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Quality Function Deployment (QFD) : A Method For Improving Concrete Characteristics Made From Recycled Aggregate Concrete (RAC)

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Quality Function Deployment (QFD): A method For Improving Concrete Characteristics Made From Recycled Aggregate Concrete (RAC)

وبعد المناقشة العلنية التي تمت اليوم الأربعاء 02 صفر 1433هـ، الموافق 2011/12/28م الساعة العاشرة صباحاً بمبنى القدس، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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

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بسم الله الرحمن الرحيم

ABSTRACT

This study aims at developing a procedure for integrating the Quality Function Deployment (QFD) method as an effective design tool into recycled concrete ready mix concrete industry improvement; design, and prioritizing Engineering characteristic for concrete mix. The significance of this work lies in its attempt to provide some performance data of Recycle aggregate Concrete (RAC) made in Gaza Strip so as to draw attention to possible use of Recycled Concrete Aggregate (RCA) in ready mix concrete industry.

This work is limited to the development of a suitable concrete mix design that satisfies the requirements of mix proportion in the plastic stage using Recycled Concrete Aggregates (RCA) and then to determine the strength and permeability of such concrete mix when exposed to stressing at different ages: 7, 28 for compressive strength, 28 days for flexure, split strength and 120 days for water penetrations.

Moreover, it involves a comparative study of the strength and permeability of four concrete mixtures at various water cement ratio and Traditional Mix Approach (TMA) and Two Stage Mix Approach (TSMA) to specify which the best mix fit on economical and technical requirements.

During the mix design, Quality Function Deployment (QFD) identified which components were the most critical to fulfilling customer requirements. As the products cost is analyzed, the QFD analysis could be used to support decisions to require a higher level of quality, and therefore a higher cost per unit quantity, for certain components. The biggest benefit of QFD analysis occurs when integrated into the mix design. As the final design is completed and refined, critical RAC specifications were made more stringent to reduce or eliminate the failure concrete sample.

In practice, four replacement ratios (0.00, 030, 0.50, and 0.70) of the recycled aggregate, reduction of water cement ratio from 0.55-to-0.45-to-0.35 and cement content (330 kg/m^3, 350 kg/m^3 and 380 kg/m^3) were considered to determine their effects on the improvement physical properties of the RAC and to obtain an acceptable quality of

concrete with maximum utilization of recycled aggregate in place of natural aggregate using TMA,159 samples were prepared and measurements of compressive strength, splitting strength, flexure strength at 28days.

In addition, the mix method was refined using TSMA with the same conditions and construct 135 samples and avoiding 30% replacement for water depth penetration test because it was not achieve economical requirements. Due to the laboratory test which is performed to ensure and prove the developmental shift on workability, strength and permeability of new concrete mix (RCA mix), it can be clearly seen that the permeability and the strength of the RCA concrete is very dependent on the properties of the RCA aggregate, percent substitutions, w/c and mixing method.

According to the results of this study, concrete incorporating very well graded RCA replacing 50% of NCA and with accepted properties showed satisfactory results regarding water permeability and strength comparing with those of the standard concrete mixes, and consequently, it is recommended that the RCA concrete according to the final design proportions (with RCA replacing 50% of NCA) can be used as a sustainable material in structural applications and produced concrete structure grade B250- B300-B350 at w/c 045, 0.45 and 0.35 respectively, and can be widely used in construction works with optimum cost and water depth penetration less than 3cm (low permeability) due to using TSMA.

ملخص البحث

تهدف هذه الدراسة لتطوير خطوات تطبيق طريقة QFD في تحسين أداء الخرسانة المصنوعة من الحصمة المعادة التدوير، وكذلك تحديد أولويات السمات الهندسية لمكونات الخليط التي تعمل على تحقيق رغبات الزبائن. ويهدف هذا البحث عمليا لإنجاز بعض المعلومات المتعلقة بالخرسانة المصنوعة من الحصمة المعادة التدوير (RAC) ولفت الانتباه لاستخدامها في صناعة الخرسانة الجديدة في قطاع غزة.

يهدف هذا البحث لتطوير خلطة خراسانية مناسبة وذلك بتصميم خلطة خراسانية ذات نسب خلط مناسبة لحالات الخرسانة الطرية وكذلك المتصلدة عند تعرضها لاجهادات التحميل عند فترة فحص 7أيام و 28 يوما لفحص الضغط والانفلاق وكذلك الانحناء وبالنسبة للنفاذية عند 120 يوما تحقق نفاذية للمياه اقل من 3سم حيث أن هذه التجارب تجرى بعد عملية الخلط التقليدية وكذلك عملية الخلط على مرحلتين ثم تحديد نسب الخلط والطريقة النسب للخلط من ناحية اقتصادية وفنية.

إن طريقة QFD المستخدمة في هذا البحث تعمل على تحديد المركبات الأكثر تأثيرا على متطلبات الزبون وأولوياتهم مثل السعر ومستوى الجودة العالي وكذلك السعر لكل مكون من مكونات الخليط الداخل فيتصميم خلطة خرسانية مناسبة تلبي نسب خلط تتلاءم مع حالة الخرسانة الطازجة وكذلك المتصلدة بالنسبة للخرسانة المصنوعة من الحصمة المعادة التدوير وذلك عند تعرضها للإجهاد وكذلك مقاومتها للنفاذية، من خلال عمل مقارنة بين الخرسانة المصنوعة من الحصمة المعادة التدوير كذلك المصنوعة من الحصمة الطبيعية فيما يتعلق بالإجهاد والنفاذية لطريقتي الخلط التقليدية TMA وكذلك عملية الخلط على مرحلتين TSMA.

عمليا تم إجراء أربع عمليات إحلال تمت للحصمة المعادة التدوير وتخفيض نسبة ماء الخلط من 0.55-إلى-0.45-إلى-0.35 ولنسب خلط 330كغم/م3، 350كغم/م3، و380كغم/م3 بالتتابع وتم صب 159 عينة لفحص كل من مقاومة الضغط عند 7 أيام، ومقاومة الانحناء ومقاومة الانشقاق عند 28 يوم للفحوصات الثلاث، وكذلك عند 120 يوم لفحص النفاذية باستخدام طريقة الخلط التقليدية TMA، وتم صب 135 عينة للفحص باستخدام طريقة الخلط على مرحلتين TSMA تحت نفس الشروط.

بناءا على نتائج المختبر تبين لنا أن التحسينات للخلطة الخراسانية المصنوعة من الحصمة المعادة التدوير لكل من قابلية التشغيل وكذلك القوة والنفاذية تعتمد بشكل أساسي على خواص الركام المعاد التدوير و نسب الخلط و طريقة الخلط. وكذلك فإن الحصمة المصنوعة من الحصمة المعادة التدوير وجيدة التدرج وبنسبة إحلال 50% من الحصمة الطبيعية وبطريقة خلط TSMA وعند نسب ماء خلط 0.55-0.45-0.35 تحقق القوة لخلطات B250، B300، وB350 وتتناغم مع صفات الخرسانة المصنوعة من الحصمة الطبيعية وبنفاذية أقل من 3سم (نفاذية قليلة) وتوصي الدراسة باستخدام خلطات RCA بحسب النسب التصميمية النهائية (وبنسبة إحلال 50%) في الأعمال الإنشائية لأنها تحقق الجدوى الاقتصادية القصوى مع الخصائص الهندسية المرضية.

DEDICATION

This research study is humbly dedicated to the suffering people of my beloved homeland, Palestine

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Abbreviations

QFD: Quality Function Deployment

HOQ: House of Quality**.**

VOC: Voice of Customer.

DR,s : Design Requirements**.**

CN,s : Customer Needs

RAC : Recycled Aggregate Concrete.

CWD : Construction Waste Demolish.

RCA : Recycled Concrete Aggregate.

NCA : Natural Concrete Aggregate.

V_{RM} :Volume of residual of mortar.

RMC: Residual of Mortar Contents**.**

$B.S.G_{SB}$ **:** Bulk Specific Gravity.

$B.S.G_{SSD}$ **:** Bulk Specific Gravity of Coarse Aggregate (SSD) Saturated Surface Dry

WRA : Water Reducer Admixture.

SP : Super Plasticizer

LA %; Los Anglos.

RMC: Residual Mortar Content in RCA

TMA : Traditional Mix Approach.

TSMA : Two Stage Mix Approach.

ITZ: Interfacial Transition Zone

ASTM: American Society for Testing and Materials

NA: Natural Aggregate

Chapter One

1.1 Background

Recently, many papers reports findings regarding the durable concerns and related characteristics of fresh and hardened concrete, proposed as an important customer group of ready mixed concrete products firms. and provides specific suggestions regarding the content of Recycled Concrete Aggregate (RCA) maintaining targeting this group. It is advocated that the improvement facilities of hardened concrete made from RCA. This substitution in the concrete mixed products would reduce Natural Aggregate (NA) substitution (natural resources), environmental pollution impact, land fill and construction cost (Tam and Tam, 2006).

Accordingly several studies have revealed an important substitution of NA by recycled aggregate concrete materials in residential construction industry. Consistently, the work housing building that RAC have made significant gains against ready mixed concrete in residential construction as result its available with big quantity after the 2008 war on the Gaza Strip and cost reduction.

This research is designed to identify the importance of specific Customer Needs (CNs) for satisfying customer expectations and needs. Such a methodology would help the companies of concrete to improve Ready Mix Concrete (RMC) made from Recycled Aggregate Concrete (RAC) characteristics orientation, as it was believe that the concrete product industry is too competitor oriented, and big gains can be made from both a customer and a competitor focus.

To remain competitive, organizations must design products and services that meet or exceed customer expectations. However, it is impossible to remain cost competitive and offer every feature desired by customers. Therefore, marketing, engineering, and operations need to work together to determine the profit-maximizing bundle of product features. Engineers, technical development personnel, and quality experts have tended to use Quality Function Deployment (QFD) to translate customer needs into product design characteristics (Pullman et al., 2002).

To sum up, the mass needed for both covering the lack of fresh recycled concrete aggregate, and satisfying the customer needs encourage us to seek for modeling and designing practical solution in order to maximize the profit, reduce the cost, environment impact, and improve the RAC within the limited alternatives at Gaza Strip. The current study is planned to employ the QFD method as an effective design tool in recycled concrete industry improvement.

1.2 A Note on Important Definitions and Acronyms

In order to facilitate the discussion in the current study, the following terminology and acronyms will be consistently used throughout this thesis:

- NA (Natural Aggregate) = aggregate obtained from crushed rock.
- RCA (Recycled Concrete Aggregate) = aggregate obtained from crushing demolition concrete, normally comprising original virgin aggregate (OVA) coated with cement paste residue and/or lumps of paste residue, called residual mortar (RM).
- RM (Residual Mortar) = the mortar fraction attached to original virgin aggregate in RCA.
- NAC (Natural Aggregate Concrete) = concrete produced with crushed rock as coarse aggregate, Gaza sand as fine aggregate, and cement paste as binder material.
- RAC (Recycled Aggregate Concrete) = concrete produced with combination of RCA and NA as coarse aggregate and Gaza sand as fine aggregate, and cement paste as binder material. Recycled fine aggregate is not used as replacement for sand due to its proven inferior properties. RAC in this study refers to recycled aggregate concrete in a generic sense.
- ITZ (Interfacial Transition Zone) = the interface between the natural aggregate particles and the mortar in conventional concrete.

1.3 Research Significance

Recycling of demolished concrete and its utilization as aggregate in new concrete is increasingly being considered for production of sustainable concrete construction. Much is known about properties of RCA concrete, some physical properties and durability aspects of concrete made with old RCA, obtained from building and structures, is still not well understood. (Movassaghi, 2006).

In choosing aggregates for particular uses, attention should be given to three general requirements: economy of the mixture, potential strength of the hardened mass and probable durability of the concrete. It has proved beneficial economically because of a number of factors, namely: Reduction construction waste, Greater freedom in design, and Safe working environment (reducing environment impact).

As limited applications of RCA are attributable to their poor qualities, and to solve the problems of RAC, some more techniques need to be developed for improving the quality of RAC, such as QFD which optimizes the mixed design criteria, defines the process improvement, and defines the target design.

In order the optimization mix blend presented herein attempts to improvement the quality of fresh and hardened concrete properties of very well hydrated RCA. Also, improving the effects of Recycled Concrete Aggregate RCA on the durability aspects of concrete such as permeability (corrosion of reinforcing steel), which were comprehensively compared with that of concrete made with natural aggregate.

1.4 QFD Deployment and implementation

1.4.1 QFD Deployment

In a few words, the voice of the customer translated into the voice of the engineer. To design a product well, a design teams needs to know what it is they are designing, and what the end-users will expect from it. Quality Function Deployment (QFD) is a systematic approach to design based on a close awareness of customer desire, coupled with the integration of corporate functional groups. It consists in translating customer desires into design characteristics for each stage of the product development. (Chen & Weng, 2006)

Ultimately the goal of Quality Function Deployment (QFD) is to translate often subjective quality criteria into objective ones that can be quantified and measured and which can then be used to design and manufacture the product, where the product is the concrete made from recycled concrete aggregate. The worth mentioning is that the main goals in implementing QFD are: prioritize spoken and unspoken customer wants and needs, translate these needs into technical characteristics and specifications, build and deliver a quality product or service by focusing everybody toward customer satisfaction (Akoa, 1990).

1.4.2 QFD Implementation

QFD is to be implemented as a tool for designing concrete mixes that fit according to concrete compressive strength and durability dimensions and according to their needs and to determine the technical descriptors required to satisfy those needs.

1.5 Problem statement

The RAC is derived from the crushed materials of concrete structures, buildings, its usage in the building industry is restricted because of the lack of scientific data. There is not yet sufficient information available to show that recycled materials meet standard technical criteria for use or match the performance of natural materials. So QFD is used as a quality tool to improve ready mixed concrete characteristics made from RAC and draw target value which affect on strength and durability of concrete that prevent concrete sample failure in construction project at Gaza Strip.

1.6 Scope

The scope of this research is to develop a procedure for integrating QFD into ready mix concrete industry; design, and prioritizing Engineering characteristic for composite mix. The work is limited to the development of a suitable concrete mix design that satisfies the requirements of mix proportion in the plastic stage using recycled aggregates (RAC) and then to determine the strength and durability of such concrete mix when exposed to stressing at different ages: 7 days and 28 days.

1.7 Objectives

The purpose of this research is to propose using QFD as design tools which can be beneficial to determine the design requirement of concrete made from RCA, and develop characteristic design in order to solve the problems resulted from using recycled aggregate. Therefore the study aims to achieve the following objectives:

1. Utilizing Quality Function Deployment (QFD) in concrete ready mix design as a tool for ensuring quality requirement according to customer demands.
2. Identification of RCA properties, its effects on fresh concrete, hardened concrete properties including strength, permeability and workability.
3. Obtaining an acceptable quality of concrete with maximum utilization of recycled aggregate in place of natural aggregate.

1.8 Methodology

With respect to the research methodology using QFD as a method for improving RAC characteristics, Figure 1.1 reveals the required tasks in order to achieve the research objective, where these tasks are classified into three phases, and two research approaches, analytical & experimental investigation methods, are utilized to obtain results and draw recommendation. From the Figure 1.1 it can be clearly seen that the research work is divided into three phases, where the following is detailed description of needed tasks at each phase:

Phase One includes necessary information about RAC problem, functional analysis, system components and principles (recognized needs).

Phase Two mainly explore the construction of the model for selecting design requirements in QFD, where the following steps are included:

1. Define Customer Needs (CNs) and design requirements (DRs) for satisfying CNs and resource constraints,

2. Prioritizing the design requirement part of composite mixed concrete that affect on workability , strength of concrete and durability,
3. Benchmarking of the products (RAC) against best performance in the strength, durability and cost.

Phase Three basically focus on optimizing materials & traceability, where the following steps should took place:

Defining materials using and resources and materials properties.

Formulate the problems of interest with an appropriate mathematical programming model (Linear programming) in consideration of resource constraints and determine an optimal blended aggregate.

Prepare the concrete mixed design with appreciate percentage of natural and recycled aggregate using Two Stage Mixed Approach (TSMA) to optimizing concrete mixed and its properties.

Testing verification concluded: Laboratory testing studies are emerging highlighting the use of recycled aggregate concrete. Using substitution methods: for fresh concrete (density and workability), and for hardened concrete (density, strength and durability).

Determine an optimal target value of composite mixed concrete that satisfying the customer requirements (cost, quality, strength, and durability) and comply with standards ASTM and specification.

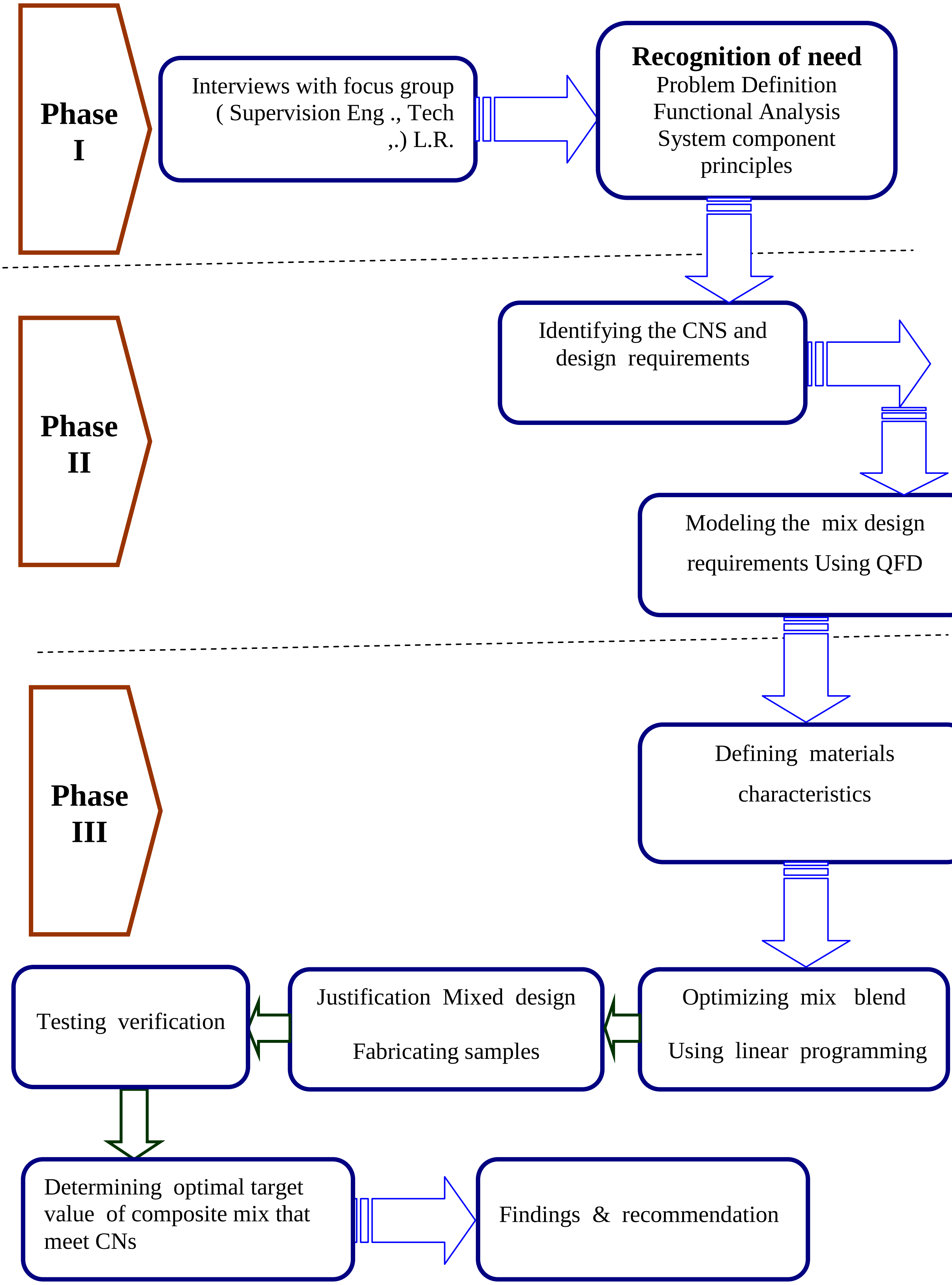


Figure 1.1: The methodology for RAC characteristics improvement

1.9 Thesis Layout

Following this chapter, the remaining content is organized as follows:

- **Chapter 2 (Literature Review RCA):** Presents a literature review on the utilizing recycled concrete aggregate (RCA) in engineering application, quality RCA properties and its effect on recycled aggregate concrete (RAC) properties on plastic stage and hardened stage, and
- **Chapter 3 (Literature Review QFD):** Presents a literature review on the history, concepts, and theories of QFD in addition the practical application of QFD in construction industry and others.
- **Chapter 4 (Modeling and Optimization):** Presents the modeling of research problem in the study using QFD as method improvement of RAC characteristics.
- **Chapter 5 (Result and Discussion)**: Presents the analysis of data and the final mixed design of ready mixed concrete that is economic and meet customer requirements through the implementation of QFD and durability principles.
- **Chapter 6 (Conclusions and Recommendations):** Presents the target values of effectiveness concrete mixed, conclusion, and recommendations based on the results of the research, and recommended future studies.

Chapter Two

Literature Review RAC

2.1 Introduction

Since much of the published literature is on the use of crushed concrete from existing concrete structures in engineering application road work and back fill etc, this literature review is intended as a summary of effecting RCA on RAC properties, but will pertain to the use of recycled crushed concrete aggregate (RCA) as well as NCA in ready mix concrete industry.(Fathifazel,2008)

The process of recycling aggregate materials has several advantages: it saves money by cutting disposal costs, reduces waste going to the landfill, facilitates a cleaner and safer construction site, keeps the environment from pollution and improves community relations. So the recycle technique can be defined as employing wastes as raw materials in other valuable applications.(Li x., 2008)

This phase covers two main items: RAC and QFD. Regarding RAC, a comprehensive literature survey and data collection in the following areas:

Definition and production of RAC,

Utilizing recycled aggregate in engineering application,

Effect of RAC on hardened recycled aggregate properties,

Development RAC due to using QFD methods.

2.2 Economic and Environmental Benefits of RAC

One advantage of recycling is landfill avoidance, which implies saving of waste dump capacity, i.e. space: a very important and scarce resource nowadays (Blengini and Garbarino, 2010).

From the viewpoint of environmental preservation and effective utilization of resources, it is beneficial and necessary to reuse waste concrete as recycled concrete aggregate (RCA) for new concrete, often referred to as recycled aggregate concrete. The process of recycling aggregate materials have more one advantages, it saves money by cutting disposal costs, reduces waste going to the landfill, facilitates a cleaner and safer construction site, and keeps the environment from pollution and improves community relations. So the recycle technique can be defined as employing wastes as raw materials in other valuable applications. (RAC) (Li x., 2008).

One of the best ways to manage this acute environmental problem is by recycling construction waste. As concrete waste forms the major source of construction solid waste, which contributes to about 50% of total C&D waste, recycling the concrete waste is the best option to mitigate quantities of construction waste. (Tam and Tam, 2007).

When considering a recyclable material, three major areas need to be taken into account: (1) economy; (2) compatibility with other materials; and (3) material properties. (Tam and Tam, 2006).

Recycling, being one of the strategies in minimization of waste, offers three benefits: (i) reduce the demand upon new resources; (ii) cut down on transport and production energy costs; and (iii) use waste which would otherwise be lost to landfill sites. (Tam and Tam, 2006).

Application of recycled aggregate to concrete structures, it is necessary to provide a suitable balance between quality, cost-effectiveness and environmental impact. From the view point of life-cycle assessment (LCA), the cost of recycled concrete as aggregate would be more efficient if its quality is competitive with that of natural aggregates while improves the environmental conditions (Movassaghi, 2006).

Figure 2.5, shows the required optimum balance between the demand quality, cost effectiveness and environmental impact of recycling concrete as aggregates (Movassaghi, 2006).

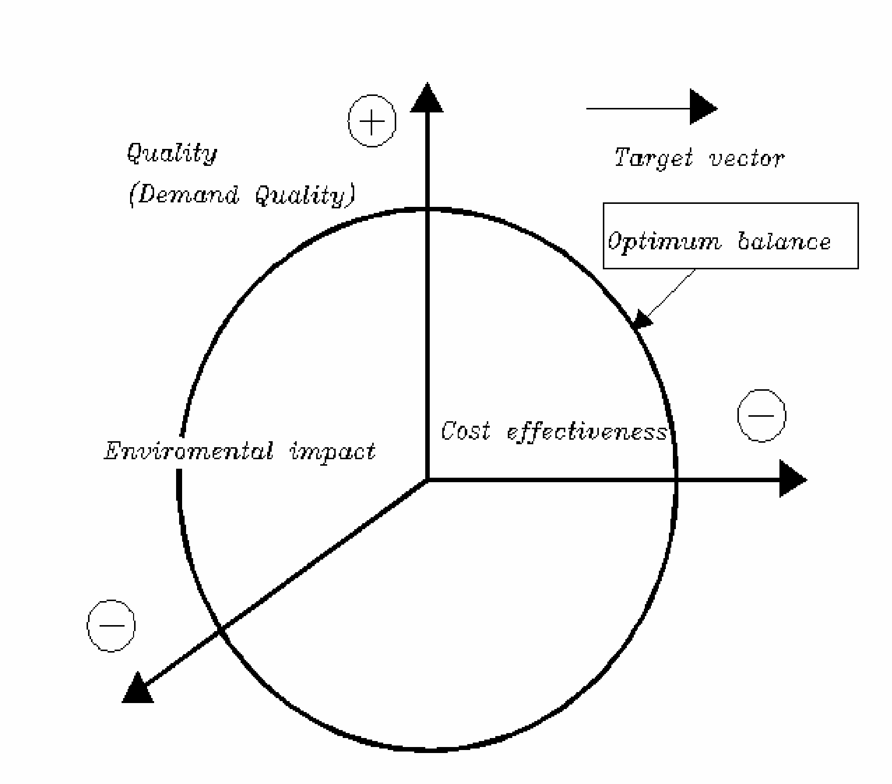


Figure 2: Evaluation of demolished and waste concrete recycling (Movassaghi, 2006)

2.3 Production of Recycled Concrete Aggregate as Aggregates (RCA)

Recycled aggregate concrete is referred to as concrete produced using old crushed concrete in place of natural aggregates (mainly coarse aggregates). Recycled aggregates are referred to as aggregates produced by the crushing of the old concrete. Such aggregates can be coarse or fine aggregates (Salem, 1996).

RCA concrete is made with crushed RCA used as partial or full replacement of conventional coarse or fine aggregate in new concrete. Since RCA come from different sources and occupies around 75% of the volume of concrete, it is necessary to maintain the high quality of aggregate during the entire course of recycling system (Movassaghi, 2006).

Figure 2.1a and 2.1b illustrates crusher machine used to produce RCA and a local crusher machine used to produce RCA concrete in the Gaza Strip, and Figure 2.2 show large capacity sieve shaker. Figure 2.3 illustrates the stock pile of crushed concrete chunks obtained from the reinforced concrete building which was demolished by Crusher.

Figures 2.4, illustrate sorting of the inert part of the construction and demolition (C&D) waste into three main fractions according to sizes: (a) equal 25 mm, (b) 19.5 mm and (c) 9.5mm from the left side to the right side respectively.

Figure 2.1a: Crusher used to produce RAC at the ready mix concrete plant

Figure 2.1b: Local crusher machine used to produce RAC at Gaza Strip

Figure 2.2: Large Capacity Sieve Shaker

Figure 2.3: Stock piling of crushed demolished concrete coarse aggregate in Gaza City

Figure 2.4: Stock piling of crushed demolished concrete fine aggregate in Gaza City

Figure 2.5: Size fraction 25, 19..5., and 9.5 mm respectively

2.4 Utilizing RA in Engineering Applications

2.4.1 Utilizing RCA in Construction Roads Work.

Courard et al.,(2010) studied the optimization of roller compacted concrete with recycled concrete aggregate and found recycled aggregates may present very good performances for use in RCA: avoided very small content of fine particles, specific gravity of 2634 kg/m3, absorption coefficient of 4.58% and LA coefficient equal to 25 and optimum Proctor modified.

Debieb et al., (2009) checked the ability used of using recycled aggregate in construction roads with acceptable behavior with time if the aggregate satisfying the durability condition and LA condition and washing it before used.

Tam et al. (2008) found that recycled demolished concrete (DC) as recycled aggregate (RA) and recycled aggregate concrete (RAC) is generally suitable for most construction applications. Low-grade applications, including sub-base and roadwork, have been implemented in many countries; however, higher-grade activities are rarely considered.

Movassaghi (2006) stated that recycled construction materials derived from construction and demolition waste, rehabilitation, natural and technological disasters are an example of construction material in harmony with this concept. Equals 10%of the global sand and rock consumption is the amount of construction and demolition waste generated each year that about half of the waste has potential for recycling.

Table 2.1 gives a rough estimation of construction and demolition (C&D) waste generated in countries using the most percentage of recycled concrete as aggregates (RCA) according to (Movassaghi, 2006).

Table 2.1: Global consumption of construction and demolition wastes as aggregates

Country	C&D waste (million tons/year)	Percentage of C&D waste recycled	Recycled concrete (million tons/year)
United state	650	20 - 30	150
Europe	200	28	50
Japan	85	85	35
Hong Kong	14	50	3.5
Canada	11	21	2.3
Australia	3	50	1.5

Most of the aggregates produced by the recycling plants are used as road base in urban paving activities. Some tentative applications of selected recycled aggregates for concrete component production (concrete blocks and paving blocks) have been made, in the cities of Vinhedo, Belo Horizonte and Santo André (Angulo et al., 2006).

Poon et al., (2002) proved through his result that recycled aggregates can be used to produce subbase materials because of the partial replacement of 25% up to 50% of natural aggregate by recycled aggregate showed little effect on the compressive strength of the brick and block specimens. They also recommended using recycled aggregate with the total replacement (100%) in producing paving blocks for footways and aprons with compressive strength of 30 MPa.

One major area where recycled concrete has been successfully used is in the reconstruction of concrete pavements. The first successful utilization of an old pavement as aggregates for the' new pavement was in the state of Iowa. The 42 years old concrete pavement was crushed into aggregates, which were used in a new one-mile long and 10-inch thick highway pavement (Salem, 1996).

2.4.2 Utilizing RCA in Construction Building works

Courard et al, (2010) found that recycled aggregates may present very good performances for use in RCA: avoided very small content of fine particles, specific gravity of 2634 kg/m3, absorption coefficient of 4.58% and LA coefficient equal to 25, and water content optimum is spread on a large range of values, which is very profitable on site. Their is ability to produce recycled aggregate with minimum grade C20 to intermediate grade C30.

Poon et al, (2009) confirmed the ability for using the RCA in block manufacturing and found the following: i) The density of blocks decreased with the increase in RFA content, ii) The compressive strength of the blocks decreased with an increase in the RFA content, iii) The drying shrinkage of the blocks increased with the increase in the RFA content, and iv) The compressive strength, transverse strength of the blocks increased but the drying shrinkage of the blocks decreased with a decrease in the aggregate-to-cement ratio.

Recently many researches concerned with the using recycled aggregate in construction building and produce recycled aggregate concrete RAC medium and low compressive strength in countries like China and Hong Kong. There are successful application examples for building structures in China. And the application leads to both good economical and environmental benefits (Li x., 2009).

2.4.3 Utilizing RCA in Construction works in Gaza Stripe

Many studies practically has been conducted investigated the applicability using RCA in engineering applications, three fields cover red were ; concrete mixes and proprieties RAC , roads construction and hollow block production Figure 2.6 illustrated reused RCA to produce hollow blocks. The main findings were:

- Concrete compressive strength made with recycled aggregate concrete less than concrete made from natural aggregate 27-30 %. Rustom et. al. (2007)
- No swelling is noticed in CBR test. The result of physical test indicate the applicability of recycled aggregate in road construction. Rustom et. al. (2007)

- Concrete Hollow Blocks made with recycled aggregate has compressive strength about (12-21 %) less than Hollow Block made with natural aggregate. And for the same compressive strength the cost of block made with recycled aggregate less than the block made with natural aggregate. Rustom et. al. (2007)

Figure 2.6: Shows new Hollow block product by utilization of RCA, in Gaza city

Other research were conducted to locally studies the quantities, sources of construction demolition waste, construction demolition C&D management and recycled aggregate behavior. It was stated by Enshasi and Riyati in 2008 that the estimated generation rate of construction and demolish waste in Gaza strip have reached more than 0.625 M3 Per year rather than 1.5 million M3 were generated due to Israel destruction in ex-settlements and Palestinian homes in Gaza strip. More over, they stated that rather than 1 million M3 were generated due to Israel ware 2008 according to UNDP organization.

In addition, Zuhud in 2008 sited that: i) the dry density of recycled aggregate less than of the dry density of natural aggregate concrete, ii) the workability of recycled aggregate concrete mix is lower than natural aggregate, concrete mix with 30% recycled aggregate concrete has satisfied workable concrete, iii) the flexure strength of recycled aggregate was good indicator of the behavior of recycled aggregate concrete and flexure strength concrete proportioned to compressive strength, and iv) concrete compressive strength made from recycled aggregate concrete less than concrete made from natural aggregate 28 %.

2.5 Effect of Quality RCA on RAC Properties

Fine recycled aggregates are seen as the last choice in recycling for concrete production. Many references quote their detrimental influence on the most important characteristics of concrete: compressive and tensile strength; modulus of elasticity; water absorption; shrinkage; carbonation and chloride penetration (Brito and Evangelista, 2010).

Juan and Gutierrez (2009) found in their study the influence of attach mortar content on the quality of recycled concrete aggregate, as follows:

- The amount of mortar attached to fine fraction is higher than to coarse fraction: wide ranges of 23–44% for 8/16 mm fraction and 33–55% for 4/8 mm fraction have been obtained in fifteen samples, which also shows the great heterogeneity of recycled aggregates..
- General relationships covering a wide range of recycled aggregate qualities have been adjusted for them. These relationships can be used to establish the recycled aggregates requirements for different applications.
- Recycled aggregate of good quality for the production of structural concrete could be obtained selecting aggregates with mortar content under 44%.
- With this criterion, aggregates with bulk specific density higher than 2160 kg/m3, water absorption lower than 8% and Los Angeles abrasion loss under 40% (LA40), are obtained.
- This quality of recycled aggregate can be produced controlling original concrete strength, over 25 N/mm2.

Juan and Gutierrez (2009) stated that quality of recycled concrete aggregate is lower than natural aggregate quality, due to the mortar that remains attached to natural aggregate.

The poor quality of RAC resulted from the high water absorption, high porosity, weak interfacial behavior between RA and new cement mortar renders the applications of RAC for higher-grade applications is difficult (Tam and Tam, 2008).
The quality required for the concrete is ensured by adjusting the volume ratio of the recycled coarse aggregate to the total coarse aggregate. Hereinafter it is referred to as the replacement ratio (RR). (Eguchi et al, 2007).

The poor quality of RAC resulted from the higher water absorption, higher porosity, weaker ITZ between RA and new cement mortar hampers the application of RAC for higher grade applications. The quality of RA is weaker than that of virgin aggregate (water absorption of virgin aggregate at only 0.77% and 0.57% for 20 and 10 mm, but for the same grading of RCA 5% and 8.1% respectively), indicating that the major weakness of RA is its high porosity (Tam et al, 2005).

2.6 Effects of RCA on Fresh Concrete Properties

Recycled concrete mixes require more water than conventional concrete to maintain the same slump without the use of admixtures. This affects the quality and strength of the concrete, resulting in lower concrete strength (Tabsh and Abdelfatah, 2009).

The water absorption of recycled aggregate increases with an increase in strength of parent concrete from which the recycled aggregate is derived, while it decreases with an increase in maximum size of aggregate. Higher water absorption of recycled aggregate necessitates adjustment in mix water content to obtain the desired workability (Padmini, 2009).

Many studies have shown that as RCA content in concrete mixtures increases, their workability decreases. The most important feature of RCA concrete is the presence of adhered mortar in RCA. Due to the higher porous nature of adhered mortar, the physical and mechanical properties of RCA and concrete made with this aggregate are significantly different from ordinary concrete. For instance, the workability of fresh concrete decreases with increase in the surface area of recycled aggregate. In turn, the surface area is influenced by grading, shape, texture and maximum size of the recycled aggregate. Therefore, for the successful use of RCA in fresh concrete production, the properties of RCA must be accurately determined (Movassaghi, 2006).
Some studies found that in order to produce similar workability as VA concrete 5% more mixing water was required when using just the coarse fraction of recycled concrete aggregates (coarse RCA) and up to 15% more mixing water when using both the coarse and fine fractions of RCA (Olba et al, 2006).

2.7 Effects of RCA on Hardened Concrete Properties

2.7.1 Effect of RCA on Compressive Strength

The percentage loss in compressive strength due to use of recycled aggregate is more significancant in a weak concrete than in stronger one. The use of coarse aggregate made from recycled concrete with strength equal to 50 MPa will result in concrete compressive strengths comparable with that 30 MPa (Tabsh and Abdelfatah, 2009).

Etxeberria et al. (2007) proved through his result after experiment the following:Concrete made with 100% of recycled coarse aggregates has 20-25% less compression strength than conventional concrete at 28 days, with the same effective w/c ratio (w/c = 0.50) and cement quantity (325 kg of cement/m3).

- Concrete made with 100% of coarse recycled aggregate requires high amount of cement to achieve a high compressive strength and consequently is not an economic proposition as it is not cost effective. These recycled aggregates should be used in concretes with low–medium compression strength (20–45 MPa).

- Medium compression strength (30–45 MPa) concrete made with 25% of recycled coarse aggregates achieves the same mechanical properties as that of conventional concrete employing he same quantity of cement and the equal effective w/c ratio.

The compressive strength is considered as the most significant property because reinforced concrete structures are mostly required to bear against compressive loads and the other strength properties of concrete constructions are dependent to compressive strength (Movassaghi, 2006).

2.7.2 Effect of RCA on Tensile Strength

The percentage loss in tensile strength due to use of recycled aggregate is more significancant in a weak concrete than in stronger one. The use of coarse aggregate made from recycled concrete with strength equal to 50 MPa will result in concrete tensile strengths comparable with that 30 MPa (Tabsh and Abdelfatah, 2009).

Evangelista and Brito (2007) found that the tensile splitting and modulus of elasticity are reduced with the increase of the replacement ratio; however, the values obtained for both properties are still acceptable, especially for reasonable levels of the replacement ratio.

From the relations between RA value and average frequency under loading tests, it is found that tensile and shear cracks in concrete of recycle aggregate is different from normal concrete, but recycle concrete given vibration becomes similar to it (Watanabe, 2007).

Fathifazl (2008) mentioned that flexure and tensile strengths of recycled aggregate concrete is within the range of ± 15% of those of conventional concrete. They suggested that the tensile strength of recycled aggregate concrete may be comparable to that for the natural-aggregate concrete owing to the presence of higher cement paste content in the former.

2.7.3 Abrasion Resistance of RCA

The resistance of aggregates to degradation caused by loads, stockpiling, mixing, placing and compacting of fresh mixed concrete is defined as abrasion resistance (Mamlouk and Zaniewski 2006)

Any literature about abrasion resistance of RCA could not find. However, recycled concrete as aggregate has lower strength compared to natural aggregate due to the presence of weak mortar adhered to the aggregate particles. Accordingly, the assessment of abrasion loss in mass of recycled aggregate indicates general characteristic of its quality particularly when it is subjected to wear or impact during the mixing or after concrete placement. The mechanical wearing of recycled aggregate surface caused by friction during mixing can increase the presence of silt on the surface of aggregate. This, in turn, can lower the bond characteristics, increase the water demand of concrete mix and increase scaling off the concrete during the finishing. The Los Angeles, abrasion tests evaluate the toughness and abrasion resistance of aggregates. (Movassaghi 2006).

2.8 Effect of RCA on RAC Durability

2.8.1 Effect of RCA on RAC Permeability

Fathifazl (2008) Stated that durability is one of the most important characteristics of concrete and is determined by its ability to endure its physical and environmental surroundings without compromising the functional properties and structural quality of the original design.

The permeability of concrete is a physical property related to the rate of the flow of water into the porous cement paste or the ability of water to penetrate the hardened paste. The permeability coefficient depends strongly on the capillary porosity in which the latter is a function of the water-cement ratio and the age of hydration. (Zaharieva et al, 2003). Also he confirmed in his papers the following :

- The main disadvantage of the permeability testis the sensitivity of the measurements to the moisture content of the concrete
- A good relation between surface permeability and porosity, diffusivity and water absorption capacity is assessed.
- The problems of durability are mainly due to the used recycled sand. Therefore, the use of fine RA aggregate needs to be restricted. Another way of increasing the durability of RAC is to use extended curing using a moist environment.
- The measured permeability (water penetration) allows distinguishing the permeation properties of RAC and those of NAC.

2.8.2 Effect of RCA on RAC Creep

Creep of concrete is proportional to the content of paste or mortar in it. To that end, it is understandable that RCA undergoes increased creep because it can contain about 70% more paste volume than concrete made with virgin aggregate, with the exact amount dependent upon the amount of RCA replacing the VA, and paste volume in the RCA and the new concrete. Researchers have observed creep to be 30%-60% greater in concrete manufactured using RCA compared to concrete with VA. Like creep, increased shrinkage rates are also related to increases in cement paste contents (Olba et al., 2006).

Cabo et al,. (2009) found that the shrinkage in the recycled concretes increased after 28 days. The recycled concretes elaborated with a substitution level of 20% showed a similar shrinkage to the conventional concretes in the early stages. In the case of a substitution level of 50%, the shrinkage increase was 12% greater than that of the conventional concrete after 6 months. The shrinkage trend in the recycled concretes elaborated with substitution levels of the coarse aggregate lower than 50% is similar to that shown by the conventional concrete.

2.9 Optimization & Improvement RAC Properties

2.9.1 Optimization of RAC by Substitution

Optimization of RA substitution is modeled. Around 25–40% of RA substitution is found to be most favorable in using TSMA. Further, around 50–70% of RA replacement can also give some improvement although the enhancements are less significant when compared with that of 25–40%. (Tam and Wang, 2007).

2.9.2 Optimization RAC Concrete Using TSMA

Optimization RA in concrete using TSMA to improvement the RCA absorption and RAC permeability. Double Mixing (DM) or TSMA method is one solution to improve the new Interfacial Transition Zone ITZ, particularly. Figure 2.6 and 2.7, compares the procedure of mixing by using normal and double mixing method (Tam et al, 2005).

Applying the double mixing method divides the required water to the mixture into two stages through which a thin layer of cement slurry can be coated on the surface of RCA and fill up the old cracks and pores in adhered mortar with a lower water-cement ratio. In this way, a stronger ITZ leads to a greater compressive strength of RCA concrete can be provided (Tam et al., 2005).

The concept of double mixing method is outlined in Figure 2.8 (Movassaghi, 2006)

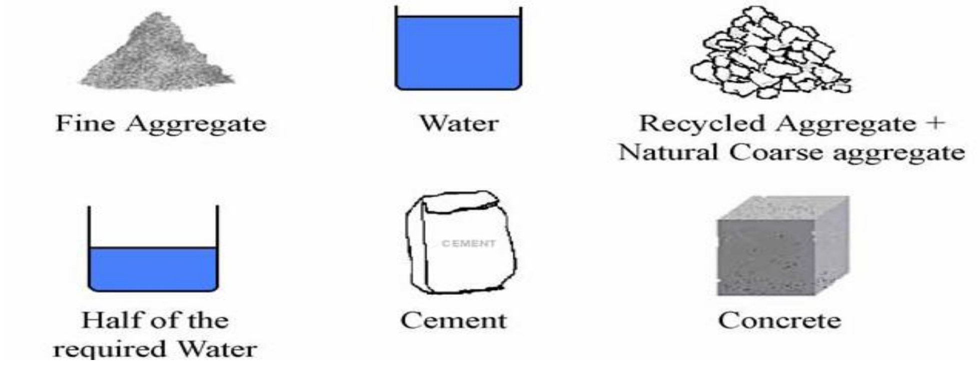


Fig.2.7: Symbols used for representing various materials (Tam et al. 2005)

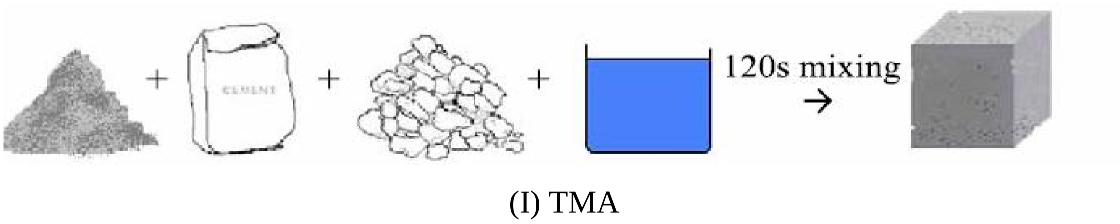


Fig.2.8: Mixing procedure of the (TMA) and (TMSA)from (Tam et al 2005)

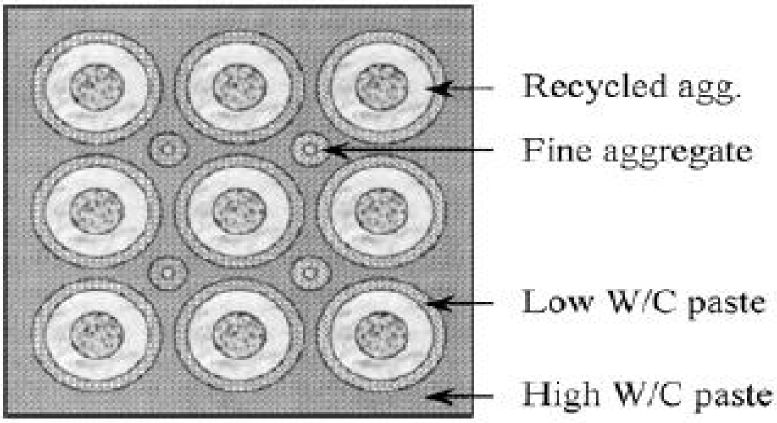


Figure 2.9: Schematic of RCA concrete using two stage mixing approach TSMA (Movassaghi, 2006)

The use of TSMA can develop a denser old cement mortar by filling up the old pores and cracks with mortar. The TSMA is further proposed for enhancing the interfacial behavior between RA and cement paste, which adopts certain amount of cement, providing a stronger interfacial zone, and thus a higher compressive strength of RAC. From the laboratory testing results, TSMA can achieve a higher improvement in comparison with TSMA. The TSMA can provide an effective methodology for enhancing the strength behavior of RAC when compared with TMA. (Tam and Tam, 2008)
Poon et al, (2004) stated that the interfacial transition zone microstructure in concrete with recycled aggregates appeared to be an important factor in governing strength development of the recycled aggregate concrete. The mechanical properties of recycled aggregate concrete can be improved by modifying the surface properties and the pore structure of the recycled aggregates.

Using (DM) mixing method, Double mixing method (DM) has been investigated as another method for improving RAC properties (Poon et al., 2004). In this method, the necessary water is added at two different times during the mixing process. Using this method Ryu reported an increase of 17% and 26% in the compressive and tensile strengths of RAC, respectively, compared to NAC. This can be attributed to the improvement of the quality of ITZ due to double mixing.

Tam et. al. (2005) provided in experiment that the two-stage mixing approach is proposed to strengthen the weak link of RAC, which is located at the interfacial transition zone (ITZ) of the RA. The two-stage mixing approach gives way for the cement slurry to gel up the RA, providing a stronger ITZ by filling up the cracks and pores within RA. From the laboratory experiments, the compressive strengths have been improved. This two-stage mixing approach can provide an effective method for enhancing the compressive strength and other mechanical performance of RAC, and thus, the approach opens up a wider scope of RAC applications

2.9.3 Improvement RAC Properties

Padmini et al. (2009) for a given target mean strength, the achieved strength increases with an increase in maximum size of recycled aggregate used. Also stated that for achieving a design compressive strength, recycled aggregate concrete requires lower water–cement ratio and higher cement content to be maintained as compared to concrete with fresh granite aggregate.

The replacement ratio increases, the compressive strength and elastic modulus decreases, and the drying shrinkage strain increases. However, by estimating the decrease in quality by the relative quality values and adjusting the replacement ratio, the quality required for the concrete can be ensured (Eguchi et al, 2007).
Watanabe (2007) confirmed that the vibration after mixing increases the strength in concrete of recycled aggregate, micro-cracking in concrete of recycled aggregate is observed at lower stress level than normal concrete and the vibration after mixing decreases micro-cracking as observed, and active cracks and impending failure in concrete of recycled aggregate is earlier than normal concrete.

Improvement due to using SP: Admixture is defined as: a material other than water, aggregates, hydraulic cement, and fibre reinforcement, used as an ingredient of concrete or mortar, and added to the batch immediately before or during its mixing. American Concrete Institute (2000).

Also chemical admixtures are materials that are added to the constituents of concrete to either enhance its properties; either in its plastic or hardened state, or to modify some specified and desired chemical reaction within the concrete itself.

Abu Dagga (2009) wrote ASTM sets the standards that an admixture must meet. The ASTM sections concerning chemical admixtures are:

- **ASTM C 260** - Air-entraining admixtures: improve the durability of concrete, through increased resistance to the cycle of freezing and thawing. Also they have the effect of improving the workability and handling characteristics of the fresh concrete mix.
- **ASTM C 494 - F**

  Type A - Water-Reducing admixtures: increase the fluidity of the cement paste with out significantly affecting the air content of a mix. They increase the workability of concrete at constant water-to-cement ratio, or permit concrete to be made with an equal workability using a decreased amount of water and resulting in an increase in compressive strength**.**

Type B - Retarding admixtures: decrease the initial rate of reaction between cement and water. They are commonly used in hot countries to counteract the effects high temperatures. A slight reduction in water content can usually be made with retarding admixtures.

Type C - Accelerating admixtures: increase the initial rate of reaction between cement and water. These are commonly used to facilitate early stripping of formwork, particularly in winter conditions.

Type D - Water-reducing and retarding admixtures: combine the functions of retarders and water-reducers. Placing in hot weather is the main applications where these admixtures are used.

Type E - Water-reducing and accelerating admixtures: combine the functions of accelerators and water-reducers.

Type F - High-range water-reducing admixtures: also called integral water proofing admixtures. They are used to reduce the permeability of concrete. They can also increase the workability of a mix, particularly where aggregates are poorly graded.

Hameed (2005) mentioned that some of the benefits of a high-range water reducer are: Higher strength can be achieved at "normal" workability without the need for additional cement, reduction in water content typically reduces bleeding, produces cohesive and workable concrete at high slump, and reduction in striking times. Also stated that the main purpose of using a super plasticizer is to produce flowing concrete with very high slump that is to be used in heavily reinforced structures and in places where adequate consolidation by vibration cannot be readily achieved. Specified strength can be achieved at high workability, faster placing with reduced labors and equipment costs, and Low permeable concrete leading to enhanced durability.

2.9.4 Improvement RAC Permeability

Preserving the quality of recycled aggregates (namely cohesive mortar) and the water-cement ratio at the desired level, curing conditions and using admixtures have a significant impact on permeability of the recycled concrete (Tam, Tam and Wang, 2007), (Juan and Gutierrez, 2009), (Tam, Gao and Tam, 2005) and (Brito and Evangelista, 2010).

The water permeability test, which is most commonly used to evaluate the permeability of concrete, is the one specified by DIN 1048. This test is useful in evaluating the relative performance of concrete made with varying mix proportions and incorporating admixtures. The Concrete Society (1987) provided some indication of typical and specified results for various concrete, as shown in Table 2.2.

Table 2.2: Assessment of Concrete Permeability according to Water Penetration Depth (The Concrete Society, 1987)

Depth of penetration, mm	Permeability
Less than 30	low
30 to 60	Moderate
More than 60	High

It is known that most specifications control the durability of concrete almost exclusively by specifying certain requirements for concrete composition, strength and permeability. (Hameed, 2005)

Chapter Three

Quality Function Deployment (QFD)

3.1 Quality Function Deployment (QFD)

In this chapter, a brief literature review on QFD is presented. First some of QFD definitions are mentioned. Then, a brief historical review of QFD. After that, the methodology of QFD is presented, followed by a description of why and where QFD can be applied. Finally the benefits and limitations of QFD as quality tool are introduced.

3.1.1 Definitions QFD

The QFD is defined as “a technique to deploy customer requirements into design characteristics and deploy them into subsystems, components, materials, and production processes (Lee and Arditi, 2006).

Quality Function Deployment (QFD) is “a systematic method for translating the voice of customers into a final product through various product planning, engineering and manufacturing stages in order to achieve higher customer satisfaction” (Chen & Weng, 2006).

QFD is broadly a total quality management (TQM) implementation technique requiring clear assessment of client/end-user expectations apart from the basic needs of a project to convert them into design targets (Dikmen et al, 2005).

3.1.2 QFD Concepts

Deros et al. (2009) said that QFD is an effective technique that helps both manufacturing and non-manufacturing industries to improve their quality, performance, customer satisfaction, understanding the customers’ needs, benchmarking against competitors, and clear vision of customer, market intangible requirements, and other quality and business characteristics by integrating the voice of customer with the firm's processes.

Eldin and Hikle (2008) stated that Quality function deployment QFD is a process that has been used for managing the development of new manufactured products. In this process, both spoken and unspoken needs of the customers are determined, prioritized, and translated to design parameters. Such design parameters are assigned specific target values and are frequently checked against customers' needs throughout the development cycle to ensure customers' satisfaction with the end product.

The QFD method concept is divided in two basic activities: product quality development and quality function development. Product quality development turns the voice of customer into quality management characteristics. For quality function deployment activities the quality defined from customer must be realizable. QFD researching enterprise answer on voice of customer by means of organized team approach. (Curcic and Milunovic, 2007)

QFD can be defined as concept that provides a means of translating the needs of customers through the various stages of product planning, engineering and manufacturing into a final product. QFD is accomplished through a series of charts which are a conceptual map, providing the means for inter functional communications. The chart is usually called a house of quality (HOQ). HOQ relates the variables of one design phase to the variables of the subsequent design phase. (Han et al, 2004)

The basic concept of QFD is to translate the desires of customers into product design or engineering characteristics, and subsequently into parts characteristics, process plans and production requirements. Each translation uses a matrix, called the house of quality HOQ., for identifying Customer Requirements CRs. And establishing priorities of Design Requirements DRs. to satisfy the CRs (Park and Kim, 1998).

3.1.3 QFD History

QFD was first used in the Kobe shipyards during the 1960s by Mitsubishi Heavy Industries because ships needed early design freezes as a result of the large capital investment and the long lead times involved in their development. Later during the 1970s it was used by Toyota to investigate rust prevention in vehicles and has been introduced by car manufacturers worldwide to help increase customer satisfaction levels (Hernandez et al. 2007).

3.1.3.1 Development of QFD in Japan

The ideas of QFD were first applied in 1971 in the design of an oil tanker by Mitsubishi Heavy Industry. Then Akao wrote a paper on QFD in 1972 and called it hinshitsu tenkai (quality deployment). Also in 1972, Nishimura at Kobe produced a quality table (House Of Quality, HOQ) that showed the correlation between the customer required quality functions and the counterpart engineering characteristics. At the same time, Katsuyoshi Ishihara introduced the value engineering principles which are used to describe how a product and its components work, and this was expanded to describe business function necessary to assure quality of the design process itself. Since 1972, its use has grown rapidly and it has realized competitive advantages in quality cost and timing. After that, QFD was introduced to Toyota's Hino Motor in 1975 and to Toyota Auto-body in 1977 with impressive results and was later introduced into the whole Toyota group.The first Japanese book on QFD was under the title of Quality Function Deployment: A Company Wide Quality Approach and was edited by Mizuno and Akao in 1978 (Chan & Wu, 2002a).

Dr. Yoji Akao the co-founder of QFD convinced that the substantial evolution and contribution of QFD world wide merited the recognition of those who had made it possible; so he proposed to create a Prize in his honor in 1996. This Prize is now awarded to individuals around the world who have demonstrated excellence in their practice and dissemination of QFD for many years from the QFD Institute. The prize takes into consideration research, authorship, teaching, practical applications, and personal commitment and service to the QFD community world wide including participation in and presentation at the International Symposium on QFD (Akao, 1997).

3.1.3.2 Development of QFD in US

The introduction of QFD to America and Europe began in 1983 when an article of Akao was published in Quality Progress by the American society of Quality Control, at the same time Akao was invited to give a four day seminar in Chicago on "Company Wide

Quality Control (CWQC) and Quality Development". This was followed by several QFD lectures presented by Akao to American audiences sponsored by Bob King and Growth Opportunity Alliance of Lawrence/Quality Productivity Center (GOAL/QPC) in Boston for every year starting in 1986 (Chan & Wu, 2002a).

From an organizational point of view, American Supplier Institute (ASI) and GOAL/QPC did great job to give QFD its popularity in the US. Especially, they have sponsored the annual QFD Symposium held in Novi, Michigan since 1989, and the transactions of these symposia have become the important publications on QFD. In 1993, a more specialized institute, the QFD Institute, was founded as a non-profit, research and educational organization for the advanced study of QFD. Since then, the QFD institute organized the US QFD Symposium (Chan & Wu, 2002a). Figure 3.1 summarizes the history of QFD in both Japan and US.

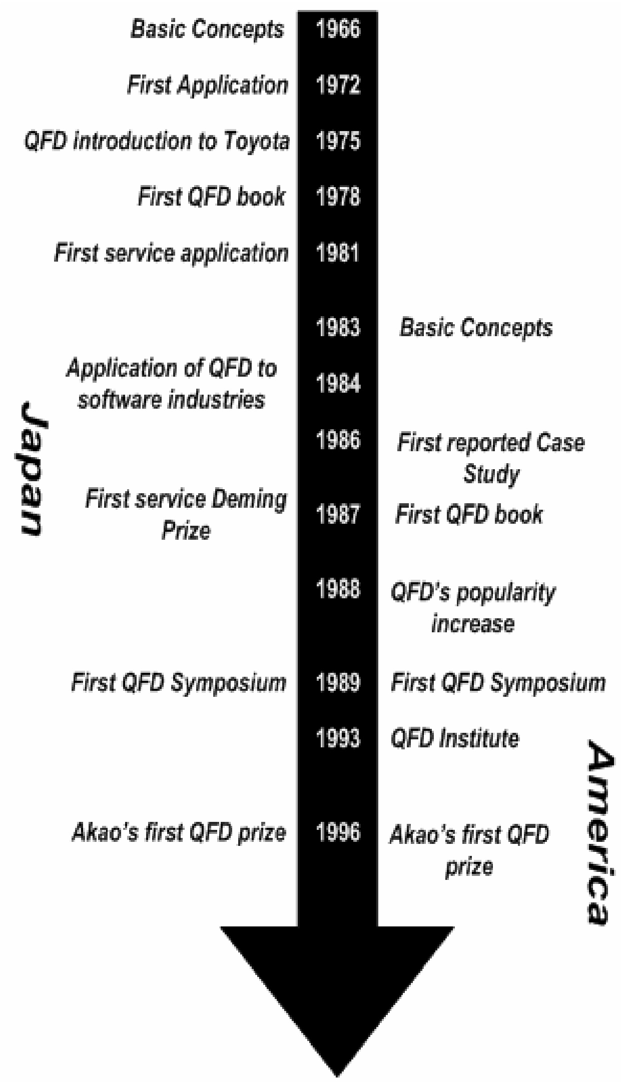


Fig. 3.1: History of QF

3.1.4 Objectives of a QFD Process

Gargione (1999) reported the objectives of using QFD in the project are:

- Define design and specifications for the residential units meeting the highest level as possible of customer requirements and satisfaction.
- Ensure consistency between customer requirements and product's measurable characteristics such as dimensions and features of rooms and finish materials used in the construction work.
- Ensure consistency between the design phase and the construction work. QFD can minimize the problems that usually are detected on the interaction between design and construction phases (including "constructability" problems and construction (reworks).
- Optimize the integration of customers' perceptions and variables that can affect the RoI (Return on Investment) such as construction cost, speed of sales, schedule and cash flow. Reduce the time to perform quality features throughout product development.

3.1.5 QFD Methodology

QFD methodology begins with the customer's requirements. The customer's perception on competitive products helps to set the goals and opportunities. Along with the customer's requirements, the design specifications are established. The interrelationship between the design requirements, which is used as a constraint in limiting a particular design, is denoted in the roof matrix. After establishing the design requirements, another matrix translates the design specifications as input for product or part characteristics deployment. (Chakraborty and Dey, 2007) and (Dikmen et al. 2005). Also they drawn general format of the HOQ matrix, as shown in Figure 3.3, made up of the following six major components:

- Customer requirements (HOWs): a structured list of requirements derived from the customer statements.
- Technical requirements (WHATs): a structured set of relevant and measurable product characteristics.

- Planning matrix: illustrates customer perceptions observed in the market surveys. It includes relative importance of the customer requirements and the performance of the organization and competitors in meeting these requirements.
- Interrelationship matrix: demonstrates the QFD team's perception of interrelationships between the technical and customer requirements. The matrix is generally filled up with numerical values taken from an appropriate scale, often illustrated with symbols or figures. Concentrating on key relationships and minimizing the number of requirements are the useful techniques to ease out the matrix development task.
- Technical correlation (Roof) matrix: used to identify the situations where the technical requirements support or impede each other in the product design stage. It also provides innovation opportunities.
- Technical priorities, benchmarks and targets: used to record priorities assigned to the technical requirements by the matrix, measure the technical performance achieved by the competitive products, and determine the degree of difficulty involved in fulfilling each requirement. The final output of the matrix is a set of target values for each technical requirement to be met by the new design that is again linked back to the customer requirements.

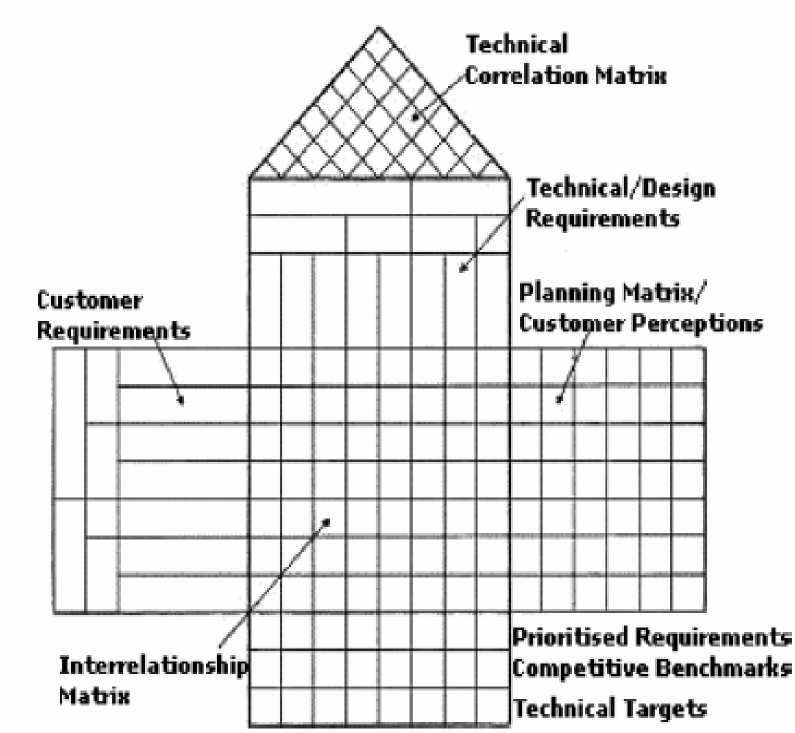


Figure 3.2: The house of quality (HOQ) matrix (Chakraborty and Dey, 2007)

Park and Kim,(1998) HOQ is presented HoQ in a matrix form which shows:

A) Prioritizing CRs

1. CRs in rows and DRs in columns,
2. their relation- ships within the matrix, and,
3. the correlations., dependencies. of DRs at the top of the matrix. See Fig. 3.4. The conventional HOQ employs a rating scale, 1–3–9, or 1–5–9.to indicate the degree, weak–medium–strong. of strength between CRs and DRs.

B) Prioritizing DRs

DRs is easy to understand and use, there are several methodological issues associated with it, namely:

1. determination of the degree of importance of CRs,
2. assignment of the relationship ratings between CRs and DRs,
3. adjustment of the relationship ratings between CRs and DRs, called normalization, in order to insure a more meaningful representation of the DR priorities,
4. incorporation of the correlations between DRs to a decision pro cess for determining appropriate DRs, and
5. consideration of cost trade-offs among DRs.

C) QFD Matrix health check: Check if theirs empty row and empty column.

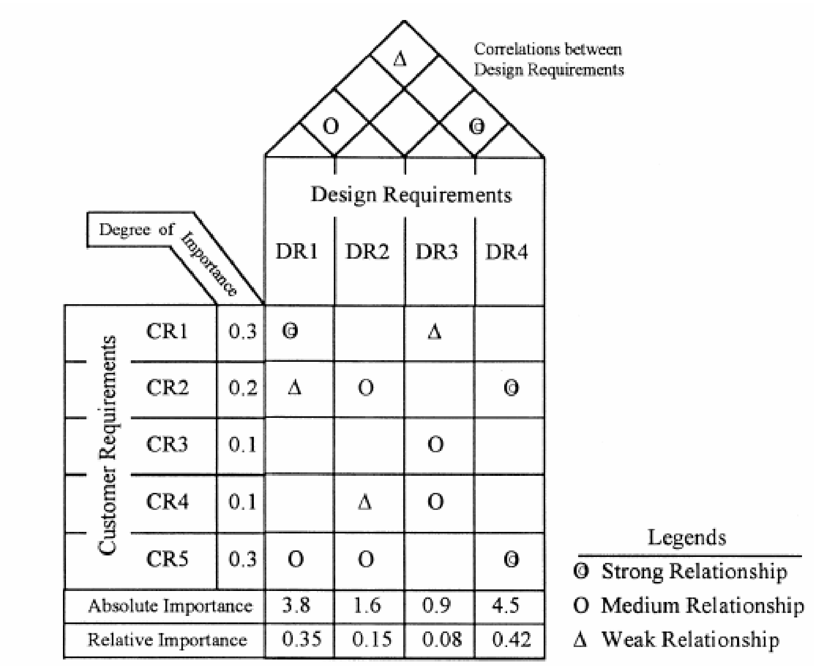


Fig. 3.3:HOQ matrix a 1-3-9 rating scheme and QFD Calculation

3.1.5.1 QFD Phases

QFD process passes through four phases when applied by any organization. The phases are as follows:

Phase 1: Product Planning (the House of Quality): Many QFD's applications only get through this phase. During this phase, customer needs are translated into technical measures. This phase documents customer requirements, warranty data, competitive opportunities, product measurements, competing product measures, and the technical ability of the organization to meet each customer requirement. Getting good data from the customer in this phase is critical to the success of the entire QFD process. With its design-oriented nature, the HOQ serves not only as a valuable resource for designers but also as a way to summarize and convert feedback from customers into information for engineers. HOQ is the most common QFD process. It is created by a multidisciplinary team who translate a set of customer requirements that are drawn upon market research and benchmarking data, into engineering targets to be met by a new product or service design.

Phase 2: Product Design: This phase is led by the engineering department and translates important technical measures into part characteristics. It requires creativity and innovative team ideas. Product concepts are created during this phase and part specifications are documented. Parts that are considered to be most important to meet customer needs are deployed into the next phase.

Phase 3: Details part design: In this phase, the important technical measures are translated into parts characteristics. During process planning phase, flowcharts of the manufacturing processes are constructed and process parameters are documented.

Phase 4: Operator Instruction: To monitor the production process, schedules, and performance indicators are created. Also, in this phase decisions are made as to which process poses the most risk and controls are put in place to prevent failures. Figure 3.4 illustrates the sequence of transformation during the QFD process and traceability.

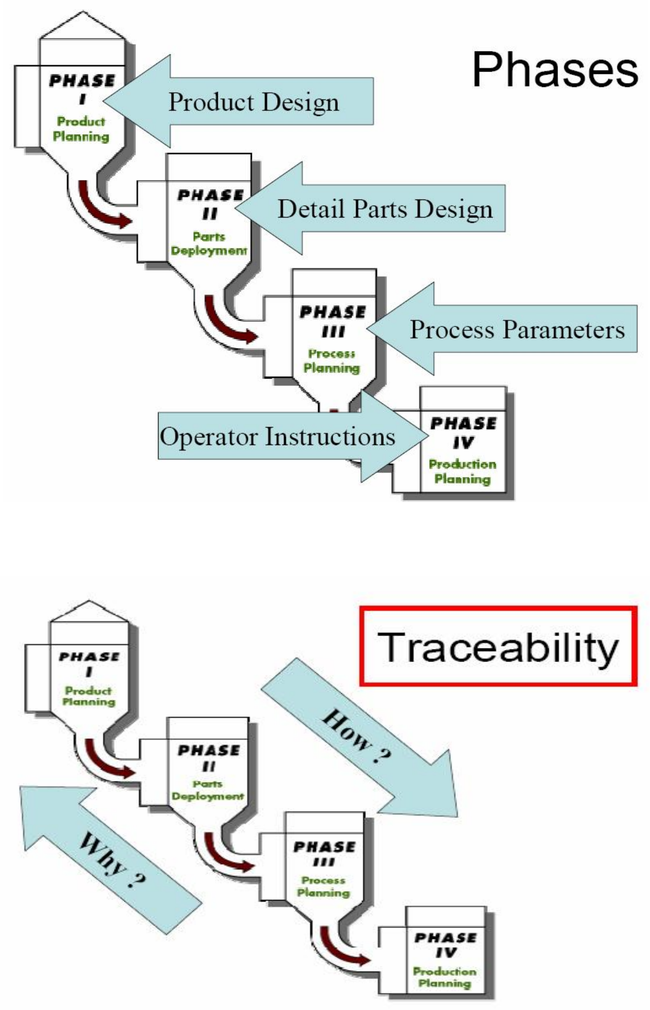


Figure 3.4: The QFD process

3.1.6 Functional Fields of QFD

According (Chan & Wu, 2002). to the functional fields of QFD may be:

Quality management: QFD helps in finding and solving problems at the very beginning of the product development which helps the organization on quality process. Quality management is an important part of the QFD process and essential for the success of product development process, and many publications can be found in this field. QFD has been applied to expert systems for quality management, process improvement, quality control, quality information systems, quality systems, service improvement, service quality management systems, and software process improvement

Customer needs analysis: Customer needs analysis is the very first step of a QFD process, so it is an important functional field of QFD. It helps in the achievement of quality management and product development. Publications in this field focus mainly on two key aspects of customer needs analysis, collecting/translating customer needs and satisfying customer needs. There are QFD applications addressing some specific aspects of customer needs analysis, such as customer involvement, customer preference, customer responsiveness, customer services, data collection, defining quality requirements, processing client requirements, and prioritizing customer needs

Product design: QFD can be referred to as designed-in quality rather than traditional inspected-in quality in the sense that it helps a company shift from inspecting the product's quality to designing quality into the product through customer needs analysis. There are a wealth of studies in this field that focus on the design of different products as well as on the different issues in product design, including 3D geometry- based product design, course design, design for manufacturability, design methods, design of information systems and services, designing customer-driven marketing programs, engineering design, flight control design, housing design, information system design, instructional design, internal service system design, manufacturing system design, process design, product conception, product definition, product/process innovation, product redesign, product/service introduction, questionnaire design, robust design, service design, system design, system redesign, training module design, and value design.

Engineering: QFD is also related to and can be applied to other fields such field as concurrent engineering. QFD linkages have been reported with knowledge intensive engineering, quality engineering, rehabilitation engineering, requirements engineering, simultaneous engineering, strategic re-engineering, system engineering, and value engineering.

Management: QFD can be directly used as a management tool. It has been applied in this field to the management of advanced manufacturing enterprises, business, business processes, capital budget, culture, customer complaints, customer–supplier relationships, information infrastructure in small cities, maintenance, manufacturing, organization’s competitive advantages, policies, processes, programs, projects, radar-based position reporting systems, research portfolios, risk, road traffic accidents, services, supply chain, strategic performance, strategies, and technologies.

3.1.7 QFD Benefits and Limitations

In general, QFD helps in focusing on development efforts in order to achieve objectives that create values to customers. So, QFD keeps the organization from designing products or services from which the customers neither need nor use. This section briefly summarizes the benefits, and limitations of QFD.

3.1.7.1 QFD Benefits

Dwask. (2009) stated that quality function deployment is widely spreading into the world because of its outstanding usefulness. Stated that the main benefits reasons of using QFD are:

(1) To save design time and development time

(2) To focus on the satisfaction of customer.

(3) To improve communication at all levels of the organization.

Chakraborty and Dey (2007) recognized that some of the major benefits of QFD are enlisted as: reduction in the number of design changes, reduction in design time, reduction in the development and start up costs, and reduced warranty claims.

Hernandez et al. (2007) reported that almost 30–50% reduction in engineering changes, 30–50% shorter design cycles, 20–60% lower start-up costs, and 20–50% fewer warranty claims as tangible benefits.

Dikmen et al (2005) they stated QFD applications have many benefits in reducing the quality related problems. These benefits have been observed to concentrate on the following headings; identification of client needs and expectations, planning, communication and concurrency; and uncertainty reduction.

Figure 3.5 presents a comparison (and reduction) of the number of design changes made by a Japanese company during product design using QFD to the number of design changes made by a U.S. company which did not use QFD. (Hauser and Clausing, 1996) sited in. (Mohanan, 2008).

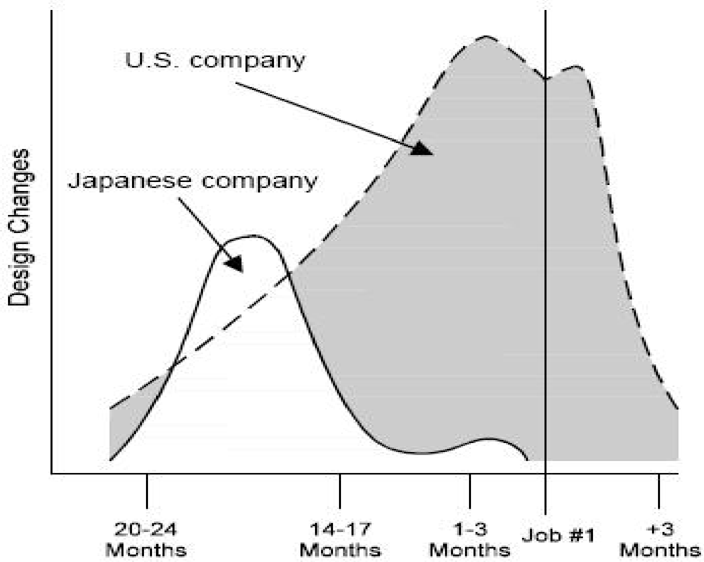


Figure 3.5: Comparison of design changes necessary with and without QFD. (Hauser and Clausing, 1996)

3.7.1.2 Limitation

Hernandez et al.(2007), Dikmen et al. (2005) and Ertay and Atac (2005) drew critical problems and limitations of using the QFD method:

1. One of the major problems faced in the QFD applications is poor definition of the customers.

2. size of the matrices in HOQ matrix may vary according to the project but generally speaking, large and complex matrices are formed in the implementation of QFD. This sometimes leads to misleading steps through the matrix formations as also experienced in the case study example.

3. As a remedy, the process can be computerized but this would incur capital investments for the formation of the necessary infrastructure. Formation of the team for QFD implementation is another challenge faced during the implementation of the methodology.

4. One of the most important tasks is the team formation phase since their experience and intuition determine the necessary design attributes and solve conflicts among them. The better the team is formed, the more accurate will be the completion of the matrices. Inadequacy of the professionals having knowledge on QFD, quality standards or design attributes will also hinder the successful implementation of the methodology

Chapter Four

Modeling and Optimization

4.1 Background

Methodology starts from identifying specific group of customer that the concrete firm deals with in order to get their feedback (voice of customer) on the design concrete mix RAC. The study was designed to give detailed feedback needed for making optimization and improvement to provided RAC product quality. This study includes information about the importance weight of customer requirements, quality performance, competitive assessment and customer suggestion (open ended questions) on the customer requirement field.

The author will integrate these voices of customer into the mix design RAC product provided by incorporating these collected data into QFD matrix (house of quality). In general at litrature review, there is no right or wrong ways to choose samples for measuring customers, satisfaction surveys. However, it is important that the samples are consistent with the evaluation objectives. For constructing the house of quality, it involves establishing the primary inputs to QFD matrix such as customer requirements (WHATs), technical design requirement (HOWs). The relationship matrix between (WHATs) and (HOWs), and correlation between (HOWs) will also be established. Other QFD matrix parameters that shall be included are the importance weight of design requirement, competitive assessment, relative and absolute weight of design, requirements and technical materials spcifications, technical difficulties and target.

First establishing customer requirements is the most important step in QFD process. Second establishing design requirements DRs. Third management product planning establishing technical specifications, evaluation of materials used in RAC ; and problems analysis and sampling and testing of concrete materials; concrete mixture optimization; development; specification review;

In order to meet customer requirements, the experts (Structured eng., lab. Engineer and supervision eng. had identified the technical specification (HOWs). Other parameters for

QFD matrix had also been identified. These parameters include the importance weight of customer requirements and competitive assessment. The relative and absolute weights of customer requirements and technical design specifications were calculated from QFD equations, the quality person assess the technical difficulties and target.(Hernadez, 2007).

To achieve research goals, quality performance and quality characteristics that need to be enhanced are defined during data analyses and evaluation. The data from customer group has been integrated and analyzed to the QFD matrix. Then, the critical technical design requirements and technical materials specification were identified. These shall have the highest relative and absolute weights that the quality person should focus on and improve, in order to meet or exceed customer expectations and improve the quality performance and improvement characteristics of RAC.

4.2 QFD and Recycled Aggregate Concrete RAC

As a preliminary step for applying QFD in improving and optimizing the concrete mix production using RCA is the identification of the current study problem, where the following shows the detailed steps of QFD implementation including the preliminary step.

Basically, Gaza Strip suffers from a hard situation because of Gaza war and siege which encourage the author to employ the RCA in the ready mix concrete industry as an alternative of virgin aggregate.

However, as limited applications of RCA are attributable to their poor qualities. To solve the problems of RAC, some techniques need to be developed for improving the quality of RAC, such as QFD. Optimizing mix blended from the economical and technical issues. Practically, the critical problems that result from using recycled aggregate are concrete cracked after installation, mortar crakes after hardening, permeability and reinforced corrosion, and inadequately support loads. The main point, from the functional analysis point of view, recycled concrete aggregate RCA is being absorbed water as result of existing adhered old mortar which causes stiff slump in fresh concrete and negative effects on structured durability and concrete properties.

4.2.1 QFD Methodology & Results

The following Figure (4.1) reveals the detailed ordered 10-steps needed for applying QFD, where these steps are derived from the tasks mentioned in Figure (1.1)

The purpose of applying QFD was to define the most important variables and characteristics for the final product RAC based on the customers' voice. As it is known worldwide, QFD is a method for ensuring that the voice of the customer is deployed throughout the product planning and design stages

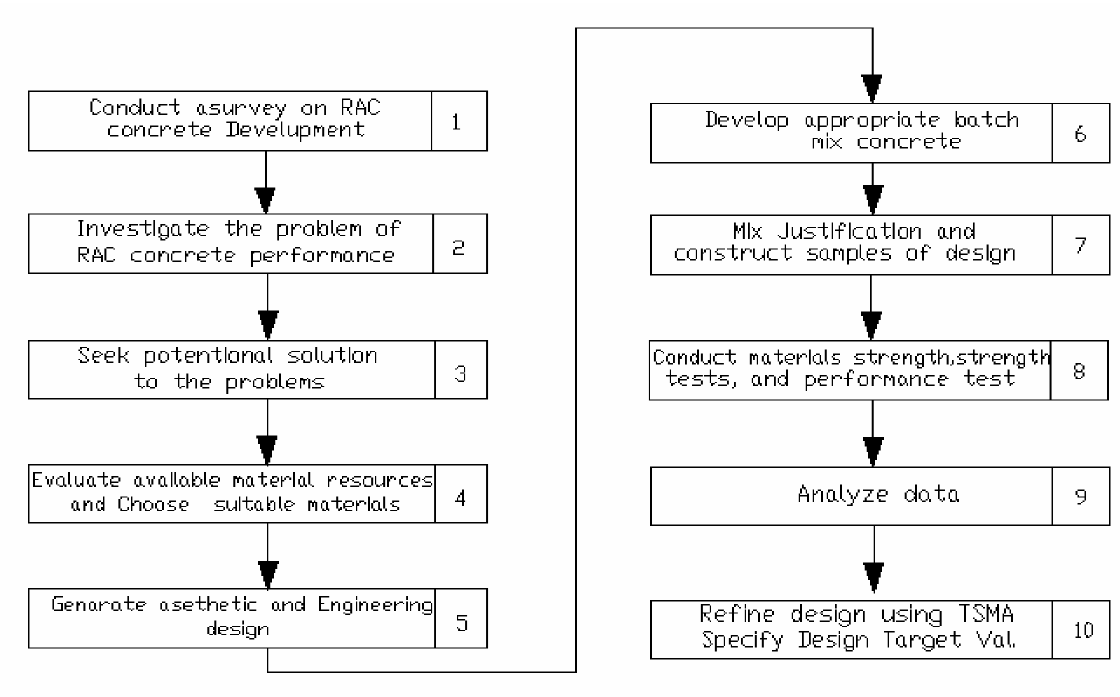


Figure 4.1: QFD methodology in improving concrete characteristic RAC

Several researches has conducted in the Gaza Strip for using the RAC in construction work, road work, and in concrete block industry, such as Rustom (2003) and Rustom (2007). Recently, the research of Zuheud (2008) worked on the improvement of properties of RAC concrete performance with focus on compressive strength, tensile strength, flexure strength and pull out strength.

However, to sum up, Zuheud (2008) did not investigate the quality improvement of RAC through improvement of permeability, RCA absorption, optimization of mix blended, mixed process, water reduction, and residual of mortar (RM) which are already covered in this study, where the problem of RAC concerned the customer needs correspond to material design attributes that go beyond the recycled concrete aggregate material.

These design attributes allow a comparison between natural aggregate concrete NA and substitute RCA concrete products, therefore assessing which attributes constitute features that RCA must better satisfy in order to gain strength and durability share from competing natural concrete products, where the following table shows the problems of RAC and unwanted access.

First, some of the main factors affecting the expected performance of the RAC, as listed in Table 4.1. Then the two main points for seeking potential solutions for these problems are specifying customer needs (CNs) and hence design requirement (DRs) for satisfying CNs. For determining CNs, this stage consists of three different steps: customer group selection, customer needs identification, and customer needs weights.

Table 4.1: Some problems of the RAC

Some problems of RAC													
Mix and Concrete				Structural Durability							Workability		
Physical Properties				Weather Extreme		Chemical Attack		Sustain Loads			Fluidity Degree		
Low Density for (Hardened & Fresh)	RM (Residual Mortar) High Absorption	RCA High Absorption	RCA Low Specific Gravity	Permeability Of Hardened Concrete	Cracks of Surface	Positive Acid Attach	Positive Alkalis Attach	Low Compressive Strength	Unsatisfactory Tensile Strength	Unsatisfactory Flexural Strength	Hard To Pumping	Hard To Maintain	Roughness Surface

4.3 Seek Potentional Solution to the Problem

With respect to the third step, specifying customer needs(CNs) and Design requirement (DRs) for satisfying CNs are the two main points for seeking potential solution.
First, determining Customer Needs, this stage consists of 3 different steps: customer group selection, customer needs identification. and customer needs weights.

Regarding customer group selection, according to Murillo (1993), civil engineers are selected as the key customer group in this study for several reasons. In practice, interviews with construction materials laboratory technician engineer, structured civil engineers supervision and ready mixed concrete engineer both backed this assertion.
Laboratory technician engineer are especially influential in any project where there is intent to differentiate, like higher quality condominiums, durability, stability, etc. On the other hand, the importance of civil engineers increases in construction and structured projects performance.
With regard to Customer needs identification, the identification of structured needs regarding construction materials was done through a set of 20 personal direct interviews with practicing civil engineering: 4 laboratory technician engineers, 8 site engineers, and 8 directors of ready mixed concrete firms in the Gaza Strip.

During the interviews, laboratory technician engineers were asked about the positive and negative characteristics of RCA ready mix concrete products. They were also asked about the factors that can increase the appeal of RCA in ready mix concrete industry so that it will be preferred over competing RCA characteristic materials, like concrete block structures or waste concrete cubes testing, respondents answered the same question for each of the three product groups.

The actual attributes determined through the interviews are communicated in Table 4.2. It can be clearly seen that there are 3 sets of customer requirements where each section reveals the responses of one of 3 customer group categories: structural group, supervision group, engineered ready mixed concrete products.
With respect to CN weights as a final step in determining CNs, in order to assess the importance of attributes identified through the interviews, the targeted groups were

studied separately according to the level of importance that the feature has in the material specification process, quality performance, cost and time. The scale used corresponded to "a-c" and 1 to 5 scales: least important (1) to most important (5). We categorize attributes into importance groups based on statistical significance. In that respect, we defined that attributes will be categorized in a maximum of three groups "A" for important attributes of (Mean ≥ 4.00), "B" for attributes of medium importance of (3.00 ≤ Mean < 4.00), and "C" for low importance attributes of (Mean < 3.00). Then as shown in Table 4.3, the customer priority is ranged from 4 to 5 where customer requirements that assigned the highest priorities were as follows:

- Supplying as quickly as possible (adequate supply).
- Minimum materials cost.
- Quality performance.
- Minimizing construction demolished waste CDW.

As to prepare a reliable database for the next step for the QFD methodology, a group of senior specialized engineers were targeted to answer a prepared category questions regarding the most important factors affecting the quality of recycled aggregate concrete (RAC). These seniors were of three different proficiencies: Structural engineering, Supervision engineering, and ready-mix concrete engineering.

Table 4.2: Attributes weights and categorization for concrete products RAC

Importance Groups	Mean	Structural Group
A	4.95	Structural properties
A	4.80	Durability and maintenance
A	4.60	Uniform quality
A	4.20	Compactness (moldings and leveling)
A	4.15	Low cost
B	3.80	Supplying as quickly as possible
B	3.05	Adequate for laying finishing and pumping
A	4.60	Minimizing construction demolished waste (CDW) (Economical & environment benefit)
Importance Groups	Mean	Supervision Group
A	4.60	Compactness (moldings and leveling)
A	4.20	Supplying as quickly as possible (on time)
A	4.80	Durability and maintenance
B	3.35	Materials easy to refurbish
B	3.45	Low cost
Importance Groups	Mean	Engineered Ready Mixed Concrete Products
A	4.10	Uniform quality materials
A	4.05	Durability and maintenance
A	4.05	Supplying as quickly as possible (on time)
A	5.00	Compactness, pores'(moldings and leveling)
A	4.85	Feasibility to pumping
A	4.75	Super plasticizer quality
B	3.90	Low cost
B	3.85	Adequate for laying finishing and pumping (Workability)

Table 4.3: The customer requirement prioritization.

Recognition customer needs and priorities (Customer requirement plan)		Customer Priority
On Time	Supplying as quickly as possible (adequate supply system)	4
Cost	Minimum materials cost	4
Quality Performance	Quality materials (Design mixed to fulfill classified work)(Define unwanted access)	5
	Design materials	5
	Durability building	5
	Support Loads	5
	Comply with codes and standards ACI	4
Minimizing CDW (Benefit or RAC)	Keep environment from pollution	4
	Minimization CDW (safer construction sit.)	4
	Keep natural aggregate sources	4

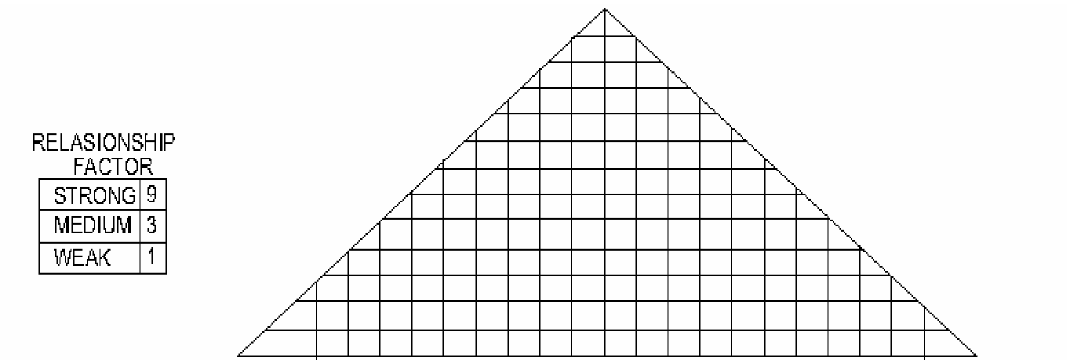
Design Requirement (DRs) for Satisfying CRs.

It is considered as a second stage in seeking the potential solution to the problems of RAC, in development of ready mixed concrete made from RCA, the QFD method would select design requirements which reflect ways in which the engineering characteristic would satisfy customer needs.

As design requirement are the mixed concrete products and technical characteristic that incorporated into design to fulfill customer requirements, it is clearly seen that design requirements are further broken down into more detailed requirements, as shown in Figure 4.2. Design requirements are further remedy of most important RAC problems.

These requirements involve specifying certain material qualities and components: strength of RAC, durability, and providing certain functions.

Accordingly, the main point is to show using the first built HOQ matrix the design requirement major components where CNs in rows and DRs in columns, their relationships within the matrix, and the correlations, dependencies of DRs at the top of the matrix. The conventional HOQ employs a rating scale of (e.g., 1–3–9) indicating the degrees weak, medium, and strong, respectively, for the strength effects among CNs and DRs



WHATS		REQUIREMENTS Quality Characteristic / WHATS Substitute Quality Characteristic	Customer Priority From (1 -5)	Design Rquirements DRs — Fluidity: (degree of fluidity) Workability	Fluidity: Ordering quantity pluse	Structure Prorerties (Durability Components): Permeability	Corrosions	Chemical attach	Alkils attach	Compressive Strength	Structure Prorerties (Sturdy Loads): Tensile Strength	Flexural Strength	Pullout strength	Quality Mix Components: Cement	W/C %	RCA Sustitution %	(RM) Residual of mortar %	(NA) Natural Coarse Agg..	(NA) Natural Fine Agg.	Superplastisizer SP %	Relationship Factor 1-3-9	Total	Max
Time		Supply as quik as possible	4	9	9	9	1	1	1	3	3	3	3	9	9	9	9	9	9	9	1-3-9		
Cost		Minimum Materials cost	4	9	9	9	3	1	1	9	9	9	3	9	9	9	3	9	3	9	1-3-9		
Qualityperformance	Quality materials	Quality Materials	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	1-3-9		
Qualityperformance	Quality materials	Design Materials	5	9	3	9	3	3	3	9	9	9	3	9	9	9	9	9	9	3	1-3-9		
Qualityperformance	(Functional Quality)	Durability	5	9	9	9	9	9	9	9	9	9	3	9	9	9	9	9	9	9	1-3-9		
Qualityperformance	(Functional Quality)	Support Loads	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	1-3-9		
Minimizing CDW (Benifit RAC)		keep environment from pollution	4	1	1	1	1	1	1	3	1	1	1	1	1	9	3	3	1	1	1-3-9		
Minimizing CDW (Benifit RAC)		Keep natural aggregate source	4	1	1	1	1	1	1	3	1	1	1	1	1	9	1	1	1	1	1-3-9		
Minimizing CDW (Benifit RAC)		Minimization CDW	4	1	1	1	1	1	1	3	1	1	1	1	1	3	1	1	1	1	1-3-9		
		Importance Factor		264	234	264	178	170	170	264	240	240	156	264	264	336	210	272	240	234		4000	336
		Weigth Percentage %		6.6	5.85	6.6	4.45	4.25	4.25	6.6	6.00	6.00	3.9	6.6	6.6	8.4	5.25	7.01	6.00	5.85			
		Priority		3.92	3.48	3.92	2.65	2.53	2.53	3.92	3.57	3.57	2.32	3.92	3.92	5.00	3.12	4.04	3.57	3.48			
				4	3	4	2	2	2	4	4	4	2	4	4	5	3	4	4	3			

Figure 4.2: Customer Needs vs. Design Requirements

Now in order to complete the first HOQ matrix, there are three steps involved: a) evaluate the relationships between CNs (WHATs) and DRs (HOWs), b) calculate an importance factor (IF), and c) calculate a priority for each design requirement.

a) The relationship rating among WHATs and HOWS are evaluated as either strong (9), medium (3), weak, (1), or nonexistent (Zero).

b) Calculating important factor (IFs). To calculate the IFs for a matrix design requirement (HOW), each customer relationship RF is multiplied by the respective priority (calculated from above) associated with the customer requirement (WHAT). For each design requirement this quantity is summed to determine the important factor IF.

c) The weighted percentage for each design requirement is calculated by dividing its IF by the sum of IFs for the matrix. This gives an indication of the relative importance of each design requirement (HOW) to fulfilling customer requirements (WHATs). The priority (relative importance, RI) for each design requirement is calculated by dividing its IF by the greatest IF in the matrix, as listed in Table 4.4, and explained hereafter.

Table 4.4: The relationships among CNs and DRs.

Customer Requirement	Priority	Relationship Factor (RF)	Relative Importance RI (Priority ×RF)
Supplying as quickly as possible	4	9	36
Material cost	4	9	36
Quality materials	5	9	45
Design materials	5	9	45
Durability building	5	9	45
Ability to support loads	5	9	45
Keep environment from pollution	4	9	36
Safer construction site	4	9	36
Keep natural aggregate sources	4	3	36
IF			336

For the matrix, the total of all the IFs (TOT) is 4000. The highest IF calculated (MAX) was for the design requirement mix components, (RA) with an IF of 336. For the design set design component (RA), the weighted percentage is calculated to be IF/Total IF = 336/4000 = 8.4 % the corresponding priority, on a scale of I to 5, is 5×IF/MAX = 5×336/336 = 5

From this analysis, three components received a priority of 3, 4, and 5, indicating correlation to customer satisfaction. The HOQ identifies these components will satisfy the customer requirements.(WHATs) these components for further analysis during the detailed design requirement.

As a direct output, Table 4.5 lists all the design requirements with their priorities due to the analysis of the first HOQ matrix, where the design requirement with priority greater than or equal 3 are only considered.

Table 4.5: The priorities of DRs after HOQ1.

Design Requirement	Priority
I) Durability	
Permeability.	5
II) Sustain loading	
Compressive strength	5
Tensile strength	4
Flexural strength	4
III) Quality mix component	
RCA % replacement	5
NA. % (deferent type of aggregate)	4
Water/cement ratio	4
RM residual of mortar content	3
Admixtures	3
Ordering quantity plus	3

The data shows that the aggregate RCA has the highest perceived influence on RMC characteristics, followed by the NA., water cement Ratio and RM residual of mortar, admixture. Ordering quantity plus came later as target value of quality performance.

The next step is the evaluation of materials which is to be done through laboratory testing as a result of matrix one and found the most important feature that affecting on design requirements of RAC. It should be mentioned that the factor of ordering quantity plus, despite it got a rank of importance of 3, was excluded from this stage since it has no effect on the evaluation of the involved raw materials. But this factor will later be included for determining the target values of the RAC.

In the second matrix of HOQ, the QFD team uses the HOWs from the first HOQ matrix (DRs) as WHATs. The HOQ2 then identifies technical responses which components will satisfy the design requirements. The same procedures are used to evaluate relationships and calculate final priorities.

From this analysis, two components receive a priority of 4 and 5, indicating correlation materials evaluation to design requirements. The team identifies these components will satisfy the design requirements.(WHATs) for further analysis during the detailed materials engineering characteristics, as shown in Figure 4.3. Then Table 4.6 shows the materials characteristics with their priorities due to HOQ2, where the materials characteristic will be found and improvements that characteristic which affecting on design requirement with priority greater than or equal 4 is considered. The data shows that the aggregate RCA has the highest perceived influence on RAC characteristics, followed by the NA., characteristics and specific area of cement.

4.4 Evaluate Material Characterization of RCA and NCA

The evaluation of materials to be don through testing laboratory as result of matrix one and found the most important feature that affecting on design requirements of RAC.

In the second matrix, the QFD team uses the HOWs from the first matrix (Design Requirements) as WHATs. The HOQ2 then identifies technical responses which components will satisfy the design requirements. The same procedures are used to evaluate relationships and calculate final priorities.

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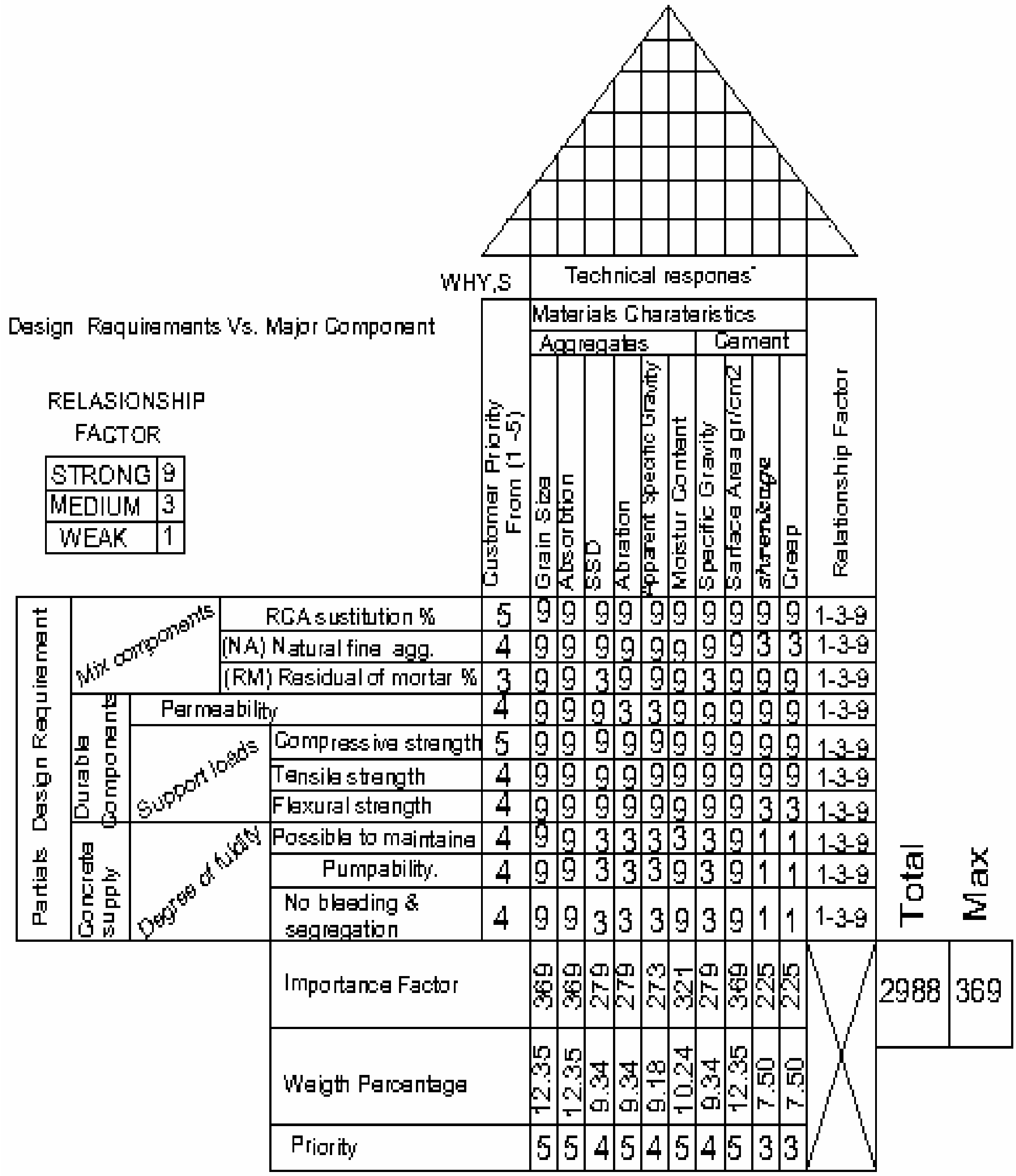

Figure 4.3: Design Requirements vs. Characteristic Materials. (HOQ2)

From this analysis, two components receive a priority of 4 and 5, indicating correlation materials evaluation to design requirements. The team identifies these components will satisfy the design requirements. (WHATs) for further analysis during the detailed materials engineering characteristics: see Fig.4.3 (HOQ2). The following Table 4.6 shows the materials characteristics with their priorities due to HOQ2, where the materials characteristic will be found and improvements that characteristic which affecting on design requirement with priority greater than or equal 4 is considered .

Table 4.6: The priorities of materials characteristic & design requirements after HOQ2.

Materials characteristics.	Priority
I) Mixing blend characteristics.	
(1) Physical properties RCA.	
Grain size.	5
Absorption& Moisture content.	5
Abrasion.	5
Specific gravity.	4
Residual mortar content. (RMC)	5
(2) Physical properties NA.	
Grain size.	5
Absorption & Moisture content .	4
Abrasion.	4
Specific gravity.	4
II) Cement characteristics (Surface area).	5

The materials used in this research for the natural concrete were typical of those normally used in the production of commercial Portland cement concrete. These materials included Portland cement, coarse and fine aggregates (Gaza sand), and chemical admixtures. The properties of these materials are described hereafter. Table 4.7 illustrated the evaluation test and ASTM standard

Table 4.7: Evaluation materials tests according to ASTM.

Test Type	Test Standard
Sieve Analysis of Coarse Aggregate of NCA & RCA	ASTM C 136
Sieve Analysis of Fine Aggregate Gaza Sand.	ASTM C 136
Moisture Content of Coarse Aggregate of NCA & RCA	ASTM C 566
Moisture Content of Coarse Aggregate of Sand	ASTM C 566
Absorption Specific Gravity of Coarse & Fine Aggregate of NA & RCA	ASTM C 127 , C 128
Unit Weight of Coarse Aggregate NCA & RCA	ASTM C 29
Residual of Adhered Mortar Content RMC	ASTM C 33

4.4.1 Cement

The cement used was Type I Portland Cement (Turkish). Its physical and chemical properties according to Turkish standards and specifications are given in Table 4.8.

Table 4.8: Cement properties

Standard Number	TS EN 197-1
Cement Type	CEMI /A-L 42.5N Portland Cement
Insoluble Residue (%)	0.62
Magnesium Oxide (MgO) (%)	2.45
Sulphur Trioxide (SO3) (%)	2.65
Loss on Ignition (%)	6.38
Chloride (Cl) (%)	0.02
Specific Weight (g/cm3)	3.15
Blaine (cm2/g)	3916

4.4.2 Water

The mix water used through the research was tap water. The specific gravity of the water, was used in the mix proportion calculation, was assumed to be 1 ton/m3.

4.4.3 Chemical Admixtures (SUPLAST TB 101)

Description:

Suplast Creet TB 101 is a water reducing type concrete admixture. Plast TB101 is based on water soluble polycondensates and selected polymers enabling concrete mix performance. Plast B101 Water-Reducers Admixture (WRA) was used in this study to integral the workability of a mix, particularly, while the range water reducer complied with the requirement of ASTM (C494-type E-A-F) "Chemical Admixtures for Concrete" type (F) named "Plast TB 101 – Egyption", as listed is Table 4.9. Practically some benefit can be achieved by using SP at "normal" workability 75mm to 120 mm without the need for additional cement, due to (WRA)

- Specified strength can be achieved at WRA workability,
- Faster placing with reduced labors and equipment costs, and
- Low permeable concrete leading to enhanced durability

Product Features:

In Plastic Concrete

- Improves workability, finishing and setting time,
- Reduce water requirement, bleeding and segregation.

In Hardened Concrete

- Increase all strength
- Improve finishing appearance
- Reduce cracking and permeability.

Dosage:

0.5 -4.5% by weight of cement or compendious materials. To determine the optimum dosage lab trials are recommended.

Table 4.9: Concrete admixture specifications

Admixture Type	Plast Ceet TB101 Super Plasticizer for concrete
ASTM- C494	Type (E, A and F)
Appearance	Brown liquid
Density	1.20 ±0.03 gr/cm3 (20oC)
pH	6.0-8.0
Chlorine (Cl)	< 0.05 % (EN 480-10)
Composition	0.5 – 4.5 cement weight
Shelf life	12 month in the original un-opened containers.
Storage	Keep away from sunlight and extreme heat

4.4.4 Natural Aggregate Characteristic

Bulk Specific Gravity (Dry): The bulk specific gravity of a material is the ratio of the weight of a specific absolute volume of the material, excluding the weight of water within the pores, to the weight of an equal volume of distilled water. Simply stated, it is the unit weight of a dry material divided by the unit weight of water (ASTM C127) and (ASTM C128) for coarse and fine aggregate. Bulk specific gravity applies to porous materials. For non-porous materials the specific gravity and bulk specific gravity are the same, and the output results are listed in Table 4.10a and 4.10 b for NCA and RCA respectively.

Bulk Specific Gravity - Saturated Surface Dry (SSD): The bulk specific gravity saturated surface dry of a material is the ratio of the weight of a specific absolute volume of the material, including the weight of water within the pores, to the weight of an equal volume of distilled water. Simply stated, it is the unit weight of a saturated material divided by the unit weight of water and is computed according to ASTM C127and ASTM C 128 for coarse and fine aggregate, and the output results are listed in Table 4.10a and 4.10 b for NCA and RCA respectively.

Water Absorption: Water absorption is the process by which water is drawn into and tends to fill permeable pores in a porous solid material. It is expressed as a percentage of the dry weight of the material. The water absorption of aggregate is determined by measuring the increase in weight of an oven-dried sample when immersed in water, for 24 hours. Water absorption is calculated according to ASTM C127, and the output results are listed in Table 4.10a and 4.10 b for NCA and RCA respectively

Moisture Content - Saturated Surface Dry (SSD): Any water on the surface of the aggregate will contribute to the water in the mix. The surface moisture is expressed as a percentage of the weight of the saturated and surface dry aggregate, and is termed as moisture content on saturated surface dry basis. Determination of moisture content was done according to ASTM C566., and the output results are listed in Table 4.10a and 4.10 b for NCA and RCA respectively.

Unit Weight: The unit weight of bulk density of aggregate is the weight of aggregate per unit volume. The bulk density value is necessary to select concrete mixtures proportions. The test was done according ASTM C29. Table 4.11 illustrates the aggregate unit weight values at SSD condition. and the output results are listed in Table

Table 4.10a: Aggregate Specific Gravities and Moisture Contents of NCA

Commercial name & Size Fraction (mm)	S.G.(dry)	S.G.(SSD)	Moisture Content (%)	Absorption (%)
Type 1 (25 – 12.5mm)	2.58	2.60	0.34	0.995
Type 2 (19.5 – 9.5mm)	2.6	2.63	0.65	1.17
Type 3 (12.5-4.75 mm)	2.52	2.65	1.1	1.66
Type 4 (9.5 – 2.63 mm)	2.53	2.65	1.5	2.1

Table 4.10 b: Aggregate specific gravities and moisture contents of RCA

Commercial name & Size Fraction (mm)	S.G.(dry)	S.G.(SSD)	Moisture Content (%)	Absorption (%)
Type 1 (25 – 19.5mm)	2.31	2.42	1.25	4.36
Type 2 (19.5 – 12.5mm)	2.29	2.4	0.65	4.55
Type 3 (12.5-9.5 mm)	2.27	2.39	1.74	4.82

Table 4.11: Aggregate dry unit weights NCA

Size Fraction (mm)	Dry Unit Weight γ dry (kg/m3)	SSD Unit Weight γ dry (kg/m3)
Type 1 (25 – 12.5mm)	1463	1468
Type 2 (19.5 12.5mm)	1520	1553
Type 3 (12.5-9.5 mm)	1493	1542

Grading (Sieve Analysis): To produce good quality concrete, the aggregates should be grouped according to sizes at least into two. The classification of aggregate into fine and coarse is referred to ASTM C33. Fine Aggregate (sand): Fine aggregate includes the particles that passes through 4.75 mm sieve and retain on 0.075 mm sieve. While aggregate particles with sizes 0.002-0.075 mm is called as silt and particles smaller than that known as clay. Table 4.12 shows the maximum and minimum passing according to ASTM C33.

The sieve analyses of aggregate includes the determination of coarse and fine aggregate by using a series of sieves .ASTM C136 procedure was used to determine the sieve analysis of coarse and fine. Figure 4.4 illustrated superimposed square opening wire-mesh sieves used in analysis.

Table 4.12: Grading requirement for coarse aggregate - ASTM C33

Nominal Size mm (sieves with square openings)	Amount Finer than Each Laboratory Sive					
	25 mm (1 in)	19 mm (3/4 in)	12.5 mm (1/2 in)	9.5 mm (3/8 in.)	4.75 mm (No. 4)	2.36mm
25.0 to 4.75	100	90-100	25-60	20-35	5-15	0-5

Figure:4.4,Superimposed sieves used for grading the aggregates

Coarse Aggregates

The coarse aggregate used in this testing program was crushed limestone of 25 mm maximum aggregate size grading. Table 4.13 shows the particle size fraction of aggregate 25 mm maximum size used as well as their commercial name used locally. Figure 4.5 illustrates the four size fraction according size of coarse aggregate NA 25mm, 19.5mm, 9.5mm and 4.5 mm from the left to the right respectively.

Sieve analysis determination of coarse aggregate by measuring the weights of aggregates retained in each sieve after shaking, the percentage of weight passing through or retained in each sieve was determined. according to the obtained weight values, after sieving. The output results are interpreted in Figure 4.6.

Table 4.13: Coarse aggregate used in the testing program , maximum agg. size 25 mm

Size Fraction (mm)	Commercial Name in Gaza	Fineness Modules	Symbol Used
Type 1 (25-12.5)	Folia #5	7.42	CA_{F5}
Type 2 (19.5-12.5	Adasiya	6.8	CA_{AD}
Type 3 (12.5-9.5mm)	Semsimiya	5.5	CA_{SM}
Type 4 (9.5 -4.75	Semsimiya	4.2	FA_{SM}

Figure:4.5, Size fraction NCA = 25 mm, 19 mm, 9.5 mm and 4.5 mm

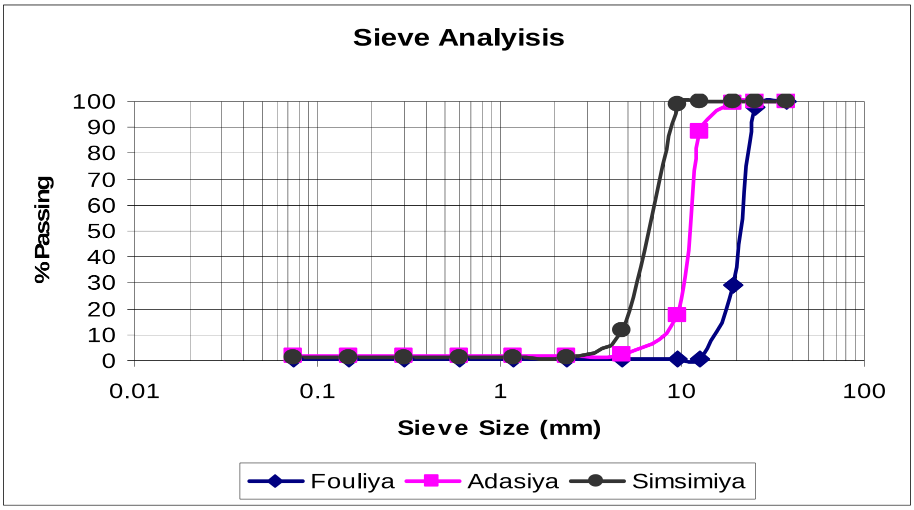

Figure 4.6: Grading curve of three types aggregate fraction NA

4.4.5 Recycled Concrete Aggregate (RCA)

Coarse recycled aggregates: Same sieve analysis as in natural aggregate were done on coarse aggregate. Sieve grading shown in Tables 4.14, the output results for sieving analysis are interpreted in Figure 4.7 and the appearance is shown in Figure 4.8.It can be used this grading in RAC industry combining by four type of NCA as in Table 4.13. The sample were taken from EL Motaheda Company crushed crashed by El Mawsay crusher.

Table 4.14: Mechanical sieve analysis of recycled coarse aggregate

Sieve Size(mm)	Fraction Retrained, gr.	Fraction Retrained, %	Cumulative Retrained, %	Passing, %	ASTM C 33 03 Stander Grading	ASTM Check C33 03
25	0	0	0	100	100	OK
19	200	4	4	96	90-100	OK
12.5	3000	60	64	40	25-60	OK
9.5	500	10	74	26	20-35	OK
4.75	1300	26	100	0	0-5	

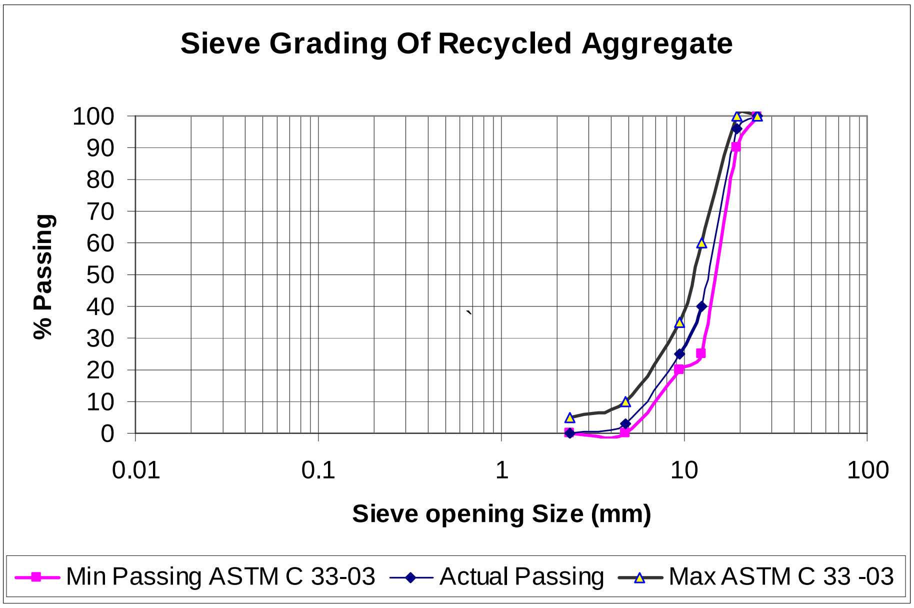

Figure 4.7: Gradation for typical recycled aggregate

Figure 4.8: A sample of coarse recycled aggregate

Determination of RCA Adhered Mortar Cement

The determination of adhered cement on recycled aggregates was made by using the ASTM C 33 (the standard specification for concrete aggregates) test method for the estimation of an acid-insoluble substance in any type of cement. 500 grams of RCA with gradations of 8.5 % passing of 25 mm, 72.5 % passing of 19.5 mm and 40 % passing 12.5mm, sizes were used for this test. The aggregates were weighed and digested in 20 % nitric acid. The solution was heated gently on a hot plate while the aggregates were stirred by the flattened end of a glass rod. This process was continued for a few minutes until adhered cement paste started to dissolve. Figure 4.9a illustrated the mortar adhered set up during chemical reaction, and the effect of Nitric acid on RCA due to reaction. Figure 4.9b illustrated the RCA at left side and RM at right side after reaction and separating.(after abstrictions). The adhered cement loss after dissolving in nitric acid for RCA was (23%). The related calculations and test procedure are included in Appendix B. Through the recent performed by Juan and Gutierrez (2009). Recycled aggregate of good quality for the production of structural concrete could be obtained selecting aggregates with mortar content under 44%.

Figure 4.9a: RCA specimen placed in nitric solution and reaction

Figure 4.9b: Illustration of RCA and RM after abstraction

Abrasion resistance assessment of aggregates (Loss Anglos Test)

ASTM C131 standard test methods were used for evaluate the toughness and abrasion resistance of mineral aggregate standard gradation, grading resulting from a combination of actions including abrasion or attrition, impact, and grinding in a rotating steel drum, containing a specified number of steel spheres. The test is carried out to compare between the Los Angeles's value of RCA and NCA.

Accordingly, the assessment of abrasion loss in mass of recycled aggregate indicates general characteristic of its quality particularly when it is subjected to wear or impact during the mixing or after concrete placement. The mechanical wearing of recycled aggregate surface caused by friction during mixing can increase the presence of silt on the surface of aggregate. This, in turn, can lower the bond characteristics, increase the water demand of concrete mix and increase scaling off the concrete during the finishing. The Los Angeles, abrasion tests evaluate the toughness and abrasion resistance of aggregates. (Mamlouk and Zaniewski, 2006).

According to ASTM standards, Los Angeles crush test of coarse aggregate must be a maximum of 40 %. The Los Angeles crush test results were 37.4%. Table 4.15 shows the result of two type and apparatus shown in Figure 4.10.

The related calculations are included in Appendix B

Figure 4.10 Loss Anglos instrument used for aggregate abrasion resistance test

Table 4.15: Average properties of recycled aggregate RCA & NA

Aggregate Type	Moisture Content %	Absorption Content %	Specific Gravity		RM (%)	LA %
			Bulk	SSD		
RCA-WCS	1.3	4.65	2.33	2.40	23 %	37.4
Lime Stone (Blend)	0.55	1.43	2.52	2.60	--------	20.35

Figure 4.11 (a and b) shows texture comparison between natural coarse aggregate and recycled coarse aggregate.

Figure 4.11 a) Illustration The NCA used in mix design

Figure 4.11 b) Illustration The RCA used in mix design

4.4.6 Natural Fine Aggregate (Gaza Sand)

Due to the negative effects, reported in the literature (Brito and Evangelista, 2010)., of using RCA with small size on the workability and strength of recycled concrete, coarse recycled aggregate and natural sand as fine aggregate were considered for the fresh concrete mixture design.

The natural aggregate was natural Gaza sand. This aggregate was kept in the saturated surface dried condition until it was used. The specific gravity of the fine aggregate was 2.65. As defined in ASTM C33–03, fine aggregate is determined according to sieve grading as shown in Table 4.16 and Figure 4.12.

The Fitness Modulus (F.M.) is parameter can be used to describe the grading curve and is useful for checking the uniformity of grading. The fineness modulus can be determined as the cumulative percent retained on standards sieves (sieve No.4 to No.100)/100.

Table 4.16: Aggregate grading analysis – Gaza sand

Sieve No	Opening mm	Passing %	ASTM Limits		Check ASTM
			Min	Max	
(3/8")	9.5	100	100	100	O.K
# 4	4.75	100	95	100	O.K
# 8	2.63	100	80	100	O.K
# 16	1.18	100	50	85	N.OK
# 30	0.6	100	25	60	N.OK
# 50	0.3	50	5	30	N.OK
# 100	0.15	4	2	10	O.K
# 200	0.075	3	0	0	N.OK

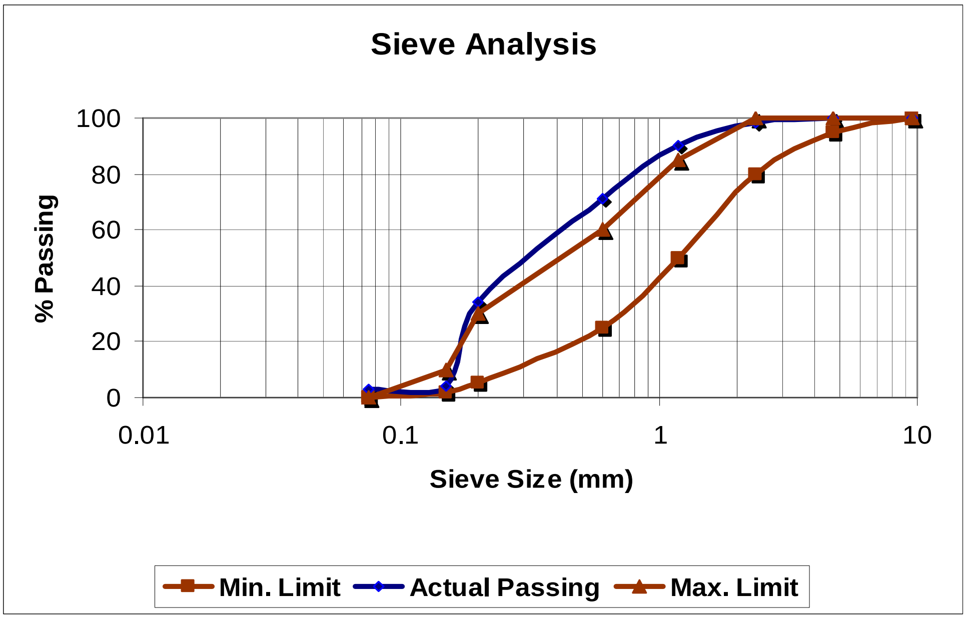

Figure 4.12: Sieve grading Gaza sand & ASTM Limits

The fineness modulus must be from 2.3 up to 3.1 as value required for mix proportion. The results showed that F.M. for Gaza sand is 1.83 which is less than 2.3, so the sand should be mixed to improve its quality. Gaza Sand is poorly graded according ASTM.

4.5 Generate Aesthetic and Engineering Design

This step continues on the basis of the output of previous steps where improvement characteristic mixed design due to the five control factors were identified as: (1) water /cement ratio, (2) water reducer, (3) volume ratio of recycled coarse aggregate, (4) replacement ratio of lime stone crushed rock , and (5) using double mix (DM or TSMA). The worth mentioning is to employ optimization process first mix proportioning and second mix method using TSMA to obtain a mix that satisfies the economical and technical conditions including CNs, where the water slump could be determined.

Mix Proportioning Method

In order to investigate the effect of RCA content on the fresh and hardened properties of the mixes in this study, first natural aggregate NA mixes with coarse aggregate comprising only natural aggregate NA were proportioned using the conventional mix design method of ACI211.1-97 (ACI committee 211, 1997), but the lower specific gravity and higher absorption capacity of RCA, were taken into account.

Water reducing admixtures (WRA) were used. Three w/c ratios, 0.35, 0.45 and 0.55, were used to produce non-air-entrained mixes. Mixes with combined NA and RCA were made in which the RCA was replaced by NA at 0.0%, 70%, 50%, and 30% replacement levels based on weight. The selection of the mix ingredients (water, air, cement, and coarse/fine aggregate contents) are described at optimization stage. The mixes produced were B250, B300 and B350 of RAC with low coast and comply with cods and standards.

Estimation of water contents

As a result of utilizing mix proportional method, slump in the range of 75 to 100 mm is suitable for most types of structural applications such as reinforced foundation, beams, slabs and columns (ACI Committee 211, 1997); therefore, this slump range was selected for the RAC specimens investigated in primary mix. For our research it was 0.55 and equivalent 181 kg, and RCA springing. Reduction water content from 0.55 to 0.35 and maintain slump by adding SP.

4.6 Development of Appropriate Batch Mix Design

In this step we try to adjust RAC & NA grading, FA that comply with codes and standards in order to satisfy CNs. We optimized the mixed blended NA by using linear programming LINDO version 6.1 for mixed blended for natural aggregate concrete, and next applying it as reference of RAC mixed.

4.6.1 Optimization Process

Referring to previous section (4.4), Figure 4.6 and Figure 4.12 the fine aggregate Gaza sand was poorly graded wherever the coarse aggregate and fine aggregate needed optimization as technical requirements to confirm ASTM C33. So the optimization process are included economical requirements.

Aggregate Blending

The objective of the blend is satisfy the economical (cost minimization) requirements as well as technical requirements, of a mix.

Economical Requirements: The cost of the blend aggregate must be as minimum as possible based on the cost of the aggregate, CA_{F5}, CA_{AD}, CA_{SM}. The cost of the aggregates are given in Table 4.17, the value in table are according to local prices.

Table 4.17: Coarse aggregate prices

Aggregate	Price/ton ($)
CA_{F5}	37
CA_{AD}	38
CA_{SM}	46

B) Technical Requirements: based on the grading of aggregates, , CA_{F5}, CA_{AD}, CA_{SM}, the blend must conform to ASTM C33 for maximum aggregate size (25 mm) grading curves. Both the economical and technical requirements are achieved by solving a set of equations by linear programming model. The model constructed based on the economical and technical data of different aggregates, CA_{F5}, CA_{AD}, and CA_{SM}.

Coarse Aggregate Blending Model

To produce a coarse aggregate that meet the ASTM C33 requirement the coarse aggregate properties are presented in Table 4.15 at previous section was blended to produce a new aggregate that conforms to ASTM for maximum aggregate size of 25 mm. The procedure in which these aggregate were blended will be discussed in the following section. The solution is listed in Table 4.18.

1) MIN 38 CA_{AD} + 37 CA_{F5} + 46 CA_{SM}.

Subject To:

2) 0.598 CA_{AD} +0.0345 CA_{F5}+ CA_{SM} <= 0.600 condition at sieve 12.5 mm

3) 0.598 CA_{AD} +0.0345 CA_{F5} + CA_{SM} >= 0.250 condition at sieve 12.5 mm

4) 6.89 CA_{AD} +7.42 CA_{F5} +5.84S CA_{SM} <= 7.120 F.M condition

5) 6.89 CA_{AD} + 7.42 CA_{F5} +5.84 CA_{SM} >= 6.600 F.M condition

6) CA_{AD} + 0.576 CA_{F5} + CA_{SM} <= 0.850 condition at sieve 19 mm

7) CA_{AD} + 0.576 CA_{F5} + CA_{SM} >= 0.700 condition at sieve 19 mm

8) 0.1 CA_{AD} + 0.0019 CA_{F5} + 0.960 CA_{SM} <= 0.450 condition at sieve 9.5 mm

9) 0.1 CA_{AD} + 0.0019 CA_{F5}+ 0.960 CA_{SM} >= 0.180 condition at sieve 9.5 mm

10) CA_{AD} + CA_{F5} + CA_{SM} = 1.000 Total = 1

11) CA_{SM} <= 0.350 extra limitation

12) CA_{SM} >= 0.250

13) CA_{F5} <= 0.600 extra limitation

14) CA_{F5} >= 0.532

15) CA_{AD} >= 0.100 extra limitation

16) CA_{AD} <= 0.150

END

Table 4.18: Solution of CA blending model

VARIABLE		VALUE
SM		% 25
F5		% 60
CA_{AD}		% 15
Price	$39.4	

Table 4.18 shows that the best combination was of SM 25%, F5 60%, and AD 15% to obtain a concrete mix with the minimum cost with the optimum level of quality for this

mix. This fact was enhanced by the objective function analysis which showed that the reduced cost factor is zero.

Where:

Equation 1 is the objective function used to minimize the blended aggregate cost related with an acceptable level of quality within the available conditions, subject to constraints shown in equation 2 to 16 Subject to following constraints ASTM C33 see Table 4.12.

Equation 2 and 3 are constraint function for the total percent of the blend passing sieve 12.5mm diameter that must be less than or equal to 60% according to ASTM requirements. The coefficients for CA_{F5}, CA_{AD}, and CA_{SM} are the percentages passing sieve 12.5mm diameter. The same applies for equations, 4, 6, and 8.

Equation 4 and 5 are constraint function for the fineness modulus of the blend. The fineness modulus should be less than or equal to 7.12 and 6.6 according to calculate fineness modulus of ASTM grading limit curves. Equation 10 dictates that the total sum of fractions of CA_{F5}, CA_{SM}, CA_{SM}, should be equal to 1.00.

Equations 11 through 16 are constraint function depending on experimental data taken from local concrete factories. The percentages of, CA_{F5}, CA_{SM}, and CA_{AD} were calculated by solving the above model using linear programming (LINDO computer program), and the result was:

% of CA_{F5} = 60

% of CA_{SM} = 25

% of CA_{AD} = 15

Cost of blend = $ 39.4

Fineness modulus of blend = 6.94

Blending of Fine Aggregate

According to the obtained results, the local sand available is too fine; therefore blending with coarser fraction is adopted to increase the fineness modulus of fine aggregate. Blending of fine aggregate was made to satisfy a fineness modulus between 2.3 -3.1 as recommended by ASTM C33.

Fineness Modulus of Gaza sand = 1.86

Fineness Modulus of FA_{SM} = 4.2

Therefore:

$1.86\ Sand + 4.2\ FA_{SM} = 2.3$

$Sand + FA_{SM} = 1$

By solving the above two equation we get:

% Sand = 82 %

% FA_{SM} = 18 %

Blending of Coarse Aggregate

The objective of this blend is to produce a new aggregate made up from the coarse aggregate (D = 25mm) and the blended fine aggregate to produce fineness modulus at least 5.0 as required. Since the fineness modulus of blended fine aggregate (FA) is 2.3 (ASTM 2.11-97) and fineness modulus of blended coarse aggregate (CA) is 6.95 then,

$2.3 \times FA + 6.85 \times CA = 5.0$

$FA + CA = 1.0$

By solving the above two equation the proportions of FA and CA are:

Fine Aggregate = 40.66 %

Coarse Aggregate = 59.34 %

Mixed Blend

The following mix is designed for fineness modulus of 5.0. Table 4.19 shows the proportions of aggregates as determined from the optimization procedure outline before. Based on the above results and the grading of the used aggregates, the grading curves modify of the blend as well as the ASTM grading limits of maximum size 25 mm are shown in Table 4.22 as present, and represents gradation sieve analysis of NA Figure 4.13a represents the grading limits. Figure 4.13 represent the grading limits of combination. Sieve analysis fit on the ASTM C 33.

Table 4.19: Illustrated optimization CA and FA fractions

Percent of Aggregate Fraction, %				
Coarse Aggregate,%			Fine Aggregate, %	
59.34			40.66	
CA_{F5}	CA_{AD}	CA_{SM}	Sand	FA_{SM}
60	15	25	82	18

Table 4.20 Mechanical sieve analysis of NCA (Max grain size 25mm)

Sieve Size(mm)	Fraction Retrained, gr.	Fraction Retrained, %	Cumulative Retrained, %	Passing, %	ASTM C 33 03 Stander Grading	ASTM Check C33 03
25	0	0	0	100	90-100	OK
19	301.2	6	6	94	85-100	OK
12.5	2208.8	44	50	50	25-60	OK
9.5	1255	25	75	25	20-35	OK
4.75	753	15	90	10	0-15	OK
2.63	351.4	7	97	3	0-5	O.K
Pan	150.6	3	100	0		

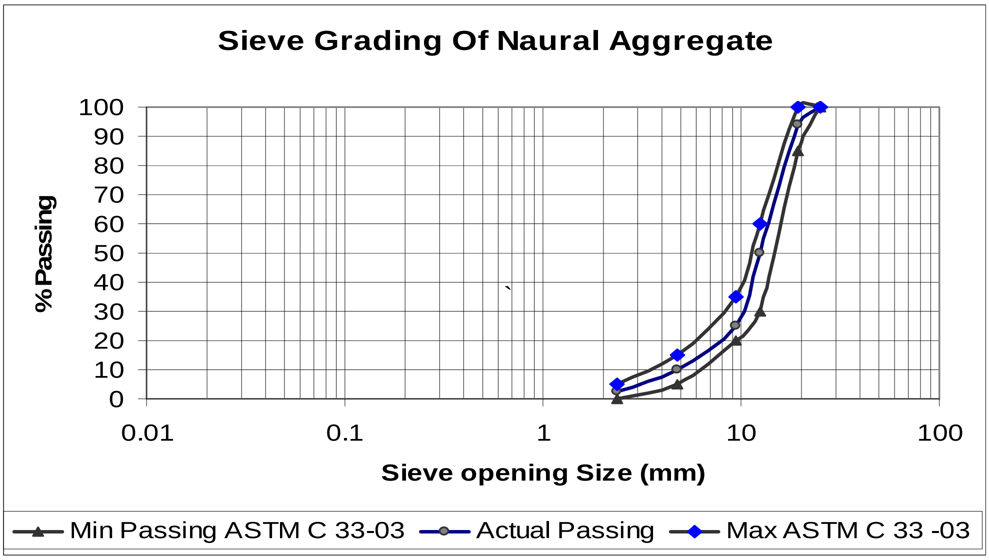

Figure 4.13: Gradation for natural aggregate after optimization

Grading and Sieve Analysis RCA & NCA: Gradation of aggregates plays a key role in the concrete mix proportions. When a range of graded aggregates is used, the smaller particles fill the spaces between the larger aggregates, thus lowering the void content and decreasing the cement paste requirement. Therefore selection natural coarse aggregate mix blend was with four fraction size 25mm,19.5mm, 9.5 mm and 4.75mm and RCA was with three fraction size 25mm, 19.5mm and 9.5mm.Wherever smaller grain size contain RM grater than big grain size. The calculation and selection grain size are included in Appendix B.

4.7 Mix Justification and Construct Samples of Design

A flow-chart describing the procedure for design of RAC mix is shown in Figure 4.14.

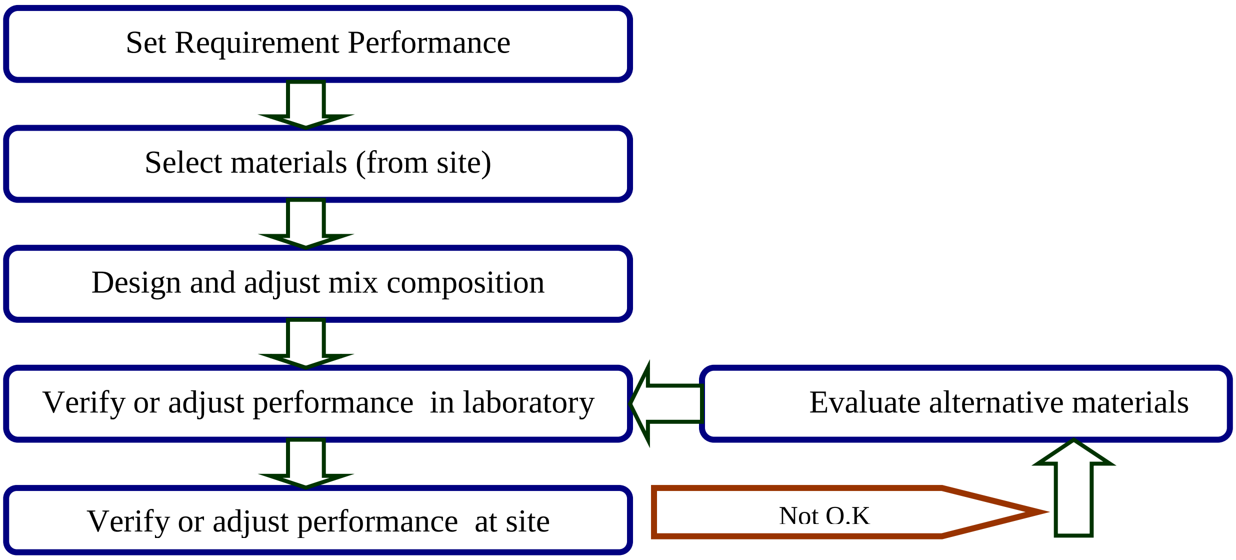

Figure 4.14: Illustration mix design procedure

Preparation of Mixes

The PM were made following three main steps:

1) Preparation of materials

2) Adjustment of mixing water

3) Concrete mixing

Identification of Mix Design

Procedures used for concrete mixture development, verification testing and validation for conformance to specification requirements throughout the laboratory program for this research and after using computer program to specify the mixed blend aggregate parameters, the standard B250, B300 and B350 which known as intermediate strength of concrete mix was used as a reference for testing the recycled concrete aggregate RCA concrete mixes, and then for determining the different mix design Table 4.21 and 4.22 are summarized the mix blend by weight for 1m3 for natural coarse aggregate NCA an RCA respectively. The related calculation are included in Appendix A

Table 4.21: Summery concrete mix proportion by weight (kg/m3) NCA according grain size

Cement (kg/m3)	Water (kg/m3) W/C	Grain size 25 mm- 12.5	Grain size 19.5mm- 9.5mm	Grain size 9.5mm- 4.75mm	Grain size 4.75 mm- 3.65mm	Total CA kg/m^3	Sand 0.1 – 0.6 mm
C25 330	0.55	650	275	166	136	1227	620
C30 350	0.45	667	281	170	140	1258	635
C35 380	0.35	697	294	177	143	1311	650

Table 4.22 Concrete mix proportion by weight RCA (kg/m3) (w/c = 0.55 to 0.35)

Cement (kg/m3)	Water (kg/m3) W/C	Grain size 25 mm- 19.5mm	Grain size 19.5 mm- 12.5mm	Grain size 12.5 mm- 9.5mm	Total CA kg/m^3	Sand 0.1 – 0.6 mm
C25 330	0.55	588	245	148	981	620
C30 350	0.45	605	252	151	1006	635
C35 380	0.35	640	264	158	1063	650

According to ACI-211.1-97 (ACI Committee 211, 1997), the required weight of coarse aggregate can be found from the volume of the dry-rodded coarse aggregate per unit volume of concrete w/c = 0.55 for B 300 – aggregate volume = $0.71m^3$ Table A1.5.3.4 (a) ACI Committee 211, 1997. In our calculations the volume of coarse aggregate range = $0.7014m^3$,$72m^3$and $0.73m^3$ for w/c 0.55, 0.45 and 0.35 and cement content 330 kg/m^3, 350 kg/m^3 and 380 kg/m^3 to produce structure concrete grade C25, C30 and C35 respectively. Tables 4.23 present the weight of NA and RCA for mix design. for C25, C30, and C35. The weight of RCA in three structure grade at replacement RCA 100 % were 981kg/m^3,1006kg/m^3,1063kg/m^3,respectively. As (ACI Committee 211, 1997) for NCA structure, and research performed by (Fathifazel,2008), (Movassaghi,2006) and (Salem,1996) for RAC concrete structure.

Mixing Method

Traditional Mixing Approach (TMA) Mix I: All mixing was conducted under laboratory conditions accordance with the provisions of ASTM C192 "Standard Method of Making and Curing Concrete Test Specimens in the Laboratory". Prior to mixing, the aggregates were air dried to low moisture content. The aggregates and cement were added and for about 3 minutes before water was added. After water was added, following procedure was followed: three minutes of initial mixing followed by three minutes of rest, followed by two minutes of mixing. Using absolute volume method.

Another mixing method was used which is the Two Stages Mixing Approach (TSMA) Mix II: Prior to mixing, the fine aggregates were air dried to low moisture content. The coarse aggregates was added and mixed for about 1 minute before half of water with half of the plasticizer were added and mixed another 1 minute. After that cement was added and mixed for half a minute, then the remaining water and plasticizer were added and mixed for two minutes to obtain a homogenously mixed concrete, as shown in Figure 2.7. (Tam and Tam,2008).

A slump test was then run to determine if it was within the targeted range. If the slump was too low, a water reducing admixture was added to the mixture, which was then mixed for two more minutes. Another slump test was run, and this was repeated until the described slump was reached to examine four parameters (Splitting tensile, compressive strength, flexure strength and permeability)

4.8 Refined Mix Method

Refine the mix design by using (TSMA) for development RCA characteristics with the same w/c and RCA% to show the effect of this method on mix design for developing compressive strength, tensile, flexure and permeability and then define the optimum target value for C25, C30, and C35. Using Table 4.23 mix design (D, E and F).

Two Stage Mixing Approach : Applying the double mixing method divides the required water to the mixture into two stages through which a thin layer of cement slurry can be coated on the surface of RCA and fill up the old cracks and pores in adhered mortar with a lower water-cement ratio. To compare the procedure of mixing by using normal and double mixing method back to Figure 2.7 chapter two. Figure 4.15 shows the mixing machine used in the project. Figure 4.15 shows mixing machine which used in the project.

Table 4.23 Mix portions for RAC and NAC of Mix A, B and Mix C using (TMA)

MIX (A) Using Traditional Mixed Approach (TMA)								
Mix ID	RCA %	Admix. WRA % By cement weight	W/C %	Mix Proportion of mixes kg/m^3				
				Water	Cement	Sand	Coarse Aggregate	
							RCA	NA
RAC 1	70	2	0.55	181.5	330	620	687	368
RAC 2	50	1.5	0.55	181.5	330	620	491	614
RAC 3	30	1	0.55	181.5	330	620	294	859
NAC 1	0	0.5	0.55	181.5	330	620	0	1227
Mix (B) Using Traditional Mixed Approach(TMA)								
RAC 4	70	3.0	0.45	158	350	635	704	377
RAC 5	50	2.5	0.45	158	350	635	503	629
RAC 6	30	2.0	0.45	158	350	635	302	880
NAC 2	0	1.5	0.45	158	350	635	0	1258
Mix (B) Using Traditional Mixed Approach(TMA)								
RAC 7	70	4.5	0.35	135	380	650	743	393
RAC 8	50	4	0.35	135	380	650	531	655
RAC 9	30	3.5	0.35	135	380	650	319	917
NAC 3	0	3	0.35	135	380	650	0	1290

Figure 4.15: Mixing machine

4.9 Conduct Materials Strength Tests and Performance Tests

This section discuss the last step of QFD method traceability, evaluation of concrete performance; and problems analysis, sampling and testing of concrete materials; concrete mixture optimization; development; specification review. And also, the details of casting and testing of the selected RAC mix for evaluating its hardened properties are presented.

4.9.1 Testing Program and Standards

This study concerned on satisfying the economical cost minimization and optimum as well as technical requirements that the mixed confirm to standards and specification with respect to C25, C30 and C35 strength and durability. A total of 294 concrete specimens were tested for both RAC and NAC. Table 4.24 presented test type test standards and testing program of RCA & NCA. Figure (4.15) Summarized the experiment and step carried out in this study to investigate the optimization and improvement RAC.

Table 4.24: Illustration testing program & standards of hardened concrete properties

Test type & standards	Mix I (T.M.A)		Mix II (T.S.M.A)	
Slump test measurements (ASTM C143)	RCA 0.00 %		RCA 0.00 %	
	RCA 30 %		RCA 30 %	
	RCA 50 %		RCA 50 %	
	RCA 70 %		RCA 70 %	
Compressive strength Cube 150 mm (ASTM C39)	Age (Day)	No. of Sample	Age (Day)	No. of Sample
	7	2	7	-
	28	3	28	3
Modulus of Rupture (100x100x500mm) (ASTM C78)	28	3	28	3
Tensile (Split Cylindrical) 150 x 300 mm (ASTM C496-6)	28	3	28	3
Depth of water penetration Cube 150 mm (DIN 1048)	120	3	120	3

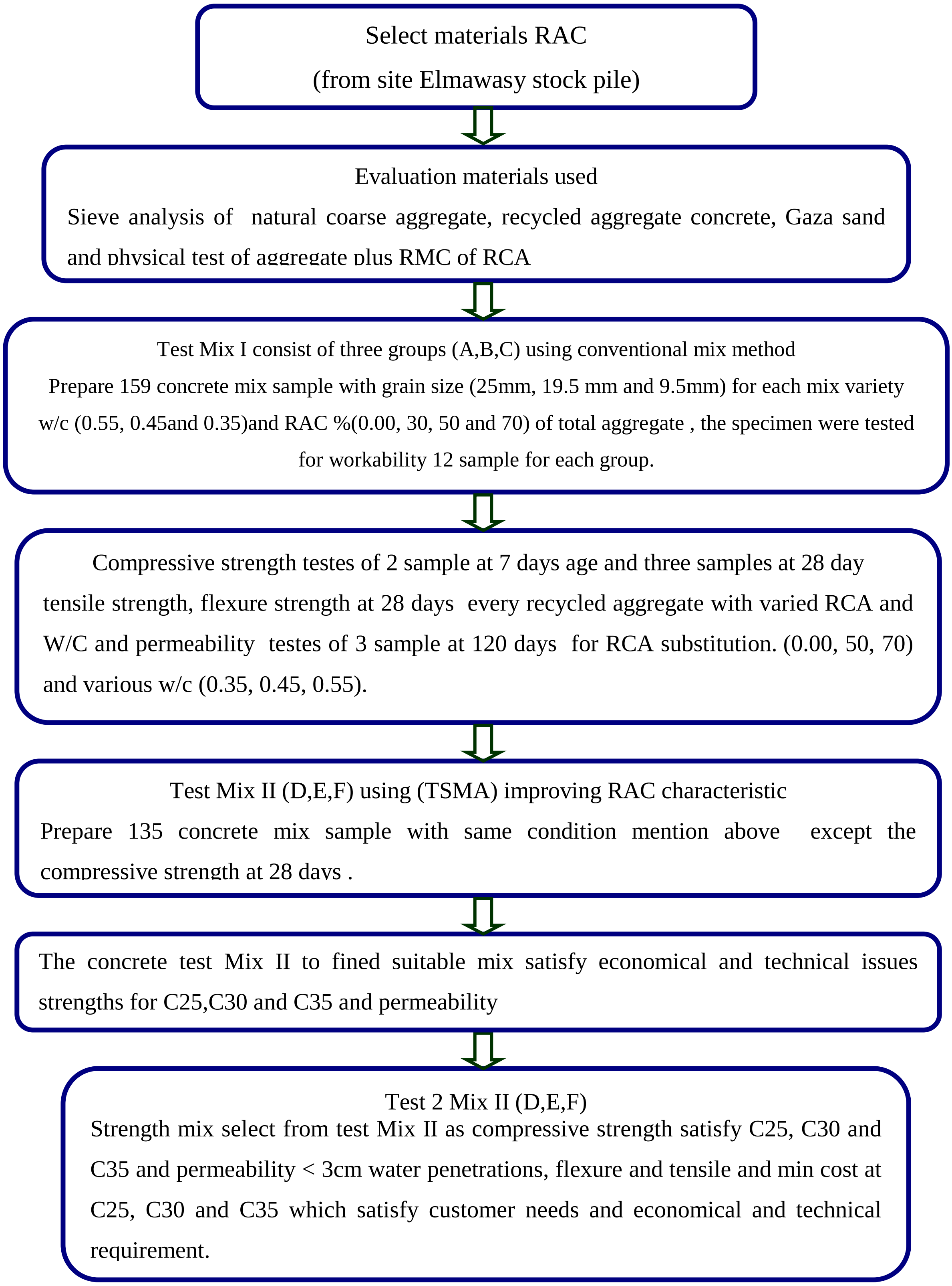

Figure 4.16: Summarized experiments and steps carried out in this study

4.9.2 Equipment and Samples Fabricated

Casting of Concrete Specimens

From each mix, samples 3 cylindrical concrete specimens, 150 mm in diameter and 300 mm high for tensile strength, and 5 sample cube concrete 150×150×150 mm^3 were cast for determining the compressive strength after 7, and 28 days, beam specimens, standard 100×100×500 mm3 steel and plastic molds were used for flexure, tensile and flexure strength 28 days of water curing and permeability at 120 days respectively. The moulds were oiled properly for easy remolding. The moulds were filled with concrete in three layers compacted and vibrating by electrical machine. Figure 4.16 illustrated casting and vibration sample. The calculation of mix testing samples are included in Appendix A.

Figure 4.17: Illustration electrical vibration machine & casting samples

Curing of Concrete Specimens

Approximately 20 to 24 hours after initial curing, specimens were stripped and kept in the standard moist room where curing continued at about (23 CO) and 100 percent relative humidity until the time of testing. The continuation of curing under these conditions-very important for the development of the physical properties of the concrete. tensile strength, flexure strength and permeability.

Fresh Concrete Test (Workability)

The conventional slump test as per ASTM C143 was used to measure the slump of the mixes.All of the minimum observed slump values are practically within 75 ± 25 mm, which is the specified range for minimum target slump and comply with slump specified at the beginning . And comply with (ASTM 211-1997). Figure 4.17a shows the accessories used for the slump level test and Figure 4.17b show the slump measurements.

Figure 4.18: Accessories for slump test

Hardened Density

The hardened density of RAC was obtained by weighing the 150 mm cubes in air and in water 24 hours after their casting. The density was calculated by dividing the weight of the specimen in the air by the volume of the specimen.

Compressive Strength

The compressive strength was determined according to ASTM C39. Compressive strength was calculated by dividing the failure load by the average cross sectional area of the specimen. The compressive strength testing of cubes and test machine is shown in the Figure 4.18. The concrete specimens RAC were tested for compressive strength after seven and 28 days of water curing. The testing procedure was similar to that for the specimens for the NAC mixes. The compressive strength was calculated by dividing the failure load by average cross sectional area.

Figure 4.19: Illustration compressive strength test apparatus

Splitting Tensile Strength

The splitting tensile strength was determined according to ASTM 496-6. The splitting tensile strength test is used in the design of structural concrete members to evaluate the shear resistance provided. This test method follows the ASTM C-496 procedure where the cylindrical hardened concrete specimens with 15 cm diameter and 30 cm length are loaded longitudinally tensile failure, as illustrated in Figures 4.19. The concrete specimens RAC were tested for tensile strength after 28 days of water curing. The testing procedure was similar to that for the specimens for the NAC.

The tensile strength was computed as follows:

f t =2P/π x DL

where : f t = tensile strength in kg/cm^2.

P = the maximum applied load at splitting in kg.

L =length of the cylinder, in cm.(usually 30cm).

D = diameter of cylinder, in cm. (usually 15cm).

Figure 4.20: Splitting testing apparatus

Flexure Strength

Flexural strength tests were performed according to ASTM D-790, as shown in Figure 4.20b. The flexural test measures the force required to bend a beam under one point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. This test method follows the procedure where the 10×10×50cm^3 hardened concrete specimen lies on two 40 cm apart supporting spans and the load is applied to the center by the loading nose producing one point bending at a specified rate failure.

The flexure strength was computed as follows:

$\sigma = 3/2 \{(PL)/(bh2)\}$

where:

σ = flexural strength or modulus of rupture, in kg/cm^2.

P = maximum applied load, in kg,

L = span length in cm.= 40cm (center to center of supports)

b = width of specimen, in cm.= 10 cm

h = depth of specimen, in inches.= 10 cm

Theoretical : $\sigma = 3.18 \checkmark fc$kg/cm2, sited in (Zuhud, 2008)

Figure 4.21a: Illustration of flexure strength test apparatus

Figure 4.21b: Specimens placed in flexure strength test apparatus

Water Permeability

The water permeability of RAC concrete specimens was evaluated by conducting DIN 1048 through conducting the Water Penetration Test, as illustrated in Figures 4.21 and 4.22. The depth of water penetration was determined after four months of exposure to laboratory dry conditions.

The concrete specimens were exposed to a water pressure of 0.5 N/mm^2 which is equivalent to a pressure of five bars. This pressure was maintained invariant for a period of 72 hours. Immediately, after the completion of the test, the specimens were taken out and split open into two halves with the face which was exposed to water facing down.

Figure 4.22: Specimens placed in water penetration cell.

Figure 4.23: Water penetration test set-up

Chapter Five

Results and Discussion

5.1 QFD Results and Analyses

As mentioned earlier, the main aims of this study are to improve the RAC characteristics, identified critical characteristic of RCA that need to be enhanced in order to improve RAC characteristic made from RCA, obtaining an acceptable quality of concrete with maximum utilization of recycled aggregate and customer satisfactions.
This was achieved after the implementation of construction QFD matrix.

Referring to Table 4.3, the most important customer needs and priorities greater than or equal 4 was as follow:

- Supplying as quickly as possible (adequate supply system)
- Minimum materials cost.
- Durability building.
- Support loads.
- Comply with codes and standards ACI.
- Minimization CDW (safer construction).

There are three different competitive assessment DRs that have been improved first permeability (Figure 4.2), compressive strength and quality mix components that have highest relative factor and absolute factor which strong conducted to the reinforced concrete and corrosion. Quantity plus RAC concrete supply have the third relative factor and absolute factor.

Technical specifications RCA and NCA are show in Figure 4.3 for quality and continuous improvement implementation grain size, absorption, abrasion, specific gravity and residual of mortar content.
Main process that remedied unwanted features of concrete mixed made from RAC.

- Varity RCA % replacement

- Water reductions using SP.
- Selected NA. with good quality
- Select natural sand (Gaza sand)
- Reduction in water /cement ratio
- Reduce RMC residual of mortar content
- Prinking RCA since 24 hours before use.
- Mixing process

Using TSMA instead of TMA. to improve and optimize the products of RAC which conducted with manufacturing process.

.

The final design of RAC that is satisfing economical, technical optimization, quality performance and meets the customer requirements through the implementation of QFD principles for C25, C30, and C350 were done.

The results were built up on the questionnaires and interviews. By experiments we found that the compressive strength, tensile strength, flexure strength and permeability affecting by design requirements and materials characteristics and improvement this parameters leads to optimizing and improving the RAC characteristics, which confirmed with laboratory results and published papers.

5.2 Summery Results and Dissections.

One of the primary objectives of this study was integrate QFD method to improve RAC characteristics and quality performance of RAC. Optimizing mix blend and mixing process through evaluate and compare the physical properties of both recycled aggregate concrete containing various amounts of recycled aggregates and natural aggregate concrete were achieved.

5.2.1 Grading of RCA and NCA.

Gradation of aggregates plays a key role in the concrete mix proportions. When a range of graded aggregates is used, the smaller particles fill the spaces between the larger aggregates, thus lowering the void content and decreasing the cement paste requirement.

Figure 4.7 shows an actual grading curve for a typical recycled aggregate. It can be seen that all gratings fall within the allowable limits for the respective aggregate as specified in ASTM C33. From the practical point of view, it may be concluded that producing a well-graded recycled aggregate that complies with ASTM requirements would not be difficult.

Figure 4.13 shows an actual grading curve for a typical natural aggregate. It can be seen that all after technical optimization, gratings fall within the allowable limits for the respective aggregate as specified in ASTM C33. Due to optimization using computer program, it may be concluded that producing a well-graded recycled aggregate that complies with ASTM requirements would possible.

5.2.2 Absorption of RCA and NCA

The water absorption of recycled aggregates given in Table 4.15 ranged around 4.65 percent, depending on the source from which they were derived and RMC. Those values were certainly much higher than the corresponding value of the natural aggregates, which had only a 1.43 percent absorption capacity. This difference may be due to the higher absorption of the old mortar attached to the recycled aggregate. Due to its significant effects on both the fresh and hardened concrete properties as shown later, the high absorption capacity of the recycled aggregates was considered the most remarkable characteristic in their physical properties when compared with natural aggregates.

5.2.3. Specific Gravity of RCA and NCA

The specific gravity of the recycled aggregates in saturated surface dry conditions (S.S.D) as given in Table 4.15 was 2.40, while that of the natural aggregates was 2.60. Again, the noticeable difference was due to the relatively low density of the old mortar, which was attached to the recycled aggregates. The low value of the specific gravity of recycled aggregates is expected to have some effects on the weight of the recycled aggregate concrete on which the fundamental natural frequency depends.

5.2.4 Residual of Mortar Content RMC

The adhered cement loss after dissolving in nitric acid for RCA was (23%). Recycled aggregate of good quality for the production of structural concrete could be obtained by selecting aggregates with mortar content under 44%, as recent research performed by Juan and Gutierrez (2009).

5.2.5 Abrasion Resistance (Loss Anglos test)

According to ASTM standards, Los Angeles crush test of coarse aggregate must be a maximum of 50 % and 40 % as B.S standards. The Los Angeles crush test results was 37.4%.Accordingly, the assessment of abrasion loss in mass of recycled aggregate indicates general characteristic of its quality particularly when it is subjected to wear or impact during the mixing or after concrete placement. As research performed by Mamlok and Zaniewski (2006).

5.3 Development of Fresh Concrete Properties.

5.3.1 Workability

The workability of all mixes as given in Table 5.1 was observed in terms of the slump test. Mixes that contained recycled aggregate were harsher and stiffer than mixes that contained natural aggregates. To achieve the same level of slump for both mixes, more superplasticizer was added to mixes of recycled aggregate concrete. This lower workability for the recycled concrete could be attributed to the highly absorbent mortar, which was attached to the recycled aggregates. For the same reason, loss of workability was also noticed to be faster for recycled aggregate concrete than for natural concrete, especially after the first 5 to 10 minutes at TMA. Also we see the different between TSMA and TMA wherever the slump at TSMA were the slump minimum value 9cm-12cm maximum and minimum 6.0cm -9cm for TMA so the increment by 10-15% at the same quantity of SP.

Figures 5.1, illustrate the slump level at TMA and TSMA. The Figures clearly revealed that slump level of fresh concrete mixes increase due to applying TSMA. It is referring to the improvement of the ITZ and filling pores with cement paste due to applying TSMA that caused reduction of actual water absorbent of the RAC. This results comply with the research performed by Tam et al., (2005).

Figure 5.2, shows the slump level measurement.

Table 5.1 Development of workability using TSMA

<table>
<tr><td colspan="7">Type of Mixing Approach</td></tr>
<tr><td colspan="3">Traditional Mixing Approach (TMA)</td><td rowspan="3">W/C</td><td colspan="3">Two Stage Mixing Approach (TSMA)</td></tr>
<tr><td colspan="3">MIX A</td><td colspan="3">Mix D</td></tr>
<tr><td>MIX ID</td><td>Slump cm</td><td>SP % By cement weight</td><td>MIX ID</td><td>Slump cm</td><td>SP % By cement weight</td></tr>
<tr><td>RAC170 %</td><td>7.5</td><td>2</td><td rowspan="4">H
0.55</td><td>RAC170 %</td><td>8.5</td><td>2</td></tr>
<tr><td>RAC2 50%</td><td>8.5</td><td>1.5</td><td>RAC2 50%</td><td>9.5</td><td>1.5</td></tr>
<tr><td>RAC3 30%</td><td>9</td><td>1</td><td>RAC3 30%</td><td>10</td><td>1</td></tr>
<tr><td>NAC1 0 %</td><td>9.5</td><td>0.5</td><td>NAC1 0 %</td><td>10.3</td><td>0.5</td></tr>
<tr><td colspan="3">MIX B</td><td rowspan="5">M
0.45</td><td colspan="3">MIX E</td></tr>
<tr><td>RAC170 %</td><td>7</td><td>3</td><td>RAC170 %</td><td>8</td><td>3</td></tr>
<tr><td>RAC2 50%</td><td>8</td><td>2.5</td><td>RAC2 50%</td><td>9</td><td>2.5</td></tr>
<tr><td>RAC3 30%</td><td>8.5</td><td>2</td><td>RAC3 30%</td><td>9.5</td><td>2</td></tr>
<tr><td>NAC1 0 %</td><td>9.5</td><td>1.5</td><td>NAC1 0 %</td><td>10.2</td><td>1.5</td></tr>
<tr><td colspan="3">MIX C</td><td rowspan="5">L
0.35</td><td colspan="3">MIX E</td></tr>
<tr><td>RAC170 %</td><td>6</td><td>4.5</td><td>RAC170 %</td><td>7.5</td><td>4.5</td></tr>
<tr><td>RAC2 50%</td><td>7.5</td><td>4</td><td>RAC2 50%</td><td>8.5</td><td>4</td></tr>
<tr><td>RAC3 30%</td><td>8</td><td>3.5</td><td>RAC3 30%</td><td>9</td><td>3.5</td></tr>
<tr><td>NAC1 0 %</td><td>9</td><td>3</td><td>NAC1 0 %</td><td>10</td><td>3</td></tr>
</table>

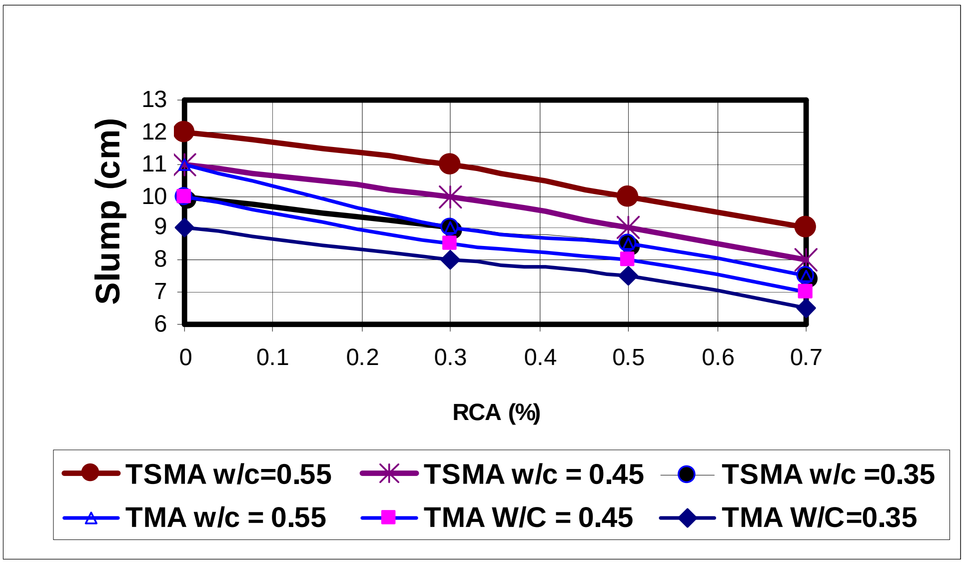

Figure 5.1: Development slump vs. RCA content and different w/c ratios

Figure 5.2: Slump level measurement

5.4 Development of RCA of Hardened Concrete Density

Table 5.3. present hardened density values. All the reported values in this table are based on the average of three replicate test samples. The hardened density ranged from 2297 kg/m3 for % 70 replacement at w/c 0.55 and 2395 kg/m3 for NAC 0 % replacement at w/c 0.35. According to the range of hardened density values as expected, the hardened densities of mixes are generally lower than natural concrete density. It has been reported

in the literature that an increase in the RCA content of a mix leads to a decrease in its hardened density.

5.4.1 Effect of Water-Cement ratio on Development Hardened Density

Fig. 5.4 illustrate the general effect of w/c ratio on the hardened density of the current RAC mixes. It appears that the densities of RAC mixes are related to their w/c ratios. From these figures, it is evident that the density of RAC is linearly correlated to its w/c ratio. With reference to the current test results plotted in Fig. 5.2, the preceding trend can be easily observed higher water content resulted in lower hardened density mixes for all w/c ratios.

5.4.2 Effect of RCA Substitutions on Development Hardened Density

It has been reported in the literature that an increase in the RCA content of a mix leads to a decrease in its hardened density. As shown in Figure 5.3, an increase in RCA content of mix leads to a decrease in its hardened density. As the proportion of recycled concrete aggregate increases, the density and unit weight decrease in the hardened concrete. Through the research performed by (Topcu and Sengel, 2004), it was observed that, the unit weight of concrete incorporating 50% of waste concrete as aggregate was higher (2315 kg/m3) than the one for concrete made with 70% waste concrete aggregate replacement which was 2295 kg/m3 at w/c = 0.45.

Table 5.2 Development hardened density value by versus RCA

Mix ID.	W/C	Hardened density (kg/m3)
Mix A		
RAC1 70 %	0.55	2285
RAC2 50%		2305
RAC3 30 %		2330
NAC1 0 %		2372
Mix B		
RAC4 70 %	0.45	2285
RAC5 50 %		2315
RAC6 30 %		2340
NAC2 0 %		2390
Mix C		
RAC6 70 %	0.35	2305
RAC7 50 %		2325
RAC8 30 %		2350
NAC3 0 %		2405

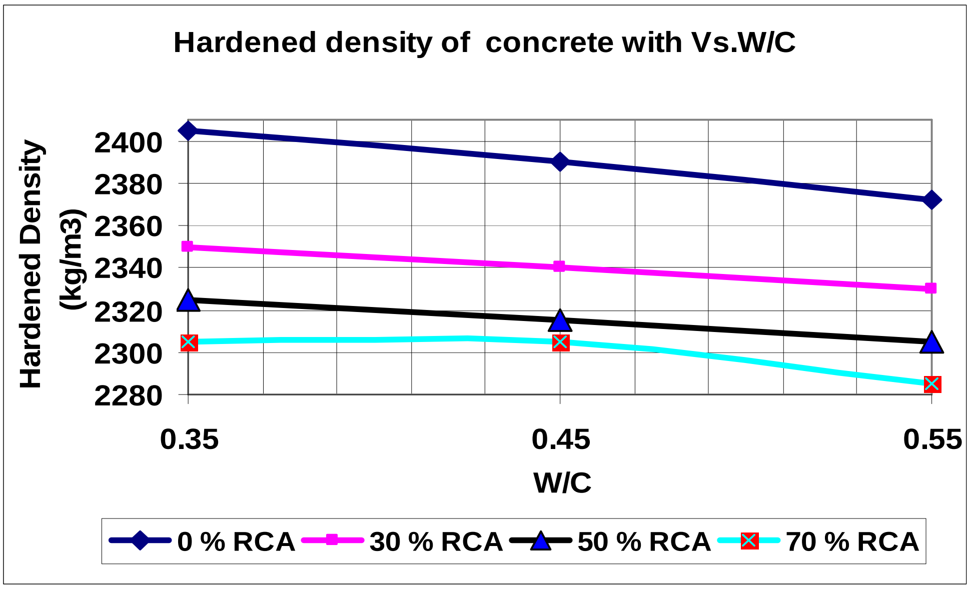

Figure 5.3: Development of hardened density at various w/c

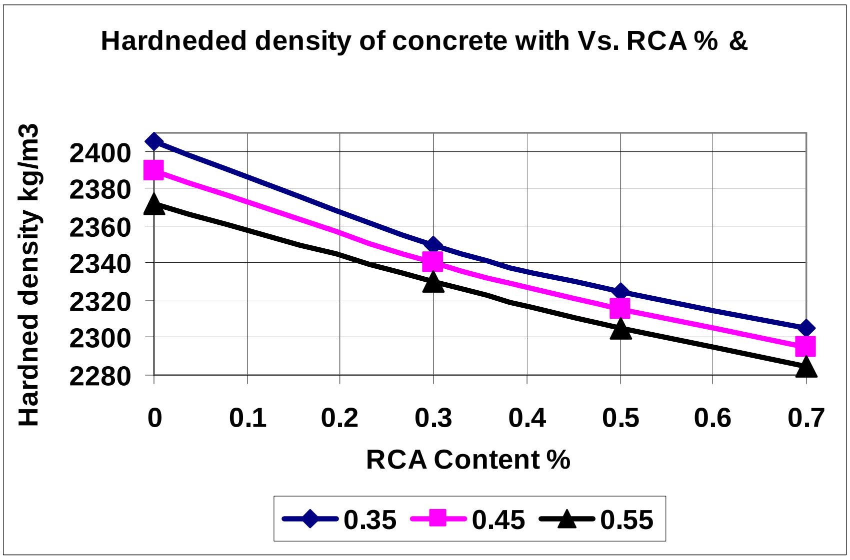

Figure 5.4: Development of hardened density various RCA content

5.5 Development Compressive Strength of RAC

Table 5.2. present compressive strength values before and after using TSMA .Figure 5.8 illustrated failure compressive shape of 50 % replacement and w/c = 0.35.

5.5.1 Effect of Reduction Water-Cement ratio on Development RAC Compressive Strength.

One of the main factor affecting the compressive strength of RAC is the w/c ratio of fresh mix. Compressive tests results of RAC and NAC are summarized in Table 5.2, through Figure 5.5, to 5.7. Figure 5.5 illustrate the effect of w/c ratio on compressive strength of the current RAC mixes. As expected, a reduction in the water cement ratio increased the compressive strength for both the RAC and the NAC. However, the rate of increase in the RAC,s compressive strength was not equivalent to that of the NAC,s. For instance, at w/c 0.35 and 28 days age, the NAC compressive strength increased from 360 Kg/cm2 at w/c= 0.55 to 420 kg/cm2 (20% increased) at w/c= 0.45, while the RAC,s for replacement, 0.50 of recycled aggregate compressive strength change from 230 kg/cm2 to 270 kg/cm2, (22% increased) at w/c 035. Practically, it is referred to avoiding use of fine recycled aggregate FRA and using big size aggregate, reduction of water cement-ratio and increased of quantity of cement which have positive affect on cement past content required to cover the aggregate. As recent research for achieving a design compressive strength, recycled aggregate concrete requires lower water–cement ratio and higher cement content to be maintained as compared to concrete with natural aggregate. Padmini et al.(2009)

5.5.2 Effect of RCA Substitutions on Development RAC Compressive Strength

Figure 5.6, illustrate the effect of replacement ratio on compressive strength of current RAC mixes. From this Figures, it is evident that there is a correlation between the compressive strength and the RCA content. The decrease in RCA leads to increase compressive strength it depends on the RCA % replacement and percentage of RM content.

As shown in Figure 5.5, for replacement ratio of 0.50 the compressive strength of RAC at w/c 0.45, was increase (310 kg/cm2) by 17 percent higher than of replacement 0.70, it was (265 kg/cm2) at the same w/c, while the replacement ratio of 0.30, the compressive strength (360kg/cm2), was increased by 35 percent higher than of replacement 0.70, the compressive strength was (265 kg/cm2), at the same w/c. As recent research for achieving a design compressive strength, recycled aggregate concrete requires lower water–cement ratio, higher cement content, adjusting RCA% and select big grain size to be maintained as compared to concrete with natural aggregate. Poon. and Lam (2008)

5.5.3 Effect of Mixing Method Development RCA Compressive Strength

Figure 5.7, illustrate the effect of mixing methods for development of compressive strength of RAC.

For a replacement ratio of 0.70, 0.50 and 0.30 at w/c 0.55, the compressive strength of recycled aggregate concrete mixed by TSMA was 11.4 percent, 13.2 percent and 9 percent higher than those mixed by TMA 28 days, respectively. Whatever the compressive strength were (270, 230 and 200 kg/cm^2) due to applying TMA, and it become (305, 265 and 220 kg/cm^2) due to applying TSMA. This improvement comply with recent researches.

.

For a replacement ratio of 0.70, 0.50 and 0.30 at w/c 0.45, the compressive strength of recycled aggregate concrete mixed by TSMA was 14.3 percent, 14.8 and 8.5 percent higher than those mixed by TMA 28 days, respectively. Whatever the compressive strength were (315, 270 and 235 kg/cm^2) due to applying TMA, and it become (360, 310 and 255 kg/cm^2) due to applying TSMA. The improvement as recent research.

For a replacement ratio of 0.70, 0.50 and 0.30 at w/c 0.35, the compressive strength of recycled aggregate concrete mixed by TSMA was 13 percent, 15 percent and 14.5 percent higher than those mixed by TMA 28 days, respectively. Whatever the compressive strength were (370, 315 and 265 kg/cm^2) due to applying TMA, and it become (420, 370 and 310 kg/cm^2) due to applying TSMA. Using (TSMA) mixing method, an increase of 17% and 26% in the compressive and tensile strengths of RAC, respectively, compared to NAC. This can be attributed to the improvement of the quality of ITZ due to double mixing. Poon et al. (2004).

The compressive strength of concrete is usually considered as its most important property because:

- Compressive strength is usually a good indicator of the quality of concrete since it is directly related to the properties of the hydrated cement paste.
- Compressive strength is an essential element in structural design and is usually required for compliance purposes.
- Other concrete properties, such as its tensile and shear strengths and its elastic modulus are functions of its compressive strength.

Table 5.3 Development of compressive strength using TSMA

Type of Mixing Approach						
Traditional Mixing Approach (TMA)			W/C	Two Stage Mixing Approach (TSMA)		
MIX A				Mix D		
MIX ID	Comp. Strength (Kg/cm2) 7 days	Comp. Strength (Kg/cm2) 28 days		MIX ID	Comp. Strength (Kg/cm2) 7 days	Comp. Strength (Kg/cm2) 28 days
RAC170 %	145	200	H 0.55	RAC170 %	156	220
RAC2 50%	164.5	230		RAC2 50%	185	265
RAC3 30%	200	270		RAC3 30%	214	305
NAC1 0 %	250	360		NAC1 0 %	255	360
MIX B			M 0.45	MIX E		
RAC170 %	166	235		RAC170 %	202.8	255
RAC2 50%	193	270		RAC2 50%	234	310
RAC3 30%	218	315		RAC3 30%	260	360
NAC1 0 %	298	430		NAC1 0 %	302	430
MIX C			L 0.35	MIX E		
RAC170 %	188.5	265		RAC170 %	231	310
RAC2 50%	236	315		RAC2 50%	247.5	365
RAC3 30%	220	370		RAC3 30%	262.5	420
NAC1 0 %	348	500		NAC1 0 %	350	500

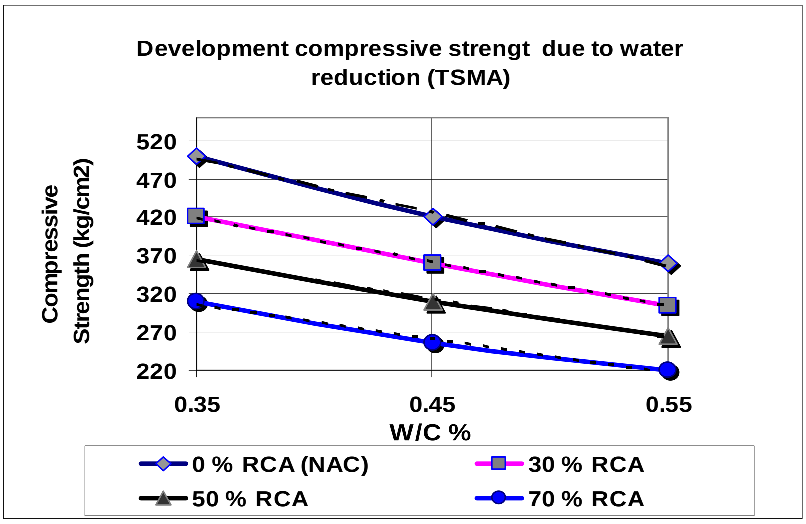

Figure 5.5: Development of 28- day compressive strength various w/c ratios with different RCA content

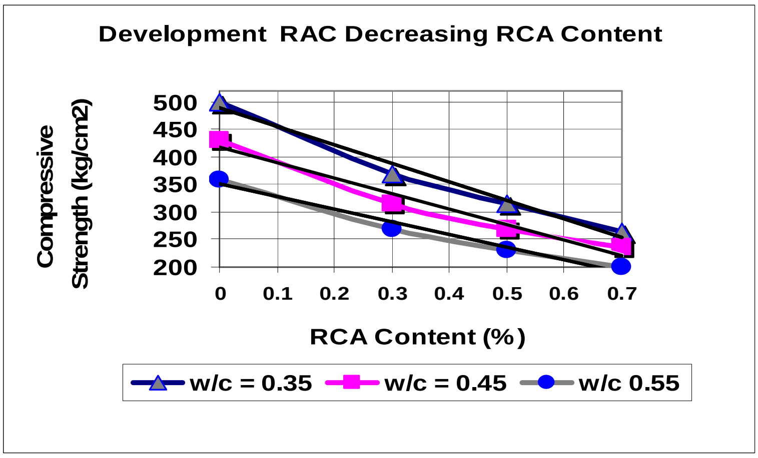

Figure 5.6: Development of 28- day compressive strength various RCA content (TMA)

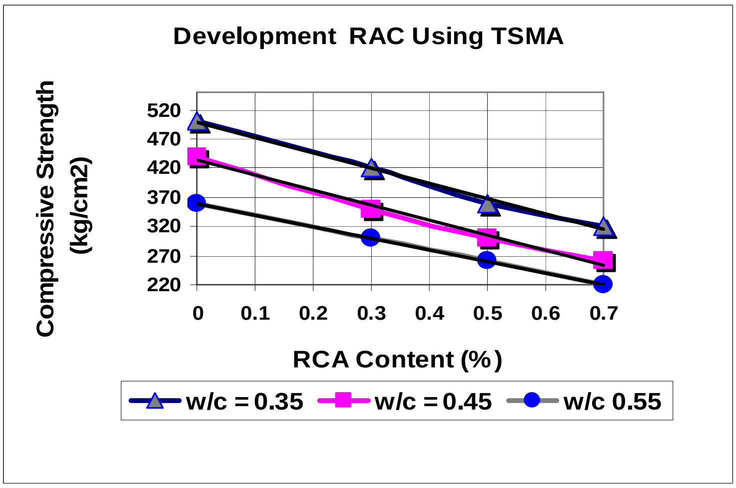

Figure 5.7: Development of 28- day compressive strength various RCA content (TSMA)

Figure 5.8: Typical testing cubs after failure for determine concrete compressive strength

5. 6 Development of Modulus of Rupture (Flexure Strength)

Test results of flexure strength and tensile strength are summarized in Tables 5.3, through Figures 5.9 and 5.12 show the result data interpretation for the effect mixing method on improving flexure strength and splitting strength for various RAC Varian w/c. Figure 5.14 and 5.15 shows the flexure failure shape and splitting failure shape respectively.

5.6.1 Effect of RCA Substitutions on Development RAC Flexure Strength

The correlation between the flexure strength and the RCA content are demonstrated in Figure 5.9. From this Figures, it is evident that there is a correlation between the flexure strength and the RCA content. The decrease in RCA leads to increase flexure strength which depends on the RCA % replacement. The flexure strength, for the all mixes is basically within expected range. It varies from 45 to 71 kg/cm^2.

5.6.2 Effect of Mixing Method on Development Flexure Strength

As shown in Figure 5.10, the flexure results for all a replacement ratio of RAC at w/c

0.55,0.45 and 0.35 and RCA 70% were increased by 9 %, 10.4% and 13.7 as result to applying TMA. (45, 48 and 51 kg/cm^2) and become (49, 53 and 58 kg/cm^2) respectively as result to applying TSMA.

For replacement 50% and w/c 0.55,0.45 and 0.35 were increased by 5.2 %, 7.7 % and 7% as result to applying TMA. (48, 52 and 56 kg/cm^2) and become (50.5, 56 and 61 kg/c m^2) respectively as result to applying TSMA. This improvement comply with recent researches as a result to improvement ITZ.

5.7 Development Splitting Tensile Strength

The splitting tensile tests are summarized in Table 5.4. The splitting tensile strength, for the all mixes is basically within a narrow range. It varies from 30 to 44 kg/c m^2.

5.7.1 Effect of RCA Substitutions on Development RAC Tensile Strength

As shown in Figure 5.11, it is evident that there is a correlation between the flexure strength and the RCA content. The decrease in RCA leads to increase flexure strength it depends on the RCA % replacement.

5.7.2 Effect of Mixing Method on Development Tensile Strength

Figure 5.12, shows summery of tensile strength improvement of RAC at various w/c 0.55, 0.45 and 0.35, the tensile strength of recycled aggregate concrete mixed by TSMA was around 7 percent, 9.5 percent and 13.5 percent higher than those mixed by TMA 28 days, respectively for all w/c mixes contain 50% RCA. Where the result due to applying TMA (30, 32 and 34 kg/cm2) and (32, 35 and 38.5 kg/cm2) due to applying TSMA.

Using this method reported an increase of 17% and 26% in the compressive and tensile strengths of RAC, respectively, compared to NAC. This can be attributed to the improvement of the quality of ITZ due to double mixing. (Poon et al., 2004).

Table 5.4 Development of split strength & flexure strength using TSMA

Type of Mixing Approach						
Traditional Mixing Approach (TMA)			W/C	Two Stage Mixing Approach (TSMA)		
MIX A				Mix D		
MIX ID	Flexure Strength (Kg/cm2) 28 - days	Tensile Strength (Kg/cm2) 28 - days		MIX ID	Flexure Strength (Kg/cm2) 28 - days	Tensile Strength (Kg/cm2) 28 - days
RAC170 %	45	27	H 0.55	RAC170 %	49	30
RAC2 50%	48	30		RAC2 50%	50.5	32
RAC3 30%	52	32		RAC3 30%	54	34
NAC1 0 %	61	36		NAC1 0 %	61	36
MIX B			M 0.45	MIX E		
RAC170 %	48	30		RAC170 %	53	33
RAC2 50%	52	32		RAC2 50%	56	35
RAC3 30%	56.5	35		RAC3 30%	59	38.5
NAC1 0 %	65	41		NAC1 0 %	65	41
MIX C			L 0.35	MIX E		
RAC170 %	51	32		RAC170 %	58	36.5
RAC2 50%	56	34		RAC2 50%	61	38.5
RAC3 30%	61	38		RAC3 30%	65	41.5
NAC1 0 %	71	45		NAC1 0 %	71	45

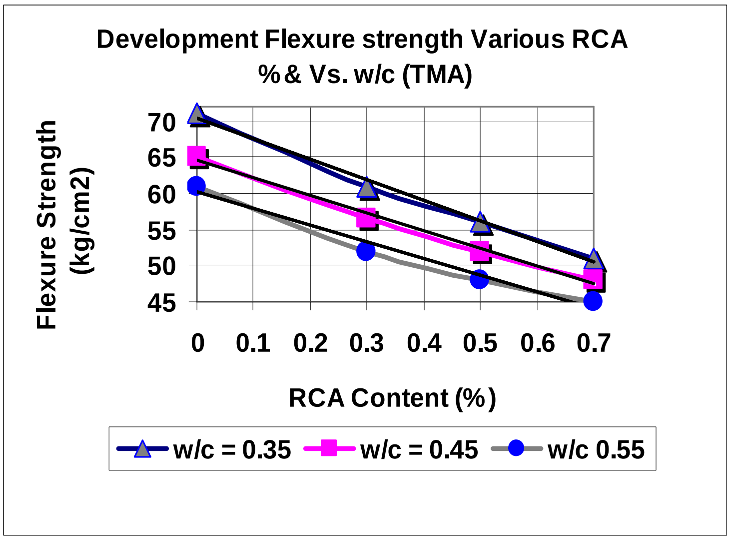

Figure 5.9: Development of flexure strength diff. RCA contents and with c/w ratio

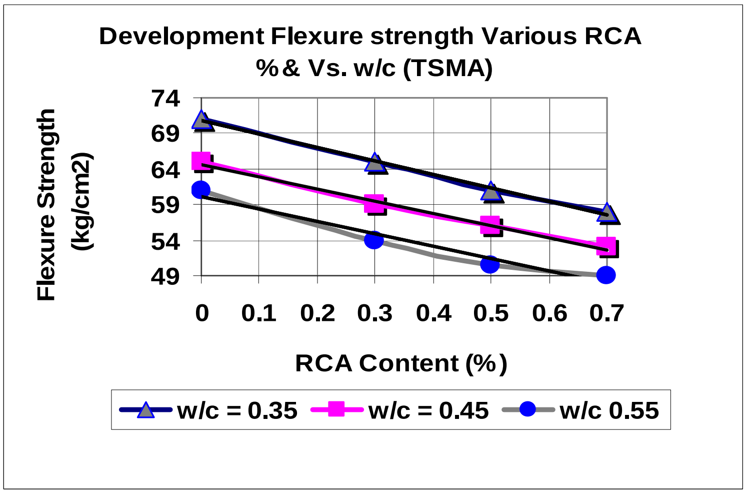

Figure 5.10: Development of flexure strength diff. RCA contents and Vs. w/c ratio (TSMA)

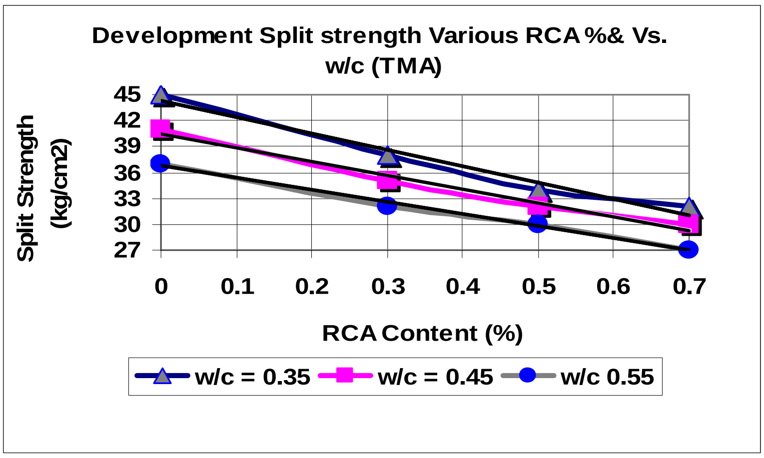

Figure 5.11: Development of 28- days split strength at diff. RCA contents and c/w ratio

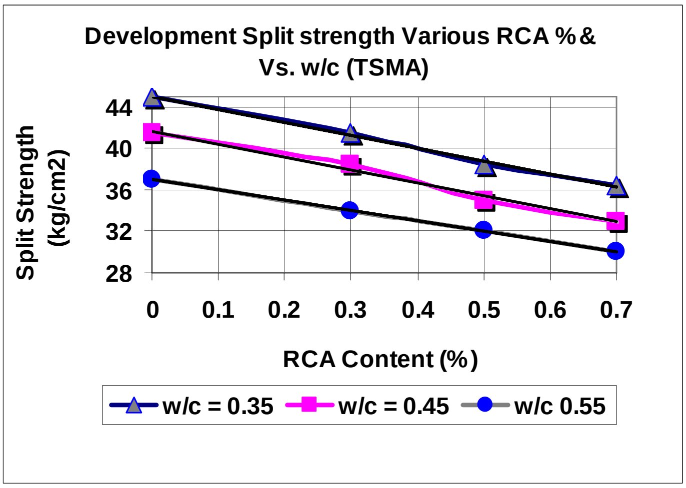

Figure 5.12: Development of 28 days split strength at diff. RCA contents TSMA

Figure 5.13: Illustration of days flexure strength testing specimens after failure

Figure 5.14: Illustration of splitting strength testing specimens after failure

5. 8 Development Water Penetrations of RAC (Permeability)

5.8.1 Effect of RCA Substitutions on Development Depth Water Penetration

Table 5.5, summarized the results average value of water penetration through Figure 5.11 and 5.12, due to using the mix methods (TMA and TSMA). The correlation between the permeability and the RCA content are demonstrated in Fig.5.11, it is evident that there is a correlation between the water depth penetration and the RCA content. Increase the RCA leads to increase of water depth penetration .

5.8.2 Effect of Mixed Method on Development Depth Water Penetration

Figure 5.12 showing the development depth of water penetration due to using TSMA at different replacement and various W/C, the water penetration of RAC at replacement ratio 0.70, decreased by 25 percent, and at replacement 0.50 decrease by 28.8 percent for w/c 0.55, were the result (5 and 3.8) due to applying TMA and become (4 and 2.95) due to applying TMSA.

At replacement ratio 0.70, 0.50 decreased by 18.4 percent, 34 percent respectively for w/c 0.45. were the result (4.5 and 3.5) due to applying TMA and become (3.8 and 2.6) due to applying TMSA.

At replacement ratio 0.70, 0.50 decreased by 17.65 percent, 45 percent respectively for w/c 0.35, were the result (4 and 3.5) due to applying TMA and become (3.4 and 2.4) due to applying TMSA. This referred to applying electrical vibration instead of manual vibrated and using SP and good aggregate with good graded.

`A good relation between surface permeability and porosity, diffusivity and water absorption capacity is assessed. The deployment of the double mixing method significantly improved the compressive strength of concrete and ITZ which have positive effect on RAC impermeability. Tam and Tam (2008)

.

Figure 5.13 shows the split permeability specimen showing depth of water penetration. The water penetration profile on the concrete surface was then marked and the maximum depth of water penetration in three specimens was recorded and average values are reported.

From theses results, it appears that replacement of natural aggregates with recycled at fifty was found to be advantageous and beneficial to produce C25, C30 and C35, the results strength was within the expected range for the above structural-grade concrete and not have adverse effects on tensile strength and Flexure strength. So the water depth penetration has been done at RCA replacement 0.50 and 0.70 as technical and economical parameters and comparing results with 0.00 replacements. The water depth penetration was measured after splitting the sample into two half's split with the face which was exposed to water facing down to the maximum penetration by using caliper. See Figure 5.17.

Table 5.5 Development of Water penetration value by versus RCA content

Type of Mixing Approach				
Traditional Mixing Approach (TMA)		W/C	Two Stage Mixing Approach (TSMA)	
MIX A			Mix D	
MIX ID	Permeability (as depth of water penetration		MIX ID	Permeability(as depth f water penetration
RAC170 %	5.00	H 0.55	RAC170 %	4.00
RAC2 50%	3.8		RAC2 50%	2.95
NAC1 0 %	2.7		NAC1 0 %	2.6
MIX B		M 0.45	MIX E	
RAC170 %	4.5		RAC170 %	3.8
RAC2 50%	3.5		RAC2 50%	2.6
NAC1 0 %	2.4		NAC1 0 %	2.3
MIX C		L 0.35	MIX F	
RAC170 %	4.0		RAC170 %	3.5
RAC2 50%	3.40		RAC2 50%	2.4
NAC1 0 %	2.2		NAC1 0 %	2.0

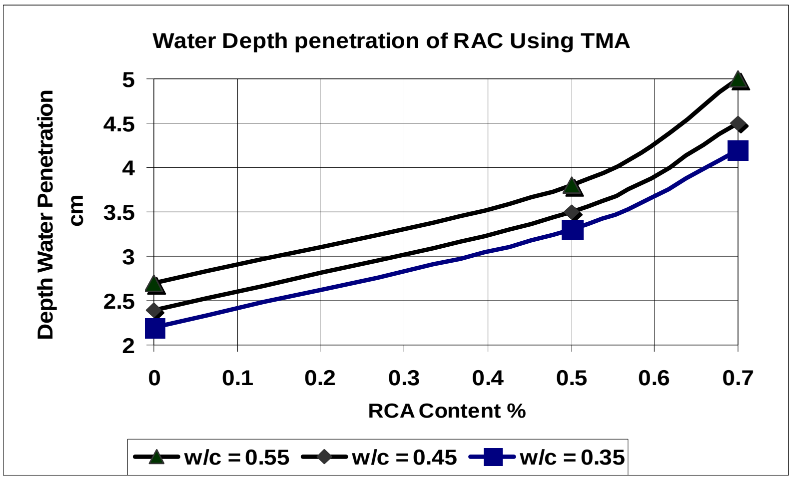

Table 5.15: Development of penetration depth vs. RAC content and W/C

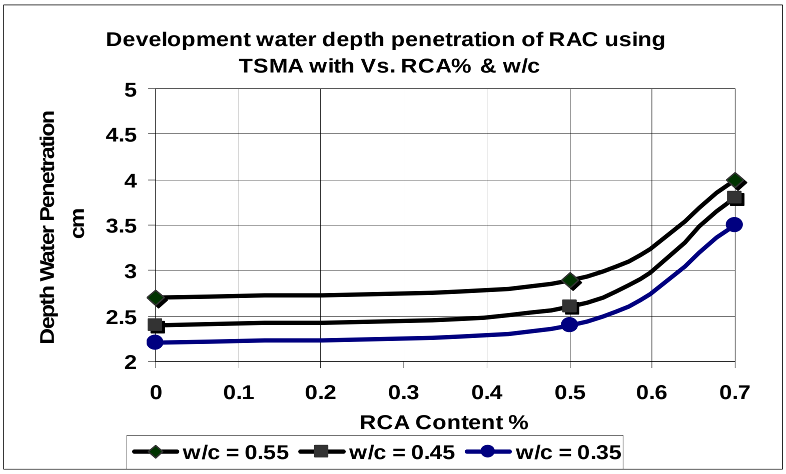

Table 5.16: Development of penetration depth vs. RAC content and w/c

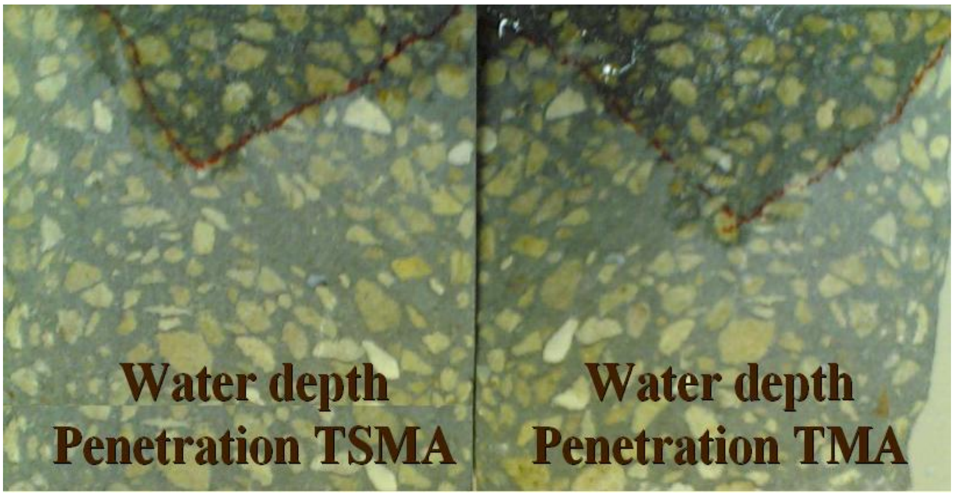

Figure 5.17: Concrete specimen showing development depth of water penetration

Summery Results

From theses results, it appears that replacement of natural aggregates with recycled at fifty was found to be advantageous and beneficial to produce C25, C30 and C35, the results main highlights were within the expected range for the above structural-grade concrete and not have adverse effects on tensile strength, Flexure strength and the water penetration which the most important parameter that affect on reinforced concrete and causes carrion.

Chapter Six

Conclusions and Recommendations

6.1 Conclusions

The objective of this study was to evaluate the use of QFD as design tool to benefit the Mix design of RAC. Quality Function Deployment, as design tool, assists to clearly identify customer requirements and emphasize those requirements throughout the RAC manufacturing process.

In RAC mix design, QFD was able to provide useful information to the product RAC design themes. By emphasizing fulfillment of customer requirements during the design process, the themes should be able to improve service by reducing the number of design trial required after construction mix has begun.

During the mix design, QFD used to identify which components were most critical to fulfill customer requirements. As the products cost, the QFD analysis could be used to support decisions to require a higher level of quality performance of RAC for certain components.

Other less critical components could suffice with average or economy quality levels, while still fulfilling customer requirements. Moreover, the analysis identifies which components that should receive priority for further analysis during completion of the mix design.

The biggest benefit of QFD analysis occurs when integrating it into the mix design. As the final mix design is completed, critical RAC specifications can be made more stringent to reduce or eliminate the unwanted concrete properties.

The analysis also allows the quality control and assurance plans to focus on eliminating unwanted and deficiencies of concrete sample during the manufacturing process. Through the use of QFD analysis, the QFD person should be able to improve the quality of its mix process by focusing the design process on providing for customer requirements, and minimizing quality control problems and design changes.

On the basis of the results obtained by a performing a comparative study on physical and mechanical properties such as water depth penetration permeability, and strength of different aggregates and their influence on concrete durability, the conclusion are expressed as follows.

1. The durability of the RCA concrete is very dependent on the RCA aggregate properties. Using a very well hardened old recycled concrete as coarse aggregate with 25 mm nominal maximum size accompanying natural sand in structural concrete can be efficient if the properties such as compressive, permeability, of RCA concrete meet the required acceptance limit obtained by the same concrete made with natural aggregate.

2. The strength and the quality of the RCA were competitive enough with those of natural aggregates to be used as an aggregate in structural applications C25,C30and C35.

3. A two-stage mixing approach (TSMA) was an efficient method that showed acceptable results for all types of concretes, improving ITZ, RAC strength and permeability.

4. The properties such as grain size, absorption and specific gravity, RM and LA. of RCA as well as the durability aspects of the RCA concrete should be evaluated before the possible use of these aggregates in structural concrete.

5. To improve the quality of RAC made from RCA, the ready-mixed plant can minimize the amount of water added to the RAC. By adjusting the amount of R.W.A. and ordering the pluses greater or equal 2 m3.

6. Optimizing mix blend by using linear programming to get mix blend comply with economical and technical issues is feasible.

7. The production of well-graded recycled aggregates that meet with the ASTM specifications is feasible.

8. Due to the old attached mortar in recycled aggregates, their water absorption capacity is higher than that of limestone coarse aggregates. The specific gravity of recycled aggregates is lower than that of the natural aggregates.

9. Lowering the water-cement ratio to a certain level was highly beneficial to the development of the durability of the NAC. At a water-cement ratio of 0.35, the permeability of the NAC performed extremely well.
However, using the same water-cement ratio for the RAC was successes to provide water penetration of less than 3 cm at RCA 50%.

As a final conclusion, it should be mentioned that the refined design parameters and guidelines obtained from the experimental approach confirmed those identified earlier by the QFD for the improvement of RAC properties.

6.2 Recommendations

- Construct data base for research done on the RAC to enable the researchers to utilize it in their researches.
- Using proof water admixture to improve permeability RWA.
- Using TSMA to optimizing the RAC strength properties and permeability.
- Go to further study to measure RAC Absorption, Elastic Modulus, Corrosion, Creep, and Shrinkage.
- Define target value for C25, C30 and C35

The following parameters are recommended for producing RAC using local aggregates with replacement 0.50 ratio and water depth penetration (permeability) lower than 3 for C25, C30, and C35:
Due to using TSMA for three structure grade.

The mix composition for C25 – which wide used

Maximum grain size 25mm with RMC 23%, LA 34.7 % and using TSMA

1. FA 620 kg/m^3
2. RCA Content: 490 kg/m^3 (50% RCA)
3. NCA Content: 613 kg/m^3 LA 20.35%

4. Super Plasticizer: 1.5 % - 2.5%

5. W/C: 0.55   181 kg/m^3

6. Cement: 330 kg/m3

7. Plus must equal or greater than 2m^3

8. Water penetration less than 3cm

9. Cost 1m3 = 90$ instead of 110$ for NCA

The mix composition for C30 - which wide used in foundations

Maximum grain size 25mm with RMC 23% , LA 34.7 % and using TSMA

1. FA 629 kg/m3

2. RCA Content: 502 kg/m3   (50% RCA)

2. NCA Content: 629 kg/m3   LA 20.35%

3. Super Plasticizer: 2.0 %

4. W/C: 0.45   158 kg/m^3

5. Cement: 360 kg/m3

6. Plus must equal or greater than 2m^3

7. Water penetration less than 3cm

8. Cost 1m3 = 100$ instead of 124$ for NCA

The mix composition for C35 which used for other structures

1. FA 650 kg/m3

2. RCA Content: 531 kg/m^3 with RMC 23% , LA 34.7 %

2. NCA Content: 655 kg/m^3 LA 20.35%

3. Super Plasticizer: 4.5 %   W/C: 0.35

5. Cement: 380 kg/m3

6. Plus must equal or greater than 2m^3

7. Water penetration less than 3cm

8. Cost 1m3 = 112 $ instead of 133$ for NCA

6.3 Suggestion for Future Research

The following are some suggestions for future research:

1. The durability properties of RAC can be improved by determination of RMC of RCA and total RMC and subtract the RMC content of RCA from the TRMC and minimizations the sand content.

2. Long-term study on durability of RAC considering rebar corrosion monitoring in addition to other durable properties of concrete.

3. Effect of RAC on plumb ability.

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Appendix A

Natural Coarse Aggregate by weight

The mix design calculation

Notice: all calculation at SSD condition

Procedure: Mix design calculations NCA. ACI. Volume method for 1 m^3 are done C25 as follows

Natural aggregate by weight.

Given

B.S.G_{SB} of CA_{F5} = 2.60

B.S.G_{SB} of CA_{AD} = 2.63

B.S.G_{SB} of CA_{SM} = 2.65

B.S.G_{SB} of FA_{SM} = 2.65

B.S.G_{SB} of FA Gaza sand = 2.65

Amount of cement: 330 kg/ m^3

Water/cement ratio 0.55

Admixture 1% from cement

Density = mass/volume

Mass = density x volume

Volume of cement = (330/3.15*1000)= 0.1048 m3,(3.15 Specific Weight of Cement)

Volume of water = 0.55 x330 /1000 =0.1815 m3,(1 Specific Weight of Water)

Volume of admixture =(3.3/1.17*1000)=0.00282 m3 (1.17 Specific Weight of Admixture)

Volume of total aggregate ={1-0.01–0.00282 – 0.1048 – 0.1815 = 0.700918 m^3

Optimization sample: 40.66 % Fine aggregate dived into(82% sand and 18% FASM , and 59.34 % coarse aggregate divided into (60% CA_{F5} ,15% CA_{AD} , 25% CA_{SM}) according to optimization process see (Table 4.18).

Volume for 1m3 of FA 0.700918 x 0.4066 = 0.285 m^3

Volume for 1m3 of CA 0.700918 x 0.5934 = 0.416 m^3

Coarse aggregate proportion by weight.

CA_{F5} = 0.6 x 0.416 m3 x 2.60x1000= 649 kg/ m^3, (2.60 Specific Weight of CA_{F5})

CA_{SM} =0.25x 0.416 m3x2.65x1000=275.6 kg/ m^3,(2.65 Specific Weight of CA_{SM})

CA_{AD} =0.15 x 0.416 m3x2.63x1000 =164.11 kg/ m^3,(2.63 Specific Weight of CA_{AD})

Weight of fine aggregate (Sand) = 0.82 x 0.285 m^3 x 2.65 x1000=620 kg/ m^3,(2.65 Specific Weight of Sand).

Weight of FA_{SM} aggregate = 0.18 x 0.285 m3 x 2.65 = 136 kg/ m^3,(2.65) Specific Weight of FA_{SM}).

Total weight of blend mix CA for 1 m3 = (650 CA_{F5} + 276.5 CA_{AD} + (164 CA_{SM} + 136 FA_{SM}) kg/m3 = 1224 kg/ m^3

Table A0 Illustrated the cost ingredients composition for one cube meter of natural aggregate concrete

Table A0 Cost Mix Blend of NCA according to optimization.

NCA 100 & 0 % replacement

Ingredients Description	Cost $/ kg	Qua. kg/m3	Cost$/ m^3 Cost $xQ.
Cement	0.1388/kg	330	45.804
Water	0.001	181.5	0.1815
SP 0.5 %	1.66	1.65	2.739
NCA 0 % replacement			
CA_{F5}	0.037	650	24.05
CA_{AD}	0.046	164	7.544
CA_{SM}	0.038	275.6	10.473
FA_{SM}	0.046	136	6.258
Sand	0.00208	620	1.3
Delivery	6.5/m3	1m3	6.5
Total =			104.85$

Coarse aggregate RCA by weight

Procedure: Mix design calculations RAC . ACI. Volume method for 1 m3 are done

Given:

RCA $B.S.G_{SB}$ of CA_{F5} = 2.42

RCA $B.S.G_{SB}$ of CA_{AD} = 2.40

RCA $B.S.G_{SB}$ of CA_{SM} = 2.39

$B.S.G_{SB}$ of FA Gaza sand = 2.65

Amount of cement: 330 kg/m3

Water/cement ratio 0.55

Volume of water = 0.55 x330 /1000 =0.181m3,(1 Specific Weight of Water)

Volume of admixture =(3.3/1.17*1000)=0.00282 m^3 (1.17 Specific Weight of Admixture)

Volume of total aggregate ={1-0.01–0.002821 – 0.104762 – 0.1815 = 0.700918 m^3

Optimization sample: 40.66 % Fine aggregate dived into(82% sand and 18% FASM , and 59.34 % coarse aggregate divided into (60% CA_{F5},25% CA_{AD} , 15% CA_{SM}) (Table 4.26).

Volume for 1m3 of FA 0.700918 x 0.4066 = 0.285 m^3

Volume for 1m3 of CA 0.700918 x 0.5934 = 0.416 m^3

Coarse aggregate proportion by weight.

RCA CA_{SM} = 0.25x 0.416 m3 = 0.104 m^3

RCA CA_{AD} = 0.15 x 0.416 m3= 0.0624 m^3

RCA CA_{F5} = 0.6 x 0.416 m3 = 0.2496 m^3

RCA FA_{SM} = 0.18x 0.285 m3 =0.0513 m^3

Total of RCA volume = 0.4673 m^3

Net RCA volume = Total of RCA volume – Volume of RMC = 0.4673 - 0.06 (RMC volume) = 0.4073 m^3

RAC Coarse aggregate proportion by weight. kg/ m^3

RCA CA_{SM} = 0.25 x 0.4073 m3x2.39 x 1000= 243.5 kg/ m^3

RCA CA_{AD} = 0.15 x 0.4073 m3 x 2.4 x 1000 = 147 kg/ m^3

RCA CA_{F5} = 0.6 x 0.4073 m3 x 2.42 x 1000 = 591.4 kg/ m^3

Volume of fine aggregate (Sand) = 0.82 x 0.285 m^3 = 0.2337 m^3

Weight of sand = 0.2337x 2.65x 1000 = 619 kg/ m^3

Table A01 Illustrated the cost ingredients composition for one cube meter of recycled aggregate concrete

Table A.1: Concrete Percent Mix Proportion and weight 1m3(kg/m3) NCA according grain size (w/c = 0.55,0.45 and 0.35)

Percent proportions %	Water (kg/m3) W/C (kg/m3)	Grain size 25 mm (kg/m3)	Grain size 20 mm (kg/m3)	Grain size 10 mm (kg/m3)	Grain size 4.75 mm (kg/m3)	Total CA (kg/m^3)
C25 – 330 kg/m3 ,w/c = 0.55						
0%	0.55	650	275	166	136	1227
30%	0.55	195	82.5	50	41	368
50%	0.55	325	137.5	83	68	613.5
70%	0.55	455	192.5	116	95	859
C30- 350 kg/m3 ,w/c = 0.45						
0%	0.45	667	281	170	140	1258
30%	0.45	200	84	51	42	377
50%	0.45	333.5	140.5	85	70	629
70%	0.45	467	197	119	98	880.5
C30-380 kg/m3 ,w/c = 0.35						
0%	0.35	697	294	177	143	1311
30%	0.35	209	88	53	43	393
50%	0.35	349	147	88.5	71.5	655.5
70%	0.35	488	206	124	100	918

Table A2: Concrete percent mix proportion and weight RCA for 1m3 (kg/m3) (w/c = 0.55,0.45 and 0.35)

Percent proportions %	Water W/C (kg/m3)	Grain size 25 mm kg/m3	Grain size 20 mm kg/m3	Grain size 10 mm kg/m3	Total CA kg/ m^3
C25 – 330 Cement kg/m3 w/c = 0.55					
0%	181	588	245	148	981
30%	181	176.5	73.5	44.5	294
50%	181	294	122.5	74	491
70%	181	411.6	171.5	103.5	687
C30 - 350 Cement kg/m3,w/c = 0.45					
0%	158	605	252	151	1006
30%	158	181.5	76	44	302
50%	158	303	126	75.5	503
70%	158	424	176	106	704
C35 - 380 Cement kg/m3,w/c = 0.35					
0%	135	640	264	158.5	1062
30%	135	192	79	47.5	319
50%	135	320	132	79	531
70%	135	448	185	111	743

Mix design for the concrete prisms used for properties measurements

Compressive strength measurements

The volume of each standard concrete cube = (0.15)3 = 0.003375 m3

The total volume of three concrete prisms = 0.003375 m3 * 3 = 0.010125 m3

Depth water Penetration Permeability

The total volume of three concrete prisms = 0.003375 m3 * 3 = 0.010125 m3

Tensile strength

The volume of each standard concrete cylinder = (0.075)2 *3.14*0.3 = 0.0053m3

The total volume of three concrete cylinder = 0.07065 m3 * 3 = 0.016m3

Flexure Strength

The volume of each standard concrete presim = 0.1*0.1*0.5 = 0.005 m3

The total volume of three concrete prisms = 0.015 m3

The total batch mixed volume =0.01012 m3+ 0.01012 m3+0.212 + 0.0150 m3 = 0.0515 m3

Volume coarse aggregate of testing samples = 0.0515 m3

Appendix B

Determination of density and absorption of RCA and NCA as mix blend

The value for this parameter were determined for each type as mix blend.

After following the test procedure, the results were obtained as listed bellow:

Where

A = weight of oven-dry test aggregates in air, g

B = weight of saturated-surface-dry test aggregates in air, g

C = weight of saturated-surface-dry test aggregates in water, g

For the natural aggregates: NCA

A= 3266.42

B=3313.35

C=2058.3

$B.S.G_{SB}$ = 3266.42 / (3313.5-2058.3) = 2.6

$B.S.G_{SSD}$ = ((3313.35)/(3313.35-2058.3)) = 2.64

Absorption, % = = (3313.35 – 3309.42)/(3309.42) x 100 = 1.43%

For the natural aggregates: RCA

A= 2960.25

B=3105.85

C=1825.5

$B.S.G_{SB}$ ((2960.25)/(3105.85-1825.5)) = 2.31

$B.S.G_{SSD}$= ((3105.85)/(3105.85-1825.5)) = 2.42

Absorption, % = (3247.08 – 2916.67)/(2041.93) x 100 = 4.92%

Abrasion resistance of coarse aaggregate for NCA & RCA

The los,s Anglos abrasion for two types of aggregate RCA and NCA was determined as below:

Where

A= weight of samples before test.

B= weight of samples after test.

Table B.1 Los Angeles Crash Test NCA.

Type	No of Cycles	Weight in grams Before Test (A)	After Test (B)	Weight Difference	Crash Test %
A	500	5010	3990.5	1019.5	20.35

% Loss for natural aggregates due to abrasion = (A-B)/A = (5010-3990.5)/5010

% Loss for natural aggregates NCA = 20.35 %

Table B.2 Los Angeles Crash Test RCA

Type	No of Cycles	Weight in grams Before Test (A)	After Test (B)	Weight Difference	Crash Test %
A	500	5020	3142	1878	37.4

% Loss for recycled aggregates RCA = 37.4 %

Determination of RCA adhered cement

Test Procedure:

Preparing recycled aggregate contained 10 of 25 mm, 50 % of 19.5 mm and 25 % and 15 of 9.5 mm.Aggregates were thoroughly washed and dried at 110° C over night. After air cooling for 1 to 3 hours, the aggregates were weighed and digested in 20 % nitric acid. The solution was heated gently on a hot plate while the aggregates were stirred by the flattened end of a glass rod. This process was continued for a few minutes until adhered cement paste started to dissolve. Thereafter, the mixture was covered and heated to near boiling temperature for 2- 3 hours and the residue of adhered mortar and aggregates were separated. The solution of adhered paste was filtered through a medium-textured paper in a new beaker and the residue on the filter and the undissolved aggregates were washed and dried in the oven at 110° C over night and weighed again. The difference between the dried mass before dissolving and the mass of residue particles after second drying gives the amount of adhered cement paste in the RCA. (Movassaghi, 2006).

Calculations :

Where

V_{RM} = Volume of residual of mortar

$V_{RM} = W^{RM}_{OD} / SG_b^{RM}$

SG_b^{RM} = Specific gravity of residual mortar.

SG_b^{RCA} = Specific gravity of recycled aggregate.

SG_b^{OVA} = Specific gravity of original virgin aggregate

Calculation:

Original mass of aggregate = 520 g

Dried mass before dissolving = 500 g

The mass of RCA after second drying = 385.2 g

Adhered mortar percent =100 x(dried mass before dissolving – the mass after dissolving after second drying)/dried mass before dissolving .

Adhered mortar percent of RCA RMC = $\frac{500 - 385.2}{500} \times 100 = 22.96\%$

SG_b^{RM} = RMC /((1/ SG_b^{RCA} - (1- RMC/ SG_b^{VOA})) ---------- (Fathifazel,2008)

SG_b^{RM} = (0.23/ (1/2.4)-(1- 0.23)/2.63)) = (0.23/(0.4167 - .0.296) = 1.905

$V_{RM} = W^{RM}_{OD} / SG_b^{RM}$ = 114.8 / (1.905x1000)) = 0.06 m3

Appendix C

Figure C1: abstractions RM from RCA

Figure C2: Mix ingredient preparation

Figure C3: Specimens, Testing (slump measurements)

Figure C4:Oiling mold, casting and vibrating samples

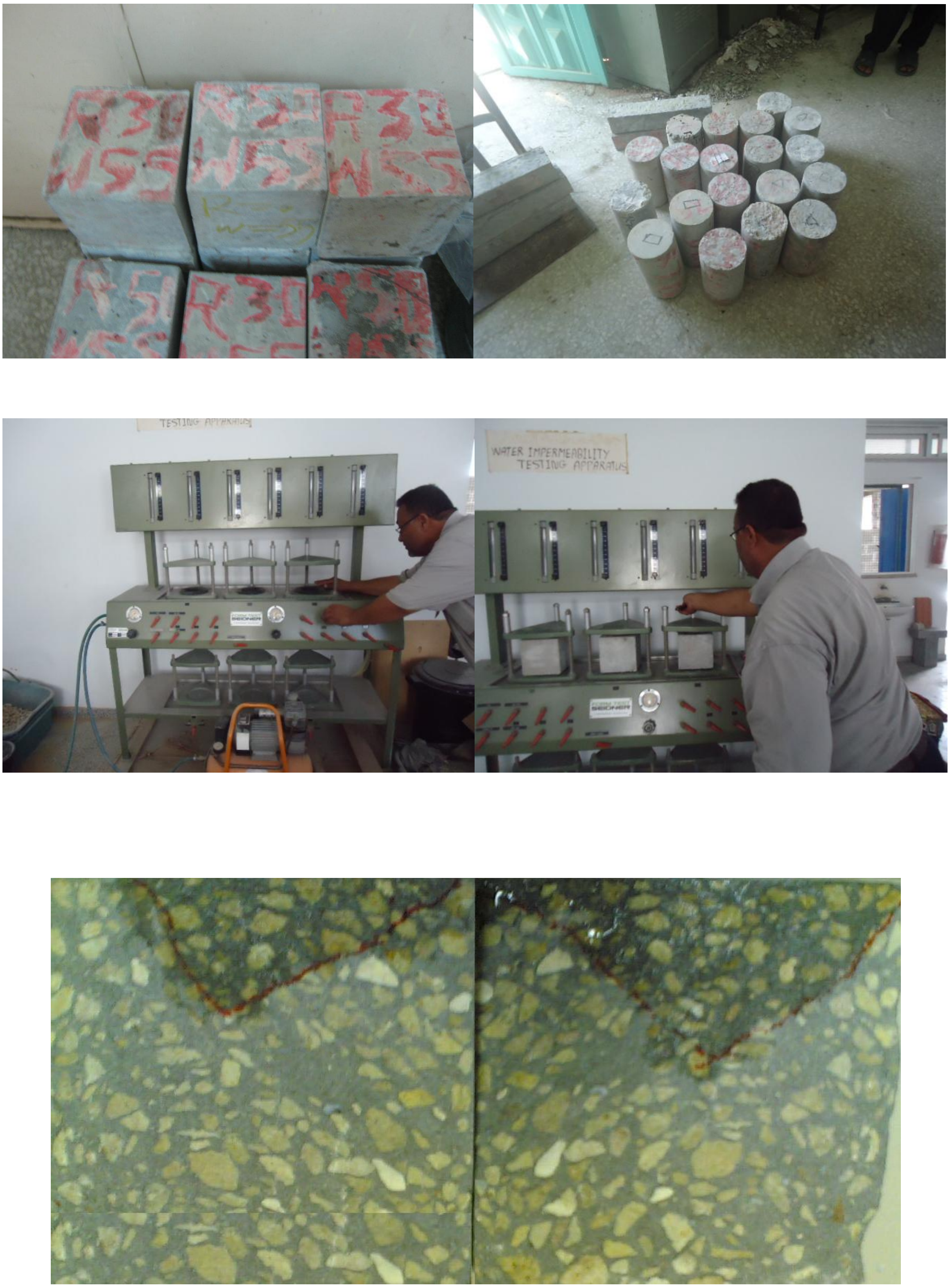

Figure C5: Preparing samples and tests

Figure C6: Space mines, Testing (compressive, tensile and flexure)strength