the following points represents the research's scientific objectives:

- Study the influence of adding scraped PVC waste granules on the mechanical and physical properties of the normal concrete in order to enhance its behavior.
- determine the optimal percentage of plastic PVC can used as a partially replacement for fine aggregate in the concrete.
- Create new types of applications, support natural aggregate sources and study the possibility of applying this work in reality and benefiting from it in wide applications.
- Finally, knowing how these materials effect on the flexural behavior of the beams.

1.6 Thesis Layout

The research is divided into five chapters, occur in the following:

- The first chapter presents an overview of population increase and how it relates to the amount of waste disposed of and the manufacturing of concrete. Additionally, a discussion of the advantages of sustainability, green concrete, and an overview of the management of plastic waste in general, particularly PVC waste, as well as some global statistics, are also included. Recycle PVC waste in concrete mixture as well.
- The second chapter reviews the results from previous research's and discusses how different plastic waste and especially PVC waste
- as a sand replacement affect the characteristics and behavior of concrete mixtures.
- The third chapter contained information on the specifications of material, samples details, equipment's, mixing ratios, and tests that were used in the study.
- The fourth chapter presents and discusses the work's results and relationships between them.
- The fifth chapter presents the summary of the research findings, as well as some recommendations and proposals that document this study and strategies to achieve them for the scientific benefit of future researches.

CHAPTER TWO: LITERATURE REVIEW

2.1 General

The technology of replacing aggregate (fine aggregate especially) in concrete mixtures and mortars by many types of plastic wastes has recently appeared because of the huge amount of plastic waste in cities and landfills. Polyvinyl waste is a type of plastic that is abundant in the environment, but there are few studies to recycle of it as solid waste in construction and concrete in particular. This chapter summarizes the studies that dealt with replacing sand of various types of plastic waste. The first part represents the studies that include different types of plastic wastes without PVC plastic as a fine aggregate in concrete mixtures and mortars. The second used the PVC particles as a sand replacement.

2.2 Recycle of Plastic Wastes as Fine Aggregate

In 2005, Y. Choi et al. [21] used waste of polyethylene terephthalate (PET) bottles in the size range of 5–15 mm Figure 2.1 to replace fine aggregate in concrete with volumetric ratios (0%, 25%, 50%, and 75%) and investigated different w/c ratios (0.45, 0.49, and 0.5). The results showed that the mix improved in workability and reduced in density and compressive strength when the percentage of replacement increased (the max reduction in compressive strength is about 33% when the ratio of replacement is 75% compared with the reference mix.

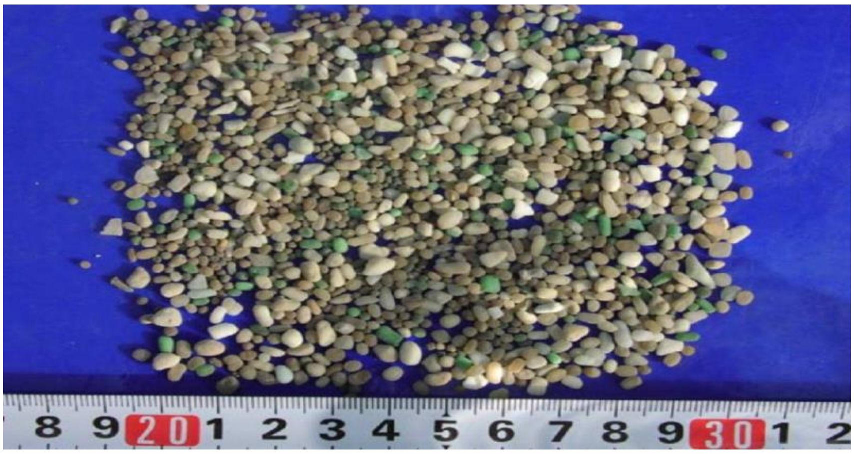


Figure 2.1 PET Wastes [21].

In 2008, Z. Ismail and E. Al-Hashmi [22] investigated the plastic waste from plastic containers (it is made of 20% polystyrene and 80% polyethylene) with various lengths and widths of 0.15–12mm and 0.15–4mm, respectively, as shown Figure 2.2. Sand is replaced in partial ratios, which are 0%, 10%, 15%, and, 20% by weight in the mixture of concrete. They used mixed proportions (1cement: 1.88 sand: 2.68 gravel) with w/c 0.53. These mixtures were cured for 3, 7, 14, and 28 days for fresh and hardened concrete. noted that increasing in plastic ratio led to decrease the values of slump, dry density, compressive strength, and flexural strength in all ages.

Figure 2.2 Particles of PET Waste [22].

In 2009, A. Kan and R. Demirbog˘a [23] used waste obtained from expanded polystyrene foam (EPS) to replace a partial amount of aggregate (sand and gravel) in the concrete mixture. The maximum particle size of EPS was 4 mm and 16 mm for sand and gravel, respectively, with volumetric dosages of (0%, 25%, 50%, 75%, and 100%). The results of this study showed a decrease in the workability but a good ease of compacting and finishing. The density was also reduced when the ratio of EPS increased, followed by compressive strength, tensile strength, and ultrasonic pulse velocity. It was also discovered that as the aggregate size decreased, the strength of MEPS concrete increased slightly.

In 2009, C. Albano et al. [24] replaced fine aggregate with recycled Polyethylene Terephthalate (PET) of particles sizes from 0.26 cm to 1.14 cm with a different water to cement ratios of 0.50 and 0.60. The percentages of replacement were 10%, and 20% by volume. it found that the decreasing of the properties by increasing PET content as represented by compressive, tensile, flexural strengths, ultrasonic pulse velocity and modulus of elasticity. Because PET has less workability than concrete, it increases the porosity of the mixture, which raises the water absorption percentage in concrete-PET mixes when these factors change. In general, it is claimed that used PET bottles can be recycled into concrete aggregates, which will result in less concrete weight and environmental protection. Figure 2.3 shows the failure modes of compressive strength testing that demonstrated in the cylinders.

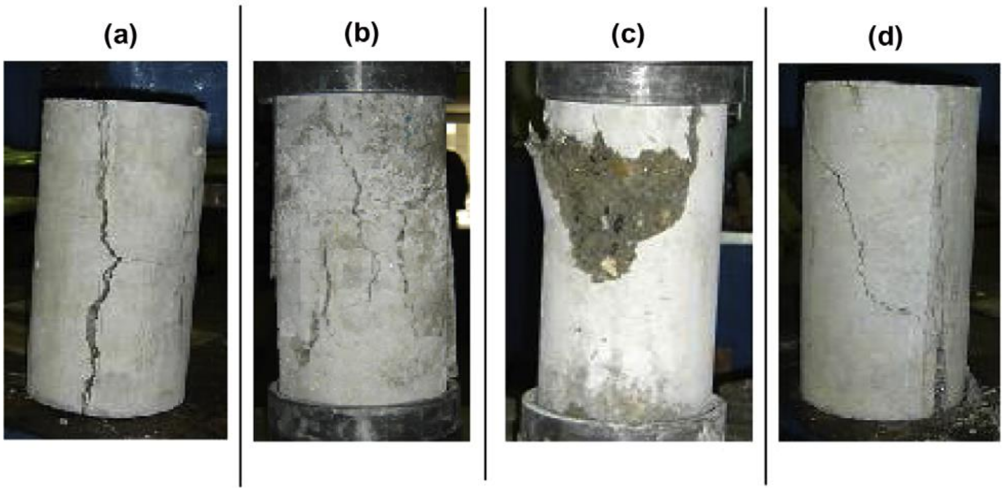


Figure 2.3 Failure Modes of Cylinders Under Compressive Load [24].

In 2010, M. Frigione [25] replaced fine aggregate with PET form bottle waste of sizes 0.1–5 mm and a ratio of 5% by weight. The content of mixture and w/c is about 300-400 kg/m^3 and 0.45-0.55; respectively. The results pointed out that there was a slight reduction in compression strength and tensile strength of about 0.4% and 1.9%, respectively, under the reference mixture, with little increase in ductility.

In 2011, J. Galvãoet al. [26] investigated the impact of incorporating low-density polyethylene (LDPE), crushed polyethylene terephthalate (PET) and rubber from unwanted tires with maximum sizes of 2.4, 12.5 and 2.4 mm respectively as fine aggregate replacement. The ratios of partial replacement were 0.5%, 1.0%, 2.5%, 5.0%, and 7.5% by weight. The mixing proportions were (1 cement: 1.93 sand: 3.07 gravel) with a 0.45 water to cement ratio. The result showed a reduction in the value of slump and compressive strength with an increase of polymers added to the concrete. The addition of polymeric waste to the concrete increased the material's resistance to underwater erosion-abrasion testing.

In 2012, R. Wang and C. Meyer [27] used recycled high impact polystyrene (HIPS) to replace sand in cement mortar. As displayed in Figure 2.4, the PVC waste, with a particle size smaller than 4 mm, was replaced with ratios of 10%, 20%, and 50% by volume of sand. The mix proportions were 1 cement to 3 sand, and water to cement ratio of 0.55. The results indicated that the use of HIPS in mortar reduced the dry density where the mortar qualified as lightweight mortar at 50% HIPS substitution. At the same time, the compressive and tensile strength decreased at 10%, 20%, and 50% by 12%, 22%, 49%, and 1.1%, 1.2%, and 1.8%, respectively. On the other hand, the strain increased when the partial ratio of HIPS increased and the elastic modulus decreased, which led to the mortar becoming more ductile.

Figure 2.4 HIPS Waste Particles [27].

In 2013, E. Rahmani et al. [28] used the PET bottle as a partial substitute for fine aggregate in the concrete mixture at a volume replacement rate of 5%, 10%, and 15% with a maximum aggregate size of 7 mm, as shown in Figure 2.5 with two mixtures (used two w/c 0.42 and 0.54). Tests were conducted for both fresh laid and hardened concrete. As the percentage of plastic waste rose, it saw that the slump reduced. In addition, w/c = 0.42 results in greater strength, and it was found that the ideal percentage for sand replacement was 5%, although 10% substitution of sand produced the same compressive strength as control specimens.

Figure 2.5 Waste Of PET Plastic [28].

In 2015, S. Yang et al. [29] studied the effect of adding polypropylene plastic waste (PP) to the lightweight concrete mixture as a fine aggregate. As shown in Figure 2.6, they used short columns of 1.5–4 mm length with partial substitution ratios of 10%, 15%, 20%, and 30%. The proportions of the mix were (1 cement: 1.27 sand: 0.5 gravel) with w/c equal to 0.255, in addition to fly ash and admixture ratios equal to 30% and 0.1%, respectively. The findings indicated enhanced workability, reduction in dry density and modulus of elasticity when the ratio of plastic increases. Also noticed improvements in compressive, splitting tensile and flexural strength by increasing the variables above when the ratio of replacement increases up to 15%.

Figure 2.6 PP Particles Used [29].

In 2016, A.M. Azhdarpour et al. [30] investigated using plastic waste from polyethylene terephthalate bottles to replace sand in concrete with two different diameter sizes. The first size was 2–4.9 mm (Pc) and the second size was finer at 0.05–2 mm (Pf), as shown in Figure 2.7. Sand is replaced in partial ratios, which are 0%, 5% 10%, 15%, 20%, 25% and, 30% by weight of sand. They used mixed proportions (1cement: 2.5 sand: 2.5 gravel) with w/c 0.5. They observed that the increase in plastic ratio led to decreased value of wet and dry density. Compressive strength increased by 39% and 7.6% at 5% and 10% replacement. The flexural strength started to reduce when the replacement ratio was greater than 10%. In addition, the tensile strength increased by 26–34% when the replacement ratio was increased from 5% to 15%. They also observed that the deformability of concrete increased with a decrease in elastic modulus.

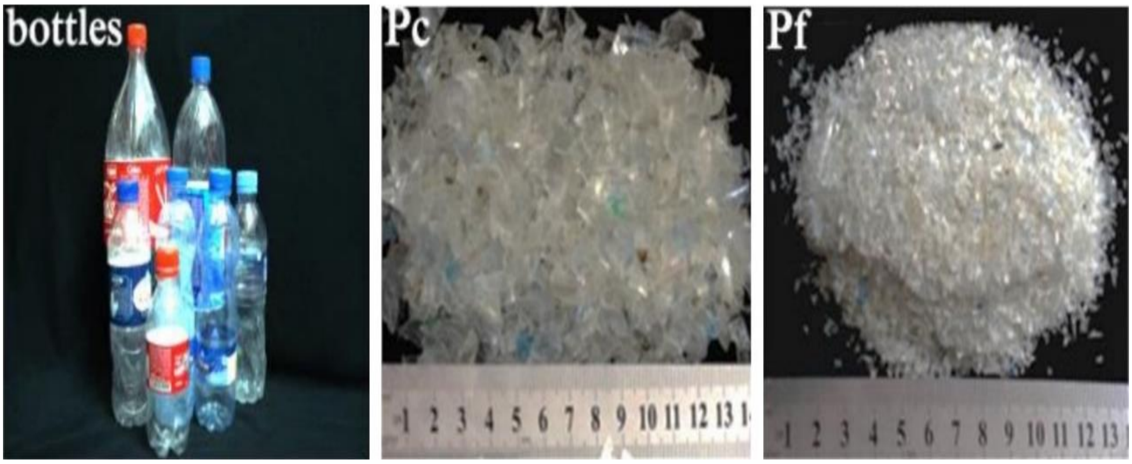


Figure 2.7 Waste Samples With Different Sizes [30].

In 2018, A. Badacheet et al. [31] used waste from high density polyethylene (HDPE) pipes with maximum size particles of 3.15 mm as displayed in Figure 2.8, to replace sand in mortar with volumetric ratios of (0%, 15%, 30%, 45%, and 60%) with water to cement ratio of 0.5. The results indicated that the increase of HDPE in mortar improve some properties of the material by decreasing the density by about 25% in the case of 60% HDPE and reducing the modulus of elasticity by 73%, which led to increasing the ductility of mortar. The rise of HDPE reduced the mechanical properties like compressive strength, which decreased by 38%, and ultrasonic pulse velocity, which also decreased Figure 2.9 showed the failure mode of the specimen under a compression-bending test.

HDPE waste HDPE particles

Figure 2.8 Waste and Particle Size of HDPE [31].

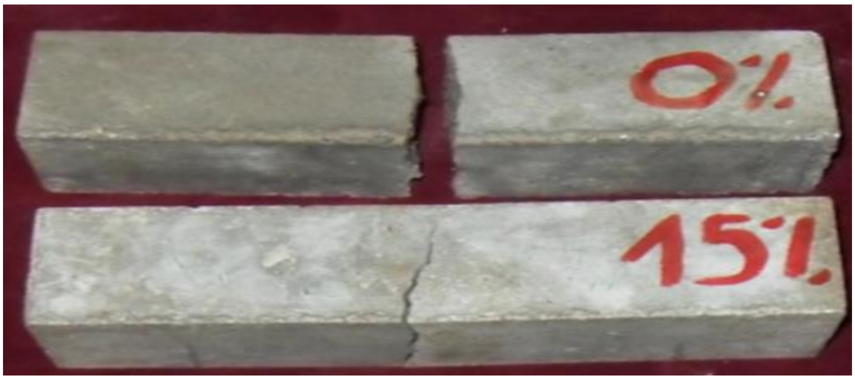


Figure 2.9 The Failure Mode Under a Compression Bending Test [31].

In 2019, H. Chen et al. [32] recycled polypropylene (PP) as sand with lengths 2-3.5 mm as shown in Figure 2.10. The ratios of PP were (0%, 20%, 40%, and 60% by sand volume in the mortar. The mix proportions were (1: cement 1.3: sand) and water to cement ratio of 0.3 with various ratios of superplasticizer. Results of testing showed this form of plastic wastes could effectively be utilized as aggregate in mortar. When the replacement ratios increased the bulk density, compressive strength, and flexural strength of plastic mortar decreased while water absorption increased. Also because of an increase in the flexural compressive ratio, the toughness is enhanced.

Figure 2.10 Recycled PP Particles [32].

In 2020, I. Almeshal et al. [33] investigated the impact of incorporating PET particles on the physical and mechanical properties of hardened concrete. They used PET as a sand replacement with maximum size of 0.075-4 mm and thickness of 1-1.5mm as shown in Figure 2.11. The ratio of partial replacement and mixing proportions were 10%, 20%, 30%, 40%, and 50% and (1 cement: 1.6 sand: 3.37 gravel) with a 0.54 water to cement ratio. The result showed a reduction in the variables of slump, dry density (31.6% decreased at 5% PET) and ultrasonic pulse velocity (which dropped from 4.5 to 1.9 km/s at 50% PET). In addition to the decrease in compressive strength, splitting tensile strength and flexural strength by 90.6%, 85.5%, and 84.2% at 50% replacement ratio.

Figure 2.11 Crushed Plastic Used [33].

In 2021, O. Olofinnade et al. [34] studied the impact of incorporating polystyrene (HIPS) and low-density polyethylene (LDPE) plastic particles to produce light-weight concrete of high strength. They used the type of plastic above as a partially sand replacement with size of particles 2 mm, as illustrated in Figure 2.12. the ratios of partial replacement were 0%, 10%, 30%, and 50% by weight, and the mixing ratios of 1 cement: 1.5 fine aggregate: 3 coarse aggregates with a w/c of 0.5. The result showed a reduction in the variables of slump, dry density, and compressive strength below the values of reference concrete when plastic content increased. In summary, it found the concrete with plastic up to 10% replacement gave good performance compared with reference concrete.

Polystyrene particles low-density polyethylene

Figure 2.12 Plastic Waste Particles [34].

In 2021, A. Dawood et al. [35] replaced the fine aggregate by PET of bottle waste with a maximum size of 4.75 mm as shown in Figure 2.13 and ratios of 5%, 7.5%, 10%, 12.5%, 15%, and 20% by weight of sand. The proportions of mix were 1 cement: 1.5 fine aggregate: 3 coarse aggregate. They used w/c and admixture (superplasticizer) equal to 0.41 and 0.4% respectively. The results were contained on the positive side by increasing the values of compressive, splitting tensile, and flexural strengths by 26.8%-43.64%, 18.6%-26.9%, and 18.1%-30.2%, respectively, when the ratio of replacement was increased from 5% to 12.5%. Also, showed a decrease in workability, density, ultrasonic pulse velocity, and elastic modulus. On the other hand, an increase in water absorption and ductility occurs when the percentage of plastic increases in concrete mixture.

Figure 2.13 Particles of PET Waste [35].

In 2021, H. Adnan and A. Dawood. [36] studied the effect of replacing sand with plastic particles obtained from box waste on the flexural behavior of reinforced concrete beams in partial weight percentages of 2.5%, 5%, and 10%. The particles of box waste are crushed to a size that passes through sieve no. 4.75 mm, as shown in Figure 2.14. The proportions of the concrete mixture were 1 cement: 1.3 sand: 2.06 gravel with 0.41 w/c and 0.8% of superplasticizer. The findings of the testing indicated a reduction in the workability and tensile strength of the concrete mixture. While the compressive strength and rupture modulus were enhanced with rice, the ratio of plastic up to 5% and 2.5 was the ideal ratio that increased by 30.2% and 8.17%, respectively. In addition, the results showed some structural properties represented by: a small rise in load of ultimate failure; a low reduction in max load; an improvement in the strength of the first crack by 14.2%; a significant enhance in ductility; and a decrease in initial and secant stiffness.

Figure 2.14 Box Waste Particles Used [36].

In 2022 R. Falih et al. [37] used PET waste to investigate its impact on the structural behavior of reinforced concrete beams. The same material, ratio of replacement, and mix proportions that were used in [35]. The results of this study showed the ultimate failure load of the reference beam was very close to all ratios of beams used. At a maximum substitution ratio of 20%, they also observed increases in maximum deflection, ductility, compression strain, energy absorption, and load at first crack when the percentage of added PET increased by 97%, 91.37%, 1140%, 2749%, and 121.19%, respectively.

2.3 Recycle PVC Plastic Waste as Fine Aggregate

In 2009, S. Kou et al. [20] used scraped PVC pipe waste to substitute sand from rivers partially as fine aggregates in concrete. Fine aggregate was replaced by PVC particles in ratios of (0%, 5%, 15%, 30%, and 45%) by volume. PVC plastics particles sizes were passed from sieve 5mm as shown in Figure 2.15.

a b

Figure 2.15 PVC Waste: a. Before Grinding b. After Grinding [20].

The results showed a positive impact: firstly, by reducing the dry density and dry shrinkage of concrete; and secondly, by improving the ductility (by decreasing modulus of elasticity) and increasing resistance penetration of chloride ions, While The negative side indicated a decrease in workability, compressive (The max reduction is about 47.3% when the replacment ratio is 45%) and tensile splitting strengths of the concrete mixture when the ratio of replacment was increased.

In 2015, Y. Senhadji et al. [38] in this study, they used PVC plastic waste as an aggregate (sand and gravel) in concrete with two classes of granules, 0/3 and 3/8, as shown in Figure 2.16, with volumetric dosages of replacement of 30%, 50%, and 70%. The mix proportions were 1 cement: 1.175 sand with a size of (0–1 mm): 2.625 medium aggregate with a size (3–8 mm): 0.675 Coarse aggregate with a size (8–15 mm)) and water to cement ratio of 0.48. The investigation of results showed improvements in workability and resistance to penetration by chloride ions, which may provide good protection to the reinforcement of steel. The results also indicated that there was a reduction in density, ultra-sonic wave velocity, and compressive strength when the dosage of PVC was increased Figure 2.17 show the failure mode of specimens of compressive strength test.

(a) The difference Between Natural and PVC Sand.

(b) The difference Between Natural and PVC Aggregate (3/8).

Figure 2.16 PVC Wastes [38]

0% PVC 30% PVC 50% PVC 70% PVC

Figure 2.17 Failure Mode of Specimens [38].

In 2016, H. Bolat et al. [39] replaced aggregate by PVC waste in two types: granules and powder, with sizes of 2–4 mm and 0-0.25 mm, respectively, as shown in Figure 2.18. The percentages of replacement were 10%, 20%, and 30%) by volume. They made two mixtures, which are normal concrete with proportions mix (1 cement: 2.27 sand: 2.46 gravel) with w/c 0.53, and high weight concrete with proportions mix of (1 cement: 1.5 sand: 1.68 gravel) with w/c 0.39. They found enhanced by increased resistance to abrasion, decreased absorption of water and reduced the wet and dry densities of concrete, while the negative effects were decreased slump and compressive strength values Figure 2.19 showed the cross section of concrete with PVC waste.

a b

Figure 2.18 PVC Particles a-Powder, b-Granules [39].

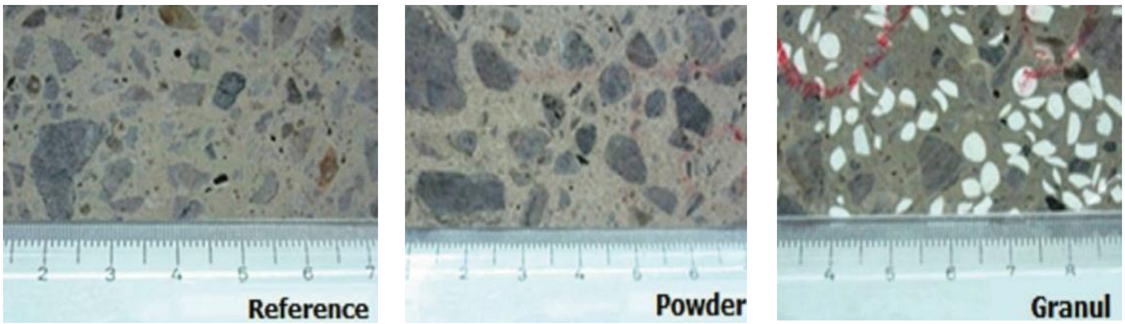


Figure 2.19 The Cross Section of Concrete with PVC Waste [39].

In 2016, N. Haghighatnejad et al. [40] replaced sand with PVC as fine aggregate in conditions with different curing. They used scraped PVC pipes, the maximum size of particles was 5 mm as illustrated in Figure 2.20, and made four concrete mixtures containing PVC of 20%, 30%, 40%, and 50% in addition to the reference mixture with mix ratios of 1 cement: 2 sand: 2.6 gravel. the w/c ratio used was 0.4. The finding showed the incorporating of PVC reduced the workability by slump test 48% under the control ratio and decreased the mechanical properties of samples, which are represented by compression, splitting tensile strengths, and elastic modulus. Also reduced in the water absorption of value, which was a sign that it was concrete of good quality.

Figure 2.20. PVC Waste Particles [40].

In 2017, H. Hussein et al. [41] used PVC obtained from windows and doors to replace a partial amount of sand in the concrete mixture. The particle size of PVC was passed from the sieve at 4.75mm, as shown in Figure 2.21. with weight dosages of (2.5%, 5%, 7.5%, 10%, 12.5%, and 15%). mix proportions were 1 cement: 1.63 sand: 2.4 gravel with w/c equal to 0.4 and superplasticizer (HRWRA) equal to 1 liter for each 100 kg of cement. The results of this study showed a decrease in the workability, wet and dry density when the ratio of PVC increased. Also noticed, the higher ratio of PVC led to a decrease in compressive (about 68.9% reduction), splitting tensile and flexural strength. The positive side of this study was the enhancement of the acoustic and thermal characteristics when the ratio of replacement increased.

Figure 2.21 PVC Fine Aggregate [41].

In 2017, H. Patel, et al. [42] replaced sand with powder of PVC with sizes of 90-600 microns and glass with sizes of 150-600 microns and ratios of 0%, 5%, 10%, 20%, 25%, and 30% in the concrete mixture. The mix proportions were (1: cement 1.3: sand 2.8: gravel) with three water to cement ratios of 0.44, 0.5 and 0.55. The results showed the replaced mixture behaves like normal concrete up to 15%. When the replacement ratios increased, this led to a negative effect on mechanical properties (compressive and flexural strengths), while being noticeably enhanced in workability, density, and water absorption, in addition to durability considerations.

In 2018, C. Aciu et al. [43] used PVC waste to replace sand in mortar. The PVC waste, with a maximum size of 8 mm, was replaced with ratios of (0%, 25%, 50%, and 100%) by weight of sand. The mix proportions were (1 cement: 4.5 sand), and water to cement ratio of 0.5. The results indicated the increase of PVC replacement will decrease the density, compressive and flexural strengths of mortar, but the ratio of 25% gave the best results and is close to the reference mix. Figure 2.22 shows the failure section in prisms of mortar.

0 % PVC 25 % PVC 50 % PVC 100 % PVC

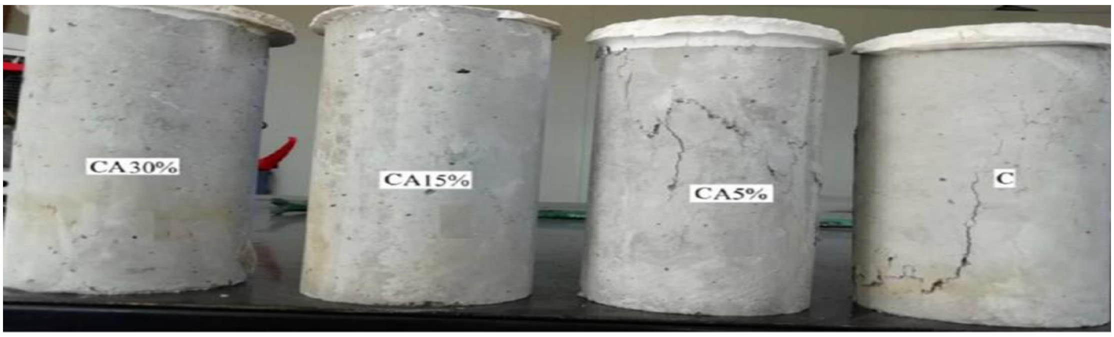
Figure 2.22 The breaking section of mortar prisms [43].

In 2019, A. Mohammed et al. [17] they replaced fine and coarse aggregate partially with PVC from waste sheets. The size is between fine and coarse aggregate, as shown in Figure 2.23 the replacement was in percentages of 5%, 15%, 30%, 45%, 65%, 85%, by weight for fine and coarse aggregate separately. The mix proportions were (1 cement: 1.25 sand: 2.5 gravel) with a w/c of 0.52. The results indicated there is no obvious change in slump, density, and absorption values when sand is replaced by PVC (except in the high ratios of PVC). While noticing a slight reduction in the compression and splitting tensile strengths when ratio of replacement was increased, Figure 2.24 also noticed an obvious decrease in abrasion value, ultrasonic pulse velocity and modulus of elasticity when the ratio of PVC increased.

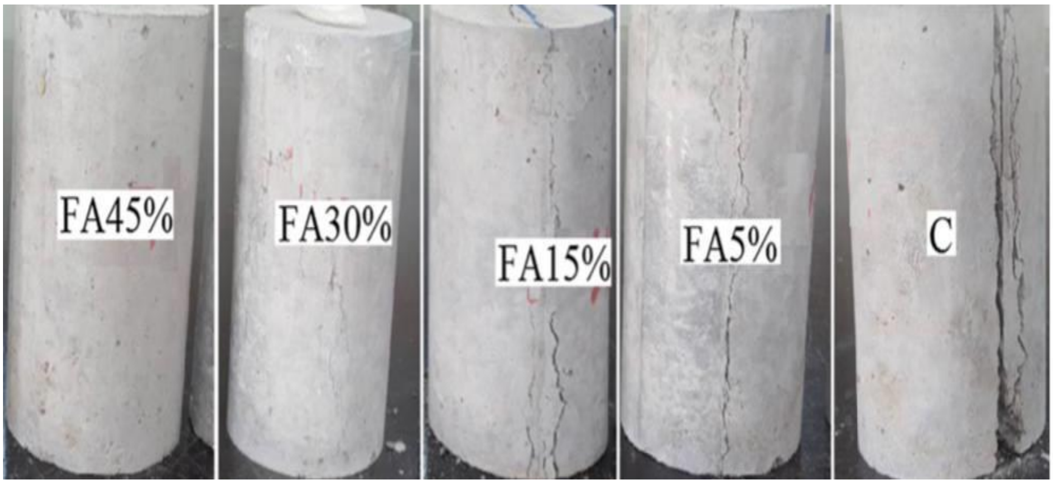
(a)

(b)

Figure 2.23 (a) PVC Waste in Landfill, (b) PVC Waste After Crushing [17].



(a)



(b)

Figure 2.24 Failure Mode By (a) Compressive Stress, (b) Splitting Tensile Stress [17].

In 2020, M. Belmokaddem et al. [44] they used plastic (PVC, HDPE, and PP) waste in three types to replace fine and medium aggregate with sizes of 0-3 mm and 3-8 mm, respectively, in the concrete mixture, as shown in Figure 2.25 with ratios of (0%, 25%, 50%, and 75%) by volume. The mix proportions were (1 cement: 1.72 sand (0-3 mm): 2.57 medium aggregate (3-8 mm): 0.77 coarse aggregate) with w/c equal to 0.48 and a superplasticizer of (0.6-1 %). The findings showed positive sides when the ratio of plastic increased in the mixture by reducing the density, improving thermal insulation and increasing ductility by reducing the modulus of elasticity. In addition, the increased replacement ratio led to a decrease in the ultrasonic pulse velocity and compression strength.

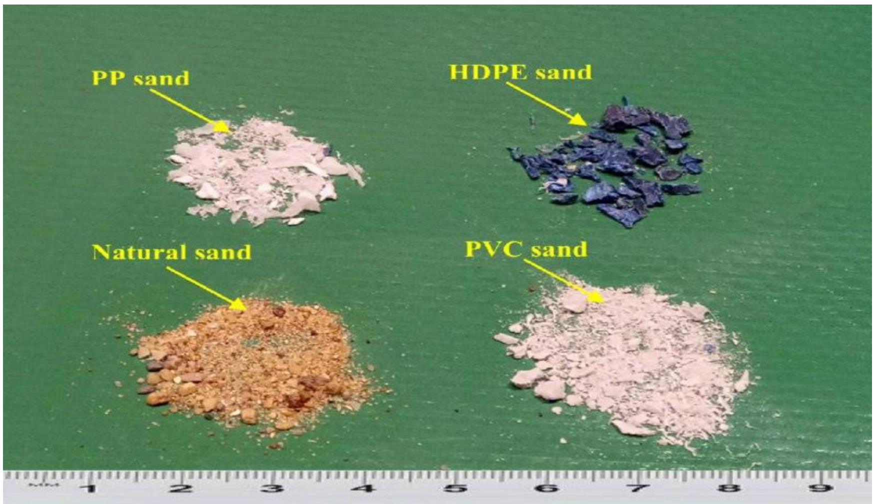


Figure 2.25 Natural Sand and Different Types of Plastic Wastes [44].

2.4 Summary

The outlines of previous studies related to the current study are presented. The main variables that the researchers studied are summarized as follows:

- In general, replacing sand with plastic waste led to a reduction in workability, except in several studies that led to an improvement in slump value.
- All studies indicated a decrease in density when the replacement ratio increased.
- For some studies, the compressive, splitting tensile, and flexural strengths increased by increasing the plastic to a limited level (maximum 10%), and for other studies, they decreased by increasing the plastic content.

- All researchers that examined the effect of replacing plastic on the value of ultrasonic pulse velocity confirmed that it is decreased with an increase in the amount of plastic.
- All studies that tested the elastic modulus indicated to decrease of elastic modulus and increase in the ductility through increasing the percentages of plastic as a partial substitute for sand.

The present study differs from other previous studies in the type of plastic used large range of replacement percentages as fine aggregate and tested various properties of concrete mixture. Also, for first time used the PVC waste as a sand replacement reinforced concrete beam of semi-full scale of length 2300 mm and study its effect on the flexural behavior of these concrete beams.

CHAPTER THREE: EXPERIMENTAL WORK

3.1 General

In this chapter the evaluation of materials properties which are used in the concrete mixture, are included. The details of materials and their proportions ,the physical and chemical characteristics, mix design of concrete, the details of specimens, their ages, curing and methods of test on these specimens are introduced, also PVC waste nature are described to compare the mixture of concrete without and with PVC particles. In addition, in this chapter, includes the details of concrete beams with dosages of PVC wastes. Every test was performed in the laboratory of construction and material and at Engineering college in Misan University and Technical Institute of Amarah.

3.2 Properties of Material

The materials that locally available were used in this study, which included ordinary Portland cement, fine and coarse aggregate, tap water, PVC waste particles, and the additives (superplasticizer), which are used to enhanced the workability of the concrete mixture.

3.2.1 Cement

The ordinary Portland cement of type I (christa) used in this study. It remained away from the impact of moisture in a dry area. Its physical properties and chemical composition are shown; in Table 3.1 and Table 3.2; respectively. Both tests were carried out at the material and construction laboratory at Amarah Technical Institute in accordance with the Iraqi specification No.5/1984 [45].

Table 3.1 Physical Properties of Cement.

Physical properties	Tests results	Iraqi specification limits NO.5/ 1984 [45]
Fineness by using Blain Air Permeability method m^2/kg	388	≥230
Soundness by using Autoclave method	0.24	< 0.8
Initial and Final setting time by using Vicat method		
Initial hrs:min	2.05	≥ 45 min
Final hrs:min	3.48	≤ 10 hrs
Compressive Strength of cement mortar		
3 days MPa	21.8	≥ 15
7 days MPa	28.7	≥ 23

Table 3.2 Chemical Compositions of Cement.

Oxide compositions	Abbreviations	Content by weight %	Iraqi specification limits No. 5/1984 [45]
Silica	SiO_2	21.43	---
Lime	CaO	63.94	---
Alumina	AL_2O_3	4.59	---
Sulphate	SO_3	2.5	< 2.8 %
Iron Oxide	Fe_2O_3	3.22	---
Magnesia	MgO	2.83	≤ 5 %
Insoluble residue	I.R	1.04	≤ 1.5 %
Loss on Ignition	L.O. I	3.55	≤ 4%
Lime Saturation Factor	L.S. F	0.96	0.66- 1.02
Main Compounds (Bogue's Equation)			
Tetra Calcium Alumina	C_4AF	9.88	---
Di Calcium Silicate	C_2S	18.38	---
Tri Calcium Aluminates	C_3A	8.15	---
Tricalcium Silicate	C_3S	50.94	---

3.2.2 Fine Aggregate

The fine aggregate (sand) from Basra governorate in the south of Iraq was used. Table 3.3 represent the grading of fine aggregate according to the requirements of Iraqi specifications No. 45/1984 [46], Zone No.2.

Table 3.3 The Grading of Fine Aggregate.

Standard sieve size	Cumulative Passing %	Cumulative passing % Iraqi specifications limits No.45/1984[46]
10 mm	100	100
4.75 mm	95.44	90-100
2.36 mm	85.33	75-100
1.18 mm	68.66	55-90
0.6 mm	37.15	35-59
0.3 mm	14.2	8-30
0.15 mm	5.1	0-10

3.2.3 Coarse Aggregate

In this study, coarse aggregate, which available naturally in a region in eastern Amarah (a city in Iraq) called Chilat were used, with a maximum size of 20 mm. Table 3.4 shows the coarse aggregate grading in accordance with the requirements of Iraqi specifications No .45/ 1984 [46].

Table 3.4 The Grading of Coarse Aggregate.

Standard sieve size	Cumulative passing %	Iraqi specification No.1984/45 [46]
37.5 mm	100	100
20 mm	96.8	95-100
10 mm	43.53	30-60
5 mm	4.345	0-10

3.2.4 Water

For the purposes of casting and curing, the drinking water was used for all the specimens.

3.2.5 Admixture

Due to the existence of polyvinyl chloride (PVC) in this study, super plasticizer admixture was used to enhance the workability of concrete mixture. The liquid Type Sika viscocrete-5930L is used, and it meets the requirements for super plasticizer according to ASTM C494-Types G and F [47]. Table 3.5 shows the international technical specifications of Sika viscocrete- 5930L.

Table 3.5 Technical Description of Sika Viscocrete -5930L [47].

Chemical base polymer	Modified polycarboxylate based
Appearance/colors liquid	Turbid liquid
Density	1.1 kg/lt
Dosages	0.2 - 0.8 % liter by weight of cement
Storage condition/ Shelf Life	Stored at temperature from +5 º C to 35 º C for 12 months only

3.2.6 Steel Reinforcing

The bars of deformed steel of diameter equal to 12 mm and 10 mm were used for tension reinforcement and stirrup. The steel reinforcement characteristics are shown in Table 3.6. [48]

Table 3.6 Characteristics of Reinforcing Bars [48].

Type of bar	Dia. of bar (mm)	Area of bar mm^2	Yield strength f_y (MPa)	Tensile strength f_u (MPa)
Steel stirrups	10	78.5	518	627
Longitudinal steel bars	12	113.04	495	585

3.2.7 PVC Waste

Crushed pipes of Polyvinyl chloride (UPVC) were collected from the Factory of plastic in Misan. They are small irregular (non-spherical) pieces with color of gray and blue produced by grinding undesirable pipe portions using special machines, as shown in Figure 3.1

Figure 3.1 PVC Pipes Waste in Misan Plastic Factory.

The machine is called as pipe crushing machine which is specially designed for the purpose of the grinding and crushing process. Its weight is equal to 800 kg, with a capacity up to 30 HP, and dimensions of (1.5 m length, 0.8 m width, and 2.2 m height), Figure 3.2. It has a door at the top that opens to put in the pipes to be ground, with ten moving sharp fans and two fixed sharp fans one on each side to grind the PVC pipes, and a filter in the bottom with dimensions of (1m *0.6m) as illustrated in Figure 3.3. The standard machine is designed to crush 4 or 6 inch pipes and then sieved by its filter with 6mm openings, Figure 3.4,a while larger pipes (larger than 6 inch) are crushed by modified the same machine and using a 12 mm openings filter.

Figure 3.2 Pipe Crushing Machine.

The crushing process is carried out by inserting the pipe through the door of the machine and then cutting it by sharp fans and sieving it by its filter and returning the residual to be crushed again. In this study, we used pieces of PVC plastic with maximum size of 6 mm, as shown in Figure 3.4,b. PVC particles were sieved by sieve size of 4.75. According to Iraqi specification No.45/1984 [59], the PVC waste particles may be classified as poorly graded sand as shown in Table 3.7. In addition, Table 3.8 and Figure 3.5 include compare between some properties of sand and PVC, which include grading, density and finesses modulus.

a b c

Figure 3.3 Main Parts of Machine. a-Door, b-Sharp Fan, c-Filter.

a b

Figure 3.4 a-Filter With 6 mm Openings b- Graded PVC Particles.

Table 3.7 Grading of PVC Particles.

Standard sieve size(mm)	PVC cumulative passing %	Cumulative passing% Limits of Iraqi specification No.45/1984[46]
10	100	100
4.75	98.46	90-100
2.36	17.3	75-100
1.18	7.1	55-90
0.6	3.7	35-59
0.3	1.5	8-30
0.15	0.2	0-10

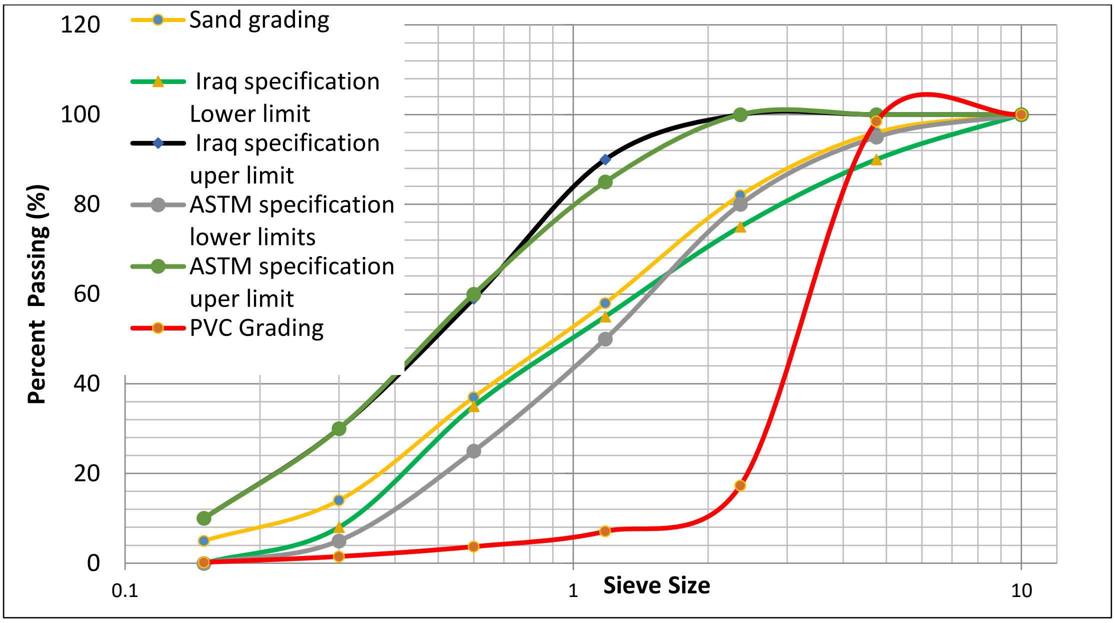


Figure 3.5 Curve of Grading for Sand and PVC Particles.

Table 3.8 Comparison Between Sand and PVC Physical Properties.

Physical properties	Sand	PVC
Density (kg/m3)	1550	1400
Fineness modulus	2.94	4.7

3.3 Program of Experimental Work

The program of experimental work includes two main parts. The first part deals with adding PVC wastes in different percentages as a sand replacement to the concrete mixture and investigating its effect on the mechanical and physical characteristics of concrete. While the second part includes the effect of adding these percentages of PVC on the flexural performance of reinforced concrete beams.

3.3.1 Part One: Replacing Sand with Scraped PVC Wastes in the Mixture of Concrete

In this study, the experimental work was relied upon to give a priority and specific indication of the properties and behavior of concrete that contains recycled plastic waste, focusing on the quantities and proportions of materials, as well as the nature of replacement. The gradation of the material used (PVC waste) and how its size is close to that of the replaced sand, as well as the difference in densities of the two materials (sand and PVC), have also been considered. Therefore, trail mixtures were made to find out the proportions that could be used in the concrete mixture. Several random weight ratios were entered into the concrete mixture: 5%, 10%, 15%, 20%, and 30%, and 50%, in addition to the reference ratio (without

PVC). The mixing ratio was 1 cement: 1.5 sand: 2.45 gravel, and the ratio of water to cement was 0.38, with superplasticizer of 0.5%. After that, a compression and density test were carried out on 42 cubes with dimensions of 150 * 150 * 150 mm, six cubes for each percentage of replacement; three were tested at the age of 7 days and the other three were examined at the age of 28 days. The results showed that density decreased with increased PVC replacement while the compression strength of concrete cubes increased with increasing the partial content of PVC up to 10% (equal to 52.5 MPa) and that the ratio of replacement represents the optimum percentage of substitution. After that, the compressive strength began to drop under the value of 10%, but it remained at a normal level within and close to the reference value (equal to 52 MPa and 50.1 MPa for the ratios of 20% and 30%). Up to the ratio of 50% of substitution, the value of compression dropped under the reference value. Therefore, it was excluded from the replacement percentages used in the experimental work program. As a result of this trail work, the experimental work scope is ranged 5%–30%, i.e., five ratios of PVC as a partial sand replacement, in addition to the reference ratio, will be used, namely 0%, 5%, 10%, 15%, 20%, and 30%.

3.3.1.1 Mixture of Concrete

The proportion of mixing is 1:1.5:2.45, which is used as a weight concrete mixture according to trail mixtures. Materials weights are 456 kg/m^3, 684 kg/m^3 and 1117.2 kg/m^3 for cement, sand and gravel; respectively. The ratio of water to cement is 0.38 with 0.5% of admixture (superplasticizer) to enhance the workability of the mixture. In this study, used five percentages of scrapped PVC waste as replacements of fine aggregate, which are 5%, 10%, 15%, 20%, and 30%, in addition to reference of free PVC. This part of the work focuses on the mixture proportions and the ratio of replacement. Table 3.9 includes all quantities of material in one cubic meter and percentages of replacement.

Table 3.9 Proportions of Concrete Mixture for All PVC Substitutions.

PVC/sand%	**Cement kg/m^3**	**Sand kg/m^3**	**Gravel kg/m^3**	**Water kg/m^3**	**PVC kg/m^3**	**SP Kg/m^3**
0% (Ref.)	456	**684**	1117.2	173.28	**0**	2.28
5%	456	**649.8**	1117.2	173.28	**34.2**	2.28
10%	456	**615.6**	1117.2	173.28	**68.4**	2.28
15%	456	**581.4**	1117.2	173.28	**102.6**	2.28
20%	456	**547.2**	1117.2	173.28	**136.8**	2.28
30%	456	**478.8**	1117.2	173.28	**205.2**	2.28

3.3.1.2 Specimens of Experimental Work

The specimens that used for tests of mechanical and physical properties of concrete included: twelve cubes of 150*150*150 mm dimensions for density, compressive strength, ultrasonic pulse velocity, abrasion and absorption tests, nine cylinders of 200*100mm dimensions for splitting tensile strength test; six prisms of 500*100*100 mm dimensions for flexural strength test and three cylinders of 150*300 mm dimensions for modulus of elasticity test. These specimens are cast for each replacement percentage of PVC wastes, as shown in Figure 3.6.

Figure 3.6 Molds of Work Specimens.

3.3.1.3 Procedure of Mixing

An electric mixer (240 L), in the structural lab at the engineering college/ university of Misan, by some steps, mixed the components as follows:

1- Firstly, all materials that are used in each percentage mix are prepared washed and weighed near the mixer.

2- In the mixer the gravel added firstly then the replaced amount of plastic is added together with sand and mixed until they are homogeneous.

3- Then, the cement is added to the mixture and mixed with the other materials.

4- Finally, the water, which has already been mixed with superplasticizer (admixtures), is added to the mixture while mixing continues up to 5 minutes.

3.3.1.4 Details of Casting and Curing

Casting and curing procedures were achieved according to specifications. Firstly, the molds are cleaned and oiled, then the process of casting the mixture into the molds (cubes, cylinders, and prisms), tamping the sample with a tamper, and levelling the upper surface of the specimen, as shown in Figure 3.7.

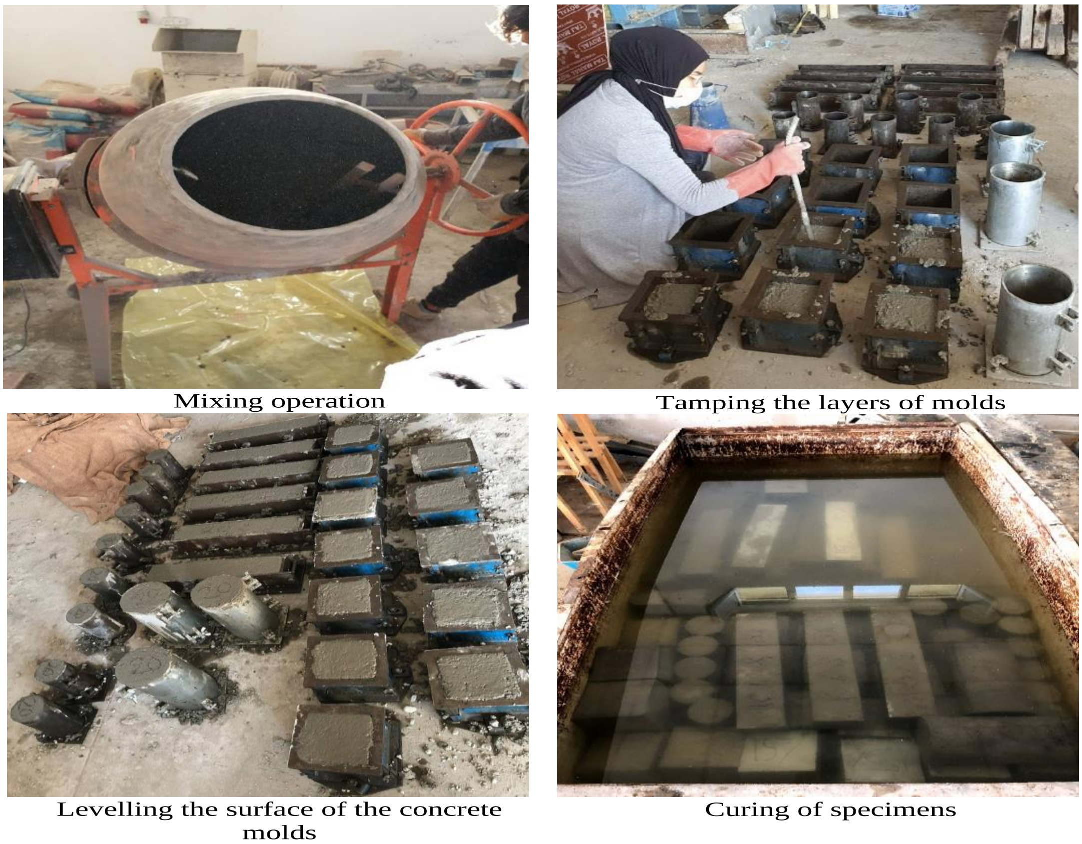


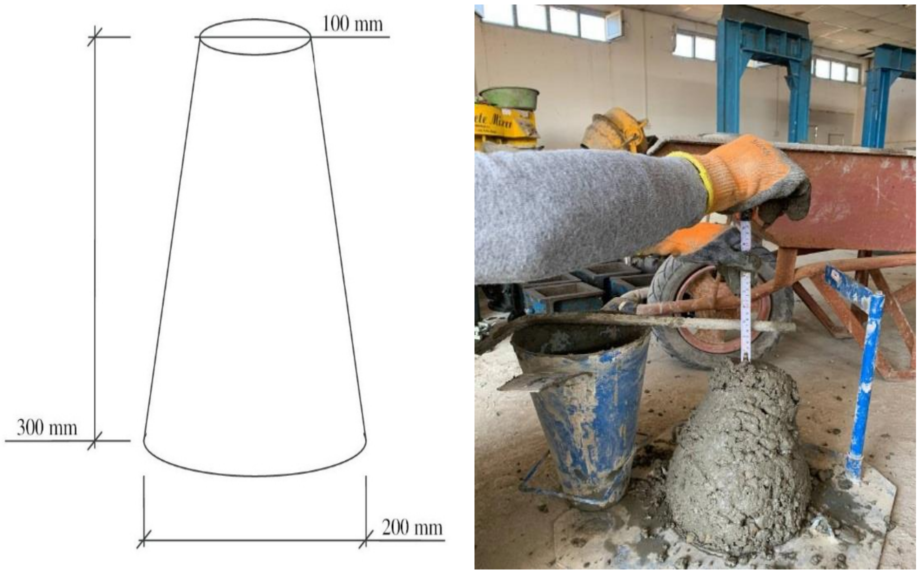
Figure 3.7 Process of Casting and Curing.

3.3.1.5 Concrete Tests

3.3.1.5.1 Test of Fresh Concrete

3.3.1.5.1.1 Slump Test

The slump test is one of the most substantial properties of a concrete mixture. It is an indicator of the consistency and the simplest way to control the quality of the concrete mixture. The concrete is called workable when it has a suitable consistency, no segregation when handled with it, maintains homogeneity when cast, and requires minimum effort when compacted. The test is specified according to ASTM C143 [49], the slump cone is used with dimensions of a base diameter of 20 cm, a top diameter of 10 cm, and a height of 30 cm. The concrete mixture was placed in the cone by three layers, each one approximately 1/3 the volume of the mold, and rodded each layer with 25 strokes by the tamper rod. The value of slump is found immediately by measuring the difference between the mold height and the height of the vertical axis of the specimen, as shown in Figure 3.8.



Dimensions of slump cone Measuring of slump value

Figure 3.8 slump Test.

3.3.1.5.2 Mechanical Tests of Hardened Concrete

3.3.1.5.2.1 Density Test

The dry density of hardened concrete cubes is measured before the compressive strength test by using concrete cubes with dimensions of 150*150*150 mm. The test is examined according to British standards-BS 1881-part 114-83 [50]. Where the specimens are weighed at the age of 28 days and then divided by the volume of the specimen to find the density of concrete containing scraped PVC waste as a partial sand replacement as shown in the Figure 3.9.

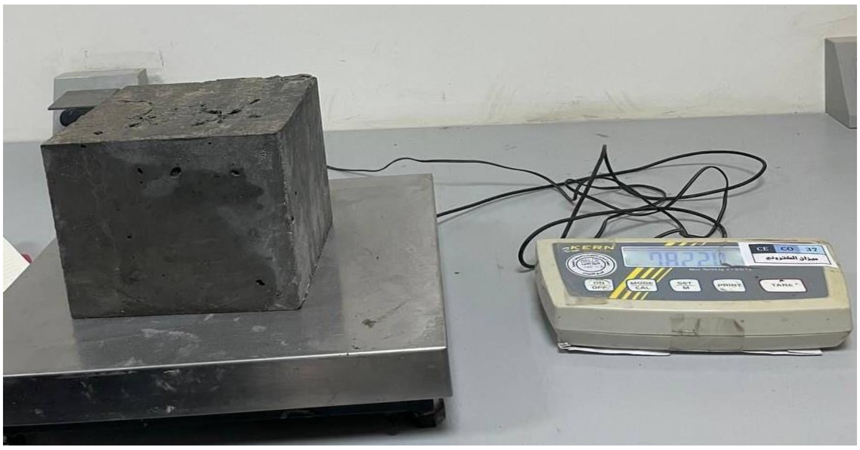


Figure 3.9 The Density Test.

3.3.1.5.2.2 Compressive Strength Test

The compressive strength test is done immediately after the density test, the same concrete cubes with dimensions of 150*150*150 mm are used to perform the compression test. This test is done according to the British standards-BS 1881-part 116-83 [51], by using compressive strength machine with a capacity of 2000 KN as shown in Figure 3.10, a.

3.3.1.5.2.3 Splitting Tensile Strength Test

The splitting tensile strength is measured by using cylinder specimens of concrete with dimensions of 100*200 mm. This test is done according to the ASTM-C496 [52], also by a compressive strength machine of capacity 2000 KN, in the civil engineering department laboratory at the University of Misan, as shown in Figure 3.10, b.

The splitting tensile strength is determined by applying the following equation:

$$f_t = \frac{2P}{\pi D L} \qquad 3.1$$

Where:

f_t: splitting tensile strength in MPa. P: the maximum applied load in N.

L: the length of the cylinder in mm. D: the diameter of the cylinder in mm

a b

Figure 3.10 a. The Compressive Strength Test, b. The Splitting Tensile Strength.

3.3.1.5.2.4 Flexural Strength Test

The flexural strength is measured by using prism specimens of concrete with dimensions of 100*100*500 mm. the test is done according to the ASTM-C78 [53], by using flexural machine of capacity 5000 KN, in the laboratory at civil engineering department/ University of Misan, as shown in Figure 3.11.

The flexural strength is determined by applying the following equation:

$$f_r = \frac{3PL}{2bd^2} \qquad 3.2$$

Where:

f_r: the modulus of rupture in MPa. P: the maximum applied load in N.

L: the length of span in mm. b: the average width of specimen in mm.

d: the average depth of specimen in mm.

Figure 3.11 The Flexural Strength Test.

3.3.1.5.2.5 Modulus of Elasticity Test

Modulus of elasticity is carried out according to specification ASTM-C469 [54] by using a compressive machine of 2000 KN capacity. The test is done by using three cylinders with dimensions of 150*300 mm, as shown in

Figure 3.12. The modulus of elasticity is determined by applying the following equation:

$$\boldsymbol{E} = \frac{\boldsymbol{S_2} - \boldsymbol{S_1}}{\boldsymbol{\epsilon_2} - \mathbf{50} \times \mathbf{10^{-6}}} \quad 3.3$$

Where:

S_2: Stress equivalent to 40% of the ultimate load.

S_1: Stress equivalent to longitudinal strain $50*10^{-6}$.

ϵ_2: Longitudinal strain founded by S_2.

Figure 3.12 The Elastic Modulus Test.

3.3.1.5.2.6 Abrasion Test

The abrasion resistance is evaluated by using concrete cubes specimens with dimensions of 150*150*150 mm, the method of test accordance to ASTM C131 [55]. The test is particularly recommended for determining aggregate resistance to abrasion utilizing the Los Angeles Machine as shown in Figure 3.13. The concrete surface degradation that caused by a series of processes such as grinding, abrasion and impact in the rotational steel drum had twelve steel spheres inside, is evaluated in this test. The contents are removed after the appropriate number of rotations from the drum, and each cube sample is weighted. The abrasion value is calculated as a percentage of weight loss.

$$\text{Abrasion resistance}=\frac{\boldsymbol{W_2 - W_1}}{\boldsymbol{W_1}} \times \mathbf{100}\% \qquad 3.4$$

Where:

W_1= cube weight before the abrasion.

W_2= cube weight after the abrasion.

Figure 3.13 Los Angeles Machine.

3.3.1.5.3 Physical Tests of Hardened Concrete

3.3.1.5.3.1 Absorption Test

The absorption value is determined by using concrete cube specimens with dimensions of 150*150*150 mm. The test is examined according to ASTM-C642 [56]. Firstly, the dry weight (W_D) is measured by drying the specimens in the oven for 72 hours at a temperature of 100 ^{O}C as shown in Figure 3.14. then the wet weight (W_W) is determined by immersing the same specimens in water for 24 hours. Finally, the absorption rate is measured by the following relationship:

$$\text{Absorption Rate} = \frac{W_{W} - W_{D}}{W_{D}} \times 100\% \qquad 3.5$$

Figure 3.14 Drying the Specimens in The Oven.

3.3.1.5.3.2 Ultrasonic Pulse Velocity Test

The ultrasonic pulse velocity is found by using specimens of concrete cubes with dimensions of 150*150*150 mm. The test is carried out according to the requirements of ASTM-C597 [57], via the apparatus of UPV as shown in Figure 3.15. this test is achieved by PUNDIT PC-1012 with a 0.1 microsecond accuracy and a direct method through both directions.

Figure 3.15 The Ultrasonic Pulse Velocity Test.

3.3.2 Part Two: Specimens of Reinforced Concrete Beams Scraped PVC Waste as Replacement for Sand

In this part, the same materials of part one was used as shown previously in Table 3.9. This part considered with flexural behavior of reinforced concrete beams contained PVC waste as sand replacement.

3.3.2.1 Specimens of Reinforced Beams

Five beams of 2300*150*300 mm dimensions were used to investigate the effect of using scrapped PVC particles as a sand partial replacement. For each replacement ratio, it used one beam as well as the reference ratio (beam without PVC waste, i.e., 0% PVC). The beams are cast by using a wood mold. The wooden formwork that is used in this part is made from a firm wooden base, which is connected to movable sides by nails and screws. All specimens of concrete beams are simply supported and consist of a rectangular cross section area with dimensions of length equal to 2300 mm, width equal to 150 mm, and height equal to 300 mm. The beams of concrete were designed in method to fail in flexural and to prevent shear failure. As described in Figure 3.16, this study used two supports of 2000 mm clear span and two points of load with a distance of 660 mm separated between them. The distance between both points of load and support (a) is equal to 660 mm and the effective depth of the beam section is equal to 264 mm. Therefore, the a/d value is equal to 2.5, which indicates the beam section resists shear force. According to ACI 318-14, [58] the reinforced concrete beam is designed to fail the compression and tension zones of the section in flexural and to ensure its resistance to shear force. The details of the reinforcement of beams are as follows: the number of reinforcement bars in tension and compression areas is 3 and 2 respectively, with Φ 12 mm, and stirrups of Φ 10 mm with a space of 120 mm from center to center at the middle span and 60 mm from center to center for the shear span, as shown in Figure 3.16. All the details above were used for all reinforced concrete beams containing scraped PVC waste as fine aggregate replacement.

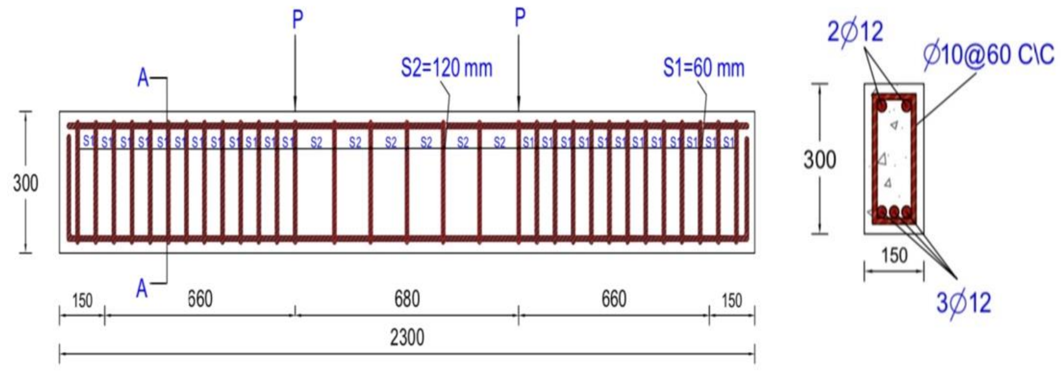


Figure 3.16 The Details of Reinforcement and Method of Loading for Concrete. Beams.

3.3.2.2 Casting and Curing Procedure of Beams

Casting and curing procedures of beams are done according to requirements as shown in Figure 3.17. Firstly, the interior sides of molds are greased with oil, the cages of reinforcement are entered into the molds, and then the casting process of concrete started and compacted by vibrator. Finally, the upper surface of beams smoothed and levelled. After completing the casting of concrete, the curing of beams is done for 28 days, Figure 3.18.

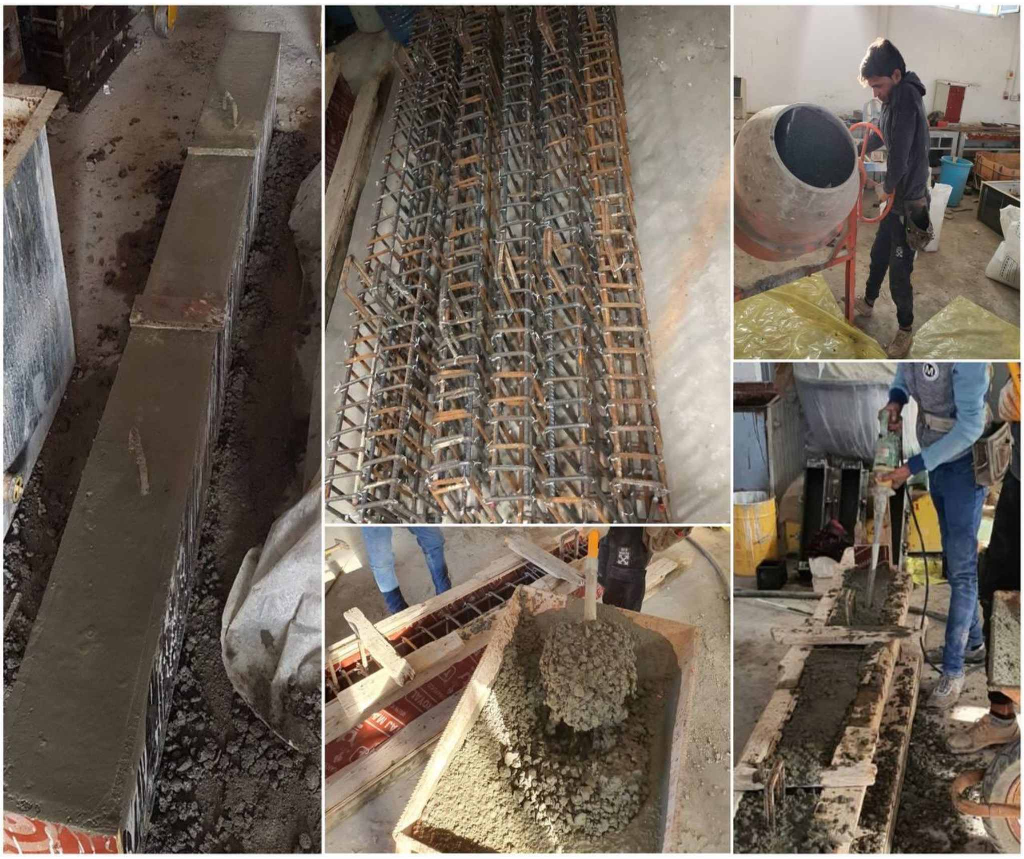


Figure 3.17 The Details of Beams Casting.

Figure 3.18 The Curing of Beams.

3.3.2.3 Concrete Beams Test

A. Machine of Test

For the purpose of testing all beams, the automatic compression machine with 600 KN capacity in the structural laboratory in Engineering College at the University of Misan was used as shown in Figure 3.19.

Figure 3.19 The Compression Test Machine.

B. LVDT

A Linear variable differential transformer (LVDT) was used to measure the deflection of all beams in the mid span area, which recorded the reading automatically as shown in Figure 3.20.

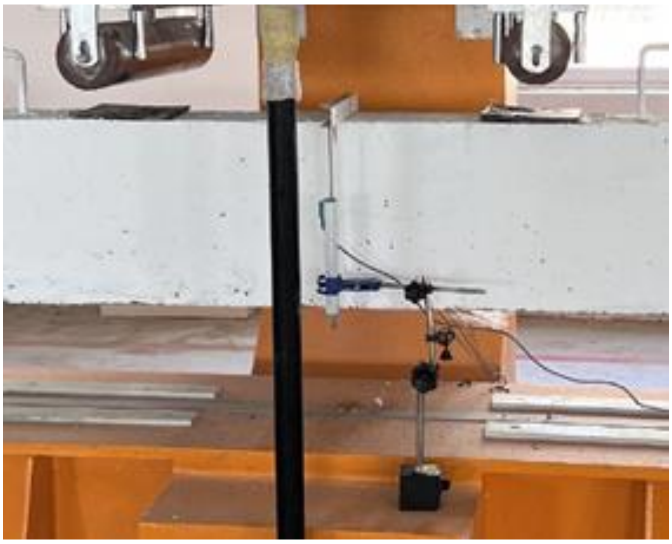
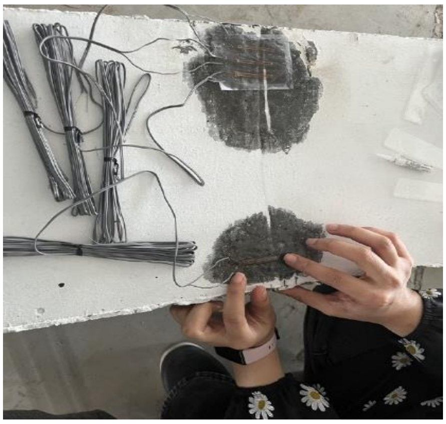


Figure 3.20 The Position of LVDT On the Beam.

C. Strain Gages

For percentages of replacement of 0%, 10%, and 30%, four strain gages of 30 mm length were used, one is placed in the tension zone and the other three are attached in the compression zone. All the strain gages were located in the center of each beam before testing. While the other percentages of replacement were 5%, 15%, and 20%, only one strain gage (with the same length) was placed in the compression zone, also in the center of the beam, as shown in Figure 3.21. to obtain a reading of strain at each load increment, the strain gages were connected to a data logger (a data acquisition device that contained 16 channels supplied with DATACOMM software for PC data acquisition.

a. strain gages used



b. strain gages attaching for 0%, 10% and 30% ratios

c. strain gages attaching for 5%, 15% and 20% ratios

Figure 3.21 Strain Gages and Their Attaching.

D. Test Methodology

The testing of beams is done by using a universal testing machine at Misan University—College of Engineering, as seen in Figures 3.22 and 3.23. To show crack growth, all beams were cleaned and colored white. The machine applied a concentrated load to the structural member via a steel loading roll over a thin rubber strip, achieving uniform contact between the load and the beam. the rate of loading was in small increments, with deflection, strain, and load values recorded at each increment. The load increased gradually until it collapsed.

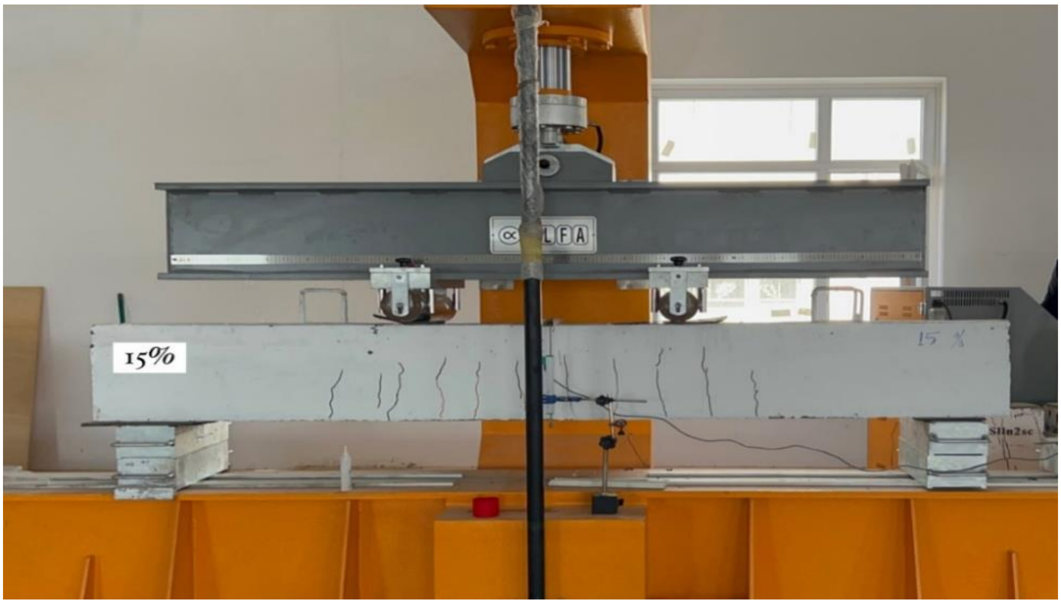


Figure 3.22 Flexural Test of Beams.

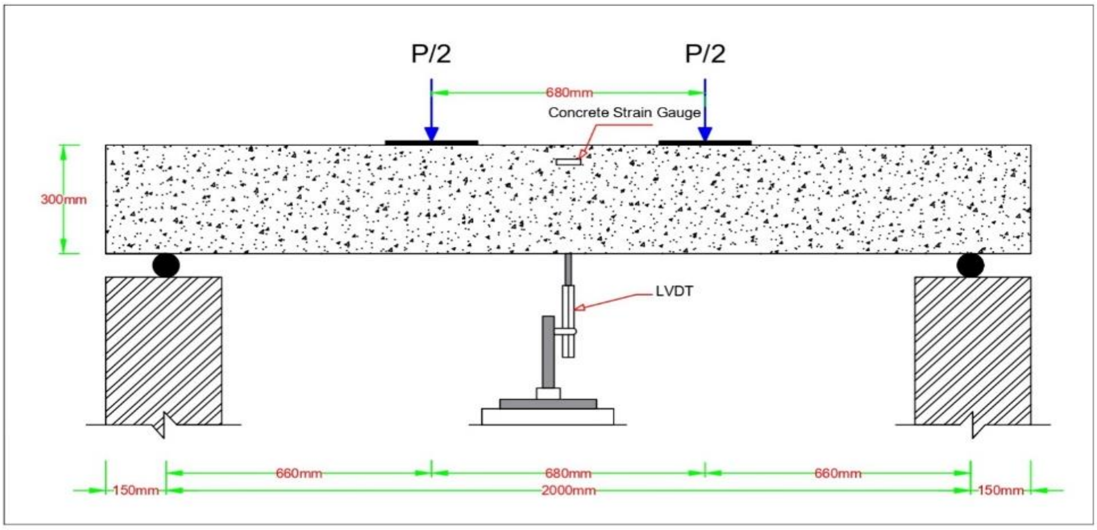


Figure 3.23 Test Setting.

CHAPTER FOUR: TEST RESULTS AND DISCUSSION

4.1 General

The results and discussions for mechanical, physical and structural properties for concrete contained scraped PVC waste as a sand replacement are represented. Six concrete mixtures were used, five-mix designed with fractional substitution of fine aggregate by PVC waste particles and one as a reference mix. The fresh concrete result was represented by the slump test. The findings of mechanical and physical properties for hardened concrete involved: compressive strength, flexural strength, splitting tensile strength, elastic modulus, abrasion, dry density, absorption, and ultrasonic pulse velocity test. Finally, the results of structural conducted for reinforced concrete beams involved one beam for each percentage of replacement. The results are represented by: ultimate load, energy absorption, maximum deflection, ductility, stiffness, compression strain, and cracks that are represented by load generated at first crack, crack spacing, and length of cracks. In addition, all parameter relationships are represented by fitting curves. For testing the mechanical and physical properties of concrete, 180 specimens are used as follows: 72 specimens of cube with dimensions of 150*150*150 mm, 54 specimens of cylinder with dimensions of 100*200 mm, 18 specimens of cylinder with dimensions of 300*150 mm, and 36 specimens of prism with dimensions of 500*100*100 mm. While the structural properties, included 6 specimens of reinforced beams with dimensions of 150*300*2300 mm for each percentage replacement of PVC plastic.

4.2 Part One: Test Results of Mechanical and Physical Properties

It includes the results of properties for fresh and hardened concrete which contains various percentages of scraped PVC waste as partial replacement of fine aggregate in concrete mixture in different ages 7, 14, and 28 days of concrete curing as shown in Figure 4.1.

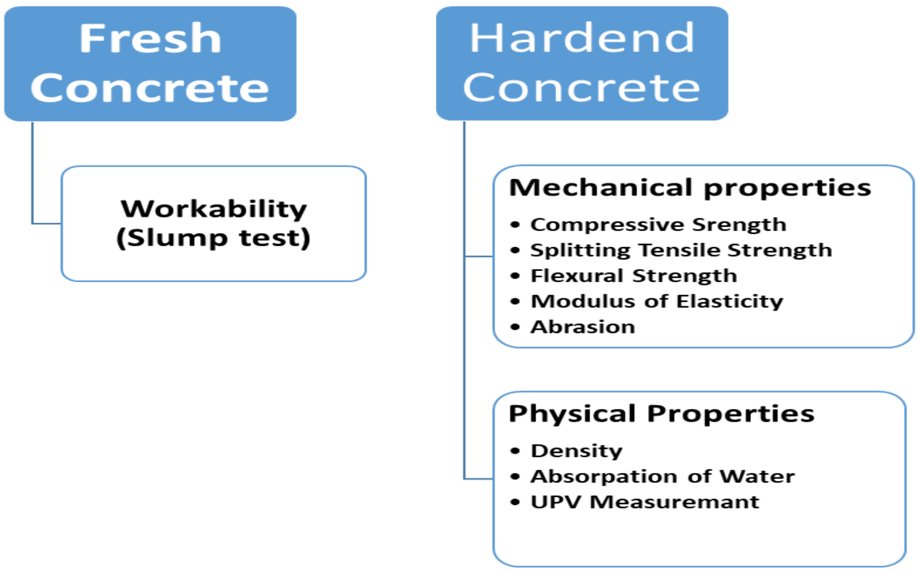


Figure 4.1 The Tested Properties for Fresh and Hardened Concrete.

4.2.1 Workability (Slump Test)

The slump test was conducted directly after the preparation of the concrete mixture for all mixes, which contained different percentages of scraped PVC particles. The aim of this test was to ensure the mix with a constant value of w/c of 0.38 met the requirements for workability. The results indicated that as the percentages of replaced PVC increased, the workability of concrete decreased, as shown in Table 4.1 and Figure 4.2. When compared the results with the reference mixture, there is a high reduction occurred when the ratio of replacement was 30% by 69.7%. The reduction is caused due to the angularity of the shape of PVC particles and their sharp edges. Also, because the surface area of PVC particles is greater than sand particles, which make the concrete mixture will be inhomogeneous. Facing this problem is either by increasing the water to cement ratio (this option is not desirable because it has an effect on the performance of concrete), or adding the superplasticizers that improve the workability of the mixture, and which was used in this study. According to Figure 4.2 the relationship between slump of PVC ratio to slump of reference ratio and PVC percentage is governed by the liner equation:

$$S = SR\ (1 - 2.62\ PVC\%) \qquad 4.1$$

Where SR= the slump of Reference mixture (0 % PVC)

S= the slump of PVC % ratio

Table 4.1 Results of Slump Test for Sand Replaced By PVC.

PVC/ SAND %	Slump (mm)	Variation in slump %	S/SR	Consistency
0%	165	0	1.00	High
5%	150	9	0.87	High
10%	120	27.3	0.74	High
15%	113	31.5	0.61	High
20%	80	51.5	0.48	Medium
30%	50	69.7	0.21	Medium

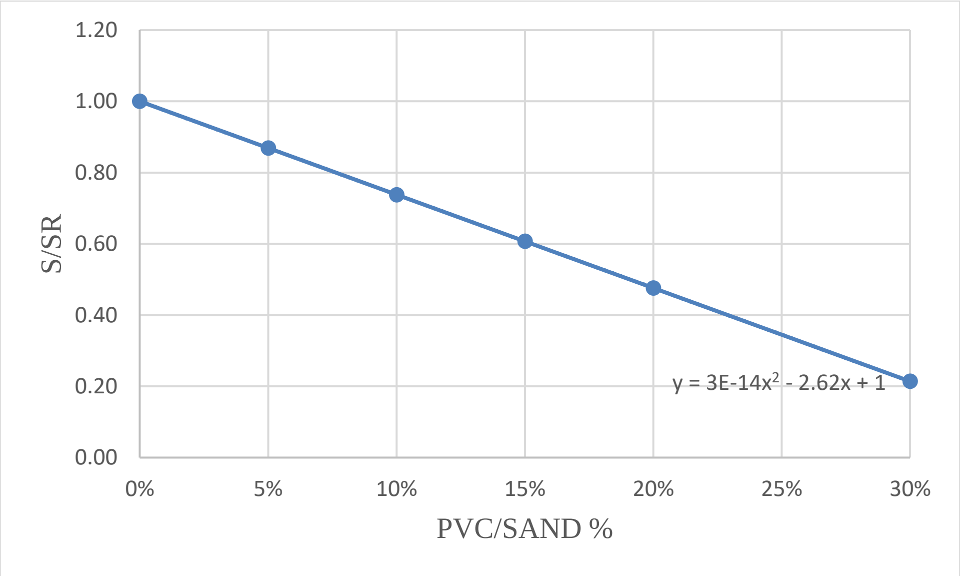


Figure 4.2 S/SR to (PVC/SAND) Relation.

4.2.2 Results of Mechanical Properties

4.2.2.1 Compressive Strength

The results of compressive strength are displayed in Table 4.2 and Figure 4.3. It showed that the percentages of replacement between 5% and 10% had a positive effect by increasing the compressive strength when compared to the reference mixture of concrete cube, and this increase was noticed at 7, 14, and 28 days of concrete age in different proportions. It can be explained in detail as follows:

At the age 7 days: The results after 7 days indicated an increase in compressive strength when the substitution ratios increased up to 10% of sand above the reference ratio (0% PVC). The ratio of 10% gives the higher value of compressive strength with an increase of 34.01%. the ratio of 10% followed by the ratios of 15%, 5%, and 20%, which achieved a rise of 24.91%, 17.44%, and 12.53%, respectively, when compared to the value of the reference ratio.

At the age 14 days: the increase in strength is maintained when compared to the strength of the reference mixture. Also, the maximum rise occurred when the percentage of replacement was 10% by 32.05%, followed by the percentages of 15%, 5%, and 20%, with an increase of 25%, 21.82%, and 17.5%, respectively, compared to the reference percentage.

At the age 28 days: there was also a noticeable variation in the compression strength curve at age of 28 days but with a change that was less than the previous ages (7 and 14 days) when compared to the reference cube. The percentage 10% made the higher increase in compressive strength by 21.08% when compared to the reference cube. While the percentages of 15% and 5% and 20% increased by 18.07% and 15.86%, and 12.25% respectively.

In general, at the ages 7, 14 and 28 days, the compressive strengths of specimens were found to be similar, with replacement percentages of 10% and 15% representing the higher values. In addition, it was observed that the percentage of 30% caused a decrease in compressive strength in three ages of 7, 14 and 28 days by -6.37%, -2.27%, and -9.24%; respectively. As displayed in Figure 4.3. The reason for increasing compressive strength in percentages up to 10% is that if the plastic percentage is low, the plastic particles can fill some of the pores in concrete more efficiently. On the other hand, the reduction in compressive strength when the replacement PVC percentage exceeded 10% may be affected by some factors, such as the low bonding between PVC particles and paste of cement and the shape and particle size of PVC waste, which are coarser than sand particles. From Figure 4.3, the relationship between compressive strength at 28 days of PVC ratio to compressive strength of reference ratio and PVC percentage is represented by the following equation:

$$f_{cu} = f_{cuR}\,(-10.404PVC\%^2 + 2.7017PVC\% + 1.0226) \qquad 4.2$$

Where f_{cuR} = the compressive strength of Reference mixture (0 % PVC)

f_{cu} = the compressive strength of PVC % ratio

Table 4.2 Compressive Strength Results for PVC Percentages Replaced as A Sand

PVC/ SAND %	Average compressive strength (3 cubes) *fcu* (MPa)			Variation in compressive strength% (28 days)	fcu/fcuR
	7 days	14 days	28 days		
0 (R)	42.83	44	49.8	---	1.00
5	50.3	53.6	57.7	+15.86	1.16
10	57.4	58.1	60.3	+21.08	1.21
15	53.5	55	58.8	+18.07	1.18
20	48.2	51.7	55.9	+12.25	1.12
30	40.1	43	45.2	-9.24	0.91

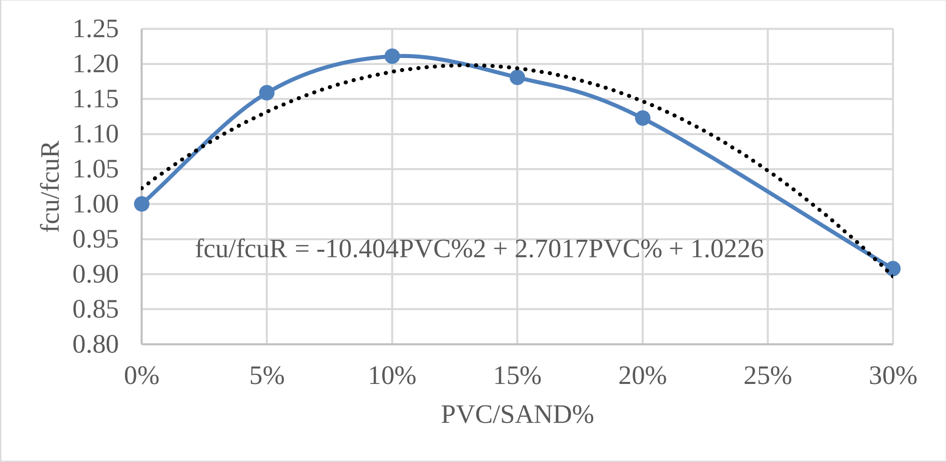


Figure 4.3 f_{cu}/f_{cuR} to (PVC/SAND) Relation.

Figure 4.4, showed a comparison of failure modes between reference ratio of cube and other PVC cubes, which indicated that the specimen of reference percentage failed in a sudden way with smashing when it reached the failure stress, while the percentages that contained PVC particles as sand replacement were cracked without smashing or crushing at the phase of failure, and the reason is due to the ductility produced by PVC particles.

Figure 4.4 The Failure Mode of Concrete Cubes for Reference and All PVC/SAND Percentages.

4.2.2.2 Splitting Tensile Strength

For the test of splitting tensile strength, nine cylinders of 100*200 mm dimensions were cast for all percentages of PVC that were used in this study. For each age of concrete, 7, 14, and 28 days, three cylinders were tested to find the strength of the splitting tensile. As shown in Table 4.3 and Figure 4.5, the results indicated that replacing sand with scraped PVC in percentages from 5% to 10% increased the concrete's splitting tensile strength.

At the age of 7 days: the splitting tensile strength has risen to a percentage of 20%. The variation was 7.69%, 19.23%, 11.53%, and 5% when the percentages of substitutions were 5%, 10%, 15%, and 20%, respectively, whereas the replacement of 10% represented the ideal percentage.

At the age of 14 days: there was an observed increase and development in the value of tensile strength with a variation of 13.21%, 24.53%, 20.75%, and 9.81% for percentages of 5%, 10%, 15%, and 20% respectively. Also, the percentage of 10% represents the optimum value of tensile strength.

While at the age of 28 days: the increasing of tensile strength occurred in the same way. When the ratios of replacement were 5% and 10%, 15% and

20% the increment by 14.29%, 21.43%, 17.86% and 10.71%, respectively compared with the reference ratio specimen.

As mentioned in the compressive strength, increasing the replacement of sand with PVC waste particles in the range of 5–10% will increase the splitting tensile strength. The splitting tensile strength was slightly reduced in the specimens with 30% PVC replacement in 7, 14 and 28 days by -1.5%, -5.66 %, and -10.71%, respectively above the reference ratio. The flexibility and sharp angles of PVC granules led to a decrease in the slipping of PVC granules compared with sand granules and thus the splitting tensile strength was increased up to 10%. In the same way as with compressive stress, the reduction that occurred in the tensile stress when the percentage of replacement was greater than 10% was influenced by the poor bond between particles of PVC and cement paste, which may have resulted from the smoothness of PVC particles and excess water around the surface of PVC granules. Another reason for poor bonding was that after reaching the ultimate load, most particles of PVC were separated and did not fail in the concrete mixture, which led to the reduction in splitting tensile strength. From Figure 4.5 the relationship between splitting tensile strength at 28 days of PVC ratio to splitting tensile strength of reference ratio and PVC percentage is represented by the following equation

$$f_t = f_{tR} \,(-10.544PVC\%2 + 2.7041PVC + 1.0187) \qquad 4.3$$

Where f_{tR} = the splitting tensile strength of Reference mixture (0 % PVC)

f_t = the splitting tensile strength of PVC % ratio

The failure mode is shown in Figure 4.6, where it refers to the obvious fracture in the reference sample suddenly when it reaches the phase of ultimate failure, while the samples that contained plastic PVC particles did not break or split into two parts, and the crack pattern is not clear. The reason is, the ductility of the PVC particles, as mentioned previously in the compressive strength failure mode.

Table 4.3 Splitting Tensile Strength Results for PVC Percentages Replaced as A Sand.

PVC/ SAND %	Average splitting tensile strength ft (MPa)			Variation in splitting tensile strength % (28 days)	fc ' MPa	f_t/f_{tR}
	7 days	14 days	28 days			
0 (R)	2.6	2.65	2.8	---	42.3	1.00
5	2.8	3	3.2	14.29	49.05	1.14
10	3.1	3.3	3.4	21.43	51.26	1.21
15	2.9	3.2	3.3	17.86	49.98	1.18
20	2.73	2.91	3.1	10.71	47.52	1.11
30	2.56	2.5	2.5	-10.71	38.42	0.89

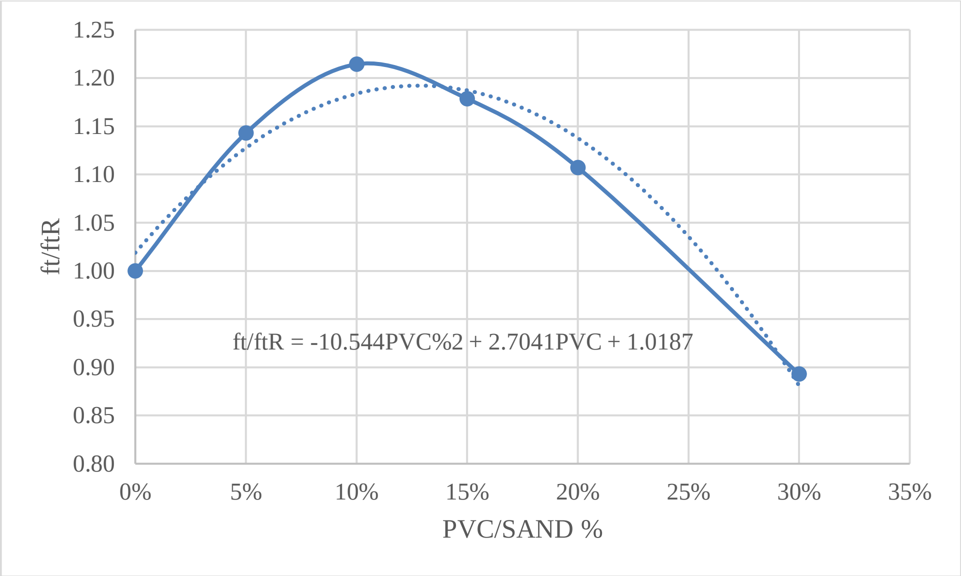


Figure 4.5 f_t / f_{tR} to (PVC/SAND) Relation.

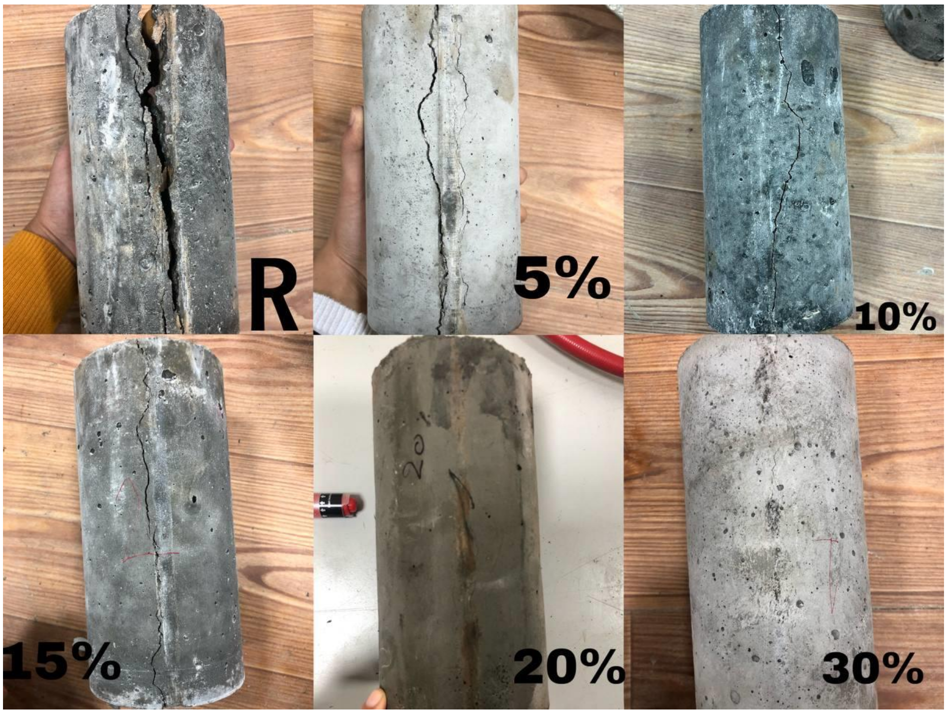


Figure 4.6 The Failure Mode of Concrete Cylinders for Reference and All PVC/SAND Percentages.

4.2.2.3 Flexural Strength

The flexural strength was found by testing six samples of prism of 500*100*100 mm dimensions for each ratio of replacement by PVC waste. Three samples were used to test the strength concrete at 7 days' age and the other three samples were for 28 days' age. As displayed in Table 4.4 and Figure 4.7, the results pointed out to increasing the flexural strength with increasing the PVC replacement percentage up to 15% when compared to the reference sample.

At the age of 7 days: the replacement of sand by scraped PVC achieved an increase in flexural strength in the range of 5–20% with a variation of 10.91% 7.27%, whereas the percentage 10% represented the highest value of flexural strength by 14.55%, while the percentage 30% gave result that were approached from the reference percentage.

At the age of 28 days: In comparison to the reference samples, the results demonstrated that partial replacement of sand with PVC at percentages ranging from 5% to 20% increased flexural strength with an increment of 5% to 3.33%. For the sample containing 30% PVC, the flexural strength showed a slight decrease from the reference concrete by -1.67 %. The replacement percentage of 10% obtained the highest flexural strength with an increase of 6.67% when compared to the reference concrete.

The adding of PVC plastic waste to the concrete mixture in a limited range will enhance the flexural strength of concrete due to the ductility and flexibility of PVC particles and make the concrete more deformable before failure compared with sand particles. In contrast, the use of PVC waste in proportions greater than 10% decreased the modulus of rupture because the transition area between PVC granules and cement paste is very weak and caused an accumulation of free water around the PVC particles. From Figure 4.7, the relationship between flexural strength at 28 days of PVC ratio to flexural strength of reference ratio and PVC percentage is represented by the following equation:

$$\mathbf{f_r = f_{rR}\,(-2.873\ PVC\%^2 + 0.7586\ PVC + 1.0093)} \qquad 4.3$$

Where f_{tR} = the flexural strength of Reference mixture (0 % PVC)

f_t = the flexural strength of PVC % ratio

The failure mode is very evident in Figure 4.8, which shows the difference between the reference specimen, that separated into two parts under failure load, and the 30% PVC specimen that failed with no sudden fracture or separation. It refers to the ability of PVC particles to improve the flexural behavior of concrete and thus effect on the flexural behavior of beams by reducing the width of cracks and protecting the reinforcement bars.

Table 4.4 Flexural Strength Results for PVC Percentages Replaced as A Sand.

PVC/ Sand %	Average flexural strength *fr* (MPa)		Variation in flexural strength % (28 days)	*fc '* MPa	$fr=0.62\sqrt{fc'}$	f_r / f_{rR}
	7 days	28 days				
0 (R)	5.5	6	---	42.33	4.0	1.0
5	6.1	6.3	+5.00	49.05	4.3	1.1
10	6.3	6.4	+6.67	51.26	4.4	1.1
15	6	6.33	+5.50	49.98	4.4	1.1
20	5.9	6.2	+3.33	47.52	4.3	1.0
30	5.4	5.9	-1.67	38.42	3.8	1.0

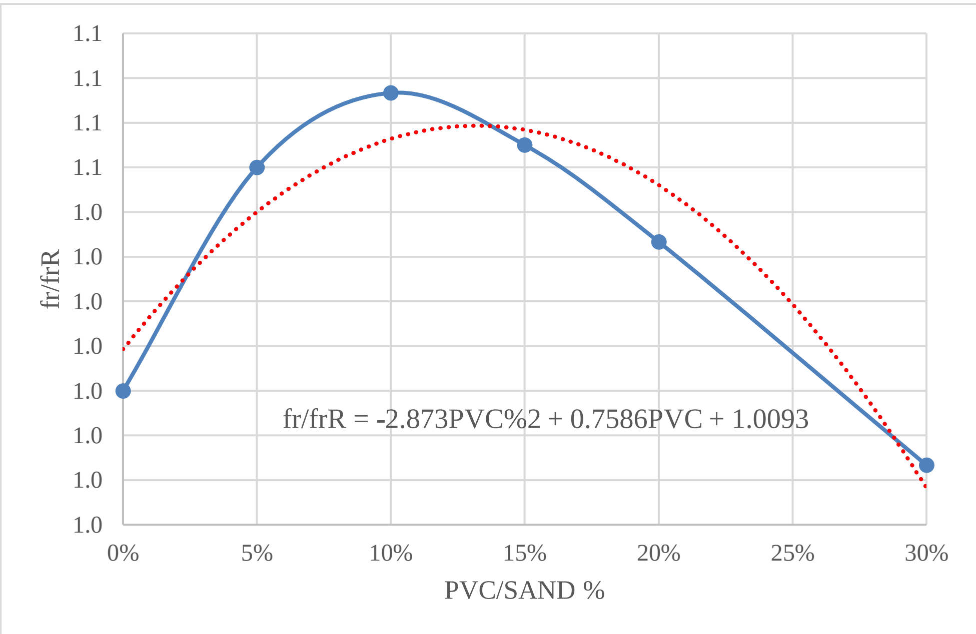


Figure 4.7 f_r / f_{rR} to (PVC/Sand) Relation.

Figure 4.8 The Failure Mode of Concrete Prisms for Reference(R) And 30% PVC/Sand Percentages.

4.2.2.4 Modulus of Elasticity

The modulus of elasticity is calculated from the stress-strain curve in accordance with ASTM-C 469-02 [67]

The elastic modulus results are shown in Tables 4.5 and Figure 4.9. The results and relationships clearly show that the modulus of elasticity significantly reduces as the ratio of recycled PVC plastic particles increases. Firstly, the cylinder with no PVC waste (reference ratio) achieved an elastic modulus with a value of 29.97 GPa, which is considered the maximum recorded value of modulus of elasticity. Then the elastic modulus values are gradually decreased with an increase in strain values as the percentages of PVC particles increase in the concrete mixture. The replaced percentages of 5%, 10%, 15%, 20%, and 30% recorded a spicific value of 28.67, 26.26, 22.65, 20.43, and 18.36 GPa with a change of -4.34%, -12.37%, -24.41%, -31.83%, and -38.74%; respectively. The laboratory results showed that the relationship between strain and modulus of elasticity is an inverse relationship, and this conforms to the law of modulus and proves the validity of the results. In addition, the PVC particles have an elastic modulus lower than sand particles and more ductility, which affected the concrete modulus completely. The Figure 4.9, shows the relationship between the modulus of elasticity and the percentage of PVC used in concrete mixture through the following equation:

$$E_c = -42.208\ (PVC\ \%) + 30.024 \qquad 4.6$$

$$R^2 = 0.9612$$

In this study, a change was observed in the constant that governs the equation between the compressive strength and the modulus of elasticity for each of the replacement ratios. Depending on the formula of the equation in ACI 318-14 [71]:

$$E_c = \mathbf{4700}\sqrt{\boldsymbol{fc'}} \qquad 4.7$$

it can deduce the constants that represent the different ratios as shown in the Table 4.5

Table 4.5 Modulus of Elasticity Results for PVC Percentages Replaced as A Sand.

PVC/SAND%	Modulus of elasticity values (GPa)	Variation %	*fc '* MPa	Factor
0%	29.97904	---	42.33	4607
5%	28.67632	-4.34	49.05	4095
10%	26.26905	-12.37	51.26	3669
15%	22.65857	-24.41	49.98	3205
20%	20.43446	-31.83	47.52	2963
30%	18.36268	-38.74	38.42	2962

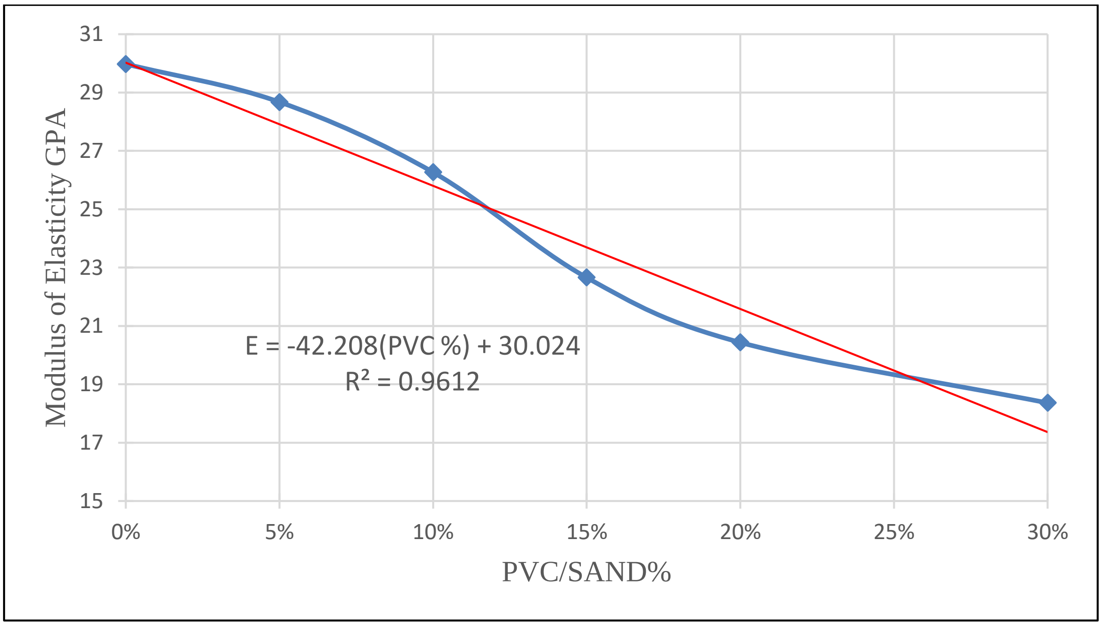


Figure 4.9 The Modulus of Elasticity to (PVC/Sand %) Relation.

4.2.2.5 Abrasion

The results of the abrasion test can be expressed as the percentage of the lost weight from a cube that is subject to abrasion in Table 4.7 and Figure 4.10. The results indicated that when the ratio of PVC plastic waste as partial substitution of fine aggregate in the concrete increases, the abrasion value decreases. which means that the concrete's resistance to abrasion increases when the PVC content is increased. The abrasion value of the reference specimen recorded the highest value of 21.3 followed by percentages of 5%, 10%, 11%, 20%, and 30% with weight loss values of 19.7, 15.6, 14.1, 9.9, and 9 in clear variation to the reference percentage of -7.6%, -26.8%, -34%, -53.6, and -57.5%, respectively.

Table 4.6 The Abrasion Results for PVC Percentages Replaced as A Sand.

PVC/SAND%	Abrasion %	Variation %
0	21.3	0
5	19.7	-7.6
10	15.6	-26.8
15	14.1	-34.0
20	9.9	-53.6
30	9.0	-57.5

The Figure 4.10, the following equation demonstrates the relationship between the abrasion value and the ratio of PVC used in the concrete mixture.:

$$\text{Abrasion} = -0.4459\ (\text{PVC}\ \%) + 20.879 \qquad 4.8$$

$$R^2 = 0.953$$

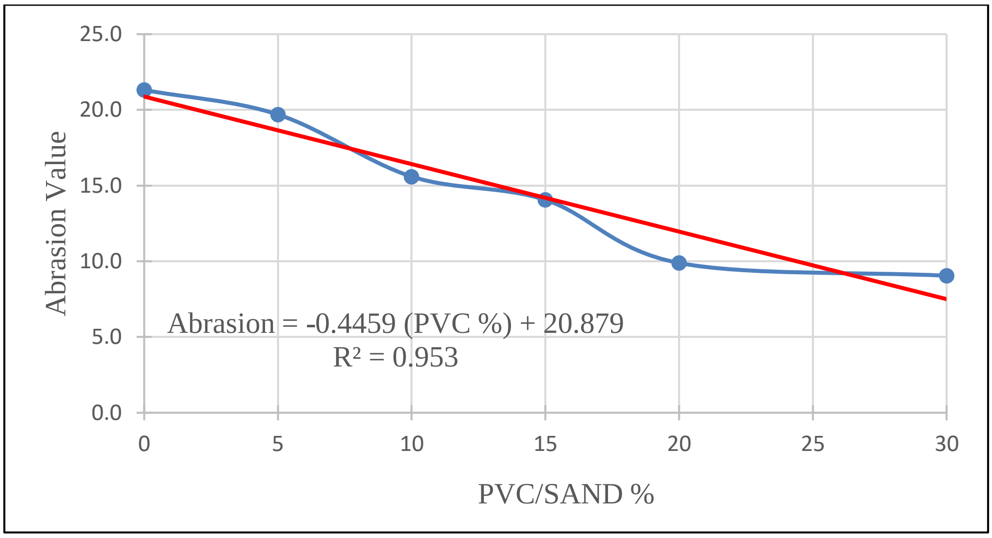


Figure 4.10 The Abrasion to (PVC/Sand %) Relation.

The reason for the increase in abrasion resistance with an increase in the percentage of replaced scraped PVC can be attributed to the ability of the PVC particles to absorb the energy generated by abrasion impact as a result of its high ductility compared to sand particles. Figure 4.11 shows the reference ratio and the different percentages of scraped PVC specimens subjected to abrasion in the Los Angeles machine.

Figure 4.11 The Cubes Specimen Subjected to Abrasion.

4.2.3 Results of Physical Properties

4.2.3.1 Density

Before the compressive strength test, dry density measurements were taken on all specimens of cubes at ages 7, 14, and 28 days by using the same procedures as for the compressive strength test. As given in Table 4.8 and Figure 4.12. The results indicated that density decreased as the particle percentage of PVC increased in concrete. The density of the reference sample is 2460.8 kg/m^3 at age 28 days, and it gradually decreases as the substitution percentage increases. The density of 5% PVC was 2440.38 kg/m^3, with a decrease of 0.83% when compared to the reference sample. In contrast, increasing the PVC replacement percentage to 30% resulted in a concrete density of 2313.08 kg/m^3, with a 6% decrease from the reference mix. The main cause of the decreasing concrete density is the low density of PVC granules, which was 1440 kg/m^3.

Table 4.7 Results of Density for PVC Percentages Replaced as A Sand.

PVC/ SAND %	Density ɣ (kg/m^3)			Variation in density % (28 days)	*fc '* MPa	*fc'/ ɣ*
	7 days	14 days	28 days			
0	2489.43	2494.61	2460.8	---	42.3	17.2
5	2449.67	2467	2440.38	-0.83	49.05	20.1
10	2426.9	2430.3	2423.8	-1.50	51.26	21.1
15	2413.15	2410.6	2404.66	-2.28	49.98	20.8
20	2402.48	2398.8	2376.09	-3.44	47.52	20.0
30	2328.4	2312.91	2313.08	-6.00	38.42	16.6

As shown in Figure 4.12. The relationship between density at 28 days and PVC waste percentage represented by the following equation:

$$\gamma = -484.59\ (PVC\%) + 2467.7 \qquad 4.9$$

$$R^2 = 0.9796$$

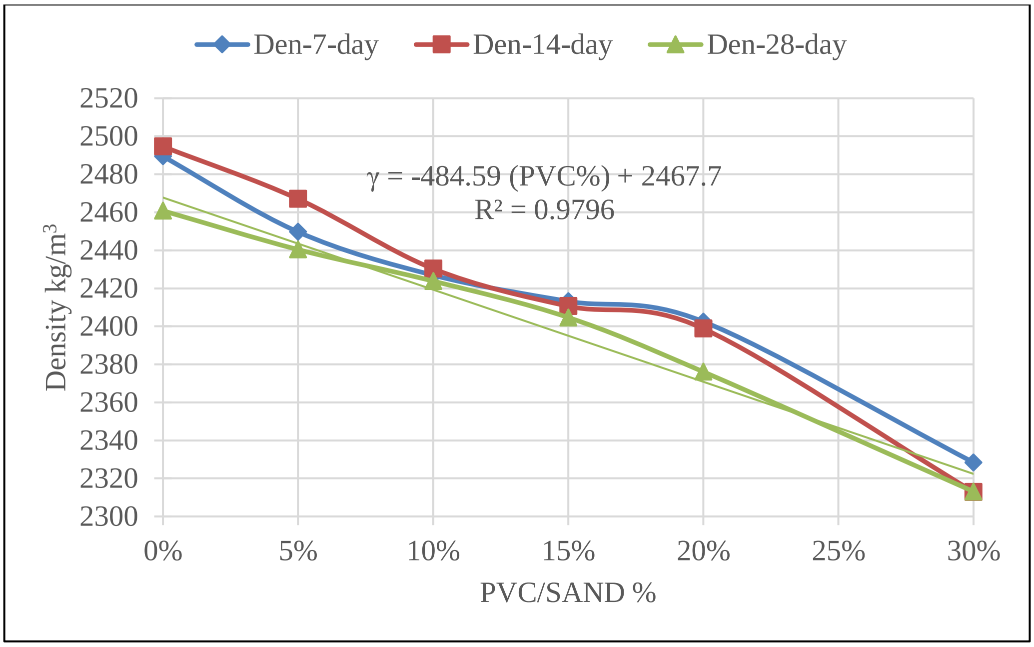


Figure 4.12 Density to (PVC/Sand) Relation.

4.2.3.2 Absorption

The absorption test was carried out using six cubes of concrete. Each ratio of PVC particles was represented by one cube. The cubes were dried in the oven for 72 hours and obtained their dry weight before being submerged in water at a temperature of 105 °C for 24 hours to determine their wet weight according to ASTM C642 [69]. The results are displayed in Figure 4.13 and Table 4.9. The results indicate that the absorption ratio increases as the amount of PVC waste increases in the concrete mixture. The cube of reference percentage recorded an absorption ratio of 1.79%, and as the PVC replaced ratio increased, the absorption ratio kept increasing. The percentages of PVC represented by 5%, 10%, 15%, 20%, and 30% gave an absorption ratio of 1.89%, 1.96%, 2.05%, 2.29%, and 2.72%, namely higher than those for the reference specimen by 5.8%, 9.75%, 14.52%, 28.1%, and 51.87%, respectively. The irregular and sharp edges of the PVC granules resulted in weak bonding between the PVC particles and cement paste, resulting in cracks and voids within the mass of concrete, causing absorption to increase with increasing PVC percentage in the concrete mixture. From Figure 4.13. the relationship between absorption value and PVC waste percentage represented by the following equation:

$$\text{Absorption}=3.0629(\text{PVC }\%)+1.7083 \qquad 4.10$$

$$R^2=0.9417$$

Table 4.8 Results of Absorption for PVC Percentages Replaced as A Sand.

PVC/ sand %	Dry weight (D.W) kg	Wet weight (W.W) kg	W.W-D.W kg	Absorption ratio %	Variation %
0	7.928	8.07	0.142	1.79	----
5	7.915	8.065	0.15	1.89	5.8
10	7.885	8.04	0.155	1.96	9.75
15	7.849	8.01	0.161	2.05	14.52
20	7.801	7.98	0.179	2.29	28.1
30	7.72	7.93	0.21	2.72	51.87

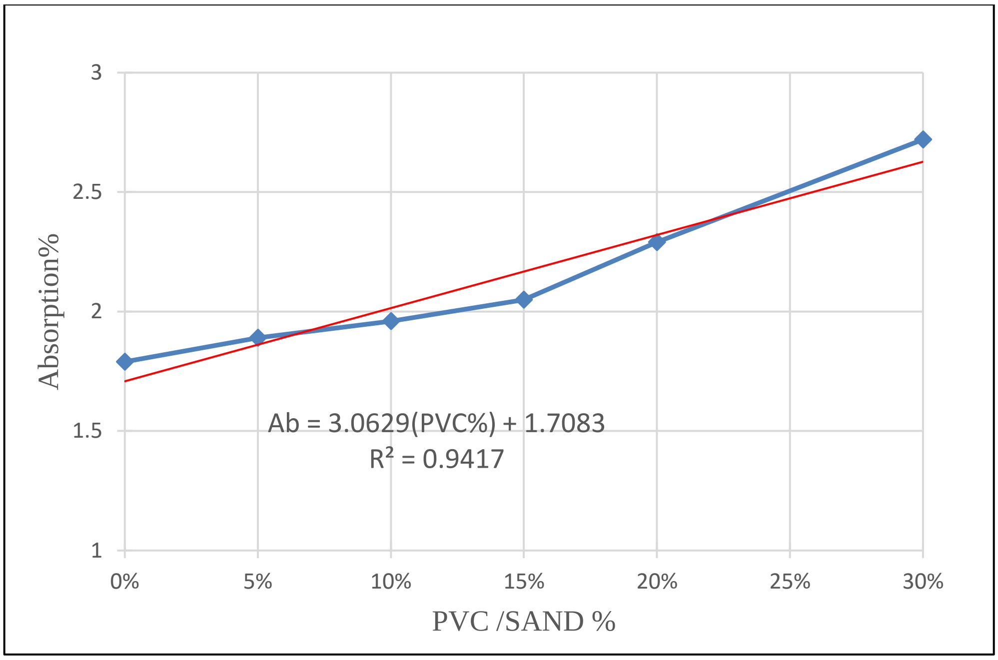


Figure 4.13 Absorption to (PVC/Sand) Relation.

4.2.3.3 Ultrasonic Pules Velocity

Ultrasonic pulse velocity was determined by testing six concrete cubes at age of 28 days, one cube for each ratio of PVC waste to ensure the quality of the concrete by using the direct transmission. The test was conducted in two directions simultaneously. The results are shown in Figure 4.14 and Table 4.10, which indicate that as the substitution percentage of scraped PVC waste increased, the pulse velocity gradually decreased in both directions. The pulse velocity of the reference specimen recorded the highest value of 5199 m/s followed by percentages of 5%, 10%, 15%, 20%, and 30% with pulse velocity values of 5140, 5137, 5093, 4992, and 4865 m/s in slight variation to the reference percentage of 1.13%, 1.19%, 2.03%, 3.98%, and 6.42%, respectively. With an increase of PVC waste as a sand, the density and pulse velocity decreased in the same way where the 30% PVC percentage recorded the lower values by decreasing 6 and 6.42 for density and UPV, respectively. The following equation represented the relationship between the pulse velocity and PVC waste percentage which derived from Figure 4.14:

$$UPV=-1101.4\ (PVC\ \%) + 5217.9 \qquad 4.11$$

$$R^2 = 0.9478$$

Table 4.9 The Ultrasonic Pulse Velocity Results for PVC Percentages Replaced as A Sand.

PVC/ Sand %	Readings of ultrasonic velocity (Km/s)			Variation %	Quality of concrete according to the BS 1881[72] limits Standard
	Axis 1	Axis 2	Average velocity (Km/s)		
0	5.226	5.172	5.199	---	Very good
5	5.016	5.264	5.140	-1.13	Very good
10	5.102	5.172	5.137	-1.19	Very good
15	5.067	5.119	5.093	-2.03	Very good
20	5.000	4.984	4.992	-3.98	Very good
30	4984	4746	4865	-6.42	Very good

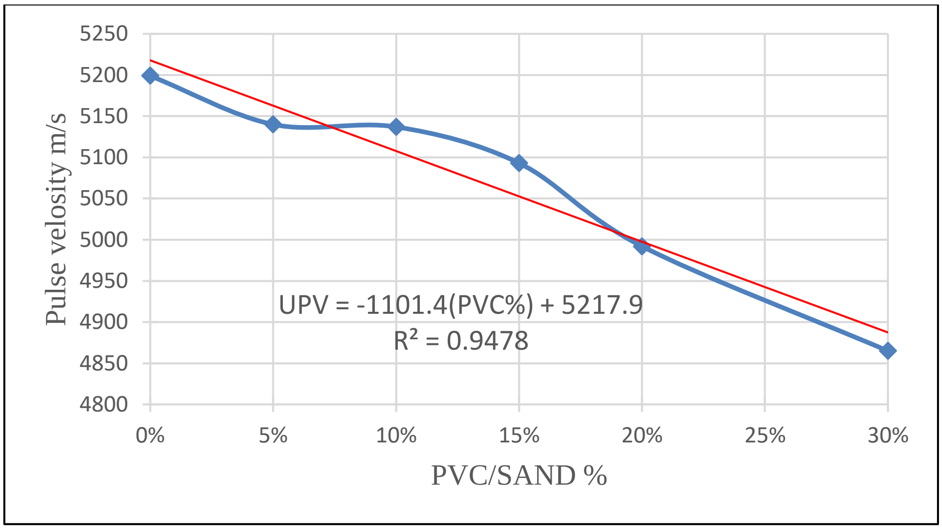


Figure 4.14 Pulse Velocity to (PVC/Sand) Relation.

For 5% to 20% partial range of PVC percentages as sand replacement, the following modified version of Raouf and Ali equation [73], may be used to calculate the compressive strength in term of UPV:

$$f_c` = 1.1*2.016\ e\text{^}(0.61*V) \quad 4.12$$

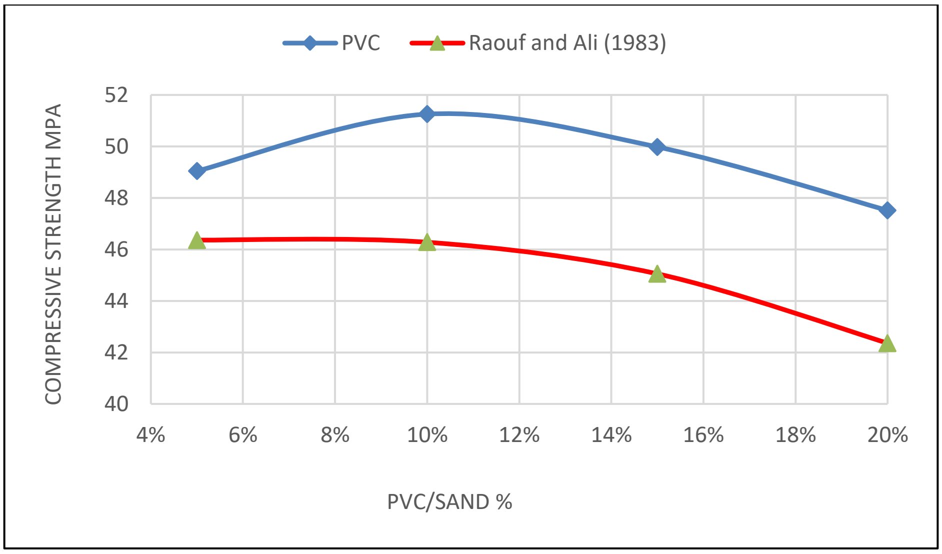


Figure 4.15 Calculating the Compressive Strength By UPV.

4.3 Part Two: Flexural Behavior of Reinforced Concrete Beams Contained Scraped PVC

The flexural behavior of concrete beams is inspected by:

- Ultimate load
- Deflection at mid span
- Flexural Compression Strain
- Ductility index
- Stiffness
- Energy absorption
- Crack pattern

As shown in Figure 4.16, five specimens with various percentages of PVC particles replacement and one for reference percentage were tested. Based on the crack path development for each load increment, the mid-span deflection and the crack pattern are determined.

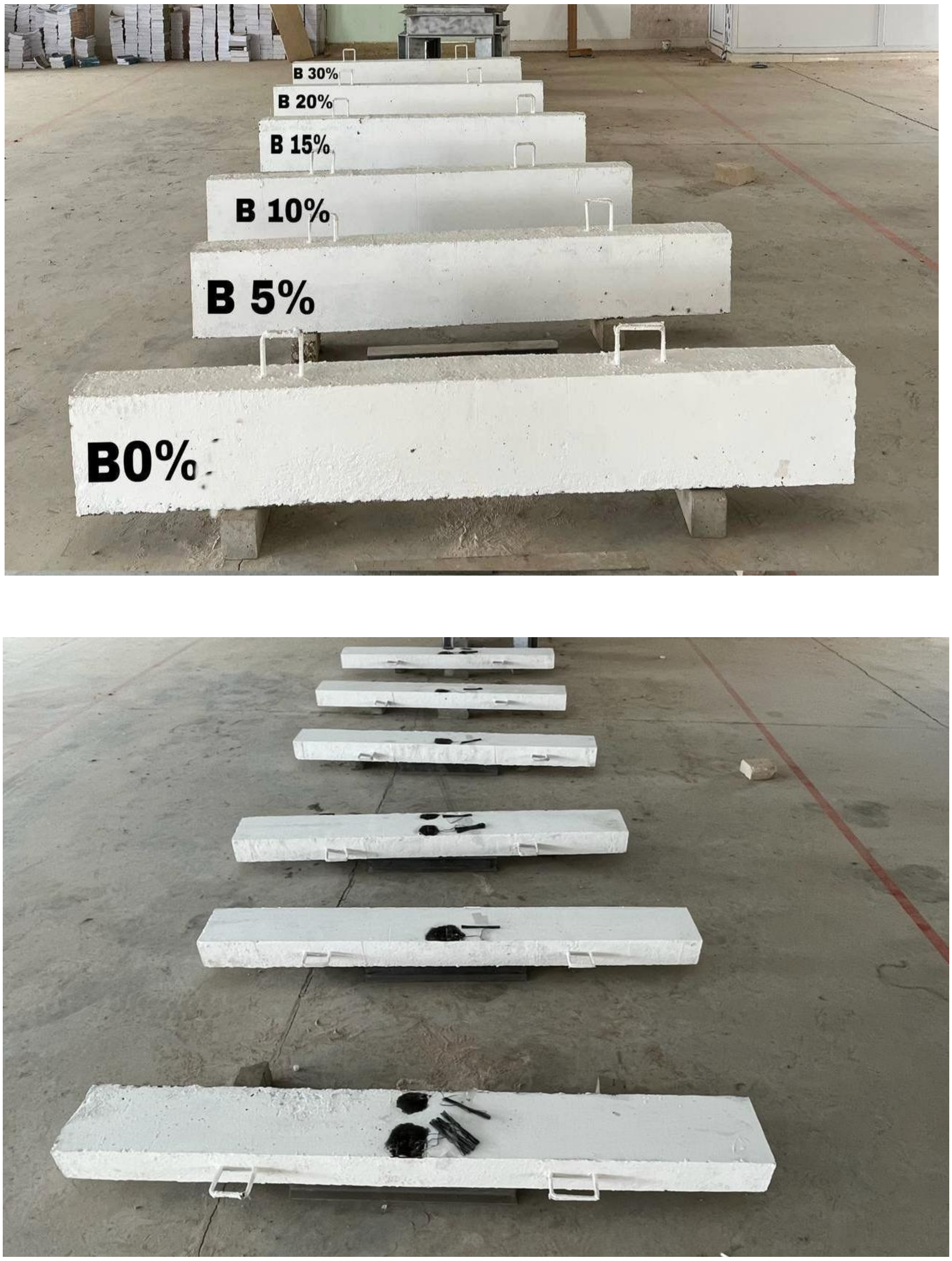


Figure 4.16 Reinforced Concrete Beams Used for All PVC/SAND Percentages.

4.3.1 Ultimate load

In Table 4.11, the ultimate load is determined and displayed for all reinforced concrete beams. The beam without PVC waste, B 0% C (reference beam), recorded an ultimate load at failure of 169 KN, followed by the beams of 5% and 10% scraped PVC as sand replacement (B 5% and B 10%), with max failure loads of 171 and 173.9 KN, which is very close to the reference beam with an increment of 1.18% and 2.9%, respectively. It is observed that the beam concrete of 15% PVC waste (B 15%) has a higher ultimate load of 175.3 KN with an increase of 3.73 % compared to the reference beam. After that, the ultimate load showed a slight decrease when the percentages of replacement 20% and 30% by 174 and 166 KN, with a variation of +2.96% and -1.78%, respectively, when compared with the beam of reference percentage. The relation between the ultimate failure load and the PVC waste particle substitution percentages for each beam is shown in Figure 4.17. the specimen of 15% PVC showed the best characteristic of failure load. The little variance in the failure load values could be caused by a difference in the quality of the concrete used or a type of test machine control.

Table 4.11 The Ultimate Load Results for PVC Percentages Replaced as A Sand.

Beam I. D.	f_{cu} MPa	f_c' MPa	*Pu* kN	*Pu/Pu* % (reference beam)	Ultimate load variation
B 0% C	49.8	42.33	169	100.0	---
B 5%	57.7	49.05	171	101.2	1.18
B 10%	60.3	51.26	173.9	102.9	2.90
B 15%	58.8	49.98	175.3	103.7	3.73
B 20%	55.9	47.52	174	103.0	2.96
B 30%	45.2	38.42	166	98.2	-1.78

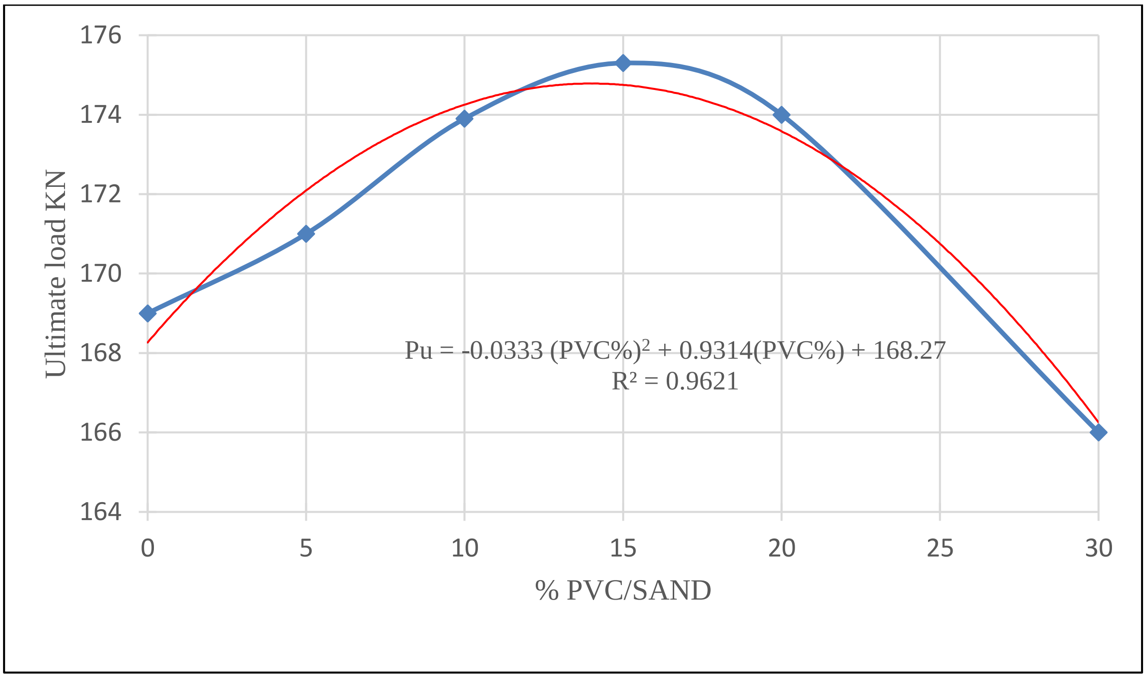


Figure 4.17 The Ultimate Load To (PVC/Sand %) Relation.

4.3.2 Load-Deflections Behavior

The deflection for each reinforced beam is displayed in Table 4.12. The findings showed that as the amount of PVC in the concrete mixture increased, the beam's deflection increased. Whereas the specimen of reference beam noted the lowest value of deflection by 19.13 mm. Also, the results showed a progressive increase in the deflection in the beams with percentages of 5%, 10%, 15%, and 20% by 20.02, 22.97, 23.98, and 26.9 mm with changes of 4.64%, 20.06%, 25.34%, and 40.58%, respectively, when compared to the reference beam. The beam of 30% PVC particles reached the highest deflection value of 28.86 mm with increasing of 50.87% compared to the beam without PVC. Load-deflection curves at mid-span were plotted for all beams, as illustrated in Figures 4.18 and 4.19. Concrete behaves differently when PVC waste is present than when it doesn't, as seen by the behavior of concrete beams along the upward max deflection path, which increases as the amount of PVC particles in the beams increases. is clear evidence that the presence of PVC waste caused concrete's brittle nature to change to another that is more flexible. In Figure 4.19, The relationship between the ultimate failure load and the maximum deflection indicates that the beam B15% was optimal. It also indicates that the fraction time is being extended and that an early warning of failure is being sent. It is a critical property of concrete for minimizing the effects of dynamic loads, earthquakes, and impulsive loads.

Table 4.12 The Maximum Load Results for PVC Percentages Replaced as A Sand.

Beam I.D.	Maximum load Pu (KN)	Maximum deflection Δu (mm)	Δu/Δu % (Reference beam)	Variation in deflection%
B 0% C	169	19.13	100	---
B 5%	171	20.02	104.64	4.64
B 10%	173.9	22.97	120.06	20.06
B 15%	175.3	23.98	125.34	25.34
B 20%	174	26.90	140.58	40.58
B 30%	166	28.86	150.87	50.87

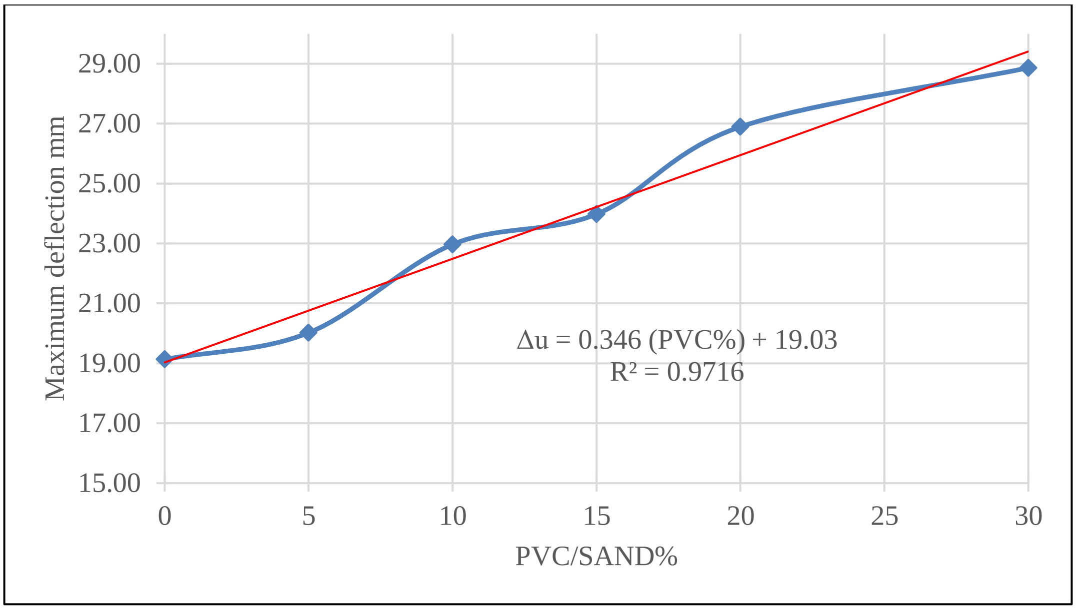


Figure 4.18 The Maximum Deflection To (PVC/Sand %) Relation for Concrete Beams.

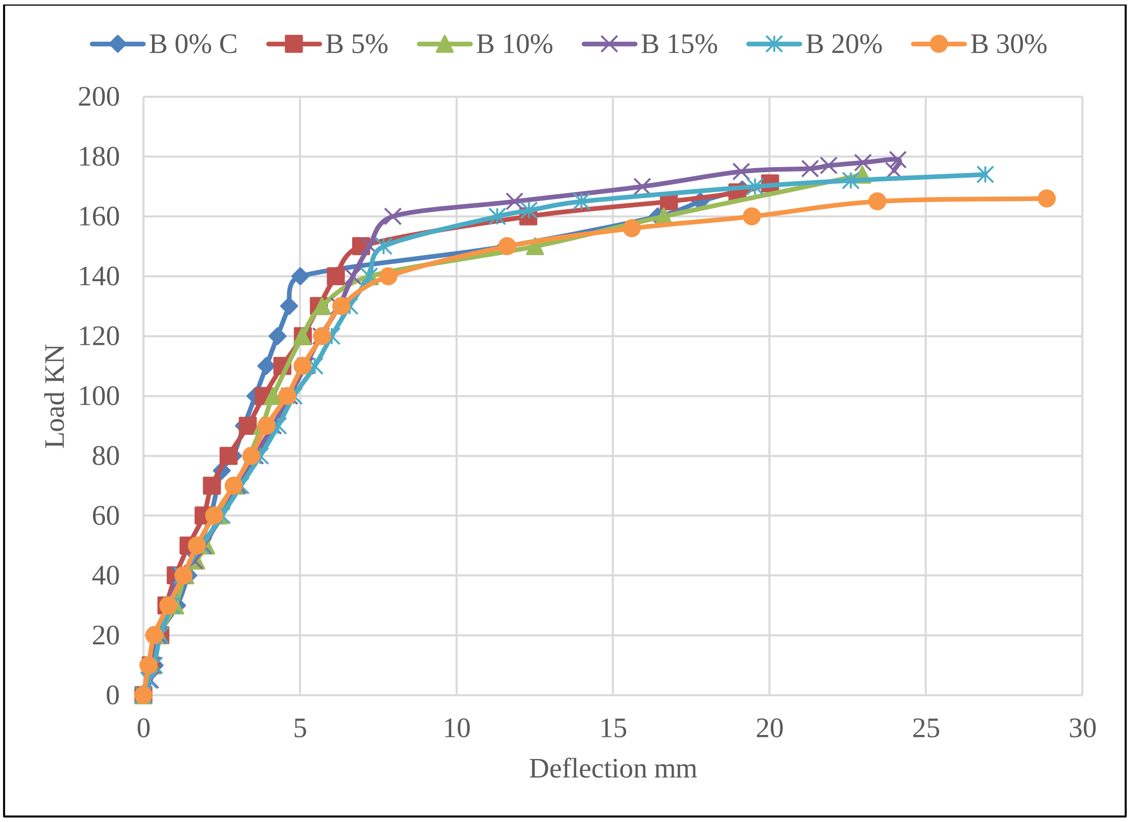


Figure 4.19 The Load To Deflection Relation for Concrete Beams.

4.3.3 Ductility Index

The ability to endure the significant deflections in reinforced concrete elements before failure is called ductility. The ductility index (μ) can be calculated from the load-deflection curve by dividing the maximum deflection (Δu) by the yield deflection (Δy) calculated in accordance with N. Priestley's study [74]. The measurements of ductility for all concrete beams are arranged and plotted in Table 4.13 and Figure 4.20 respectively. Due to the direct relationship between ductility and maximum deflection, the results showed a similarity in the path between the two variables that were referred to when compared to the reference specimen. The ductility of the reference beam started with a value of 3.83 and gradually increased as PVC percentages increased. The beams of 5%, 10%, 15%, 20%, and 30% achieved a ductility of 4.17, 5.1, 5.85, 6.72, and 9.62 with an increment of 9%, 33.4%, 52.87%, 75.72%, and 151.44%, respectively, as compared to the beam of reference percentage.

Table 4.13 The Ductility Index Results for PVC Percentages Replaced as A Sand.

Beam I.D.	Maximum Deflection Δu(mm)	Yield Deflection Δy (mm)	Ductility Index D. I	Variation in Ductility %
B 0% C	19.13	5	3.83	----
B 5%	20.02	4.8	4.17	9.01
B 10%	22.97	4.5	5.10	33.41
B 15%	23.98	4.1	5.85	52.87
B 20%	26.90	4	6.72	75.77
B 30%	28.86	3	9.62	151.44

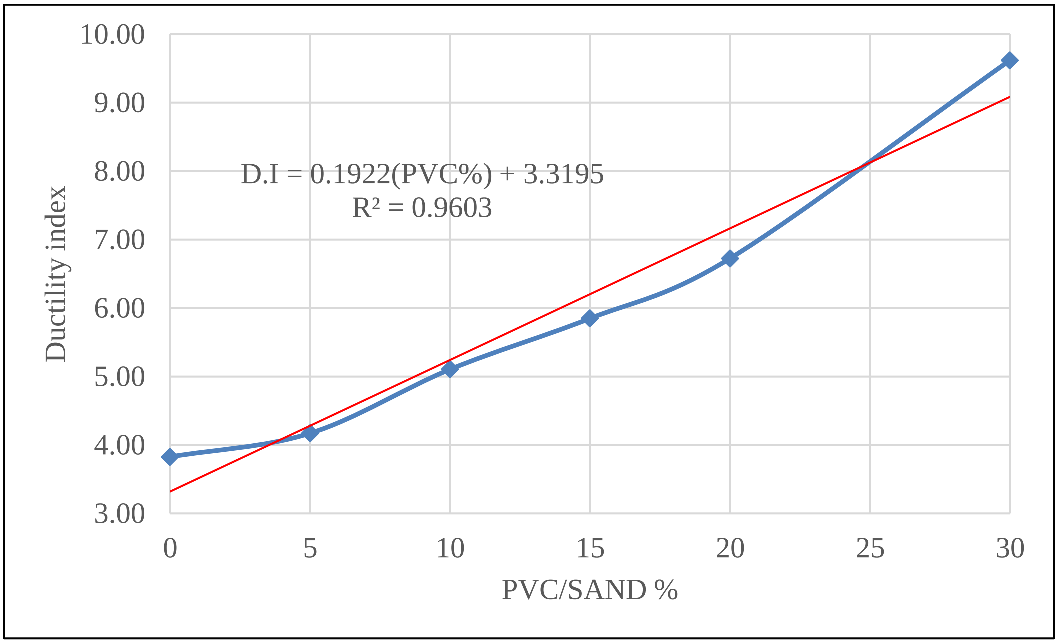


Figure 4.20 The Ductility Index To (PVC/Sand %) Relation for Concrete Beams.

4.3.4 Flexural Compression Strain at Failure Load

The results of the flexural compression strain at failure loads are shown in Table 4.14. The numbers refer to increasing the compression strain by increasing the amount of PVC in the reinforced concrete. At start the control beam (B 0% C) recorded compression strain of 0.0034341, then observed a notably increased in compression strain with percentages of 5%, 10%, 15%, 20%, and 30% by 0.003501, 0.003552, 0.003556, 0.003657 and 0.0036876 with an increment of 1.94%, 3.44%, 3.55%, 6.5% and 7.38, respectively when compared to the control beam. It should be noted that all compression strain values exceeded the compressive (crushing) flexural strain limit of 0.003 due to the increase in ductility caused by the increase in PVC content in concrete beams. The load-strain curves for each specimen in Figure 4.22 show how the reference concrete beams' brittle behavior differs from that of beams that contain PVC particles.

Table 4.14 The Compression Strain at Failure Load Results for PVC Percentages Replaced as A Sand.

Beam I.D.	Compression Strain	Variation in Compression Strain %
B 0% C	0.0034341	---
B 5%	0.0035009	1.94
B 10%	0.0035522	3.44
B 15%	0.0035561	3.55
B 20%	0.0036573	6.5
B 30%	0.0036876	7.38

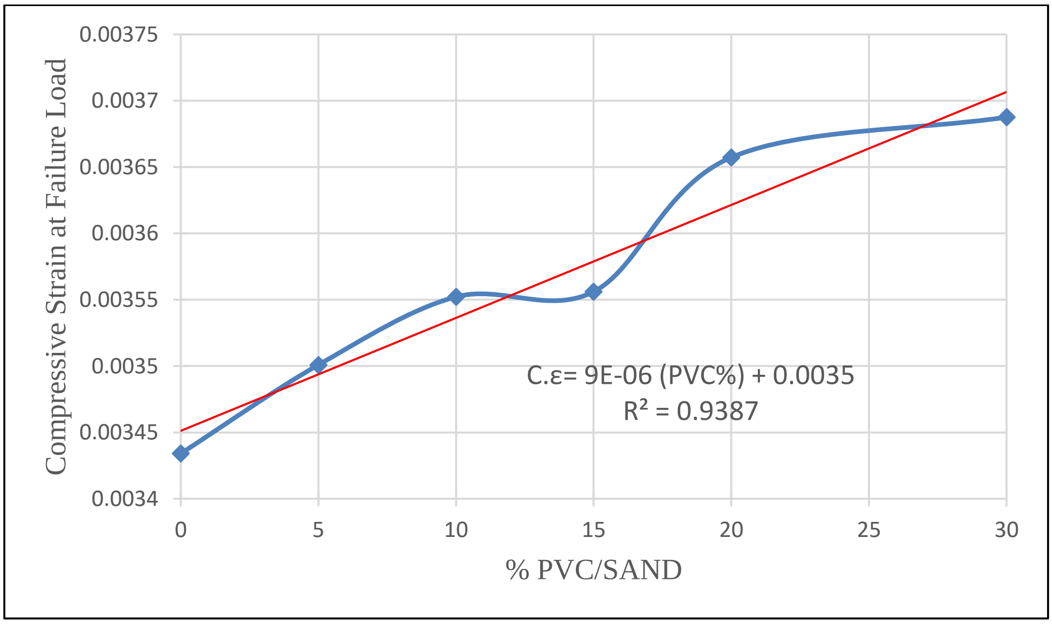


Figure 4.21 The Compression Strain at Failure Load To (PVC/Sand %) Relation for Concrete Beams.

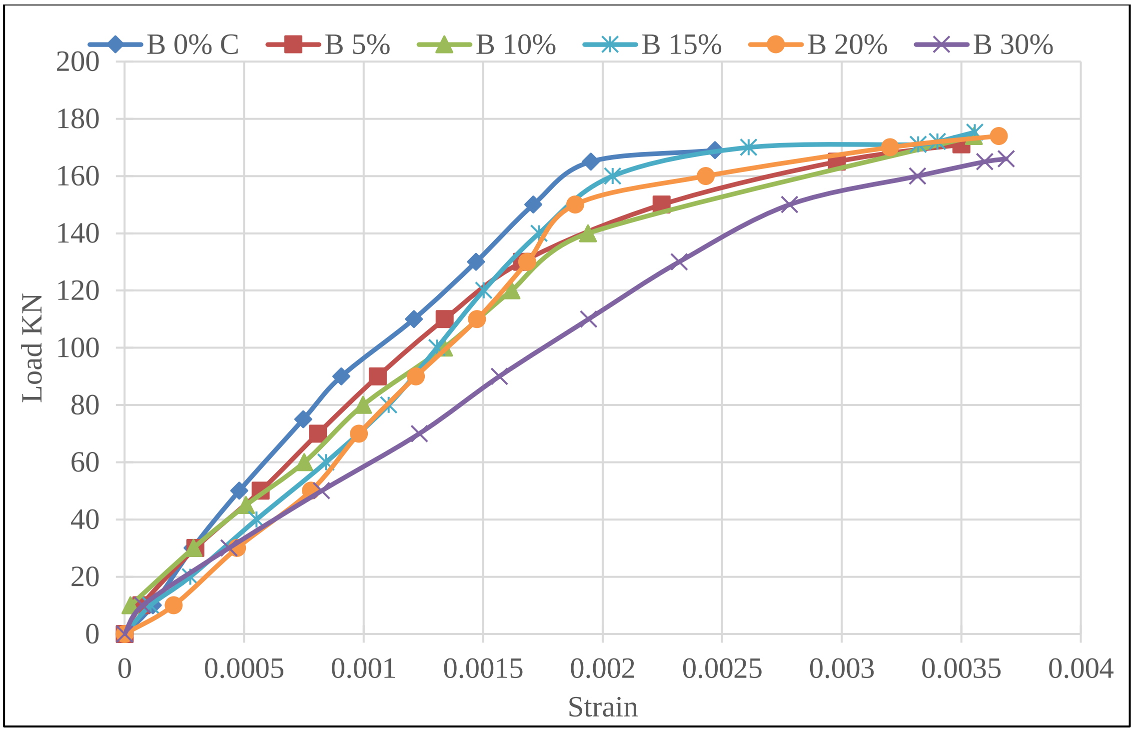


Figure 4.22 The Load To Strain Relation for Concrete Beams.

4.3.5 Stiffness

The stiffness measurements are calculated in accordance with N. Priestley's study [61] as displayed in Figure 4.23. Initial and secant stiffness were determined from the load-deflection curve. The initial stiffness is the ratio of yield load (Py) to the yield deflection (Δy) while the secant stiffness is equal to the ratio of maximum applied load (Pu) to the maximum deflection (Δu) for all PVC percentage replacement, as shown in the equations below:

$$\text{Initial Stiffness}=Py/\Delta y \qquad 4.13$$

$$\text{Secant Stiffness}=Pu/\Delta u$$

The results of initial and secant stiffness are shown in Table 4.15, which shows a decrease in values of the initial stiffness when the percentage of replacement increased in beams, where the reference specimen recorded an initial stiffness of 40.82 KN/mm. The initial stiffness progressively decreased, reaching values of 37.11, 35.71, 34.81, 32.31, and 29.33 KN/mm for the beams B5%, B10%, B15%, B20%, and B30%, respectively, with a reduction ratio of 9.09%, 12.5%, 14.71%, 20.84%, and 28.15% compared to the reference specimen. The results also showed a reduction in the secant stiffness when the PVC content was increased in reinforced concrete beams, where the reference specimen beam recorded a secant stiffness value of 8.83 KN/mm followed by other secant stiffness values of percentages of PVC used as sand replacement in concrete beams of 5%, 10%, 15%, 20%, and 30% by 8.54, 7.57, 7.31, 6.47, and 5.75 KN/mm with a gradual decrease of 3.3%, 14.3%, 17.3%, 26.8%, and 34.9%, respectively, compared to the reference specimen. This finding is in agreement with the findings on beam deflection, which show an inverse relationship between the deflection and stiffness.

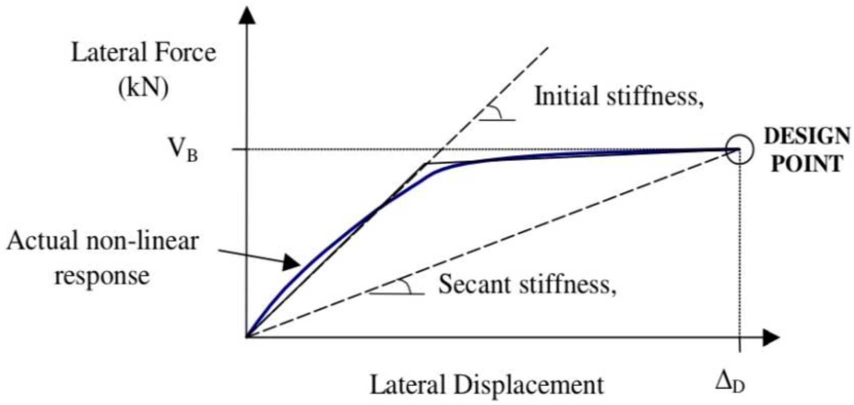


Figure 4.23 The Initial and Secant Stiffness Calculation Technique [61]

Table 4.15 The Initial and Secant Stiffness Results for PVC Percentages Replaced as A Sand.

Beam I.D.	Initial stiffness kN/mm	Variation in initial stiffness %	Secant stiffness kN/mm	Variation in secant stiffness %
B 0% C	40.82	---	8.83	---
B 5%	37.11	-9.09	8.54	-3.3
B 10%	35.71	-12.5	7.57	-14.3
B 15%	34.81	-14.71	7.31	-17.3
B 20%	32.31	-20.84	6.47	-26.8
B 30%	29.33	-28.15	5.75	-34.9

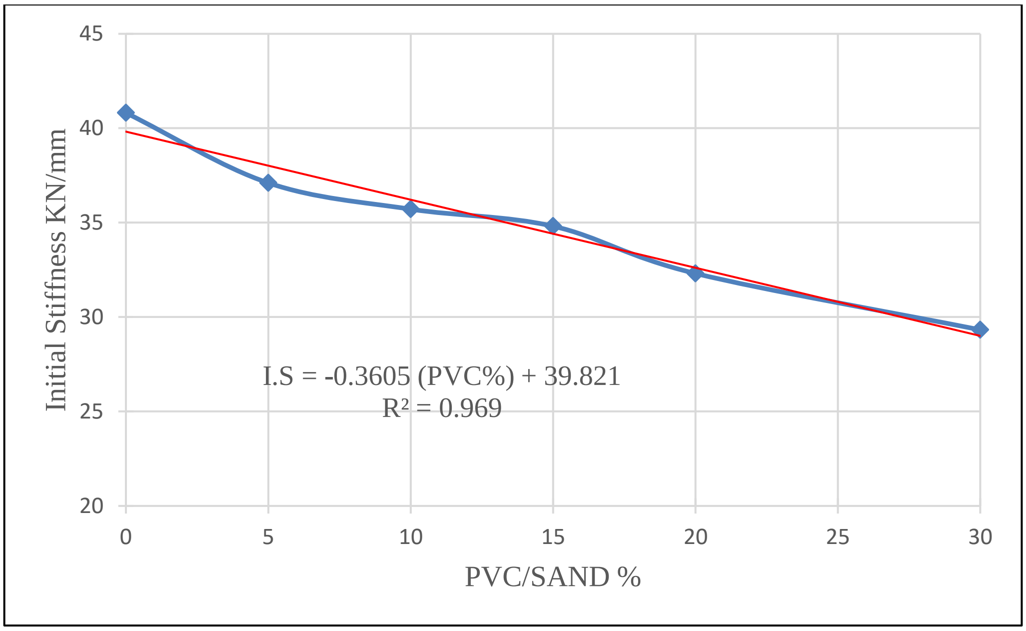


Figure 4.24 The Initial Stiffness To (PVC/SAND %) Relation for Concrete Beams.

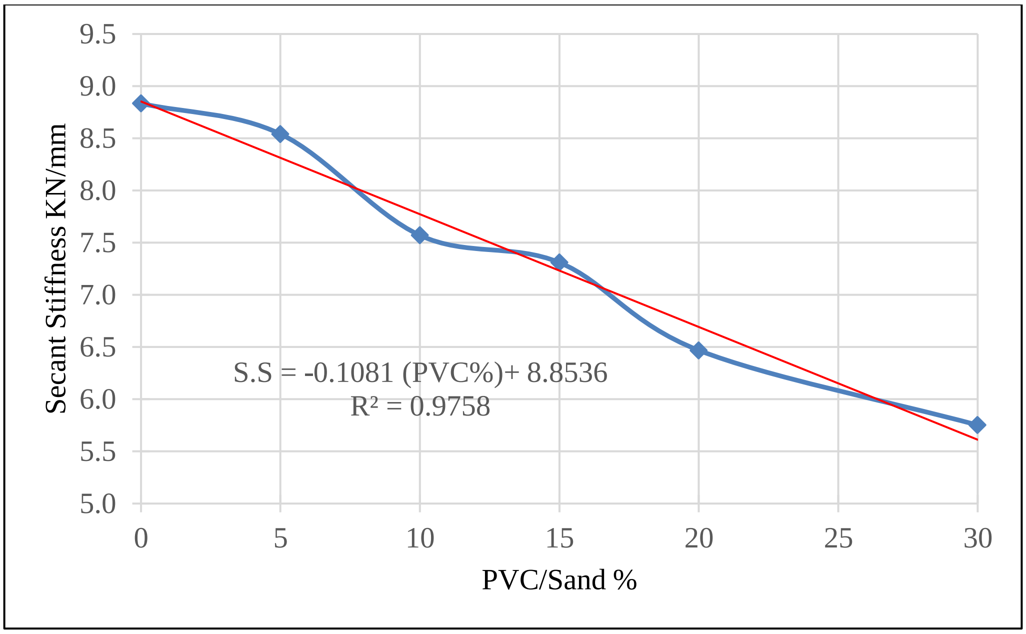


Figure 4.25 The Secant Stiffness To (PVC/SAND %) Relation for Concrete Beams.

4.3.6 Energy Absorption

The energy absorption of a reinforced concrete beam can be found from the area under the curve of load-deflection. Table 4.16 and Figure 4.26 displayed the results and relationship between energy absorption and PVC percentages for all reinforced concrete beams. As shown in Table 4.16, the increase of scraped PVC waste in the concrete mixture led to an increase in the toughness of the material. The beam of reference percentages achieved an energy absorption of 2502.56 KN.mm followed by the percentages of 5% and 10% by 2710.57 and 3060.76 KN. mm with an increment of 8.31% and 22.3%, respectively. When compared to the reference beam, the beams of percentages 15%, 20%, and 30% recorded high toughness values of 3422.26, 3810.76, and 3985.12 KN.mm with close increments of 36.75%, 52.27%, and 59.24%, respectively.

Table 4.16 The Energy Absorption Results for PVC Percentages Replaced as A Sand.

Beam I.D.	Energy Absorption kN.mm	Variation in Energy Absorption %
B 0% C	2502.56	---
B 5%	2710.57	8.31
B 10%	3060.76	22.31
B 15%	3422.26	36.75
B 20%	3810.76	52.27
B 30%	3985.12	59.24

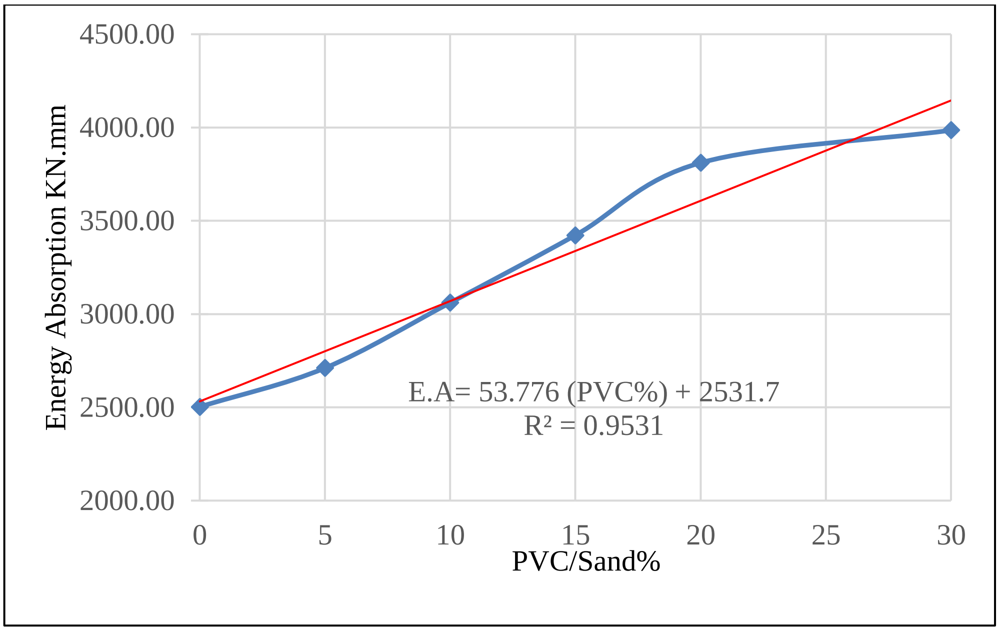


Figure 4.26 The Energy Absorption To (PVC/Sand %) Relation for Concrete Beams.

4.3.7 Cracking

The cracks are developed in concrete when the applied tensile stress is greater than the tensile stress of reinforced concrete beam. The following objects are used to examine for cracks in all concrete beam specimens:

1. First cracking load (P_{cr})
2. Cracks pattern

4.3.7.1 First Cracking Load (Pcr) for Concrete Beams

All reinforced concrete beams' first crack loads were measured and shown in Table 4.17 and Figure 4.27. The first crack in the reference beam starts at a load of 30 KN, but as the quantity of PVC waste in the concrete increases, the load at which the first crack develops gradually rises. When compared to the reference beam, the first crack of the beam 5% PVC appeared at load 35 KN, increasing by 16.67%. However, the first cracks of the beams 10%, 15%, 20%, and 30% PVC waste appeared at loads 38, 44, 49, and 53 KN, respectively, increasing by 26.67%, 46.67%, 63.33and 76.67%.

Table 4.17 The First Crack Results for PVC Percentages Replaced as A Sand in Concrete Beams.

Beam I.D.	Pcr (KN)	Pu (KN)	Pcr/Pu %	Variation in Pcr %
B 0% C	30	169	17.75%	---
B 5%	35	171	20.47%	16.67
B 10%	38	173.9	21.85%	26.67
B 15%	44	175.3	25.10%	46.67
B 20%	49	174	28.16%	63.33
B 30%	53	166	31.93%	76.67

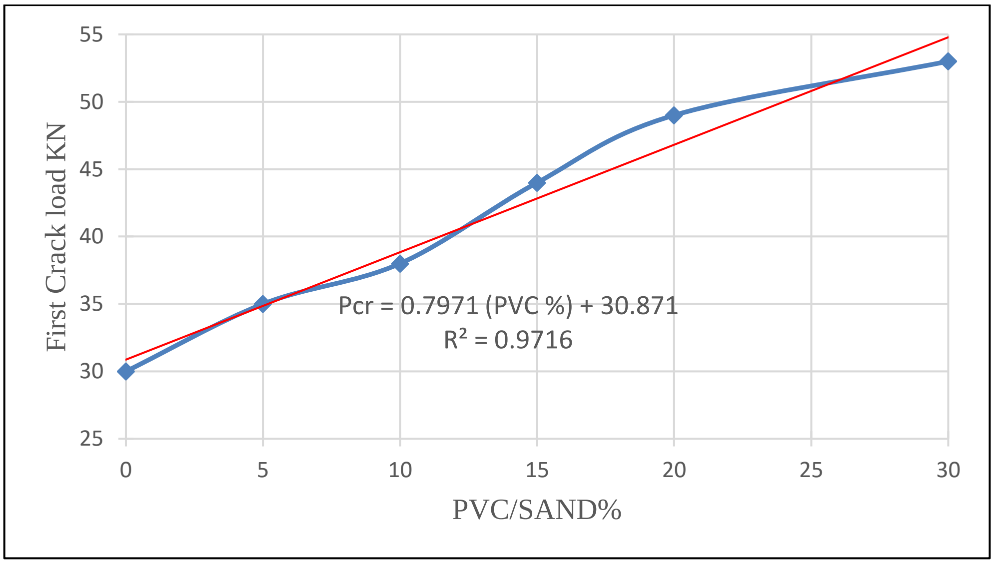


Figure 4.27 The First Crack Load To (PVC/Sand %) Relation For Concrete Beams.

4.3.7.2 Cracks Pattern

Figure 4.28, displays the crack patterns for all failed beams. Additionally, the initial load in which the crack first appeared is displayed. The cracks in the beams have various patterns and have different shapes. At the mid span, the cracks started to form in the tension zone of all beams that included varying amounts of scraped PVC waste in the concrete mixture, and they grew until they reached the compression zone.

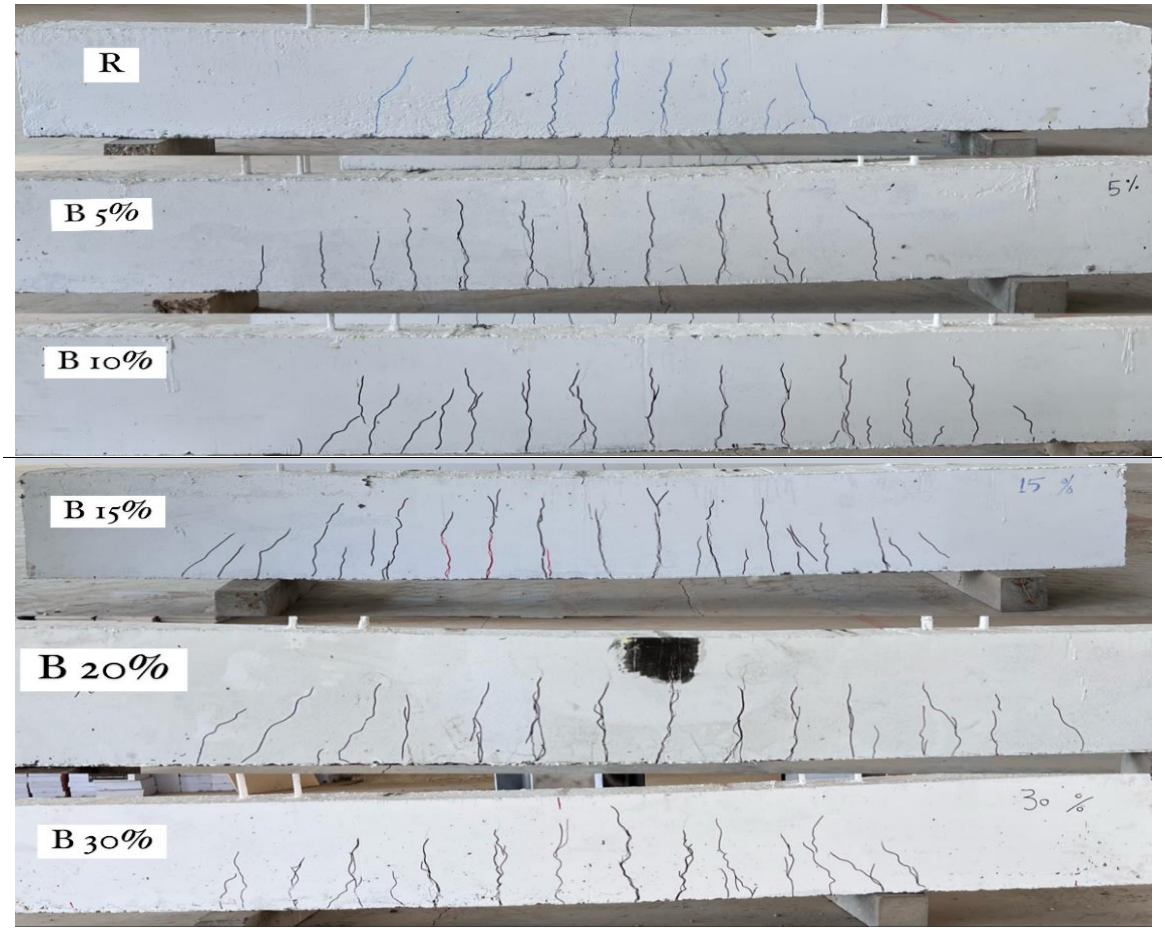


Figure 4.28 The Pattern of Cracks for Concrete Beams Contained PVC As Sand Replacement.

The summary of experimental test results for mechanical, physical, and structural properties of concrete mixtures containing scraped PVC plastic waste as a replacement for sand is represented in Tables 4.18 and 4.19 respectively:

Table 4.18 The Results of Mechanical and Physical of Concrete Mixture Containing PVC Waste as A Replacement for Sand.

PVC/ SAND %	Slump (mm)	Compressive strength MPa	Splitting tensile strength MPa	Flexural strength MPa	Modulus of elasticity GPa	Abrasion	Density Kg/m^3	Absorption ratio %	UPV m/s	fc'/γ
0%	165	49.8	2.8	6	29.98	21.3	2460.8	1.79	5199	17.2
5%	150	57.7	3.2	6.3	28.68	19.7	2440.38	1.89	5140	20.1
10%	120	60.3	3.4	6.4	26.27	15.6	2423.8	1.96	5137	21.1
15%	113	58.8	3.3	6.33	22.66	14.1	2404.66	2.05	5093	20.8
20%	80	55.9	3.1	6.2	20.43	9.9	2376.09	2.29	4992	20.0
30%	50	45.2	2.5	5.9	18.36	9.0	2313.08	2.72	4865	16.6

Table 4.19 The Results of Structural Behavior of Reinforced Concrete Beams Containing PVC Waste as A Replacement for Sand.

Beam I.D.	Ultimate load KN	Maximum deflection mm	Ductility	Compression Strain	Initial stiffness KN/mm	Secant stiffness KN/mm	Energy Absorption KN.mm	First crack load (KN)
B 0% C	169	19.13	3.83	0.0034341	40.82	8.83	2502.56	30
B 5%	171	20.02	4.17	0.0035009	37.11	8.54	2710.57	35
B 10%	173.9	22.97	5.10	0.0035522	35.71	7.57	3060.76	38
B 15%	175.3	23.98	5.85	0.0035561	34.81	7.31	3422.26	44
B 20%	174	26.90	6.72	0.0036573	32.31	6.47	3810.76	49
B 30%	166	28.86	9.62	0.0036876	29.33	5.75	3985.12	53

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This chapter includes the summary of main results from the experimental work. The conclusions are classified into two sections:

1. The results of the mechanical properties and the physical characteristics for the concrete mixture contained waste of scraped PVC used as partial replacement with sand.
2. The results of reinforced concrete beams' flexural behavior containing scraped PVC particles as a partially substitution with sand.

This chapter also includes recommendations for future investigations.

5.2 Conclusions

5.2.1 The Mechanical and Physical Properties

This following of conclusions were based on the experimental program of determining the mechanical properties and the physical characteristics for concrete mixture contained waste of scraped PVC as being a partial substitution for sand.

1. At constant w/c ratio, the workability reduces when the ratio of PVC that used in the mixture of concrete increasing. The reference mixture had the highest workability, while the other PVC ratios of 5%, 10%, 15%, 20%, and 30% had a reduction of 9.01%, 27.27%, 31.5%, 51.5%, and 69.69% with comparison to the workability of reference mixture.
2. As PVC percentages that replaced with sand increases up to 10%, the compression strength of concrete increases, with optimum replacement percentages 10%. While the 30% PVC percentage reduced compressive by -9.24%, when compared to the reference specimens.
3. The splitting tensile strength improved as the PVC percentages as a sand replacement in concrete increased up to 10%, whereas the 30% PVC percentage decreased the tensile by 10.71% in comparison to the reference specimens.
4. Flexural strength increased as PVC replacement ratio for sand in concrete increased up to 10%, with 10% being the optimum replacement rate. Comparing the specimens with the 30% PVC percentage to the reference specimens, the flexural was reduced by 1.67%.

5. The elastic modulus decreased when the ratio of replaced PVC increased. PVC percentages of 30% resulted in the lowest young's modulus value, which decreased by 38.74% when compared to reference specimens.
6. The abrasion resistance increases as PVC ratio increases. The reference specimen is found to have the lowest abrasion resistance, whereas concretes with 30% PVC granules have the highest, increasing by 57.54%.
7. When the replaced PVC percentage was increased, the values of concrete density and ultrasonic pulse velocity reduced while absorption increases. The reference specimens had the highest density, pulse velocity, and lower absorption rate. This clearly shows the consistency of the results, as the pulse velocity decreases with decreasing density, and thus the void space increases, increasing the absorption rate.
8. The failure mode in the various specimens tested confirmed that the reference specimens were totally destroyed and divided into separate parts, whereas the specimens containing PVC replacement percentages granules showed pattern stability and the failure was constrained to the presence of small cracks, the numbers and lengths of that which decreased as the ratio of substitute increased.

5.2.2 The Flexural Behavior of Reinforced Concrete Beams

We reached to the following conclusions by using six reinforced concrete specimens to study the structural behavior for reinforced concrete beams that incorporated waste of PVC particles as a partially substitution for sand.

1. With increasing PVC content in reinforced beams up to 15% PVC, the ultimate load at failure for all reinforced beams increases. The failure loads for the beams B5%, B10%, B15%, and 20% increased by 1.18%, 2.9%, 3.73%, and 2.96%, respectively, whereas the failure load for the beam 30% decreased by 1.78% when compared to reference specimens.
2. As the percentage of scraped PVC particles increased the deflection and ductility of the beam was increased, with the beam B30% recording the highest deflection and ductility index increments of 50.87% and 151.44%, respectively, when compared the results to the results of the reference specimen.
3. The results indicated to the increasing of compression strain when reached to the failure load when the percentage of PVC particles increased in the concrete beams, at the same point the energy absorption was significantly increased. The increments of the axial strain and the energy absorption that produced by

the specimen B30% were higher than those caused by the reference beam by 7.38% and 59.24%, respectively.

4. The initial and secant stiffnesses in concrete beams diminish as the PVC content rises. The beam B30% was having the lower initial and secant stiffness, its reduced by 28.15% and 34.89%, respectively with comparison to the values of reference beam.
5. The load capacity that appeared in the first crack showed up gradually increased as the content of the PVC increased in the concrete beams, with recorded the highest first crack load at the beam B30% by 76.67% increase over the reference beam.

5.3 Recommendations

For future studies, the suggestions listed below are recommended.

1. It is recommended to try the investigation of scraped PVC on the behavior of other structural members such as beam under shear, slabs and concrete filled steel tubes (CFST) under biaxial bending and uniaxial bending due to its good role when used as a partially substitution for sand to improving the concrete characteristics and structural behavior of beams.

2. Study quality standards, the mechanism of compaction, and ways to improve workability for concrete using PVC waste as a substitute for some of the sand.
3. Investigate the effect of recycled PVC waste used to replace sand in R.C. beams when subjected to dynamic loadings.
4. Studying the effect of firing on polyvinyl chloride (PVC) concrete specimens as a partial replacement for aggregates.
5. Investigate the impact of scraped PVC in form of coarse aggregate size (gravel) on the structural behavior of beams in addition to the concrete's mechanical and physical characteristics.
6. Studying the possibility of replacing coarse and fine aggregate of the normal concrete in two sizes of fine and coarse scraped PVC to produce a slightly lighter and more durable concrete.
7. Investigate the effect of burning on concrete specimens containing PVC waste as a partial replacement for aggregates.

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APPENDIX

Flexural reinforcement

All beams were designed according to ACI318-14 Code. The steps of analysis of the reference beam as follows:

From the design of the beam in Figure 3.17

$\because \rho = \frac{As}{bd}$

$$d = h - cover - ds - \frac{db}{2}$$

Let concrete cover = 20 mm.

So, d =264 mm

$As = 2 * \frac{\pi}{4} * d^2 = 226.2$

$\therefore \rho = \frac{226.2}{150*264} = 0.0057$

$\because \rho max = 0.75\, \rho b = 0.75 * [\, 0.85\, \beta 1 * \frac{f`c}{fy} * \frac{600}{600+fy}\,]$

$\beta 1 = 0.85 - 0.005 \frac{f`c-28}{7} > 0.65$ for f`c > 28 MPa

∵ concrete strength f`c equal to 31 MPa and yield strength of reinforcement equals 495 MPa

$\therefore \beta 1 = 0.8478$

$\therefore \rho_{max} = 0.0185$

$\because \rho < \rho max$

∴ Ignore the compression reinforcement and analysis as simply reinforced beam

∵ ρ = 0.0057

And $\rho b = \ 0.85\, \beta 1 * \frac{f`c}{fy} * \frac{600}{600+fy} = 0.0247$

So, ρ< ρb

∴ fs = fy

From Whitney Block

C = T

∴ 0.85 * f`c *b *a = As * fy

∴ a = 28.3 mm

$\because Mn \ = \ C \ \left(d - \frac{a}{2}\right) = \ 0.85 \ * \ f`c \ * \ b \ * \ a \ * \left(d - \frac{a}{2}\right) \ = \ 31.11\, kN.m$

ML = Mn – Md

Md $= \frac{Wu\ L^2}{8}$

Wu = 1.2 W_{beam} = 1.2 * density * volume

= 1.2 * 2460.8 * 0.15 * 0.3 * 2.3 = 3.05 kN

Md $= \frac{3.05 * 2.3^2}{8} = 2\ kN.m$

ML = 31.11 – 2 = 29.11 kN.m

ML $= \frac{p}{2} * 660$

∴ $P_{flexural}$ = 88.21 kN

الخلاصة

في هذه الدراسة تم التحري عن تأثير استخدام نفايات البولي فينيل (PVC) كبديل جزئي للرمل الطبيعي لدراسة الخواص الميكانيكية والفيزيائية للخرسانة بجانب تأثيرها على السلوك الإنشائي للعتبات الخرسانية الكاملة. تم تقسيم الدراسة إلى جزئين. يتناول الجزء الأول تأثير الاستبدال الجزئي للرمل بجزيئات مخلفات PVC على الخواص الميكانيكية والفيزيائية للخرسانة ، حيث تم استخدام خمسة نسب استبدال في هذه الدراسة 5٪ ، 10٪ ، 15٪ ، 20٪ ، 30 ٪ . تم إجراء الفحوصات الميكانيكية للخرسانة بأعمار 7 و 14 و 28 يومًا وتشمل فحوصات الانضغاط والانشطار والانثناء ومعامل المرونة والتآكل ، بالإضافة إلى الاختبارات الفيزيائية كالكثافة والامتصاص والسرعة فوق الصوتية. أظهرت النتائج أن العينات المحتوية على نسب إحلال جزئي تتراوح بين (5٪ - 12.5٪) أظهرت زيادة تتراوح بين (15.86%–21.08%)،(14.29%–21.43%) ،(5%–6.67%) في مقاومة الانضغاط والشد والانثناء على التوالي ، مقارنة مع العينات المرجعية. وكانت نسبة الاستبدال الأمثل لجزيئاتPVC هي 10٪ وتنخفض الخواص الميكانيكية عندما يتجاوز محتوىPVC نسبة 15٪ كبديل عن الركام الناعم . كما أظهرت النتائج انخفاض معامل المرونة و التآكل والكثافة وسرعة الموجات الصوتية وزيادة معدل امتصاص الماء مع زيادة محتوى PVC في الخرسانة بشكل عام.

يتناول الجزء الثاني تأثير استخدام نفايات PVC كبديل جزئي للركام الناعم على السلوك الإنشائي للعتبات الخرسانة المسلحة. تم فحص خمسة عتبات خرسانية بتفصيل تسليح متماثل و بإبعاد 150 * 300 * 2300 مم بواقع عتبة واحدة لكل نسبة PVC ، بالإضافة إلى العتبة الخرسانية المرجعية. تم اختبار الحزم من خلال الحمل الاقصى للفشل ، والهطول النهائي ، وامتصاص الطاقة ، والصلابة ، ومؤشر الليونة ، والانفعال. كما تم دراسة التشققات والتي تشمل حمل الشق الأول ونمط التصدع ، ثم مقارنتها مع العتبة المرجعية لتقييم تأثير نفايات PVC على سلوكها الإنشائي. أظهرت النتائج أن زيادة محتوى نفايات البولي فينيل كلوريد في العتبات

الخرسانية أدى إلى زيادة الحمل الأقصى للفشل الى حد معين ، والهطول النهائي ، ومؤشر الليونة ، والانفعال ، وامتصاص الطاقة وحمل الشق الاول بمعدل يتراوح بين(1.18%-3.73%) ،(4.64%-50.87%) ، (9.01%-151.44%) ،(1.94%-7.38%)، (8.31%-59.24%) و(16.67%-76.67%)على التوالي. بينما لوحظ انخفاض في الصلابة الابتدائية والثانوية بمعدلات تتراوح بين (9.09%-28.15%) و(3.3%–34.9%) على التوالي.

وزارة التعليم العالي والبحث العلمي

كلية الهندسة/ جامعة ميسان

قسم الهندسة المدنية

سلوك الانحناء للجسور الخرسانية المسلحة بأستعمال جزيئات مخلفات انابيب البلاستك (PVC) كبديل للرمل

من قبل

مريم صبيح جبار

بكالوريوس هندسة مدني 2017

رسالة

مقدمة الى كلية الهندسة في جامعة ميسان

كجزء من متطلبات الحصول على درجة الماجستير في علوم الهندسة المدنية / الانشاءات

جمادى الآخر 1444 هـ

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