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Mechanical Properties of Concrete Using Recycled Plastic

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ABSTRACT

Concrete is the most common material for human beings to use in construction. In this study, the behavior of the recycled plastic as aggregate in concrete has been investigated on compressive, tensile, and flexural strengths, weight reduction and workability. Also the impact resistance of concrete contains plastic aggregate has been carried out deeply in this study.

Polyethylene terephthalate (PET) bottles, one of the waste plastic types, is used in this study .The reason to choose the PET bottles to develop a novel method to transfer it to valuable product and to solve the problem of dumping the tons of plastic waste, also PET bottles not used to produce any recycled material locally in Gaza Strip due to the difficulties in recycling it.

A series of four concrete mixes were prepared with replacement ratios of PET 0%, 15%, 30%, and 45% by volume of natural aggregate. Also the same ratios used by adding PET without replacing the natural aggregate in the impact resistance test. Special impact machine was designed and fabricated adopting the technique of drop weight impact test in ACI committee 544.

The results of experiments show the feasibility to use PET plastic in concrete mixes. There is a possibility to produce concrete with reduction in weight reaches to 12% compared to traditional concrete in case of replacing 45% of natural aggregate by PET aggregate. No significant changes are observed for mixtures containing up to 15% of PET-aggregates in compressive strength results, for 30% and 45% PET replacement there is a noticeable reduction in compressive strength up to 11% and 24% respectively. The results reveal that the capacity of concrete to resist impact loading at failure can be improved by increasing the content of PET.

الخلاصة

الخرسانة هي المادة الأكثر شيوعا واستخداماً بين مواد البناء. في هذه الدراسة، تم فحص سلوك البلاستيك المعاد تدويره كركام في الخرسانة بالنسبة لقوة الضغط وقوة الشد وعزم الانحناء وخفض الوزن والتشغيلية. أيضا تم دراسة مقاومة الاصطدام للخرسانة التي تحتوي علي البلاستيك المعاد تدويرة كركام.

زجاجات البولي ايثلين، هي واحدة من أنواع النفايات البلاستيكية التي تم استخدامها في هذه الدراسة. والسبب في اختيار زجاجات البولي ايثلين هو لتطوير طريقة جديدة لتحويلها إلى منتجات ذات قيمة ولحل مشكلة تكدس الاطنان من النفايات البلاستيكية، وكذلك لانها لا تستخدم لإنتاج أي مواد محليا في قطاع غزة بسبب صعوبة إعادة تدويرها.

تم اعداد مجموعة من اربع خلطات خرسانية باستبدال البولي ايثلين بنسبة 0%، 15%، 30% و45% من حجم الركام الطبيعي. ايضا تم استخدام نفس النسب ولكن بدون استبدال الركام الطبيعي في اختبار مقاومة الاصطدام. تم تصميم وتركيب جهاز خاص لفحص الاصصدام بناءا علي تقنية اختبار الاصطدام باسقاط الوزن الموجودة في لجنة المعهد الامريكي للخرسانة رقم 544.

اظهرت النتائج الجدوي في استخدام بلاستيك البولي ايثلين في الخلطات الخرسانية. هناك امكانية لانتاج الخرسانة خفيفة الوزن مع انخفاض في الوزن يصل الي 12% مقارنة مع الخرسانة التقليدية في حال استبدال نسبة 45% من الركام الطبيعي بالبلاستيك. لم يلاحظ اي تغيرات ملموسة في الخلطات التي تحتوي علي نسبة 15% من البولي اثيلين كركام بالنسبة لقوة الضغط, اما لنسب استبدال 30% و45% هناك انخفاض ملحوظ في قوة الضغط يصل الي 11% و24% علي التوالي. بينت النتائج ان قدرة الخرسانة علي تحمل الاصطدام تتحسن مع زيادة كمية البولي ايثلين.

DEDICATION

I dedicate my dissertation work to my family and my friends. A special feeling of gratitude to my loving parents, my brother and my sisters, whose words of encouragement and push for tenacity ring in my ears. My wife, the woman who has been and still encouraging and supporting me. Finally, I dedicate this work to my unborn daughter.

ACKNOWLEDGMENT

I deeply thank my advisors, Prof. Samir Shihada and Dr. Mohammed Arafa, whose help, advice and supervision was invaluable.

I would like to extend special thanks to the Islamic University Labs staff for their effort in helping me during the experimental studies and to all of the people that made this project possible.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Concrete is the most widely used construction material in the world. There is a concern to more understanding and to improve its properties. Using waste and recycled materials in concrete mixes becoming increasingly important to manage and treat both the solid waste generated by industry and municipal waste.

Plastic is one of the most significant innovations of 20th century material. The amount of plastic consumed annually has been growing steadily and becomes a serious environmental problem. For solving the disposal of large amount of recycled plastic material, use of plastic in concrete industry is considered as feasible application.

Concrete volume contains from 65–80% aggregate and it plays a substantial role in concrete properties such as workability, strength, dimensional stability, and durability, so the use of waste materials in concrete as aggregates can effect in the amount of waste materials deeply. Lightweight aggregate is an important material in reducing the unit weight of concrete. A work has already been done on the use of plastic waste as polyethylene terephthalate (PET) bottle such as Lightweight aggregates (Choi et al 2005).

A review on the use of plastic waste in preparation of cement mortar and concrete preparation is already available, physical and mechanical properties for the application of concrete modified with plastic were studied (Siddique et al).

Data about using plastic as aggregate were provided only for some of properties, several important properties such as impact resistance, toughness, failure characteristics, thermo-physical properties, durability performance of cement mortar and concrete containing plastic as aggregate need more study.

This study aims at examining the effect of recycled plastic in concrete as coarse aggregates in the impact resistance, through a better understanding the behavior of recycled plastic in concrete structures, experimenting fresh and hardened concrete mixtures containing recycled plastic.

1.2 Problem Statement:

Gaza Strip is a small closed coastal area (365 Km^2) and a densely populated area with population of 1,760,037 according to year 2014 Based on estimates prepared by Palestinian Central Bureau of Statistics (PCBS).

Solid waste management continues to be seen as an important issue because the areas for landfill disposal of waste are limited. Figure (1) details the components of solid waste in Gaza strip (UNDP-PAPP, 2012).

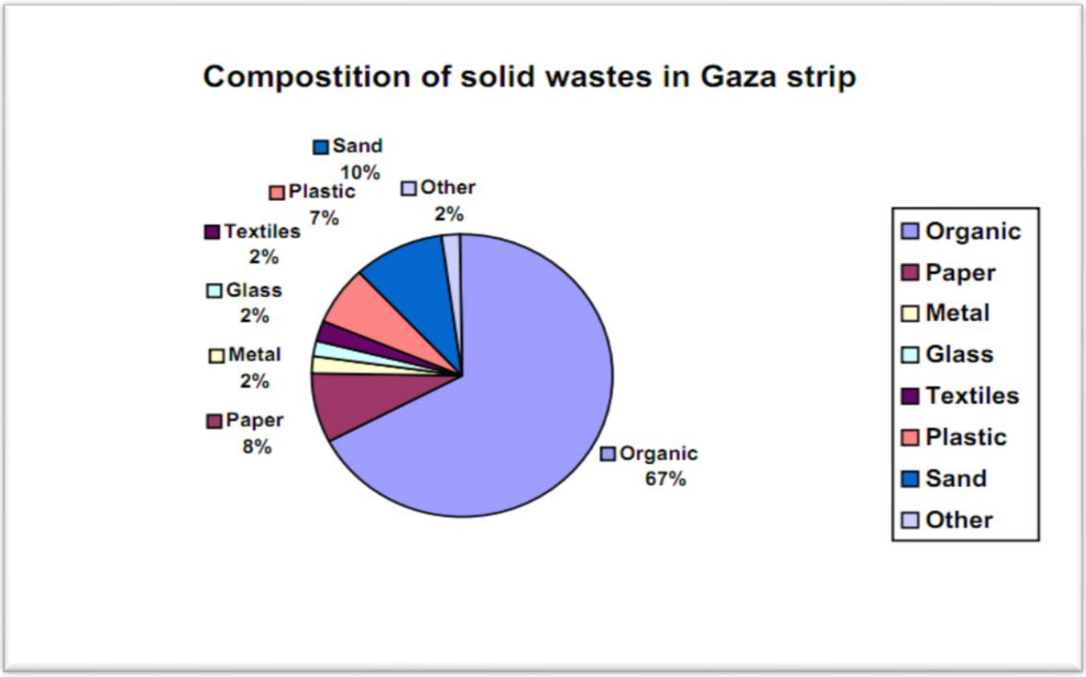


Figure 1.1: The composition of solid wastes in Gaza strip

Pressures experienced on landfills and the hazardous nature of some of these materials makes the use of these materials as aggregates a very attractive option. One of the new waste materials used in the concrete industry is recycled plastic.

Few studies carried out in Gaza strip on recycled plastic wastes, focused on using recycled plastic as shrinkage reinforcement in non-structural concrete slabs (Shihada and Al_Buhaisi, 2013). Therefore, there is an urgent need to investigate the behavior of recycled plastic as aggregate in concrete, and study the physical and mechanical properties of this concrete.

1.3 Objectives of the Proposed Research:

The main objective set for this research is to study the potential use of recycled plastic as a coarse aggregate of concrete material. This can be achieved through the following objectives:

I. To study the physical and mechanical performance of recycled plastic used in concrete mixtures in lieu of natural aggregate.
II. To examine the possibility of using recycled plastic in concrete mixes.
III. To find the optimum of plastic coarse aggregate to natural aggregate replacement ratio, which produces the best concrete properties.
IV. To investigate the impact resistance of concrete with recycled plastic.

1.4 Methodology:

To achieve research objectives the following tasks are needed:

1. To conduct comprehensive literature review related to subject of recycled plastic.
2. Site visit to the recycled plastic plants.
3. Bringing samples of the recycled plastic from the plastic plants.
4. Making sieve analysis of the coarse plastic aggregate samples and natural aggregate.
5. Performing physical and mechanical laboratory tests on the coarse plastic aggregate samples and compare the results to the available standards.
6. Analyze the results and draw conclusions.

1.5 Research Scope:

This research is to produce concrete with coarse plastic coarse aggregate in the IUG lab, and investigates the fresh and hardened properties of this production.

1- Characteristics of fresh concrete

The following aspects are considered:

- Mix design
- Workability
- Outstanding flowability
- Unit weight
- Air content
- Homogeneity

2- Characteristics of hardened concrete

In order to obtain the characteristics of hardened concrete the following tests will be carried out:

- Impact resistance
- Compressive strength
- Splitting tensile strength
- Flexural strength

1.6 Thesis structure:

The study consists of seven chapters arranged as shown below. This section presents a brief description of these chapters.

Chapter (1): In this chapter background, statement of problem, objectives, methodology and scope of the research are included.

Chapter (2): Provides an overview of previous studies related to the subject of this research work.

Chapter (3): The experimental details, experimental program, mixes preparation, materials properties, and used tests are included in this chapter.

Chapter (4): This chapter describes the results of the test program

Chapter (5): Conclusion and Recommendations are included in this chapter

References

Appendices

CHAPTER TWO
LITERATURE REVIEW

This chapter provides an overview of previous studies related to the subject of this research work. This is done in order to scope out the key data collection requirements for the primary research to be conducted, and it formed part of the emergent research design process.

2.1 Introduction

Plastics are polymers, a very large molecule made up of smaller units called monomers which are joined together in a chain by a process called polymerization. The polymers generally contain carbon and hydrogen with, sometimes, other elements such as oxygen, nitrogen, chlorine or fluorine (UNEP, 2009).

Plastics have become an integral part of our lives. The amount of plastics consumed annually has been growing steadily. Its low density, strength, user-friendly designs, fabrication capabilities, long life, lightweight, and low cost are the factors behind such phenomenal growth. Plastics have been used in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, housing, communication materials, security systems, and other uses. With such large and varying applications, plastics contribute to an ever increasing volume in the solid waste stream. The world’s annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly100 million tons in 2001 (Siddique et al., 2008).

Quantities of waste plastic have been rising rapidly during the recent decades due to the high increase in industrialization and the considerable improvement in the standards of living, but unfortunately, the majority of these waste quantities are not being recycled but rather abandoned causing certain serious problems such as the waste of natural resources and environmental pollution.

2.2 Types and Uses of Plastic:

Plastic are classified according to the basis of the polymer, from which they are made.

The types of plastics that are most commonly reprocessed are polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET), polystyrene (PS), and polyvinyl chloride (PVC). Table 2.1 details the types and uses of plastic and recycled plastic.

Table (2.1): Types and uses of plastics and recycled plastics (Siddique et al., 2008), (UNEP, 2009)

Type of plastic	Description	Some uses for virgin plastic	Some uses for recycled plastic
Polyethylene terephthalate(PET)	Clear tough plastic, may be used as a fiber	Soft drink and mineral water bottles	clear film for packaging, carpet fibers, fleecy jackets
Low density polyethylene (LDPE)	Soft, flexible plastic, milky white, unless a pigment is added	Lids of ice-cream containers, garbage bags, and garbage bins	Film for builders, industry, packaging and plant nurseries
High density polyethylene(HDPE)	Very common plastic, usually white or coloured	Crinkly shopping bags, freezer bags, and milk	Compost bins, detergent bottles, crates, and mobile rubbish bins
Unplasticised Polyvinyl chloride (UPVC)	Hard rigid plastic, may be clear	Clear cordial and juice bottles, plumbing pipes and fittings	Detergent bottles, tiles, and plumbing pipe fittings
Plasticized Polyvinyl chloride (PPVC)	Flexible, clear, elastic Plastic	Garden hose, shoe soles, blood bags and tubing	Hose inner core, and industrial flooring
Polypropylene (PP)	Hard, but flexible plastic	Ice-cream containers, potato crisp bags, stools and chairs	Compost bins, kerb side recycling crates, and worm factories
Polystyrene (PS)	Rigid, brittle plastic. May be clear, glassy	cheap, transparent kitchen ware, light fittings, bottles, toys, and food containers	Clothes pegs, coat hangers, and video/CD boxes
Polyester (EPS)	Foamed, lightweight, energy absorbing, and thermal insulation	Hot drink cups, and takeaway food containers	spools, rulers, and video/CD boxes
Polyamides (PA)	Nylons	fibers, toothbrush bristles, and fishing lines	

2.3 Previous studies related to using recycled plastic as aggregate:

Plastic aggregates used in many studies prepared from plastic waste obtained from different sources. As example plastic bottles were grinded in the laboratory by using a grinding machine and then sieved to get the suitable size fraction. (Frigione, 2010), (Saikia and Brito, 2014)

Al-Manaseer and Dalal, (1997) investigated the effect of plastic aggregates on the bulk density of concrete. For this purpose, they made 12 concrete mixes with different w/c containing varying percentages (0%, 10%, 30%, and 50%) of plastic aggregates. Angular post-consumer plastic aggregates having a maximum size of 13 mm were used. They concluded that: (i) bulk density of concrete decreased with the increase in plastic aggregates content; (ii) reduction in bulk density was directly proportional to the plastic aggregates content; and (iii) density of concrete was reduced by 2.5%, 6%, and 13% for concrete containing 10%, 30%, and 50% plastic aggregates, respectively. Reduction in density was attributed to the lower unit weight of the plastics.

Marzouk et al. (2007) reported the bulk density of cement mortar mixes prepared by replacing 0–100% in volume of sand by two different sizes of PET aggregates. Their results showed that the reduction of bulk density remained small when the volume occupied by aggregates varies between 0% and 30%, regardless of their size. However, when this volume exceeded 50%, the composite bulk densities started to decrease until reaching a value 1000 kg/ m3. They also found that for the same volumetric percentage of substitution the bulk density decreased with decreasing particle size.

Ismail and Al-Hashmi,(2008) presented the possibility of using various plastic wastes, containing approximately 80% polyethylene and 20% polystyrene, as fine aggregates, up to 4.75 mm in concrete. By increasing the plastic waste content, the compressive tests showed the tendency for compressive strength values of plastic waste concrete to decrease below the reference concrete at each curing age. The concrete with 10% of plastic waste displayed the lowest compressive strength at 28 days curing age, about 30% lower than that of the reference concrete mixture. Also the study found 5%, 7%, and 8.7% lower densities of concrete mix containing 10%, 15%, and 20% plastic aggregates respectively.

Choi et al. (2005) studied the effects of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the density of concrete. Mixture proportions of concrete were planned so that the water/cement ratios were 45%, 49%, and 53%, and the replacement ratios of WPLA were 0%, 25%, 50%, and 75% by volume of fine aggregate. Density of concrete mixtures decreased with the increase in WPLA content. In their study the influence of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the splitting tensile strength of concrete was observed. Mixture proportions of concrete were planned. The water/cement they concluded that: (i) splitting tensile strength of concrete mixtures decreased by 19%, 31%, and 54% with the increase in PET aggregates by 25%, 50%, and 75% respectively; and (ii) for a particular PET aggregate content, splitting tensile strength increased with the reduction in w/cm ratio. Also the study investigated the effect of polyethylene terephthalate (PET) bottles lightweight aggregate (WPLA) on the modulus of elasticity of concrete. According to the authors, modulus of elasticity of concrete mixtures decreased with the increase in PET aggregates.

Saikia and Brito, (2014) presented the effects of size and shape of recycled polyethylene terephthalate (PET) aggregate on the fresh and hardened properties. Three types of PET aggregate, collected from a plastic recycling plant, two were shredded and separated fractions of similar types of PET bottles and one was a heat-treated product of the same PET bottles with sieve size from 0.5-11.2mm. 5%, 10% and 15% in volume of natural aggregate in the concrete mixes were replaced by an equal volume of three differently shaped and sized PET aggregates with deferent W/C ratios. Test results showed that density of fresh concrete decreased as the content of plastic aggregate increased. Differences in the size and shape of PET-aggregates affect the slump of fresh concrete mixes, which ultimately change the mechanical behavior.

The study also observed a reduction in the compressive strength of concrete due to the addition of PET-aggregates to replace natural aggregates. For 5% replacement the 28-day compressive is more than 75% of the compressive strength of reference concrete. For concrete with 10% and 15% plastic aggregate are respectively 71% and 59%. According to the authors, natural aggregates and PET-aggregate cannot interact with cement paste and therefore the interfacial transition zone in concrete containing PET-aggregate is weaker than that in the reference concrete, which lowers the resulting compressive strength.

The study presented the abrasion behaviour of concrete specimens (depth of wear and weight loss) containing various types and contents of PET-aggregate, and the reference concrete. In this paper, 5%, 10% and 15% in volume of natural aggregate in the concrete mixes were replaced by an equal volume of three differently shaped and sized PET-aggregates. According to the authors, the abrasion resistance of the concrete mixes with the various types of PET-aggregate is better than that of the normal concrete, also they found that the behaviour of the abrasion resistance of concrete arising from the incorporation of various types and contents of PET-aggregate suggests that this property depends on the compressive strength of concrete as well as on the properties of plastics.

Albano et al. (2009) carried out a study include concrete with 10% of recycled PET exhibits a compressive strength that meets the standard strength values for concrete with moderate strength between 21 and 30 MPa for a curing age of 28 days. They reported that the compressive strength at the age of 28 days is near the values for 60 days. Several factors were taken in consideration such as the type of failure and the formation of honeycombs, low workability, particle size, which are responsible for lower compressive strength of concrete containing PET aggregate than concrete containing natural aggregate. The reduction in compressive strength was more in concrete containing larger flaky PET aggregate than smaller one.

Hannawi et al. (2010) investigated the effect of using Non-biodegradable plastic aggregates made of polycarbonate (PC) and polyethylene terephthalate (PET) waste as partial replacement of natural aggregates in mortar. Various volume fractions of sand 3%, 10%, 20% and 50% are replaced by the same volume of plastic. The authors found a decrease in compressive strength when the plastic aggregates content increases. The drop in compressive strength seems to be not proportional to the volume fraction of sand replaced by plastic aggregates. a decrease of 9.8%, 30.5%, 47.1% and 69% for mixtures with, respectively, 3%, 10%, 20% and 50% of PET-aggregates, and of 6.8%, 27.2%, 46.1% and 63.9% for mixtures containing, respectively,3%, 10%, 20% and 50% of PC-aggregates is observed. According to authors the drop in compressive strengths due to the addition of plastic aggregates can be attributed mainly to the poor bond between the matrix and plastic aggregates.

The study presented the variations in the flexural strength of different mixtures as a function of the percentage of sand (in volume) replaced by the same volume of plastic aggregate. By comparing to control mixture, no significant changes are observed for mixtures containing up to 10% of PET-aggregates and up to 20% of polycarbonate (PC) aggregates. According to the authors, a decrease of 9.5% and 17.9% for mixtures with, respectively, 20% and 50% of PET-aggregates is observed. For mixtures with 50% of PC-aggregates, a decrease of 32.8% is measured. The authors found that the calculated flexural toughness factors increase significantly with increasing volume fraction of PET and PC-aggregates. Thus, addition of PC and PET plastic aggregates in cementitious materials can give a good energy absorbing material which is very interesting for several civil engineering applications like structures subjected to dynamic or impact.

Frigione (2010) founds lower values of splitting tensile strength in concrete containing PET aggregate prepared using high w/c value than in a similar mix prepared at low w/c value.By replacing 5% by weight of fine aggregate (natural sand) with an equal weight of PET aggregates manufactured from the waste un-washed PET bottles. Specimens with different cement content and water/cement ratio were manufactured.

Kou et al. (2009) investigated the fresh and hardened properties of lightweight aggregate concretes that are prepared with the use of recycled plastic waste sourced from scraped PVC pipes to replace river sand as fine aggregates. Concrete mixes were tested, in which river sand was partially replaced by PVC plastic waste granules in percentages of 0%, 5%, 15%, 30% and 45% by volume. Splitting tensile strength 28-day values are 3.06, 2.89, 2.82, 2.58 and 1.83 MPa, respectively.

Akçaözoglu et al. (2010) carried out a study of using shredded waste PET bottles as aggregate in lightweight concrete. Investigation was carried out on two groups of mortar samples, one made with only PET aggregates and, second made with PET and sand aggregates together. The authors found average values of flexural strength similar to those of normal weight mortar.

Rahmani et al. (2013) investigated the effects of replacing 5%, 10% and 15% substitution of sand with PET processed particles. To determine the effect of the percentage of sand replacement with PET on concrete flexural strength, some beam specimens with dimensions of 50 × 10 × 10 cm^3 were casted.

According to the authors, the flexural strength has an increasing trend at first when the amount of PET particles increases, but it drops after a while.

For example, the 5% replacement of sand volume with PET particles with w/c ratios of 0.42 and 0.54 shows 6.71% and 8.02% increase in flexural strength, respectively. However, 15% substitution of PET particles with w/c ratio of 0.42 and 0.54 yielded 14.7% and 6.25% reduction in the flexural strength, respectively. Also the study observed the effects of PET particles on tensile strength. By replacing 15% of sand volume with PET particles, the reduction occurred in tensile strength were 15.9% and 18.06%, respectively.

2.4 Concrete Impact Resistance

ACI Committee 544-89 proposed a drop-weight impact test (Fig. 2.1) to evaluate the impact resistance of fibre concrete. This test yields the number of blows necessary to cause prescribed levels of distress in the test specimen. This number serves as a qualitative estimate of the energy absorbed by the specimen at the levels of distress specified. The equipment for the drop-weight impact test consists of: (1) a standard, manually operated 10 lb. (4.54 kg) compaction hammer with an 18-in. (457-mm) drop, (2) a 2 .5 in. (63.5 mm) diameter hardened steel ball, and (3) a flat baseplate with positioning bracket. In addition to this equipment, a mold to cast 6 in. (152 mm) diameter by 2 .5 in. (63.5 mm) thick [±1/8 in., ± (3mm)] concrete specimens is needed.

2.5 in. (63.5 mm) thick by 6 in. (152mm) diameter concrete samples are made in molds according to procedures recommended for compressive cylinders but using only one layer. The molds can be filled partially to the 2 .5 in. (63.5 mm) depth and finished, or they can be sawn from full-size cylinders to yield a specimen size of the proper thickness.

Specimens cut from full-size cylinders are preferred. If fibers longer than 0.80 in. (20 mm) are used, the test should be cut from a full-size cylinder to minimize preferential fiber alignment. According to the committee, results of tests exhibit a high variability and may vary considerably with the different types of mixtures, fiber contents, etc.

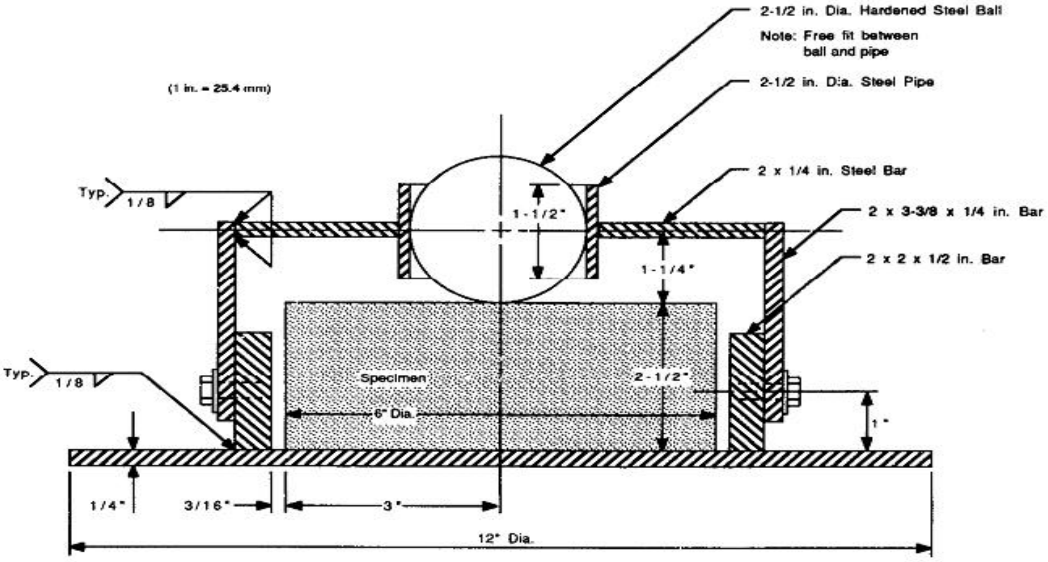


Figure 2.1: Drop-weight impact test [ACI Committee 544-89]

Soroushian et al. (2003) studied the effect of recycled plastic on the impact resistance of concrete using the repeated dropping test recommended by ACI Committee 544. The specimens were moist-cured for 28 days, and then allowed to air dry in the laboratory at 50% relative humidity and 22 °C for an additional 3 months. The mean values and 95% confidence intervals were derived using nine specimens for each concrete material. It is evident that all discrete reinforcement systems considered herein yielded important gains in the impact resistance.

2.5 Concluding Remarks

The previous studies showed that lot of efforts have been done for investigating the effect of using waste/recycled plastic materials as a component in the concrete mix, but all of them are trying to confirm the situation and the relevant specifications in their local areas. This research aims to implement a similar task but with applying the available locally used materials specially using PET plastic bottles as a coarse aggregate replacement.

CHAPTER THREE

EXPERIMENTAL PROGRAM

3.1 Introduction

This chapter presents the experimental program and the constituent materials used to investigate the potential usefulness of using recycled plastic in the concrete mixes as aggregates.

In this experimental work, effects of recycled plastic on different properties of concrete will be seen by adding different amounts to the concrete. Several parameters were considered in the test program such as the way of using recycled plastic, the type of recycled plastic, the particles shape, and the percentages of recycled plastic in concrete mixes. This work presents the test procedure, details and equipment's used to assess concrete properties.

The laboratory investigation consisted of tests for both fresh and hardened concrete properties. Fresh concrete was tested for slump flow to ensure reasonable workability of concrete. The tests for hardened concrete included compression tests for strength, indirect tensile tests (split cylinder and flexural strength tests) and impact resistance test.

The properties of different constituent materials used to produce concrete with plastic aggregates are also discussed such as moisture content, unit weight, specific gravity and the grain size distribution. The test procedures, details and equipment used to assess concrete properties are illustrated in the following sections.

3.2 Materials

The materials were used in the test program include ordinary Portland cement, natural coarse aggregate, sand, water and recycled plastic . Material properties were as follows:

3.2.1 Cement

Portland cement type CEM II/A-M (SLV) 42.5 N was used throughout the investigation. The cement was obtained from local concrete manufacture and kept in dry location. The cement source is Sanad Company. The cement met the requirements of

ASTM C 150 specifications. The results of physical and mechanical analyses of the cement are summarized in Table 3.1 along with the requirements of relevant ASTM specifications for comparison purposes.

Table 3.1: Physical and mechanical properties of cement (CEM II 42.5 N) in IUG Lab.

TEST	**RESULTS**	**ASTM C 150 Requirements**
Setting Time (vicat test) Initial final	 130 min 3 hrs. 30 min	 >60 min <6 hrs. 15 min
Compressive Strength(MPa) 3 days 7 days 28 days	 16.47 29.81 44.03	 Min. 12 Min. 19 ---------
Fineness(cm^2 /gm)	3223.6	Min. 2800
Normal Consistency (%)	25.5	---------

3.2.2 Water

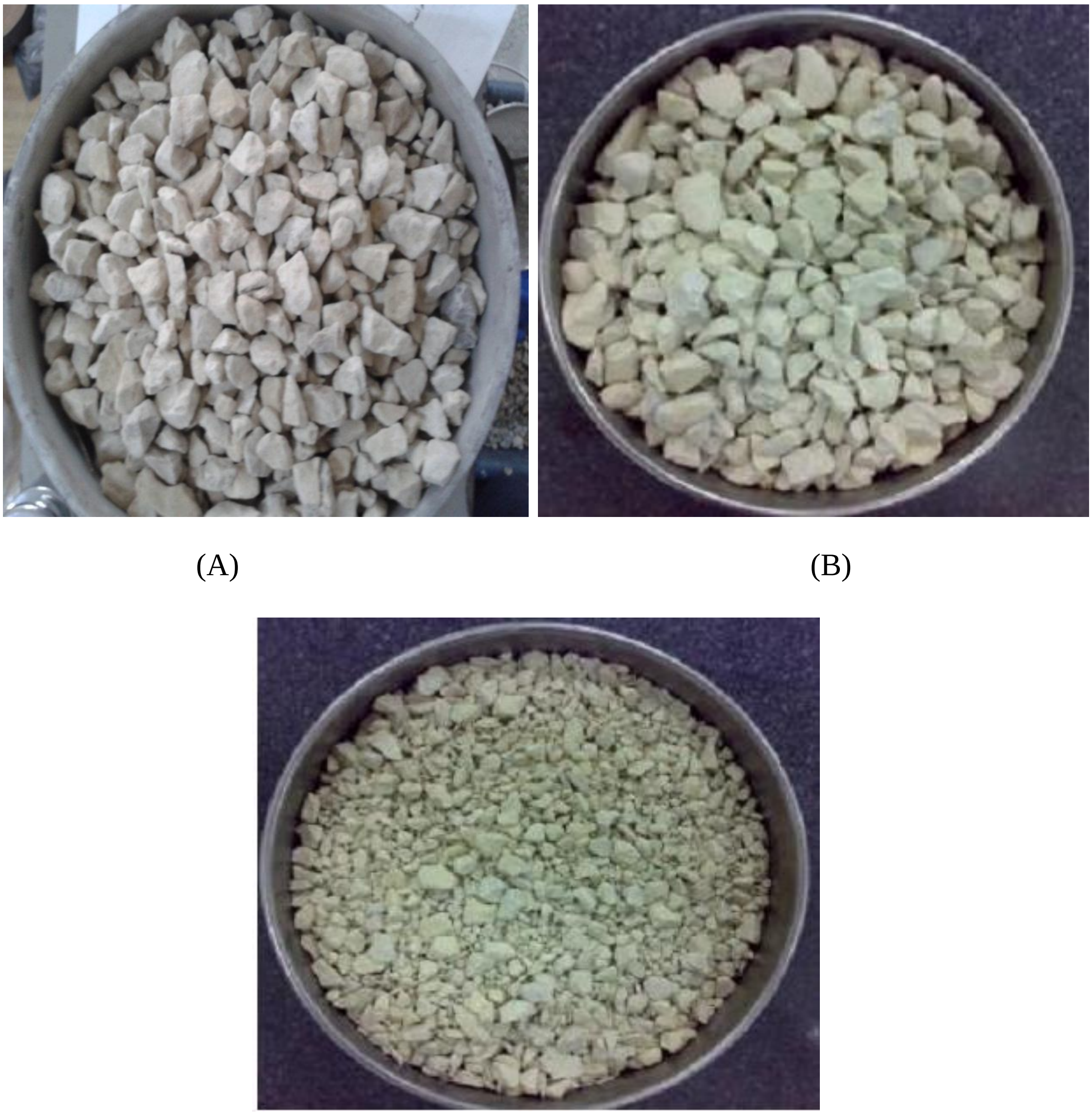
Tap water, potable without any salts or chemicals was used in in all concrete mixtures and in the curing of specimens. The water source was the soil and material laboratory in Islamic University Gaza.

3.2.3 Aggregates

Two main categories of aggregate were used, coarse and fine aggregates, according to ASTM C33 for aggregate classification.

3.2.3.1 Coarse aggregate

Locally available crushed limestone coarse aggregate was used in this study. The maximum nominal size of coarse aggregate is (25mm). Figure (3.2) shows samples of various types of coarse natural aggregates that were used for composing the concrete mixes throughout the experimental testing program for this research study.



(A) (B)

(C)

Figure 3.2: Types of coarse aggregate by max size: (A) 25mm (B) 19mm (C) 9.5mm

- **Coarse Aggregate properties:**

  To prepare concrete mix we need to now the properties of aggregate which include specific gravity, unit weight, absorption, sieve analysis and moisture content.

  - **Specific Gravity**

    The determination of specific gravity of coarse was done according to ASTM C 127. The aggregate specific gravity is a dimensionless value used to determine the volume of aggregate in concrete mixes. Table (3.2) illustrates the specific gravity value for all coarse aggregate types which used in the preparation of concrete mixes.

Table 3.2: Specific Gravity values for Coarse Aggregates

Aggregate Type	**G_{sg}(dry)**	**G_{sg}(SSD)**
25mm size	2.52	2.59
19mm size	2.44	2.54
9.5mm size	2.50	2.58

- **Unit Weight (Bulk Density)**

The unit weight or bulk density of aggregate is the weight of aggregate per unit volume. ASTM C 29 procedure was used to determine aggregate unit weight. Table (3.3) illustrates the aggregate unit weight values.

Table 3.3: Bulk Density values for Coarse Aggregates

Aggregate Type	**γ dry (Kg/m^3)**	**γ SSD(Kg/m^3)**
25mm size	1476	1491
19mm size	1448	1463
9.5mm size	1507	1500

- **Absorption**

Absorption of aggregate is the weight of water present in aggregate pores expressed as percentage of aggregate dry weight. ASTM C127 was used to determine coarse aggregate absorption. Table (3.4) illustrates the absorption percentages of all aggregates.

Table 3.4: Aggregate Absorption

Aggregate Type	**Absorption (%)**
25mm size	2.7
19mm size	4.0
9.5mm size	3.0

- **Moisture Content**

The aggregate moisture content is the percentage of water present in a sample of aggregate either inside pores or in the surface. Moisture content of coarse and fine aggregate was done according to ASTM C 566. The moisture content was 1% for all types.

- **Sieve Analysis**

  The sieve analysis of aggregate includes the determination of coarse and fine aggregate by using a series of sieves. ASTM C136 procedure was used to determine the sieve analysis of coarse and fine aggregate. Table (3.5) and Figure (3.3) show the sieve grading of the three types of aggregates.

Table 3.5: Aggregate Sieve Analysis

Sieve Size (mm)	% Passing		
	Coarse	Medium	Fine
76	100	100	100
50	100	100	100
37.5	96.71	100	100
25	86.94	99.26	100
19	15.33	59.79	99.32
12.5	3.71	13.80	77.03
9.5	2.44	3.41	10.14
4.75	1.94	2.82	7.43
2.36	1.93	2.67	6.42
1.18	1.93	2.67	5.88
0.6	1.93	2.67	5.88
0.3	1.93	2.67	5.68
0.15	1.93	2.67	5.54
0.075	1.68	2.37	5.41

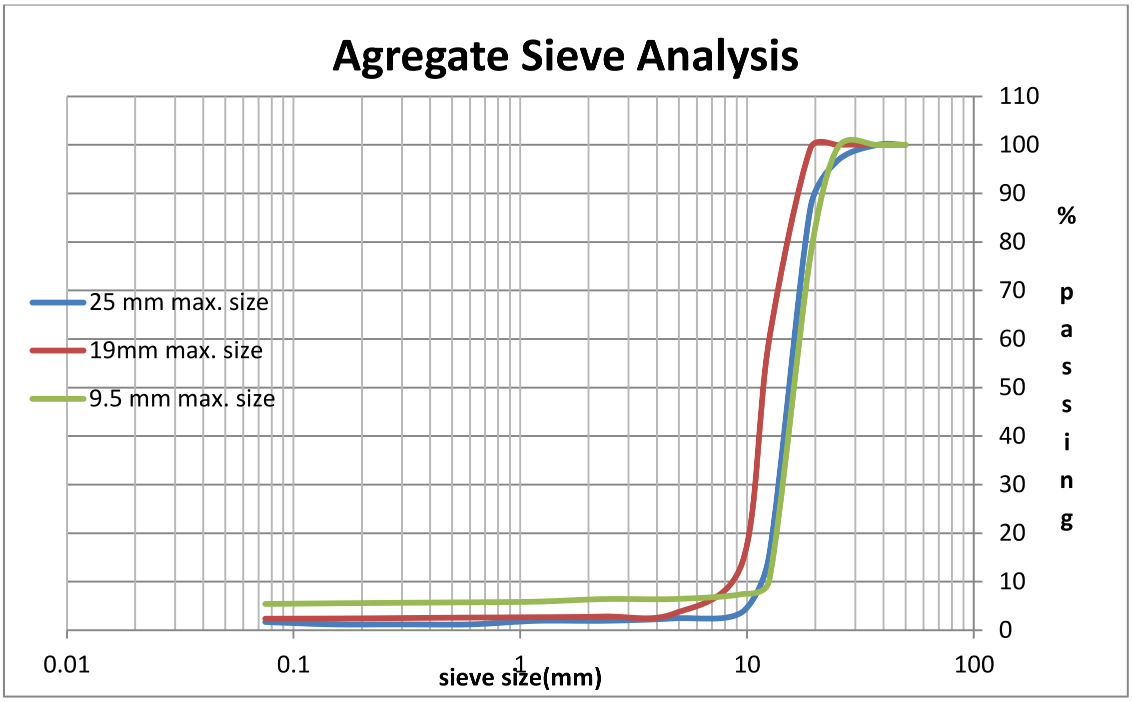


Figure 3.3: Sieve analysis of aggregate

3.2.4 Sand

Sand is a natural material, and it is available in Gaza strip. Sand was tested for physical properties as shown in Table(3.6).The appearance of Gaza sand is shown in Figure(3.4):

Figure 3.4: Natural Sand Sample

Table 3.6: Sand physical Properties

G_{sg}(SSD)	2.54
G_{sg}(Dry)	2.44
Absorption %	4.0
Moisture content	1.4
Dry unit weight (kg/m^3)	1656

Results of sieving Gaza sand in Table (3.7), indicate that sand is poorly graded according to ASTM C33-03 ,so the sand as a fine aggregate should be mixed with other fine aggregates to improve its properties.

Table 3.7: Sand Sieve Analysis

Sieve Size (mm)	% Passing
4.75	100
2.36	100
1.180	100
0.600	98.99
0.300	45.81
0.150	3.74
0.075	0.21

3.2.5 Plastic (PET) Aggregate

In this study, Polyethylene terephthalate (PET) bottles waste collected from a disposal area in Gaza is used. It was shredded and crushed in a plastic recycled plant to small fraction and washed to remove the foreign particles. Figure (3.5) illustrates two samples of PET waste after crushing and shredding.

The same standard procedure like natural aggregate was applied to conduct the properties of plastic aggregates according to the ASTM specifications such as specific gravity, unit weight, absorption, and sieve analysis.

(A)

(B)

Figure 3.5: (A) Crushed PET Bottles sample / (B) shredded PET Bottles sample

The experimental results of the PET plastic aggregate properties are presented in Table (3.8).

Table 3.8: Properties of PET aggregate

Property	Result
Specific Gravity	1.348
Absorption %	0.02
Unit weight (kg/m^3)	589

- **Grading and Sieve Analysis**

  The sieve analysis of plastic PET aggregate includes the determination of coarse and fine aggregate by using a series of sieves. As natural aggregate, ASTM C136 procedure was used to determine the sieve analysis of coarse and fine plastic PET aggregate. Table (3.9) and figure (3.6) show the sieve grading of the plastic aggregate.

Table (3.9): Sieve analysis of PET Aggregate

Sieve Size	% Passing
76	100
50	100
37.5	100
25	100
19	96.23
12.5	72.69
9.5	68.31
4.75	22.72
2.36	2.74

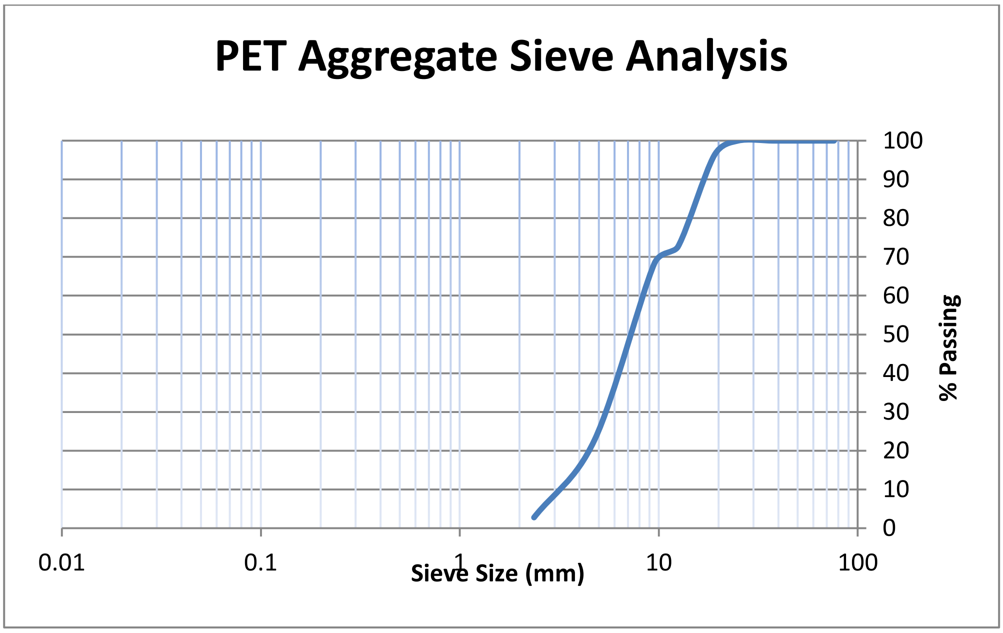


Figure 3.6: Sieve Analysis of PET Aggregate

3.3 Mix Preparation

In this study, the mix proportions were prepared according to ACI 211.1 as shown in appendix (A). The concrete mixes were all prepared using the same method, developed by

the research team, which implies the use of exactly the same aggregates grading curve and concrete composition in terms of cement content, coarse and fine aggregate quantities and slump value.

Four concrete mixes were prepared in this study with compressive strength B300. One concrete mix contains only natural aggregate as reference and three concrete mixes contain PET aggregate by replacing 15%, 30% and 45% in volume of natural aggregate by an equal volume of PET aggregate.

Three samples for every concrete mix were prepared to be tested for compressive strength at 28 days. Also, Three specimens were prepared for Splitting tensile strength and the same number for flexural test, these specimens were tested at age 28 day. Concrete containing PET aggregate has to comply with the same requirements as concrete made with natural aggregate.

The mix operation of concrete for all samples was taken place in a conventional blade-type mixer according to ASTM C192. Table (3.10) summarized the mix operation procedure which followed for natural aggregate and PET aggregate concrete mixes.

Table (3.10): Mixing procedure according to ASTM C 192

Step #	**Description**
1.	Prior to start mix, add coarse aggregate, some of mixing water which may contain admixture if required.
2.	Start mixer.
3.	Add fine aggregate contained sludge, cement, and remaining water with mixer running.
4.	With all ingredients in the mixer, mix for 3 minutes.
5.	Stop mixing for 3 minutes.
6.	Mix for 2 minutes.

3.4 Mix proportions

A total of four concrete mixes(PET0, PET15, PET30, PET45) containing three percentages of PET-aggregate, plus one reference concrete (exclusively with Natural Aggregate) mix, were prepared in this work. The compositions of the concrete mixtures are shown in Tables (3.11) through (3.14). The volume of the PET-aggregate for PET0, PET15, PET30, and PET45 are 0 m^3, 0.065 m^3, 0.13 m^3 and 0.269 m^3 respectively.

Table (3.11): Mix (PET0) proportions

Material Description	Size/Type	Weight (Kg/m^3)	Source
Cement	CEM II	300	Nisher
Aggregate	25mm	650	Crushed Limestone
Aggregate	19mm	270	Crushed Limestone
Aggregate	9.5mm	270	Crushed Limestone
water	Tap	200	IUG Lab
sand	0.6	630	Gaza
PET	19-4.75 mm	0	Gaza
Total		2320	

Table (3.12): Mix (PET15) proportions

Material Description	Size/Type	Weight (Kg/m^3)	Source
Cement	CEM II	300	Nisher
Aggregate	25mm	560.75	Crushed Limestone
Aggregate	19mm	225.38	Crushed Limestone
Aggregate	9.5mm	225.38	Crushed Limestone
water	Tap	200	IUG Lab
sand	0.6	630	Gaza
PET	19-4.75 mm	87.47	Gaza
Total		2228.98	

Table (3.13): Mix (PET30) proportions

Material Description	Size/Type	Weight (Kg/m^3)	Source
Cement	CEM II	300	Nisher
Aggregate	25mm	471.5	Crushed Limestone
Aggregate	19mm	180.75	Crushed Limestone
Aggregate	9.5mm	180.75	Crushed Limestone
water	Tap	200	IUG Lab
sand	0.6	630	Gaza
PET	19-4.75 mm	174.93	Gaza
Total		2137.93	

Table (3.14): Mix (PET45) proportions

Material Description	Size/Type	Weight (Kg/m^3)	Source
Cement	CEM II	300	Nisher
Aggregate	25mm	332.25	Crushed Limestone
Aggregate	19mm	136.12	Crushed Limestone
Aggregate	9.5mm	136.12	Crushed Limestone
water	Tap	200	IUG Lab
sand	0.6	630	Gaza Sand
PET	19-4.75 mm	362.40	Gaza
Total		2096.89	

3.5 Testing Program

The present study concentrated on developing the most straightforward mix design and preparation techniques to produce concrete containing recycled/waste PET plastic with acceptable properties in fresh and hardened states. The influence of recycled PET on concrete properties was studied by preparing several concrete mixes involving different amount and shape of recycled PET plastic. In this work, two main sizes of recycled PET were used in concrete mixes. These two sizes included crushed and shredded recycled/waste PET.

For the testing program, a series of standard tests were conducted with variable amounts of PET aggregate as follow:

- To evaluate the effect of PET aggregate on compressive strength of concrete, total of 24(100x100x100 mm) concrete cubes will be made according to ASTM specifications.
- To see the effect of PET aggregate on tensile strength of concrete, total of 12 (150 x 300mm) cylinders will be made based on ASTM specifications.
- A total of 12(100 x 100 x 500 mm) concrete beams will be set to check the effect of PET aggregate on flexural strength of reinforced concrete, in accordance ASTM specifications. Table (3.15) illustrates the different tests which conducted for every concrete mix with constant water/cement ratio.

Table (3.15): Test Program for concrete with different amounts of PET aggregate

W/C Ratio %	0.5				TOTAL
Replaced % of Natural Aggregate by PET aggregate (by volume)	0%	15%	30%	45%	
Compressive strength at 28 days	3	3	3	3	12
Splitting tensile strength at 28 days	3	3	3	3	12
Flexural strength at 28 days	3	3	3	3	12
Impact resistance at 28 days	3	3	3	3	24
Slump value	3	3	3	3	12
Bulk density (Unit weight)	3	3	3	3	12
Total number of different tests					96

3.6 Equipment and testing procedure

The laboratory work consists of fresh and hardened concrete tests. Fresh concrete tested for slump value. Hardened concrete tested for compressive strength, splitting tensile test, flexural test and impact resistance test.

3.6.1 Fresh concrete tests

3.6.1.1 Slump Test

Slump test was conducted to assess the workability of fresh reference concrete and concrete containing PET aggregate. The slump test was carried out according to ASTM C143. For each mix in the experiment program, a sample of freshly mixed concrete is placed and compacted by rod in a frustum of cone mold. As shown in figure (3.7), the slump value is equal to vertical distance between the original and displaced position of the center of the top surface of the concrete after raising a mold.

Figure 3.7: Slump Value Test

3.6.1.2 Density

In this study, the density of concrete cube specimens is the theoretical density. The density is calculated by dividing the weight of each cube on the cube volume. The same cube specimens which used to determine compressive strength were used to determine the density in the same procedure.

3.6.2 Hardened concrete tests

3.6.2.1 Compressive Strength Test

Twenty four cubic specimens of size 100 mm × 100 mm × 100 mm were casted for conducting compressive strength test, three for each percentage (0%,15%,30% and 45%) of PET aggregate. The cubes were filled with fresh concrete in two layers and each layer was tamped 25 times with a tamping rod. Immediately after prepared cubes, the specimens were covered to prevent water evaporation. The compressive strength test (Fig.3.8) was based on ASTM C109 and was tested at the end of the 7 and 28 days of curing. The compressive strength of any mix was taken as the average strength of three cubes.

Figure 3.8: Compressive strength test machine

After 24 hours, cubes extracted from forms and stored in water (curing phase) up to the time of test. Before testing, specimens were air dried for 10 to15 minutes.

The compressive strength of the specimen, σ comp (in MPa), is calculated by dividing the maximum load carried by the cube specimen during the test by the cross sectional area of the specimen.

3.6.2.2 Splitting Cylinder Test

The splitting tensile strength of concrete specimens was measured based on ASTM C496

Standard test. Twelve cylindrical specimens of size 150 mm in diameter and in height 300 mm were cast. Three specimens for each percentage (0%, 15%, 30% and 45%) of PET aggregate.

The tensile strength of concrete is evaluated using a split cylinder test, in which a cylindrical specimen is placed on its side and loaded in diametrical compression, so to induce transverse tension. Practically, the load applied on the cylindrical concrete specimen induces tensile stresses on the plane containing the load and relatively high compressive stresses in the area immediately around it. When the cylinder is compressed by the two plane-parallel face plates, situated at two diametrically opposite points on the cylinder surface then, along the diameter passing through the two points, the major tensile stresses are developed which, at their limit, reach the fracture strength value ASTM C496 indicates that the maximum fracture strength can be calculated based on the following equation:

$F = 2P/ \pi DL$

Where: P is the fracture compression force acting along the cylinder;

D is the cylinder diameter;

$\pi = 3.14$;

L is the cylinder length.

3.6.2.3 Flexural strength test

The flexural strengths of concrete specimens are determined by the use of simple beam (100 x 100 x 500) mm with center point loading in accordance to ASTM C293 as shown in Figures (3.9) and (3.10). Twelve beam specimens of size 100 x 100 x 500 were casted.

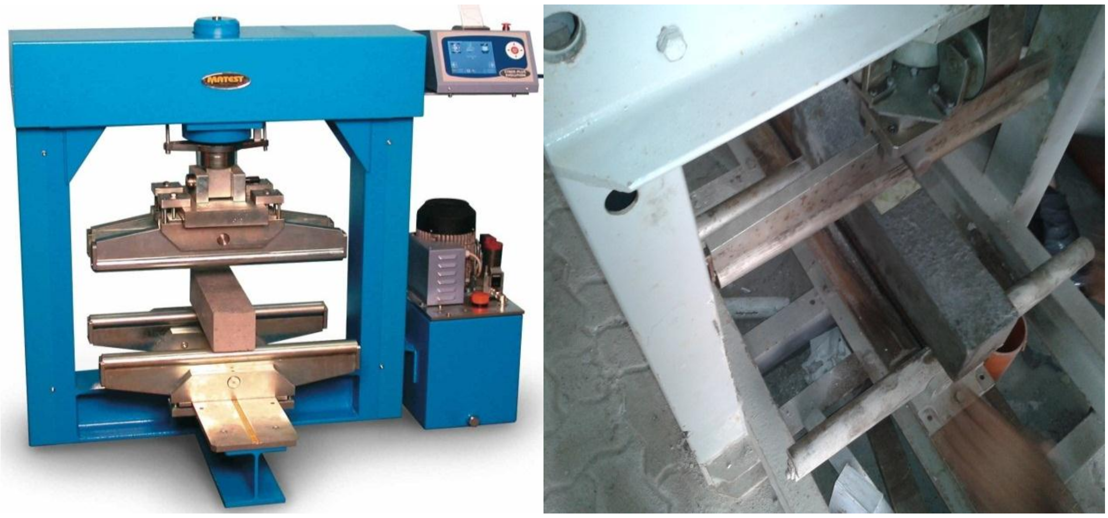


Figure 3.9: Flexure strength test machine

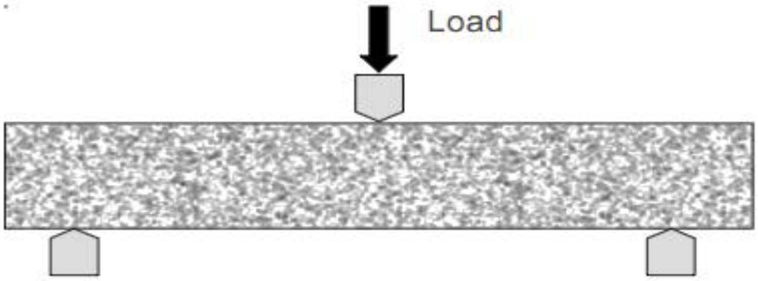


Figure 3.10: Center point loading for flexural strength test

The flexural strength of the beam in MPa can be calculated by using the following equation:

Flexural Strength (MPa) = $\frac{3PL}{2bh^2}$

Where:

P: Maximum applied load;

L: Material span length between points in the test setup;

b: Width of the material specimen;

h: Average depth of the specimen.

The center point loading device is adjusted so that its bearing edge is at exactly right angles to the length of the beam and parallel to its top face as placed, with the center of the bearing edge directly above the center line of the beam and at the center of the span length. The load contacts with the surface of the specimen at the center. If full contact is not obtained between the specimen and the load applying or the support blocks so that there is a gap, the contact surfaces of the specimen are capped. The specimen is loaded continuously and without shock at until rupture occurs. The maximum load indicated by the testing machine is recorded.

3.6.2.4 Impact resistance test

The impact test was performed in accordance with the impact testing procedures recommended by ACI Committee 544 as shown in figure (3.11). The test was carried out by dropping a rod weighing 49 N (11 lb.) in a tube with a height of 460 mm (18.1 inch) repeatedly on a 48 mm diameter (2 inch) hardened steel ball, which is placed on the top of the center of the cylindrical specimen (disc).

Special impact machine was designed and fabricated using local materials adopting the technique of drop weight impact test. The impact machine was manufactured according to ACI recommendations. Figure (3.12) shows the test machine.

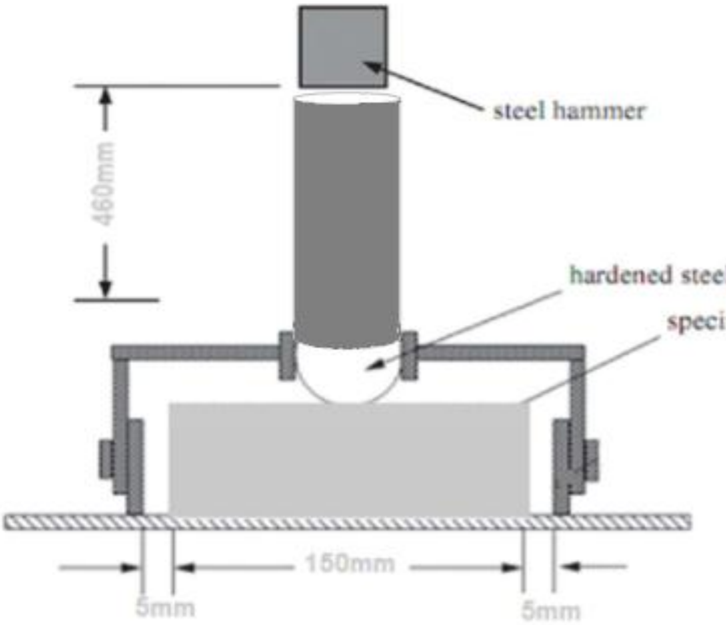


Figure 3.11: Drop-weight test device

Figure 3.12: impact test apparatus

The test continued until failure. For each specimen, two values were identified corresponding to initial and ultimate failure. The former value measures the number of blows required to initiate a visible crack, whereas the latter measures the number of blows required to initiate and propagate cracks until ultimate failure. According to the ACI committee, the ultimate failure occurs when sufficient impact energy has been supplied to spread the cracks enough so that the test specimen touches the steel lugs. However, in this study, if the specimen separated completely into halves before touching the lugs, then this was declared the point of ultimate failure.

Concrete specimens as shown in Figure (3.13) were cast in steel molds. After 24 hours the specimens were de-molded and water cured for 28 days. All specimens were cast and treated under the same environmental conditions.

Figure 3.13: impact test specimens

3.6.3 Curing conditions

All concrete samples were placed in curing basin after 24 hours from casting. The samples were remained in curing basin until tested at the specified age. The curing condition of material laboratory basin followed the ASTM C192 standard. The curing water temperature is around 25^0C.

CHAPTER 4

TEST RESULTS AND ANALYSIS

4.1 Introduction

This chapter describes the results of the test program designed to study the physical and mechanical properties of the various PET aggregate concrete mixes as described in chapter 3. Slump test, density, compressive strength, flexural strength, splitting tensile strength and impact resistance test of concrete specimens were discussed to investigate the influence of PET aggregate on concrete properties.

The test results of this study, focus on the behavior of recycled PET aggregate in concrete mixes. The quantity of PET aggregate was calculated according to ACI 211.1 code provisions. Four mixes of concrete were used with 0%, 15%, 30% and 45% replacing of natural aggregate with recycled PET aggregate. The physical and mechanical properties were discussed as follows:

4.2 Fresh concrete properties tests results

4.2.1 Slump (workability)

The slump value was used as indication of mix workability and all the mixes was designed for 80-100mm slump value. Table (4.1); shows the results of the slump tests of PET plastic aggregate concrete mixtures, these results indicate that the slump value of fresh concrete is prone to decrease with increasing the plastic aggregate ratio. The reductions of slump are 10%, 28%, and 50% for 15%, 30%, 45% replacement of natural aggregate by PET aggregate respectively.

The slump was about 100 mm for concrete without any plastic aggregate and the slump was about 7 mm for PET aggregate concrete. As shown in Figure (4.1) the reasons for the lower slump value of the concrete mix containing PET aggregate are the sharp edges and angular particle size of PET aggregate.

Table (4.1): Effect of recycled PET aggregate on slump test results

Mix #	% PET Aggregate	Slump (mm)	W/C Ratio
PET 0 (Reference)	0	100	0.67
PET 15	15	90	0.67
PET 30	30	72	0.67
PET 45	45	50	0.67

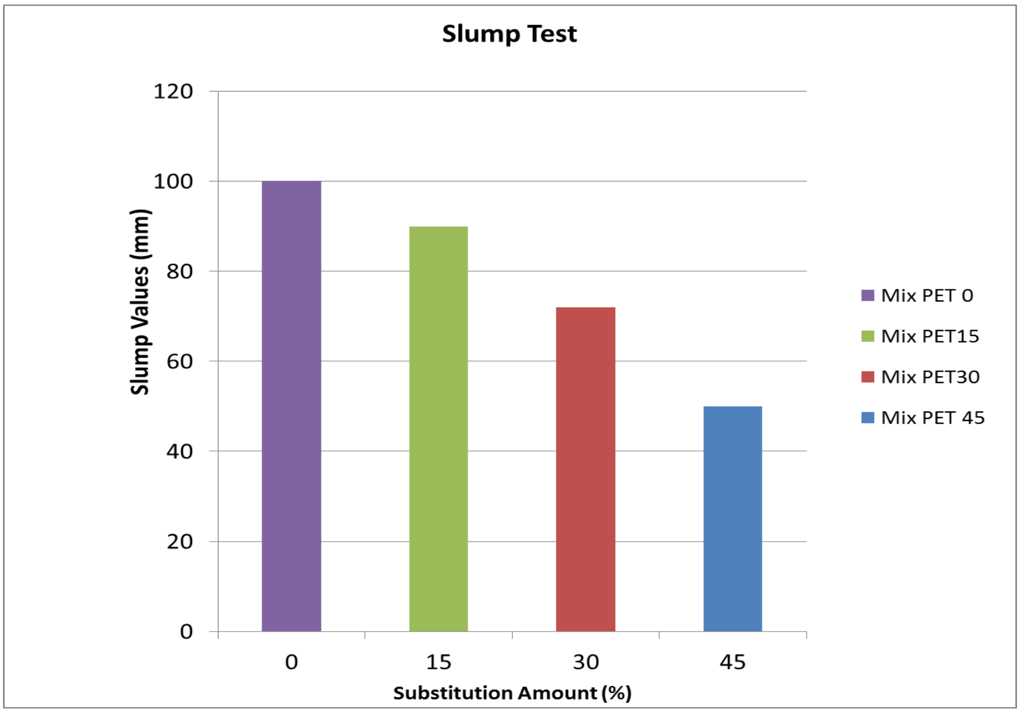


Figure 4.1: Slump values of plastic concrete mixes

4.2.2 Density

Table (4.2) illustrates the average 28-day density of concrete specimens for all mixes of concrete. The results indicate that the concrete containing 15%, 30% and 45% PET aggregate as replacement of natural aggregate tends to decrease in density below the reference concrete by 2.9%, 5.8%, and 12% respectively. The use of plastic aggregate reduced the dry densities of all mixtures with increasing the plastic ratio, because the density of plastic is lower than that of natural aggregate by 51%.

Table (4.2): Effect of recycled PET aggregate on concrete density

Mix #	% PET Aggregate	Average Density (Kg/m^3)	W/C Ratio
PET 0 (Reference)	0	2398.6	0.67
PET 15	15	2328.7	0.67
PET 30	30	2258.9	0.67
PET 45	45	2110.6	0.67

4.3 hardened concrete properties tests results

4.3.1 Compressive Strength Results

Tables (4.3), (4.4), (4.5) and (4.6) show the reported results of 28-day compressive strength performance of concrete containing various percent of plastic PET waste as partial substitution of coarse natural aggregates with constant w/c ratio (0.67).

Table (4.3): 28 days- Compressive strength results of mix PET 0 (Reference mix)

Sample #	PET Aggregate (%)	Dimension (mm)			Weight (g)	Failure Load (KN)	Stress (Kg/cm^2)
		L	W	H			
1	0	100	101	100	2470	284	286
2	0	100	102	101	2425	295	294
3	0	101	103	101	2515	309	302
Average							**294**

Table (4.4): 28 days- Compressive strength results of mix PET 15

Sample #	PET Aggregate %	Dimension (mm)			Weight (g)	Failure Load (KN)	Stress (Kg/cm^2)
		L	W	H			
1	15	100	102	101	2450	280	280
2	15	101	102	101	2415	299	298
3	15	101	101	101	2515	290	292
Average							**290**

Table (4.5): 28 days- Compressive strength results of mix PET 30

Sample #	**PET Aggregate %**	**Dimension (mm)**			**Weight (g)**	**Failure Load (KN)**	**Stress (Kg/cm^2)**
		L	**W**	**H**			
1	30	102	102	100	2338	265	260
2	30	102	100	101	2316	262	262
3	30	101	100	101	2314	260	260
Average							**261**

Table (4.6): 28 days- Compressive strength results of mix PET 45

Sample #	**PET Aggregate %**	Dimension (mm)			Weight (g)	Failure Load (KN)	Stress (Kg/cm^2)
		L	W	H			
1	45	102	101	100	2128	225	223
2	45	102	100	101	2116	223	223
3	45	101	100	101	2162	217	217
Average							**221**

The results indicate that the compressive strength at age 28 days of concrete containing 15% plastic PET aggregate exhibits a compressive strength that meets the standard strength values of the reference concrete mix.

For 30% aggregate replacement compressive strength shows a reduction up to 11% of the original strength. For 45% aggregate replacement the compressive strength decreases about 24% from the original strength.

Several factors such as the type of failure and the formation of honeycombs, low w/c ratio, particle size, which are responsible for lower compressive strength of concrete containing PET aggregate than concrete containing natural aggregate. Figure 4.2 illustrates the average compressive strength for several mixes of concert containing PET aggregate. This result agrees with the finding of Saikia and Brito, (2014) and Albano et al. (2009).

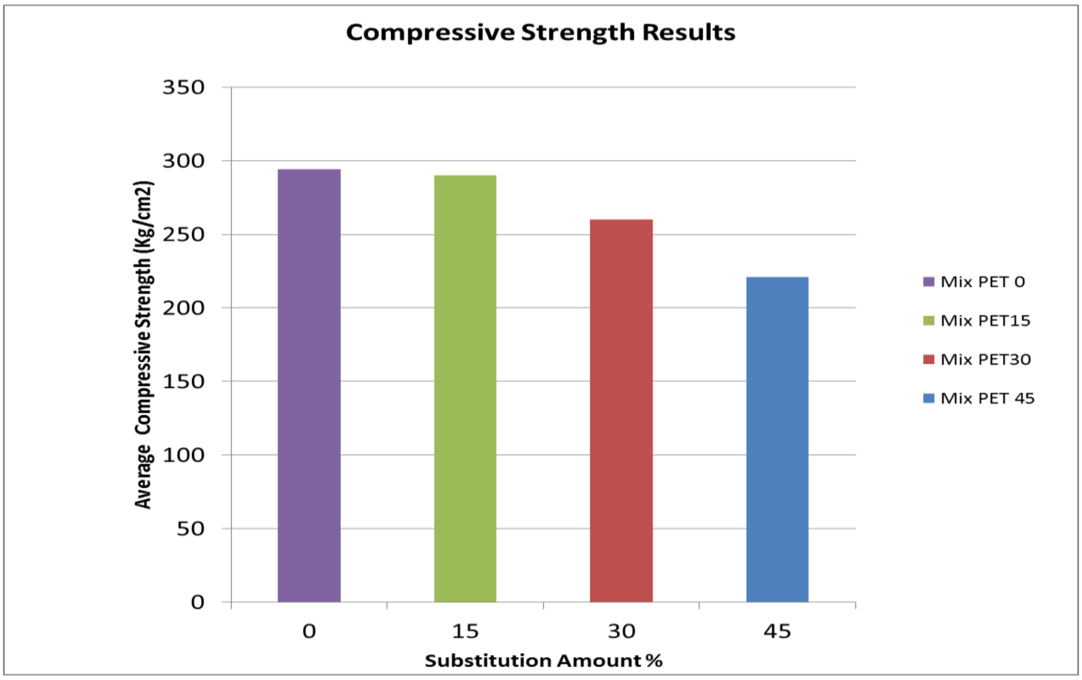


Figure 4.2: 28 day-Average Compressive Strength of concrete mixes

4.3.2 Splitting Tensile Strength Results

The splitting tensile strength results were evaluated at 28 days of cure. In table (4.7) and figure (4.3) the effect of adding PET aggregate was illustrated. From the data presented we can see that the behavior is similar to the compressive strength, attributing it to the same reasons mentioned above. For a w/c ratio of 0.67 there is a decrease in the splitting tensile strength with respect to the reference concrete mix independently of the amount of the PET added. There was 5%, 17%, and 34% reduction in the tensile strength for concrete containing 15%, 30%, and 45% plastic PET aggregates. These results were also observed by Choi et al. (2005).

Table (4.7): Effect of Recycled PET Plastic on Splitting Tensile Strength at Age of 28-days

Mix	PET Aggregate %	Dimension (mm)		Weight (g)	Failure Load (KN)
		D	H		
PET 0	0	150	300	12389	149.5
PET 15	15	150	300	12323	142.2
PET 30	30	150	300	11298	123.3
PET 45	45	150	300	10879	98.5

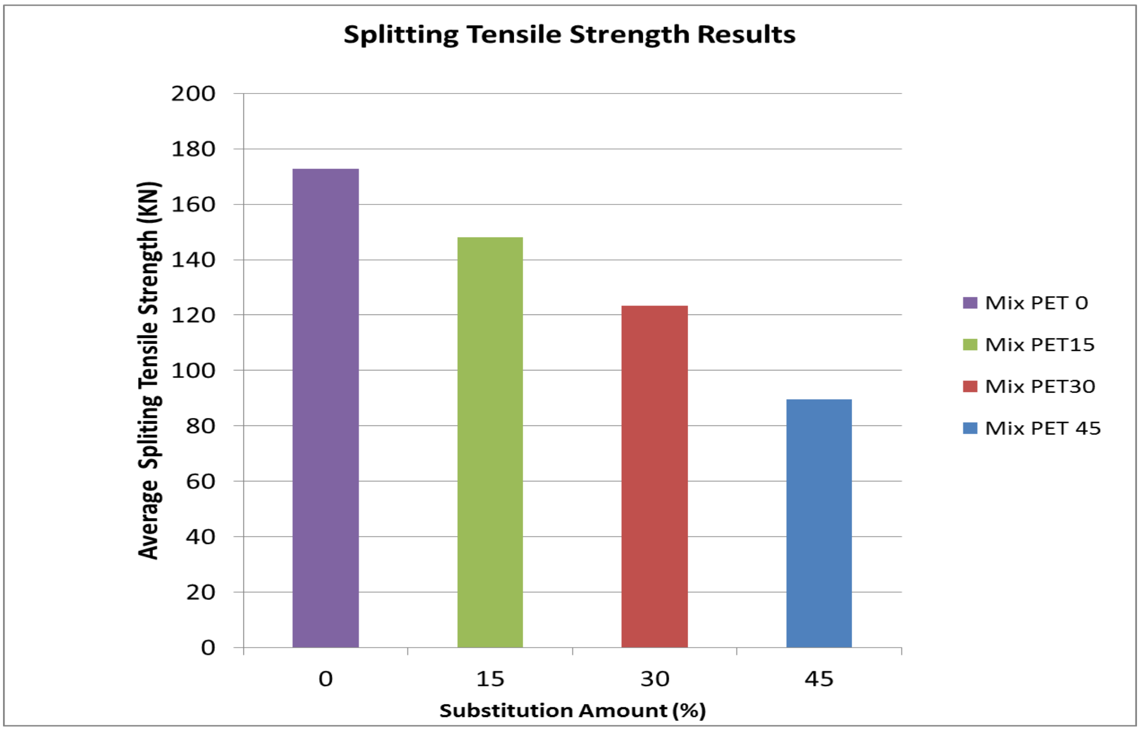


Figure 4.3: 28 day-Average Splitting Tensile Strength of concrete mixes

4.3.3 Flexural Strength Test Results

The results of the flexural strength tests for the plastic PET concrete mixtures PET0, PET15, PET30, and PET45 are illustrated in table (4.8) and figure (4.4). These results show that the flexural strength of PET concrete mixtures at 28-days curing age is prone to decrease with the increase of the PET ratio in these mixtures. This trend can be attributed to the decrease in adhesive strength between the surface of waste plastic particles and the cement paste, as well as the hydrophobic nature of plastic material which may limit the hydration of cement. Therefore the hydration developed slightly with time. However the flexural strengths of the waste plastic PET concrete composites compared similarly with those of previous work (Hannawi et al., 2010; Rahmani et al., 2013)

Table (4.8): Effect of Recycled PET Plastic on flexural Strength at Age of 28-days

Mix	**PET Aggregate %**	Dimension (mm)			Failure Load (KN)	Flexure Strength (MPa)
		L	W	H		
PET 0	0	500	100	100	8	4.8
PET 15	15	500	100	100	7.1	4.26
PET 30	30	500	100	100	6.5	3.9
PET 45	45	500	100	100	5	3

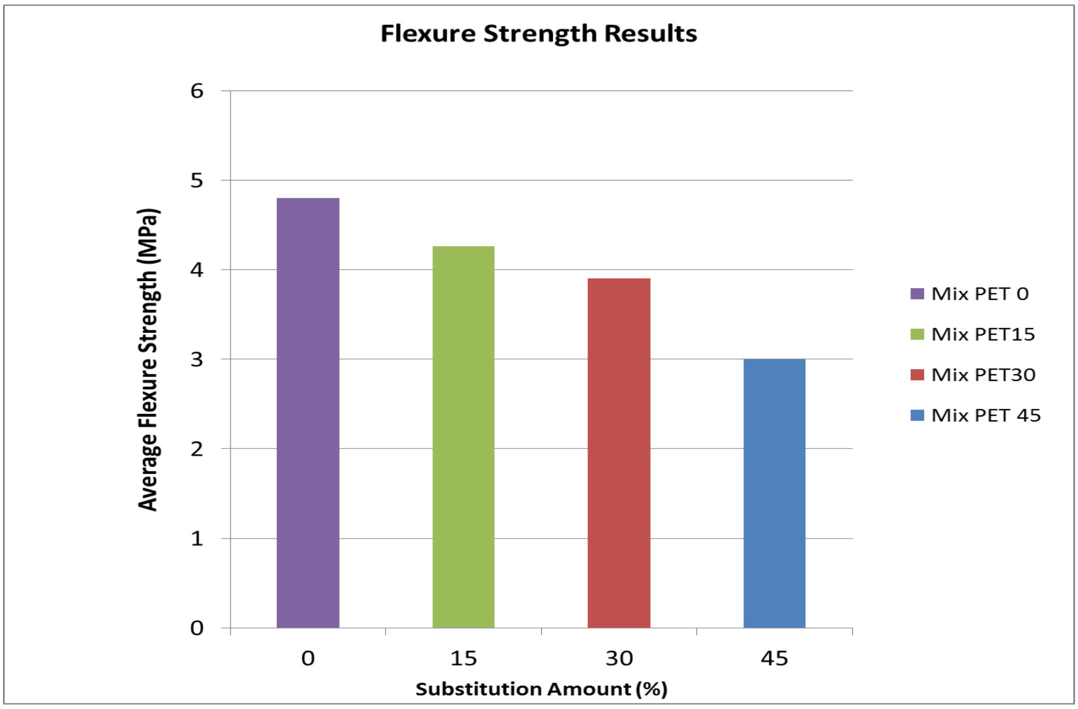


Figure 4.4: 28 day-Average Flexural Strength of Concrete Mixes

As shown in Figure (4.5), after reaching the ultimate strength, most of the PET aggregate in the concrete matrix do not fail, but they are debonded from the cement paste, which is additional evidence of the poorer bonding between the PET aggregate and the cement paste.

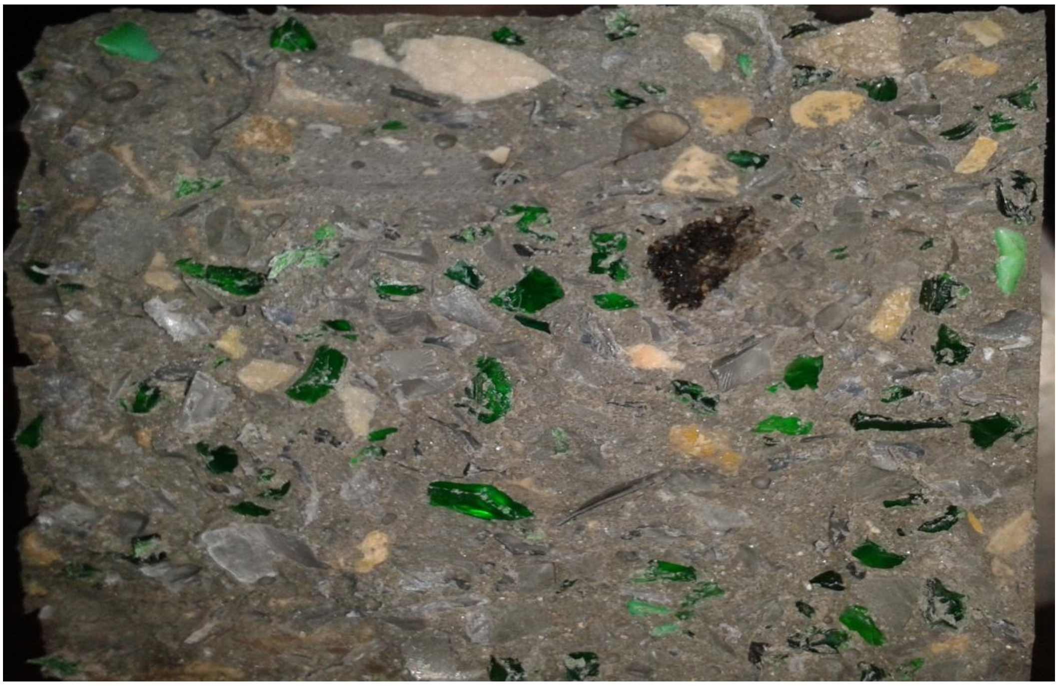


Figure 4.5: Concrete specimen containing PET aggregate after failure in the flexural strength test

4.3.4 Impact Resistance Test Results

Impact resistance is measured by the number of blows required to enable the first tensile crack to appear on the test specimen. Ultimate failure is defined by the ACI committee 544.

In terms of the number of blows required to open the cracks in the test specimen to enable the fractured pieces touch the positioning lugs in the base plate. If the specimen separated completely into halves before touching the lugs, then this was declared the point of ultimate failure. Table (4.9) and figure (4.6) illustrate the results of impact resistance test for the plastic PET concrete mixtures PET0, PET15, PET30, and PET45 with replacement natural aggregate by 0%, 15%, 30%, and 45% of plastic PET aggregate by volume.

Table (4.9): Drop Weight Impact Test Results (28-days)

Mix Type	Sample No.	No. of Blows		Average No. of Blows	
		First Crack	Final Failure	First Crack	Final Failure
PET 0	1	12	12	13	13
	2	14	14		
	3	12	12		
PET 15	4	10	11	11	12
	5	12	13		
	6	10	12		
PET 30	7	13	16	13	15
	8	14	15		
	9	13	15		
PET 45	10	23	24	23	24
	11	21	23		
	12	24	25		

Based on the data in Table (4.9), it can be seen that in term of the blows to the first crack and to the final failure, the impact resistance of PET 15 the same as the PET 0. For PET 30 the average blows are 13 and 15 for initial and final failure respectively, with increase of 0% and 13% compared with PET 0 (normal concrete). Also for PET 45 Compared with PET 0 the result shown that the impact resistance increased by 43% and 45% in term of blows to the first crack and to the final failure.

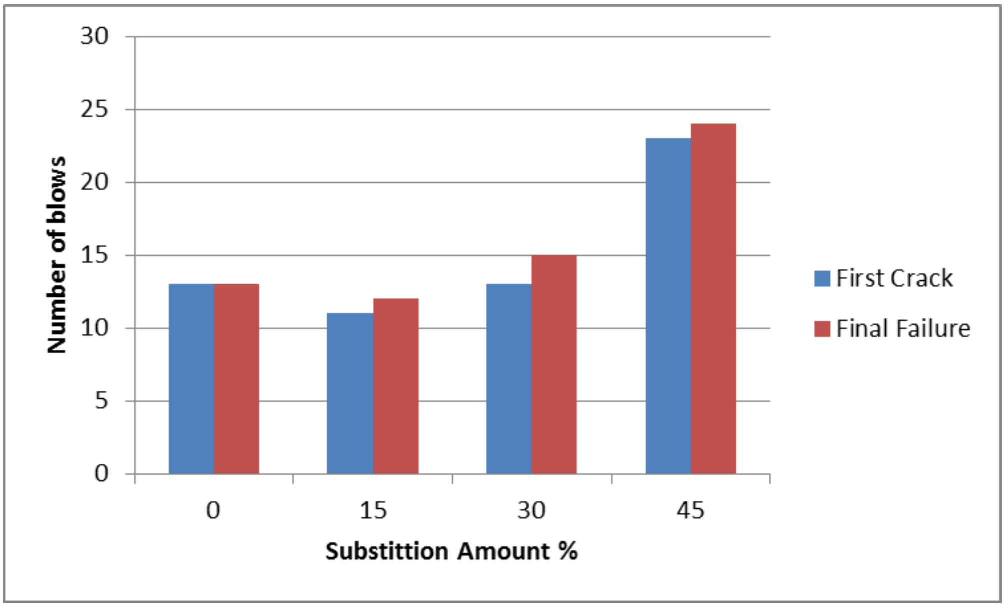
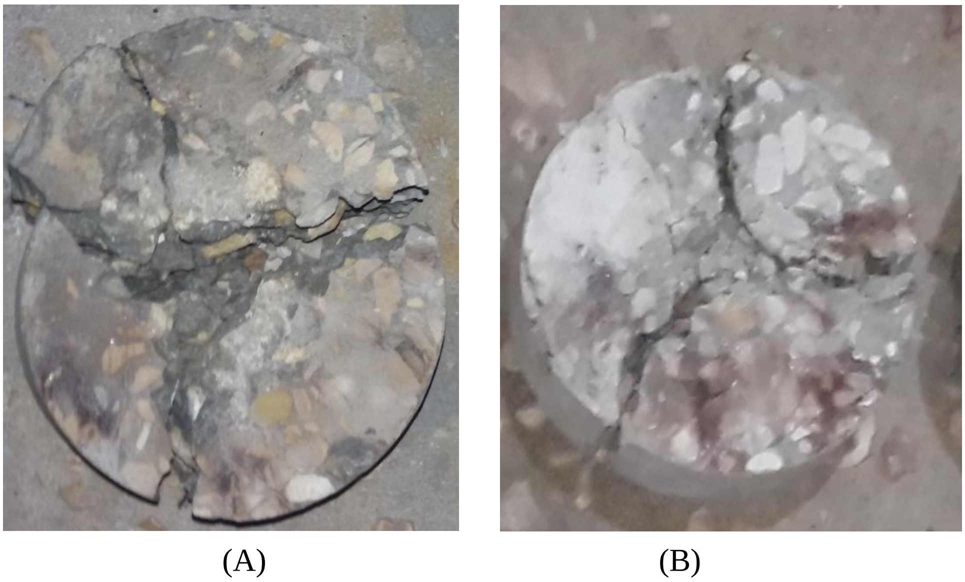


Figure 4.6: Comparison of first crack and final failure values between concrete specimens

Figure (4.7) illustrates the different failure patterns of specimens with different PET percent. It can be observed that the normal concrete discs are usually show a brittle behavior, whereas the PET15, PET30, PET45 discs are normally broken into four or more pieces and show well ductile properties. This phenomenon indicates that the addition of PET plastic like aggregate allows enhancing the impact resistance of concrete.



(A) (B)

(C) (D)

Figure 4.7: Comparison of failure patterns of specimens with different PET ratio: (A) PET0; (B) PET15; (C) PET30; (D) PET45

The same specimens was prepared with the same PET aggregate ratios but without replacing the natural aggregate and tested by the impact machine to see the effects of PET on concrete. Table (4.10) and Figure (4.8) illustrates the average results of impact resistance test for the plastic PET concrete mixtures (PET0, PET15A, PET30A, and PET45A).

Table (4.10): Average Drop Weight Impact Test Results (28-days)

Mix Type	Average No. of Blows	
	First Crack	Final Failure
PET0	13	13
PET15A	11	15
PET30A	12	16
PET45A	19	21

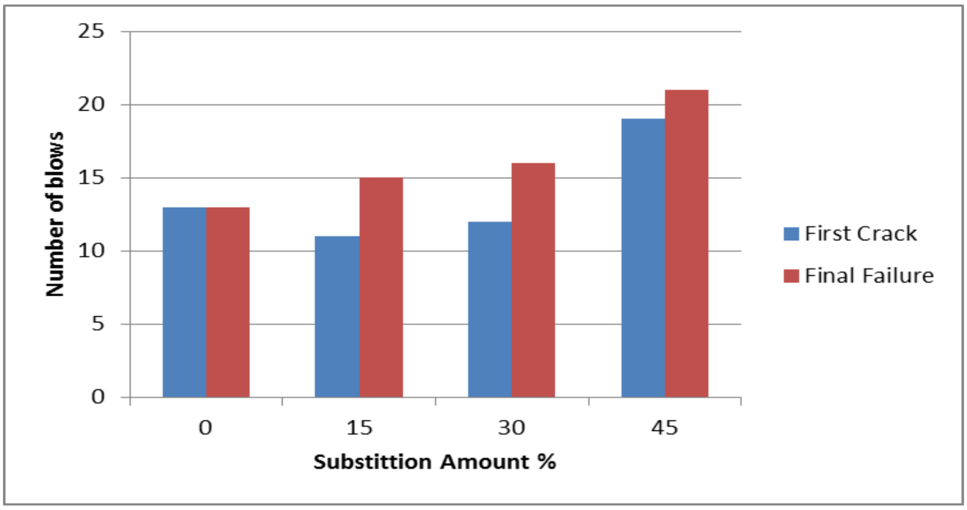


Figure 4.8: Comparison of first crack and final failure values different PET ratio: (A) PET0; (B) PET15A; (C) PET30A; (D) PET45A

CHAPTER FIVE

CONCLUSIONS AND RECOMEDATIOS

5.1 Introduction

The increase in the awareness of waste management and environment-related issues has led to substantial progress in the utilization of waste products like plastic. This study has presented various aspects on recycled plastic and its usage in concrete.

The main objective of this work was to investigate the use of waste/recycled plastic and especially PET plastic as aggregate in concrete mix. This study included the preparation of concrete mixes containing PET aggregate and the evaluation of its properties in fresh and hardened states. The studying properties involved mix workability, density, compressive strength, splitting tensile strength, flexural strength and impact resistance.

5.2 Conclusion

- Recycled PET plastic can be used as a partial replacement of natural aggregate with a percentage can be reached to 45%.

- Increasing recycled PET aggregate from 15% to 30% and then to 45% leads to a decrease in the slump values and the filling ability of the concrete mix.

- The use of the recycled plastic in the concrete reduced the overall concrete bulk density when compared to conventional concrete which lead to produce light-weight concrete.

- Compressive strength decreased with the increase in recycled plastic content. Reduction in the compressive strength was between 11% and 24% for concrete containing 15–45% recycled PET plastic.

- Splitting tensile strength of concrete made with plastic aggregates was found to decrease with increase in the percentage of plastic aggregates. The splitting tensile strength was found to decrease by 5%, 17%, and 34% for concrete containing 15%, 30%, and 45% plastic aggregates, respectively.

- Flexural strength decreases as the PET aggregate content increases. By replacement of 15%, 30%, and 45% of natural aggregate by PET aggregate, reduction in flexural strength were noticed by 11.2%, 18.7%, and 37.5%, respectively.

- It was observed that the impact resistance of concrete increased against the first crack initiation and final fracture by addition of PET plastic aggregate because the recycled plastic enhances the ductility of concrete. For PET 45 Compared with PET 0 the result shown that the impact resistance increased by 43% and 45% in term of blows to the first crack and to the final failure.

5.3 Recommendations

- The recycled PTE can be used in concrete mixes as aggregate with 15% without large reduction in compressive strength.

- More types and sizes of recycled plastic need to be taken into consideration.

- The effect of different W/C ratios on the mechanical property of concrete with recycled plastic aggregate need to further research.

- Other studies are encouraged to obtain the effect of using different percent of PET plastic bottles in nonstructural elements.

- The influences of the addition of super plastisizers on the mechanical property of concrete mixes contain recycled plastic need to be taken into consideration.

- The durability performance of concrete containing plastic aggregates needs more studies.

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APPENDIX A

Appendix (A)

Design of Concrete Mixtures

ACI 211.1 Method

The American Concrete Institute (ACI) mix design method is but one of many basic concrete mix design methods available today. This section summarizes the ACI absolute volume method because it is widely accepted in the U.S. and continually updated by the ACI. Keep in mind that this summary and most methods designated as "mix design" methods are really just mixture proportioning methods. Mix design includes trial mixture proportioning (covered here) plus performance tests.

This section is a general outline of the ACI proportioning method with specific emphasis on PCC for pavements. It emphasizes general concepts and rationale over specific procedures. Typical procedures are available in the following documents:

The American Concrete Institute's (ACI) Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91) as found in their ACI Manual of
Concrete Practice 2000, Part 1: Materials and General Properties of Concrete. The Portland Cement Association's (PCA) Design and Control of Concrete Mixtures, 14th edition (2002) or any earlier edition.

The standard ACI mix design procedure can be divided up into 8 basic steps:

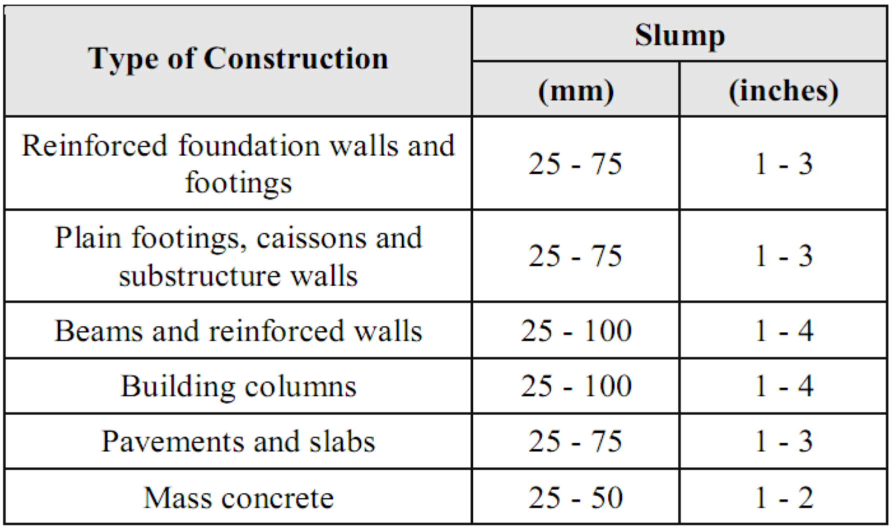
1. Choice of slump
2. Maximum aggregate size selection
3. Mixing water and air content selection
4. Water-cement ratio
5. Cement content
6. Coarse aggregate content
7. Fine aggregate content
8. Adjustments for aggregate moisture

Choice of Slump

The choice of slump is actually a choice of mix workability. Workability can be described as a combination of several different, but related, PCC properties related to its theology:

- Ease of mixing
- Ease of placing
- Ease of compaction
- Ease of finishing

Generally, mixes of the stiffest consistency that can still be placed adequately should be used (ACI, 2000). Typically slump is specified, but Table A-1 shows general slump ranges for specific applications.



Type of Construction	Slump	
	(mm)	(inches)
Reinforced foundation walls and footings	25 - 75	1 - 3
Plain footings, caissons and substructure walls	25 - 75	1 - 3
Beams and reinforced walls	25 - 100	1 - 4
Building columns	25 - 100	1 - 4
Pavements and slabs	25 - 75	1 - 3
Mass concrete	25 - 50	1 - 2

Choice of maximum size of aggregate

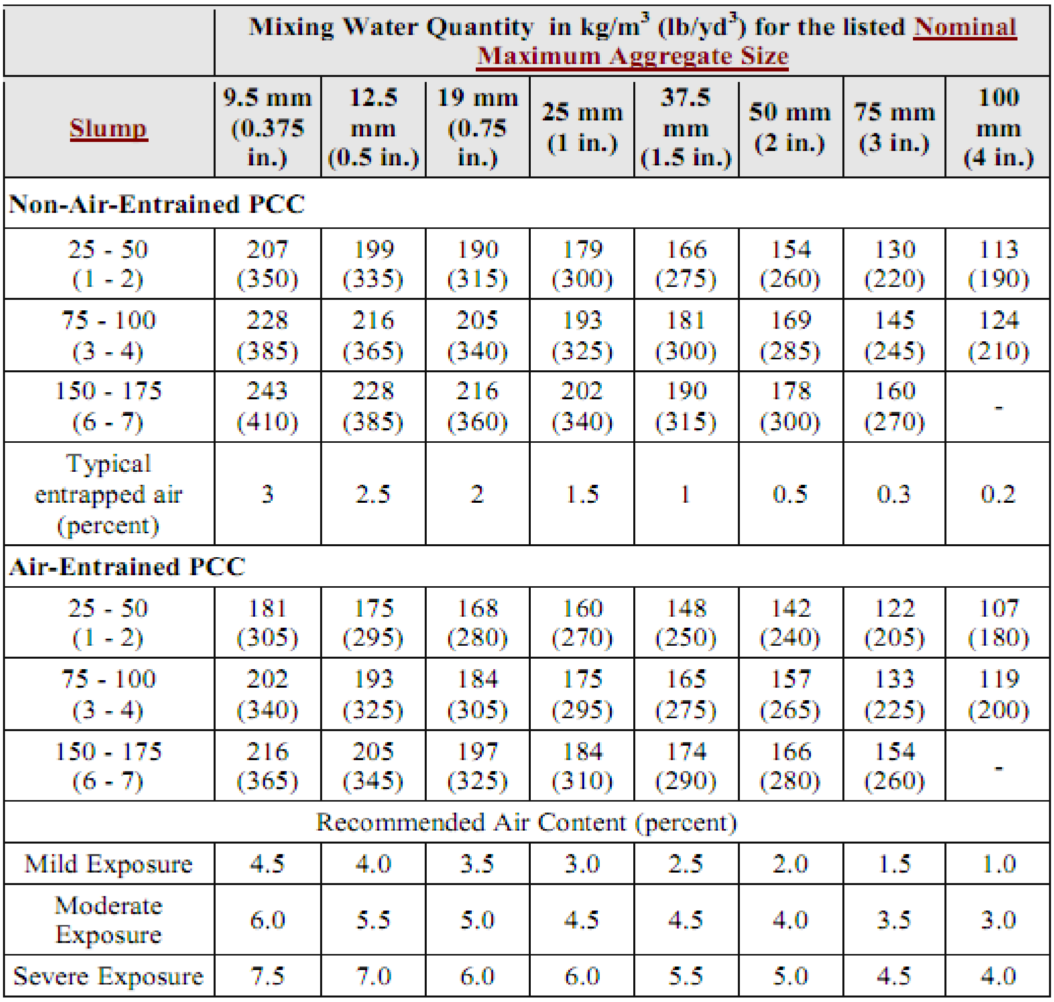
Large maximum sizes of aggregate produce fewer voids than smaller sizes. Hence, concrete with the larger-sized aggregate require less mortar per unit volume of concrete, and of course it is the mortar which contains the most expensive ingredient, cement. Thus the ACI method is based on the principle that the maximum size of aggregate should be the largest available so long it is consistent with the dimensions of the structure. In practice the dimensions of the forms or the spacing of the rebars controls the maximum coarse aggregate size.

ACI 211.1 states that the maximum CA size should not exceed:

- One-fifth of the narrowest dimension between sides of forms,
- One-third the depth of slabs,
- 3/4-ths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pre-tensioning strands.

Estimation of mixing water and air content

The ACI Method uses past experience to give a first estimate for the quantity of water per unit volume of concrete required to produce a given slump. In general the quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum CA size, the shape and grading of both, CA and FA, as well as the amount of entrained air. The approximate amount of water required for average aggregate is given in Table A-2.

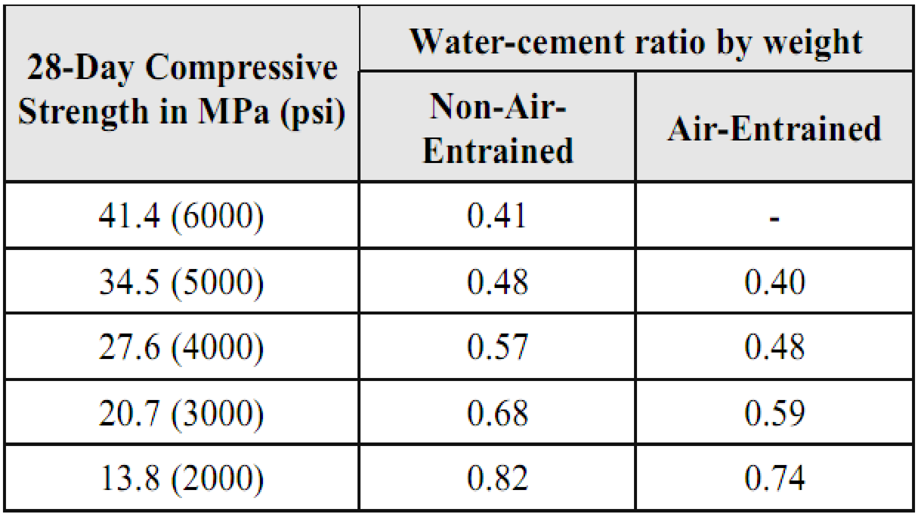


	Mixing Water Quantity in kg/m^3 (lb/yd^3) for the listed Nominal Maximum Aggregate Size							
Slump	**9.5 mm (0.375 in.)**	**12.5 mm (0.5 in.)**	**19 mm (0.75 in.)**	**25 mm (1 in.)**	**37.5 mm (1.5 in.)**	**50 mm (2 in.)**	**75 mm (3 in.)**	**100 mm (4 in.)**
Non-Air-Entrained PCC								
25 - 50 (1 - 2)	207 (350)	199 (335)	190 (315)	179 (300)	166 (275)	154 (260)	130 (220)	113 (190)
75 - 100 (3 - 4)	228 (385)	216 (365)	205 (340)	193 (325)	181 (300)	169 (285)	145 (245)	124 (210)
150 - 175 (6 - 7)	243 (410)	228 (385)	216 (360)	202 (340)	190 (315)	178 (300)	160 (270)	-
Typical entrapped air (percent)	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-Entrained PCC								
25 - 50 (1 - 2)	181 (305)	175 (295)	168 (280)	160 (270)	148 (250)	142 (240)	122 (205)	107 (180)
75 - 100 (3 - 4)	202 (340)	193 (325)	184 (305)	175 (295)	165 (275)	157 (265)	133 (225)	119 (200)
150 - 175 (6 - 7)	216 (365)	205 (345)	197 (325)	184 (310)	174 (290)	166 (280)	154 (260)	-
Recommended Air Content (percent)								
Mild Exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0
Moderate Exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5	3.0
Severe Exposure	7.5	7.0	6.0	6.0	5.5	5.0	4.5	4.0

Selection of water/cement ratio

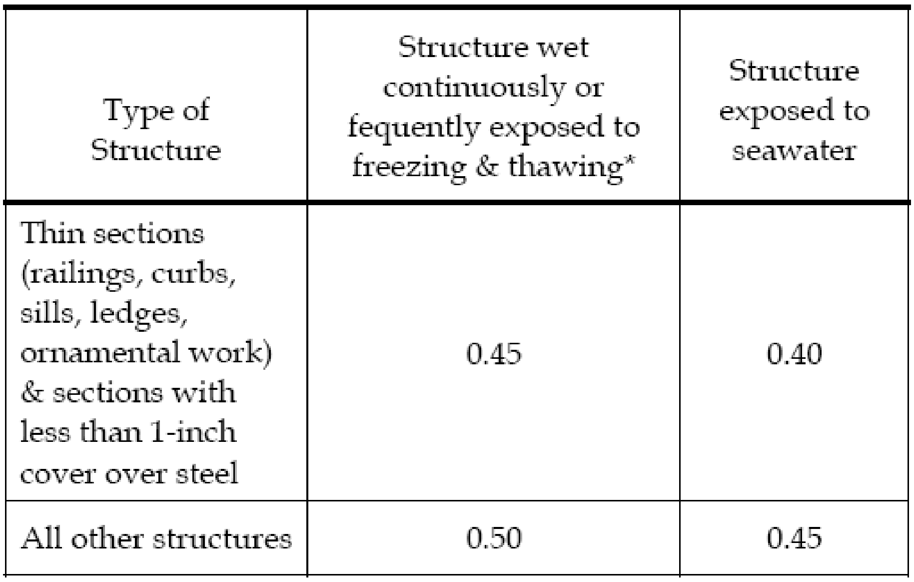
The required water/cement ratio is determined by strength, durability and finishability. The appropriate value is chosen from prior testing of a given system of cement and aggregate or a value is chosen from Table A.3 and/or Table A.4.

Table A.3: Water-Cement Ratio and Compressive Strength Relationship



28-Day Compressive Strength in MPa (psi)	Water-cement ratio by weight	
	Non-Air-Entrained	Air-Entrained
41.4 (6000)	0.41	-
34.5 (5000)	0.48	0.40
27.6 (4000)	0.57	0.48
20.7 (3000)	0.68	0.59
13.8 (2000)	0.82	0.74

TABLE A.4: Maximum Permissible Water/Cement Ratios For Concrete in Severe Exposures



Type of Structure	Structure wet continuously or fequently exposed to freezing & thawing*	Structure exposed to seawater
Thin sections (railings, curbs, sills, ledges, ornamental work) & sections with less than 1-inch cover over steel	0.45	0.40
All other structures	0.50	0.45

Calculation of Cement Content

Cement content is determined by comparing the following two items:

- The calculated amount based on the selected mixing water content and water-cement ratio.
- The specified minimum cement content, if applicable. Most states DOTs specify minimum cement contents in the range of 300 - 360 kg/m^3 (500 - 600 lbs. /yd^3).

An older practice used to be to specify the cement content in terms of the number of 94 lb. sacks of Portland cement per cubic yard of PCC. This resulted in specifications such as a "6 sack mix" or a "5 sack mix". While these specifications are quite logical to a small contractor or individual who buys Portland cement in 94 lb. sacks, they do not have much meaning to the typical pavement contractor or batching plant who buys Portland cement in bulk. As such, specifying cement content by the number of sacks should be avoided.

Estimation of coarse aggregate content

The most economical concrete will have as much as possible space occupied by CA since it will require no cement in the space filled by CA.

Table A.5: Volume of Coarse Aggregate per Unit Volume for Different Fine aggregate Fineness Moduli

Nominal Maximum Aggregate Size	Fine Aggregate Fineness Modulus			
	2.40	**2.60**	**2.80**	**3.00**
9.5 mm (0.375 inches)	0.50	0.48	0.46	0.44
12.5 mm (0.5 inches)	0.59	0.57	0.55	0.53
19 mm (0.75 inches)	0.66	0.64	0.62	0.60
25 mm (1 inches)	0.71	0.69	0.67	0.65
37.5 mm (1.5 inches)	0.75	0.73	0.71	0.69
50 mm (2 inches)	0.78	0.76	0.74	0.72

Notes:

1. These values can be increased by up to about 10 percent for pavement applications.
2. Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29.

Estimation of Fine Aggregate Content

At this point, all other constituent volumes have been specified (water, Portland cement, air and coarse aggregate). Thus, the fine aggregate volume is just the remaining volume:

Unit volume (1 m3 or yd3)

- Volume of mixing water
- Volume of air
- Volume of Portland cement
- Volume of coarse aggregate
- Volume of fine aggregate

Adjustments for Aggregate Moisture

Aggregate weights: Aggregate volumes are calculated based on oven dry unit weights, but aggregate is typically batched based on actual weight. Therefore, any moisture in the aggregate will increase its weight and stockpiled aggregates almost always contain some moisture. Without correcting for this, the batched aggregate volumes will be incorrect.

Amount of mixing water: If the batched aggregate is anything but saturated surface dry it will absorb water (if oven dry or air dry) or give up water (if wet) to the cement paste. This causes a net change in the amount of water available in the mix and must be compensated for by adjusting the amount of mixing water added.

Trial Batch Adjustments

The ACI method is written on the basis that a trial batch of concrete will be prepared in the laboratory, and adjusted to give the desired slump, freedom from segregation, finishability, unit weight, air content and strength.