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برنامج تصميم وتـأهيل المنشــــآت

# INVESTIGATING THE USE OF RECYCLED PLASTICS AS SHRINKAGE REINFORCEMENT IN NON-STRUCTURAL CONCRETE SLABS

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# نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة عمادة الدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **خليل عثمان خليل البحيصي** لنيل درجة الماجستير في **كلية *الهندسة*** **قسم الهندسة المدنية- تصميم وتأهيل منشآت** وموضوعها:

**Investigating the use of recycled plastic as shrinkage reinforcement in non structural concrete slabs**

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***واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.***

والله ولي التوفيق ،،،

**عميد الدراسات العليا**

**أ.د. فؤاد علي العاجز**

# إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان :

Investigating the use of recycled plastics as shrinkage reinforcement in non structural concrete slabs

اقر أنا بان ما شملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص،باستثناء ما تمت الإشارة إليه حيثما ورد ، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

# Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

| | |
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# ABSTRACT

Solid waste management is one of the major environmental topics in our modern life. The purpose of this study is to investigate the potential of using recycled plastics waste as reinforcement in non-structural concrete slabs. Two types of recycled plastics are used: 1) the Recycled High Density Polyethylene (RHDPE) in random distribution of shredded pieces in the percentages of 1%, 2%, and 3%, by slab volume and 2) the Recycled Low Density Polyethylene (RLDPE), in cylindrical shape of 5mm diameter. Mesh reinforcement is made out of these fibers with percentages of 0.1%, 0.2%, and 0.3%, per cross-sectional area. Furthermore, it is tested for drying shrinkage and compared with slab reinforcement based on the ACI318-08 code limits for shrinkage reinforcement. In addition, the changes in the mechanical properties of the concrete, such as slump, compressive strength and split tensile strengths are investigated.

The results show that adding recycled plastics to the concrete mixes can limit the drying shrinkage, even better than the steel reinforcement, when used in certain percentages. On the other hand, it has a negative impact on tensile and compressive strengths. Therefore, it can be stated that recycled plastics can be efficiently used in non-structural concrete. Thus, taking advantage of the large amounts of waste plastics can solve their environmental problem and reduce the non-structural concrete cost.

# الملخص


إدارة النفايات الصلبة هي واحدة من المواضيع البيئية الرئيسية في حياتنا المعاصرة. والغرض الرئيسي من هذه الدراسة هو التحقيق في إمكانية استخدام نفايات البلاستيك المعادة التدوير في العناصر الخرسانية الغير إنشائية كبلاطات الأرضيات. في هذه الدراسة تم استخدام نوعين من البلاستيك المعاد تدويره. النوع الأول المستخدم " البولي ايثيلين عالي الكثافة " (RHDPE) على شكل بلاستيك مجروش موزع بشكل عشوائي بنسب مؤوية مختلفة 1 %، 2 % و 3% ، من حجم البلاطة الخرسانية. أما النوع الثاني فهو من " البولي ايثيلين منخفض الكثافة المعاد تدويره " (RLDPE)، بأشكال اسطوانية ذات قطر 5 ملم، حيث تم عمل شبكات منها بنسب مؤوية مختلفة 0.1 %، 0.2 % و 0.3 % من مساحة المقطع. وتم فحصها للانكماش الجاف ومقارنتها مع بلاطات خرسانية تحتوى حديد تسليح للانكماش حسب مواصفات معهد الخرسانة الأمريكي ACI 318 -08. بالإضافة إلى ذلك، تم استكشاف التغيرات التي طرأت على الخواص الميكانيكية للخرسانة مثل " الهطول، مقاومة الضغط و مقاومة الشد "، ومقارنتها مع عينات خرسانية تم إضافة البلاستيك المعاد تدويره إليها .

أظهرت النتائج أن إضافة المواد البلاستيكية المعاد تدويرها إلى الخلطات الخرسانية يمكن أن تحد من الانكماش الجاف أفضل بكثير من حديد التسليح وذلك عند استخدامها بنسب مئوية معينة. من ناحية أخرى، إضافة البلاستيك المعاد تدويره له تأثير سلبي على قوة الضغط ومقاومة الشد. ولذلك يمكن القول أنه يمكن استخدام البلاستيك المعاد تدويره بكفاءة في العناصر الغير إنشائية. هكذا، يمكن الاستفادة من الكميات الكبيرة من النفايات البلاستيكية الملقاة في حل المشكلة البيئية والتقليل من تكلفة الخرسانة الغير إنشائية.

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May god bless you all

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| | |
|---|---|
| P | plastics |
| RP | Recycled Plastic |
| PET | Polyethylene Terephthalate |
| RHDPE | Recycled High Density Polyethylene |
| RLDPE | Recycled Low Density Polyethylene |
| HDPE | High Density Polyethylene |
| LDPE | Low Density Polyethylene |
| PP | Polypropylene |
| PS | Polystyrene |
| PVC | Polyvinyl Chloride |
| POF | Polyolefin Fibers |
| BLWA | Bottles Lightweight Aggregate |
| BLWAC | Bottles Lightweight Aggregate Concrete |
| CA | Corse Aggregate |
| FA | Fine Aggregate |
| W/C | Water Cement Ratio |
| FM | Fineness Modulus |
| SG | Specific gravity |
| MC | Moisture Content |

# CHAPTER 1: INTRODUCTION

## 1.1 General

Different studies have been proposed in the literature for the use of by-products to augment the properties of concrete. Recently, efforts have been made to use industrial by-products, such as fly ash, silica fume, furnace slag, glass, tires and plastics in civil constructions *(Yadav, 2008)*. Adding recycled plastics fiber to concrete is a potential application of industrial by-products use. The use of these materials in concrete comes from the environmental constraints in the safe disposal of these products.

Attention is being focused on the environment and safeguarding of natural resources and recycling of wastes materials. Many industries are producing a significant number of products which incorporate scrap. In the last two decades, different research studies concerning the use of several kinds of urban wastes in building materials have been published. Many researchers have been studied new types of wastes to deeply investigate particular aspects. Taking advantage of wastes, apart from the environmental benefits, produces good effects on the properties of final products.

One of the new waste materials used in the concrete industry is recycled plastic. For solving the disposal of large amount of recycled plastic material, reuse of plastic in concrete industry is considered as the most feasible application.

Concrete is the most important building material. The only disadvantage of concrete is its brittleness. Fibers have been used since biblical times to strengthen brittle materials. Since then, the concept of dispersed fiber in cement-based materials has been considerably developed *(Shihada, 2010)*.

The two main types of shrinkage are plastic and drying shrinkage. Plastic shrinkage is caused by evaporation of water during the first hours of casting before setting. Drying shrinkage is also caused by evaporation of cement past water after setting. Technically, drying shrinkage will continue for the life of the concrete but most shrinkage will occur within the first three or four months after placement.

In the past, several techniques have been proposed for studying shrinkage induced cracking in cement based materials including a ring type specimen, a linear specimen with anchored ends, a linear specimen held between a movable and a fixed grip and a plate type specimen. These tests are well idealized in nature but do not represent the actual condition of restraints in practice. A technique producing restraints comparable to the reality was recently developed *(Siddique et al., 2007)*.

This study investigates the use of recycled plastics to reduce drying shrinkage in non-structural concrete slabs by comparing it with (*ACI 318-08, 2008)* and obtaining the ratios of the recycled plastic materials that contribute to the reduction of drying shrinkage.

## 1.2 Problem Statement

Drying shrinkage is most common on horizontal surfaces of pavements and slabs during the summer. Drying shrinkage cracks caused by evaporation of cement past water after setting, where rapid evaporation occurrence, which destroys the integrity of the surface and reduce its durability, is possible. To increase the life of a concrete structure, it is necessary to avoid the formation of drying shrinkage cracks.

Similarly, the use of industrial and municipal recycled waste materials (e.g., plastic) in fiber reinforced concrete presents potentials to create durable concrete. Fiber recycled plastics, particularly polyethylene and polypropylene, have become popular in recent years for the reinforcement of concrete materials, mainly due to their effectiveness in reducing cracking.

The non-decaying waste materials cause a disposal problem, which has negative environmental effects. Most of these materials are left as stockpiles, landfill material or illegally dumped in selected areas.

In this research, two types of recycled plastics in different shapes and contents are used in the concrete mix to study the potential of reducing drying shrinkage for ground slabs.

Using the waste plastics in non–structural concrete is not only cost effective, but it can:

- Reduce the need for steel reinforcement which is relatively expensive.
- Reduce the corrosion of reinforcement.
- Solve the problem caused by dumping large amount of plastic materials in the dumping site.

## 1.3 Objectives

In this research, extensive experiments are carried out in order to:

1. Investigate the potential of using recycled plastic waste as shrinkage reinforcement in non-structural concrete slabs .
2. Determine the appropriate amounts of RHDPE & RLDPE that should be used to decrease the drying shrinkage in the ground slabs.
3. Compare the results with those obtained from the American Concrete Institute Building Code Requirement for Structural Concrete and Commentary (ACI318M-08).
4. Study the effect of recycled plastics on the mechanical properties of concrete.
5. Reduce the environmental solid waste problem caused by waste plastic materials.
6. Reduce the economic problems through reducing the cost of materials used in the ground slabs.

## 1.4 Methodology

### 1.4.1 General

All necessary data used in this study are obtained from the literature resources. Tests on concrete reinforced with recycled plastics (Polyethylene) are carried out to study the mechanical properties of concrete. This research is performed to reduce the problem of drying shrinkage in concrete with acceptable compressive strength.

### 1.4.2 Research Methodology

1. Review available literature related to:
    - recycled plastics: history, types and uses.
    - recycled plastics properties.
    - recycled plastics in concrete.
    - Shrinkage cracking.
2. Execute a testing program which will cover the following:
    - Determination of the constituent materials (e.g., cement, fine aggregate, coarse aggregate, steel reinforcement, etc.).
    - Investigating the potential of using two types of recycled plastic fibers in non-structural concrete to reduce its drying shrinkage.
3. Tests which investigates the influence of adding recycled plastics on the mechanical properties and draying shrinkage.
4. Determine the appropriate mix proportions.
5. Perform the required tests and analyze the data.

### 1.4.3 Flowchart of Research Methodology:

Figure *(1.1)* shows the flowchart of the adopted research methodology.

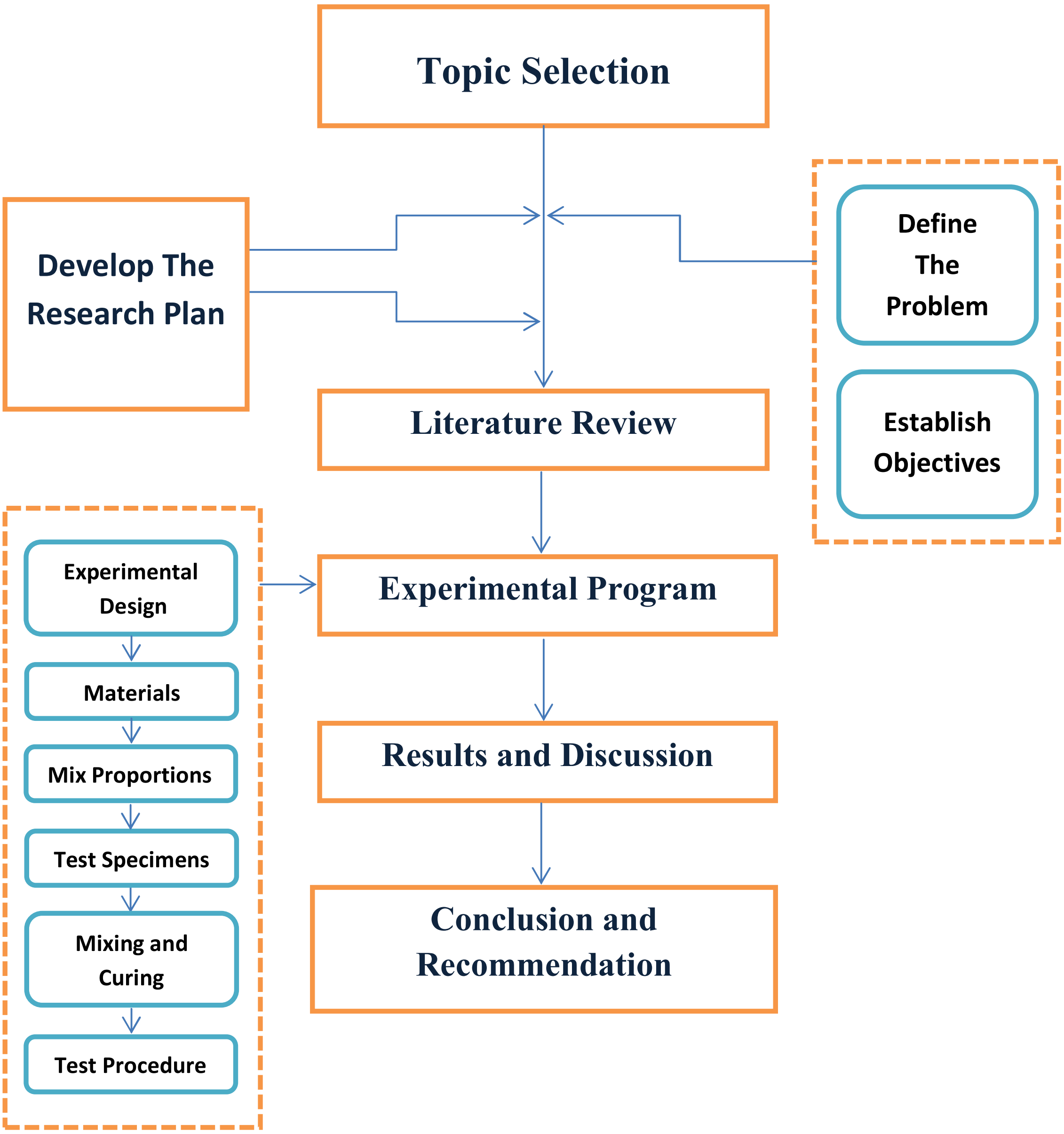


**Figure 1-1: Research Methodology Flowchart**

## 1.5 Formation of Thesis

This thesis is presented in five chapters:

**Chapter-1** introduces the use of plastic fiber, especially the recycled plastics in the concrete slabs. Also, it includes a description of research importance, scope, objectives, methodology, and the report organization.

**Chapter-2** presents the work done in the field of concrete structures.

**Chapter-3** presents the scheme of the experimentation and the used materials. Furthermore, the involved variables, concrete mix, mix design, casting and testing of specimens and materials are also illustrated.

**Chapter-4** provides and discusses the results of various studied parameters and a comparison with control concrete specimens.

**Chapter-5** presents the study conclusions and the future researches.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Concrete is a main structural material. However, it cracks and fails in a brittle manner under tensile stresses, caused by external loading or restrained shrinkage movements. Fibers have been used since biblical times to strengthen brittle materials. Since that time, the concept of dispersed fiber in cement-based materials has been considerably developed.

In civil constructions, research is conducted on the potential applications of industrial use of waste products in concrete. Plastics have become an inseparable and integral part of our lives. The use of these materials in concrete not only makes it economical but also helps in reducing disposal problems associated with these products.

Some types of plastic waste can be recycled to be used in concrete. Recently, many researchers investigated the potential of adding recycled plastic fibers to concrete. The use of these plastic in a non-structural concrete can help in controlling the shrinkage cracking and overcoming problems with the brittleness of concrete.

This chapter provides a comprehensive review of the research work carried out by various researchers in the field of using recycled plastics in concrete.

## 2.2 Plastics

### 2.2.1 Background

The word "plastic" means substances which have plasticity, and accordingly, anything that is formed in a soft state and used in a solid state can be called a plastic. Plastics can be separated into two types: 1) The thermoplastic, which can be melted for recycling in the plastic industry, such as the polyethylene and polypropylene, and 2) the thermosetting plastic, which cannot be melted by heating because the molecular chains are bonded firmly with meshed crosslink. The quantity of solid waste is rapidly expanded. It is estimated that the rate of expansion is doubled every 10 years. This is due to the rapid growth of the population and the industrial sector. Landfill areas are depleting and the cost of solid-waste disposal is increased. Among the solid-waste materials, plastics have received high attention. This is because they are, in general, not biodegradable. On a weight basis, there are about 10 billion kilogram of plastic wastes in the U.S. per year, which represents about 7% of the weight of the total solid wastes. In addition, plastic wastes constitute about 30% of the volume of the total solid wastes *(Yadav, 2008)*. The various types of plastics in municipal wastes are Polyethylene terephthalate (PET), High density polyethylene (HDPE), Low density polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS).

The major users of plastic are the packaging industries, consuming about 41%, 20% in building and construction, 15% in distribution and large industries, 9% in electrical and electronic, 7% in automotive, 2% in agriculture and 6% in other uses *(Yadav, 2008)*.

Among the various types of plastics, the largest component of the plastic waste is the linear Low Density Polyethylene (LDPE) at about 23%, followed by 17.3% of high density polyethylene, 18.5% of polypropylene, 12.3% of polystyrene, 10.7% polyvinyl chloride, 8.5% polyethylene terephthalate and 9.7% of other types *(Siddique et al., 2007)*.

One of the environmental issues with the plastics is that in most regions the large number of plastic bottles, polyethylene and other plastic materials are deposited in domestic wastes and landfills. These plastic materials are not easily biodegradable even after a long period of time. Due to this, more landfill space is needed for disposal every year. However, the plastics have many good characteristics, including versatility, lightness, hardness, low linear dilation coefficient and good chemical resistance. These characteristics make plastics suitable for concrete production or other uses in the building industry. Thus, plastics can be utilized as inert matter in cement matrix. In particular, plastic material particles can be incorporated as aggregates in concrete.

## 2.3 Plastic Recycling

Recycling is the practice of recovering used materials from the waste stream and then incorporating them into the manufacturing process. Recycling is one of the prominent issues in this environmentally conscious era. There are three main arguments for recycling: 1) it preserves the precious natural resources, 2) it minimizes the transportation and its associated costs, and 3) it avoids the environmental load caused by waster material, i.e. space requirement. The efforts have been made to increase recycling rates world widely. The major consideration to support recycling over the world is the expansion of the infrastructure for recycling.

The need to recycle plastics is obvious. Over 22 million tons of plastics are discarded each year in the trash. While plastics count for only 9.2% of the trash that Americans generate each year, plastic products do not decompose in landfills and are difficult to reduce in size *(Yadav, 2008)*. There are few technological and economic constraints that currently limit the full and efficient recycling of plastic wastes into useful products.

### 2.3.1 Types of Recycled Plastic

The quantity of plastics consumed annually all over the world has been greatly growing. Its user-friendly characteristics/features, unique flexibility, fabricatability and process ability coupled with immense cost-effectiveness and longevity are the main reasons for such growth. Besides, its wide use in packaging, automotive and industrial applications, plastics are also extensively used in medical delivery systems, artificial implants and other healthcare applications, water desalination and bacteria removal, preservation and distribution of food, housing appliances, communication and the electronics industry, etc.

There are about 50 different groups of plastics, with hundreds of different varieties. All types of plastic are recyclable. To make sorting and thus recycling easier, the American Society of Plastics Industry developed a standard marking code to help consumers identify and sort the main types of plastic. These types and their most common uses are shown in *Table (2.1)*.

**Table 2-1: Types of recycled plastics** *(Yadav, 2008).*

| ***Plastic ID Code*** | ***Name of Plastic*** | ***Uses for Plastic Made From Recycled Waste Plastic*** |
|---|---|---|
| 1 | **Polyethylene Terephthalate**<br>**PET** | - Fizzy drink bottles and oven- ready meal trays. |
| 2 | **High-density polyethylene**<br>**HDPE** | - Bottles for milk and washing-up liquids. |
| 3 | **Polyvinyl chloride**<br>**PVC** | - Food trays, cling film, bottles for squash, mineral water and shampoo. |
| 4 | **Low density polyethylene**<br>**LDPE** | - Carrier bags and bin liners. |
| 5 | **Polypropylene**<br>**PP** | - Margarine tubs, microwaveable meal trays. |
| 6 | **Polystyrene**<br>**PS** | - Yoghurt pots, foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys. |
| 7 | **Any other plastics**<br>**OTHER** | - that do not fall into any of the above categories. - An example is melamine, which is often used in plastic plates and cups. |

### 2.3.2 Recycled Plastics in Gaza Strip

The plastics industry is one of the developed local industries. According to recent statistics, the total investment in the plastic sector in Gaza Strip reached 11 million US Dollars. 60% of the local production is marketed in Gaza, 30% in the West Bank and 10% in Israel. Furthermore, 65% of plastic factories in Gaza market 80-100% of their production in Gaza, while 75% of the factories in the West Bank market around 50% of their production in Israel *(El-Kourd et al., 2007)*.

Starting in 1978, the plastic industry in Gaza is relatively a new industrial sub-sector that employs around 400 workers. The sector began the production in the area of blown film, producing plastic containers and plastic fittings for agricultural and construction purposes *(Abu-Ramadan, 2003)*.

As the industry improved, it entered a new subcategory centered on injection molding. Later, plastic production expanded once again to produce electrical wires covering and water pipes of various diameters. Recently, the blow molding subcategory appeared. Plastic mats production is now available in the Gaza Strip, such as plastic tanks and children toys manufacturing by rotational molding. Approximately 57 factories are in operation in Gaza, operating more than 200 machines. Total plastic production runs at 600 tons per month *(El-Kourd et al., 2007)*, and the manufacturing base is broad, producing various items such as containers, fittings, water hoses, and blown films. Manufacturing processes needed to produce this base including extrusion, injection molding, blow molding, and thermoforming.

Currently, raw materials are imported into Gaza through a variety of sources. Israeli producers and agents are the main importers. Direct external resources, particularly from Europe, account for a minority of inputs. Most of the high-density polyethylene originates in Europe. Low density polyethylene and polypropylene come from Israel. Polyvinyl chloride is imported from Israel and Europe.

In Gaza Strip, separation of recyclable components from wastes is only carried out on a very small scale. A group of scavengers, mostly kids, separate some types of plastics, metals, glass and paper from the waste. They sell the waste to recycling companies which turn these recyclables into intermediate or final products.

A study of the waste generation in Gaza strip indicated that there is high potential of recycling of waste such as; paper, plastic, metals and glass. *Table (2.2)* shows the quantity of recyclable waste in Gaza strip according to the Ministry of Industry *(Altanna et al.,* 2004).

**Table 2-2: Quantity of Recyclable waste in Gaza strip (Tonnes)**
*(Altanna et al., 2004)*

| *Year* | *Paper* *12%* | *Plastic* *11%* | *Metals* *3.5%* | *Glass* *1.5%* |
|---|---|---|---|---|
| **2001** | 38339 | 35144 | 11182 | 4792 |
| **2002** | 41061 | 37639 | 11976 | 5133 |
| **2003** | 43976 | 40311 | 12826 | 5497 |
| **2004** | 47255 | 43318 | 13783 | 5907 |
| **2005** | 50611 | 46393 | 14761 | 6326 |
| **2006** | 54204 | 49687 | 15809 | 6775 |
| **2007** | 59289 | 54348 | 17293 | 7411 |
| **2008** | 63499 | 58207 | 18520 | 7937 |
| **2009** | 68007 | 62340 | 19835 | 8501 |
| **2010** | 72836 | 66766 | 21244 | 9104 |
| **2011** | 78007 | 71506 | 22752 | 9751 |
| **2012** | 83545 | 76583 | 24367 | 10443 |
| **2013** | 89477 | 82021 | 26098 | 11185 |
| **2014** | 95830 | 87844 | 27950 | 11979 |
| **2015** | 102634 | 94081 | 29935 | 12829 |
| **2016** | 109921 | 100761 | 32060 | 13740 |
| **2017** | 117725 | 107915 | 34337 | 14716 |
| **2018** | 126084 | 115577 | 36774 | 15760 |
| **2019** | 135036 | 123783 | 39385 | 16879 |
| **2020** | 144623 | 132571 | 42182 | 18078 |
| **Total** | 1,621,959 | 1,486,796 | 473,071 | 202,745 |

There are 17 recycled plastic factories in Gaza Strip According to the Ministry of Industry (*Abu-Ramadan, 2003*). *Table (2.3)* shows some of these and there location.

**Table 2-3: Recycled Plastic factories in Gaza city** *(Abu-Ramadan, 2003)*

| No | Factory Name | The Location |
|---|---|---|
| 1 | Alramlawi Factory | Al Toffah Neighborhood – salah eldin st. |
| 2 | Fathy Deeb Factory | Jabalia intersection |
| 3 | Abu-Ragheb Mahany | Zeimo Roundabout ( jabalia ) |
| 4 | Hedar Company | Al-Zaytoon ( car's market) |
| 5 | Soror Factory | Beit Hanon |
| 6 | Mohammad Murad Factory | Beit Hanon |

### 2.3.3 Use Effect of Recycled Plastics in Concrete

Concrete is the most important building material. It consists aggregates bound by hydrated cement paste. The only disadvantage of concrete is its brittleness. Numerous waste materials are generated from manufacturing processes, service industries and municipal solid wastes. The increasing awareness about the environment has greatly contributed to the concerns related with disposal of the generated wastes. Solid waste management is one of the major environmental topics in the world. With the scarcity of space for land filling and due to its increasing cost, waste utilization has become an attractive alternative to disposal. Research is being carried out on the utilization of waste products in concrete. Such waste products include discarded tires, plastic, glass, steel, burnt foundry sand, and coal combustion. Each of these waste products provides a specific effect on the properties of fresh and hardened concrete. The use of waste products in concrete not only makes it economical, but also helps in reducing disposal problems.

Reuse of bulky wastes is considered the best environmental alternative for solving the problem of disposal. One such waste is the plastic, which could be used in various applications. However, efforts have also been made to explore its use in concrete and asphalt. The development of new construction materials using recycled plastics is important to both the construction and the plastic recycling industries (*Siddique et al., 2007* ).

Various researches have presented a detailed review about using recycled plastics in concrete and the effect of recycled plastic on the fresh and hardened properties of concrete. The effect of recycled and waste plastic on workability, compressive strength, splitting tensile strength will be discussed later.

*Batayneh et al.* (2007) discussed the various testing of the concrete by recycled plastics aggregates. Their research gives a comprehensive review of the work in the field of using recycled plastics in concrete as full or partial replacement of aggregates.

They investigated the effect of ground plastic on the slump of concrete. Concrete mixes of up to 20% of plastic particles are proportioned to partially replace the fine aggregates. Details of mixture proportions and slump test results are given in *Table (2.4*). It was observed that there is a decrease in the slump with the increase in the plastic particle content. As shown in *Figure (2.1)*, for a 20% replacement, the slump has decreased to 25% of the original slump value with 0% plastic particle content. This decrease in the slump value is due to the shape of plastic particles, i.e., the plastic particles have sharper edges than the fine aggregate. Since the slump value at 20% plastic particle content is 58 mm, this value can be considered acceptable and the mix can be considered workable.

Along with plastics, glass and crushed concrete was also used as replacement of coarse aggregates and it was observed that use of crushed aggregates leads to maximum slump reduction, while using crushed glass has least effect on slump of resultant concrete.

**Table 2-4: Mix proportions and fresh concrete properties** *(Batayneh et al., 2007)*

| Plastic (%) | proportions($kg/m^3$) | | | | w/c Ratio | Slump (mm) |
|---|---|---|---|---|---|---|
| | Cement | CA | FA | Plastic | | |
| 0 | 446 | 961 | 585 | 0 | 0.56 | 78 |
| 5 | 446 | 961 | 555.7 | 17.8 | 0.56 | 73 |
| 10 | 446 | 961 | 526.5 | 35.5 | 0.56 | 69 |
| 15 | 446 | 961 | 497.2 | 53.2 | 0.56 | 63 |
| 20 | 446 | 961 | 468.0 | 71.0 | 0.56 | 57 |

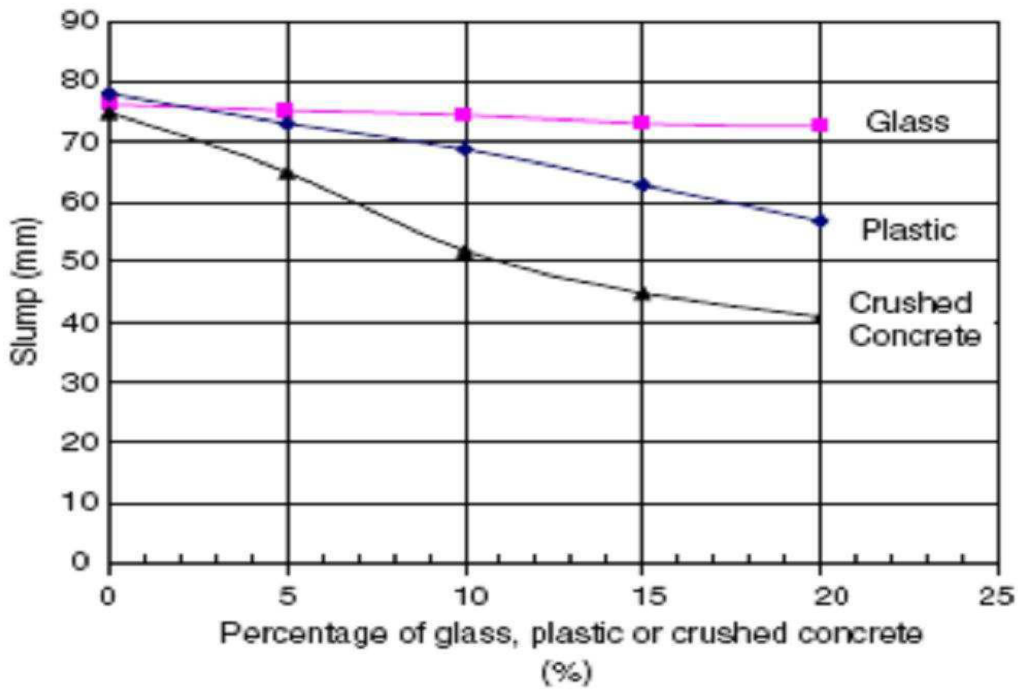


**Figure 2-1: Workability versus percentage of different wastes in the concrete mixes.**

*(Batayneh et al., 2007)*

Also they investigated the effect of ground plastic on the splitting, flexural strengths and compressive strength of the tested samples. Therefore, both the use of concrete with plastic particles and the percentage of replacement should be controlled, according to the allowable strength of the structural element to be constructed. They concluded that the addition of plastic particles led to a reduction in the strength properties. For a 20% replacement, the compressive strength exhibited a sharp reduction of up to 72% of the original strength. On the other hand, with 5% replacement the compressive strength showed a 23% reduction. This reduction in strength was due to the fact that the strength of the plastic particles is lower than that of the aggregate. *(Batayneh et al., 2007)*, observed similar behavior in splitting and flexural strengths of the tested samples. They concluded that both the use of concrete with plastic particles and the percentage of replacement should be controlled, according to the allowable strength of the structural element to be constructed.

The test results demonstrated that the addition of the plastic particles led to a reduction in the strength properties. For a 20% replacement, the compressive strength shows a sharp reduction up to 72% of the original strength, while with 5% replacement the compressive strength shows a 23% reduction as shown in *Figure (2.2).*

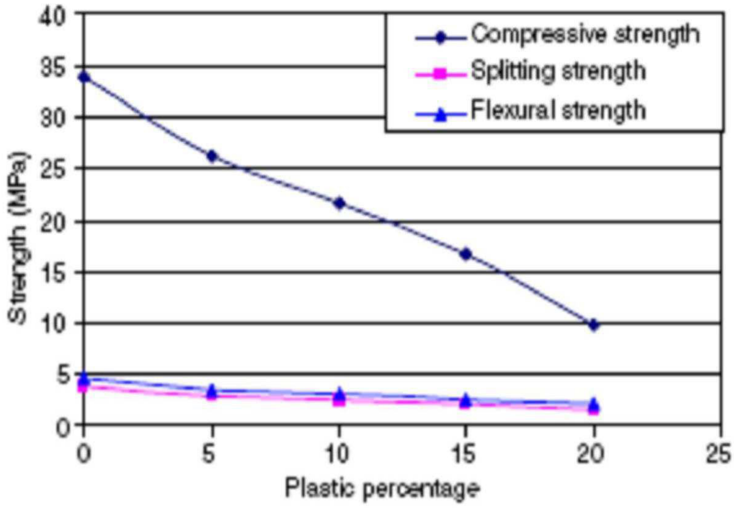


**Figure 2-2: Relationship between the compressive , tensile strength and percentage of plastic content** *(Batayneh et al., 2007)*

*Choi et al.* (2005) investigated the influence of Polyethylene Terephthalate (PET) bottles lightweight aggregate (BLWA) on the workability (slump) and strength of concrete. Mixture proportions of concrete were planned so that the water–cement ratios were 45%, 49%, and 53%, and the replacement ratios of (BLWA) were 0%, 25%, 50%, and 75% by volume of fine aggregate. They reported that slump value of waste (PET) bottles lightweight aggregate concrete (BLWAC) increased with the increase in water-cement ratio and the replacement ratio. The improvement ratios of workability represent 52%, 104%, and 123% in comparison with that of normal concrete at the water–cement ratios of 45%, 49% and 53%, respectively. This may be attributed to not only the spherical and smooth shape but also to the absorption of BLWA. They also stated that the compressive and splitting tensile strength of concrete mixtures decreased with the increase in PET aggregates and for a particular PET aggregate content, compressive and splitting tensile strength increased with the reduction in w/c ratio.

*Ismail and Al-Hashmi* (2007) investigated concretes that are prepared with the use of recycled plastics. This research found that the compressive strength and tensile splitting strength of the concretes are prone to decreasing sharply with increasing the waste plastic ratio. They also stated that there is an increase in slump when plastic aggregates are incorporated in concrete, as shown in *Figure (2.3*). This reduction can be attributed to the fact that some particles are angular and others have non-uniform shapes resulting in less fluidity. In spite of the slump reduction, the waste plastic concrete mixtures have easy workability and are suitable for use in precast applications and large sites.

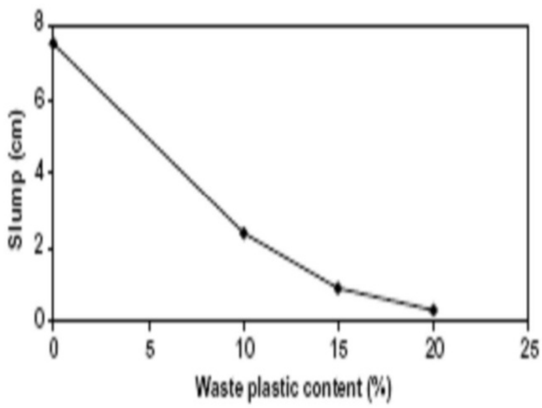


**Figure 2-3: Slump of waste plastic concrete mixes** *(Ismail and Al-Hashmi, 2007)*

*Marzouk et al.* (2007) studied the innovative use of consumed plastic bottle waste as sand-substitution aggregate within composite materials for building application. Bottles made of polyethylene terephthalate (PET) were used as partial and complete substitutes for sand in concrete composites. Various volume fractions of sand varying from 2% to 100% were substituted by the same volume of granulated plastic, and various sizes of PET aggregates. They concluded that substituting sand at a level below 50% by volume with granulated PET, whose upper granular limit equals 5mm, affected the compressive strength of composites and plastic bottles shredded into small PET particles may be used successfully as sand-substitution aggregates in cemented concrete composites. It can be seen that once the sand volume substituted with aggregates increased from 0% to 50%, the compressive strength of composites slightly decreased by15.7%, in comparison with the reference mortar. These composites provides an attractive low-cost material with consistent properties. Moreover, they can help in resolving some of the solid waste problems created by plastics production and saving energy.

*Al-Manaseer and Dalal* (1997) investigated the effect of plastic aggregates on the strength of concrete. They reported that there was increase in slump when plastic aggregates were incorporated in concrete. The concrete containing 50% plastic aggregates had a slightly higher cone slump than the concrete without plastic aggregates. The strength of concrete was measured at different water-to-binder ratios and for various percentages of plastic aggregates. It was concluded that the compressive strength and the splitting tensile strength are decreased by increasing the plastic aggregates percentage.

*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. A number of laboratory prepared 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. Two major findings are identified. The positive side shows that the concrete prepared with a partial replacement by PVC was lighter (lower density), was more ductile, and had lower drying shrinkage. The negative side reveals that the workability, compressive strength and tensile splitting strength of the concretes were reduced. The results gathered would form a part of useful information for recycling PVC plastic waste in lightweight concrete mixes.

## 2.4 Shrinkage Cracking in Concrete

A commonly known concern in concrete curing is maintaining the moisture level in fresh concrete. Two common problems found in concrete installation which are the plastic shrinkage cracking and the dry shrinkage cracking.

### 2.4.1 Plastic Shrinkage Cracking

Plastic shrinkage is caused by evaporation of water during the first hours of casting before setting. Plastic shrinkage may cause fresh concrete to crack due to development of negative capillary pressures, which will result in volume reduction of cement paste.

Plastic shrinkage cracking is most common in case of slabs and large horizontal surfaces, such as pavement that are cast in hot, windy and dry conditions (evaporation rates exceeds 0.5 $kg/m^2/hr$). These conditions cause mixing water to evaporate rapidly which will cause the cracking. Plastic shrinkage cracks reduce significantly the durability of the concrete elements.

### 2.4.2 Drying Shrinkage Cracking

Concrete is usually mixed with more water than is needed to adequately hydrate the cement. Drying shrinkage is caused by evaporation of cement past water after setting. During shrinkage, it is of greater significant than plastic shrinkage and can lead to cracking and warping of structural elements, if the design and construction were inadequate with regard to the effect of drying shrinkage. The drying shrinkage is influenced by several factors including:

- Aggregate content where shrinkage is decreased with increasing aggregate content.

- Water cement ratio where shrinkage is increased with increasing w/c ratio.
- Size of concrete element where shrinkage is decreased by increasing the size of element.
- Ambient conditions where shrinkage decreases by increasing the relative humidity and becomes stabilized at lower temperatures.
- Amount of reinforcement which resist volumetric changes.
- Admixtures where accelerators increase the shrinkage.
- Type of cement where rapid hardening cement increases the shrinkage.

### 2.4.3 Effect of Using Polyethylene Recycled Plastic Fibers on The Shrinkage of Concrete

In general, Fiber (especially polyethylene) has become popular in recent years for the reinforcement of concrete materials, mainly due to their effectiveness in the reduction of cracking at early ages under the effects of restrained plastic shrinkage.

Most current applications of fibers are nonstructural. Fibers are often used in controlling plastic and drying shrinkage cracks, a role classically played by steel reinforcing bars or steel wire mesh. Examples include floors and slabs, large concrete containers, and concrete pavements. In general, these structures and products have extensively exposed surface areas and movement constraints, resulting in high cracking potential. For such applications, fibers have a number of advantages over conventional steel reinforcements. These include: (a) uniform reinforcement distribution with respect to location and orientation, (b) corrosion resistance especially for synthetic, carbon, or amorphous metal fibers, and (c) labor saving by avoiding the need of deforming the reinforcing bars and tying them in the form-work, which often leads to reduction of construction time. Elimination of reinforcing bars also relaxes constraints on concrete element shape. This functional value of fibers has been exploited in the curtain walls of tall buildings. In some applications, the use of fibers enables the elimination or the reduction of the number of cut-joints in large continuous structures such as container sand pavements. In pavements, joints are locations of weaknesses at which failure frequently occurs. Thus, fibers have been exploited to enhance the durability of concrete elements *(Al-Hozaimy and Shannag 2009).*

Recently, there have been several studies (mostly funded by the manufacturers) and reports claiming that inclusion of POF in concrete mixes can improve crack resistance.

*Shihada* (2010) investigated the use of recycled plastics waste as reinforcement in non-structural concrete slabs. He used two types of recycled plastics:1) recycled High Density polyethylene in randomly-distributed shredded pieces for the percentages of 1%, 2% and 3%, by volume and 2) recycled Low Density polyethylene, cylindrical in shape with percentages of 0.1%, 0.2% and 0.3% tested for drying shrinkage.

Results demonstrated that the addition of recycled plastic to concrete mix can reduce drying shrinkage better than steel reinforcement, when used in certain percentages. However, it has a negative impact on compressive and tensile strength.

*Al-Hozaimy* (2006) investigated the potential of using recycled plastic waste as reinforcing fibers in concrete. The mechanical properties and plastic shrinkage cracking of RP fibrous concrete were investigated. Four different volume fractions (1, 2, 3 and 4%) of recycled plastic low density polyethylene fibers (RP fibers) and control with no RP fibers were considered. The results showed that at volume fraction of 1 to 2% of RP fibers, plastic shrinkage cracking was almost similar to plain concrete without RP fibers (i.e., 0%) while at a volume fraction of 3 to 4%, no plastic shrinkage cracks were observed, as shown in *Figure (2.4)*. Also, it was found that RP fibers have no significant effect on the compressive and flexural strengths of plain concrete at volume fractions. *Figure (2.5)* shows the effect on the compressive strength.

Based on this study, it is recommended to use recycled plastic with low density polyethylene (LDPE) as reinforcing fibers at 3% volume fraction to control plastic shrinkage cracking of concrete.

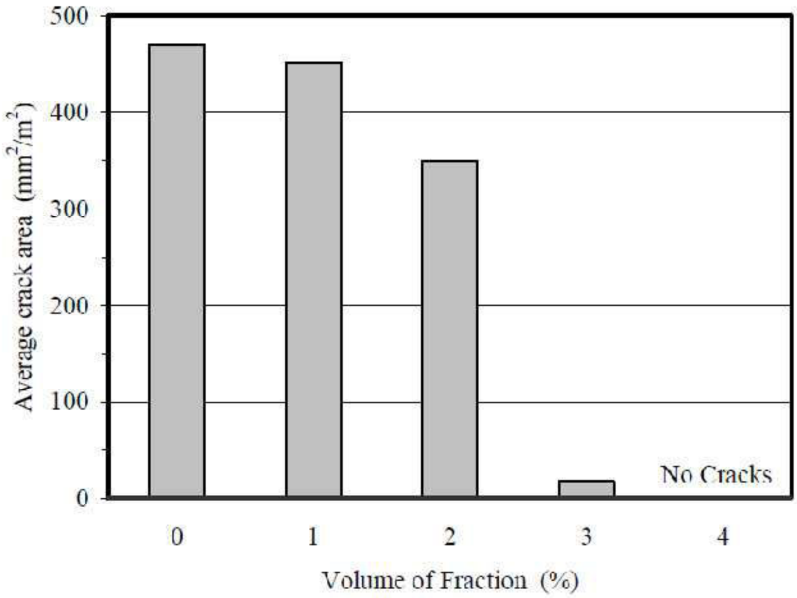


**Figure 2-4: Effect of RP fibers on plastic shrinkage crack area**
*(Al-Hozaimy,* 2006)

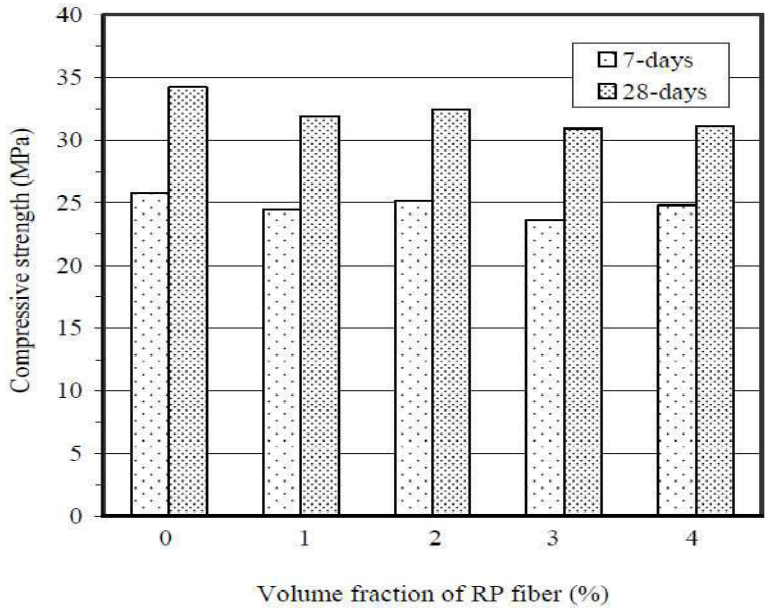


**Figure 2-5: Compressive strength results at different volume fractions**
*(Al-Hozaimy, 2006)*

*Alsayed* (2006) conducted an extensive experimental program which was carried out to investigate the influence of adding polymer fiber reinforcement POF on the plastic shrinkage cracks and drying shrinkage of concrete under laboratory and actual field conditions .

The control specimens contained no fiber reinforcement. The other specimen contained polyolefin fibers with 1.5 % by volume of the concrete. Six plastic shrinkage prisms, twelve concrete slabs and thirty six cylindrical specimens were cast as part of this study. The cast specimens were used to monitor the effect of adding POF to the concrete mix on the plastic shrinkage and drying shrinkage of the concrete. Half of the specimens was cured under controlled laboratory conditions and the other half was cured under actual hot-dry field conditions.

The test results show that adding POF to the concrete mix can arrest plastic and drying shrinkage cracks but has no influence on the flexural strength or compressive strength. However, the degree of influence of POF on engineering properties of concrete can be highly affected by the mix proportions of the concrete and the volume ratio of the fibers.

*Auchey (1998)* investigated the use of recycled high density polyethylene (RHDPE) as secondary reinforcement in concrete. RDHPE fibers were obtained by cutting plastic milk containers with a typical dimension of 19-38 mm long, 1.6 mm wide and 1mm thick. It was found that RHDPE can be used as secondary reinforcement for temperature and shrinkage and to control shrinkage crack propagation.

*Marzouk et al.* (2007) observed that shrinkage under conditions of complete saturation, shows that once the sand volume substituted with waste aggregates increases from 0% to 30%, the plastic aggregates do not exert an influence on shrinkage of composites in comparison with the reference mortar.

## 2.5 Advantages and Disadvantages of Using Plastics

### 2.5.1 Advantages of Using Plastics in Concrete

The growth in the use of plastic is due to its beneficial properties, which include:

- Lighter weight than competing materials reducing fuel consumption during transportation.
- Durability and longevity.

- Comparatively lesser production cost.
- Resistance to chemicals, water and impact.
- Excellent thermal and electrical insulation properties.
- Unique ability to combine with other materials like aluminum foil, paper, adhesives.
- Reduction of municipal solid wastes being land filled .
- Intelligent features, smart materials and smart systems.

### 2.5.2 Disadvantages of Using Plastics

The followings are the main disadvantages of using the plastics in concrete:

- Plastics have low bonding properties so that the strength of concrete is reduced such as compressive, tensile and flexural strength.
- Its melting point is low so that it cannot be used in furnaces because it melts with the high temperature.

Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not evaluated for environmental and human health risk. Example is the phthalates, which are used in the manufacture of PVC. The PVC has been used in the past for toys. However, experiments have shown that phthalates may be released when these toys are sucked (come into contact with saliva). Risk assessments of the effects of phthalates on the environment are currently being carried out. The disposal of plastic products also significantly contributes to their environmental impact. Because most plastics are non-degradable, they take a long time to break down, possibly up to hundreds of years although no one know for certain as plastics have not been existed for long enough when they are land filled. With more and more plastics products, particularly plastics packaging, being disposed, the landfill space required by plastics waste is a growing concern.

## 2.6 Concluded Remarks

Based on the extensive literature review regarding the concretes prepared with the use of recycled plastics, it can be stated that the compressive and splitting tensile strength decrease with the increasing of the percentage of recycled plastic aggregates. It is also remarkable that there is an a decrease in slump when recycled plastics are incorporated in concrete.

Based on research results regarding the reduction in compressive and splitting tensile strength, researchers recommended that concrete with plastic particles be used in non-structural concrete. Thus, recycled plastic qualifies as an advantageous and promising construction material, especially considering the cost savings and the environmental benefices that derive from the use of recycled plastic for fiber manufacturing. Different researches and techniques of using plastic fiber in concrete suggested that the addition of adding recycled polyolefin plastic fibers to concrete can be used effectively for controlling plastic and drying shrinkage cracking of concrete structures. The test results showed that adding POF to the concrete mix can arrest plastic and drying shrinkage cracks.

# CHAPTER 3: EXPERIMENTAL PROGRAM

## 3.1 Introduction

In our study, the purpose of the experiments is to investigate the reduction of drying shrinkage of concrete made with recycled plastics. An extensive experimental program was carried out to investigate the adding of recycled plastics on the engineering properties of the concrete mix. All test specimens were cast from one batch of the same mix. The experimental design and the basic tests carried out on materials used for casting concrete samples are discussed in this chapter, followed by a brief description about mix deign and curing procedure adopted. At the end, tests conducted on the specimens are discussed. This study was designed to investigate the use of two types and three different volumes of recycled plastics as fiber reinforcement in concrete slabs. The first type used is a Recycled High Density Polyethylene in randomly-distributed shredded pieces for the percentages of 1%, 2% and 3% by volume. The second type is recycled low density polyethylene, cylindrical in shape and 5-mm in diameter. Mesh reinforcement are made out of these fibers with the percentages 0.1% , 2% and 3% and tested for drying shrinkage. The experiments were formulated to investigate the mechanical properties and drying shrinkage under actual field conditions. The study of mechanical properties includes compressive strength and splitting strength. The number of specimens cast were12 for compressive strength cubes, 12 for splitting tensile strength and 21for drying shrinkage slabs. An overview of the experimental program is shown in *Figure (3.1).*

## 3.2 Materials Used

### 3.2.1 Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel, and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The ordinary cement contains two basic ingredients namely argillaceous and calcareous. In argillaceous materials clay predominates and in calcareous materials calcium carbonate predominates. Basic composition of cement are shown in *Table (3.1).*

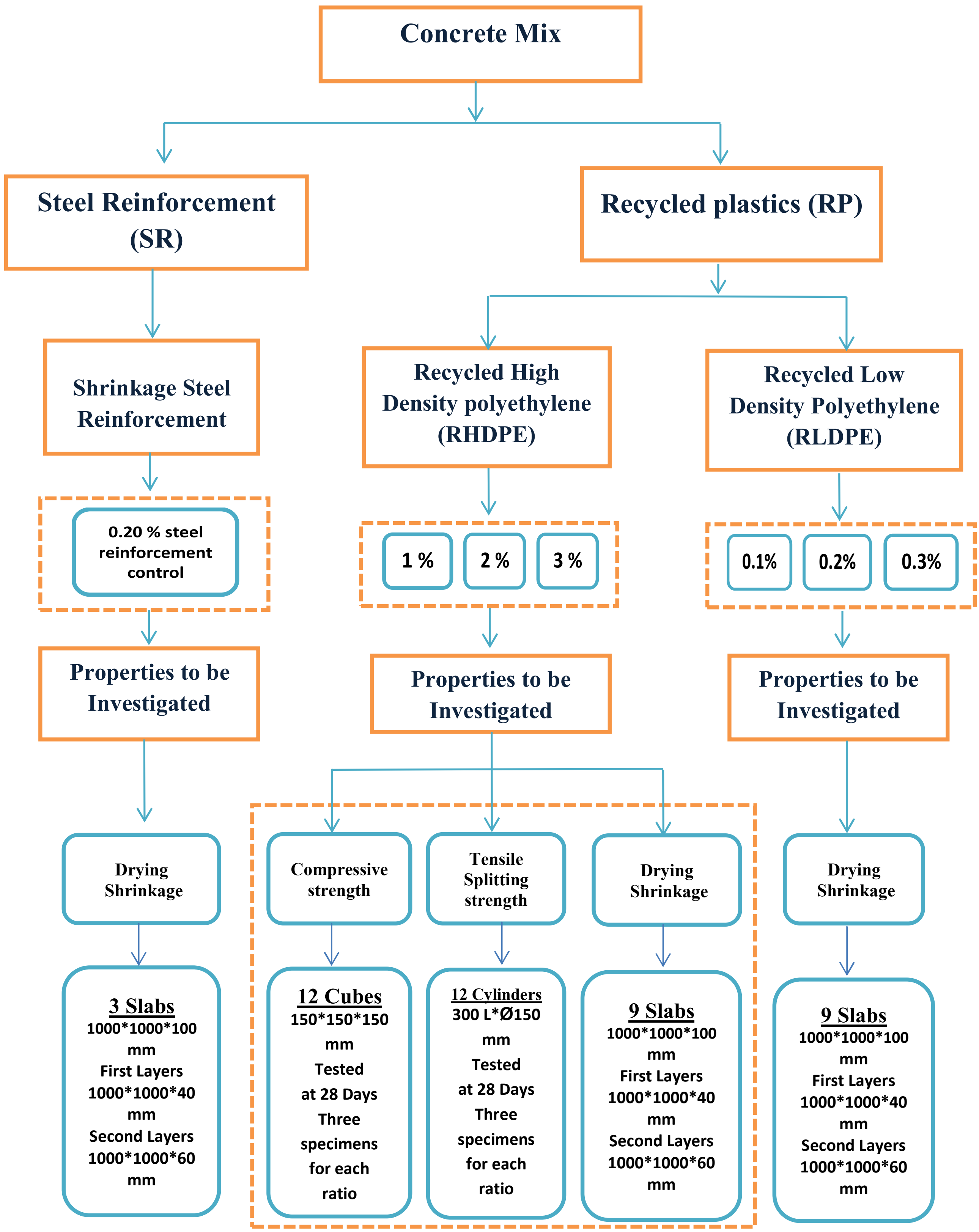


Figure 3-1: Overview of experimental program

**Table 3-1: Composition limits of Portland cement**

| *Ingredient* | *% Content* |
|---|---|
| CaO (Lime) | 60-67 |
| SiO2 (Silica) | 17-25 |
| Al2 O3 (Alumina) | 3-8 |
| Fe2 O3 (Iron Oxide) | 0.5-6 |
| MgO (Magnesia) | 0.1-4 |
| Alkalies | 0.4-1.3 |
| Sulphur | 1-3 |

Type I Portland cement conforming to (ASTM C150, 2009) was used for casting cubes, cylinders and slabs for all concrete mixes used in the study. The cement was of uniform color i.e. grey with a light greenish shade and was free from any hard lumps. Summary of the various tests conducted on cement are as given below in *Table (3.2).*

**Table 3-2: Properties of cement**

| *No.* | *Characteristics* | *Values Obtained* | *Standard Values* |
|---|---|---|---|
| 1. | Normal Consistency | 33% | - |
| 2. | Initial Setting time | 48 min | Not be less than 30 minutes |
| 3. | Final Setting time | 240 min | Not be greater than 600 minutes |
| 4. | Fineness | 4.8 % | < 10 |
| 5. | Specific gravity | 3.09 | - |
| *Compressive strength:*- Cement : Sand (1:3) | | | |
| 1. | 3 days | 24.5 $N/mm^2$ | 27 $N/mm^2$ |
| 2. | 7 days | 35 $N/mm^2$ | 41 $N/mm^2$ |
| 3. | 28 days | 53.5 $N/mm^2$ | 53 $N/mm^2$ |

### 3.2.2 Fine Aggregates

The sand used in the experimental program was locally procured and conformed to (ASTM C127, 2004) and (ASTM C128, 2004) specifications. The sand was first sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and then was washed to remove the dust. The aggregates sieve analysis is shown in *Figure (3.2)*. Properties of the fine aggregate used in the experimental work are tabulated in *Table (3.3*) with fineness modulus (FM) = 2.72 .

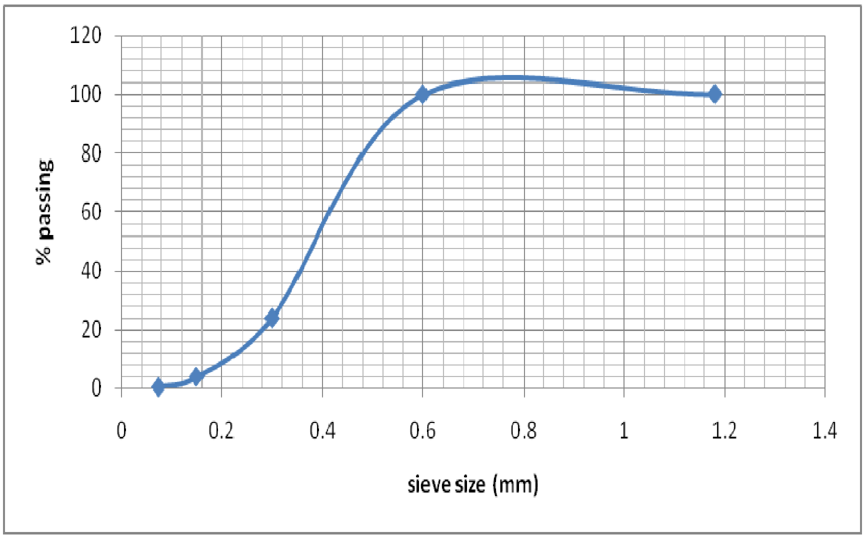


**Figure 3-2: Sieve analysis results for fine aggregates**

**Table 3-3: Properties of fine aggregates**

| *S.No.* | *Characteristics* | *Value* |
|---|---|---|
| 1. | Type | Uncrushed (natural) |
| 2. | Unit weight (γ) kg/m3 | 1600 |
| 3. | Specific gravity (SG) | 2.36 |
| 4. | Total water absorption | 1% |
| 5. | Moisture Content (MC)% | 1.6 % |
| 6. | Fineness Modulus | 2.72 |
| 7. | Grading Zone | Gaza Dune sand |

### 3.2.3 Coarse Aggregates

Crushed limestone obtained from the west bank quarries is generally used as a coarse aggregate. We decided the maximum size of the coarse aggregate. Locally available coarse aggregate having the maximum size of 20 mm was used in our work. The aggregates were washed to remove dust and dirt and were dried to surface dry condition. The aggregates were tested per (ASTM C127, 2004) and (ASTM C128, 2004) Standard Specifications. The sieve analysis results on coarse aggregate is given in *Figure (3.3),* and their properties used in the experimental work are tabulated in *Table (3.4).*

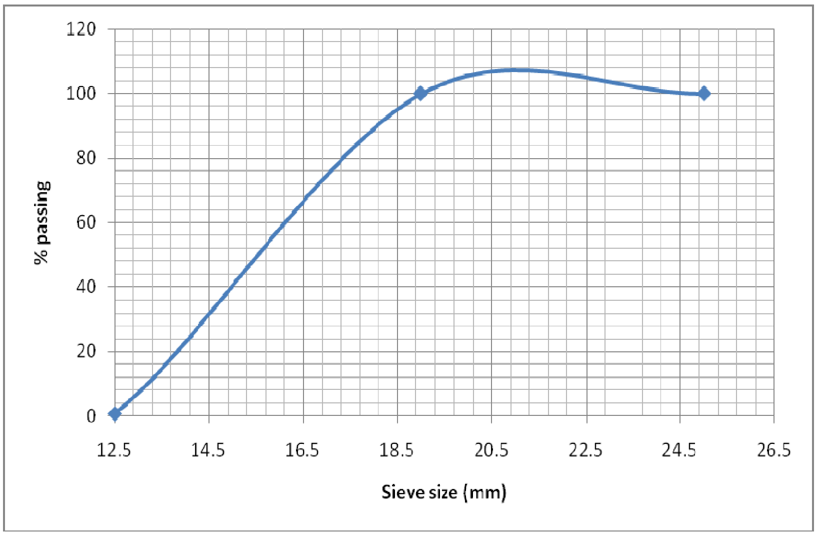


**Figure 3-3: Sieve analysis results for coarse aggregates**

**Table 3-4: Properties of Coarse aggregates**

| ***S.No.*** | ***Characteristics*** | ***Value*** |
|---|---|---|
| 1. | Type | Crushed |
| 2. | Maximum size | 20 mm |
| 3. | Specific gravity (20 mm) | 2.65 |
| 4. | Total water absorption (20 mm) | 2.2% |
| 5. | Fineness modulus (20 mm) | 7.68 |
| 6. | Grading Zone | West bank |

### 3.2.4 Recycled Plastics

Two types of Recycled Polyethylene Plastic Fibers are obtained from a local recycling plant in Gaza City are reported below:

**RHDPE:** Recycled High Density Polyethylene shown in *Figure (3.4)* and used as randomly distributed recycled shredded RHDPE pieces ranging from 0.5 cm to 1.0 cm in length and 1%, 2% and 3% per volume in fractions.

**Figure 3-4: Recycled High Density Polyethylene (RHDPE)**

**RLDPE:** Recycled Low Density Polyethylene is shown in *Figure (3.5).* cylindrical in shape and 5-mm in diameter used as mesh reinforcement bars in the slabs with ratios of (0.1, 0.2 and 0.3%). The ultimate tensile strength ($f_t$)=160 kg/cm$^2$. Number of RLDPE bars in the slab for each ratio is shown in *Table (3.5).*

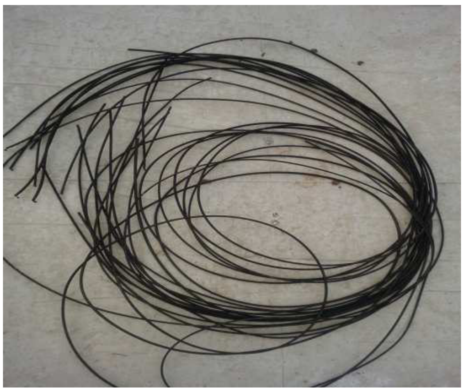

**Figure 3-5: Recycled Low Density Polyethylene (RLDPE)**

**Table 3-5: Number of RLDPE bars in the slab for each ratio .**

| *Ratios of (RLDPE)% in the Slab* | *Numbers of RLDPE bars in each direction of Slab* |
|---|---|
| **0.1** | 3 φ 5 mm |
| **0.2** | 6 φ 5 mm |
| **0.3** | 9 φ 5 mm |

*Figures (3.6), (3.7) and (3.8)* show photos of (0.1, 0.2 and 0.3%) RLPE fibers used as shrinkage reinforcement in secondary layers.

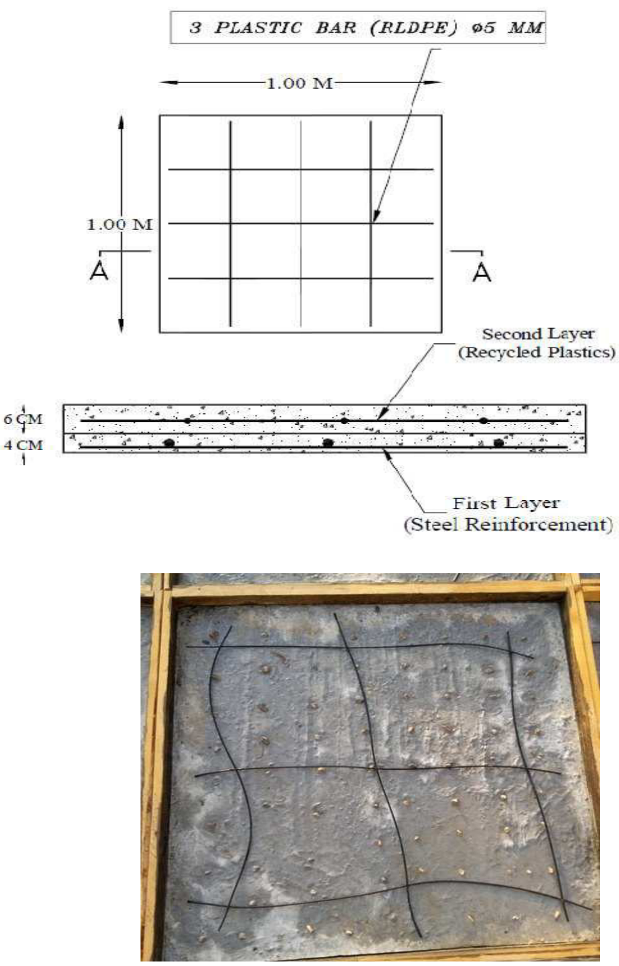


**Figure 3-6: 0.1% RLDPE fibers as secondary reinforcement.**

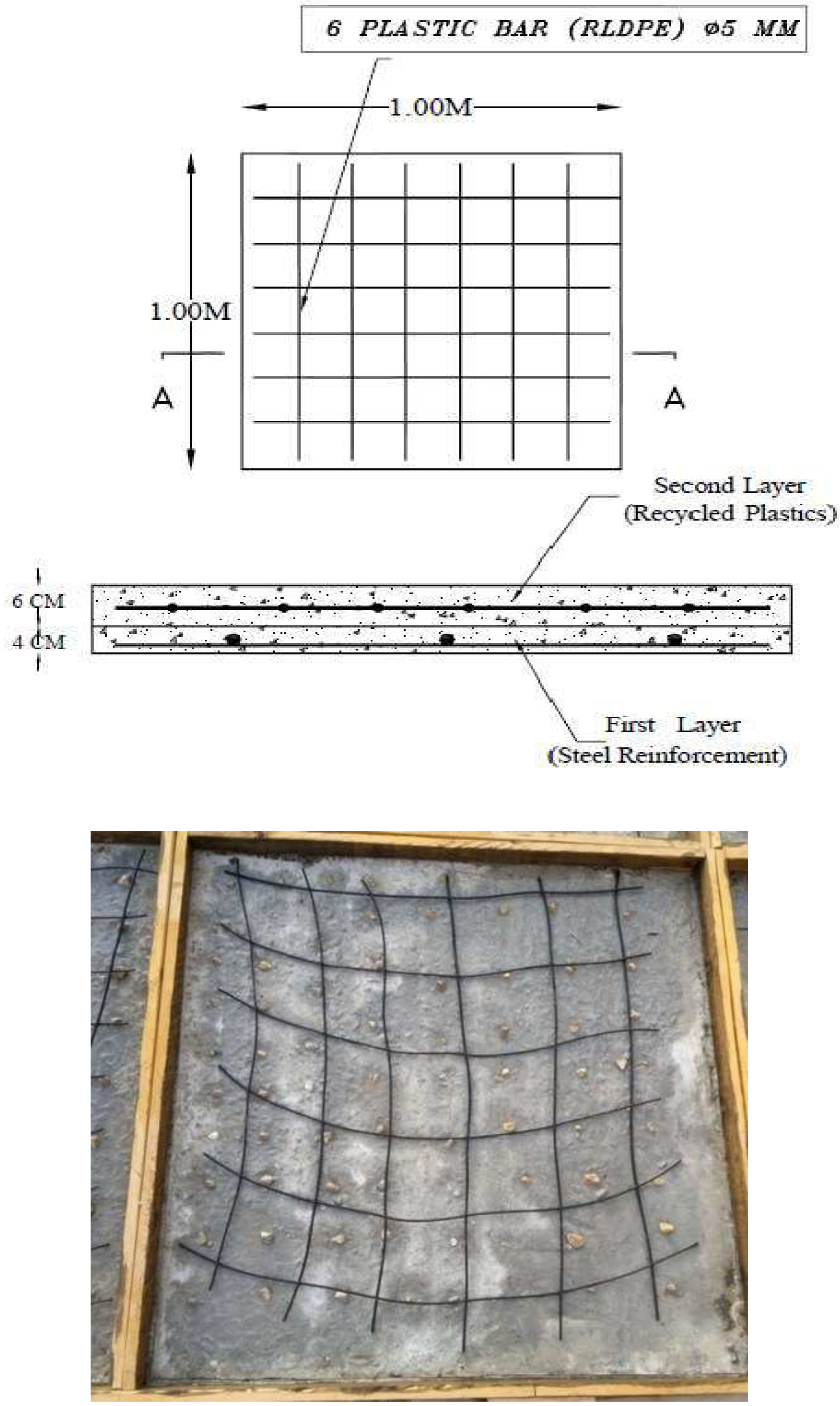


**Figure 3-7: 0.2% RLDPE fibers as secondary reinforcement.**

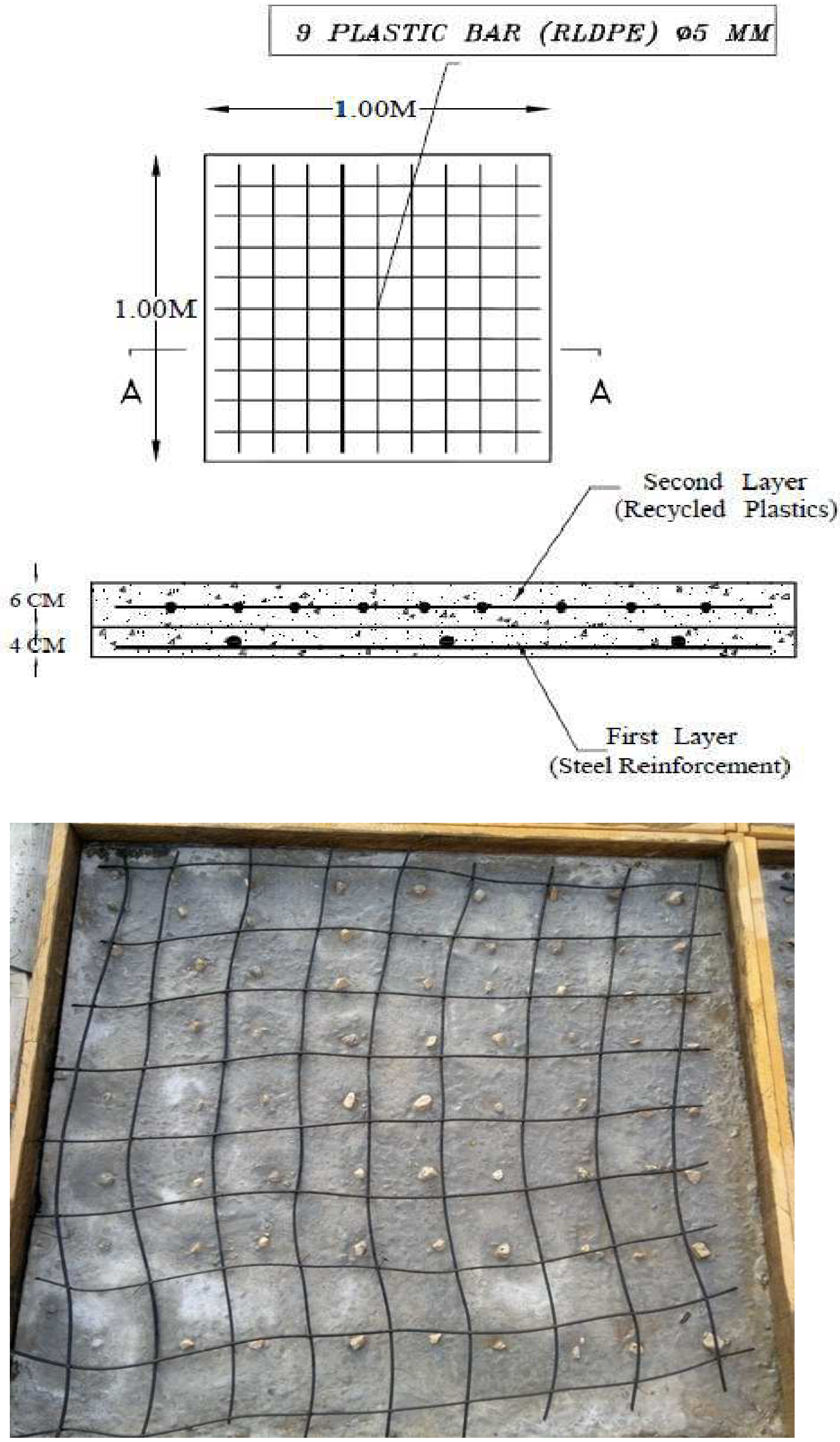


**Figure 3-8: 0.3% RLDPE fibers as secondary reinforcement.**

### 3.2.5 Steel Reinforcement

Mild steel with yield stress ($f_y$) = 3000 kg/cm$^2$, diameter 5.5 mm and reinforcement ratio of 0.002 is used for the shrinkage reinforcement as per ACI in the first and second layers, which uses minimum steel reinforcement. Thus, we use three bars of joint steel reinforcement in each direction of slab in all first layer as shown in *Figure (3.9)* and five bars of joint steel reinforcement in each direction of slab in the second layer for three control slabs as shown in *Figure (3.10)*.

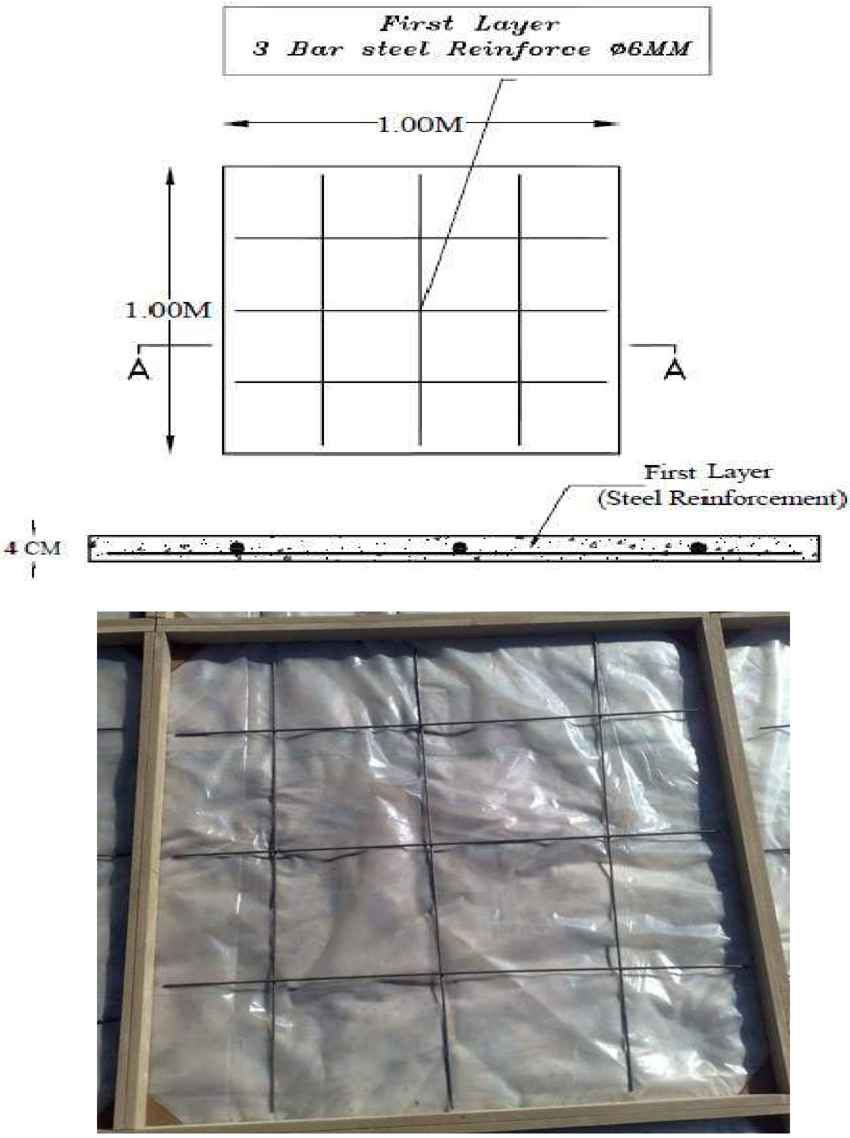


**Figure 3-9: Steel secondary reinforcement used in first layer.**

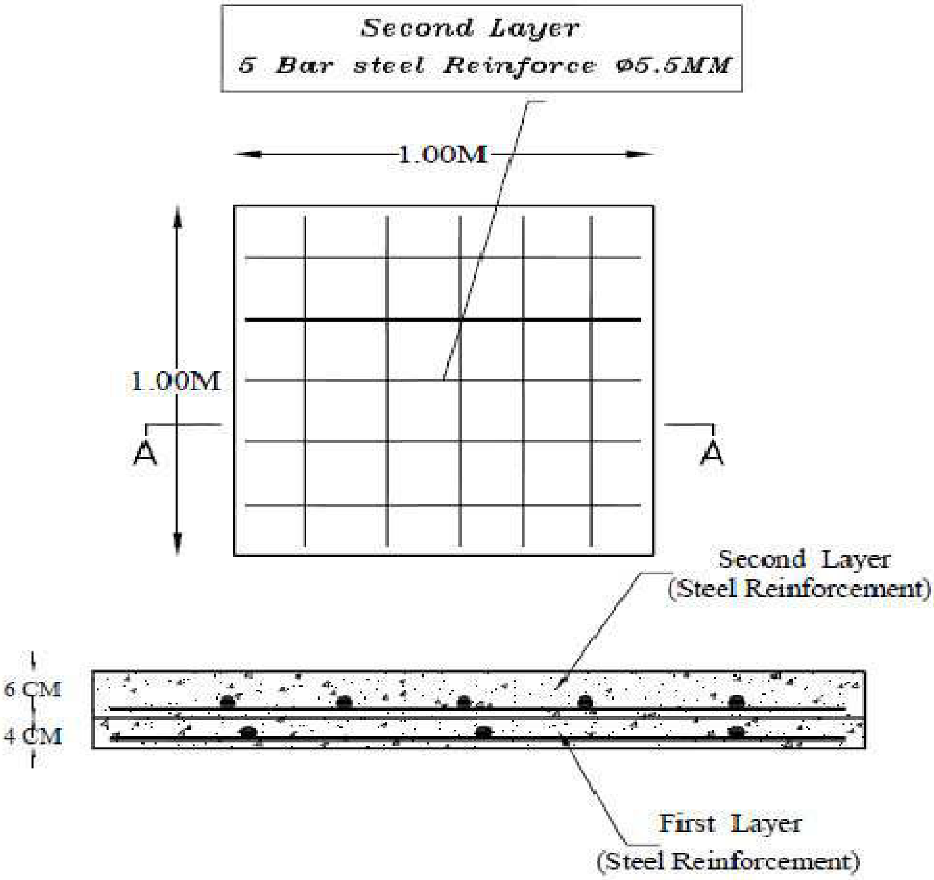


**Figure 3-10: Steel secondary reinforcement used in second layer.**

### 3.2.6 Mixing Water

Drinking water from the pipe water supply system in Gaza city is used for the preparing of the concrete mixes.

## 3.3 Mixture Proportioning

The concrete mix is designed according to (ACI 211.1, 2003) to obtain compressive strength of 25 MPa at 28 days and a 150 mm slump with water to cement ratio of 0.6. Each cubic meter of concrete consist of 775 kg/m$^3$ of sand, 1080 kg/m3 of coarse aggregates, 360 kg/m3 of cement and 185 kg/m$^3$ of water. The mix proportions of reinforcement concrete is shown in *Table (3.6)* with **(free w/c ratio = 0.50)**.

**Table 3-6: mix proportions, per one cubic meter of concrete.**

| ***Materials*** | ***Weight per one Cubic Meter kg/m$^3$*** |
|---|---|
| Cement | 360 |
| Coarse aggregate | 1080 |
| Fine aggregate (crushed sand) | 775 |
| Water | 185 |

For the RHDPE fiber slabs, four mixes with RP contents of 0, 9.5, 19 and 28.5kg/m$^3$ are used, respectively.

In case of fibrous concrete the weight of the RP for different volume fractions was calculated as follows:

$$\text{Weight of RP fibers} = \left(\frac{V_f}{100}\right) x G_s x1000$$

Where, $V_f$ = Volume fraction (%) and Gs = Specific Gravity of RP =0.95.

*Table (3.7)* shows the RHDPE fiber contents for the four mixtures used in this study .

Table 3-7: Recycled fiber contents.

| *% Volume of RHDPE Fibers* | *Plastic Content Kg/m$^3$* | *Plastic Content Kg/slab* |
|---|---|---|
| 0% Reference | 0 | 0 |
| 1%RHDPE | 9.5 | 0.57 |
| 2%RHDPE | 19 | 1.14 |
| 3%RHDPE | 28.5 | 1.71 |

## 3.4 Test Specimens

### 3.4.1 Workability

The slump test is used to determine the workability of concrete based on (ASTM C143, 2004), while (ASTM C642, 2006) is used to determine the hardened density at 28days.

### 3.4.2 Compressive Strength Test

Twelve cubic specimens of size 150 mm × 150 mm × 150 mm were cast for conducting compressive strength test, three for each percentage of RHDPE. The compressive strength test was based on (ASTM C109, 2008) and was carried at the end of the 28 days of curing. The compressive strength of any mix was taken as the average strength of three cubes.

### 3.4.3 Split Tensile Strength Test

The tensile strength of the mix is judged in terms of split tensile strength. For this, twelve cylindrical specimens of size 150 mm in diameter and in height 300 mm were cast. three for each percentage of RHDPE based on (ASTM C496, 2004). The test was conducted at the end of 28 days of curing and the average of three samples was taken as the representative split tensile strength of the mix.

### 3.4.4 Drying Shrinkage

For the drying shrinkage test, 21 slabs were cast to monitor the influence of incorporation the RP in the concrete mix, each slab was a composite of two layers; The first layer (the base) was 1000 × 1000 × 40 mm of reinforced concrete prism. It was cast three months prior to casting the second layer. When the substrate concrete was fresh, 20 mm aggregates were placed on the surface so that half of the aggregates were remained exposed. All substrate specimens were cured using water for 28 days.

After 90 days of casting the base layer, a 60 mm deep overlay layer was poured on the top of the already cast prisms bases. In the end, each slab was 1000 × 1000 × 100 mm in size. The overlay concrete of 9 slabs are cast with recycled plastics RHDPE contents of 1%, 2% and 3% of volume, where the 9 slabs are cast with recycled plastic RLDPE contents of 0.1%, 0.2% and 0.3% of the cross-sectional area. The remaining 3 slabs are reinforced by mild steel reinforcement as per article 7.12.2.1 of the (ACI 318-08, 2008) code placed at mid depth of the slabs and considered as control specimens.

All of the 21 specimens (after casting the overlay) were kept under field conditions. Further details about the drying shrinkage prisms are presented in *Figure (3.11).* A photo of the cast specimens is presented in *Figure (3.12*).

Drying shrinkage was monitored for three months under field conditions. The 21based slabs were reinforced on their bottom side by 3 bars φ 6 mm in two ways. The three references slabs were reinforced on their bottom side by 5 bars φ 5.5 mm in two ways. All specimens were measured using demec points glued at two perpendicular directions at the top surface of each slab at 200 mm distances in two perpendicular directions one day after casting of the slabs. Mechanical demic gauge model 58-C0230/20 manufactured by Controls Company, with a 200 mm gauge length and 0.001 mm resolution was used for measuring the changes in length is shown in *Figure (3.13).*

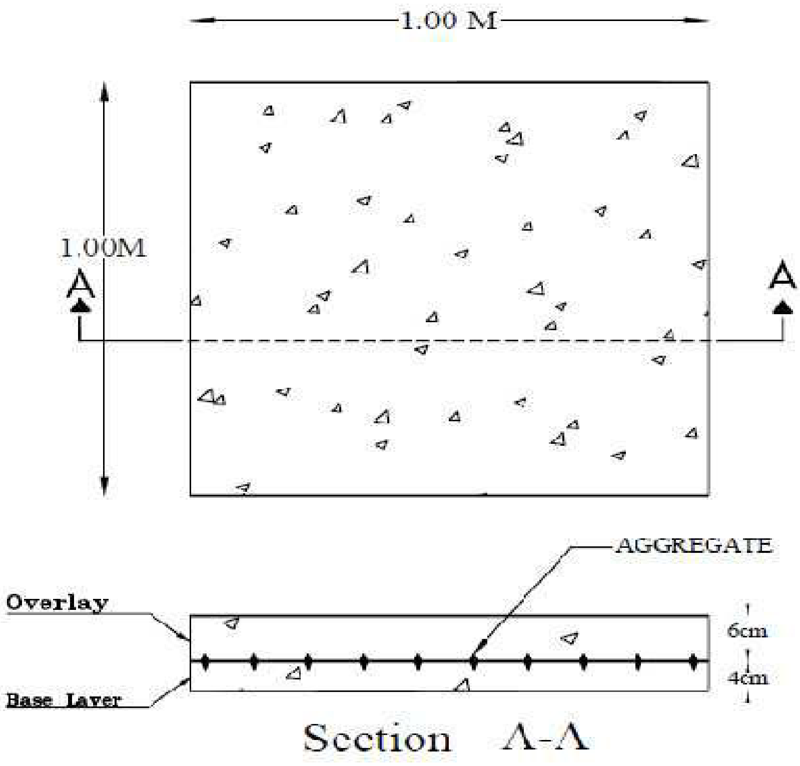


Figure 3-11: Details of the Drying shrinkage prisms.

Figure 3-12: photo of drying shrinkage slabs.

Figure 3-13: Demec gauge datum discs

## 3.5 Mixing, Casting and Curing

Mixing is done in tilting drum mixer for the first and the second layers of drying shrinkage slabs as per (ASTM C192, 2004). The method of preparing the sample is according to BS1881-108, 109, 110 at 111:1983and can be summarized in the following points:

### 3.5.1 Slump Test

Slump of concrete was determined at the site for the different contents of RHDPE, RLDPE and all concrete mixes.

### 3.5.2 Compression and Splitting Tensile Strength Test Samples

1. After preparing the required quantity, the mixing water was added to the coarse aggregate in the mixer and mixed for 3 minutes. Next, fine aggregate, cement and the rest of the mixing water were added while the mixer is running for additional 3 minutes, then recycled plastics were added to the mixture and mixed for an additional 3 minutes.

2. Emptying the concrete mixture from the mixer to a proper container.

3. After preparing the cubic molds of (15×15×15cm) and cylindrical mold of 150 dim and 300 high, the specimens mold is filled with concrete in 3 stages and tamping for each layers.

4. Level the surface of the molds and clean its external surface.

5. Put the molds in a humid place for 24 hours, remove the cubic concrete from the molds and place them in a curing tank until the time of the compressive test. *Figures (3.14) and (3.15)* show photos of concrete specimens.

**Figure 3-14: concrete cubic specimens.**

**Figure 3-15: specimens in curing tank.**

### 3.5.3 Drying Shrinkage Test Samples

For the drying shrinkage test, 21 reinforced slabs were cast to monitor the influence of incorporating the RP in the concrete mix. Each prism was a composite of two layers. The concrete temperature was 22 $C^0$ for the first layers and 25 $C^0$ for the second layers.

The first layer slabs (the base)was 1000 × 1000 × 40 mm. It was cast in wooden frame with steel reinforcement and placed out door in environment real condition during the month of March in Gaza City, as shown in *Figures(3.16) and (3.17).*

**Figure 3-16: Preparing the 4 cm template with steel reinforcement for first layers.**

**Figure 3-17: Filling the template with concrete for first layer slabs.**

After preparing the desired quantity, the mixing water was added to the coarse aggregate in the mixer then mixed for 3 minutes. Next, aggregate, cement and the rest of the mixing water were added while the mixer is running for additional 3 minutes. The finishing of the surface is done using a wooden screed as shown in *Figure (3.18).*

**Figure 3-18: Finishing the slab surface for first layers.**

When the concrete mix was fresh, 20 mm aggregates were placed on the surface so that approximately half of the aggregates were remained exposed as shown in *Figure (3.19) and (3.20).* All substrate slabs were cured by used water for 7 days.

**Figure 3-19: Fixed aggregates on the first layers surface.**

Figure 3-20: Finishing fixed aggregates on the first layers surface.

After 90 day preparing the wooden frame for Second layer slabs was 1000×1000×60 mm and preparing the desired quantity, the overlay concrete slabs poured on the top of already first slab as. The overlay concrete of 9 Slabs are casted with recycled plastics RHDPE contents of 1%, 2% and 3% percentages of the slab volume as shown in *Figure (3.21) and (3.22),* the other 9 slabs are casted with recycled plastic RLDPE contents of 0.1%, 0.2% and 0.3% percentages of the cross-sectional area as shown in *Figure (3.23) and (3.24)*, the other 3 slabs are reinforced by mild steel reinforcement placed at mid depth of the slabs and considered as control specimens as shown in *Figure (3.25)*.

Figure 3-21: Slabs with different RHDPE contents .

Figure 3-22: Filling the second template with concrete for different RHDPE contents.

Figure 3-23: Slabs with different RLDPE contents

**Figure 3-24: Filling the second template with concrete for different RLDPE contents.**

**Figure 3-25: Preparing the 6 cm template with steel reinforcement for second layers.**

After the casting, the concrete placed in the forms in overlay layer consolidated using rodding. Finishing with the surface is done using screed. All the 21 slabs (after casting the overlay) were cured twice daily over a seven-day period as shown in *Figure (3.26)*.

**Figure 3-26: Curing the second layers.**

This was done one day after casting the slabs. All specimens were measured using demec points glued at the top surface of each slab for 200 mm distance in two perpendicular directions. Mechanical demic gauge is used for measuring the change in length as shown in *Figure (3.27) and (3.28).*

**Figure 3-27: prepare the slabs for drying shrinkage test.**

**Figure 3-28: Fixed Demic Reference points in both directions.**

# CHAPTER 4: RESULTES AND DISCUTION

In this chapter, the results of our study on the effect of the recycled plastics on workability, compressive strength, flexural strength and drying shrinkage are discussed. Comparison between the control concrete and the plastic added concrete is presented.

## 4.1 Slump Test

The slump values for the different contents of RHDPE fibers are recorded as shown in *Table (4.1)*. The relationship between slump values and RHDPE contents are shown in *Figure (4.1)*. It is noticed that with the addition of recycled plastics fiber slump values are reduced. However, the mixes used are still workable. For 1% ratio of RHDPE, the slump is reduced by 16% and at 3% ratio the slump is reduced by 35% compared with plain concrete slump.

**Table 4-1: Effect of percentage of RHDPE content on Slump.**

| *% OF (RHDPE)* | *SLUMP (cm)* |
|---|---|
| 0% | 12 |
| 1% | 10.1 |
| 2% | 8.6 |
| 3% | 7.8 |

This reduction could be associated to the irregular shapes of RHDPE fibers. This finding agrees with previous research work, such as *( Shihada, 2010 & Batayneh et al.,* 2007 *& Ismail and Hashmi,* 2007 *& Choi et al.*, 2005 *& AL-Manaseer and Dalal,* 1997 *and Marzouk et al., 2007 )*.

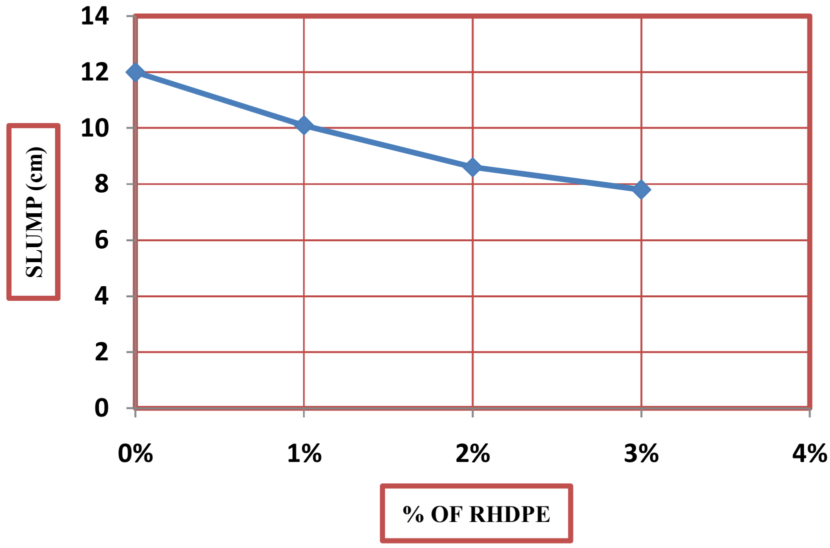


**Figure 4-1: Relationship between slump values and RHDPE contents .**

## 4.2 Compressive Strength

The compressive strength for different contents of RHDPE fibers and the control concrete were tested at the end of 28 days using compressive strength testing machine. The recycled plastic RHDPE ratios were taken as 0%, 1%, 2% and3%. Three cubes of each RHDPE ratio are casted and the average of three test results is taken for more accurate results. The values of the compressive strength obtained are presented in *Table (4.2*). Also, the relationship between compressive strength and RHDPE content is shown in *Figure (4.2)*. Also, *Figures(4.3)* and *(4.4*) show the typical failure patterns of control concrete and recycled plastic concrete, respectively. It is observed from *Figure (4.2)* that the addition of recycled plastics fibers has a negative impact on compressive strength of concrete, with the increasing of the recycled plastic content. At 3% RHDPE content, the compressive strength drops by 12% in comparison with the control concrete mix. This reduction in the compressive strength is related to the decrease in the adhesive strength between the recycled plastics and the cement paste. However, the compressive strength of concrete made with plastic is relatively constant. This is because of the reduction in bond strength between plastics and cement paste.

Recycled plastic does not play an important role in enhancing strength of plastic concrete. This finding agrees with the observation made by other researchers such as *( Shihada*, 2010 *& Yadav,* 2008 *& Batayneh et al.,* 2007 *& Ismail and Hashmi,* 2007 *& AL-Manaseer and Dalal,* 1997 *& Siddique et al., 2007 & Choi et al., 2005 & Marzouk et al., 2007 and Al-Hozaimy,* 2006).

**Table 4-2: Compressive strength of plain and RHDPE concrete specimens.**

| *% of RHDPE* | *No. of Samples* | *Average Unit Weight ( g/cm³ )* | *Compressive Stress ( kg/cm² )* | *Average Compressive Stress (kg/cm²)* |
|---|---|---|---|---|
| **0%** | 1 | 2.455 | 251.60 | 252.86 |
| | 2 | | 254.70 | |
| | 3 | | 252.30 | |
| **1%** | 1 | 2.357 | 235.20 | 236.64 |
| | 2 | | 238.44 | |
| | 3 | | 236.30 | |
| **2%** | 1 | 2.312 | 227.59 | 228.66 |
| | 2 | | 226.24 | |
| | 3 | | 232.15 | |
| **3%** | 1 | 2.210 | 220.40 | 224.31 |
| | 2 | | 228.35 | |
| | 3 | | 224.20 | |

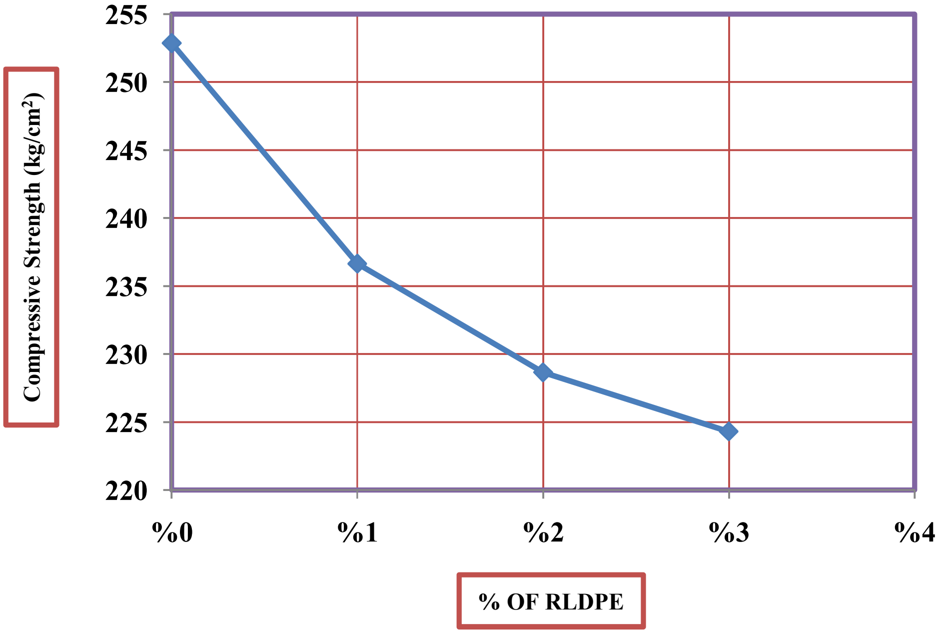


**Figure 4-2: Relationship between Compressive Strength and RHDPE content.**

**Figure 4-3: Control concrete cubes failure**

**Figure 4-4: Plastic concrete cubes failure**

## 4.3 Tensile Strength

The tensile splitting strength for different contents of RHDPE fibers and control concrete were tested after 28 days using cylinders split tensile test machine. The recycled plastic RHDPE ratios were taken as 0%, 1%, 2% and 3%. Three cylindrical specimens of each RHDPE ratio are cast and the average of three test results is taken for the accuracy of the results. The values of tensile splitting strength obtained are tabulated in *Table (4.3)*. Also, it can be shown from *Figure (4.5)* the relationship between tensile splitting strength and RHDPE content. The failure patters of control concrete and recycled plastic concrete are shown in *Figures(4.6)* and (*4.7*), respectively. The results indicate a reduction in the tensile strength of RHDPE concrete compared to control concrete specimens.

After the period of 28 days, we observed that the addition of RHDPE fibers has a negative impact on the splitting tensile strength of concrete when increasing the recycled plastics concrete. At 3% RHDPE fiber content, the splitting strength drops by 28.5% in comparison with the control concrete mix. This finding agrees with the observation made by other researchers such as *(Shihada,* 2010 *& Yadav*, 2008 *& Batayneh et al., 2007 & Ismail and Hashmi*, 2007 *& AL-Manaseer and Dalal.,* 1997 *& Siddique et al., 2007 & Choi et al., 2005 & Marzouk et al., 2007 and Al-Hozaimy,* 2006).

**Table 4-3: Splitting Strength of plain and RHDPE concretes specimens.**

| % of RHDPE | No. of Sample | Tensile Stress (kg/cm$^2$) | Average Tensile Stress (kg/cm$^2$) |
|---|---|---|---|
| 0% | 1 | 24.55 | 24.56 |
| | 2 | 24.32 | |
| | 3 | 24.82 | |
| 1% | 1 | 22.68 | 22.34 |
| | 2 | 22.44 | |
| | 3 | 21.90 | |

| % of RHDPE | No. of Sample | Tensile Stress ($kg/cm^2$) | Average Tensile Stress ($kg/cm^2$) |
|---|---|---|---|
| 2% | 1 | 19.59 | 19.19 |
| | 2 | 18.70 | |
| | 3 | 19.30 | |
| 3% | 1 | 18.43 | 17.57 |
| | 2 | 17.50 | |
| | 3 | 16.79 | |

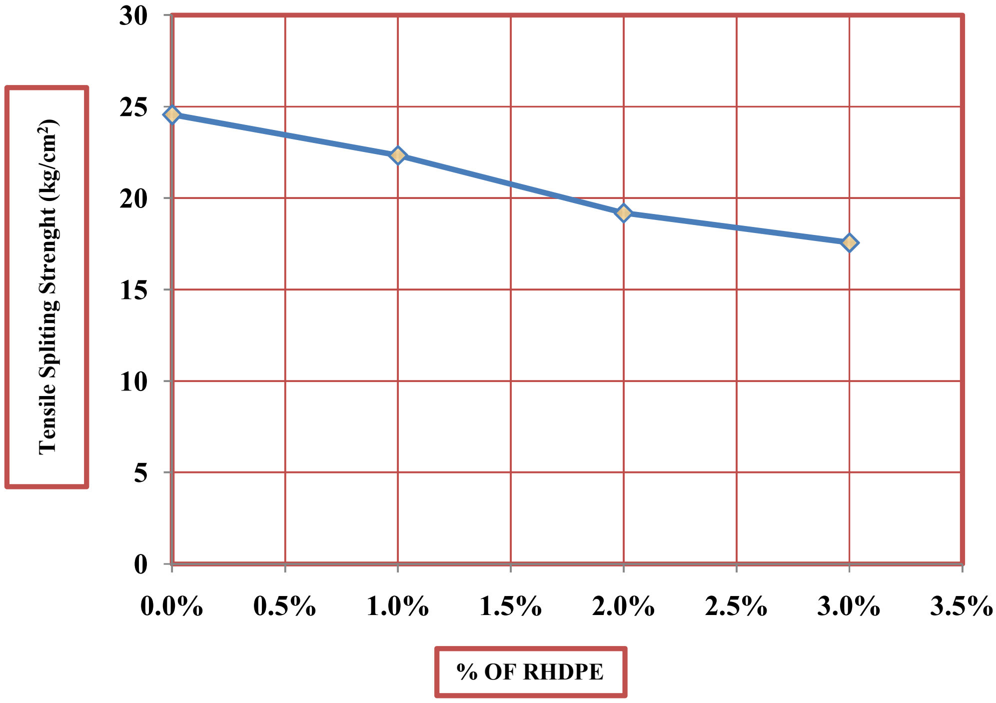


Figure 4-5: Relationship between tensile splitting strength and RHDPE content.

Figure 4-6: Failure pattern of control concrete

Figure 4-7: Failure pattern of plastic concrete

## 4.4 Drying Shrinkage

The measured strain at the end of the measured period of three months are shown in *Table (4.4).* Certain percentages of RHDPE and RLDPE that reduce the drying shrinkage far better than the control slabs (using steel shrinkage reinforcement) are indicated by the values with negative sign. The same table shows that the control slabs reinforced with ACI 318-08 shrinkage reinforcement performed better than the RHDPE slab in terms of reducing drying shrinkage for percentages lower than or equal to 2%. For RLDPE slabs, the control slabs performed better for percentages lower than 0.2%. The average measured strain for control and recycled plastic slabs cured under field conditions are presented in *Figures (4.8*) to *(4.10). Figure (4.8*) shows drying shrinkage measurement for RHDPE compared with those for shrinkage reinforcement. *Figure (4.9*) shows the drying shrinkage measurement for RLDPE compared to those for shrinkage reinforcement. *Figure 4.10* shows drying shrinkage measurement for RLDPE and RHDPE contents which yields smaller drying shrinkage strains than the ACI318-08specified shrinkage reinforcement. As it is seen in *Figures (4.8)* to *(4.11)*, the addition of recycled plastic to the concrete mixes result in increasing the rate of shrinkage at the beginning of the measuring period and increasing the ultimate shrinkage strains at the end of the measuring period. The findings of this study are in good agreement with the available literature regarding the RHDPE, which is used effectively in reducing drying shrinkage *( Shihada*, 2010 *&* Yadav, 2008 *& Batayneh et al., 2007 & Siddique et al., 2007 & AL-Manaseer and Dalal,* 1997 *& Kou et al.,* 2009 *& Al-Hozaimy,* 2006 *and Al-Hozaimy et al., 2009* ). In terms of recycled RLDPE mesh reinforcement, there are no results in the available literature to compare with.

**Table 4-4: Maximum recorded strains at 90 days.**

| *Slab Type* | *Maximum Shrinkage ( Micro Strain )* | *Increase in Strain (%)* |
|---|---|---|
| **Steel Reinforcement** | 340 | - |
| **1% RHDPE** | 410 | 20.6 % |
| **2% RHDPE** | 350 | 2.9 % |
| **3% RHDPE** | 270 | -20.58 % |
| **0.1% RLDPE** | 380 | 11.76 % |
| **0.2% RLDPE** | 335 | -1.47% |
| **0.3% RLDPE** | 230 | -32.35% |

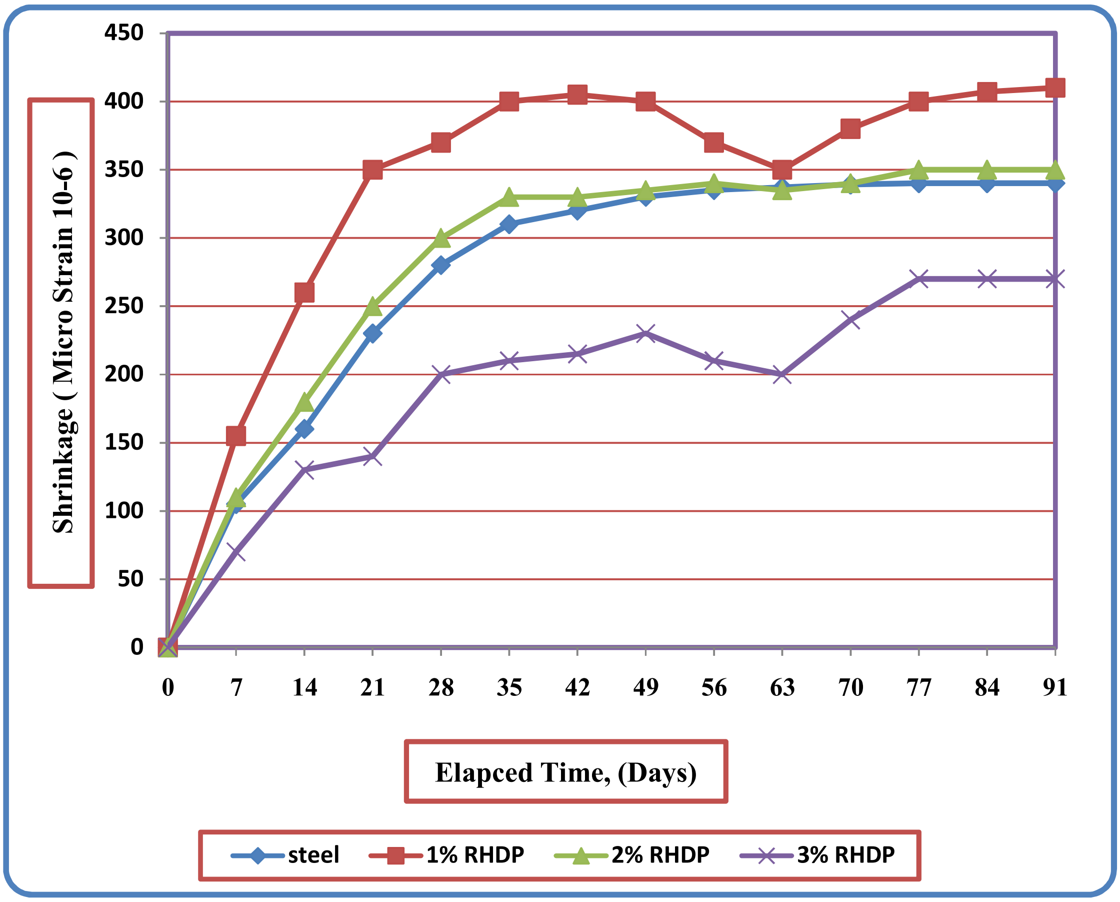


**Figure 4-8: Average drying shrinkage versus time for different RHDPE contents**

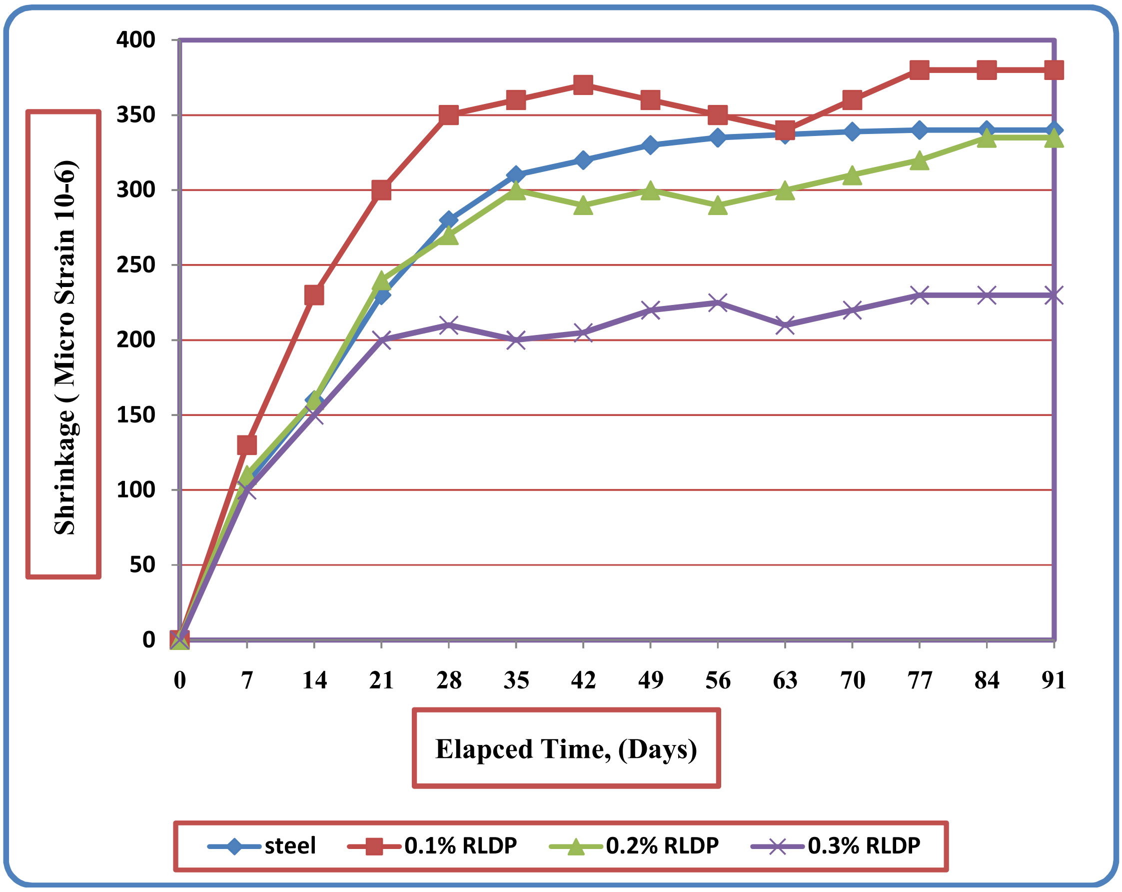


Figure 4-9: Average drying shrinkage versus time for different RLDPE contents

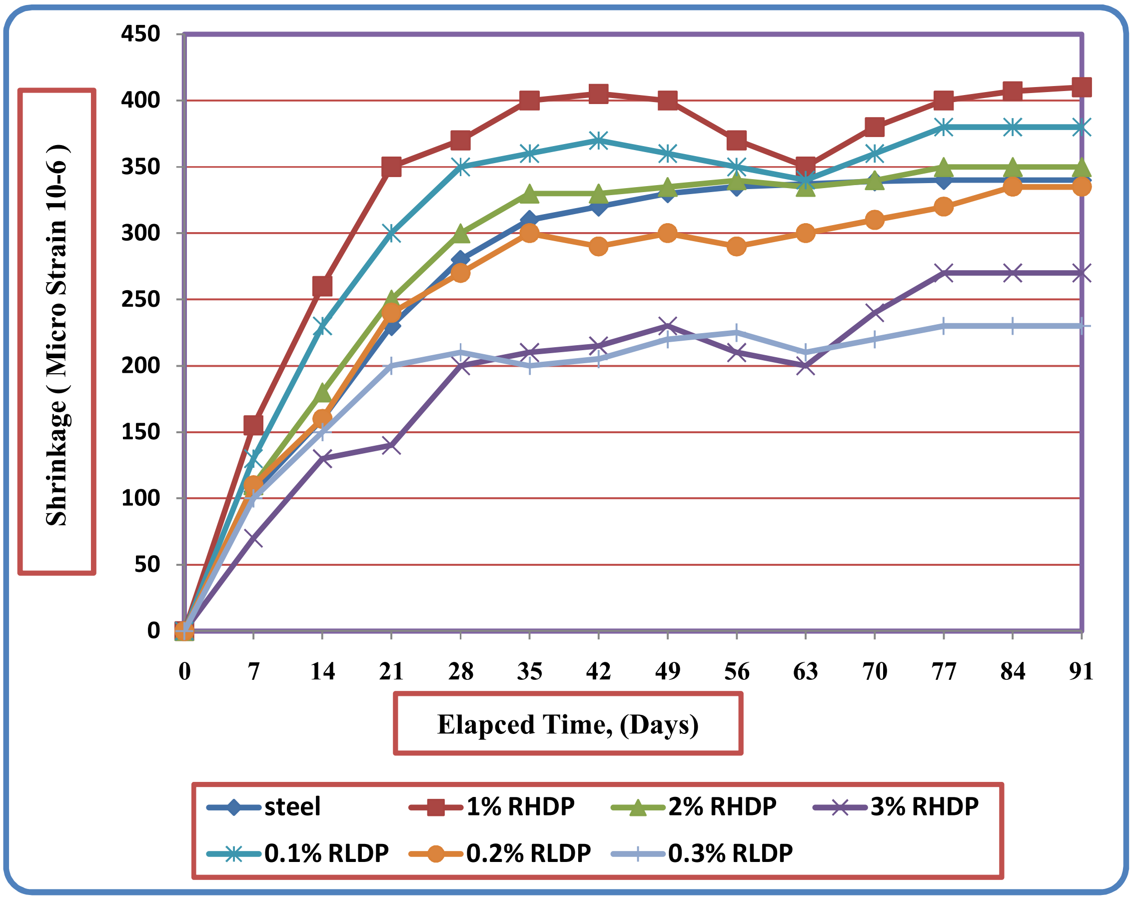


**Figure 4-10: Average drying shrinkage versus time for different RLDPE and RHDPE Contents.**

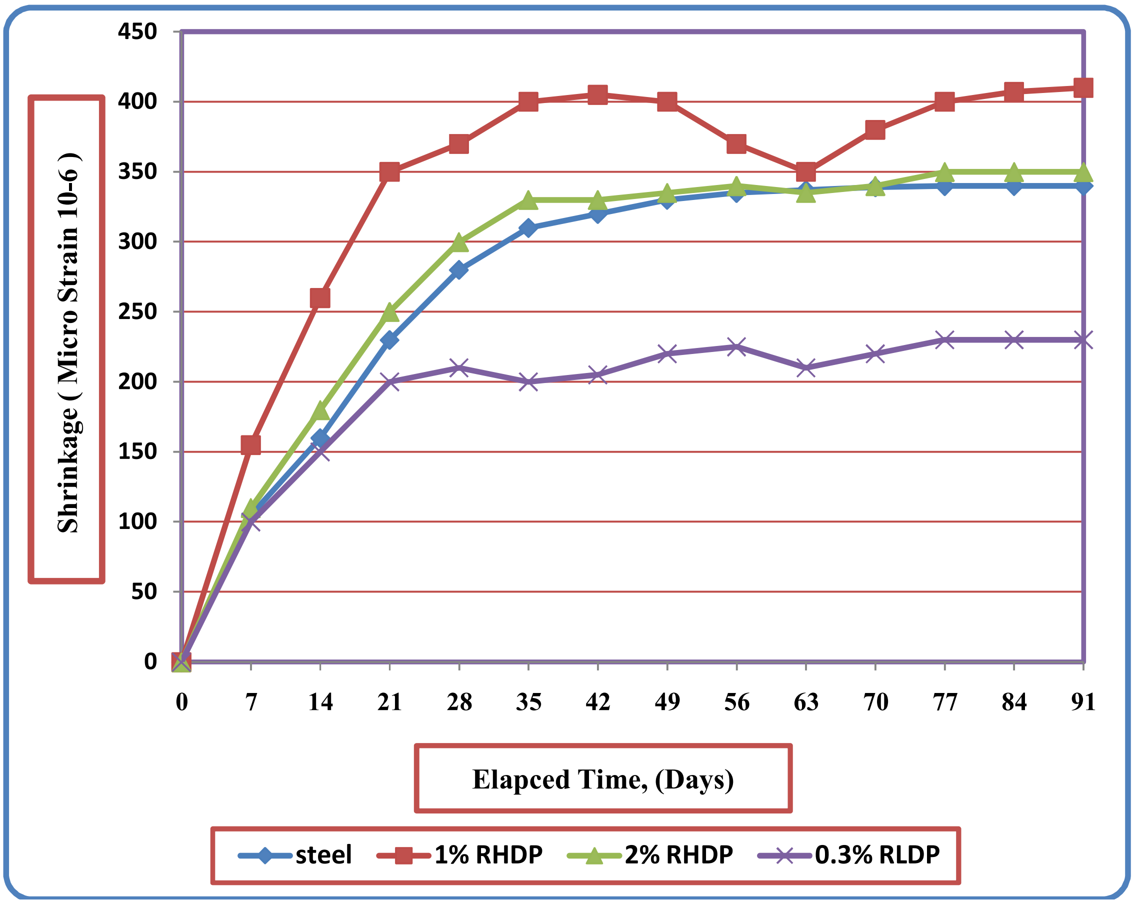


**Figure 4-11: Average drying shrinkage versus time for some different RLDPE and RHDPE Contents.**

# CHAPTER 5: CONCLUSIONS & SCOPE FURTHER RESEARCH

## 5.1 Conclusions

Two types of recycled plastics with different contents were added to the concrete and compared with the control mix. Based on the limited experimental work carried out in this study, the following conclusions can be discussed:

1. The slump values of recycled plastic concrete mixtures show a tendency to decrease below the slump of the reference concrete mixtures. Thus, those mixtures are workable based on the since the recycled plastic concrete is to be used in low-strength mixes associated with non-structural purposes (large w/c ratios).
2. For a given w/c ratio, the increase of recycled plastics ratio used in the mix reduces the unit weight of the concrete and decreases the density, the compressive strength and the tensile strength of concrete. This is useful in light weight construction.
3. The compressive and tensile splitting tensile strength values of all recycled plastic concrete mixes tend to decrease below the values for the reference concrete mixes with increasing the recycled plastic ratio. This may be attributed to the decrease in the adhesive strength between the surface of the recycled plastic and the cement paste. So, it is advisable to use these fibers in concretes assigned for non-structural purposes.
4. Randomly distributed RHDPE fibers can be used effectively as a replacement of steel shrinkage reinforcement, specified by the article 7.12.2.1 of ACI318-08 Code. Ratios of 2% or more, by volume, of recycled fibers give comparable, or less, drying shrinkage when compared with the more expensive steel reinforcement.
5. Mesh prepared from recycled LDPE fibers can effectively be used as a replacement of steel shrinkage reinforcement specified by the article 7.12.2.1 of ACI318-08 Code. Ratios of 0.2 % or more, by cross sectional area, of recycled

fibers give comparable, or less, drying shrinkage strains compared to steel reinforcement.

6. Using recycled plastic fibers in concrete mix tends to make concrete ductile, hence increasing the ability of concrete to significantly deform before failure. This characteristic makes the concrete useful in situations of extreme weather conditions.
7. Using recycled plastic fibers for controlling drying shrinkage for nonstructural concrete purposes is more economical than steel reinforcement.

## 5.2 Scope for Further Research

The use of recycled plastics in concrete is a relatively new development in the world of concrete technology. More research work should be performed before this material is actively used in concrete construction. This is because of the different types and shapes of recycled plastics. The use of plastics in concrete reduces the strength of resultant concrete. Therefore, more experimental work should be oriented towards the better understanding of using recycled plastics in concrete.

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# APPENDIX A : DRY SHRINKAGR READINGS

### TABLE A.1 : Average drying shrinkage versus time for some different RLDP and RHDPE Contents.

| Drying Shrinkage | | Elapsed Time (DAY) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **0** | **7** | **14** | **21** | **28** | **35** | **42** | **49** | **56** | **63** | **70** | **77** | **84** | **91** |
| **Shrinkage (Micro strain $10^{-6}$)** | **Steel Re.** | 0 | 105 | 160 | 230 | 280 | 310 | 320 | 330 | 335 | 337 | 339 | 340 | 340 | 340 |
| | **1% RHDPE** | 0 | 155 | 260 | 350 | 370 | 400 | 405 | 400 | 370 | 350 | 380 | 400 | 407 | 410 |
| | **2% RHDPE** | 0 | 110 | 180 | 250 | 300 | 330 | 330 | 335 | 340 | 335 | 340 | 350 | 350 | 350 |
| | **3% RHDPE** | 0 | 70 | 130 | 140 | 200 | 210 | 215 | 230 | 210 | 200 | 240 | 270 | 270 | 270 |
| | **0.1% RLDPE** | 0 | 130 | 230 | 300 | 350 | 360 | 370 | 360 | 350 | 340 | 360 | 380 | 380 | 380 |
| | **0.2% RLDPE** | 0 | 110 | 160 | 240 | 270 | 300 | 290 | 300 | 290 | 300 | 310 | 320 | 335 | 335 |
| | **0.3% RLDPE** | 0 | 100 | 150 | 200 | 210 | 200 | 205 | 220 | 225 | 210 | 220 | 230 | 230 | 230 |

# APPENDIX B : RECYCLED PLASTIC FACTORIES

**Figure B.1: Scrap Plastics**

**Figure B.2: Factory Machines**

**Figure B.3: Electrical saw**

**Figure B.4: Miller machine**

**Figure B.5: Water Tube machine**

**Figure B.6: Cylindrical In Shape 5 MM In Diameter for (RLDPE)**

Figure B.7: Recycled Low-density polyethylene (RLDPE).

Figure B.8: Shredded Pieces for Recycled Low-density polyethylene (RLDPE).

Figure B.8: Shredded Pieces for Recycled high-density polyethylene (RHDPE).

# APPENDIX C : EXPERMENTAL WORK PHOTOS

**Figure A.1: Preparing the 4 cm template with steel reinforcement for first layers.**

**Figure A.2: Filling the template with concrete for first layer slabs.**

**Figure A.3: Finishing the slab surface for first layers.**

**Figure A.4: Fixed aggregates on the first layers surface.**

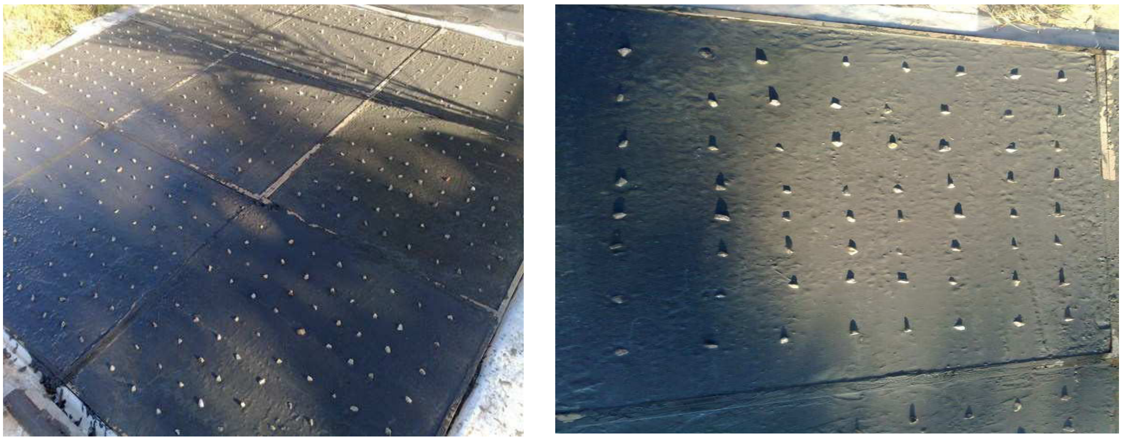

**Figure A.5 Finishing fixed aggregates on the first layers surface.**

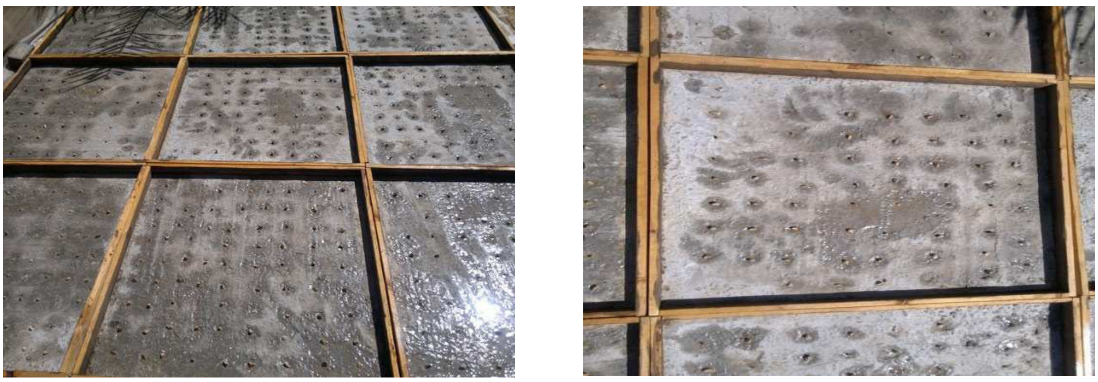

**Figure A.6: Preparing the 6 cm template for second layers.**

**Figure A.7: Preparing the 6 cm template with steel reinforcement for second layers.**

**Figure A.8: Slabs with different RLDPE contents**

**Figure A.9: Slabs with different RHDPE contents**

Figure A.10: Filling the second template with concrete for different RLDPE contents.

Figure A.11: Filling the second template with concrete for different RHDPE contents.

Figure A.12: Finishing the slab surface for second layers.

Figure A.13: Curing the second layers.

Figure A.14: Slabs after remove the Template

Figure A.15: prepare the slabs for drying  shrinkage test.

**Figure A.16: Fixed Demic Reference point in both direction.**