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Effects of pre-treated recycled tire rubber on fresh and mechanical properties of concrete

تأثير استخدام مفروم الإطارات المطاطية المعالجة على الخواص الميكانيكية للخلطات الخرسانية الطازجة والمتصلدة

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إقـــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Effects of Pre-treated recycled tire rubber on fresh and Mechanical Properties of concrete

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

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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

Student's name: اسم الطالب: **إياد فؤاد عبد المجيد رشوان**

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ إياد فؤاد عبدالمجيد رشوان لنيل درجة الماجستير في كلية *الهندسة* قسم الهندسة المدنية – تصميم وتأهيل المنشآت وموضوعها:

تأثير استخدام مفروم الإطارات المطاطية المعالجة على الخواص الميكانيكية للخلطات الخرسانية الطازجة والمتصلدة

Effects of Pre-treated recycled tire rubber on fresh and mechanical properties of concrete

وبعد المناقشة العلنية التي تمت اليوم الثلاثاء ٠٧ محرم ١٤٣٧هـ، الموافق ٢٠١٥/١٠/٢٠م الساعة الواحدة ظهراً بمبنى طيبة، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في كلية *الهندسة*/ قسم الهندسة المدنية- تصميم وتأهيل المنشآت.

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

والله ولي التوفيق ،،،

نائب الرئيس لشئون البحث العلمي والدراسات العليا

أ.د. عبدالرؤوف علي المناعمة

DEDICATIONS

To my father's soul, my mother, aunt Amera, my brothers and to my sisters.

To my friends, and to whom I belong.

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ABSTRACT

This thesis, generally, aims to explore the potential utilization of waste crumb tires in various concrete mixes for the production of light weight and non-structural concrete to study the structural behavior of concrete, and to help partially solving environmental problem produced from disposing waste tires.

As known that the strength of concrete mainly depends on properties of materials mainly coarse and fine aggregate used in mix, and depends on the adhesion between these materials and cement paste, so this thesis aims to investigate many methodologies to improve the bonding force between crumb rubber and cement baste, by making pre- treatment for rubber surface.

The necessary laboratory tests were done on fine aggregate (sand), coarse aggregate and cement, and many methods of pre-treatment were investigated such as Na OH pre-treatment, mortar pre-treatment and pre-treatment with bonding agent to increase the bonding force between crumb rubber and cement baste, several tests were made on fresh and hardened concrete, like slump, compressive strength, splitting tensile strength, unit weight and impact strength.
The results show that the last method give the best results.

Fine aggregate (sand) and coarse aggregate (size3) were replaced using volumetric method by non-treated crumb rubber tires with 0, 10, 20, and 30% replacements for the various mixes. And then many tests were made on fresh and hardened concrete, like slump, compressive strength, splitting tensile strength, unit weight and impact strength, and then Fine aggregate (sand) and coarse aggregate (size3) were replaced using volumetric method by (mortar and bonding agent) pre-treated crumb rubber tires with 0, 10, 20, and 30% replacements for the various mixes, and then many tests were made on fresh and hardened concrete, like slump, compressive strength, splitting tensile strength, unit weight and impact strength.

The study shows that the slump, compressive strength, splitting tensile strength, unit weight and impact strength decreased as the percent replacement by non-treated crumb tires increased, were when pre-treated crump rubber used the slump, compressive strength, splitting tensile strength and unit weight decreased as the percent replacement by pre-treated crumb tires increased but the decrease was less than in case of non-treated rubber, were it improvement in impact strength when the replacement ratio was 10% then it was decreased as the replacement ratio increased.

Finally, it is recommended to use waste crumb tires rubber with replacement ratio not more than 20% to produce light weight concrete that can be used, for non-structural elements, such as floor ribs, partitions, back stone concrete, concrete blocks, and other non-structural uses.

الملخص

تهدف هذه الدراسة بشكل عام لإمكانية استخدام مفروم الإطارات المطاطية التالفة في الخلطات الخرسانية، وذلك لإنتاج خرسانة ذات كثافة أقل بحيث تستخدم في العناصر الغير إنشائية بشكل مقبول، وكذلك للمساهمة جزئياً في حل المشكلة البيئية الناتجة عن الطرق الغير سليمة للتخلص من الإطارات المطاطية التالفة.

وكما هو معلوم أن قوة الخرسانة تعتمد على عدة عناصر أهمها خواص المواد المستخدمة في الخلطة الخرسانية لا سيما الركام الناعم والخشن لأنه يشكل النسبة الأكبر من حجم الخلطة، وكذلك على قوة الترابط بين تلك المكونات والعجينة الإسمنتية فلقد هدفت هذه الدراسة أيضاً لبحث عدة طرق لتحسين قوة الترابط بين جزيئات المطاط المفروم وبين العجينة الإسمنتية من خلال تحسين سطح المطاط المفروم وعمل معالجة مسبقة له.

لقد تم فحص الركام الناعم والخشن والأسمنت المستخدم في الخلطة وتم دراسة عدة طرق لتحسين سطح مفروم المطاط وهي المعالجة بواسطة محلول هيدروكسيد الصوديوم والمعالجة بواسطة العجينة الإسمنتية مع الرمل والمعالجة بواسطة العجينة الإسمنتية مع الرمل وبإضافة مادة راتنجية لاصقة تزيد الترابط بين العجينة الإسمنتية وسطح المطاط وتم دراسة خواص الخرسانة الطازجة والمتصلدة من حيث التهدل ومقاومة الضغط ومقاومة الشد والكثافة وتحمل الصدم. وتبين من نتائج الفحص أن الطريقة الأخيرة للمعالجة أعطت أفضل نتائج تقريباً.

تم استبدال نسبة حجمية من الركام الناعم وكذلك من الركام الخشن (السمسمية) بنسب 0،10،20،30% بدون معالجة لسطح المطاط وتم دراسة خواص الخرسانة الطازجة والمتصلدة من حيث التهدل ومقاومة الضغط ومقاومة الشد والكثافة وتحمل الصدم، ثم تم بعد ذلك استبدال نسبة حجمية من الركام الناعم وكذلك من الركام الخشن (السمسمية) بنسب 0،10،20،30 % بعد معالجة سطح المطاط المفروم باستخدام العجينة الإسمنتية والرمل وباستخدام مادة راتنجية لاصقة وتم دراسة خواص الخرسانة الطازجة والمتصلدة من حيث التهدل ومقاومة الضغط ومقاومة الشد والكثافة وتحمل الصدم.

وبينت النتائج أن كل من مقاومة الضغط والشد والصدم والكثافة وقيمة التهدل تقل بزيادة نسبة المطاط المفروم غير مسبق المعالجة في الخلطة، أما في حالة معالجة سطح المطاط المفروم باستخدام العجينة الإسمنتية والرمل والمادة اللاصقة فإن كل من مقاومة الضغط والشد والكثافة وقيمة التهدل تقل بزيادة نسبة المطاط المفروم في الخلطة ولكنها تقل بنسبة أقل من المطاط الغير معالج في حين كان هناك تحسن في قوة تحمل الصدم عن الخلطة المرجعية عندما كانت نسبة المطاط المستبدل 10% ثم بدأت تقل تدريجياً بزيادة نسبة المطاط.

أخيراً فإنه يوصى باستخدام الخرسانة المطاطية بنسبة استبدال لا تزيد عن 20% للحصول على خرسانة مقبولة من حيث القوة الإنشائية، وكذلك للحصول على خرسانة خفيفة يمكن استخدامها لعدة أغراض، كما يوصى باستخدام الخرسانة المطاطية للأغراض الغير إنشائية مثل الأرضيات والقواطع والطوب الخرساني وخرسانة النظافة إلخ.

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LIST OF ABBREVIATIONS

ASTM:	American Society for Testing and Materials.
CRA:	Compact rubber aggregate.
ERA:	Expanded rubber aggregates.
HNC:	Hardened Normal Concrete.
ITZ:	Interfacial transition zone.
IUG:	Islamic University of Gaza.
MNRC10:	Modified Normal Rubber Concrete by using Mortar and bonding agent pre-coating with 10% Replacement.
MNRC3:	Modified Normal Rubber Concrete by using Mortar and bonding agent pre-coating.
MNRC30:	Modified Normal Rubber Concrete by using Mortar and bonding agent pre-coating with 30% Replacement.
MNRC2:	Modified Normal Rubber Concrete by using Mortar pre-coating.
MNRC1:	Modified Normal Rubber Concrete by using Na OH pre-treatment.
MRNC:	Modified Rubber Normal Concrete.
MSW:	Municipal Solid Waste.
Na OH:	Sodium hydroxide.
NC:	Normal Concrete.
NC0:	Normal Concrete without rubber.
NRC10:	Normal Rubber Concrete with 10% Replacement.
NRC20:	Normal Rubber Concrete with 20 % Replacement.
NRC30:	Normal Rubber Concrete with 30% Replacement.
NRC:	Normal Rubber Concrete.
PRR'S:	Partial replacement ratios.
PTRTR:	Pre-treated Recycled Tire Rubber.
RTR:	Recycled Tire Rubber.
RT:	Recycling Tire.
SEM:	Scanning electron microscope.
SWM:	Solid waste management.

Chapter 1

Introduction

CHAPTER 1- INTRODUCTION

1.1 General Background

Concrete is considered the most frequently used structural material, not only because it has good mechanical proprieties after hardening, easy to use, etc. but also its dominant advantage that it is considered as an economic structural material.

Modifications of construction materials have an important bearing on the building sector. Several attempts have been therefore made in the building material industry to put to use waste material products, e.g., worn-out tires, into useful and cost effective items. Success in this regard will contribute to the reduction of waste material dumping problems by utilizing the waste materials as raw material for other products **(Shtayeh, 2007).**

Utilization of industrial waste products in concrete has attracted attention all around the world due to the rise of environmental consciousness. Accumulations of stockpiles of tires are dangerous because they pose a potential environmental concern, fire hazards and provide breeding grounds for mosquitoes that may carry disease. Tire pile fires have been an even greater environmental problem. Tire pile fires can burn for months, sending up an acrid black plume that can be seen for dozens of miles. That plume contains toxic chemicals and air pollutants, just as toxic chemicals are released into surrounding water supplies by oily runoff from tire fires **(Azmi. et al, 2008).**

During last recent years, many improvements in Gaza Strip have occurred in all parts of life such as social, industrial, economical etc. Like all countries in the world, this will lead to generate new ways of living and increase the human requirements, and will also increase types and quantities of the waste in the Gaza Strip, without any active processes to provide solution to this problem.

One of the important types of remains is waste tires, which have been classified as a part of Municipal Solid Waste (MSW), resulted from the increase of vehicle ownership and traffic volume in Gaza Strip. This eventually will increase consumption of tires over time. Current practices show that residents throw it randomly in different places such as valleys, road sides, open areas, and waste dumpsites in improper ways taking the means of open fire, and without consideration of risk on human health and environment.

1.2 Problem Statement

The growing amount of waste rubber produced from tires has been a major concern in the last decades because tires represent a huge no-biodegradable refusal with danger of fires and proliferation of rats and insects in the stocked refuse mass. The need to explore recycling strategies is so imperious. A variety of waste materials have been suggested as additives to concrete materials, due to the need to ease the intake of resources for the production of concrete and to improve some performances of concrete with economic and technological advantages. In order to reduce the environmental problem from growing, recycling tire (RT) is an innovative idea or way in this case. Recycling tire is the processes of recycling vehicles tires that are no longer suitable for use on vehicles due to wear or irreparable damage (such as punctures). The cracker mill process tears apart or reduces the size of tire rubber by passing the material between rotating corrugated steel drums tarun **(Naik and Singh, 1991).**

By this process an irregularly shaped torn particles having large surface area are produced and this particles are commonly known as crumb rubber **(Naik, 1991)**

Millions of waste rubber tires accumulate in the world. The amount of waste tires are expected to increase with the increase of vehicles. This is considered as one of the major environmental challenges facing municipalities around the world because waste rubber is not easily biodegradable even after a long period of landfill treatment. The weight of the scrap tires in Gaza strip is approximately 3000 ton/year **(Israeli Central Bureau of Statistics.2005)**

while the weights of scrap tires generating in the West Bank is 8000 ton /year, most of them were either interred in landfills or just dumped in open areas or on the side of the road **(Habil and Qomboz, 2012).**

This research presents an experimental investigation of the effects of pre-treated recycled tire rubber on fresh and mechanical properties of concrete, which would partially help in solving this environmental problem.

1.3 Aim and Objectives

The main aim of this study is to experimentally improve the bonding between the rubber aggregate and cement paste by different methodologies including Na (OH) pre-treatment, mortar pre-coating, mortar pre-coating with bonding agent study the effect of pre-treated recycled tire rubber on fresh and mechanical properties of Normal Concrete. To achieve the aim of this study, the following objectives are carried out:

1. Obtain the effect of several methods of pre-treated recycled tire rubber on normal concrete at different ages, in terms of fresh and mechanical properties; in order to select the optimum method.
2. Obtain the effect of several percentages of pre-treated recycled tire rubber at different ages, in terms of fresh and mechanical properties.
3. Identify the relationship between the recycled tire rubber (with its fibers reinforcement) percentages and the behavior of the normal concrete.

1.4 Methodology

The following tasks were done to achieve the objectives of this research:

1. Conducting a literature review about the effect of pre-treated recycled tire rubber on fresh and mechanical properties of normal concrete.
2. Preparing of material for laboratory testing and executing the testing program.

3. Preparing the mix design and samples.
4. Preparing the recycled tire rubber (crumb) at different percentages.
5. Preparing and curing the samples.
6. Applied the mechanical tests on samples after curing.
7. Test results and data analysis.
8. Conclusions and the recommendations of the research work based on the experimental program results and data analysis.

1.5 Thesis Layout

This thesis is consisted of five chapters organized as follows:

Chapter 1 (Introduction)

This chapter gives a general background about concrete, and contains research problem, aim and objectives of research, the methodology used to achieve the research objectives and describes the structure of the research.

Chapter 2 (Literature Review)

This chapter gives general review of previous research related to Normal Rubber Concrete (NRC) and the main materials used for Pre-treated Recycled Tire Rubber., advantages, disadvantages and applications.

Chapter 3 (Materials and Experimental Program)

This chapter outlines the materials were used in this research, their proportions, testing program and equipment were used in the testing procedures.

Chapter 4 (Test Results and Discussion)

This chapter explains and discusses the results of the tests that were performed on Normal Rubber Concrete and discussion are included.

Chapter 5 (Conclusions and Recommendations)

This chapter includes the concluded remarks, main conclusions and recommendations drawn from this research.

- **(References)**

- **(Appendices)**

Chapter 2

Literature Review

CHAPTER 2- LITERATURE REVIEW

2.1 Introduction

This chapter presents a background about the solid waste management (SWM), general characteristics and constituents of concrete chemical composition, tire manufacturing, typical materials used in manufacturing tire, civil engineering applications of recycled rubber (from scrap tires and many studies and research about NRC.

2.2 Tire waste management

Solid waste management is one of the major environmental concerns in the world. Each year thousands of tires are added to stockpiles, landfills, and illegal dumps across the West Bank and Gaza Strip, which causes extensive environmental and hazardous problems. Waste tires stockpiles are dangerous not only due to potential environmental threat, but also from fire hazards and creating a breeding grounds for rats, mice, vermin’s and mosquitoes **(Naik and Singh, 1991).**

Over the years, disposal of tires has become one of the serious problems for the environment. Land-filling is becoming unacceptable for waste tires because of the rapid depletion of available sites for waste disposal.

2.3 Tire Manufacturing

The tire manufacturing process includes the manufacture of rubber and placing additives in the rubber. It also includes the coating of fabrics for the radial belts and bias plies and integrating them into the rubber. Rayon, nylon, and now more commonly polyester in addition to building wire bead stock, make up the structural components of tires. The fabric with rubber, the bead stock with rubber, and the rubber tread is combined on a drum by layering (the tread is put on last). There can be as many as 40 layers of fabric and steel bead wire on a truck tire. Once the layers are put on, the tire stock is put into a mold over an inflatable steam heated tube. The tube is inflated and the mold is closed. The tire is heated and cured and the excess rubber extrudes out of weep holes in the mold. Curing times and temperatures vary widely between manufacturers and tire compositions. Typical curing times are around 20 minutes with temperatures around 160°F. The curing is the vulcanization takes place **(CIWMB, 1994).**

Table 2.1 gives the typical materials used in manufacturing tires.
Figure 2.1 below shows the physical section of tire.

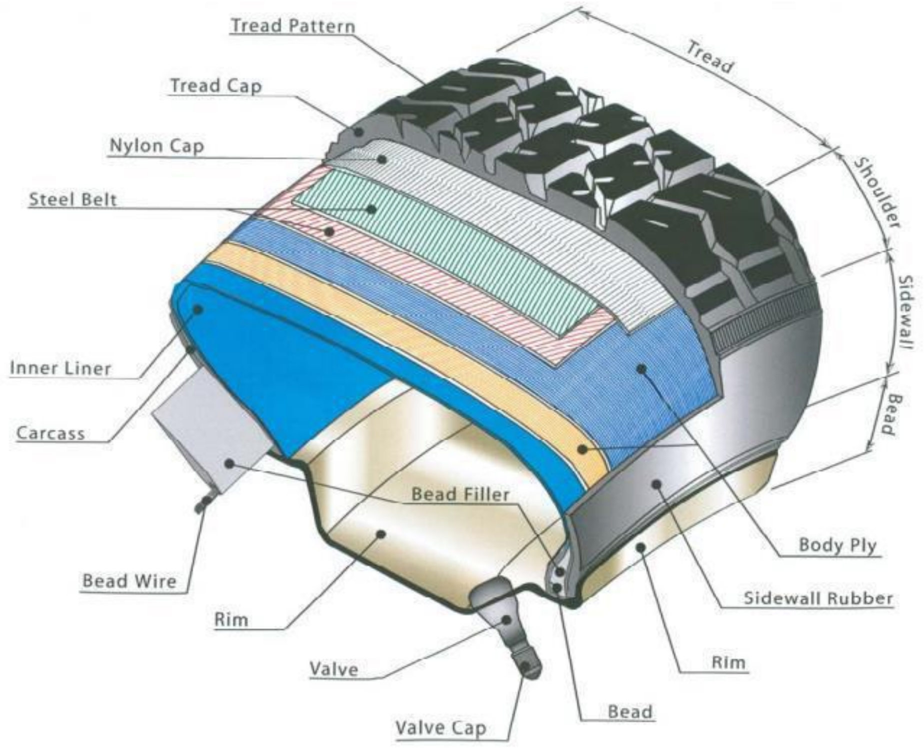

Figure 2.1 cross section of tire and it's composition

Table 2.1: Typical materials used in manufacturing tire. (Source: Siddique and Naik, 2004).

SN.	Material Name
1	Synthetic rubber
2	Natural rubber
3	Sulfur and sulfur compounds
4	Phenolic resin
5	Oil: (i) Aromatic (ii) Naphthenic (iii) Paraffinic
6	Fabric: (i) Polyester (ii) Nylon
7	Petroleum waxes
8	Pigments: (i) Zinc oxide (ii) Titanium dioxide
9	Carbon black
10	Fatty acids
11	Inert materials
12	Steel wires

2.4 Construction Engineering Applications of Recycled Rubber

Waste materials are common problems in modern life. Waste accumulates from a number of sources including domestic, industrial, commercial and construction. These waste materials have to be eventually disposed of in ways that do not endanger human health. In light of this, waste minimization increasingly seen as an ecologically sustainable strategy for alleviating the need for the disposal of waste materials, which is often costly, time and space consuming, and can have significant detrimental impacts on the natural environment. Nowadays governments and organizations have been concerned with developing policies and programs to bring about successful outcomes to waste minimization. It also emphasized that the possibility of using solid wastes as aggregates in concrete serves as one promising solution to the escalating solid waste problem. Among the waste materials in the advancement of civilization are discarded waste tires, in which rubber represents approximately (85%) of the weight of car or truck tires **(Christina, 1994).**

Crumb rubber is a finely ground tire rubber from which the fabric and steel belts have been removed. It has a granular texture and ranges in size from very fine powder to sand-sized particles. Crumb rubber has been successfully used as an alternative aggregate source in both asphalt concrete and NC. This waste material has been used in several engineering structures like highway Base-coarses, embankments, etc. No local experience have been recorded any utilization or management of this waste material, on the contrary, several cases of fatal and hazardous conditions occur on daily bases as a result of ignorance and bad handling of this waste material. It is important to note that the generation of this material on daily basis locally and world wide is beyond tolerated level, which makes it an urgent and a standing issue to deal with **(Shtayeh, 2007).**

2.5 Some examples of using scrap tires in civil applications

2.5.1 Subgrade Insulation for Roads

Excess water is released when subgrade soils thaw in the spring. Placing a 15 to 30 cm thick tire shred layer under the road cab prevents the subgrade soils from freezing in the first place. In addition, the high permeability of tire shreds allows water to drain from beneath the roads, preventing damage to road surfaces **(ASTM D6270-98).**

2.5.2 Subgrade Fill and Embankment

Tire shreds can be used to construct embankments on weak, compressible foundation soils. Tire shreds are viable in this application due to their ligh weight. For most projects, using tire shreds as a lightweight fill material is significantly a cheaper alternative.

2.5.3 Backfill for Walls and Bridge Abutments

Tire shreds can be useful as backfill for walls and bridge abutments. The weight of the tire shreds reduces horizontal pressures and allows for construction of thinner, less expensive walls. Tire shreds can also reduce problems with water and frost build-up behind walls because tire shreds are free draining and provide good thermal insulation. Recent research has demonstrated the benefits of using tire shreds in backfill for walls and bridge abutments.

2.6 Other uses of scrap tires in civil applications

- Playground surface material.
- Gravel substitute.
- Drainage around building foundations and building foundation insulation.
- Erosion control/rainwater runoff barriers (whole tires).
- Wetlands/marsh establishment (whole tires).
- Crash barriers around race tracks (whole tires).
- Boat bumpers at marinas (whole tires).
- Artificial reefs (whole tires).

2.7 General Characteristics and Constituents of Concrete

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together. In its simplest form, concrete is a mixture of paste and aggregates. The paste, composed of Portland cement and water, coats the surface of the fine and coarse aggregates. Through a chemical reaction called hydration, the paste hardens and gains strength to form the rock-like mass known as concrete. The ability of concrete to be casting to any desired shape and configuration is an important characteristic that can offset other shortcomings. Good quality concrete is a very durable material and should remain maintenance free, for many years when has been properly designed for the service conditions and properly placed. The main advantages of concrete as a construction material are the ability to be cast, being economical, durability, fire resistance, energy efficiency, on-site fabrication and its aesthetic properties. Whereas the disadvantages are low tensile strength, low ductility, volume instability and low strength to weight ratio **(Mindess et al. 2002).**

Numerous advances in all areas of concrete technology including materials, mixture proportioning, recycling, structural design, durability requirements, testing and specifications have been made.

2.8 Some methods of Pre-Treatment

The interfacial-bonding, interfacial transition zone (ITZ), and porosity are regarded as the key factors affecting hardened concrete properties, there are many different methods to improve the bonding between the rubber aggregate and cement paste such as:

- Water washing
- Na(OH) pre-treatment
- Mortar pre-coating.
- Cement paste pre-coating.

2.9 Constituents of Concrete

2.9.1 Cement

Cement is a generic name that can apply to all binders. The chemical composition of the cements can be quite diverse but by far the greatest amount of concrete used today made with Portland cements for this reason, the discussion of cement in our project is mainly about the Portland cement **(Mindess et al. 2002)**.

Portland cement, the basic ingredient of concrete, is a closely controlled chemical combination of calcium, silicon, aluminum, iron and small amounts of other ingredients to which gypsum added in the final grinding process to regulate the setting time of the concrete. Lime and silica make up about 85% of the mass. Common among the materials used in its manufacture are limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand, and iron ore. Each step in the manufacturing of Portland cement checked by frequent chemical and physical tests in plant laboratories. The finished product also analyzed and tested to ensure that it complies with all specifications **(Mindess et al. 2002)**.

Different types of Portland cement manufactured to meet different physical and chemical requirements for specific purposes. The American Society for Testing and Materials (ASTM) Designation C150 provides many types of Portland cements **(Mindess et al. 2002)**.
Like type (I, II, III, IV, V) **(ASTM C150. 2002)**

2.9.2 Aggregates

Mineral aggregates consist of sand, gravel, stones and crushed stone. Construction aggregates make up 60 – 80 % of the total concrete volume. The sources of mineral aggregates are by directly extracting from the original sources like river basins or by manufacturing them into a desired shape from the parent rock in a crasher mill. In addition, it found out that manufactured sand offers a viable alternative to the natural sand by providing a higher compressive strength and delivering environmental benefits **(Shewaferaw, 2006).**

All natural aggregate particles originally formed as part of a larger parent mass. This may have fragmented by natural processes of weathering and abrasion or artificially by crushing. Thus, many properties of the aggregate depend entirely on the properties of the parent rock, e.g. chemical and mineral composition, specific gravity, hardness, strength, physical and chemical stability, pore structure, and color. On the other hand, there are some properties possessed by the aggregate but absent in the parent rock: particle shape and size, surface texture and absorption. All these properties may have a considerable effect on the quality of the concrete, either in the fresh or in the hardened state **(Neville, 1996)**.

2.9.3 Water

Water is a key ingredient in the manufacture of concrete. Attention should give to the quality of water used in concrete. The time-honored rule of thumb for water quality is “If you can drink it, you can make concrete with it.” Mixing water can cause problems by introducing impurities that have a detrimental effect on concrete quality. Although satisfactory strength development is of primary concern, impurities contained in the mix water may also affect setting times, drying shrinkage, or durability or they may cause efflorescence. Water should avoided if it contains large amounts of dissolved solids, or appreciable amounts of organic materials (**Mindess et al. 2002**).

2.9.4 Chemical Admixtures

Admixtures are ingredients other than water, aggregates, hydraulic cement, and fibers that added to the concrete batch immediately before or during mixing. A proper use of admixtures offers certain beneficial effects to concrete, including improved quality, acceleration or retardation of setting time, enhanced frost and sulfate resistance, control of strength development, improved workability, and enhanced finish ability.

2.10 Previous Studies

Several researches have been conducted to study the effects of RTR & PTRTR on fresh and mechanical properties of NC. The Following tittles presented previous studies about using RTR in concrete.

Partially replacing the coarse or fine aggregate of concrete with some quantity of small waste tire can improve qualities such as low unit weight, high resistance to abrasion, absorbing the shocks, vibrations and high ductility.

Rubber obtained by reduction of scrap tires to aggregate sizes using two general processing technologies: mechanical grinding or cryogenic grinding. Tires have used primarily because they have physical properties, which can be substituted for existing materials, or because their properties provide an advantage over existing materials. These include Durability, low unit weight, high hydraulic conductivity, low horizontal stress, flexibility for construction and thermal resistivity **(Hallett, 2002).**

Eldin and Senouci, 1993 study the strength and toughness properties of rubberized concrete mixtures. They used two types of tire rubber with different rubber content. Their results indicate that there is about an 85% reduction in compressive strength, whereas the tensile strength reduced to about 50% when the coarse aggregate was fully replaced by rubber. A smaller reduction in compressive strength (65%) was observed when sand was fully replaced by fine crumb rubber. Concrete containing rubber did not exhibit brittle failure under compression or split tension. A more in-depth analysis of their results indicates a good potential of using recycled rubber in Portland cement concrete mixtures because it increases fracture toughness. However, an optimized mix design is needed to optimize the tire rubber content in the mixture.

Jomaa, et al. 2011 study the effect of adding %by weight of chopped rubber tire small pieces (10,20,30) % as areplacement materials from the weight of gravel to concrete as piece which have dimensions of (7*7*10)mm. The tests which were used in this study were compressive strength, absorption and density. It was found that in cooperating of chopped rubber tire in concrete affected negatively an compressive strength relative to reference mix at 28 day were (15,22,31)% for Concrete with (10,20,30)% from chopped rubber tire by weight of coarse aggregate respectively . Also there is increase in total absorption ratio relative to reference mix at 28 day were (33,63,72)% from Concrete with (10,20,30)% respectively. Also there is decrease in wet and dry density relative to reference mix at 28 day were (3,7,15)% and (3,8,16)% for concrete with (10,20,30)% from chopped rubber tires by weight of coarse aggregate respectively, and this leads to decrease in weight to dead loads and in the end on foundation and its quality .it was found that the inclusion of chopped rubber tires in concrete affects the properties of concrete matrix which indicate large value in structural manufacture, so can production light weight rubber concrete and insulator.

Zaher and Bayomy, 1999 also investigated recycled waste tire rubber as an additive to Portland cement concrete Two types of waste tire rubber were used, fine crumb rubber and coarse tire chips. The study was divided into three groups. In the first group only crumb rubber was used and only replaced the fine aggregates. In the second group tire chips were used to replace the coarse aggregates. In the third and final group both crumb and chips were used. In this group the rubber content was equally divided between crumb and chips, and again the crumb replaced fine aggregates while the chips replaced the coarse aggregates. The rubber content used in the three groups ranged from 5-100%. The aggregates were partially replaced by the rubber. They found that rubberized PCC can be made and are workable (even though greatly reduced) with the rubber content being a much as 57% of the total aggregate volume. Their results showed that the reduction in strength was too great, thus they recommended not replacing more than 20% by volume of the aggregate with waste tires.

Hernandez and Barluenga, 2003 have tried to gain different advantages from the use of waste tire in concrete. High-strength concrete (HSC) with silica fume was modified with different amounts of crumbed truck tires. They were aiming to reduce the stiffness of HSC to make it compatible with other materials and building elements, unexpected displacement of building foundations and improving the fire performance of the buildings. They found that since water vapor can escape through the channels left as the waste tire particles are burned, the inclusion of low volume fractions of rubber would reduce the risk of explosive spalling of HSC at high temperature. This was very desirable since HSC was more susceptible to explosive spalling when subjected to rapid heating than normal strength concrete.

Samples containing 0%, 3%, 5% and 8% waste tires were made. Mechanical, destructive and non-destructive tests were performed on the samples and it was found that volume fractions up to 3% do not significantly reduce the strength of the composite although it does reduce the stiffness. Higher volumes of rubber result in a reduction of strength but improve the dynamic behavior of the concrete.

Toutanji study Four different volume contents of rubber tire chips used: 25, 50, 75 and 100%. The incorporation of these rubber tire chips in concrete exhibited a reduction in compressive strength of about 75 % depending on the volume percentage of rubber chips. A significantly smaller reduction in flexural strength was observed as compared to compressive strength with increases in the tire chip contents. The flexural strength specimens lost up to 35% of their flexural strength, the failure of specimens containing rubber tire chips exhibited a ductile mode of failure as compared to the control specimens. The specimens exhibited a higher capacity to absorb energy. The toughness increased when rubber tire incorporated into concrete. Specimens with 50 and 100% rubber tire aggregate exhibit equal toughness values. Shredded rubber tires, which used in this experiment with a maximum size of 12.7 mm & a specific gravity of about 0.61. The rubber tire chips were free of steel wires. No mineral or chemical admixtures added. In general all mixes, control and rubber tire mixes, exhibited acceptable workability with respect to handling, placement, and finishing. The control mix exhibited a slump of about 76 mm (3 in) and with 100% replacement of the coarse aggregate with rubber particles the slump decreased by about half to 38 mm.

Waste tire steel beads were also used in concrete. The experimental results indicate that although the compressive strength is reduced when steel beads are used, the toughness of the material greatly increases. Moreover, the workability of the mixtures fabricated was not significantly affected **(Christos and Matthew 2006).**

Guoqiang et al. 2004 study of the development of waste tire modified concrete, two types of waste tire configurations were evaluated. One was in the form of chips, or particles and the other was in the form of fibers. Conclusions showed that fibers performed better than chips do.
Although thinner fibers perform better than thicker fibers do, the effect was not very significant. Steel belt wires in waste tires had a positive effect on increasing the strength of rubberized concrete. Truck tires performed better than car tires did.

Hadithi et al. 1999 used chopped worn-out Tires in production of light weight concrete masonry units This research, generally aimed at defining the possibility of using chopped worn-out tires to produce lightweight concrete building units.

Many experimental mixtures were made with different percentages of chopped worn-out tires after identifying the importance of produced characteristics of the mixtures. For producing lightweight chopped worn-out tires concrete mixes, many trials were adopted in selecting the required mixes.

The methodology of aggregate replacement was to substitute a certain volume of aggregate by the same volume of chopped worn-out tires, but with different partial replacement ratios (PRR'S) for the sand and the gravel. For production and testing chopped worn-out tires in hollow-concrete blocks units with a new suggested geometry, in addition to the conventional units, to enhance the structural properties of walls and the other properties which are provided by using chopped worn-out tires, five short walls were built from fine-block using both chopped worn-out tires (concrete and mortar) mixes with their corresponding plain mixes (without chopped worn-out tires). Also two short walls were built from traditional hollow-concrete block with two holes using plain mixes (without chopped worn-out tires) **(Shtayeh, 2007).**

The main conclusions from this investigations were incorporating chopped worn-out tires into the mortar and concrete mixes as a partial replacement of aggregate reduced its unit weight, compressive strength and flexural strength and increased its thermal insulation significantly, the chopped worn-out tires concrete masonry wall had numerous benefits especially in the reduction of the dead loads, improving the thermal insulation and provided a satisfactory structural function, the absorption of the chopped worn-out tires concrete units was within the range of ACI 531-83 requirements for the corresponding lightweight masonry unit, the performance of fin-blocks was superior as compared with that of conventional blocks, and cracks occurred simultaneously in masonry units and mortar, these cracks which developed in a masonry wall before failure were visible to the naked eye **(Shtayeh, 2007).**

2.11 Bond Strength between Rubber and Matrix

The main factors controlling the theoretical performance of the composite material are the physical properties of the fibers and the matrix, and the strength of the bond between the two. Bond strengths vary with a wide variety of parameters, including time.

From several experiments conducted, one of the general conclusions was that there was a reduction in compressive, flexural and tensile strength. Several authors have suggested that the loss in strength might be minimized by prior surface treatment of the waste tire **(Lee, et al. 1993), (Raghavan, et al. 1998).** The bonding between concrete matrix and waste tire is not very strong. A study was conducted **(Segre and Joekes, 2000)** in which the surface of powdered rubber tire was modified with several surface treatments including sodium hydroxide (Na OH), to increase the hydrophilicity of the rubber surface. It was assumed that by doing this, the sodium hydroxide would hydrolyze the acidic and/or carboxyl groups present on the rubber surface **(Smith and Chughtai, 1995)**. The samples were cured for 28 days then tested.

To determine the nature of the bond between the rubber-cement matrix interfaces, micrographs of the samples were obtained by using a scanning electron microscope (S.E.M.). Micrographs of the fracture surface of a cement sample with 10% rubber showed a bulk region and the rubber particles seem to have been pulled-out. It was also noted that there was less pull out from the matrix for the Na OH treated rubber than for the untreated rubber. Discontinuity was seen in the rubber-matrix interface implying that the rubber adhesion to cement paste is poor. When the same analysis was done on the waste tire treated with Na OH, an adhesive joint was observed between the rubber and the matrix. Electron microscopic examinations showed that the sodium hydroxide surface treatment improved the waste tire – matrix adhesion **(Smith Chughtai, 1995).**

Flexural strength, modulus of elasticity, compressive strength and abrasion resistance test were done using samples containing 10% of sodium hydroxide treated rubber. They found that for flexural strength the specimen with Na OH-treated rubber showed higher values than the control specimen **(Segre and Joekes, 2000).**

Ghedan and Hamza 2011 study the compressive strength and thermal conductivity of the rubberized concrete compared with the traditional one and how it affected by using a coupling agent such as SILAN which is used currently in the present study to treat the particles of rubber. Three patches were prepared. Each one consists of three cubic specimens (15x15x15)cm and two disc specimens (5x1)cm. The first patch was the control concrete, the second was the rubberized concrete, in this one 15% the volume of gravel were replaced by waste tires particles and the third was the modified rubberized concrete in this patch rubber particles were treated with SILAN of 0.1% of water as a coupling agent. Compressive strength and thermal conductivity tests were conducted for the three patches. The overall results show that the adding of rubber particles to the concrete to obtain a lightweight one cause a reduction in the compressive strength by about 49.8% from traditional concrete, so to improve this property the SILAN used as a coupling agent to treat the surface of rubber particles and it was found to be very effective in improving the compressive strength so that this strength reduced by about 12.9% from traditional concrete. Also, the added rubber particles decreased the thermal conductivity of the rubberized concrete by about 26.7% from traditional concrete while when rubber particles treated with SILAN, thermal conductivity increased by about 17.8% from traditional concrete.

Raghavan, et al. 1998 confirms that the immersion of rubber in Na OH aqueous solution could improve the adhesion leading to a high strength performance of concrete rubber. Composites. The NaOH removes zinc stearate from the rubber surface, an additive responsible for the poor adhesion characteristics, enhancing the surface homogeneity.

Segre and Joekes, 2002 mention several pretreatments to improve that the adhesion of rubber particles like acid etching, plasma and the use of coupling agents.

Cairns et al, 2004 used rubber aggregates coated with a thin layer of cement paste.

Albano et al, 2005 study concrete composites containing scrap rubber previously treated with NaOH and silane in order to enhance the adhesion between the rubber and the cement paste without noticing significant changes, when compared to the untreated rubber composites.

Chou, et al. 2010 suggest the pretreatment of crumb rubber with organic sulphur stating it can modify the rubber surface properties increasing the adhesion between the waste and the cement paste.

2.12 Fresh Concrete Properties Containing RTR

2.12.1 Slump

Raghvan, et al. 1998 reported that mortars incorporating rubber shreds achieved workability (defined as the ease with which mortar/concrete can be mixed, transported and placed) comparable to or better than a control mortar without rubber particles.

Khatib and Bayomy 1999 investigated the workability of rubber concrete and reported that there was a decrease in slump with increase in rubber content as a percentage of total aggregate volume. They further noted that at rubber contents of 40%, slump was almost zero and concrete was not workable manually. It was also observed that mixtures made with fine crumb rubber were more workable than those with coarse tire chips or a combination of tire chips and crumb rubber.

2.12.2 Air Content

Emiroglu et al. 2007 find that higher air content in rubberized concrete was reported than control mixtures. Air easily trapped by the rough surface of the tire particles created during the milling process. Rubber also has hydrophobic tendencies to repel water and cause air to adhere to rubber particles.
According to **(Fedroff et al. 1996), and (Khatib and Bayomy)** the air content increased in rubber mixtures with increased amounts of ground tire rubber. Although no air-entraining agent used in rubber mixtures, higher air contents were measured as compared to control mixtures. Since rubber has a specific gravity of 1.14, it expected to sink rather than float. However, if air trapped in the jagged surface of the rubber particles, it could cause them to float.
This increase in air voids content would certainly produce a reduction in concrete strength, as does the presence of air voids in plain concrete **(Neville, 1996).**

2.13 Hardened Concrete Properties Containing RTR

2.13.1 Unit Weight

Due to the low specific gravity of rubber, the unit weight of rubber mixtures decreases as the percentage of rubber increases. However, the decrease is almost negligible for rubber contents lower than 10 to 20% of the total aggregate volume.

2.13.2 Compressive strength

Compressive strength tests are widely accepted as the most convenient means of quality control of the concrete produced. **(Eldin and Senouci. 1993)** noted when coarse aggregate was 100% replaced by tire chips, there was approximately an 85% reduction in compressive strength.

In another study by Ling T.C. and Hasanan M.N, test results have shown that there a systematic reduction in the compressive strength with the increase in rubber content from 0 % to 30 % **(Emiroglu, et al. 2007).**

According to **(Felipe and Jeannette, 2004)**, a maximum strength reduction of 50% noted for a mix with 14% substitution in their studies. Nevertheless, in a very different approach, Hanson aggregates achieved higher compressive strength in crumb rubber concrete by reducing entrapped air in the mix **(Naik and Singh, 1992).**
In most of the previous studies, a reduction in compressive strength noted with the addition of rubber aggregate in the concrete mix but there is still a possibility of greatly improving the compressive strength by using **(Neville, 1996).**

2.13.3 Tensile Strength

The tensile strength of rubber containing concrete is affected by the size, shape, and surface textures of the aggregate along with the volume being used indicating that the strength of concretes decreases as the volume of rubber aggregate increases **(Michelle et al. 2006)**.

As the rubber content increased, the tensile strength decreased, but the strain at failure also increased. Higher tensile strain at failure is indicative of more energy absorbent mixes **(Shewaferaw, 2006)**.

Tests conducted on rubberized concrete behavior, using tire chips and crumb rubber as aggregate substitute of sizes 38, 25 and 19 mm exhibited reduction in splitting tensile strength by 50% but showed the ability to absorb a large amount of plastic energy under tensile loads **(Mindess et al. 2002)**.

2.13.4 Impact Strength and other mechanical properties

Previous investigations have shown that the addition of rubber aggregate into the concrete mixture produces an improvement in toughness, plastic deformation, impact resistance and cracking resistance of the concrete. For concrete, it is found that the higher the strength, the lower the toughness. It is difficult to develop high strength and high toughness concrete without modifications. Owing to the very high toughness of waste tires, it expected that adding crumb rubber into concrete mixture could increase the toughness of concrete considerably. Laboratory tests have shown that the introduction of waste tire rubber considerably increase toughness, impact resistance, and plastic deformation of concrete.

An analysis carried out on rubberized concrete that used 15% replacement of waste tire for an equal volume of mineral coarse aggregate. It was used as a two phase material as tire fiber and chips dispersed in concrete mix. The result is that there is an increase in toughness, plastic deformation, impact resistance and cracking resistance. However, the strength and stiffness of the rubberized sample were reduced .The control concrete disintegrated when peak load reached while the rubberized concrete had considerable deformation without disintegration due to the bridging caused by the tires. The stress concentration in the rubber fiber modified concrete is smaller than that in the rubber chip modified concrete. This means the rubber fiber modified concrete can bear a higher load than the rubber chip modified concrete before the concrete matrix breaks **(Kumaran et al. 2008)**.

Using rubber waste in concrete, less concrete module of elasticity obtained. Modulus of elasticity related to concrete compressive strength and the elastic properties of aggregates have substantial effect on the modulus of elasticity of concrete. The larger the amount of rubber additives added to concrete, the lesser the modulus of elasticity **(Gintautas et al. 2007).**

2.13.5 Freezing and Thawing Resistance

Savas et al. 1996 carried out investigations to study the rapid freezing and thawing (ASTM C 666, Procedure A) durability of rubber concrete.
Various mixtures were made by incorporating 10, 15, 20, and 30% ground rubber by weight of cement used for the control mixture. Based on their studies, they concluded that:
(1) Rubcrete mixtures with 10% and 15% ground rubber (2 to 6 mm in size) exhibited durability factors higher than 60% after 300 freezing and thawing cycles, but mixtures with 20% and 30% ground rubber by weight of cement could not meet the ASTM standards (durability factor).
(2) Air-entrainment did not provide improvements in freezing and thawing durability for concrete mixtures with 10, 20 and 30% ground tire rubber.
(3) Increase in scaling (scaling gives an evaluation of the surface exposed to freezing and thawing cycles as measured by the loss of weight) increased with the increase in freezing and thawing cycles.

Benazzouk and Queneudec. 2002 studied the freeze–thaw durability of cement–rubber composites through the use of two types of rubber aggregates. The types of the aggregates were: compact rubber aggregate (CRA) and expanded rubber aggregates (ERA). Volume-ratio of the aggregates ranged from 9% to 40%. The results showed improvements in the durability of the composite containing 30% and 40% rubber by volume. Improvement in the durability of the composite containing ERA type aggregates is better than composite made with CRA aggregates. The finding is more distinct for ERA type.

Chapter 3

Constituent Materials and Experimental Program

CHAPTER 3- CONSTITUENT MATERIALS AND EXPERIMENTAL PROGRAM

3.1 Introduction

This chapter comprises the experimental program and the constituent materials used to study the influence of RTR and PTRTR on fresh and hardened properties of NC, Concrete mix with a compressive of 25 Mpa is used. Mixes with different methods of per-treated rubber particles were used, and after selecting the best method many mixes with different percentage of rubber are studied compared with the original mix.
The materials used to develop the concrete mixes in this study were fine aggregate, coarse aggregate, shredded rubber, bonding agent, sodium hydroxide (NA OH) cement and water.

The laboratory investigation consisted of tests for both fresh and hardened concrete properties. Fresh concrete was tested for slump flow. The tests for hardened concrete included compression tests for compressive strength, Splitting Tensile Strength (cylinder),unit weight and impact Strength test.

The properties of several constituent materials used in this work 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 RNC properties are illustrated in the following sections.

The necessary tests are conducted in the laboratory of materials and soil in the Islamic University and in accordance with ASTM.

3.2 Experimental Program

Nine mixes were to be conducted as follow:

1. One control mix with no replacement of aggregates called Normal Concrete without rubber (NC0), which is required for comparative analysis.
2. Three mixes with 10%, 20%, 30% of rubber content called NRC10, NRC20 and NRC30, would be replaced by volume of coarse aggregates (50% from the main replacement ratios) and fine aggregates also (50% from the main replacement ratios).
3. Three mixes with 20% of rubber content, would be replaced by volume of coarse aggregates (50% from the main replacement ratios) and fine aggregates also (50% from the main replacement ratios) by using the following methods of treatment:
    - Pre-treatment by using NaOH solution, called Modified Normal Rubber Concrete by using NaOH pre-treatment (MNRC1).
    - Pre-treatment by using mortar pre-coating, called Modified Normal Rubber Concrete by using Mortar pre-coating (MNRC2).

- Pre-treatment by using mortar by adding bonding agent pre-coating, called Modified Normal Rubber Concrete by using Mortar and bonding agent pre-coating (MNRC3).

4. After selection of the optimum method of pre-treatment two mixes with percent 10% and 30% of rubber content would be replaced by volume of coarse aggregates (50% from the main replacement ratios) and fine aggregates also (50% from the main replacement ratios) called (MNRC10), (MNRC30).

The test program adopted is summarized in Figure 3.1 below.

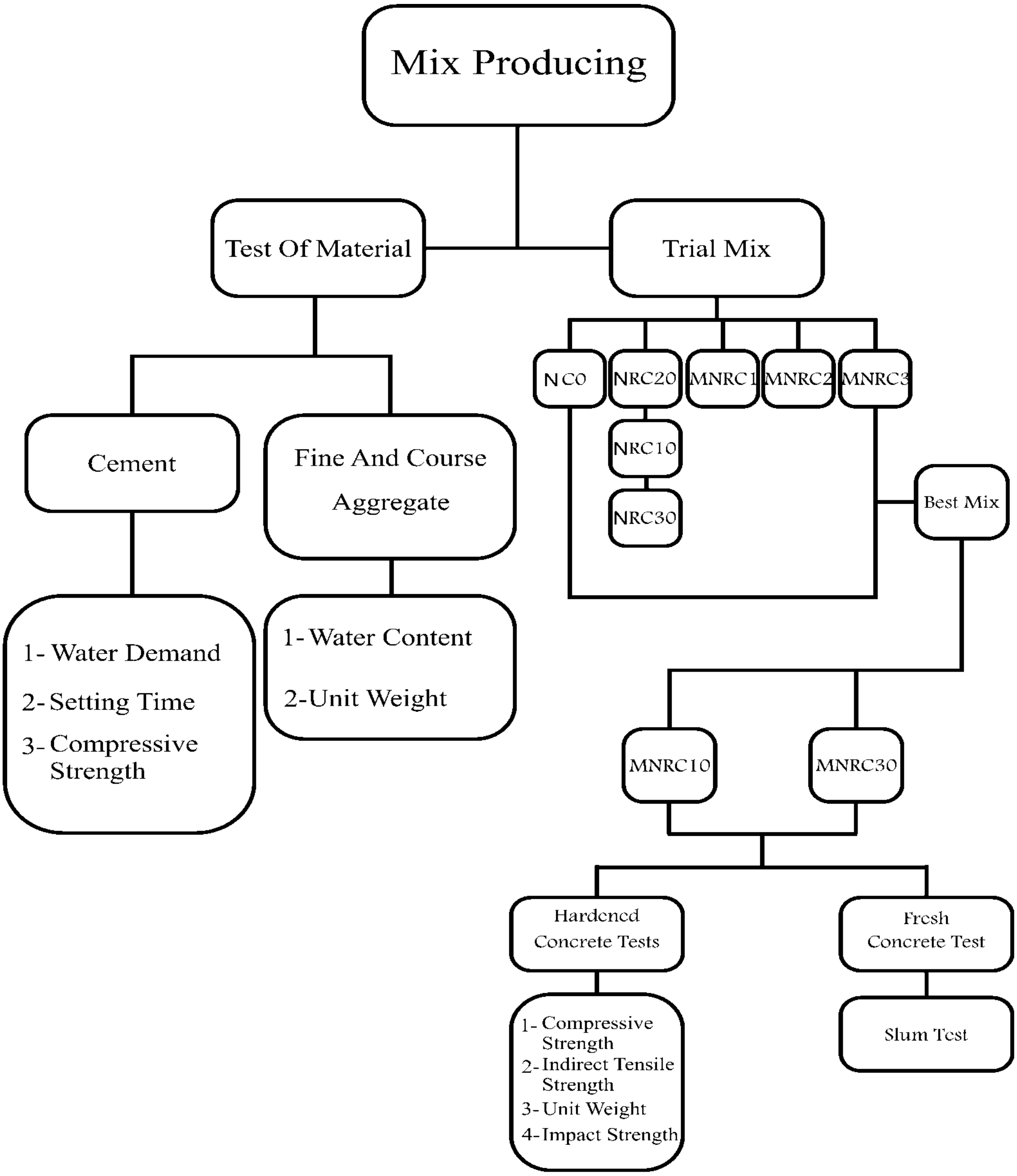

Figure 3.1 Experimental Program

3.3 Characterizations of constituent Materials

Normal rubber concrete constituent materials used in this research include ordinary Portland cement, fine aggregate (sand), coarse aggregate, water, rubber, sodium hydroxide (NA OH) and bonding agent (white glue).

Most of materials used were brought from local market, and the detailed properties discussed below.

3.3.1 Cement

In this research ordinary Portland cement CEM I 42.5R was used for the production of RNC and Modified Rubber Normal Concrete (MRNC). The cement met the requirements of ASTM C 150 specifications. The results of physical and mechanical analyses of the cements are summarized in Table 3.1 along with the requirements of relevant ASTM specifications for comparison purposes.

Table 3.1: Cement characteristics according to manufacturer sheet tests

Type of test		**Ordinary Portland Cement**	
		Results	**ASTM C 150**
Setting time (Vicat test) hr : min	Initial	1 hr 30 min	> 60 min
	Final	4 hr 40 min	< 6 hrs 15 min
Mortar compressive strength (MPa)	3-Days	25.7	Min. 12
	7-Days	36.9	Min. 19
	28-Days	53.4	No limit
Blain Fineness (cm2/gm)		3005	Min. 2800
Water demand		27.5 %	No limit

3.3.2 Fine Aggregates (Sand)

Aggregate is relatively inexpensive and strong making material for concrete. It is treated customarily as inert filler. The primary concerns of aggregate in mix design for NRC are gradation, maximum size, and strength. Providing that concrete is workable, the large particles of aggregate are undesirable for producing NRC, the nominal size ranges from 0.15 to 0.6 mm for sand (fine aggregate) which are locally available in Gaza. In addition, it is important to ensure that the aggregates are clean, since a layer of silt or clay will reduce the cement aggregate bond strength, in addition to increasing the water demand. (Figure 3.2).

3.3.2.1 Specific gravity and Unit weight

The density of the aggregate is required in mix proportions to establish weight volume relationships. The density is expressed as the specific gravity, which is dimensionless relating the density of the aggregate to that of water. The determination of specific gravity of quartz sand was according to ASTM C128.The specific gravity was calculated at two different conditions which are the dry condition and the saturated surface dry condition. Table 3.2 shows the physical properties of sand.

The unit weight or the bulk density of the aggregate is the weight of the aggregate per unit volume. The unit weight is necessary to select concrete mixtures proportions in NRC. The determination of unit weight was according to ASTM C556.
Table 3.2 illustrates the unit weight of sand.

Figure 3.2: Fine aggregate used in mixes (sand).

Table 3.2: Physical property of sand

Aggregate Size(mm)	Specific Gravity(dry)	Specific Gravity(SSD)	Unit Weight (kg/m3) (dry)	Unit Weight (kg/m3) (SSD)
0.6	2.658	2.675	1662.15	1672.588
0.5	2.663	2.68	1662.64	1673.002
0.4	2.668	2.685	1663.130	1673.416
0.3	2.680	2.697	1663.950	1674.100
0.15	2.680	2.697	1664.000	1674.614
average	2.670	2.687	1663.174	1673.544

3.3.2.2 Moisture content

The aggregate moisture is the percentage of the water present in the sample aggregate, either inside pores or at the surface. Moisture content of the fine aggregate was done according to ASTM C128, but the final moisture content was zero because fine aggregates were dried in an oven at temperature (110o C±5). Table 3.3 illustrates the absorption percentages of sand.

Table 3.3: Water absorption of sand

Aggregate Size(mm)	Water Absorption
0.6	0.620
0.5	0.625
0.4	0.628
0.3	0.636
0.15	0.639
average	**0.629**

From the previous results, it can be observed that the specific gravity ranges from 2.658 to 2.697 for sand, and the water absorption tends to increase with the size reduction.

3.3.3 Water

Drinkable and distilled water without any salts and chemicals was used in all concrete mixtures and in the curing of specimens.
The water source was the soil and material lab at Islamic University of Gaza (IUG).

3.3.4 Coarse Aggregate

Three size of coarse aggregates were used with maximum aggregate size (20mm). These are commonly types in Gaza and locally known as:

1. Size 1((25 mm) maximum size.) Foliya.
2. Size 2 ((19 mm) maximum size.) Adisya .
3. Size 3 ((9.5 mm) maximum size.) Simsymia.

Figure 3.3 Aggregate used in mixtures.

(a)

(b)

(c)

Figure 3.3 Aggregate used in mixtures

Figure 3.3: (a) Simsymia (9.5 mm) maximum size

Figure 3.3: (b) Adisya (19 mm) maximum size

Figure 3.3: (c) Foliya (25 mm) maximum size

The determination of Specific gravity and absorption of coarse aggregate was done based to **ASTM C 127,** in addition, moisture content and Unit weight of coarse Aggregate was don based to **ASTM C 566**.

Properties of coarse Aggregate for three sizes are shown in table 3.4, 3.5 and 3.6.

Table 3.4 Properties of coarse aggregates (SIZE 1)

Specific gravity (dry)	2.5
Specific gravity (SSD)	2.465
Moisture content	0% dry
Absorption capacity	1.77

Table 3.5 Properties of coarse aggregates (SIZE 2)

Specific gravity (dry)	2.5
Specific gravity (SSD)	2.548
Moisture content	0% dry
Absorption capacity	2.6%

Table 3.6 Properties of coarse aggregates (SIZE 3)

Specific gravity (dry)	2.5
Specific gravity (SSD)	2.497
Moisture content	0% dry
Absorption capacity	1.55

Tables 3.7, 3.8 and 3.9 show the sieve analysis test results and Figures 3.4, 3.5 and 3.6 show the Sieve Analysis for the three sizes of Coarse Aggregate.

Table 3.7: sieve analysis test results of coarse aggregates (SIZE 1)

Sieve No.	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	# 200
Sieve Opening Size	37.5	25. 0	19.0	12.5	9.50	4.75	2.36	0.075
% Passing	100.0	100.0	84.1	11.9	0.6	0.3	0.3	0.1

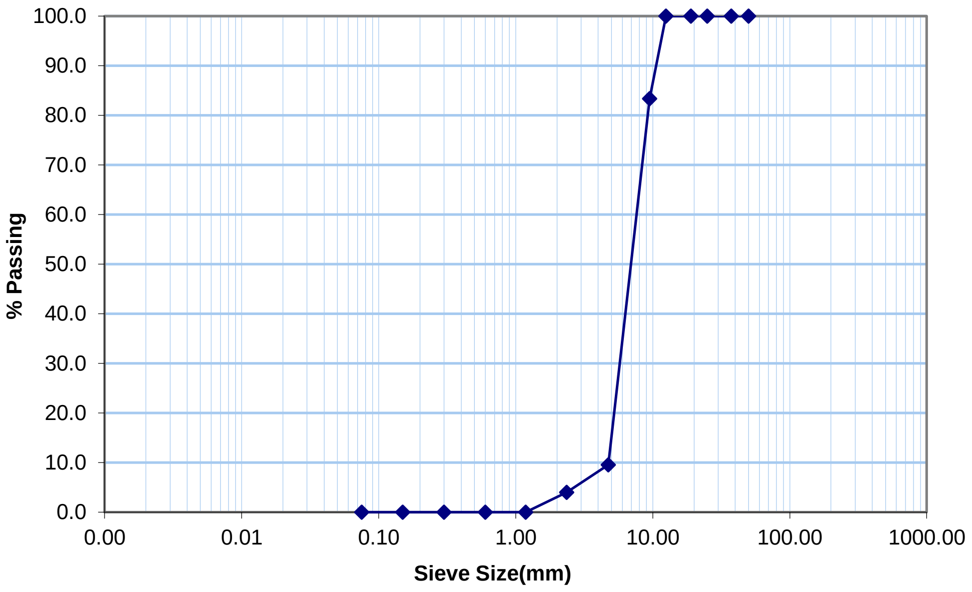

Figure 3.4: sieve analysis test results of coarse aggregates (Size 1)

Table 3.8: sieve analysis test results of coarse aggregates (SIZE 2)

Sieve No.	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	# 200
Sieve Opening Size	37.5	25. 0	19.0	12.5	9.50	4.75	2.36	0.075
% Passing	100.0	100.0	98.1	55.9	31.4	0.7	0.7	0.5

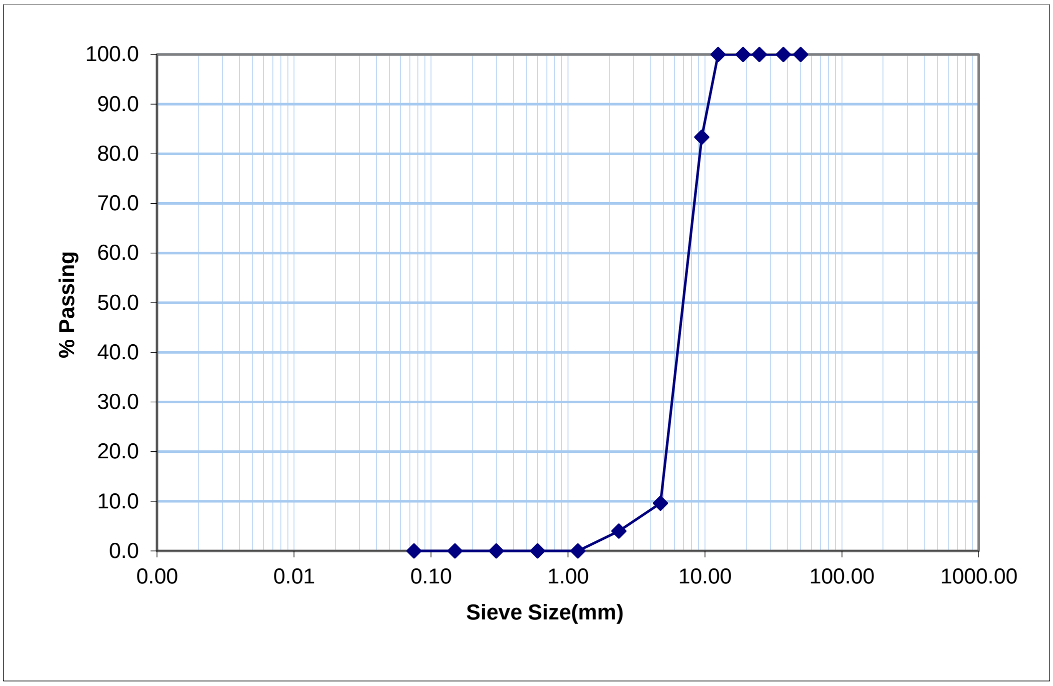

Figure 3.5: sieve analysis test results of coarse aggregates (Size 2)

Table 3.9: sieve analysis test results of coarse aggregates (SIZE 3)

Sieve No.	1 1/2"	1"	3/4"	1/2"	3/8"	#4	#8	# 200
Sieve Opening Size	37.5	25. 0	19.0	12.5	9.50	4.75	2.36	0.075
% Passing	100.0	100.0	100.0	100.0	83.4	9.6	4.0	2.1

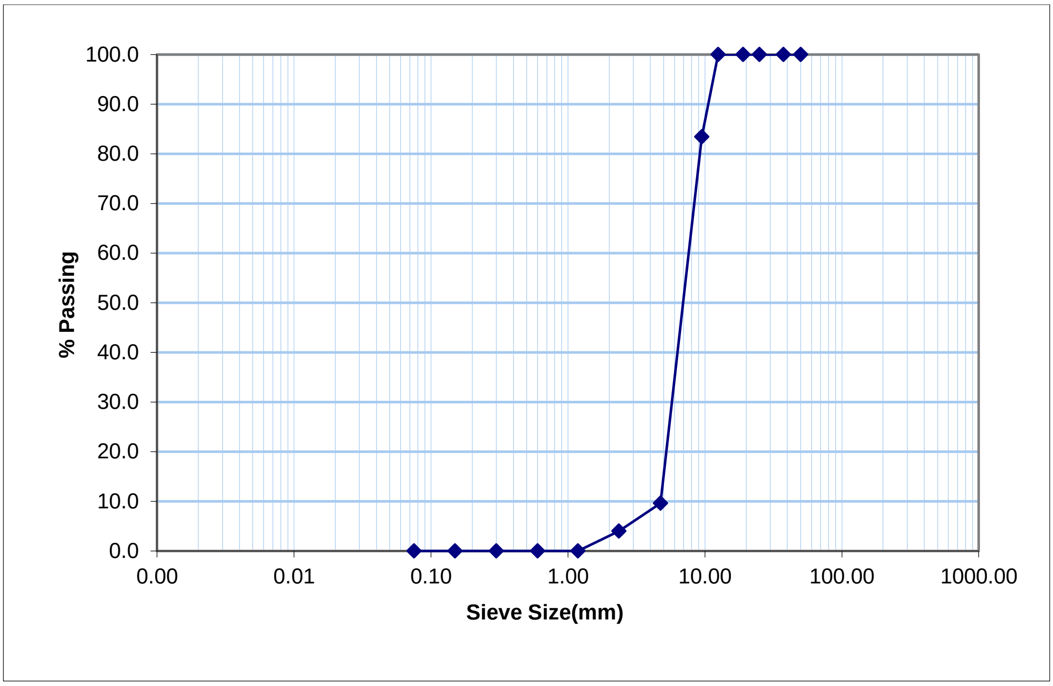

Figure 3.6: sieve analysis test results of coarse aggregates (SIZE 3)

3.3.5 Rubber

This study has concentrated on the performance of a multi gradation of crumb rubber prepared by mechanical cutting, using cutting machine.

The waste tires rubber used in this study was collected from Gaza market as a car tires then it was washed by cleaning water to remove any thing can change the properties of crumb rubber.

The rubber was crumbed with its steel fibers which were used in tiers manufacturing, by using cutting machine in Gaza, steel fibers were separate the maximum length of steel fibers measured in IUG lab was 5cm and with 1mm diameter.

The maximum size of the rubber measured in IUG lab was 15 mm, and the tensile strength of steel wires was measured in materials lab of IUG and it was 18.8 MPa.

Steel fibers are about 16% by weight from the total weight of crumb rubber.
Specific gravity is the ratio of the density of the solid phase of a material to the density of water at normal conditions. The specific gravity of tire rubber ranges between 1.02 and 1.27, **ASTM C29**. Specific gravity of rubber with steel fibers was calculated in materials lab of IUG and it was 1.13. See Figure 3.7.

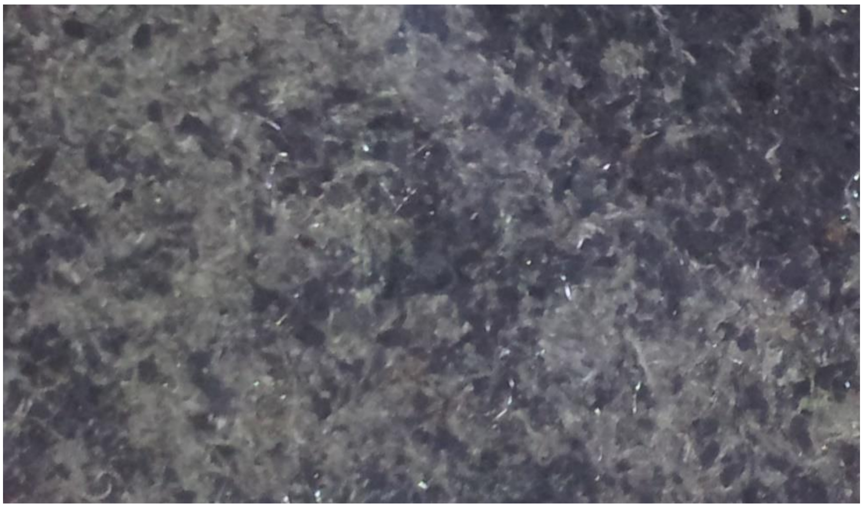

Figure 3.7 Crumb rubber with steel fibers

3.3.6 Sodium Hydroxide (NA OH)

3.3.6.1 Physical properties

Pure sodium hydroxide is a whitish solid, sold in pellets, flakes, and granular form, as well as in solution. It is highly soluble in water, with a lower solubility in ethanol and methanol, but is insoluble in ether and other non-polar solvents.

Similar to the hydration of sulfuric acid, dissolution of solid sodium hydroxide in water is a highly exothermic reaction in which a large amount of heat is liberated, posing a threat to safety through the possibility of splashing. The resulting solution is usually colorless and odorless. As with other alkaline solutions, it feels slippery when it comes in contact with skin, see Figure 3.8.

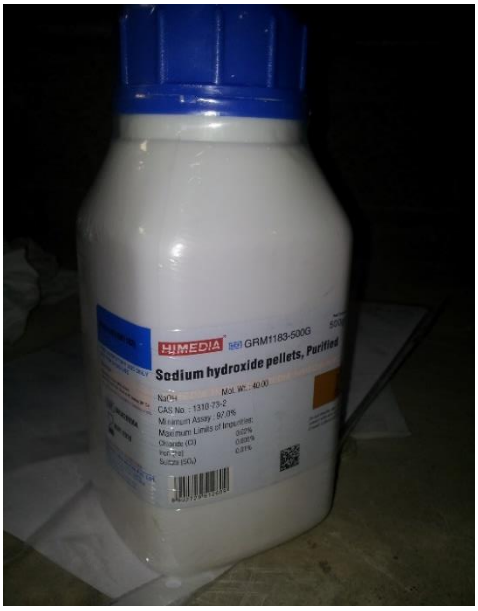

Figure 3.8: Sodium hydroxide pellets bottle

3.3.6.2 Cleaning agent

Sodium hydroxide is frequently used as an industrial cleaning agent where it is often called "caustic". It is added to water, heated, and then used to clean process equipment, storage tanks, etc. It can dissolve grease, oils, fats and protein based deposits. It is also used for cleaning waste discharge pipes under sinks and drains in domestic properties. See figure 3.9.

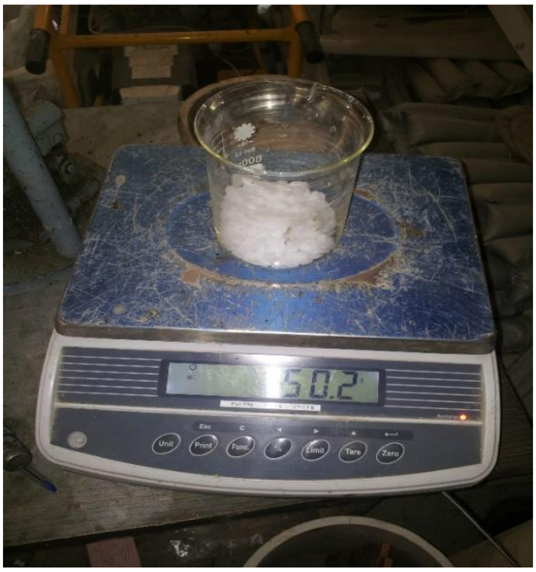

Figure 3.9: Sodium hydroxide pellets bottle

3.3.7 Bonding Agent

The chemical admixture used is bonding agent to confirm to ASTM-D4236 specifications it is a multi-purpose glue, it is provides an exceptionally strong bond for most porous materials including paper, wood, rubber, leather and cloth. See Table 3.10 and Figure 3.10.

When the bonding agent is added to mortar mix, it shows a strong bonding behavior between rubber particles and mortar and improves the properties of fresh and hardened concrete.

Table 3.10: Technical data for the white glue

Type	**Property**
Appearance	liquid
Viscosity	<100 mPa•s (25 °C)
Density	1.19 g/cm3 (25 °C)
Setting time	(20-30) min.
Toxicity	Safe and Non-Toxic

Figure 3.10: The bonding agent (White Glue)

3.4 Mix Design of normal rubber concrete

1. Determine the performance required. (What is Required, based on related specifications)).
2. Select constituent materials.
3. Mix design.
4. Verify experiment test.
5. Adjust proportions or verify.

3.5 Preparation of normal rubber concrete samples

After selection of all needed constituent materials and amounts to be used (mix designs); all materials are weighed properly. Then mixing with a power-driven tilting revolving drum mixer started to ensure that all particles are surrounded with cement paste and rubber particles and all the materials and fibers (i.e. steel fibers and rubber particles) should be distributed homogeneously in the concrete mass.
Table 3.11 below, show the constituents values of all mixes.

Tables 3.11: constituents values of all mixes

Mix	Cement Kg/m3	Water Kg/m3	Fine agg. Kg/m3	Coarse agg. (size1) Kg/m3	Coarse agg.e. (size2) Kg/m3	Coarse agg. (size3) Kg/m3	Rubber Kg/m3	% repl.
NC0	309	195	639	634	343	304	0	0
RNC20	309	195	575.1	634	343	273.6	62.63	20
MRNC1	309	195	575.1	634	343	273.6	62.63	20
MRNC2	309	195	575.1	634	343	273.6	62.63	20
MRNC3	309	195	575.1	634	343	273.6	62.63	20
RNC 10	309	195	607.05	634	343	288.8	31.32	10
RNC 30	309	195	543.15	634	343	258.4	93.95	30
MRNC10	309	195	607.05	634	343	288.8	31.32	10
MRNC30	309	195	543.15	634	343	258.4	93.95	30

3.6 Methods Of pre-treatment

When the bonding between rubber aggregate and cement baste was not very strong it will be important to improve the bonding between rubber aggregate and cement baste to produce more strong rubber concrete; in order to make that many methods of rubber pre-treatment were investigated such as NaOH solution, mortar pre-coating and mortar by adding bonding agent pre-coating which are detailed below.

3.6.1 Pre-treatment by using NaOH solution

Na OH pre-treatment: saturated Na OH solution was prepared and the rubber particles immersed for a duration of 20 min. **(Najim and Hall, 2013).**

After the specified time, the rubber particles were removed and washed in clean water followed by air drying under laboratory conditions before use. See Figure 3.11 The rubber particles were water-washed in order to remove any potential chemical effect of NaOH on the bonding between the rubber particles and cement paste as the rubber particles have negligible water absorption as it is well-known **(Emiroglu, et al. 2007)**, **(Felipe and Jeannette, 2004).**

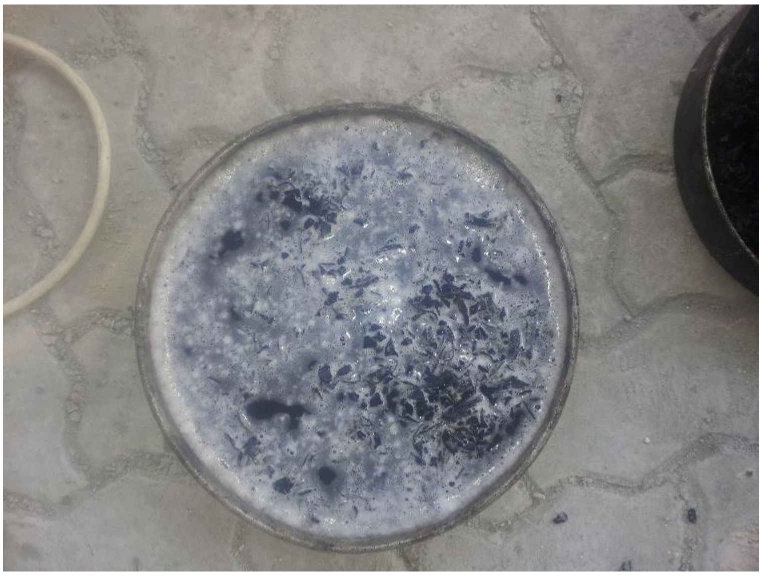

Figure 3.11: Na OH pre-treating

3.6.2 Pre-treatment by using mortar pre-coating

cement paste at 1.0 w/c ratio was prepared as slurry into which the rubber particles were submerged and stirred for c. 15 min, this high w/c is to ensure obtaining a slurry mixture. The ratio agree with **(Najim and Hall, 2013)** study whom used a similar ratio, after extraction of the coated particles from the slurry they were sprinkled with sand particles (sieved to 1–2 mm) prior to additional mixing. The sand was added at 50 wt% of the added cement powder After removal the rubber particles were left to air-dry and cure under laboratory conditions for 28 days prior to use see figure 3.12.

Figure 3.12: Rubber aggregates after mortar pre-treating

3.6.3 Pre-treatment by using mortar by adding bonding agent pre-coating

The same procedure was applied as for mortar paste pre-coating but bonding agent at 50 wt% of added water was added to slurry. see Figure 3.13.

Figure 3.13: Rubber aggregates with mortar by adding bonding agent pre-treating

3.7 Curing Procedure

Curing is an important process to prevent the concrete specimens from losing of moisture while it is gaining its required strength. Lack of curing will tend to lead the concrete specimens to perform less well in its strength required.

All concrete samples were placed in curing basin after 24 hours from casing. All samples remained in the curing basin up to time of testing at the specified age. The curing condition of lab basin followed the **ASTM C192, (2004)**.

Curing water temperature is around 25 C, see Figure 3.20.

Figure 3.20: Samples in curing basin

3.8 Testing of samples

The following tests were applied on the different concrete samples produced in this study.

1- Slump test for workability.
2- Determination of unit weight of hardened concrete.
3- Compressive strength test (7th, 14th, and 28th day).
4- Splitting tensile strength test.
5- Impact test.

3.8.1 Slump

This test method is used to determine the slump of freshly mixed concrete, which is an approximate measure of consistency. The fresh concrete is placed into a cone as for the normal slump test as shown in Figure 3.14.

Figure 3.14: Slump cone and base plate

Apparatus

1- Tamper (16 mm in diameter and 600 mm length).
2- Ruler.
3- Slump cone which has the shape of a frustum of a cone with the following dimensions:

- Base diameter 20 cm.
- Top diameter 10 cm .
- Height 30 cm.
- Materials thickness at least 1.6 mm.

Procedure

1. Place the dampened slump cone on one side of the pan. It shall be held firmly in place during filling by the operator standing on the two foots pieces.
2. Place the newly mixed concrete in three layers, each approximately one-third the volume of the mold.
3. In placing each scoopful of concrete, move the scoop around the top edge of the mold as the concrete slides from it, in order to ensure symmetrical distribution of concrete within the mold.
4. Rod each layer with 25 strokes of the tamper, distribute the strokes in a uniform manner over the cross section of the mold, each stroke just penetrating into the underlying layer.
5. For the bottom layer this will necessitate inclining the rod slightly and making approximately half of the strokes spirally toward the center. Rod the bottom layer throughout its depth.
6. In filling and rodding the top layer, heap the concrete above the mold before rodding is started.
7. After rodding the top layer, strike off the surface of the concrete with a trowel, leaving the mold exactly filled.
8. While filling and rodding , be sure that the mold is firmly fixed by feet and cannot move.
9. Clean the surface of the base outside the cone of any excess concrete. Then immediately remove the mold from the concrete by raising it slowly in a vertical direction.
10. Measure the slump immediately by determining the difference between the height of the mold and the height of the vertical axis (not the maximum height) of the specimen.

3.8.2 Compression Test

The ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength is usually obtained experimentally by means of a compressive test.

This test one judge that whether Concreting has been done properly or not. This concrete is poured in the mould and tempered properly so as not to have any voids. After 24 hours, these moulds are removed and test specimens are put in water for curing. The top surface of these specimens should be made even and smooth. Load at the failure divided by area of specimen gives the compressive strength of concrete.

Total number of 81 cubes were manufactured. For each Mix of NRC & MNRC made, 100x100x100 mm cube specimens were prepared, as shown in Figure 3.15.

Apparatus:

1. Weights and weighing device.
2. Tamper (square in cross section).
3. Tools and containers for mixing.
4. Testing machine.
5. 3 cubes (100mm x100mm x100mm).

Figure 3.15 Automatic Compression Testing Machine (ASTM)

Procedure

1. The moulds must be lightly coated with lubricated agent prevents sticking when dismantle samples.
2. The concrete sample is scooped into the mould in three equal layers and compacted between each layer (25 tamps per layer).
3. Once complete, the concrete is levelled off using a concrete float or trowel to give a smooth surface flush with the top of the mould.
4. It is very important to uniquely identify each of the cubes (and moulds) and to record where they have come from.
5. The concrete cubes are removed from the moulds after 24 hours.
6. The cubes are generally tested at 7 and 28 days unless specific early tests are required.
7. Get the cube from the water and Measure its dimension.
8. Put the cube on the break machine and take in consider does not break on the surface that we fill it.
9. Start in loading by machine with rate (0.14 – 0.34) mpa/s.
10. Calculate the compressive strength (Applied force divide Area).

3.8.3 Splitting Tensile Strength

Total number of 27 cylinders were manufactured. The splitting tensile strength of NRC and MNRC was measured based on **(ASTM C496. 2004)** Standard test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.

Apparatus

1. weighing device.
2. A circular cross-sectional rod (φl6 mm and 600 mm length).
3. Testing machine.
4. Three Cylinder (φ150 mm and 300 mm in height).

Procedure

1. Prepare three cylindrical concrete specimens.
2. After molding and curing the specimens for seven days in water, they can be tested.
3. Two bearings strips of nominal (1/8 in i.e 3.175mm) thick plywood, free of imperfections, approximately (25mm) wide, and of length equal to or slightly longer than that of the specimen should be provided for each specimen.
4. The bearing strips are placed between the specimen and both upper and lower bearing blocks of the testing machine or between the specimen and the supplemental bars or plates.
5. Draw diametric lines an each end of the specimen using a suitable device that will ensure that they are in the same axial plane. Center one of the plywood strips along the center of the lower bearing block.
6. Place the specimen on the plywood strip and align so that the lines marked on the ends of the specimen are vertical and centered over the plywood strip.
7. Place a second plywood strip lengthwise on the cylinder, centered on the lines marked on the ends of the cylinder.
8. Apply the load continuously and without shock, at a constant rate within, the range of 689 to 1380 kPa/min splitting tensile stress until failure of the specimen.
9. Record the maximum applied load indicated by the testing machine at failure. Note the type of failure and appearance of fracture.

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, as shown in Figure 3.16, 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. Total number of 27 cylinders were manufactured and tested.

$\mathbf{F_{sp} = 2P/\pi DL}$

Where: **P** is the fracture compression force acting along the cylinder;
D is the cylinder diameter;
π = 3.14;
L is the cylinder length.

Figure 3.16: Split cylinder test

The load and stress distribution pattern across the cross section if it is assumed that the load is concentrated at the tangent points then, over the cross section, only tensile stresses would be developed. In practice, however, the load is distributed over a finite width owing to material deformations. So, over the cross section, horizontal compressive stresses are developed too, in the close vicinity of the contact point between the press platens and the material. Since the compressive stresses only develop to a small depth in the cross section, it may be assumed that the tensile stresses are distributed evenly along the diameter where the splitting takes place, see Figure 3.17.

Figure 3.17: Cylinders damages after test

3.8.4 Impact Resistance Tests

The principal criteria are the ability of a specimen to withstand repeated blows and to absorb energy. Several types of tests have been used to measure the impact resistance of concrete. These can be classified broadly, depending upon the impacting mechanism and parameters monitored during impact, into the following types of tests:

1. Weighted pendulum charpy-type impact test.
2. Drop-weight test.
3. Constant strain-rate test.
4. Projectile impact test.
5. Split-Hopkinson bar test.
6. Explosive tests.
7. Instrumented pendulum impact test.

The sample size used were (40*20*7) cm.

The drop weight test, which is used in this study, would be as shown in Figure 3.18 which is agree with **Mindess et. al 1989** device.

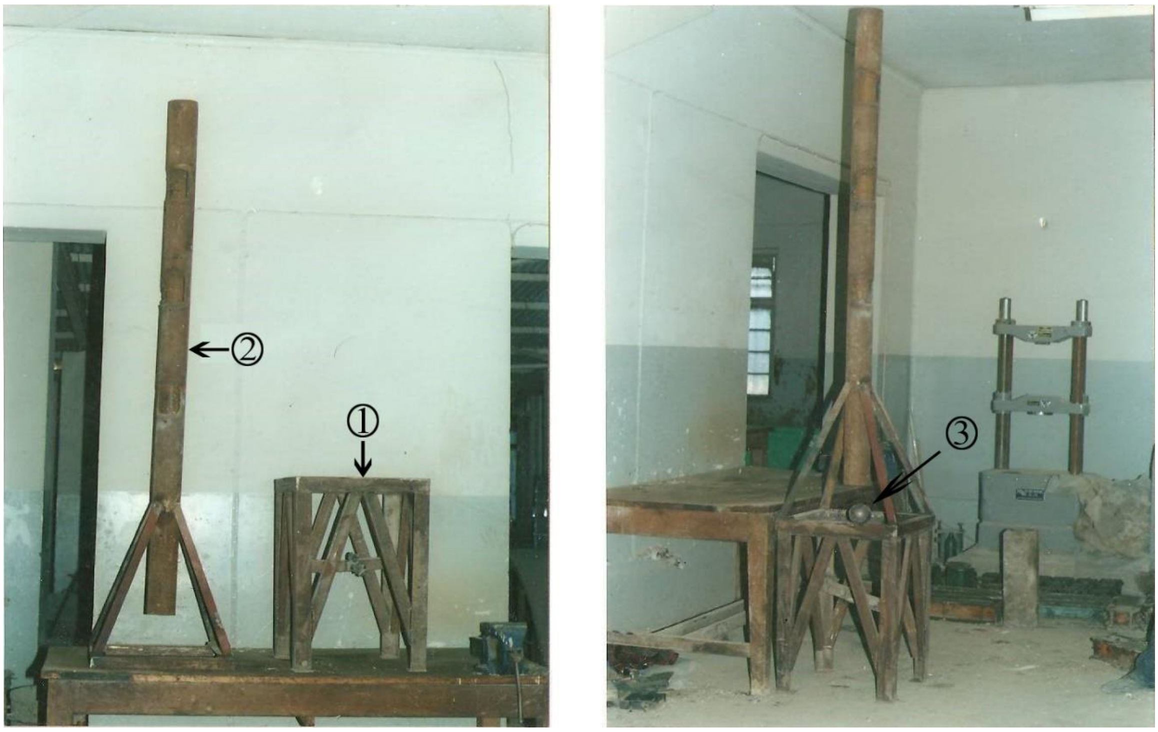

Figure 3.18: Impact Resistance Tests.
(1) Main Support Frame
(2)Drop Mass Guide system
(3)Striker

Drop weight Test

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 device, which used in this test, is not available in Gaza, a simple test was made as following.

Apparatus

1. Main Support Frame.
2. Drop Mass Guide1.2m height.
3. Striker (Iron ball) " 3.36 KG ".

The samples are placed on the two supports. The hammer is dropped repeatedly from a specific height „‟ 1.3 m „‟ and the number of blows required to cause the first visible crack on the top and to cause ultimate failure are both recorded, Ultimate failure is defined as the opening of cracks in the specimen sufficiently. Total number of 27 sample were manufactured and tested.

3.8.5 Unit Weight Test

In this research, the unit weight of the concrete cube specimen is the theoretical density. The density is calculated by dividing the weight of each cube by the volume. The same cube specimens which are used to determine the compressive strength was used to determine the density and the tests were carried out according to **ASTM C642. (2004)**. see Figure 3.19.

Unit weight (γ) is the weight per unit volume:

$$\gamma = \frac{W}{V}$$

Figure 3.19: Weight of samples.

Chapter 4

Test Results and Discussion

CHAPTER 4- TEST RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the results of the tests that were performed in order to study effects of the tests carried out to investigate different pre-treating methods of rubber surface in order to select the best method, and then to investigate the various properties of the modified rubberized concrete mixes prepared in contrast with the control mixes and with NRC. In the following sections, the results for slump, unit weight, compressive strength, splitting tensile strength and impact resistance tests are presented, Analysis and discussions are also made on the results. These tests were performed at the Materials and Soil Laboratory at the Islamic University of Gaza.

3.2 Testing of NRC samples by using different pre-treating methods

Laboratory tests were conducted to evaluate and study fresh concrete properties such as slump, and hardened properties of NRC by using previse discussed methods of pre-treatment were detailed in chapter 3. Results are the unit weight, compressive strength test, indirect tensile tests and impact test.

4.2.1 Slump Test Results

By conducting the test methods on the fresh concrete mixtures, Table 4.1 shows all results obtained in the lab for different methods of pre-treatment:

Table 4. 1: Effects of pre-treating methods on slump results of NRC

Mix #	% rubber	Slump test (mm)
NC0	0	80
NRC20	20	70
MNRC1	20	80
MNRC2	20	66
MNRC3	20	68

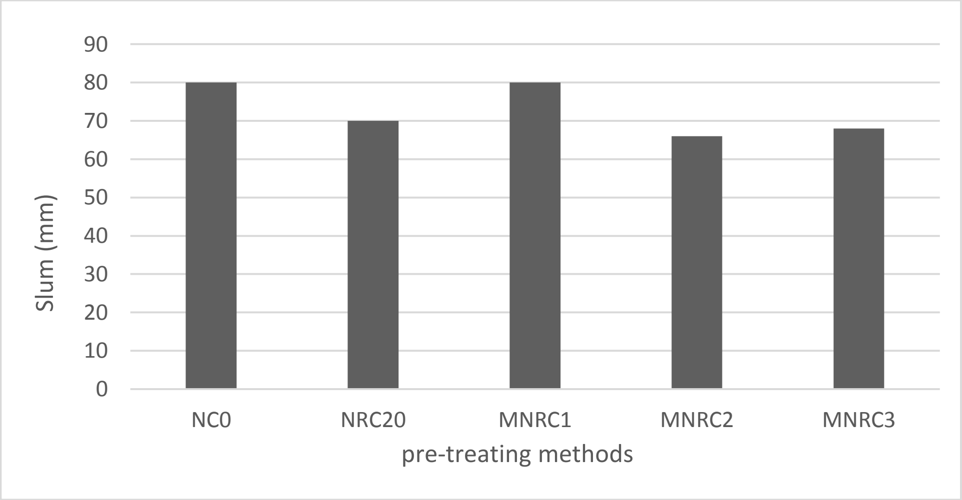

Figure 4.1 Effect of pre-treating methods on Slump Test

As a result of 20% volumetric replacement of coarse aggregates (size 3, 10%) and fine aggregates (sand, 10%) by crumb waste tires, by using different methods of pre-treatment slump value decreases as crumb waste tires used as shown in Figure 4.1, at zero replacement NC0, slump is 80 cm, while at 20% replacement NRC20 the slump decreases to 70 cm that is a decrease of 12.5%. At 20% replacement also MNRC1 is 80 cm that is no change because the crumb rubber pretreated using NA OH solution without any change in its surface. For the replacements of 20% MNRC2 the slum decreases to 66 cm that is a decrease of 17.5% from the original reference value. And for 20% replacement MNRC3 the slump drops to 68 that is a decrease of 15% from the original reference value, decrease in slump value refers to crumbed rubber and its fibers which absorbed some water from concrete mix.

4.2.2 Compressive Strength Test Results

The test results of the compressive strength of previse methods of pre-treatment and the percentage of Strength Loss are shown in Table (4.2).

Table 4.2: Effects of pre-coating on compressive strength of NRC at different ages.

Mix #	% rubber	Compressive strength (MPa)			% Strength Loss		
		7 days	14 days	28 days	7 days	14 days	28 days
NC0	**0**	**23.66**	**25.55**	**28.77**	**0.0**	**0.0**	**0.0**
NRC20	**20**	**15.1**	**18.7**	**20**	**36.18**	**26.81**	**30.5**
MNRC1	**20**	**15.5**	**18.8**	**20.2**	**34.49**	**26.42**	**29.79**
MNRC2	**20**	**16.2**	**18.9**	**20.5**	**31.53**	**26.03**	**28.75**
MNRC3	**20**	**16.6**	**19.5**	**22**	**29.84**	**23.68**	**23.53**

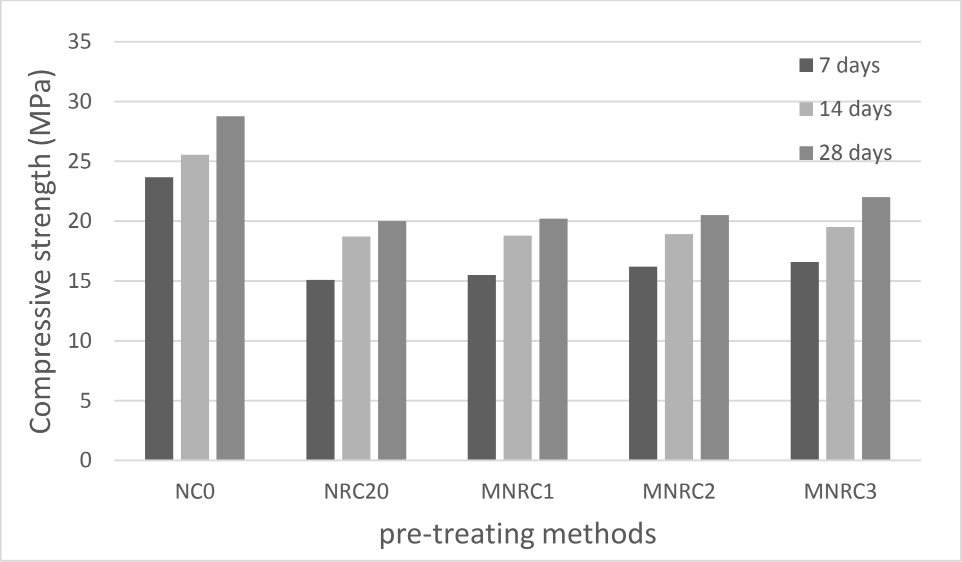

Figure 4.2 Effect of pre-treating methods on compressive strength

Figure 4.2 shows also how compressive strength changed with a volumetric replacement of percent of coarse aggregates (size 3, 10%) and fine aggregates (sand, 10%) by crumb waste tires relative to the specified compressive strength As a result, compressive strength decreases as a percent of crumb rubber used as shown in Figure

4.2, at zero replacement, compressive strength at 28 day is 28.77 MPa, while at 20% replacement NRC20 the compressive strength at 28 days decreases to 20 MPa that is a decrease of 30.5%. At 20% replacement MNRC1, compressive strength is 20.2 MPa that is a decrease of 29.79% from the original value. For the replacements of 20% MNRC2 the compressive strength decreases to 20.5 MPa that is a decrease of 28.75% from the original reference value. And for 20% replacement MNRC3 the compressive strength drops to 22 MPa that is a decrease of 23.53% from the original reference.

This reduction in compressive strength refer to several reasons, one of them that the cohesion force between the rubber surface and cement weaker than the cohesion force between the aggregates and cement, so the mechanism of stress distribution inside the concrete mix will be different from the regular one. Besides the chemical composition, gradation and the surface texture of the rubber, which adversely affect the bonding with cement, and that is reduce the compressive strength, which is essentially depending on the bonding between the aggregates and cement.

From figure 4.2 it found that the MNRC3 is the best mix by using mortar and bonding agent pre-treatment.

4.2.3 Unit weight Test Results

The test results of the unit weight of MNRC by using several pre-treating methods is shown in Table (4.3). The effects of pre-treating methods on unit weight of MNRC at 28 day are represented graphically in Figure (4.3).

Table 4.3: Effects of different pre-treating methods on unit weight of MNRC.

Mix #	% Rubber	Unit weight Ton/m3	% Loss
NC0	0	**2.39**	**0**
NRC20	20	**2.26**	**5.44**
MNRC1	20	**2.28**	**4.61**
MNRC2	20	**2.28**	**4.61**
MNRC3	20	**2.31**	**3.35**

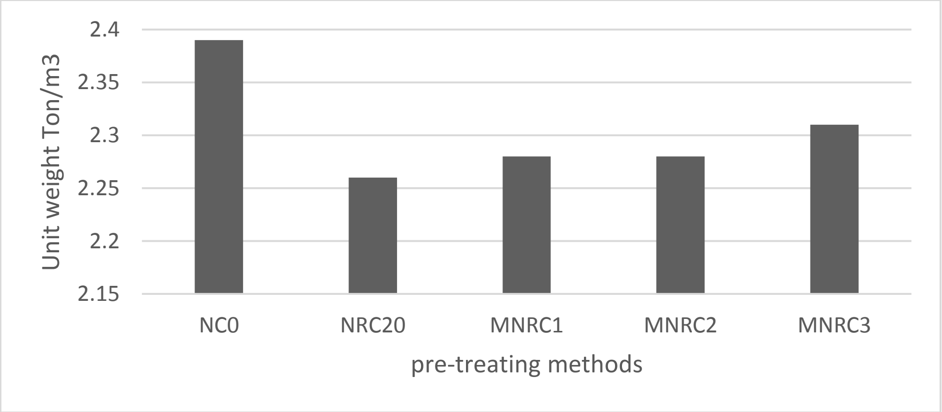

Figure 4.3 Effect of pre-treating methods on unit weight of MNRC.

Figure 4.3 shows also how unit weight changed with a volumetric replacement of percent of coarse aggregates (size 3, 10%) and fine aggregates (sand, 10%) by crumb waste tires relative to the specified compressive strength as a result, unit weight decreases as a percent of crumb rubber used as shown in Figure 4.3, at zero replacement, unit weight at 28 day is 2.39 Ton/m3, while at 20% replacement NRC20 the unit weight at 28 days decreases to 2.26 Ton/m3 that is a decrease of 5.44%.

At 20% replacement MNRC1, unit weight is 2.28 Ton/m3 that is a decrease of 4.61% from the original value. For the replacements of 20% MNRC2, the unit weight decreases to 2.28 MPa that is a decrease of 4.61% from the original reference value. And for 20% replacement MNRC3 the unit weight drops to 2.31 Ton/m3 that is a decrease of 3.35% from the original reference.

The testing of specific gravity showed that the specific gravity of the rubber is lower than the specific gravity of aggregates, so when the rubber replaced the aggregates with a high density with a low density, it is normal to reduce the unit weight for the concrete mixes.

In general, the reduction in unit weight of concrete with rubber mixes are not very large comparative to normal concrete mixes.

From Figure 4.3 it found that the MNRC3 mix is the smallest decrease from the original reference value by using mortar and bonding agent pre-treatment because it makes more cohesion between the rubber surface and the cement.

4.2.4 Splitting tensile strength Test

Table 4.3 and Figure 4.4 show the Effect of pre-treating methods on splitting tensile strength test results for MNRC. The relative percentage of strength loss with respect to the control mixes also tabulated together.

Table 4.4: Effects of different pre-treating methods on splitting tensile strength of MNRC.

Mix #	% Rubber	splitting tensile (MPa)	% Loss
NC0	0	2.6	0
NRC20	20	2.1	19.23
MNRC1	20	2.15	17.3
MNRC2	20	2.18	16.15
MNRC3	20	2.2	15.38

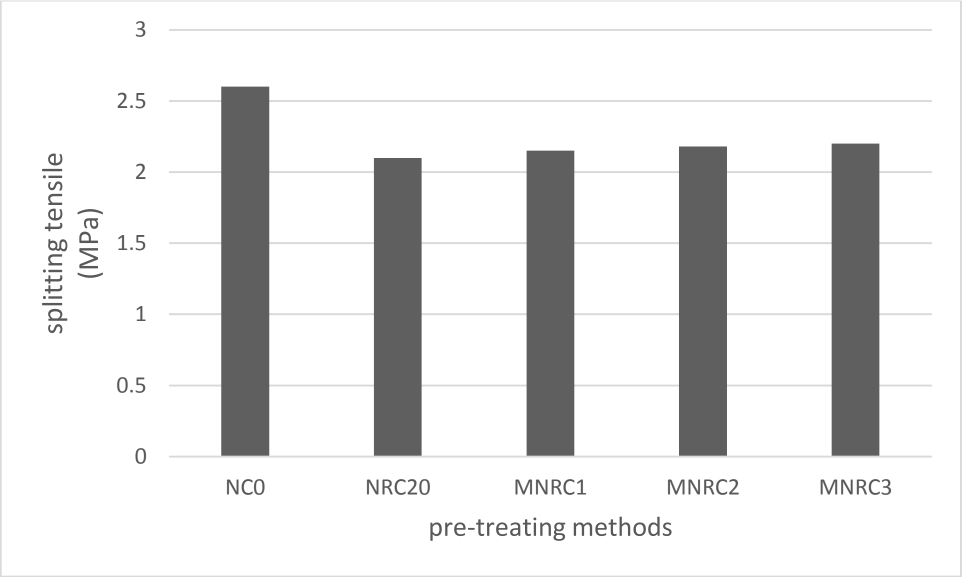

Figure 4.4 Effect of pre-treating methods on splitting tensile strength test results for MNRC

It can be said from Figure 4.4, that for the rubber mixes, the results showed that using rubber decrease tensile Strength up to 19.23 % at NRC20, 17.3% at MRC1, 16.15% at MNRC2 while 15.8 % losses at MNRC3, with respect to the NC0.

This reduction in tensile strength refer to the same reason for reduction in compressive strength, particularly the weaker cohesion force between the rubber surface and the cement.

From Figure 4.4 it found that the MNRC3 is the best mix make more cohesion between the rubber surface and the cement by using mortar and bonding agent pre-treatment.

4.2.5 Impact Test Results

The test count 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 hammer is dropped repeatedly and the number of blows required to cause the first visible crack and to cause ultimate failure are both recorded. Ultimate failure is defined as the opening of cracks in the specimen sufficiently. (Refer to Figure 3.19).

Table 4.5, Figure 4.5 below, show the results of impact test.

Table 4.5: the results of impact test

Mix #	% Rubber	NO. Blows		% Loss	% Increase
		1st .Crack	Ultimate Failure		
NC0	0	19	21	0.0	0.0
NRC20	20	17	20	10.5	
MNRC1	20	17	19	10.5	
MNRC2	20	18	20	5.3	
MNRC3	20	21	23		10.53

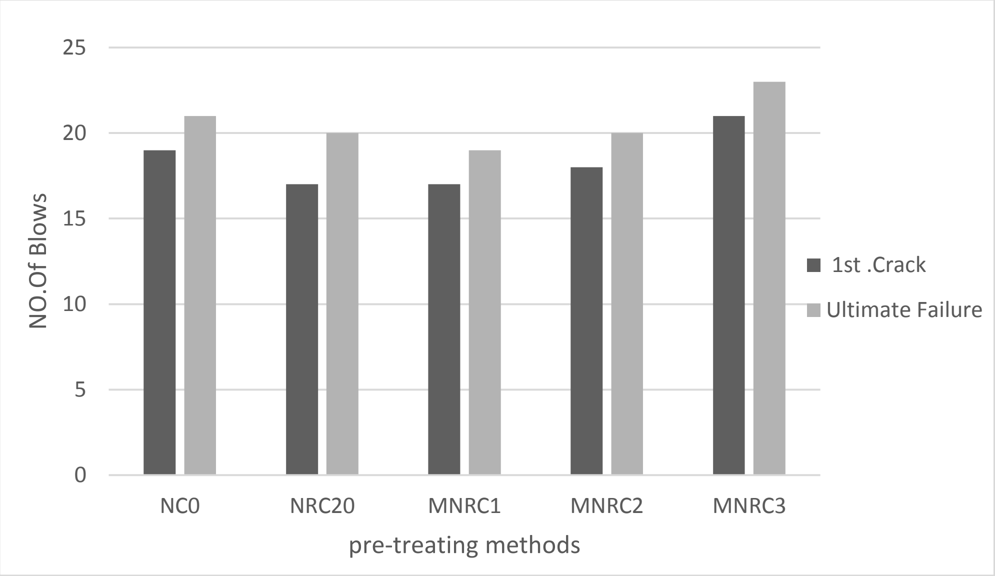

Figure 4.5: Effect of pre-treating methods on impact test for MNRC

The results from Figure 4.5 show that the addition of rubber decreases the impact strength compared with the NC0 and the maximum reduction was found at NRC20, MNRC1 by 10.5% with respect to the control mix.

But in MNRC3 it increased by 10.53% with respect to the control mix because this method of pre-treating make more cohesion force between the rubber surface and cement which give more bonding and ductility in concrete mix.

That is because although the capability of rubber to absorb the energy and this refer to the ability to improve the impact strength, however the weak cohesion force between the rubber surface and cement is bigger, and lead to decrease the impact strength in many cases.

3.3 Testing of NRC samples without pre-treating

Three mixes with percent 10%,20% and 30% of rubber called NRC10, NRC20 and NRC30 would be replaced by volume of coarse aggregates and fine aggregates.

4.3.1 Slump Test Results

By conducting the test methods on the fresh concrete mixtures, Table 4.6 shows all results obtained in the lab for producing NRC without any pre-treating:

Table 4.6: Effects of rubber on slump results of NRC.

Mix #	% rubber	Slump test (mm)
NC0	0	80
NRC10	10	77
NRC20	20	70
NRC30	30	65

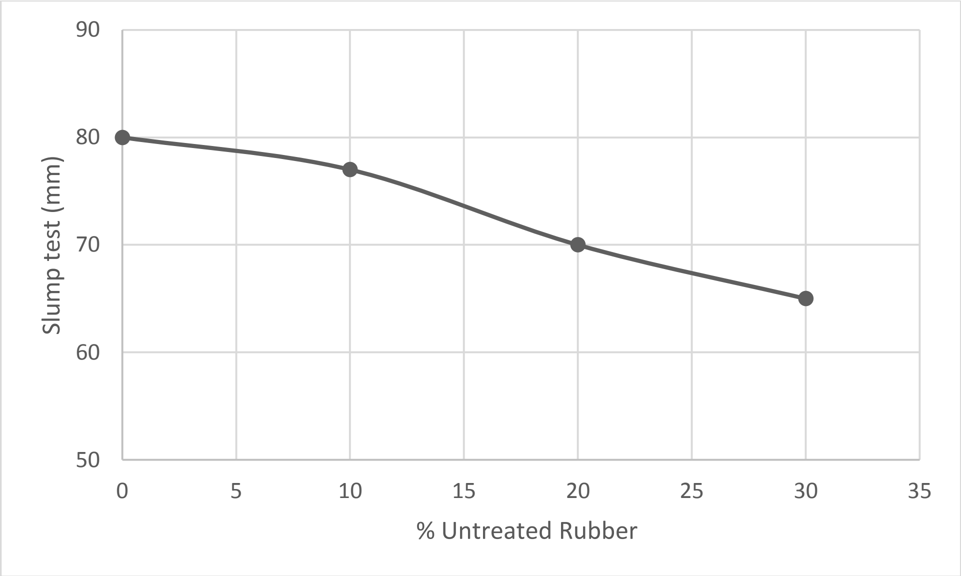

Figure 4.6 Effect of rubber on Slump Test

From Figure (4.6), It is observed that at several ratios of rubber, as a result of volumetric replacement of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires, by using different ratios of untreated rubber, slum value decreases as percent of crumb waste tires increases, as shown in Figure 4.6, at zero replacement NC0, slump is 80 cm, while at 10% replacement NRC10 the slum decreases to 77 cm that is a decrease of 3.75%. At 20% replacement also NRC20 is 70 cm that is a decrease of 12.5%.

For the replacements of 30% NRC30 the slum decreases to 65 cm that is a decrease of 18.75% from the original reference value.

The test results indicated that the slum value decrease as the rubber increased.

4.3.2 Compressive Strength Test Results

The test results of the compressive strength of NRC10, NRC20 and NRC30 and the percentage of Strength Loss are shown in Table (4.7).

Table 4.7: Effects of rubber on compressive strength of NRC at different ages.

Mix #	% rubber	Compressive strength (MPa)			% Strength Loss		
		7 days	14 days	28 days	7 days	14 days	28 days
NC0	**0**	**23.66**	**25.55**	**28.77**	**0.0**	**0.0**	**0.0**
NRC10	10	**18.9**	**22.1**	**24.5**	**20.12**	**13.5**	**14.84**
NRC20	20	**15.1**	**18.7**	**20**	**36.18**	**26.81**	**30.5**
NRC30	30	**12.2**	**15**	**17.2**	**48.4**	**41.3**	**40.2**

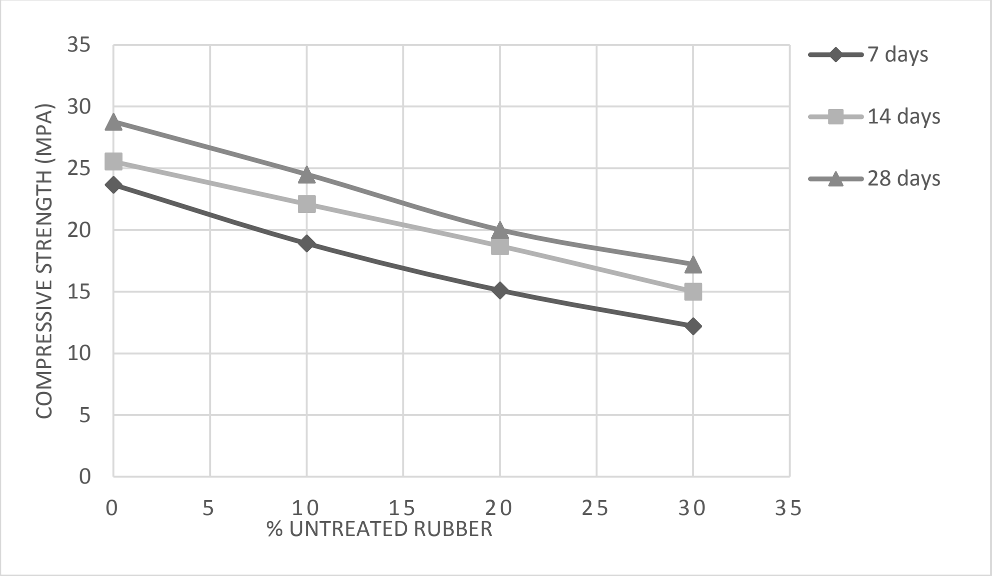

Figure 4.7 Effects of rubber on compressive strength of NRC at different ages

Figure 4.7 shows how compressive strength changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires relative to the specified compressive strength as a result, compressive strength decreases as a percent of crumb rubber increase as shown in Figure 4.7, at zero replacement, compressive strength at 28 day is 28.77 MPa, while at 10% replacement NRC10 the compressive strength at 28 days decreases to 26.6 MPa that is a decrease of 7.5%. At 20% replacement NRC20, compressive strength is 20 MPa that is a decrease of 30.5% from the original value. For the replacements of 30% NRC30 the compressive strength decreases to 17.2 MPa that is a decrease of 40.2 % from the original reference value.

This reduction in compressive strength refer to several reasons, one of them that the cohesion force between the rubber surface and cement weaker than the cohesion force between the aggregates and cement, so the mechanism of stress distribution inside the concrete mix will be different from the regular one.

Besides the chemical composition, gradation and the surface texture of the rubber, which adversely affect the bonding with cement, and that is reduce the compressive strength, which is essentially depending on the bonding between the aggregates and cement.

4.3.3 Unit weight Test Results

The test results of the unit weight of NRC10, NRC20 and NRC30 is shown in Table (4.8). The effects of adding rubber on unit weight of NRC at 28 day are represented graphically in Figure (4.8).

Table 4.8: Effects of adding rubber on unit weight of NRC.

Mix #	% Rubber	Unit weight Ton/m3	% Loss
NC0	0	**2.39**	**0**
NRC10	10	**2.31**	**3.35**
NRC20	20	**2.26**	**5.44**
NRC30	30	**2.22**	**7.11**

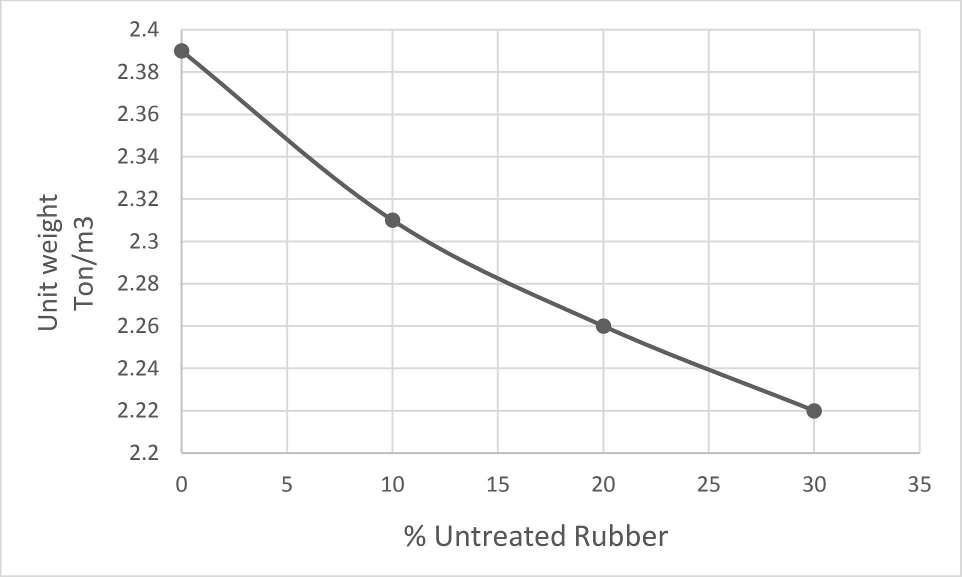

Figure 4.8 Effects of adding rubber on unit weight of NRC.

Figure 4.8 shows how unit weight changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires relative to the specified unit weight as a result, unit weight decreases as a percent of crumb rubber increase as shown in Figure 4.7, at zero replacement, unit weight at 28 day is 2.39 Ton/m3, while at 10% replacement NRC10 the unit weight at 28 days decreases to 2.31Ton/m3 that is a decrease of 3.35%. At 20% replacement NRC20, unit weight is 2.26 Ton/m3 that is a decrease of 5.44% from the original value. For the replacements of 30% NRC30 the unit weight decreases to 2.22 Ton/m3 that is a decrease of 7.11 % from the original reference value.

The testing of specific gravity showed that the specific gravity of the rubber is lower than the specific gravity of aggregates, so when the rubber replaced the aggregates with a high density with a low density, it is normal to reduce the unit weight for the concrete mixes.

In general, the reduction in unit weight of concrete with rubber mixes are not very large comparative to normal concrete mixes.

4.3.4 Splitting tensile strength Test

Table 4.9 and Figure 4.9 show the Effect rubber on splitting tensile strength test results for NRC10, NRC20 and NRC30. The relative percentage of strength loss with respect to the control mixes also tabulated together.

Table 4.9: Effects of rubber on splitting tensile strength of MNRC.

Mix #	% Rubber	splitting tensile (MPa)	% Loss
NC0	0	**2.6**	**0**
NRC10	10	**2.2**	**15.38**
NRC20	20	**2.1**	**19.23**
NRC30	30	**1.92**	**26.15**

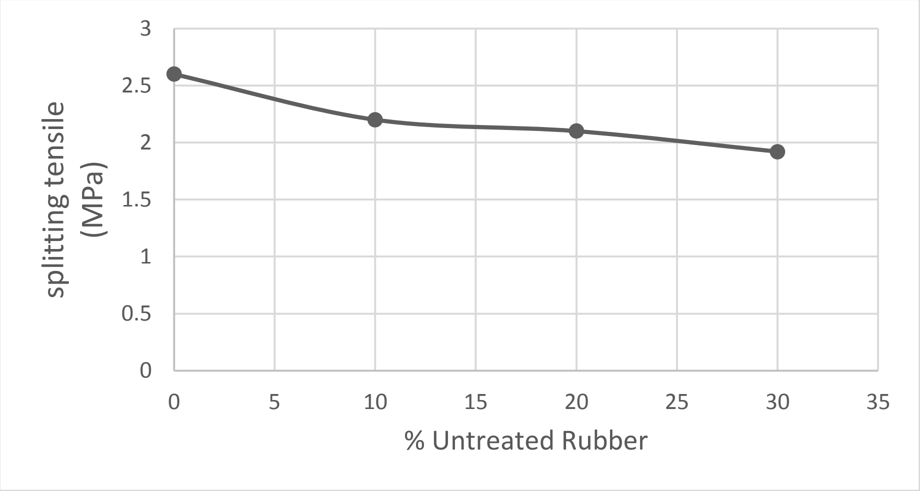

Figure 4.9 Effects of rubber on splitting tensile strength of MNRC.

Figure 4.9 shows how splitting tensile strength changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires relative to the specified splitting tensile strength as a result, splitting tensile strength decreases as a percent of crumb rubber increase as shown in Figure 4.9, at zero replacement, splitting tensile strength at 28 day is 2.6 MPa, while at 10% replacement NRC10 the unit weight at 28 days decreases to 2.2 MPa that is a decrease of 15.38%. At 20% replacement NRC20, splitting tensile strength is 2.1 MPa that is a decrease of 19.23% from the original value. For the replacements of 30% NRC30 the splitting tensile strength decreases to 1.92 MPa that is a decrease of 26.15 % from the original reference value.

4.3.5 Impact Test Results

The test count 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 hammer is dropped repeatedly and the number of blows required to cause the first visible crack and to cause ultimate failure are both recorded. Ultimate failure is defined as the opening of cracks in the specimen sufficiently. (Refer to Figure 3.19).

Table 4.10, Figure 4.10 below, show the results of impact test.

Table 4.10: Effects of rubber on impact tset of NRC.

Mix #	% Rubber	NO. Blows		% Loss	% Increase
		1st .Crack	Ultimate Failure		
NC0	0	19	21	0.0	/
NRC10	10	18	20	5.3	/
NRC20	20	17	20	10.5	/
NRC30	30	16	18	15.79	/

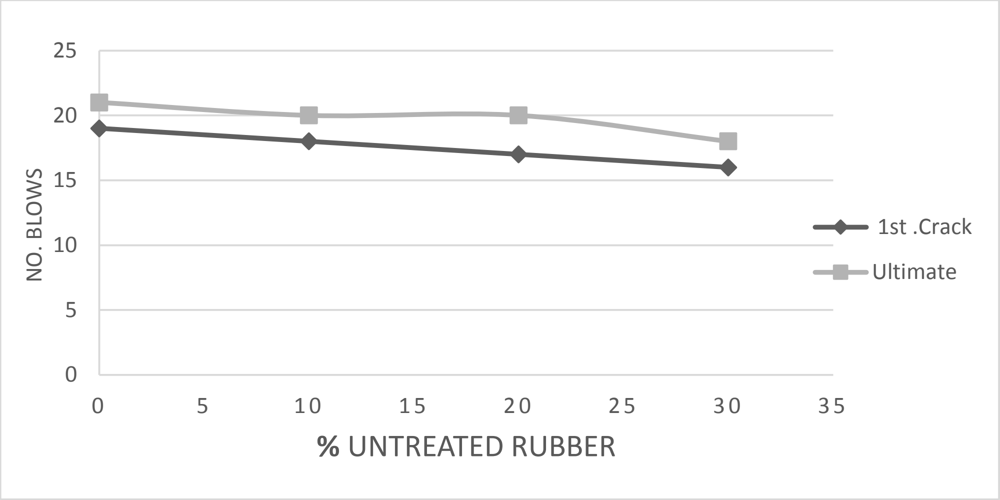

Figure 4.10: Effect of rubber on impact test for NRC

Figure 4.10 shows how impact strength changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires relative to the specified splitting tensile strength as a result, impact strength decreases as a percent of crumb rubber increase as shown in Figure 4.10, at zero replacement, impact strength at 28 day is 19 blows for first crack, while at 10% replacement NRC10 the impact strength at 28 days decreases to 18 blows that is a decrease of 5.3%. At 20% replacement NRC20, impact strength is 17 blows that is a decrease of 10.5% from the original value. For the replacements of 30% NRC30 the impact strength decreases to 17 blows that is a decrease of 15.79 % from the original reference value.

That is because although the capability of rubber to absorb the energy, and this refer to the ability to improve the impact strength, however the weak cohesion force between the rubber surface and cement is bigger, and lead to decrease the impact strength in many cases.

4.4 Testing of MNRC samples by using mortar with bonding agent pre-treating method

After investigating different methods of pre-coating of rubber, it is found that the optimum method is to use mortar with bonding agent; because it gave the best results for applied tests.

After selection of the best method of pre-treatment tow mixes called MNRC10 and MNRC30 with percent 10% and 30% of rubber would be replaced by volume of coarse aggregates and fine aggregates.

Laboratory tests were conducted to evaluate and study fresh and hardened properties of MNRC. Results are the slump, unit weight, compressive strength test, indirect tensile tests and impact test for MNRC10, MNRC20 and MNRC30.

4.4.1 Slump Test Results

By conducting the test methods on the fresh concrete mixtures, Table 4.11 shows all results for different percentages of rubber obtained in the lab for producing MNRC by using mortar with bonding agent pre-treating:

Table 4.11: Effects of modified rubber on slump results of MNRC.

Mix #	% rubber	Slump test (mm)
NC0	0	80
MNRC10	10	70
MNRC20	20	68
MNRC30	30	66

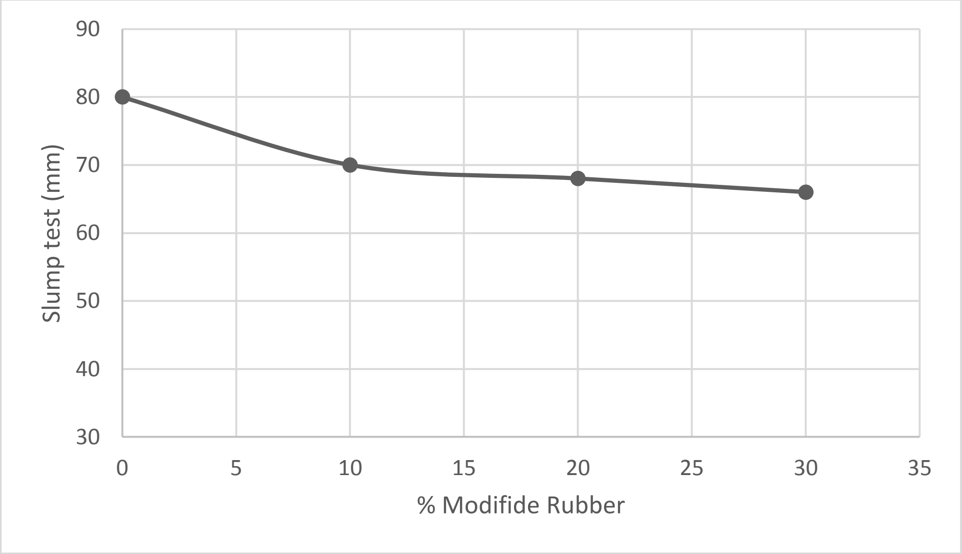

Figure 4.11 Effect of pre-treated Rubber on Slump Test

From Figure (4.11), It is observed that at several ratios of rubber, as a result of volumetric replacement of coarse aggregates (size 3) and fine aggregates (sand,) by modified crumb waste tires, by using different ratios of untreated rubber, slum value

decreases as percent of crumb waste tires increases, as shown in Figure 4.11, at zero replacement NC0, slump is 80 cm, while at 10% replacement MNRC10 the slum decreases to 70 cm that is a decrease of 12.5%. At 20% replacement also MNRC20 is 68 cm that is a decrease of 15.0%. For the replacements of 30% MNRC30 the slum decreases to 66 cm that is a decrease of 17.5% from the original reference value.
The test results indicated that the slum value decrease as the rubber increase.

4.4.2 Compressive Strength Test Results

The test results of the compressive strength of MNRC10, MNRC20 and MNRC30 and the percentage of Strength Loss are shown in Table (4.12).

Table 4.12: Effects of modified rubber on compressive strength of MNRC at different ages.

Mix #	% rubber	Compressive strength (MPa)			% Strength Loss		
		7 days	14 days	28 days	7 days	14 days	28 days
NC0	**0**	**23.66**	**25.55**	**28.77**	**0.0**	**0.0**	**0.0**
MNRC10	**10**	**19.34**	**22.5**	**26.6**	**15.26**	**11.94**	**7.5**
MNRC20	**20**	**16.6**	**19.5**	**22**	**29.84**	**23.68**	**23.53**
MNRC30	**30**	**15.7**	**18**	**20**	**25.19**	**29.55**	**30.48**

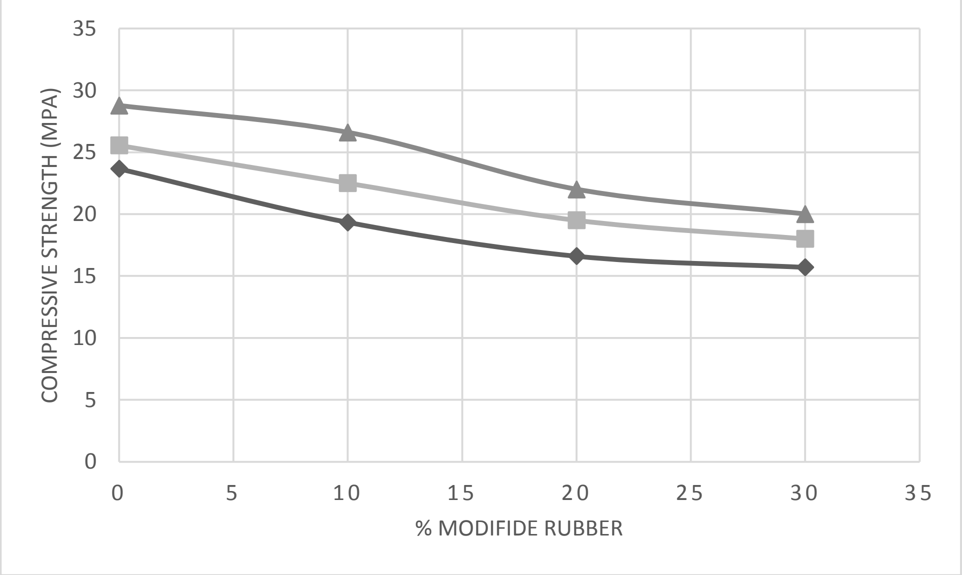

Figure 4.12 Effects of modified rubber on compressive strength of MNRC at different ages

Figure 4.12 shows how compressive strength changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by pretreated modified crumb waste tires relative to the specified compressive strength as a result, compressive strength decreases as a percent of crumb rubber increase as shown in Figure 4.12, at zero replacement, compressive strength at 28 day is 28.77 MPa, while at 10% replacement MNRC10 the compressive strength at 28 days decreases to 24.5 MPa that is a decrease of 14.84%. At 20% replacement MNRC20, compressive strength is 22 MPa that is a decrease of 23.53% from the original value. For the replacements of

30% MNRC30 the compressive strength decreases to 20 MPa that is a decrease of 30.48 % from the original reference value.

This reduction in compressive strength refer to several reasons, one of them that the cohesion force between the rubber surface and cement weaker than the cohesion force between the aggregates and cement, so the mechanism of stress distribution inside the concrete mix will be different from the regular one. Besides the chemical composition, gradation and the surface texture of the rubber, which adversely affect the bonding with cement, and that is reduce the compressive strength, which is essentially depending on the bonding between the aggregates and cement.

4.4.3 Unit weight Test Results

The test results of the unit weight of MNRC10, MNRC20 and MNRC30 is shown in Table (4.13). The effects of adding modified rubber on unit weight of MNRC at 28 day are represented graphically in Figure (4.13).

Table 4.13: Effects of modified rubber on unit weight of MNRC.

Mix #	% Rubber	Unit weight Ton/m3	% Loss
NC0	0	**2.39**	**0**
MNRC10	10	**2.35**	**1.67**
MNRC20	20	**2.31**	**3.35**
MNRC30	30	**2.24**	**6.28**

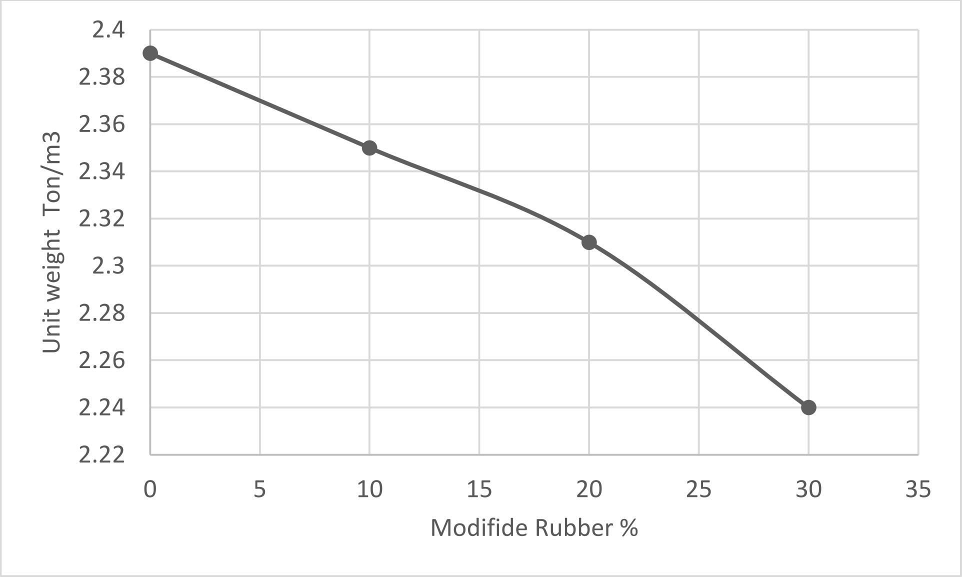

Figure 4.13: Effects of modified rubber on unit weight of MNRC.

Figure 4.13 shows how unit weight changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires relative to the specified unit weight as a result, unit weight decreases as a percent of modified crumb rubber increase as shown in Figure 4.13, at zero replacement, unit weight at 28 day is 2.39 Ton/m3, while at 10% replacement MNRC10 the unit weight at 28 days decreases to 2.35 Ton/m3 that is a decrease of 1.67%. At 20% replacement MNRC20, unit weight is 2.31 Ton/m3 that is a decrease of 3.35% from the original value. For the replacements of 30% MNRC30 the unit weight decreases to 2.24 Ton/m3 that is a decrease of 6.28 % from the original reference value.

The testing of specific gravity showed that the specific gravity of the rubber is lower than the specific gravity of aggregates, so when the rubber replaced the aggregates with a high density with a low density, it is normal to reduce the unit weight for the concrete mixes.

In general, the reduction in unit weight of concrete with rubber mixes are not very large comparative to normal concrete mixes.

4.4.4 Splitting tensile strength Test

Table 4.14 and figure 4.14 show the Effect modified rubber on splitting tensile strength test results for MNRC10, MNRC20 and MNRC30. The relative percentage of strength loss with respect to the control mixes also tabulated together.

Table 4.14: Effects of modified rubber on splitting tensile strength of MNRC.

Mix #	% Rubber	splitting tensile (MPa)	% Loss
NC0	0	**2.6**	**0**
MNRC10	10	**2.4**	**7.69**
MNRC20	20	**2.2**	**15.38**
MNRC30	30	**2.0**	**23.08**

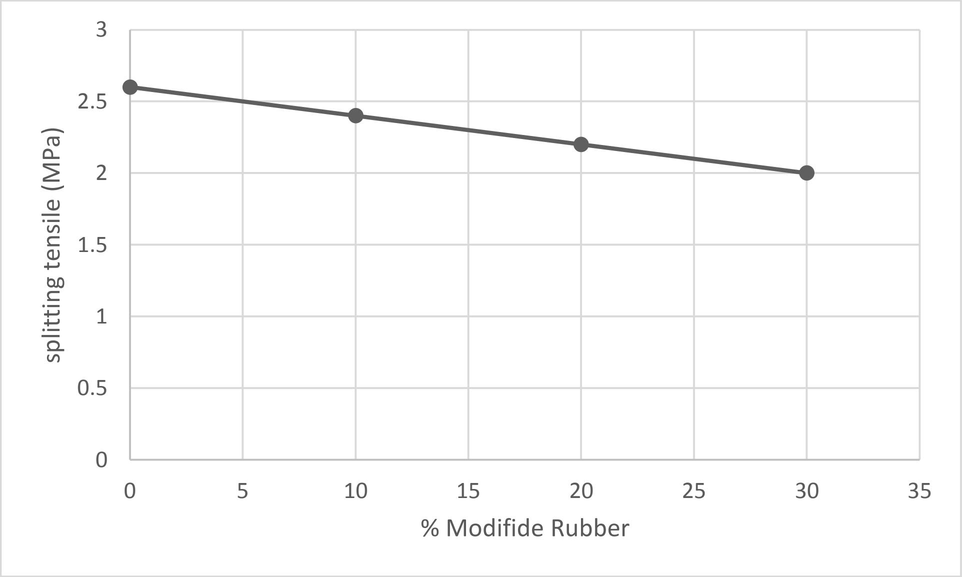

Figure 4.14: Effects of modified rubber on splitting tensile strength of MNRC.

Figure 4.14 shows how splitting tensile strength changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by modified crumb waste tires relative to the specified splitting tensile strength as a result, splitting tensile strength decreases as a percent of crumb rubber increase as shown in Figure 4.14, at zero replacement, splitting tensile strength at 28 day is 2.6 MPa, while at 10% replacement MNRC10 the unit weight at 28 days decreases to 2.4 MPa that is a decrease of 7.69%. At 20% replacement MNRC20, splitting tensile strength is 2.2 MPa that is a decrease of 15.38% from the original value. For the replacements of 30% MNRC30 the splitting tensile strength decreases to 2.0 MPa that is a decrease of 23.08 % from the original reference value.

4.4.5 Impact Test Results

The test count 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 hammer is dropped repeatedly and the number of blows required to cause the first visible crack and to cause ultimate failure are both recorded. Ultimate failure is defined as the opening of cracks in the specimen sufficiently. (Refer to figure 3.19).

Table 4.15, Figure 4.15 below, show the results of impact test.

Table 4.15: Effects of modified rubber on impact test of MNRC.

Mix #	% Rubber	NO. Blows		% Loss	% Increase
		1st .Crack	Ultimate Failure		
NC0	0	19	21	0.0	/
MNRC10	10	22	24		15.79
MNRC20	20	21	23		10.53
MNRC30	30	20	22		5.3

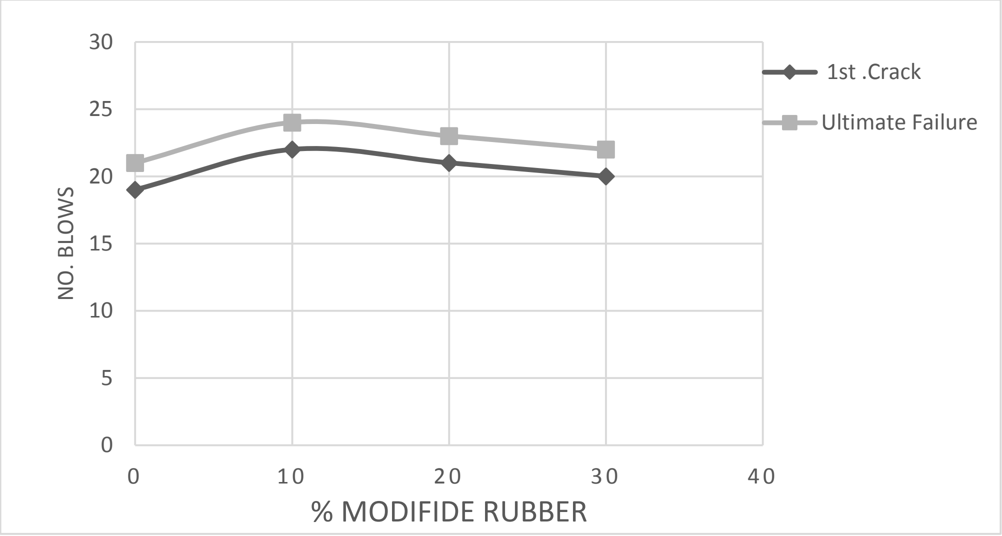

Figure 4.15: Effect of modified rubber on impact test for MNRC

Figure 4.15 shows how impact strength changed with a volumetric replacement of percent of coarse aggregates (size 3) and fine aggregates (sand) by crumb waste tires relative to the specified splitting tensile strength as a result, as shown in Figure 4.15, at zero replacement, impact strength at 28 day is 19 blows for first crack, while at 10% replacement MNRC10 the impact strength at 28 days increase to 22 blows that is a decrease of 15.79%. At 20% replacement MNRC20, impact strength is 21 blows that is increase of 10.53% from the original value. For the replacements of 30% MNRC30 the impact strength increase to 20 blows that is a decrease of 5.3 % from the original reference value.

That is because although the capability of rubber to absorb the energy, and this refer to the ability to improve the impact strength, however the enhancement of cohesion force between the rubber surface and cement by using bonding agent with mortar for rubber pre-treated, it lead to increase the impact strength.

At 10% replacement MNRC10 gives the best value of impact strength then the impact strength decrease as the replaced ratio of rubber increase, that mean the improvement caused by using little amount of rubber by using good pre-treating method with mortar and bonding agent

4.5 Comparison between untreated rubber and pre-treated rubber

4.5.1 Compressive strength Comparison

Figure 4.16 show a Compressive strength Comparison between untreated rubber and pre-treated rubber at 10, 20, and 30 % replacement.

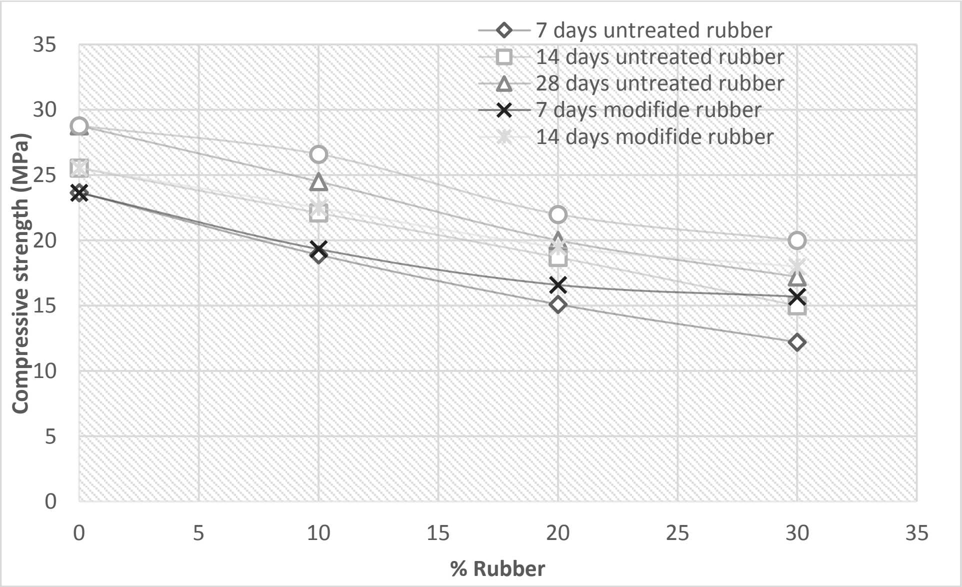

Figure 4.16: Compressive strength Comparison between untreated rubber and pre-treated rubber

Figurer 4.16 it can be noted that the pre-treated of rubber by mortar with bonding agent improve the compressive strength of concrete better than untreated rubber.

Table 4.16 and 4.17 below show % Compressive strength Loss of untreated rubber and pre-treated rubber after 7,14, and 28 days with respect to NC0.

Table 4.16: % Compressive strength Loss of pre-treated rubber

Mix #	% rubber	% Compressive strength Loss		
		7 days	14 days	28 days
NC0	0	0.0	0.0	0.0
MNRC10	10	15.26	11.94	7.5
MNRC20	20	29.84	23.68	23.53
MNRC30	30	25.19	29.55	30.48

Table 4.17: % Compressive strength Loss of untreated rubber

Mix #	% rubber	% Compressive strength Loss		
		7 days	14 days	28 days
NC0	0	0.0	0.0	0.0
NRC10	10	20.12	13.5	14.84
NRC20	20	36.18	26.81	30.5
NRC30	30	48.4	41.3	40.2

Figure 4.17 below show % Loss Comparison Of Compressive strength between untreated and pre-treated rubber at 28 days with respect to NC0.

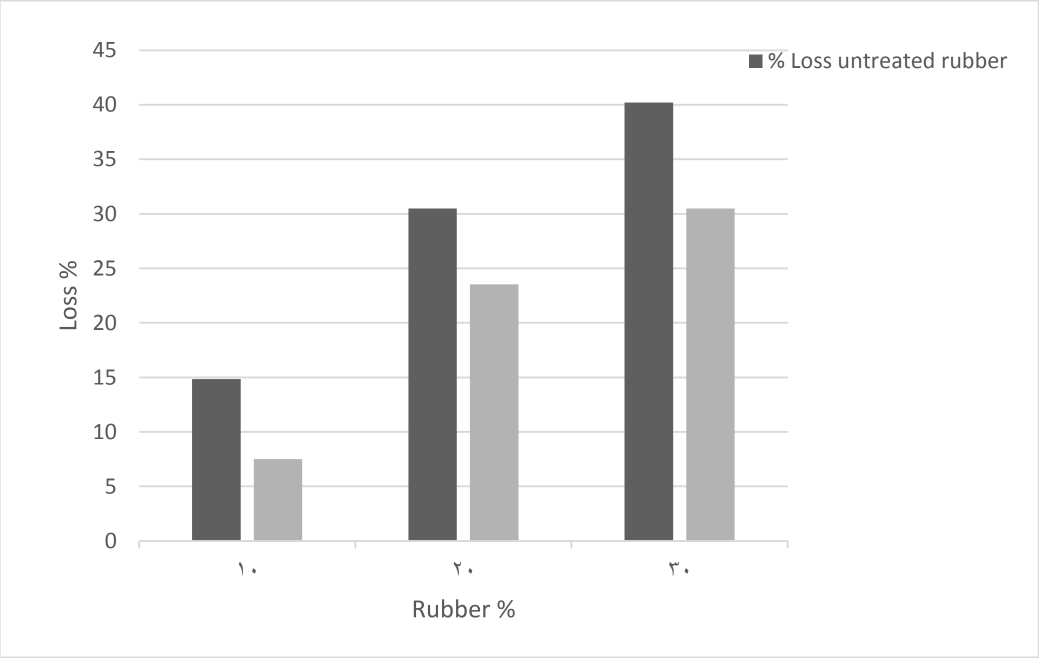

Figure 4.17: Loss percentage Comparison Of Compressive strength between untreated and pre-treated rubber at 28 days

Figure 4.17 show that at 10% replacement of untreated rubber in NRC10 the loss of compressive strength was 7.5%, but at the same replacement ratio of pre-treated rubber in MNRC10 the loss of compressive strength was 14.84%.

Chapter 5

Conclusions and Recommendations

Chapter 5- CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This thesis aims to investigate the behavior of fresh and hardened properties of concrete mixes and the effect of utilizing pre-treated and untreated waste crumb tires rubber in these mixes.

Based on the limited experimental work carried out in the current study, the following conclusions may be drawn out and recommendations for further studies also presented in this chapter that may be taken in consideration.

5.2 Effects of Pre-Treated And Non Pre-Treated Rubber on Concrete

1. Slump test results showed that the slump has decreased as the percentage of rubber was increased in all mixes of pre-treated and untreated rubber.
2. Unit weight decreases as the percent of waste crumb tire replacement increases for all mixes of pre-treated and untreated rubber.
3. Compressive strength decreases as the percent of waste crumb tire replacement increase for all mixes of pre-treated and untreated rubber.
4. The results of the splitting tensile strength tests showed that, there is a decrease in strength with increasing rubber aggregate content similar to the reduction observed in the compressive strength tests due to the weak bond strength between cement paste and tire rubber.
5. The Impact resistance test results showed that the addition of rubber decreases the impact strength compared with the control concrete mix, while the using of mortar with bonding agent pre-treatment can Improve the Impact strength, and the improvement depend on the percentage of pre-treated rubber.
6. More concrete properties depend on properties of materials those used in mixes, and the cohesion between those materials and cement baste, so the pre-treatment of rubber particles by using different methodologies can improve those properties of concrete.
7. Using of mortar with bonding agent pre-treatment for rubber particles give the best values of compressive strength, splitting tensile strength and impact strength with respect to untreated rubber.

5.4 Recommendations

The following recommendations are proposed for further research:

1. Since the addition of crumb tires decreases compressive strength, it is recommended to use waste crumb tires for non-structural elements in buildings such as underground slabs, behind building stones and in partitions etc.
2. Since the addition of crumb tires decreases the unit weight of concrete, it is recommended to use NRC for nonstructural elements to reduce the dead load.
3. It is recommended to use percent of replacements in the vicinity of 20% in the MNRC, since compressive strength still within the acceptable range.

4. It is recommended to study the effect of larger sizes of shredded tires on NRC.
5. It is recommended to further test the physical characteristics of NRC through shrinkage limit, permeability, abrasion, thermal and noise insulation etc.
6. It is recommended to explore the effect of other raw materials in these mixes and study the changes in physical characteristics of NRC.
7. It is recommended to study different grades of concrete compressive strength such as (B150, B300, B400, etc.).

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Appendices

APPENDICE

Some Laboratory Pictures

Figure(1) Drum mixer

Figure (2) Molds And Sample preparation

Figure (3) Na OH Pre-Treatment

Figure (4) Mortar With Bonding Agent Pre-Treatment

Figure (5) Samples Preparation

Figure (6) Samples Testing

Figure (7) Failure Mode