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BEHAVIOR OF LAP SPLICES IN REINFORCED CONCRETE BEAMS USING RECYCLED CONCRETE COARSE AGGREGATE

A Thesis Submitted to the Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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بسم الله الرحمن الرحيم

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا
إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ

صدق الله العلي العظيم

سورة البقرة

(الاية 32)

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I certify that this thesis entitled "**Behavior Of Lap Splices in Reinforced Concrete Beams Using Recycled Concrete Coarse Aggregate** " was prepared by "**Abbas Sadiq Mohammed**" under my supervision in the University of Diyala in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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Date: 4 / 12 /**2019**

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We certify that we have read the thesis entitled(**Behavior of Lap Splices in Reinforced Concrete Beams Using Recycled Concrete Coarse Aggregate**) and we have examined the student (**Abbas Sadiq Mohammed**) in its content and what is related with it, and in our opinion it is adequate as a thesis for the **Degree of Master of Science in Civil Engineering**.

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"In the name of Allah, the most beneficent, the most merciful"

First praise be to "Allah" who gave me the strength and health to work and enable me to finish this work.

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Finally, I would like to express my love and respect to my mother, my family, my brother, no word can express my gratitude to them.

Abbas Sadiq Mohammed

Dedication

To …

God, The greatest truth in my life.

My father spirit, the nice memory of my life

My mother, the sight of my eyes.

My wife, who supported me.

My honorable teachers who taught and rewarded me their knowledge.

Everyone, who wishes me success in my life,

I dedicate this humble work.

Abbass

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Abstract

As a matter of fact, the issue of concrete and demolition waste disposal represents a serious problem in the civil engineering work since it is accumulated in large quantities in some countries like Iraq. Using of such materials in new construction after grinding is considered a good sustainable and cost effective solution to this concern. The basic aim of this study is to investigate the behavior of lap splice when recycled coarse aggregate is used in structural members by experimental program. This program comprises the investigation and assessment to the bond stress lab splices by using 12 beam splice specimens of 250 x 350 x 2500 mm dimensions under the application of two point loads and 18 direct pull out test specimens.

Two mix designs are proposed with nominal 20 and 30 MPa compressive strength, more precisely, the degree of coarse recycled aggregate partial replacement ratio taken throughout this study as 0 %, 50 % and 100 % respectively using a crushed concrete casted originally using the same mixes defined. In addition, the beam splice specimens were devoted to investigate lap splice bond strength in both singly and doubly beams to account the desired behavior in tension and compression into consideration.

The results showed that an increasing the degree of RCA with 50% and 100% replacement decreases the ultimate load of the singly beam specimens in case of 20 MPa compressive strength by about 6% and 10%, while 3% and 8%, respectively in doubly beam specimens. In case of 30 MPa compressive strength the decreasing in ultimate load became by about 4 and 10% for singly beam specimens, 1 and 4% in doubly beam specimens, respectively.

Furthermore, increasing the degree of RCA by 50 and 100% decreases the consequent first crack load in case of singly beam specimens in 20 MPa compressive strength by 17 and 25%, while in doubly beam by about 17 and 23%, respectively. In case of 30 MPa compressive strength the decreasing in first crack load became by about 20 and 27% for singly beam specimens and 7 and 20% in doubly beam specimens.

The results also showed that replacing 50% of coarse aggregate decreases the bond stress by 2.63 to 6.25 % in singly beam specimens and 3.23 to 7.76 % in doubly beam specimens while replacing 100 % decreases such stress 5.26 to 10.42 % in singly beam specimens and 5.65 to 11.42 % in doubly beam specimens. In addition, compressive strength, modulus of elasticity, splitting tensile strength, workability and modulus of rapture have also decreased when degree of recycled coarse aggregate is increased. In other hand, the brittle failure behavior is evident in the entire beam specimens that conducted throughout this study.

Finally, the direct pull out test specimens results showed that the bond stress is generally decreased by the increase of the degree of recycled coarse aggregate for high compressive strength while this does not exist clearly in low compressive strength.

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TABLE OF ABBREVIATIONS

Abbreviation	Abbreviation
As	Area of reinforcing bars
As'	Area of compression steel reinforcement
A_{tr}	Area of tow leg stirrup
b	Width of beam
d	Effective depth of beam, distance from centroid of longitudinal tension bars to top fiber
d'	Distance from centroid of longitudinal compression bars to top fiber
Ec	Modulus of elasticity of concrete
Es	Modulus of elasticity of steel reinforcement
$f'c$	Compressive strength of concrete
fct	Splitting tensile strength of concrete
fr	Modulus of rapture
fy	Yield stress of main steel reinforcement
fs	Stress of main steel reinforcement
$f's$	Compression stress of steel in case of balance
L_d	Development length
L_s	Lap Splice
Mn	Nominal moment
n	Number of main reinforcement
p	Applied load
s	Maximum distance between stirrups
v_c	Shear capacity of concrete
v_s	Shear capacity of steel reinforcement
ρ	Tension reinforcement ratio
ρ'	Compression reinforcement ratio
ρ_b	Balanced reinforcement ratio
ρ'_b	Tension reinforcement ratio which cause balanced failure
ρ_{max}	Maximum reinforcement ratio
ρ'_{max}	Maximum tension reinforcement ratio which cause maximum strain
τ	Bond stress
ε_s	Strain of steel
$\emptyset$	Diameter of bar

ACI	American Concrete Institute
NCA	Normal Coarse Aggregate
RA	Recycled aggregate
RAC	Recycled aggregate concrete
RCA	Recycled coarse aggregate
SEM	Scanning electron microscope
SG	Strain gauge

CHAPTER ONE

INTRODUCTION

1.1 General

Actually, during the present decade, structures like bridges, roadways and buildings are still have a progressive increasing rate in the urban areas in particular. In addition, the old units of such structures may reach its service life end and / or no longer satisfy their purposes, due to that, repair or replacement processes are dictated which in turn increases the demand for a certain construction materials like concrete and asphalt aggregates. Concrete demolition aggregate or simply recycled aggregate concrete (RAC) is such type of concrete that made of recycled coarse and fine aggregate while recycled coarse aggregate concrete (RCA) is made of recycled coarse aggregate and natural fine aggregate. However, these materials were proved a significant role within this field as a cost effective and sustainable agent to substitute normal aggregate because such aggregate is generated in huge quantities every year as a waste material (Shima etal, 2005).

Consequently, RAC can be used in different ways such as soil stabilization as well as being a recycled aggregate in concrete buildings construction as illustrated in Figure (1-1).

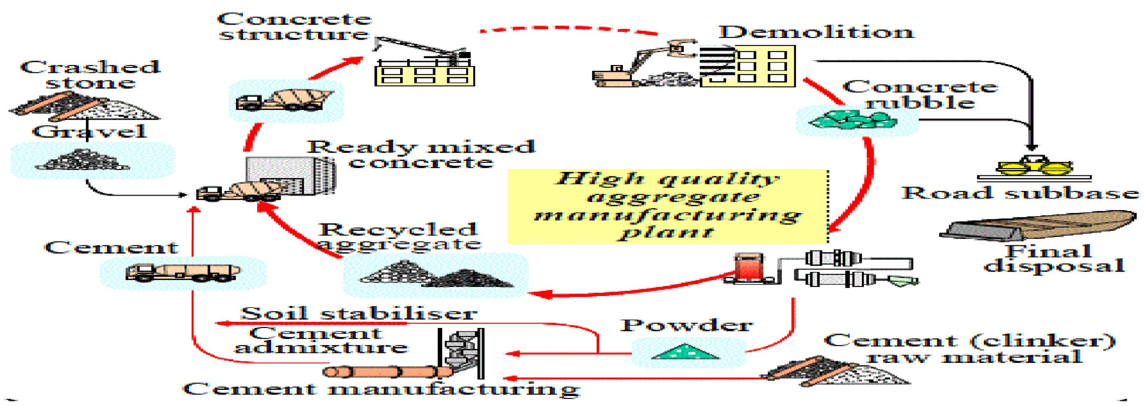

Figure (1-1): Schematic flow of concrete recycling system (Shima et.al, 2005).

1.2 Recycled and Normal Aggregate

As a matter of fact, the main difference that can be recognized between the recycled and normal aggregate is the presence of the mortar reminders around its particles, however, such presence dictates more pores evidence which means that many chemical and physical properties are dissimilar, due to that, the consequent characteristics and performance of the concrete can vary to a great concern. This variety is extended to the mechanical behavior and durability as well as low levels of density and specific gravity in addition to high water absorption compared with natural aggregate concrete (Abbas etal, 2008). As a result, the specifications related to this field are still seeking to increase confidence about the using of recycled materials in civil engineering applications (Aïtcin, 2004). Plate (1-1) shows the recycled coarse aggregate (RCA).

(a) (b)

Plate (1-1): Recycled coarse aggregate

1.3 Recycled Aggregate Quality and Identification

Generally, recycled aggregate can be defined as the crushed, graded and inorganic particles that resulted and from the demolotion debris of construction process (Ravi, et. al, 2013).

According to (BS 8500-1, 2006), the RA is defined as the generic term that refers to aggregate resulted from the reprocessing of the material that used previously in construction.

(The Concrete Society, BRE. 2005) is categorized the recycled aggregate mainly into three groups, **Type I** which represents the aggregate that have the lowest strength and the maximum level of impurities which may be have 100% brick or block masonry, whereas **Type II** is crushed concrete may comprise up to 10 % brick and up to 1.5 % other impurities like wood, asphalt and glass and exhibits high quality material characterestics. Finally, **Type III** is crushed concrete mixed with up to 50 % brick. Table (1-1) lists some limitations of recycled aggregate.

Table (1-1): Acceptable quality of recycled aggregate*

Contaminant % by mass	BS 8500-1,2006	The Concrete Society, BRE. 2005 (II)
Masonry	< 5%[a]	<10%
Lightweight material < 1000(kg/m^3)[c]	< 0.5%[b]	in other foreign material
Asphalt	< 5%[d]	in other foreign material
Other impurities (e.g. glass, plastic and metals)	< 1%	in other foreign material
Other foreign material	Contained in other impurities	< 1%
Wood	Not quoted but should be less than 0.1% as per EN 12620	< 0.5%
Total	< 11.5%	< 11.5%

*(BS 8500 and The Concrete Society, BRE. 2005)

a Limit may be increased to < 10% for exposed concrete when asphalt limit reduced to < 0.5%

b Limit set to < 0.1% for exposed concrete

c 'Floating stony' materials only

d Limit set to < 0.5% for exposed concrete.

1.4 Recycled Aggregate Production Process

In fact, the plant that usually is used to crush recycled aggregate is the same as once used for natural aggregate. Normally, there are two types of such plants, the closed system and the open system. It is common that the closed system is recommended to recycled aggregate (Hansen, 1985). The general layout of this system is shown in Figure (1-2).

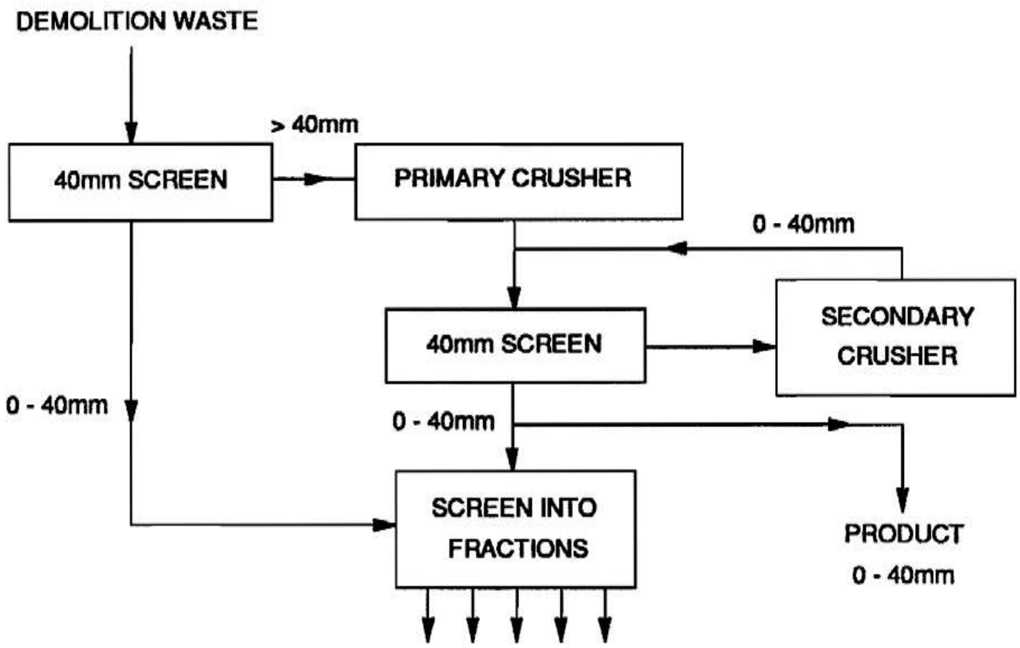

Figure (1-2): General layout of closed system (Hansen, 1985)

On the other hand, the open system is featured by its larger capacity when compared to the closed system, but oppositely, the maximum particle size of the final product is less defined. As a result of that, the final properties of such product may be varied to serious concern and the designer should take that into account. The general layout of the open system is shown in Figure (1-3).

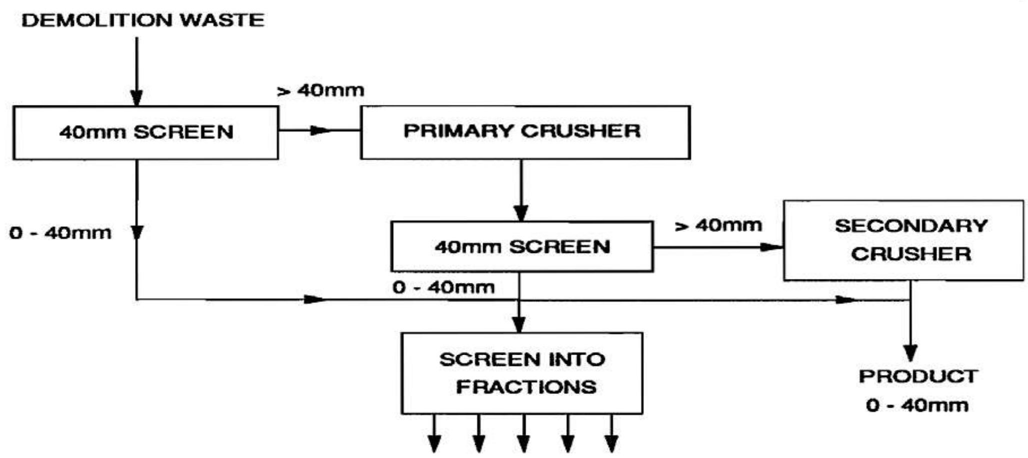

Figure (1.3): General layout of open system (Hansen, 1985)

Finally it is beneficial to mention that the recycling plants can be stationary or mobile . However, each one of these has its significant characteristics and justifications to be used (Lindsell and Mulheron, 1985).

1.5 Basic Characteristics of Concrete made of Recycled Aggregate

Actually, the presence of RCA in concrete dictates many variations in the resulted concrete properties if compared with natural aggregate concrete because the such properties are considerably detrimental to the type of aggregate used (Keith, 2009).This variations can be listed in Table (1.2).

Table (1.2): RCA compared to natural concrete (after Keith, 2009).

Property	Virgin Aggregate	RCA
Shape and Texture	Well rounded, smooth (gravels) to angular and rough (crushed rock).	Angular with rough surface.
Absorption Capacity	0.8 – 3.7 percent	3.7 – 8.7 percent
Specific Gravity	2.4 – 2.9	2.1 – 2.4
L. A. Abrasion Test Mass Loss	15 – 30 percent	20 – 45 percent
Sodium Sulfate Soundness Test Mass Loss	7 – 21 percent	18 – 59 percent
Magnesium Sulfate Soundness Mass Loss	4 – 7 percent	1 – 9 percent
Chloride Content	0 – 1.2 kg/m3	0.6 – 7.1 kg/m3

1.5.1 Shape and Texture

In general sense, the crushing process as well as the presence of paste reminders that stick continuously to particles surface have led RCA to be harsh in texture, as a result, the produced concrete mixes are difficult to finish. Furthermore, due to the same purposes above, the RCA has normally angular shape. In addition, the harshness of such concrete mixes can be minimized by using certain types of admixtures such as fly ash and water reducers.

1.5.2 Water Absorption

Generally, absorption capacity can be defined as " the amount of water that can be absorbed by aggregate". Traditionally, the presence of cement paste reminders makes RCA pouros in nature which in turn have led absorption capacity to be increased, in addition, this circumstances dictates a considerable lack in workability, therefore, the RCA can be pre wetted to overcome this shortage(Keith, 2009).

1.5.3 Specific Gravity

The specific gravity of aggregate is the usual indicator of its density, in general turn, the specific gravity of RCA is less than of natural aggregate due to the entrapped air within the cement paste reminders (Keith, 2009).

1.5.4 Abrasion Mass loss in term of Los Angeles Test

The certain pulverization level to a specific type of aggregate can be assigned by Los Angeles test, the softer aggregate, the less suitability are decided, however, the RCA normally has more loss level than natural aggregate (Keith, 2009).

1.5.5 Sulfate Soundness Mass Loss

As a matter of fact, the concrete resistance to weather and environmental effects is very important regarding concrete performance, however, a good indication can be gained by soundness test. Normally, RCA passes the magnesium soundness test but fails the sodium test.

1.5.6 Chloride Content

Actually, when steel reinforcement is exposed to deicing salts such as sodium chloride (NaCl), the hazard of corrugation is evident, as a consequence, the presence of chlorides in parallel with RCA may highly affects the durability of the new concrete. To overcome this issue, the RCA may be washed and steel bars may be coated by epoxy or resistant steel bars may be used (Keith, 2009).

1.5.7 Physical Properties of Fresh Concrete Containing RCA

Table (1-3) lists the most common physical properties of concrete with RCA (Keith, 2009).

Table (1-3): Physical properties of concrete with RCA (Keith, 2009).

Property	Mixes of RCA
Workability	Poor workability and harshness especially when both coarse and fine fractions are used. Rapid loss of slump. Problem can be alleviated by using only the coarse fraction combined with natural fines.
Water Content	Typically higher for RCA mixes due to greater absorption feature. Setting water content may be difficult due to the variable absorption.
Air Content	Tends to be higher and more variable due to higher porosity of RCA and entrained air in original mortar.

1.5.7.1 Workability

It is common that the presence of RA in the fresh concrete makes it harsh and difficult to work when compared to traditional aggregate, therefore, additional water should be added to compensate this workability lack. As a matter of fact, adding more water requires more cement to be used in order to maintain the water to cement ratio, consequently, cost will increase.

However, this shortcoming may be overcome by using of natural fine aggregate instead of recycled once or by the addition of water reducers, fly ash or combination of three (Keith, 2009).

1.5.7.2 Water Content

As mentioned before, the RCA presence makes fresh concrete mix needs more water due to the high ability to absorb water. The teetered nature of degree of absorption makes the water content level within concrete matrix are difficult to be evaluated. This in turn has led to a considerable variation in strength characteristics of the produced concrete (Keith, 2009).

1.5.7.3 Air Content

The presence of entrapped air and the porous nature within the cement paste reminders makes air content is highly variable. In this way, the target air voids in RCA mixes design should be high to achieve the same durability on conferential concrete (Keith, 2009).

1.6 Physical Properties of Hardened Concrete Containing RCA

Practically, RCA concrete should have the same strength of traditional concrete.

Table (1-4) lists the common limiting physical properties of the hardened concrete.

Table (1-4): Limiting physical properties of the hardened concrete.

Property		RCA Mixes
Compressive Strength		Generally and slightly lower due to natural aggregates reduction percentage.
Flexural Strength		Generally and slightly lower, but it varies depending on the original aggregate quality and the amount used of recycled fine aggregate.
Modulus of Elasticity		Generally 20 to 40 percent lower than natural aggregates mixes due to the lower elastic modulus of the RCA particles.
Durability	Freeze-thaw	Superior to virgin aggregate mixes
	D-cracking	Reduced potentially due to crushing of original aggregates into smaller sizes
Bond Strength with Reinforcement		Equal to virgin aggregate mixes, but reduced if using recycled fines.

1.6.1Compressive Strength

In general sense, the compressive strength of the RCA producted concrete must be equal or at least slightly less than the traditional concrete, however, no complete agreement was observed through the literature about the acceptable limits for that reduction. In addition, some studies refers to an increase in compressive strength depending upon the water to cement ratio for RCA concrete mixes (Keith, 2009).

1.6.2 Flexural Strength

Acually, many contribution in the recent studies refers that there is a considerable reduction in flexural strength when RA is used at same water to cement ratio without using fine RA. However, using such type of aggregate is highly affects the flexural behavior of the concrete structural elements which relieses in turn to the paste – aggregate bond strength (Keith, 2009).

1.6.3 Modulus of Elasticity

As a matter of fact, it is recognized through the literature that the stiffness modulus of RCA concrete is less than the rational by 20 to 40 % (Keith, 2009). In addition, it is also believed that this reduction is due the stiffness lack in RCA it self (Keith, 2009).

1.6.4 Durability

In fact, there are two concerns in durability assessment in RCA concrete, these are freeze – thaw and d-cracking susceptibility. In overall view the RCA concrete has equal or higher durability than traditional concrete (Kaith, 2009).

- **Freeze – thaw Durability:**

There is a considerable agreement that the presence of entrapped air in the cement paste reminders makes the use of RCA concrete is beneficial with respect to freeze – thaw durability due to the thermal properties of air.

- **D-Cracking Susceptibility**

Actually, RCA illustrates less D - Cracking susceptibility than the conferential concrete due to the whole crushing process. Furthermore, it is known that the addition of fly ash to the concrete mix can enhance the D - Cracking susceptibility due to the enhancement of workability and the consequent capability of using less amount of water.

1.7 Recycled construction materials advantages: (Tushar, 2006)

1. Used in construction of precast and cast in situation gutters and Krebs.

2. Cost saving: There are no effects on concrete. It is expected that the

increase in the cost of cement could be offset by the lower cost of Recycled Concrete Aggregate (RCA).

3. 20% cement replaced by fly ash is to control alkali silica reaction.

4. Save environment: There is no excavation of natural resources and less transportation and land are required.

5. Save time: There is no waiting for material availability.

6. Less emission of carbon due to less crushing.

1.8 Recycled construction materials limitations or disadvantages: (Tushar, 2006)

1. Less quality (e.g. compressive strength reduces by 10-30%).
2. Duration of materials procurement may affect life cycle of project.
3. Land, special equipments are required (more cost).
4. High water absorption (up to 6%).
5. Higher drying, shrinkage and creep.

1.9 Lap Splices

In fact, when rebar's are used in concrete construction, the entire length may be not identical to the required value due the commercial length availability and / or the nature of the construction stages, this necessarily dictates rebar's to be fastened by suitable economic and fast ways. Overlapping is one of the most common methods to perform this and to ensure the required continuity. However, such continuity should be guaranteed to avoid undesirable slips and relevant excessive cracking.

In addition, when laps are used, bars will continue to withstand stresses even these laps are failed, the confinement will also be enhanced because bars are more spaced which results in to reduce the risk of the joint brittle behavior in the post peak stage (Metelli etal, 2010) and (Cairns, 2013).

1.10 Importance of the Study

In fact, proper use of the recycled aggregate in civil engineering projects is very governing issue regarding safety as in natural aggregate.

Testing results of lap – splice in full scale structural elements is very important to formulate the bond strength equations which have an applicable concerns in structural design.

Due to above, research organizations and authors have many reasons to be motivated to understand and quantify the bond behavior in RCA.Therefore this study is an attempt to develop the knowledge about this field by applying an experimental program.

1.11 Problem Statement

Obviously, conducting a preliminary related tests alone are not enough to assess the performance of bond characteristics in RAC concrete applications as the results of such tests have a very limited dependencies in the design considerations (Gaurav and Singh, 2017). In this way, implementing a parallel full scale lap splices specimens as well as these tests are highly needed and justified.

Furthermore, it can be clearly recognized through the entire literature that there is a considerable lack of information about bond behavior and lap splice in tension and compression in particular. As a result, this stimulates scientific research within this field to understand the current issue more and more.

1.12 Aim, Objective and Scope

The basic aim of this study is to investigate the behavior of lap splice in RCA in both tension and compression and characterize a descriptive view about the presence of such type of aggregate and its role as an alternative choice to natural aggregate. Throughout this study, the following objectives are established to get the former aim:

1- Two mix designs are at first established to obtain two different nominal values of compressive strength.
2- A set of preliminary tests were conducted using the last two mixes and certain degree of replacement of RCA to observe its effects to some preliminary properties of hardened concrete.
3- Four groups of twelve specimens of full scale reinforced concrete beams were also casted at the same two values of compressive strength prepared at different values of coarse aggregate degree of replacement taking into account tension and compression lap splices representation by designing tension and compression failure flexural beams.

1.13 Layout of Thesis

The present thesis are divided into five chapters.

Chapter One: Comprises general aspects of lap splice, comparison of normal and recycled coarse aggregate, importance of the study, problem statement and the covered scope.

Chapter Two: Contains a brief review and related contributions through the literature.

Chapter Three: Includes materials characteristics used in the present study as well as the details of the experimental program.

Chapter Four: Views the results of the tests conducted in the experimental program and a brief discussion.

Chapter Five: Includes the main conclusions that can be recognized in this study in addition to some recommendations about the future work.