A PRELIMINARY LITERATURE SURVEY STUDY FOR LAUNCHING CONCRETE MANUFACTURE WITH RECYCLED MATERIALS IN NORTH CYPRUS;

STATE OF THE ART ON CONCRETE MADE WITH RECYCLED GLASS, BRICKS AND PVC

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ADEBISI, SIMEON ADEYEMI

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. İlkay SALİHOĞLU

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Civil Engineering

Examining Committee in Charge:

Prof. Dr. Ata Atun	Committee Chairman, Department of Civil Engineering, Near East University.
Assoc. Prof. Dr. Kabir Sadeghi	Commitee Member, Department of Civil Engineering, Girne American University.
Asst. Prof. Dr. Pınar Akpınar	Supervisor, Department of Civil Engineering, Near East University.

I hereby declare that all the information in these documents has been obtained and presented to the Department of Civil Engineering, Near East University, Cyprus, under the supervision of Asst. Prof. Dr. Pinar Akpinar and all sources of knowledge used have been duly acknowledged in accordance with the academic rules and ethical conducts. I fully referenced and cited all materials and results used regarding this study.

Name, Surname: ADEBISI, SIMEON ADEYEMI

Signature: …………………………………………

Date: ……………………………………………

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ABSTRACT

Solid waste management is one of the major environmental issues in our modern life. The use of recycled materials as aggregate replacement in concrete for construction purposes has been proved to be sustainable alternative to the problem of disposal of wastes and depletion of natural aggregates in all developed countries of the world.

In this study, the possibilities of launching concrete manufacture with the inclusion of recycled materials in North Cyprus have been investigated. Three potential materials; **glass**, **bricks** and **PVC** that can all be obtained from demolished structures were selected as the main focus of this study. The recycling operations, criteria of material selection and mix design, performance testing for fresh and hardened concretes made with these specified recycled materials has been studied thoroughly by carrying out an extensive literature survey on the related standards and on the research work delivered in developed countries of the world in the last forty years. In parallel to this thorough literature survey, the current status of the following issues in North Cyprus has been investigated: 1- recycling concept in general and the current attitude of North Cyprus authorities, 2- the level of technical knowledge on concrete manufacture with recycled materials included in academic studies carried out in some major parts of North Cyprus universities. During these studies, "no experiment" was carried out on the use of recycled glass, bricks and PVC as aggregates materials for concrete manufacture. All the findings of this extensive literature survey contributed to form a "State-of-The-Art on the Manufacture of Concrete with Recycled Glass, Bricks and PVC". So that future researchers will be able to use these studies as guidelines on how to use recycled materials for concrete manufacture in North Cyprus.

Some of the most critical findings that will provide insight on the manufacture as well as on the performance of concrete with recycled materials are as the following: Results of tests carried out in developed countries show that it is possible to use these three recycled materials as a replacement for conventional aggregates provided that specified standards are followed. For the application of waste glass as materials in concrete, it is concluded that glass aggregate is a granular material that will deform elastically under load. The workability of concrete made with glass is generally good and the strength of recycled glass depends on gradation and the materials properties. The use of recycled bricks as aggregates materials in concrete reduces the overall unit weight of concrete materials; it has higher thermal resistance, absorption rate and high compressive strength. Previous studies shows that the compressive strength of recycled bricks at different replacement levels yields promising results as crushed bricks aggregate materials shows better performance as the age of concrete increases, and the workability of the concrete mixes show variation according to the percentage of brick replacement. The use of recycled PVC as aggregate replacement in concrete included in previous studies shows that the compressive strength, flexural strength, tensile strength of concrete reduced when recycled PVC is incorporated in the mix.PVC inclusion in concrete yields in a little reduction in workability of the mix and it also improves the toughness of behaviour of the concrete.

Keywords: *Recycled Concrete Materials in North Cyprus, Recycled glass, Recycled bricks, Recycled PVC, Manufacture, Mix proportions, Workability and Compressive Strength of Concrete with Recycled materials*

ÖZET

Katı atık yönetimi modern hayatın getirileriyle söz konusu olan başlıca çevreselkonulardan biridir. Geri dönüştürülmüş malzemelerin beton karışımlar içerisinde kullanımı, hem atıkların ortadan kaldırılması hem de doğal agrega kaynaklarının tüketimine karşın,gelişmiş ülkelerde kullanılan sürdürebilirliği destekleyici alternatif bir yöntemdir.

Bu tez çalışması, geri dönüşümü sağlanmış malzemelerin dahil edilmesiyle üretilecek beton karışımların Kuzey Kıbrıs'ta üretilebilmesi için gerekli konuları araştırmaktadır. Yıkılmış yapılardan elde edilebilecek mazlemeler olarak geri dönüştürülmüş cam, tuğla ve PVC malzemeleri tez çalışmasının odağı olarak belirlenmiştir. Gelişmiş dünya ülkelerinde son 40 yılda yürütülmüş araştırma çalışmaları ile birlikte kullanılanstandartlar hakkında yürütülen detaylı literatür taraması esnasında, bu malzemeler ile üretilecek betonlar için malzemelerin geri dönüşüm işlemleri, malzeme seçimi ve karışım hesabı kriterleri, taze ve sertleşmiş betonların performans deneyleri konuları derinlemesine çalışılmıştır. Dünyada yürütülen çalışmalara paralel olarak; 1-) Kuzey Kıbrıs'taki yetkili mercilerin geri dönüşüm kavramı ile ilgili güncel tutumlarının, ve 2-) Kuzey Kıbrıs'taki üniversitelerde yürütülen akademik çalışmalarda yeralan geri dönüştürülmüş malzemeler ile beton üretimi hakkındaki teknik bilgi düzeyinin tespit edilmesi için de çalışmalar yürütülmüştür. Tüm bu araştırmalardan elde edilen sonuçlar ile konu üzerinde gelinen güncel teknolojik gelişim düzeyine ait, Kuzey Kıbrıs'ta kullanılması hedeflenen bir kaynakça oluşturulmuştur. Detaylı bir literatür taraması sonuçlarını içeren bu yüksek lisans tezinin ileride deneysel çalışmalara başlayacak olan araştırmacılar için temel bir kaynakça olmasıi beklenmektedir.

Yürütülen detaylı araştırma ve literatür taraması çalışmaları sonucunda varılan bazı ana sonuçlar şöyledir: Gelişmiş ülkelerde yürütülmüş olan çalışma sonuçları, geri dönüştürülmüş cam, tuğla ve PVC malzemelerinin, ilgili standartlara uygun olarak beton karışımlarına dahil edilmelerinin mümkün olduğu tespit edilmiştir. Geri dönüştürülmüş camların beton karışımlara dahil edilmesi sonucunda; camın etkiyen yükler altında elastik olarak deformasyona uğrayabilecek granüler bir malzeme olduğuna dikat çekilmiş, bu malzeme ile hazırlanacak betonların işlenebilirliğinin genel anlamda yüksek olduğu, mukavemetin ise malzeme gradasyonu ve özelliklerine göre değişeceği rapor edilmiştir. Geri dönüştürülmüş tuğlanın betona dahil edimesi sonucunda; betonun genel anlamda birim ağırlığının daha düşük olacağı, daha düşük ısıl dirence ve emme oranına sahip olacağı ve mukavemetinde de düşüşler gözlemleneceği rapor edilmiştir.Bu çalışmalarda ayrıca, geri dönüştürülmüş tuğla ile üretilmiş beton karışımlarda, betonun yaşı ilerlerdikçe mukaetinde artışların gözlemlendiği ve işlenebirliğinin de dahil edilen tuğla miktarı ile değişkenlik gösterdiği rapor edilmiştir. Geri dönüştürülmüş PVC'nin dahil edilerek üretilen beton hakkında gelişmiş ülekelerde yürütülen çalışmalar ise, genel olark basınç, çekme ve eğilme dayanımlarında ve işlenebilirlikte düşüşlerin gözlemlendiği, ancak bu betonlarda tokluk davranışının daha iyi olduğu rapor edilmiştir.

Anahtar Kelimeler: *Geri dönüştürülmüş malzemelerle Kuzey Kıbrıs'ta üretilen beton karışımlar, geri dönüştürülmüş cam, geri dönüştürülmüş tuğla, geri dönüştürülmüş PVC, geri dönüştürülmüş malzemeler ile üretilen betonların üretimi, karışım oranları, işlenebilirlik ve basıç dayanımları*

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LIST OF ABBREVIATIONS

PVC	Polyvinylchloride
TRNC	Turkish Republic of Northern Cyprus
EU	European Union
US	United States
C & D	Construction and Demolition
RIC	Resin Identification Code
NIR	Near Infrared Technology
BS	British Standard
RCA	Recycled Crushed Aggregate
ASR	Alkali Silica Reaction
ASTM	American Society for Testing and Materials
UTM	Universal Testing Machine
RG	Recycled glass
SF	Silica Fume
PFA	Pulverized fuel Ash
PE	Polyethylene
PP	Polypropylene
UTS	Ultimate Tensile Strength
PET	Polyethylene terephthalate

CHAPTER ONE
INTRODUCTION

1.1. Background

Waste management is the accumulation, conveying, and disposal of garbage, sewage and other waste products. Waste management encompasses management of all processes and resources for proper handling of unwanted materials, from conservation of garbage trucks and dumping facilities to compliance with health code and environmental regulations (Waste Management, 2013).

"Recycling" is the method of collecting and reprocessing materials that would be typically considered as waste or the methods of modifying waste materials into new brands. Recycling in a significant way helps us to save the environment and also to stimulate our economy (Letsrecycle.com, 2006).

"Recycling" has become increasingly important in the construction industry and also in the major part of the world. Waste materials are usually recycled in order to meet the goals of price reduction, reduced landfill performances, definite resources and also to manage the recycled materials easily. "Recycling" is one of the most appropriate strategies for moving towards "sustainable development" and this development will help us to meet the needs of the present, without harming or weaken the future generation to meet their own needs i.e. recycling will help to conserve natural resources for the next generation (US Environmental Protection Agency, March 2000).

Recycled materials include several types of glass, paper, metals, plastics, textiles, electronics etc. For centuries now the construction industries have been the largest consumers of raw materials for concrete manufacture and they are also responsible for the greatest waste stream (Milani, 2005). Today the world is advancing too fast and it can be seen that the environment is changing progressively. These changes in the environment have created a lot of problems in the construction world, due to the increase in industrial waste and the stockpiling of debris. In order to deal with this great significance, it is necessary to recycle this waste into something meaningful and useful for the environment. The utilization of waste materials as a secondary raw material in concrete gives solution to the problem of excessive waste in our environment. The use of waste materials in concrete involves the classification of the waste materials according to their durability, utility, strength potential etc. (Moriconi, 2007).

Concrete made with recycled materials are from demolished or renovated structures, which are reused for construction purpose. The use of recycling materials in concrete has large substantial benefits in terms of construction cost, lower environmental impacts, reduce the use of conventional aggregates and it looks more attractive. Waste materials are collected from demolished structures, which are recycled using crushing machine so as to separate them from contaminants which can affect the strength of the concrete. After separation using manual or mechanical means, these recycled materials can be reused for different construction purpose e.g. base materials for roadways, building materials for construction purpose i.e. replacing these materials with natural aggregates materials. The amount of demolition waste is increasing everyday and the use of recycling materials will be dominant construction materials in the nearest future (Poon et al., 2002).

1.2. Problem Definition

Lack of Information and Practical background on the use of Recycling Materials and Concrete Manufacture with Recycled Materials in North Cyprus.

- The authorities in North Cyprus do not control or guide any recycling activity, therefore the waste materials end up in landfills,
- The authorities in North Cyprus do not control the disposal of the waste materials, therefore the waste materials is not processed and dumped to nature in an uncontrolled manner,
- The possibilities of using Recycling Materials in Concrete has not been considered by concrete manufacturing companies in TRNC; therefore there is lack of information on the use of recycled materials for concrete manufacture in TRNC,
- There are no previous studies carried out in Universities in TRNC on the use of recycled materials for concrete manufacture, therefore there is no systematic

information or guidelines for authorities, researchers and concrete manufacturer that are willing to carry out this studies in the nearest future.

1.3. Objectives of the Study and Significance of the Work

This study aims to provide a detailed state of the art study by carrying out a systematic literature survey including the fundamentals of using recycled materials as a replacement of natural aggregates in concrete manufacture and the guidelines to manufacture concrete with certain recycled materials such as recycled glass, recycled bricks and recycled PVC in North Cyprus.

Consequently, by carrying out this study, introductory guidelines on concrete manufacture with recycled materials inclusion will be provided for the use of ready mix concrete companies as well as the academic researchers willing to carry out further scientific studies on this topic in North Cyprus in nearest future.

The **significance** of this research is to provide information to reuse, reduce and recycled waste and also to help the future researchers both in academics and in the world, the Structural designer/Civil engineer and builder with dependable information on the use recycled materials for concrete production and to determine the most efficient concrete mix using recycled materials as aggregate in concrete in North Cyprus. Therefore, these data will give a significant contribution to the knowledge of recycling in North Cyprus and to the related literature existing in other parts of the world.

1.4. Structure of Thesis

This thesis consists of six chapters. Chapter one shows the topic background, problem definition, and the objectives of the research. Chapter two give the general concepts of concrete and recycling as well as potential materials to be used in concrete. Chapter three, four and five is dedicated to glass and its properties, brick and its properties and PVC and its properties. Finally, Chapter six conclusions are drawn; general comments and recommendation are suggested.

CHAPTER TWO

2.1. General Concepts on Concrete Produced with Recycled Materials

Recycled materials in concrete are mostly obtained from demolition, and repair work. Literature survey carried out indicates that most of the construction work currently done in USA is repair work (Prairie Village, 1998). Nowadays, the world is advancing too fast and the environment is changing progressively. This has created a biggest problem of the world, accumulation of debris and industrial waste. Nevertheless, there is a need to recycle this waste into other materials which is going be beneficial and friendly to the environment. To achieve this, much emphasis must be carried out on the use of unwanted materials. Numerous researches have been carried out and it is seen that waste materials are important in the construction industries. Investigation concerning the use of this secondary product to help the properties of concrete has been going on for several years. In recent years, efforts are made in order to use some industrial by product such as silica fume, fly ash, ground granulated blast furnace slag, glass cullet, metakaolin, etc. in the construction of civil engineering projects (Glavind, 2009). The Figure 2.1 below shows the Recycling System.

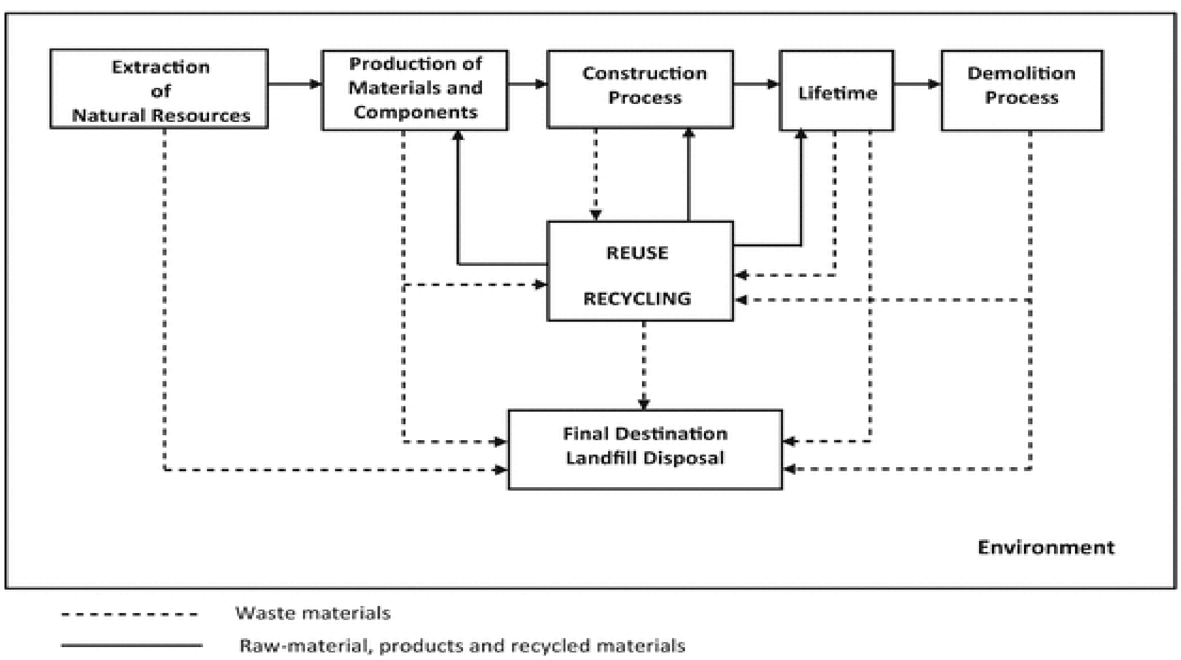


Figure 2.1: Recycling System (Rosario et al, 2012)

2.1.1 Methodology used for this study

A detailed literature survey is being carried out within the scope of forming a state of the art study on the use of recycled materials in concrete manufacture. A special focus on materials from demolished structures using Glass, Bricks and PVC for concrete manufacture.

A State of the art will include:

(a). Current status of waste management in North Cyprus,

i. Contacting related Government/Local Authority,
ii. Contacting Universities.

(b). Current Status of waste management and recycling concrete manufacture in the World.

2.2. Possibilities for Recycled Materials to be used in Concrete manufacture

Recycling materials is a major key solution in achieving sustainability that will enable the earth to support human life. The benefit of using recycled materials in construction has been carried out from previous researches e.g. in highway construction project, using recycled materials as a base and sub-base layers of a pavement helps to reduce global warming potential, hazardous waste generation, cost reduction etc. (Lee et al, 2010). There are several recycled materials used for concrete production, for the benefit of improving the quality of concrete in terms of its performance under load, some other recycled materials are also used in concrete mainly for saving energy as well as providing solutions to environmental problems. For example, about 850 millions tonnes of construction and demolition waste are generated in the EU per year, which represent like 31% of the total waste generation (Fisher and Werge, 2009).

According to the reports on demolition waste done in the US, it was shown that the construction waste produced from the demolition building alone is estimated to be 123 million tons per year (Transportation application of recycled concrete aggregate, 2004). Therefore, the possibilities to get these materials are numerous because almost on daily bases, demolitions of buildings are carried out to replace them with new ones and also materials waste such as plastic, glass etc. are also dispose daily in our environment, therefore this waste can be recycled and reuse for construction purposes (i.e. concrete production). The most common method of managing these materials is through its disposal in landfills. By doing this, huge amount of construction waste are produced.

Developmental foundation helps to increase the growth of a country, but one of the major problems faced in the construction industries is the deficiency in the supply of construction materials e.g. problem faced in the management of the construction wastes, remodeling, demolition, repair, etc. in various process thereby leading to a key factors one need to consider in order to dealt with the issue of recycling of construction materials i.e. the disposal of huge amounts of the construction waste, the location and the expenses in disposing the materials away (Fisher, 2011). Problems of handling construction waste had it first impact in the 1950s after the world war when several European nations were left with a large amount of debris. Another problem arises, thereby looking for a way to dispose the huge amount of debris after exhausting all their resources on war, and the only solution they had after some researches is to recycled this materials and use it for another purpose (Hansen, 1992).

In this study, three different recycled materials are discussed for their potential use in concrete production: Recycled glass, Recycled bricks and Recycled PVC. Among the three materials, waste glass is the least expensive of all the concrete constituents, the shape, size and gradation of these recycled materials are put into consideration which helps to show the real possibility of using these recycled materials in concrete. These recycled materials can be used for structural and non-structural components in concrete structures (Koren and Bisesi, 2002). Table 2.2 below shows the recycling of construction and demolition waste in % and tonnes per capita in the European Countries.

Table 2.2: Recycling of Construction and Demolition Waste in % and tonnes per capita

Reference: ETC/SCP, (2009c), Europe as a recycling Society.

Recycling of Construction and Demolition waste in 2005-2008	Total Recycling	Concrete, bricks and Tiles		Asphalt		Wood, glass, metals, plastics, gypsum		Dredging soil, soil and track ballast		Other mineral and C&D waste		Total recycling of C&D waste
Unit	Tonnes per cap.	Tonnes per cap	% of total	Tonnes per cap	% of total	Tonnes per cap	% of total	Tonnes per cap.	% of total	Tonnes per cap.	% of total	%
Netherlands	1.55	0.34	22.1	0.00	0	0.00	0	0.00	0	1.14	74	98.1
Denmark	1.07	0.31	29.0	0.18	17	0.02	1.6	0.41	39	0.00	0	94.9
Estonia	1.64	0.16	10.1	0.06	3.7	0.34	21.0	0.88	54	0.00	0	91.9
Germany	1.93	0.38	19.6	0.22	12	0.00	0.1	1.37	71	0.38	20	86.3
Ireland	3.14	0.00	0.0	0.00	0	0.00	0.0	1.88	60	0.45	14	79.5
Belgium	0.75											67.5
United Kingdom	1.22											64.8
France	3.41	0.00	0.0	0.00	0	0.03	0.9	0.00	0	3.39	99	62.3
Norway	0.16	0.13	79.3	0.00	0	0.02	14	0.00	0	0.01	4.3	61.0
Lithuania	0.11											59.7
Austria	0.48	0.12	26.0	0.12	25	0.00		0.03	6.2	0.21	44	59.5
Latvia	0.02											45.8
Poland	0.13	0.00	0.6	0.00	0	0.12	93	0.01	5.2	0.00	0.1	28.3
Finland	0.41											26.3
Czech Republic	0.27	0.04	14.3	0.00	0	0.00	0.1	0.00	0	0.00	0	23.0
Hungary	0.08	0.01	15.3	0.01	7.1	0.04	51	0.02	19	0.01	7.1	15.5
Spain	0.12											13.6
Cyprus	0.01											0.7

From Table 2.2 above, it is seen that among the European Union Country, Netherlands have the highest total rate of recycling while Cyprus have the least rate of recycling due to lack of information on waste management in Cyprus. Other EU country also have a high amount of recycling in construction industry, which shows that method of recycling is progressing and promising on daily basis since these recycling materials are used as aggregates in concrete which will be known worldwide in the nearest future.

2.3. Methods for Obtaining Recycled Materials

Recycled materials can be separated and processed by a combination of manual separation and mechanical means. This process involves crushing the materials in early stages of the process in order to aid mechanical separation of the materials. A major factor that needs to be considered in the recycling operation is the degree of contamination of the material (Shayan and Xu, 2003). Pureness of the retrieved products boosts higher resale prices and may also reduce some processing facilities because of the aggressive handling of the mixed waste stream. The use of durable, enticing and environmental responsible building materials is a key element of any high performance building efforts. Some construction materials have meaningful environmental impact from habitats destruction, depletion of natural resources and pollutants releases. This usually occurs during the extraction and acquisition of raw materials, production, manufacturing and transporting process (Shayan and Xu, 2003).

Table 2.3 below shows the evaluation of construction and demolition of recycled waste generated in countries using recycled materials as aggregate in concrete (Lauritzen, 2004; Kasai, 2004; Gomez, 2002; Poon et al., 2004; Shayan and Xu, 2003; Salem et al., 2003).

Table 2.3: Global Consumption of construction (C) and demolition (D) wastes

References: Illinois Environmental Protection Agency, 2012.

Country	C & D Waste (Million tonnes per year)	Percentage of C & D Waste Recycling (%)	Recycled Concrete (Million tonnes per year)
United States	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

According to Table 2.3 above, it was shown that the lack of natural resources and landfill capacities lead to an increase in the amount of construction and demolition waste. Recycling waste from the construction and demolition waste in Japan are around 85% and 50%; of which recycled waste of construction materials are largely used for backfilling.

Table 2.3.1 and 2.3.2 below shows the waste delivered to Dikmen Disposal site by private companies and military in North Cyprus in the year 2006 and 2007 respectively.

Table 2.3.1: Construction (C) and Demolition (D) waste delivered to Dikmen disposal site by private companies and military (ton) in 2006 (Adopted by Afshar, 2009).

Month in year 2006	Private Companies	Military
January	2,483.90	294.30
February	4,492.50	227.40
March	5,392.00	410.40
April	5,193.80	439.60
May	4,832.90	483.90
June	5,503.20	228.40
July	4,193.70	230.00
August	4,394.70	359.40

Table 2.3.2: Green and Commercial waste delivered to Dikmen disposal site by private companies and military (ton) in 2007 (Adopted by Afshar, 2009).

Month in year 2007	Private Companies	Military
January	2,730.90	312.70
February	4,804.90	213.30
March	6,011.80	496.20
April	5,282.60	501.60
May	276.80	791.30
June	6,862.00	298.90
July	4,425.00	381.00
August	5,096.60	415.10

Table 2.3.3: Evaluated annual waste generated in Northern Cyprus (Afshar, 2009).

Waste type	Waste Generated, thousand tons per year
Household waste	73.30
Commercial waste	33.90
Municipal waste	107.20
Construction/demolition waste	129.10
Green waste	14.90
Industrial waste	39.50
Total waste generated	290.80

From the above table, it was shown that there is lack of study in using recycled concrete materials for structural purpose in concrete industry in North Cyprus.

2.3.1 How to Obtain Recycled Glass Materials

According to the information by Glass Packaging Institute, on the article profiles in Garbage, some of the studies show that glass bottle is one of the forms of packaging and Glass containers can be reuse many times before recycling. The three main ingredient of glass are sand, soda ash and limestone. In Australia, it was shown that most of the glass that are produced contain a large amount of recycled glass and to achieve this, there are important economics and environmental advantages from the recycled glass materials, therefore glass need to be recycled correctly to avoid contamination (Lambert and Gupta, 2004).

All glass jars and glass bottle are recyclable, this include wine, beer, soft drinks, as well as coloured glass. Heat treated glass including drinkware, ceramics, plate glass (window panes) cannot be recycled using the recycled service because the melting temperature of the heat treated glass is higher than that of the of the glass and bottle jar. When there is mix up between the bottle and jar recycling, it can prevent the molten glass to extrude properly or it can make the new bottles too brittle to use. Therefore, during recycling, opaque glass, light globes should be separated from the recyclable materials in order for them not to contaminate the recycled ones; the contaminated ones are then taken to the landfills

(Colombo et al., 2003). Before glass should be recycled, the plastic lids and caps should be removed from the glass, thereby placing them in the waste bin. It is not a must to rinse glass before crushing; the remaining particles should be scraped, or preferably it should be rinse, the dish water should be use rather than fresh water, and the paper label on the glass may be removed if desired or it can also be recycled with the glass. After doing all this (collection), glass bottles and jars can be crushed using the manual means or mechanical separation. The majority of this glass is melted in the furnace and usually by the addition of other raw materials. This glass can be used for building aggregate in water filtration and for construction materials (Carless, 1992).

2.3.2 How to Obtain Recycled Bricks Materials

The earliest known bricks were found in the Middle East around 7000years ago. Traditionally, bricks were made of clay and they are formed by hand and left to dry in the sun or fired in the kiln. Once the block or clay was ready, they could be put together and secured in a place with mortar. Nowadays, bricks are likely to be made of shale, a lightweight rock that can be break apart to form other materials. Machines are used in the shaping and drying of the bricks, thereby making them to look nice and durable (fireproof, pest resistant and good insulators). Bricks are also constructed out of concrete i.e. by a blend calcium and silicone materials which helps in producing a light coloured bricks (Sophia, 2014).

Bricks have a life span of more than 200years. Recycled bricks can be found from previously used construction projects such as building, walls, paving and infrastructures like sewers and bridges. Recycled bricks include stone blocks, aerated blocks, clay bricks and concrete precast. The most common sources of recycled bricks include damage items during storage, unloading and excess due to over ordering. According to the study conducted in California in year 2008, it was shown that bricks fall in the category of construction and demolition waste and 29% of the state total waste stream is from the construction waste. For years, the only place that would take the construction waste was the local landfill. So thereby, the solid waste management companies started to be smart on how to get much space bricks, concrete and other construction debris took up (Heijung and Suh, 2002).

Recycling of bricks is very innovative because bricks are good construction materials. Bricks can be recycled using different method; some companies usually purchase crushed bricks instead of aggregate for construction projects. Bricks chippings are used in landscape as the parent materials, the chips look nice and usually compact together even when the weather is very cold, rainy climate or windy. When bricks are broken down to a fine materials, they can be use to produce another bricks or used in replacement of sand to produce another concrete materials (Khatib, 2005).

Why should Bricks be Recycled: Construction and Demolition materials usually take up an enormous amount of space in landfills. Keeping them out helps to conserve space and also prevent more landfills from been built. Instead of throwing bricks away, it need to be recycled, thereby reducing cost because the money use in disposing the bricks materials is much, so the better option is to look for a place to the bricks for free before recycling. Another example why bricks materials need to be recycle is because mining shale and other virgin materials required to make bricks is costly and also not good in the environment, so by the reuse of this materials, it will cut down on mining which is beneficial to the environment (Crowther, 2001).

The Limitation of using recycled bricks is:

- Recycled bricks can be contaminated by other construction waste e.g. plastering, paint etc,
- The load bearing capacity of recycled bricks is hard to assess,
- Cleaning of bricks is not possible sometimes and it is also time consuming,
- It is difficult to get recycled bricks from demolition project,
- To remove mortar from bricks is also difficult

2.3.3 How to Obtain Recycled PVC Materials

PVC can be explained as a synthetic thermoplastic material made by polymerizing vinyl chloride which the properties depend on the added plasticizer. Plastic recycling is the method of recovering scrap or waste plastic and converting the materials into valuable products, sometimes entirely different in form from their original state. Plastic recycling also includes the melting down soft drinks bottles and casting them down as plastics chairs and tables (Hattikaul, 2012).

Recycling of plastics is more challenging compare to other recycled materials such as glass, metal etc. because plastics have a low density. Numerous technical challenges are faced before plastics can be recycled, in order to overcome these challenges, the total amount of energy involved in mixing a big amount of plastics interacts with the environment along its entire length, and so in order to mix efficiently, plastics materials must be nearly identical. When different types of plastics are mixed together, they look otherwise e.g. oil and water set in plastics cause structural weakness in the resulting materials. This means that the blend in polymers is useful in limited application (Hattikaul, 2012).

Before recycling, plastics are sorted out to their resin type. Years ago, plastic reclaimers used the resin identification code (RIC) a method to use in categorizing the types of polymers, which was developed by the society of plastics industry in 1988. Nowadays, most plastics reclaimers do not rely on resin identification code but use automatic sort systems to identify the resins, such as near infrared technology (NIR). Some plastics products are also separated by colour before recycling. The recycled plastics are then grinded. The grinded fragments then undergo processes to eliminate impurities such as paper labels. This material is then melted and often emitted into the form of pellets which are then used for the manufactured of other products (Christian et al., 2013).

According to Griffiths (2007), talking about the recycling tonnage of PVC waste, it was shown that the collection and recycling schemes for the PVC waste streams are managed through Recovinyl. Recovinyl is an organization that is set up in year 2005 with the aim of supporting and developing PVC waste collection and recycling schemes. Recovinyl states that recycling materials applications using PVC uses 75% of the materials for floor, 15% for foils, 5% for traffic cones, 3% for hoses and 2% for other applications (Griffiths, 2007).

Vinyloop Texyloop is another example of recycling process that is used for solvent based mechanical recycling. It involves the recovering of PVC plastics from composite materials through dissolution and precipitation. This process offer a major ecological benefit, as Vinyloop based recycled PVC primary energy is around 46% in demand which is lower than that of conventional produced PVC. According to the global warming potential of recycled, PVC is 39% lower which shows a significant reduction in the ecological footprints (Vinyloop White Paper, Retrieved on 2014-01-11).

2.4. Advantages and Disadvantages of Recycled Materials Use in Concrete

2.4.1. Advantages of Recycled Materials Use in Concrete

1) Recycled Materials such as bricks, glass, are used as a base material for roadways which helps to reduce pollution of the trucking materials (Blodgett, 2004),
2) Recycled materials help to reduce mining (American Recycler, 2003),
3) It helps to save landfill space (U.S. EPA; Municipal Solid Waste Generation, 2010),
4) Recycled materials help to promote practices that conserve non renewable resources, reduce impact to landfills, reduce greenhouse gas emission, and save energy (Rajovic and Bulatovic, 2013),
5) Recycled materials have better performance properties, example slag cement has a higher reflectivity than other cementitious materials, other example is crushed glass which has higher frictional properties (Gumidi and Rikioui, 2014),
6) Recycled Materials helps to reduce repeated cost i.e. less transportation and refinement costs. The cost associated with the materials is eliminated and often cost less than convention/virgin materials (Modaresi and Muller, 2012),
7) The big advantage of recycled materials is that it does not end up in landfills (Stiwell et al., 1992).

2.4.2. Disadvantages of Recycled Materials Use in Concrete

1) Weather, performance, availability and location of the recycled materials may limit the amount of the recycled content that can feasibly be put in the project materials (Carpenter et al., 2007),
2) Workability, compaction and other performance qualities of concrete changes as amount and the type of recycled materials included in the materials change (Chui et al., 2008),

3) Transportation of recycled materials is sometimes costly, depending on the distance where the material is and availability of the materials (Horvath, 2003),
4) Additional testing and inspection is often required for higher composition of the recycled materials in some cases and may be present as an added cost (Mroueh et al., 2001),
5) Some recycled materials like fly ash with poor quality can have negative impact on concrete thereby leading to an increase in permeability (Saeed, 2008),
6) Some recycled materials like fly ash also cause a slow setting time of concrete (Saeed, 2008),
7) Some recycled materials like glass need low alkali cement which is likely to be less effective (Egosi, 1992),
8) The heavy weight of recycled bricks materials is one of the main disadvantages because it increases the dead load of the structures (Boncukcuoğlu et al., 2002),
9) Some recycled materials like PVC have lower densities (light weight), lower temperature resistance and fire performance (Murphy, 2001).

2.5. Standards for Concrete Made with recycled Aggregate Materials.

Recycled Concrete Aggregate Materials according to BS 8500-1 (2006) as a general meaning for aggregate occurring from the recycle of inorganic materials that are use earlier. The composition of recycled aggregate is mainly crushed concrete, which is define in BS 8500-1 (2006) as RCA. According to BRE (1998), recycled aggregate are subdivided into three classes, which are shown below (BRE Digest 433).

RCA (I): This defines the lowest quality materials which usually have high level of impurities and a low strength. It could comprise mainly concrete of high level of impurities which might contain up to 100% brick or block masonry.

RCA (II): This defines high quality materials consisting mainly crushed concrete that have up to 10% brick by weight but low level of impurities, less than 1.5% by weight (glass, asphalt, wood, and metals) and mostly in some cases it contain a considerable amount of natural aggregate.

RCA (III): These have a high level of impurities and have mixed materials up to 50% bricks.

Most concrete specifications use BS 882 for guidance on the properties of aggregate materials use for the production of concrete. However, the uses of recycled materials in concrete use BS 1047 for specifications. According to the new European Standard for aggregates, the use of BS EN 12620 is use for recycled aggregate materials in concrete, but it doesn't give any product specification. Moreover, BS EN 12620 also includes aggregate made from air cooled blast furnace. BS EN 12620 distinct approach to British Standards in the sense that it explains the properties of aggregate in terms of classes for each property (British Standards Institution, 2002). The tables 2.5 below show the requirements for recycled aggregates.

Table 2.5: Acceptable RCA Quality (BRE, 1998)

Contaminant % by mass	BS 8500	BRE Digest 433 RCA (II)
Masonry	<5%	<10%
Lightweight material <1000Kg/m^3	<0.5%	Included in other foreign material
Asphalt	<5%	Included in other foreign material
Other impurities (e.g. glass, plastic and metals)	<1%	Included in other foreign material
Other Foreign material	Included in other impurities	<1%
Wood	Not quoted but should be less than 0.1% as per EN 12620	<0.5%
Total	<11.5%	<11.5%

Table 2.5.1: BS 8500-2 requirements for recycled aggregates (British Standards Institution, 2006)

Type of Aggregate	Requirement					
	Maximum Masonry Content Mass Fraction (%)	Maximum Fines Mass Fraction (%)	Maximum Light weight Materials Mass Fraction (%)	Maximum Asphalt Mass Fraction (%)	Maximum other Foreign Materials e.g. glass, metals, plastics Mass Fraction (%)	Maximum Acid Soluble Sulfate (SO_3) Mass Fraction (%)
RCA	5	5	0.5	5.0	1.0	1.0
RA	100	3	1.0	10.0	1.0	1.0

2.6. Current Status of Recycling and Concrete Manufacture with Recycled Materials in North Cyprus

Recycled concrete in TRNC is a new development which no information or facts have been supported with recycling of construction materials, so there are no available studies to show if the materials are readily available and adequate to the manufacturers. However, according to the information we gathered from "Levent Tuğla" Brick Manufacturing Company, (May 2015), they explain to us that the bricks that have defects or broken are recycled in the company, before selling it out, as a result of this, there is no waste generated from it. Moreover, according another information we also gathered from "SerMus Metal Ltd" (May 2015) which they are into Windows/Glazing/PVC Company, one of their representatives explains to us that PVC can be recycled/reused perfectly for other applications, such as production of polythene bag, plastics etc. but Glass wastes that are broken or damaged cannot be recycled by them, so therefore, they send them directly to Güngör Solid Waste Management Facilities.

Furthermore, the information we gathered from Environmental Protection Department (Çevre Koruma Dairesi in Turkish) (May 2015), the Environmental Protection Department is in charge of Waste Management but the issue of demolished structures is not well defined; because there are no codes in TRNC defining how to handle such construction wastes, and currently the destination of such waste is not controlled by any authorities. However, the civil servant that we have contacted in the Environmental Protection Department has informed us there are some studies that are currently carried out to form such a code that will define construction wastes.

Similarly, another personal communication with Ministry of Internal Affairs (İç işleri Bakanlığı) - Municipal Corporations Directorate (Yerel Yönetimler Müdürlüğü) (May 2015) we were given the information that demolished structural wastes are collected either by municipality facilities or by private companies. The destination of the wastes is not clearly known, and cannot be controlled by authorities, there are no codes defining how to handle such wastes, but it is known by them that this waste cannot be and are not accepted by Güngör Solid Waste Management Facilities currently, since Güngör does not have the necessary recycling/treating/processing facilities. Moreover, another conversation with Girne (Kyrenia) Municipality (May 2015), it was revealed that such demolished construction wastes can be collected by municipal facilities and they are taken to Güngör Facilities.

Furthermore, Personal Communication with LTB- Lefkoşa (Nicosia) (May 2015) Municipality, Operations Branch (işletmeler Şubesi) also confirm that such demolished construction wastes can be collected by municipal facilities and taken to Güngör Facilities. These wastes are also stocked or used as landfills at Güngör, but not somehow processed to be recycled.

Finally, findings from Cyprus International Universities and Eastern Mediterranean Universities in TRNC shows that there are no research or projects related topics carried out from the above mentioned universities concerning the suitability of using waste materials or recycled materials as aggregates for concrete production in construction industries in North Cyprus and there is no systematic information on how to handle or go about the use of such construction waste materials for concrete manufacture. Therefore, there is no clear sense of direction from universities to support the use of these materials for concrete production in North Cyprus and also no guidelines like codes or standards for authorities, researchers and concrete manufacturer that are willing and ready to carry out these studies in the nearest future.

CHAPTER THREE
USING GLASS AS A RECYCLED MATERIALS IN CONCRETE

3.1 Theoretical Background for recycled Glass as a material in concrete

Glass is one of the oldest man made materials in the world. Glass is an irregular (non-crystalline) solid material. Glasses are usually brittle and optically transparent. Glasses is produced in many forms and the most familiar types of glass used for centuries in window vessels is soda lime glass made of about 75% silica (SiO_2) plus Na_2O, CaO and several smaller additives. Glass can also be produced in many forms these include packaging or container glass, flat glass, bulb glass and cathode ray tube glass and all these glass have a limited life span in which they are produced, and they need to be reuse or recycled for other purpose, in order not to cause environmental problems. Generally, the term glass is used in a limited sense to refer to the specific use (Vijaya et al., 2001).

In science, however the term glass is usually defined in a much broad view, including every solid that obtain a non crystalline (i.e. amorphous) structure and that exhibits a glass transition when heated towards the liquid state. In this broad sense, glasses can be made of quite different classes of materials: metallic alloys, ionic melts, aqueous solutions, microscopic liquids, and polymers. For many uses (bottles, eyewear) polymer glasses (acrylic glass, polyethylene terephthalate) are a lighter alternative to traditional silica glasses (Xiao, 2014).

According to Sobolev et al. (2006), theoretically, glasses are 100% recyclable materials and they can be indefinitely recycled without any loss in quality (i.e. it does not wear out and can be recycled over and over again without any loss or reduction in quality).

Glass as a substance plays an essential role in science and industry. Its chemical, physical, and in particular optical properties make it suitable for applications such as flat glass, container glass, optics and optoelectronics material, laboratory equipment, thermal insulator (glass wool), reinforcement materials (glass reinforced plastic, glass fiber reinforced concrete), and glass art (art glass, studio glass) (Ojovan, 2004).

When waste glass is crushed to sand like particle sizes, similar to those of the normal sand, it shows the qualities of an aggregate material (James et al., 2008). The application of many industrial by products in the construction industry is now well developed, and this helps in improving the sustainability in two ways; the reuse of the materials which otherwise will burden the environment and will occupy scarce land resources. Secondly, it minimizes the degradation of land and the surroundings, as a result of relatively less excavation. The sample of glass recycled waste is shown in Figure 3.1 and the reaction between glass material and cement paste, showing alkali silica gel extruded into cracks within the concrete is shown in Figure 3.1.1 below.

Figure 3.1: Sample of recycled glass waste cullet stockpile in West Virginia (1993).

(United States Environmental Protection Agency, 2010)

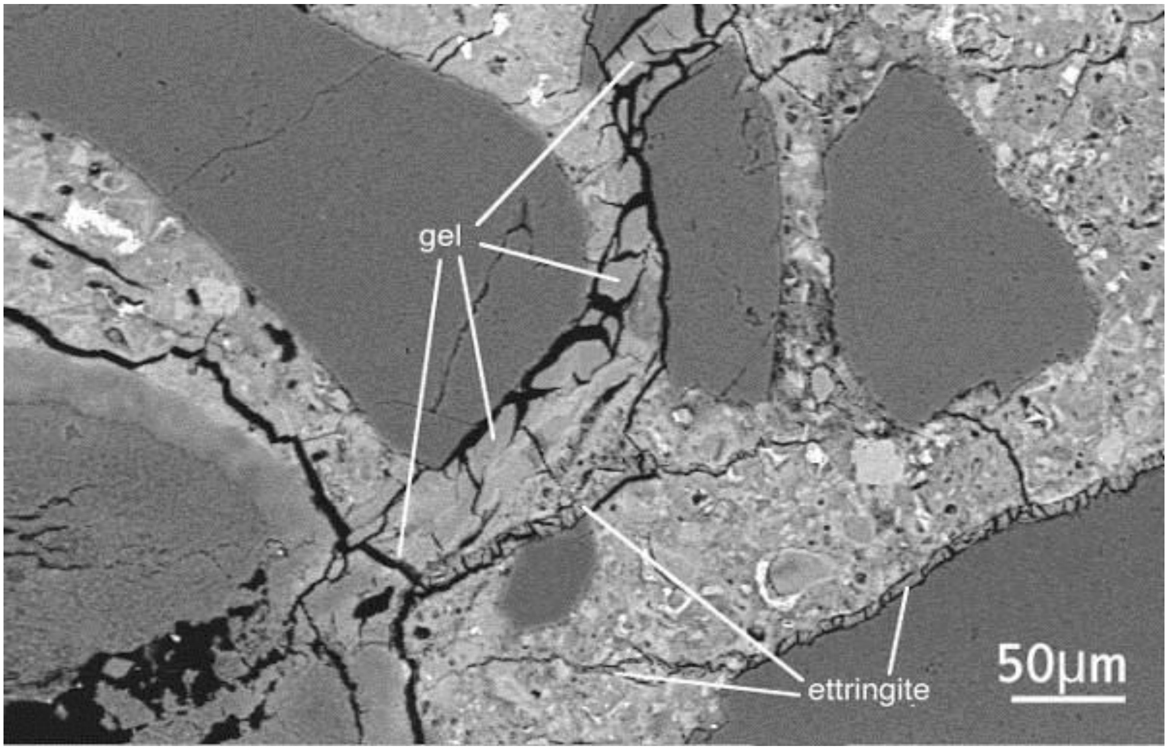


Figure 3.1.1: Reaction between glass material and cement paste, showing alkali silica gel extruded into cracks within the concrete (Meyer and Baxter, 1998).

The use of glass has qualities in which it can be re-melted severally without any degradation in its physical properties. Theoretically, recycled glass can be used 100% as a primary feedstock, but due to tolerances on contamination, there is a practical limit. The use of recycled glass is for road base, fill drainage, pipe bedding, glasphalt, sandblasting, filtration, reflective beads, hydraulic cement, and fish tanks (Ling and Poon, 2011).

The use of waste glass in concrete has been tried in the past Schwarz et al. (2008), but because of the deleterious alkali silica reaction, it was not highly preferred. Traditionally, glass has been considered not suitable for use in concrete because of the highly reactive silica content and amorphous structure. Various laboratory researches have been carried out, investigating the Alkali Silica Reaction (ASR) of glass in concrete which shows the detrimental effects and there are various ways to reduce it (Jin, 1998 and Jin et al, 2000). The possible ways to reduce ASR are as follows:

i. Sealing the concrete to keep it dry (Ceary, 2007),
ii. Using alkali-resistant glass (Day, 2003),
iii. Adding mineral admixtures such as Metakaolin or fly ash to reduce the ASR expansion (Sarfo et al., 2014),
iv. Modifying the glass chemistry (Malik et al., 2013),
v. Low alkali cements (Pontikes and Angelopoulos, 2013),
vi. Grinding glass to a particle size less than 75µm (Carsana et al., 2014).

3.1.1. Alkali-Silica Reaction (ASR) in Concrete, Mechanism and Consequences

Concrete is a composite materials that consists of aggregates (gravel and sand), with the aid of cement paste (cement and water). The cement paste contains interconnected microscopic pores in which water can penetrate. The pore water in the concrete is an alkaline solution which is the measure of the alkalinity i.e. pH. Alkali-Silica reactivity in concrete is peculiar variety of chemical reaction inside the material of concrete involving alkali hydroxides, generally derived from the alkalis present in the cement used, and the reactive pattern of silica present within the aggregate particles. This chemical reaction also involves water for it to produce the alkali-silica gel reaction products which expands with the absorption of moisture (Meissner, 1941). The swelling pressure exerted and the amount of gels varies depending on reaction temperature, gel composition, type and proportion of reacting materials etc., before this reaction could be developed, it usually takes between 5 and 12 years, though there are some exceptions and it is most severe when the concentrations of the alkali in the concrete pore fluids are high. Typical detrimental effects of alkali-silica in concrete structures include expansion, cracking, presence of gel in fractures, and indirect mis-arrangement of structural elements (Blanks, 1941). Also some research studies by Vivian shows that the reactions of alkali-carbonate and alkali-silicate differs as a result of the reaction between the alkali pore fluids in the concrete and the silicious components of the aggregate particles which produce an alkali gel that is hydrophilic in nature. As it absorbs liquid, there is an increase in volume, thereby generating enough pressure to disturb the material sample of the concrete (Vivian, 1951). An important mechanism is that of osmotic pressure of penetrating rock and gels. Despite the fact that hardens cement pastes can function like semi-permeable membranes because of the difference in the rate of water and ions in its pore structure. Below show the idealized equation for the reaction.

$$4SiO_2+2NaOH = Na_2Si_4O_9+H_2O \tag{1.1}$$

$$SiO_2+2NaOH = Na_2Si_3+H_2O \tag{1.2}$$

However, the OH- concentration that is important to the reaction is incorporated into the gel with the alkali metal. A more acceptable way of representing the chemical mechanism of the reaction is shown in two stages process below.

1) Acid-base reaction

$$H_{0.38}SiO_{2.19}+0.38NaOH = Na_{0.38}SiO_{2.19}+0.38H_2Os \tag{1.3}$$

2) Attack of the Siloxane bridges and disintegration of the silica

$Na_{0.38}SiO_{2.19}+1.62NaOH = 2Na^{2+}+ H_2SiO_4^{2-}$, the figure 3.1.2 and 3.1.3 below shows the parapet wall and waterline in piers that has been affected by ASR.

Figure 3.1.2: Parapet Wall affected by ASR (Stark, 1991a).

Figure 3.1.3: Cracking associated with stress directions. Predominant cracks are oriented longitudinally in this column (Liu, 1981).

From Figure 3.1.2 above, it is shown that the presence of the ASR are at the longitudinal cracks, closed joint, spalled concrete surfaces or relative displacements of different portions of a structure. Because the deterioration of the ASR is slow, thereby the risk of the catastrophic failure is low. ASR can cause serviceability problems and can aggravate other deterioration mechanisms such as those that occur in sulfate exposure and freeze thaw etc.

Research and Findings: Numerous study have been carried out in order to know more about the use of Recycled glass as materials in construction projects particularly in United States of America, including the Washington State Department of Transportation and it was presented that the use of this materials according to American Society for Testing and Materials (ASTM) requirements help to contribute to the industry by saving the surrounding, to inspire the government to find results to the landfills disposal of waste materials and to provide extra facts and information to the contractors on how to use recycled glass materials thereby improving the construction industry services and methods (Ganiron, 2013).

According to the investigation carried out by Barbieri et al. (2001), using ASTM requirement, the crushed bottles are crushed and used as a substitute for aggregates for concrete mixture. The research workers clean the bottles to avoid foreign materials or chemicals from impurity and crushed it manually, selecting the same bottles all through for suitable uniformity. Thereafter, he crushed all the bottles and sieves the samples in order to ensure conformity in particle size of the cullet which will be less than 2.0mm but greater than 0.0625mm with accordance to ASTM standards.

However, the researchers used only Portland Pozzolanic Cement (Type 1P), which is usually used in the field at present. The type of cement used has low hardening characteristics (Lines and Glass, 2001). The analyst used a mix ratio of 1:2:4 proportion of cement, sand and gravel respectively. He placed some percentage of the sand by crushing the recycled bottles (25%, 50%, 75%, and 100% respectively) and control mixture was also included.

Moreover, he collected three specimens from each mixture using 6'x12' cylindrical molds and the specimen was tested for compressive strength. His study comprises of the difference between the common concrete cement and concrete recycled glass bottles in terms of its properties as a fine aggregate. Later on, he tests the specimen for compressive strength using Universal Testing Machine (UTM) on 7^{th}, 14^{th}, 21^{st} and 28^{th} days of curing (Donza and Irassar, 2002).

Furthermore, the researcher's studies mainly focus on compressive strength and elastic modulus of glass bottles. In addition, his studies also determine the durability, creep, shrinkage, and water tightness (Tavakoli and Soroushian, 1996). From the researches project designs method, he believes that glass bottles can be processed in construction grade cullet using appropriate mechanical method. For cullet-aggregates blend, glass cullet can be blended with natural aggregate by any acceptable mechanical method and he took normal precaution in order for segregation not to occur. Typical aggregates for conventional concrete include sand, gravel, recycled concrete and crushed rock. Later on he compared the glass cullet and cullet aggregate blends according to standard specification for each distinct application.

Result and Discussion of the researchers

Water/Cement Ratio: From his result on water/cement ration, it was shown that the use of recycled bottles as concrete materials has no effect. The researchers use a water cement ratio which ranges from 0.55 to 0.65 in terms of mass and volume throughout the mixing and molding stage and it was observed that as the amount of crushed bottles aggregates increases, the amount of water decreases. However, when he want to measure for workability, all his mixture were tested for slump and he ensures that the value for the entire slump in the design mix is between ½ inch and 9 inches for proper workability. From his research, it was shown that the use of recycled bottles as materials for concrete has no significant effect on the quality and size of the coarse aggregates (Barbieri et al., 2001). The table below shows his results for water/cement ratio and Slump test.

Table 3.3: Water/Cement Ratio (Tavakoli and Soroushian, 1996).

Sample	Water (kg)	Cement (kg)	Water/Cement Ratio
Control	4.36	6.70	0.65
25%	4.22	6.70	0.63
50%	4.00	6.70	0.60
75%	3.82	6.70	0.57
100%	3.70	6.70	0.55

Sample	Slump (inch)
Control	4.00
25%	4.00
50%	5.00
75%	5.00
100%	3.00

Table 3.4: Slump Test Results (Tavakoli and Soroushian, 1996).

Comparison between Conventional Concrete and Concrete Recycled Bottles

Compressive Strength: Relying on the mix, water/cement ratio, and time quality of curing compressive strength of concrete is usually up to 97MPa or more. Normal concrete production with Standard aggregates is usually 21MPa to 83MPa and its ranges in cast concrete on in-situ from 21MPa to 41MPa (Pennarun, 2004). The significance of the measure of concrete is the compressive strength at 28th days of curing. The least strength of class A mix type of concrete is 20.7MPa. But according to the researchers, he use Portland Pozzolanic type of cement which has low hardening properties compared to Portland cement of Type 1. Type 1P is used because it obtains its maximum strength at a slower rate. According to his result, the average compressive strength of conventional concrete (Control) obtained from 28th day of curing is 25.54MPa while the compressive strength of the samples having crushed bottles to sand ratio at 25%, 50%, 75% and 100% are 10.96MPa, 11.60MPa, 12.08MPa and 10.12MPa. The result shows that the concrete recycled bottles of required strength have different proportions (Ganiron and Ucol-Ganiron, 2013).

Modulus of Elasticity: Concrete has no exact modulus of elasticity unlike steel and other materials. The value for the modulus of elasticity of concrete depends on the properties of cement and aggregates used, strength and the age of concrete. From the researchers experiment, the average modulus of elasticity of conventional concrete (Control) obtained from the 28th day of curing is up to 28261. 35MPa, while the modulus of elasticity of samples has crushed bottles to sand ratio at 25%, 50%, 75% and 100% respectively are 18407.76MPa, 19792.52MPa, 19733.29MPa and 17054.57MPa respectively. From his results, it is revealed that there is a great difference in modulus of elasticity of the control specimen among the other samples.

Finally, from the above findings, it is shown that the use of recycled bottles as a replacement for fine aggregate in concrete mix decreases the water cement ratio depending on the amount of aggregate present in the mixture. It also give information that using recycled bottle as a replacement of fine aggregates decreases the amount of material cost of concrete thereby lowering the construction price and giving more profit to the contractor and also, concrete made with recycled glass is lighter in weight than conventional concrete which is more beneficial in reducing the weight of the structure, thereby giving smaller base shear for earthquake design purposes.

3.1.2. Use of Waste Glass Cullet in Concrete

i. Glass aggregates may improve the flow properties of fresh concrete (Schwarz, 2008),

ii. Very finely ground glass has been shown to be excellent filler and may have a sufficient Pozzolanic behavior in order to serve as a partial cement substitute (Khatib et al., 2012),

iii. It has zero water absorption and is one of the most durable materials known to man (Schwarz, 2008),

iv. The aesthetics potential of coloured sorted post consumer glass has been explored and it shows numerous advantages for architectural purpose (Rashad, 2014),

v. The hardness of glass may give the concrete enhanced abrasion (Rashad, 2014),

vi. The effect of ASR is shown to reduced with ground glass cullet with the reduction increasing with replacement level (Tan and Du, 2013),

vii. Distinct strength increases above the control are noted after 28days; especially with a much fined ground cullet and replacement level up to 30% of the cement (Jin, 1998).

3.2 Materials Properties of Recycled Glass in Concrete

3.2.1. Physical Properties of Recycled Glass in Concrete

The physical properties of glass aggregates are those that refer to the physical structure of the particles that makes up the aggregate. Crushed glass particles are generally angular in shape and can contain some flat and prolonged particles. The degree of angularity and the amount of flat and elongated particles depend on the degree of processing. Smaller particles, resulting from extra crushing, will exhibit less angularity and reduced quantities of flat and elongated particles. Proper crushing can nearly remove sharp edges and the corresponding safety hazards associated with manual handling of the product (Disfani et al., 2012).

Crushed glass or cullet, which exhibits coefficients of permeability ranging from 10^{-1} to 10^{-2} cm/sec, is a highly permeable material, similar to coarse sand because the real coefficient of permeability rely upon the gradation of the glass, thereby depending on the degree of processing i.e. (screening and crushing) in which the glass is administered to (Chenser, 1992). The actual coefficient of permeability depends on the gradation of the glass, which in turn depends on the degree of processing (crushing and screening) to which the glass is subjected. If crushed glass is properly sized and processed, it can exhibit the same properties application to that of sand or gravel (Chenser, 1992).

3.2.2. Chemical Properties of Recycled Glass in Concrete

Glass as a recycling materials are crushed into cullet and melted into new bottles without any meaningful changes to the glass properties The effectiveness of this process rely on how the how the glass is collected and sorted according to their colours (green, clear, amber). A reports by Rindl (1998) shows that many non-container uses of glass cullet which contained asphalt paving, fiber glass insulation, road construction aggregate, glass fiber, concrete aggregate, art glass, building applications (wall panels, glass, tiles and bricks) are emphasized upon.

Another major responsibility he shows pertaining to the use of glass in concrete is the chemical reaction that take place between alkali in the pore solution (Alkali-Silica Reaction) and the silica rich glass particles, this reaction can be very harmful to the stability of concrete, unless suitable preventive measure are considered to minimize the effects. For the suitable preventive measure to be achieved, Pozzolanic materials such as silica fume, fly ash or ground blast furnace slag should be incorporated into the concrete mix at the right proportions.

Later on, Rindl summarized and presented the work conducted by other researchers for example, he cited the work done in North Carolina by Boral Company Lilesville that ground soda lime glass that contain a mesh <100 was effective against ASR. He also quoted a work done by Samtur (1974) which state and show that fine glass powder having a mesh <200 or 75μm particle size will act like a Pozzolanic materials thereby reducing the usage of aggregate undergoing ASR. However, according to Philip and Cahn (1973), it was shown that up to 35% glass cullet can be used in concrete by adding low alkali cement without any detrimental effects. Another report by Carpenter and Cramer (1999) shows that powdered glass was effective in reducing the expansion of ASR in accelerated mortar bar tests which is similar to the effects of silica fume, fly ash and slag.

According to the above results, it was shown that recycled glass could be use as materials in concrete in three segments, namely: as in powder form, coarse and fine aggregate. The coarse and fine aggregate can cause ASR in concrete but the glass powder will help to reduce the alkali silica reactivity. Therefore, there is benefit in using glass powder as a replacement for cement order than concrete aggregate (Carpenter and Cramer, 1999).

The chemical compositions of glass as well as the shape of aggregate use are largely influenced by the flexural strength. In fact, Federio and Chidiac (2001) demonstrated that glass is amorphous materials with high silica content which makes it to be potentially Pozzolanic in nature when the particle size is less than75µm. Glass formers are those elements that can be converted into glass when combined with oxygen. Silicon dioxide (SiO_2), used in the form of sand, is by far the most common glass former. Common glass contains about 70 percent SiO_2. Soda ash otherwise known as anhydrous sodium carbonate, Na_2CO_3, acts as a fluxing agent in the melt. It helps to lower the melting point and the viscosity of the formed glass, releases carbon dioxide, and helps stir the melt. Other additives are also introduced into glass to achieve specific properties (Samtur, 1974). The table 3.2.2 and 3.2.3 below shows the utilization of glass in concrete which was addressed in a research program at ARRB showing the particle size range of coarse glass aggregate, fine glass aggregate and glass powder and also the chemical composition of these products.

Table 3.2.2: Particle Size Range of Glass (Shayan and Xu, 1999)

Product	Particle Size range	Designation
Coarse glass aggregate	12mm-4.75mm	CGA
Fine glass aggregate	4.75mm-0.15mm	FGA
Glass powder	<10µm	GLP

Table 3.2.3: Chemical Composition of Various Coloured glass (Shayan and Xu, 1999)

Composition	Clear Glass	Brown Glass	Green Glass
SiO_2	72.42	72.21	72.38
Al_2O_3	1.44	1.37	1.49
TiO_2	0.035	0.041	0.04
Cr_2O_3	0.002	0.026	0.130
Fe_2O_3	0.07	0.26	0.29
CaO	11.50	11.57	11.26
MgO	0.32	0.46	0.54
Na_2O	13.64	13.75	13.52
K_2O	0.35	0.20	0.27
SO_3	0.21	0.10	0.07

3.3. Manufacture of Concrete with Recycling Glass Addition.

The construction industries have a great interest in the recycling of industrial waste and by products and these include waste glass. Recycling of waste glass by converting it to aggregate reduces the demand for extraction of natural raw materials for construction activity and also saves landfill space (Rakshvir and Barai, 2006). The use of recycled glass as materials in concrete requires extensive studies about their effects on the properties of concrete. Numerous research studies have been carried out Park et al. (2004) and reports shows that the compressive, tensile and flexural strength of concretes containing waste glass as fine aggregates shows a decreasing tendency with an increased in the mix ratio of the waste glass. It was found that when 30% of glass powder is incorporated as fine aggregate or cement replacement in concrete, it has no detrimental effects (Shayan and Xu, 2004).

Topcu and Canbaz (2004), Ling et al. (2011) and Batayneh et al. (2007) also found out that compressive strength, indirect tensile strength and flexural strength have tendency to decrease with an increase in waste glass content as a coarse aggregate in concrete mixtures. Glass has properties that are beneficial in concrete mixing such as its high chemical and frost resistance, mechanical strength and low water absorption.

Recycled glass materials use as aggregates in concrete help to reduce the water absorption and the drying shrinkage in the production of concrete, because the water absorption characteristic is close to zero, this zero water absorption of glass helps to improve the mix usage and require different mix design including the choice of admixtures which rely on whether a wet or dry technology is used. Research also shows that achieving strength in glass is not a problem because glass is extremely strong aggregate and specified standard procedure of100% concrete mixes of glass aggregate is produced and at 28days,the compressive strength exceeds 15, 000psi or 103.4MPa (Smith, 2009).

According to Sagoe et al. (2001), recycled crushed glass as materials in concrete have been used as a replacement for sand in concrete and it was shown that the strength of the glass concrete was found to reduced by 5% and 27% when the replacement of glass levels are at 5-30% respectively. And during this period, low drying shrinkage was observed in the concrete prepared with Recycled crushed glass as a partial replacement for sand because the drying shrinkage depends on the properties of the original concrete and the mortar content stick to the recycled aggregate. There are many examples of successfully recycling of waste glass as a materials in concrete, among all are, the use of glass as materials for the production of paving stone which contain 100% glass aggregate of various colours, it can be used as raw materials in the production of abrasives or to produce glass pellet or as a cullet (recycled glass) in glass production and also for Pozzolanic additives in concrete which helps to strengthen the concrete and make it harder and more durable during it service life. It can also be use as aggregate substitutes in industry etc. (Chen et al., 2002). The various uses of glass as materials in concrete are shown in Figure 3.3 below.

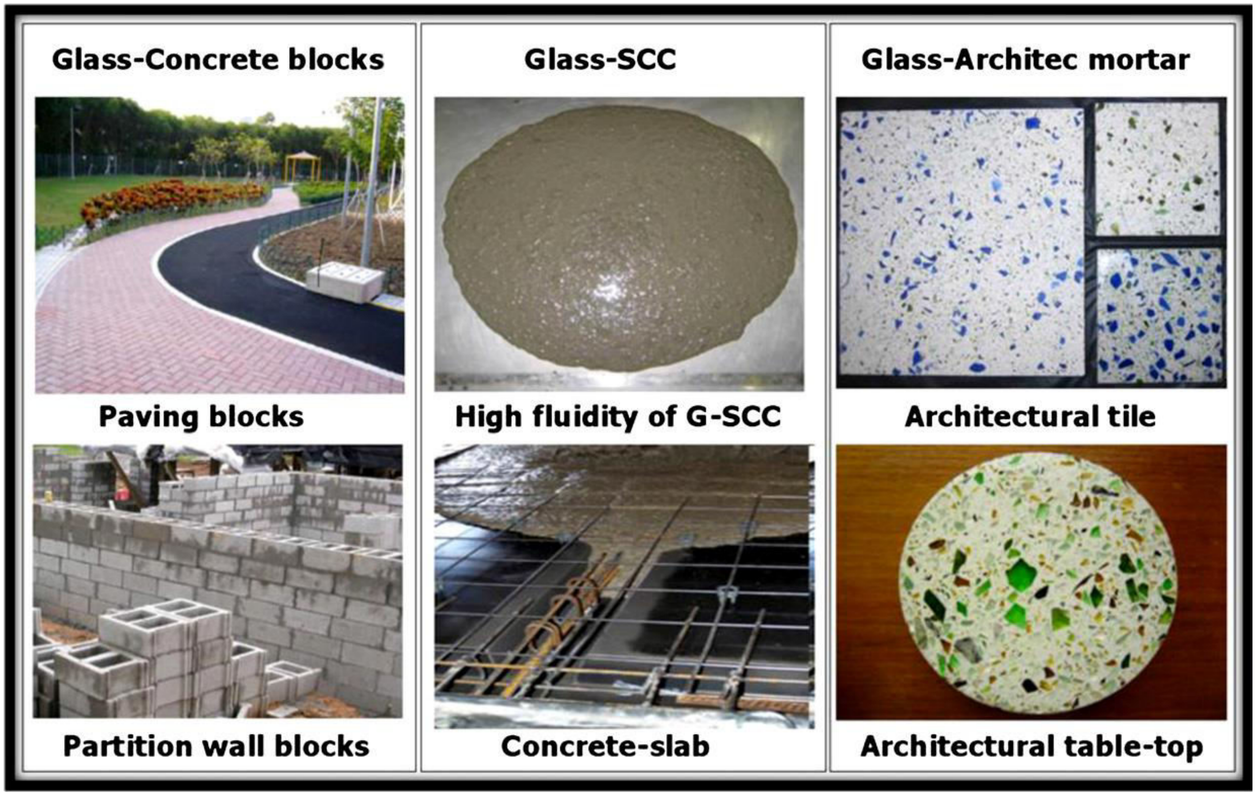


Figure 3.3: Potential developed glass concrete products in construction Industries

Reference: (Ling and Poon, 2011)

3.3.1. Criteria for Selection of Glass to be used in Concrete

The use of durable, attractive and environmental responsible building materials is a key element of any high performance building efforts (Umar et al., 2012). Many construction materials have significant environmental impact from pollutant release, depletion of natural resources and habitat destruction. This can occur during the acquisition of raw materials, production, manufacturing, and transporting the materials for construction use. Several methods are used in selecting recycled waste glass as materials in concrete but from previous research, crushed and sieve green and window glass were mostly used as a coarse and fine aggregate in concrete. The green and window glass are mostly used because they are very common and not frequently recycled. From previous research, waste glass is used in percentage order of 10%, 20%, 30%, 40% and 50% respectively. Figure 3.3.1 below shows the glass architectural mortars featuring different replacement level of RG

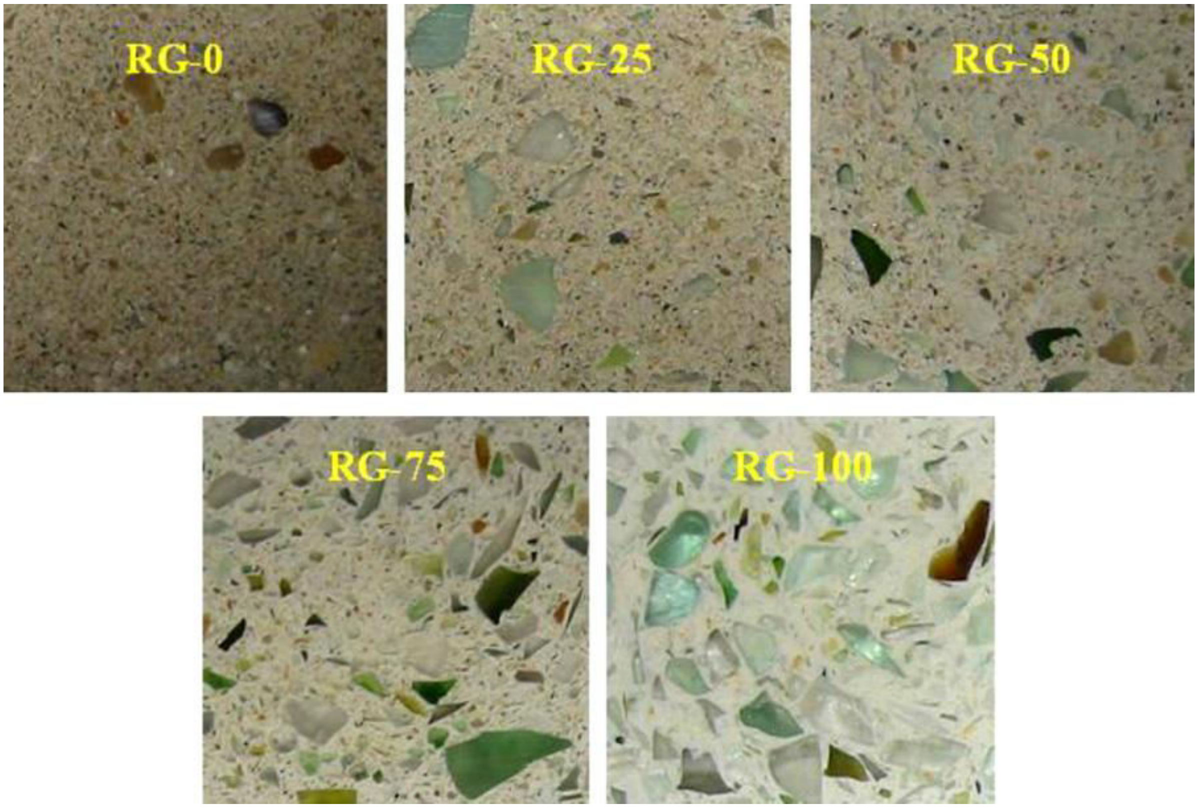


Figure 3.3.1: Glass Architectural mortars featuring different replacement level of RG

Reference: (Ling and Poon, 2011)

3.3.1.2 Materials and Equipment generally used to carry out Test on Recycled Glass.

i. Compressive testing machine
ii. Measuring cylinder
iii. Concrete cube moulds (150 X 150mm)
iv. BS sieves
v. Rammer
vi. Gauge box
vii. Steel plate
viii. Curing tank
ix. Flat steel slab mould (35 X 450 X 450mm)
x. Drying oven
xi. Riffle box
xii. Tamping rod

xiii. Thermometer
xiv. Pyncometer
xv. Sets of weights
xvi. Semi automatic balance
xvii. Stop watch
xviii. Vicat apparatus.

3.3.1.3 METHODS USED FOR GLASS MIX DESIGN

From the results shown by Shetty (2007), the concrete mix batches and testing using glass materials as aggregate i.e. crushed glass aggregate using varying proportions of 20%, 40%, 60%, 80% and 100% into the concrete mix with 20mm maximum nominal aggregate size. Testing and evaluation is required in order to compare the physical properties of the concrete mixture containing the glass aggregate components to a similar mix compose particularly mainly compose of locally available natural aggregates. The water demand, strength and workability of the concrete mixtures containing the glass aggregate were compared with the conventional concrete mix that used naturally occurring aggregate as materials in concrete.

3.3.2. Criteria for Proportioning (Mix design) used in previous studies for concrete with recycled glass inclusion

Mixing is essential for the construction of uniform, high quality concrete. Therefore, the equipment and methods should be capable of effectively mixing concrete constituents containing the largest specified aggregate to produce the same mixtures of the lowest slump practical for the work.

According to the information gathered from the result of the investigation that was presented at the second International Conference on Sustainable Construction Materials and Technologies in Ancona, Italy in 2010, from the laboratory trials which they carried out on recycled crushed glass as a replacement of natural sand and the results were presented (Dumitru et al., 2010). From the trials carried out with clear and green glass with a size distribution between 3mm-0.3mm and a particle density of 2.49t/m^3, it was shown that the concrete trial mixes using 30%, 45% and 60% crushed glass as natural sand replacement shows that the 45% sand replacement results in higher compressive strength at 28days if compared with the control mix using 100% natural sand (Dumitru et al., 2010). When powdered glass with a density of 2.48t/m^3 is used, a fineness index of 335m^2/kg and a mean diameter of 54.1 microns is used in the concrete pavement trials mixes. From the findings of the trial mixes carried out, it was concluded that the setting time up to 1-2 hours longer, the compressive strength is lower at 28days than control, the air content is higher than control and the abrasion resistance is lower. From the outcome, it shows that the mixes using powdered glass as cementitious materials as a replacement met the design criteria for concrete compressive strength and for field trials, 15% cementitious materials should be considered (Dumitru et al., 2010). Figure 3.3.2 below shows the particle size distribution of glass powder.

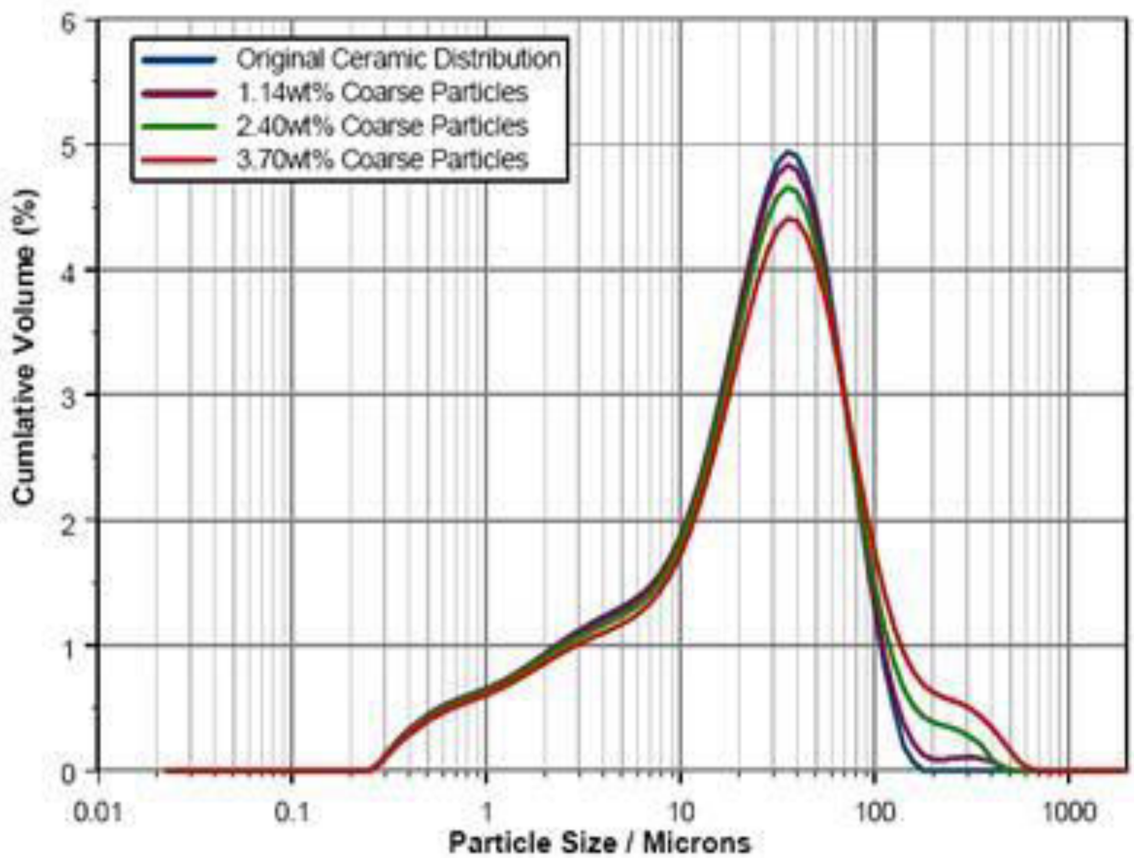


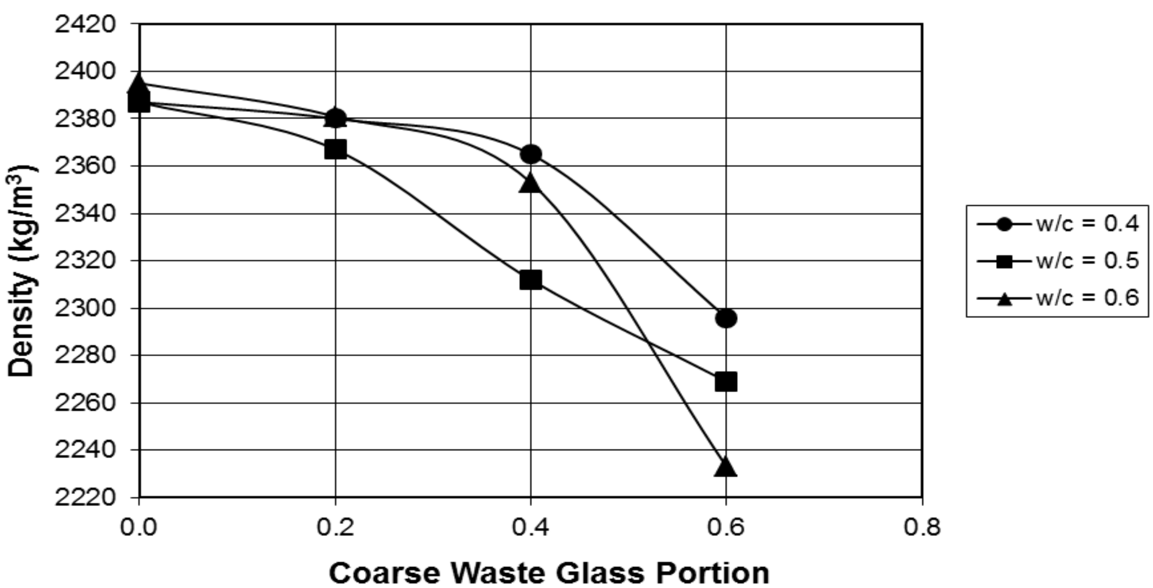
Figure 3.3.2: Particles Size Distribution of Glass Powdered (Meyer and Baxter, 1998)

3.3.3 Mixing, Compacting and Curing of Glass Concrete

The successful placement of glass concrete depends on careful mixing using the proper equipment, and adequate transportation (Delatte et al., 1998). Glass mixing in concrete is the complete blending of glass materials which are necessary for the production of a homogeneous concrete (Schwarz et al., 2008). In order to achieve a successful mixture, one need to do a proper batching of all the glass materials required. It is important that each batch is consistently mixed to design specification in order for the final strength of the glass concrete not to be compromised. There are many component of mixing that need to be considered in order to achieved a uniform concrete mixture and these are shape and angle of the mixing blade, location, shape of the mixing chamber, speed of rotation and horse power (ACI Manual of Concrete Practice, 1997). For a good concrete mix, the water-cement ratio must be considered. Water is chosen as one of the most important element in concrete mix because water is needed to begin the hydration process thereby reacting with cement to produce concrete. Water must be added to concrete in the right proportion but if too much of water is added to the concrete mix, it will reduce the strength and if the water added is not much, the reaction will not occur properly thereby making the cement to harden and bond leading to a reduction in hydration process (Shane, 2003).

According to the research carried out in Gaza, the samples of waste glass materials collected after crushing were included in concrete mix as a partial replacement of fine and coarse aggregates, using a standard series of 144 mass density tests, 72 slump tests, 144 compressive strength tests, 18 flexural tests, 18 pull out tests, and 18 splitting tests were conducted. It was shown from the result obtain in the laboratory that the concrete mixed with coarse waste glass materials as a partial replacement instead of using coarse aggregates, the optimum value of the coarse waste glass use within the concrete mix with a water-cement ratio of 0.4 when conventional aggregates was used was shown to be around 0.265 when replaced with recycled glass and the corresponding compressive strength expected was about 37.73MPa compared with 29.4MPa. For concrete mix with fine waste glass materials as a partial replacement, the optimum value of fine waste glass to be used in the concrete mix with a water-cement ratio was to be 0.4 and the water/cement ratio used was estimated as almost 0.195 and the corresponding compressive strength was almost 39.2MPa. From the above mix result, it was shown that the concrete mixes containing the optimal portion of fine and coarse waste glass materials in concrete has a slight reduction of the splitting tensile strength of the mix and considerable increase in the flexural strength (Husni, 2005). Figure 3.3.3 below shows the concrete density of coarse waste glass in concrete mix and Figure 3.3.3.1 also shows the slump test results versus portion of coarse waste glass in the fresh mix, Figure 3.3.3.2 shows the effect of fine waste glass content into the concrete mix on the mass density of the hardened concrete for different water cement ratio, Figure 3.3.3.3 shows the effect of fine waste glass content into the concrete mix on the workability of the fresh concrete mix expressed as the slump flow rate for different water/cement ratio in Gaza Strip.

Figure 3.3.3: Concrete density of coarse waste glass in the mix (Abdullah, 2007/634)



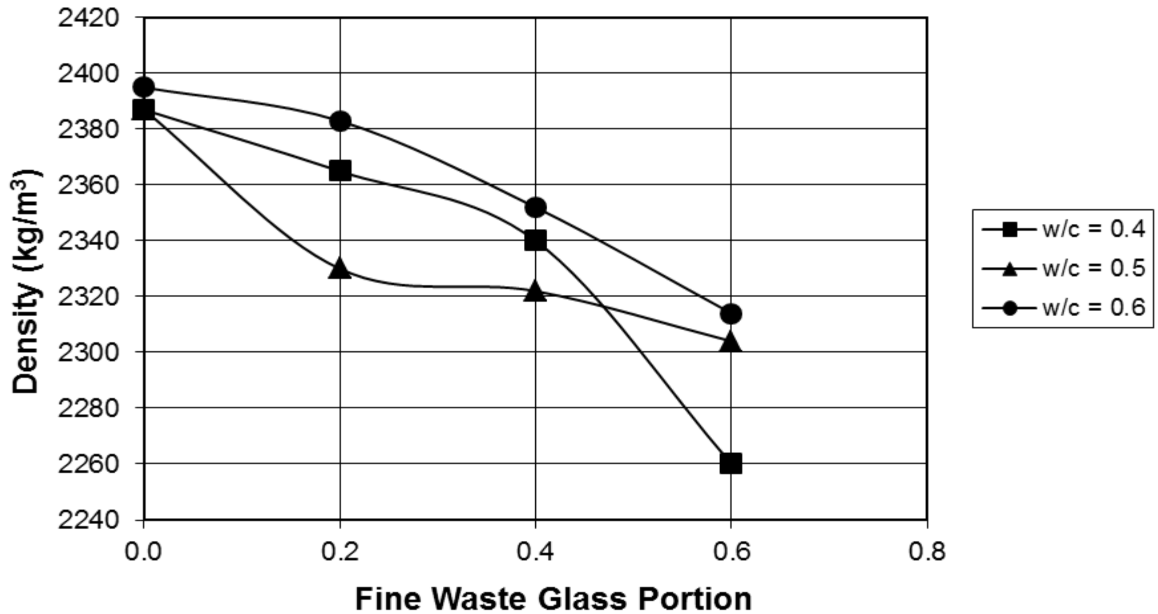


Figure 3.3.3.1: Slump test results versus portion of coarse waste glass in the fresh mix

Reference: (Abdullah, 2007/634)

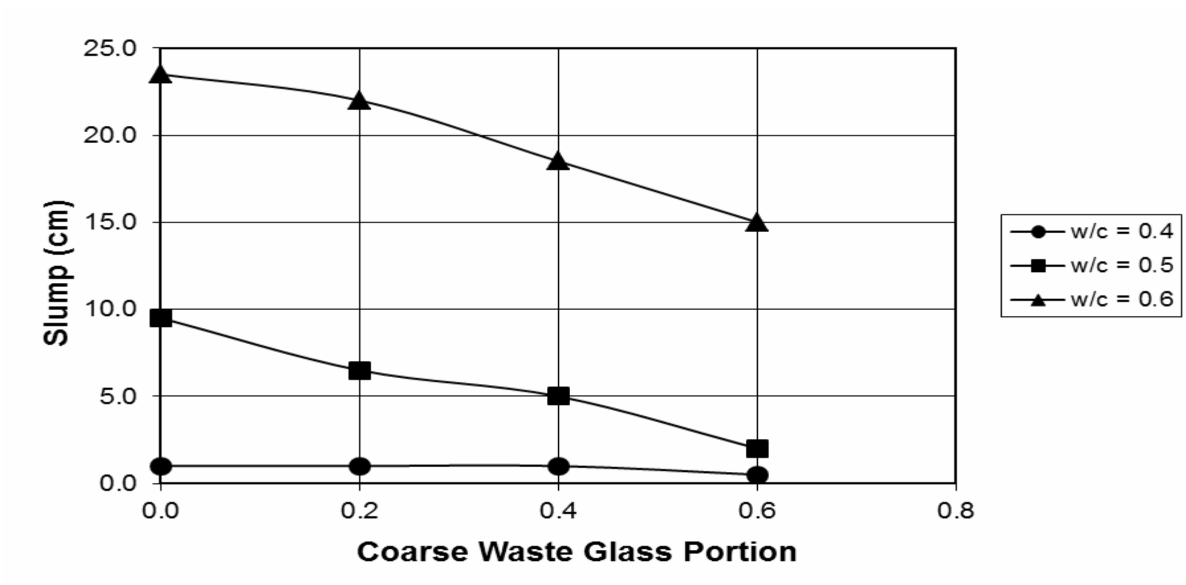


Figure 3.3.3.2: Relation of concrete density with coarse waste glass percentage of several w/c ratios (Abdullah, 2007/634)

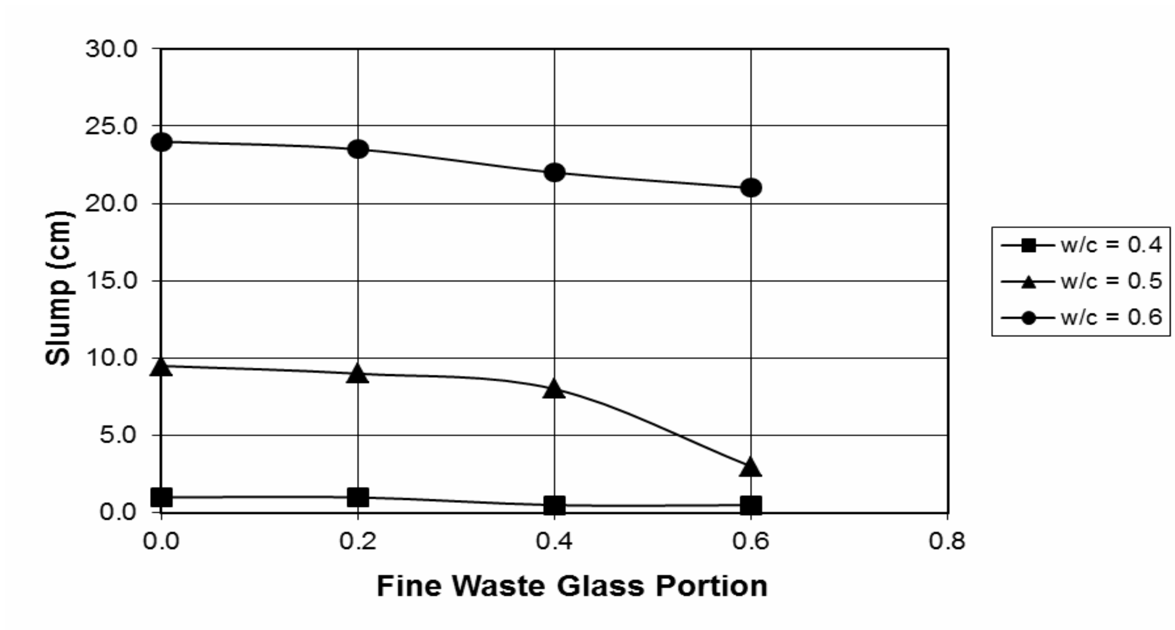


Figure 3.3.3.3: Slump test results versus portion of coarse waste glass in the fresh mix

Reference: (Abdullah, 2007/634)

3.3.3.1 Curing Applications Observed in Previous Studies

In all but the least critical applications, care needs to be taken to properly cure concrete and achieve best strength and hardness. This happen after the concrete has been placed. Cement requires a moist, controlled environment to gain strength and harden fully. The cement paste harden over time, initially setting and becoming rigid though very weak, and gaining in strength in the weeks following. In around 3 weeks, over 90% of the final strength is typically reached, though it may continue to strengthen for decades. The conversion of calcium hydroxide in the concrete into calcium carbonate from absorption of CO_2 over several decades further strengthen the concrete and making it more resilient to damage. Hydration and hardening of concrete during the first three days is critical. Abnormally fast drying and shrinkage due to factors such as evaporation from wind during placement which may lead to increased in tensile stresses at a time when it has not yet gain sufficient strength, resulting in greater shrinkage cracking. The early strength of the concrete can be increased by keeping it wet for a longer period during the curing process, thereby minimizing stress prior to curing and also cracking. High early strength concrete is designed to hydrate faster, often by increasing the use of cement that increases the shrinkage and cracking, strength of concrete changes (increases) up to three years. It depends on the cross section dimension of element and conditions of structure exploitation.

According to research by Poutos and Nwaubani (2013), it was shown that a 100mm of glass concrete cubes in size were prepared and cast using natural and green glass aggregate, and the water to cement ratio used was 0.50, the glass concrete was cast with 100% brown glass cullet as aggregate. The concrete specimen were tested and cured at a normal temperature of $20^{o}C$ and freezing curing temperature of $-10^{o}C$ to $-15^{o}C$, and the curing was combined at freezing and normal temperature. The normal curing of concrete was carried out according to BS 1881- Part 111 code, i.e. for methods of normal curing. 24hours after casting, all the specimens were demoulded and stored inside the water tank thermostically controlled at $20^{o}C \pm 2^{o}C$. The result shows that the rise in temperature for glass concrete was approximately twice of the control because the glass aggregate absorbs less heat than the control due to low specific heat and the water absorbs large amount of heat during cement hydration (Poutos et al., 2007). Later a research was made by Soroka (1993), and it was shown that the accelerating influence of higher temperature was as a result of the temperature rises from $20^{o}C$ to $40^{o}C$, thereby making the rate of cement hydration to increase by a factor of 2.5.

3.3.3.2 Workability Applications Observed in Previous Studies

Workability is the capacity of a new (plastic) concrete mix to fill the form/mold perfectly with the desired work (vibration) and without lowering the concrete quality (Mati, 2014). Workability counts on water content, aggregate (structure and size distribution), cementitious content and age (level of hydration), and can be changed by adding chemical admixtures, like superplasticizer. Uplifting the water content or adding chemical admixtures will increase concrete workability. Enormous water will lead to increased bleeding (surface water) and/or segregation of aggregates, when the cement and aggregates start to separate, with the resulting concrete having reduced quality. The use of an aggregate with an undesirable gradation can result in a very harsh mix design with a very low slump, which cannot be readily made more workable by addition of reasonable amounts of water (Meyer et al., 2001).

Workability can be measured by concrete slump test, a simplistic measure of the plasticity of a fresh batch of concrete following the ASTM C 143 or EN 12350-2 test standards. Slump is normally measured by filling an “Abrams cone” with a sample from a fresh batch of concrete. The cone is placed with the wide end down onto a level, non absorptive surface. It is then filled in three layers of equal volume, with each layer being tamped with steel rod in order to consolidate the layer. When the cone is carefully lifted, the enclosed material will slump a certain amount due to gravity. A relatively dry sample will slump very little, having a slump value of 25mm or 50mm. A relatively wet concrete sample may slump as much as eight inches. Workability can also be measured using the Flow table test. Slump can be increased by adding chemical admixtures such as plasticizer or superplasticizer without changing the water-cement ratio. Some other admixtures, most especially air entraining admixture, can increase the slump of a mix. According to Meyer et al. (2001), it was shown that the effect of coarse glass content into the concrete mix having the mass density of concrete, it was shown that the concrete mass density was inversely affected by an increase in water/cement ratio and if the glass concrete water/cement ratio is 0.6, it show a decrease in the mass density of concrete. Therefore, it can be concluded that the effect of using waste glass on the mass density of concrete is considered as marginal (Meyer et al. 2001). The “Abrams cone” and slump flow apparatus is shown in figure 3.3.3.4 and 3.3.3.5 respectively.

Figure 3.3.3.4: Abrams Cone (Gambhir, 2004).

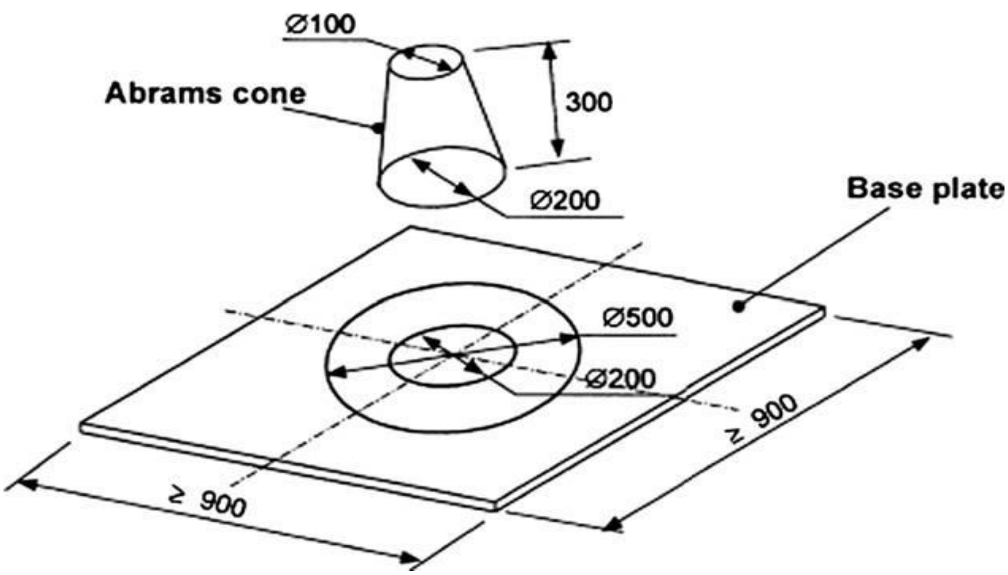


Figure 3.3.3.5: Slump flow apparatus (Gambhir, 2004).

3.4 Compressive Strength of Glass as Materials in Concrete

The compressive strength of glass is approximately 1000Mpa; an increase in glass incorporation will decrease the strength of concrete (Ribeiro et al., 2004). This is usually caused by the weak bond between glass aggregate and cement paste, and also an increase in w/c ratio of the mixture of the fine aggregate.

According to Poutos et al. (2007), he explains that glass concrete usually produces lower strength at 28 days when compared with control concrete. Moreover, glass concrete results usually have higher rates in strength development during the first 7days after casting, thereby the compressive strength of glass at 1day, 3days and 7days is higher than that of the control concrete. The higher rate in strength development of glass from 1day to the 7days is because of the higher temperature developed during the hydration of glass concrete. This may be attributed to the decrease in bond strength between the cement paste and recycled glass (Kou and Poon, 2009).

The compressive strength of concrete made with recycled glass of louvers is a bit greater than those made with green glass, this may be due to the lower content of $Si0_2$ (Silicon dioxide) in louvers when compared to green glass. It was also noted that the use of recycled glass as a partial replacement to fine aggregates has the lowest decreased when compared to other recycled glass replacement. This may be attributed to the increase in fine modulus of the fine aggregate which decreased the overall density of the concrete produced (Kou and Poon, 2009). The result is similar to that of Kou and Poon (2009) who investigated the properties of self compacting concrete prepared with recycled glass aggregate. Their results showed a corresponding reduction in the 28days strength for recycled glass RG15, RG30 and RG45 was 1.5%, 4.2%, and 8.5% respectively. These results was supported and improved upon by Park et al, (2004); Terro, (2006) and Lam et al, (2007) where the compressive strength of normal concrete was only slightly less than the strength of concrete made with recycled glass aggregate with the use of admixture like pulverized fuel ash (PFA) and silica fume (SF) to minimize alkali-silica reaction (ASR) in concrete.

CHAPTER FOUR

USING BRICK AS A RECYCLED MATERIALS IN CONCRETE

4.1 Theoretical Background for Recycled Brick as a material in concrete

Bricks can simply be defined as a ceramic masonry unit which is manufactured by firing clayey soil. Recycling or re-use of brick is a way of eliminating waste and is environmentally friendly. Recycled brick is defined as waste materials that can be obtained from demolished masonry or product which are discarded at the end of the manufacturing process. Fine recycled bricks aggregate are usually from demolition of masonry which can be used to manufacture new product. Industrial by products or recycled waste materials in concrete is one of the most well known applications. There are two major sources in which recycled brick can be obtained which are through demolition or construction waste. Construction and demolition waste usually include the left over or the unwanted materials from the construction, demolition or renovation work (Turley, 2002).

The use of bricks in structures is known for ages, there are numerous structures in the world that is made of brick; they are usually damage by natural disaster or during exploitation. In particular, crushed bricks are materials of aggregate size (0.075-50mm), while ground brick is the form of powder to cement fineness (Crushed brick and ground brick are both obtained from recycled clay brick). In European Union countries, all the masonry demolition waste constitutes about 42-92% of a typical concrete demolition waste and 30-80% of its ceramic materials. Concrete rubbles from demolished structures do not only include concrete materials but mixed with crushed bricks. This bricks comes from load bearing masonry or wall partitioning. It is not only costly but also it cannot be separated from the recycled crushed aggregate. According to Muller (2004), demolition of building in urban areas has produced a large amount of recycled waste materials. Demolition of bricks is usually more economical than renovation which usually occur when the structure want to be modernized. Demolition produces a large amount of waste materials that will be transported to the waste areas. The expenses of cleaning the ruins are increasingly considered because the transport use and need for a large ecological waste areas. Spoilage may occur in the manufacturing output of brick and roofing tile when the burning process is not done appropriately, which can also be reused. If the bricks are preserved after when they are demolished, they can be cleaned and used for construction (Hansen, 1992).

Recovery of bricks used from masonry built with Portland cement is not practical for re-use because of the strong bond. Therefore they are crushed and used with the impurity of the mortar. Nowadays, recycled bricks are used in civil engineering applications for sub-base in road construction, drainage blankets, and fill materials in embankments. Recycled brick materials are also used as overlay materials for tennis courts and tracking fields (Campbell and Pryce, 2003).

According to a study carried out by "Recycling Concrete Pavement" (1993) in Minnesota on the uses of recycled bricks as materials for base courses in pavements.

However, it was shown that recycled bricks as materials in concrete helps in saving significant amount of money compare to conventional materials and the purpose of using recycled bricks as base course materials in asphalt pavement is to reduce the total vertical stress in the sub base and subgrade in order for it not to deform (Recycling Concrete Pavement, 1993).

Furthermore, for us to achieve this the pavement must have a standard thickness, it must be conform to gradation and fines content requirements and be durable against wear and freeze thaw, the base course also helps to protects the main pavement from frost damage and also provides positive drainage. The sample of demolished brick materials is shown in Figure 4.1.1 and 4.1.2 while the typical cross-section of an asphalt concrete pavement is shown in Figure 4.1.3 and Figure 4.14 shows the concept of recycling and reuse of masonry waste below.

Figure 4.1.1: Pictures of Demolished brick material (Tara and David, 2012)

Figure 4.1.2: Pictures of Demolished brick materials loaded in the truck

(Tara and David, 2012)

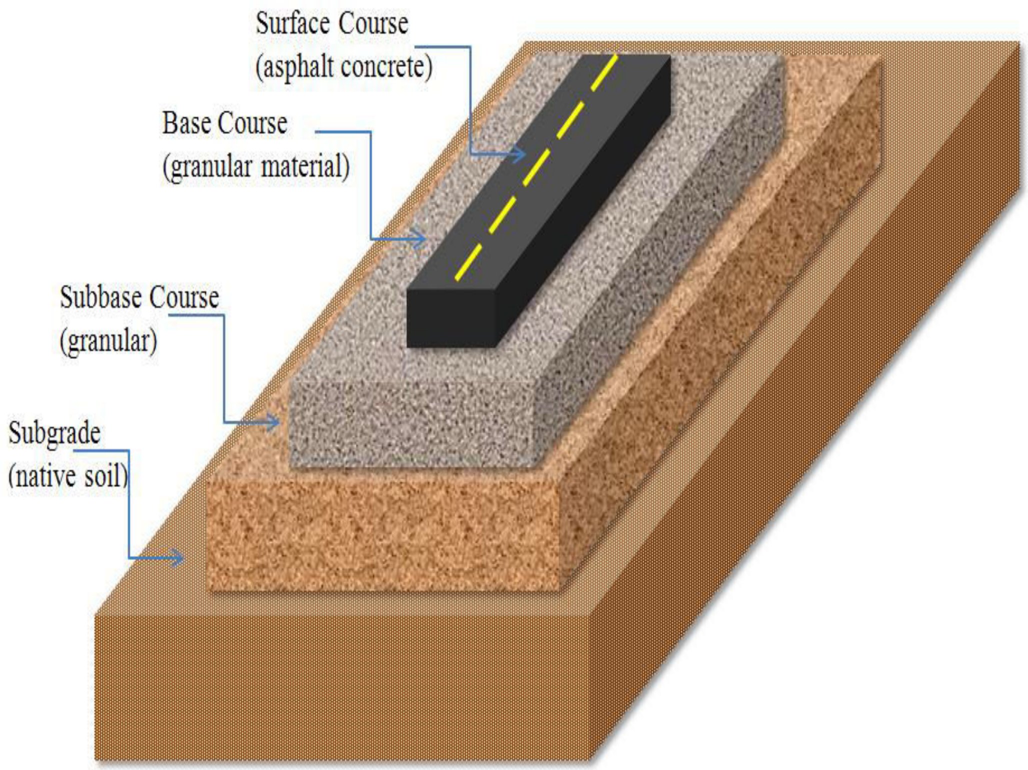


Figure 4.1.3: Typical cross section of an asphalt pavement (fhwa.dot.gov)

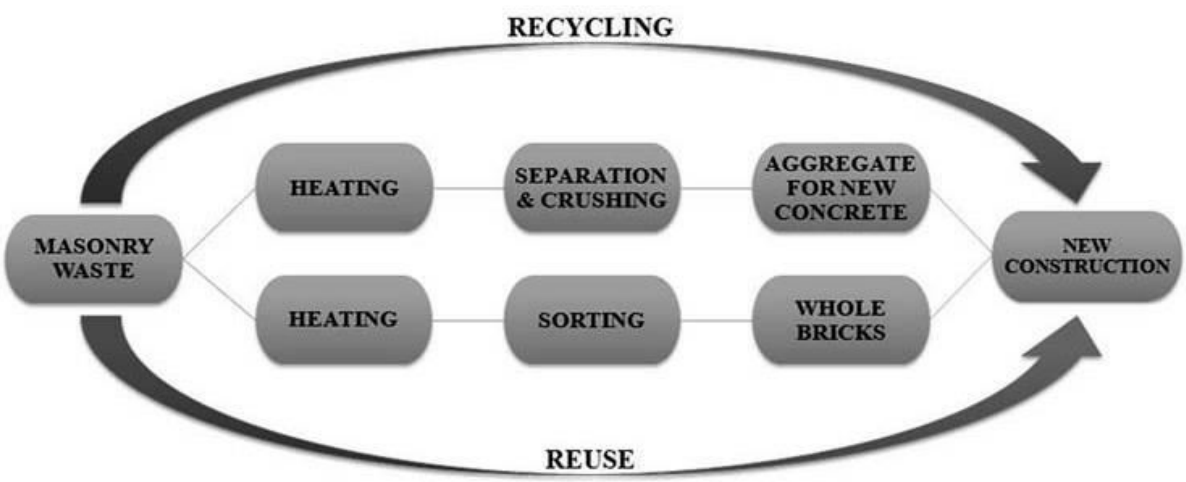


Figure 4.14: Concept of recycling and reuse of masonry waste (Hansen, 1992)

4.1.1. Use of Recycled Brick in Concrete

i. Clay paver bricks are used for light duty paving e.g. sidewalk and driveways,

ii. Fire brick or refractory bricks is used in linings furnace, fireboxes, kilns and fireplaces,

iii. The use of brick materials can increase the thermal mass of building, giving increased comfort during the heat of summer and cold in winter and can be ideal for solar application,

iv. Bricks are a very heat resistant materials thereby providing fire protection,

v. Brick does not require painting, thereby providing a structure reducing the lifecycle costs,

vi. The appearance of bricks when crafted can impart an impression of solidity and permanence,

vii. Brick enable the construction of permanent buildings in region where the harsher climate precluded the use of mud bricks.

4.2 Materials Properties of Recycled Brick in Concrete

4.2.1. Physical Property Criteria for Recycled Brick in Concrete

i. Colour: The colour of a good recycled brick should be the same i.e. uniform throughout (Zhan et al., 2013),

ii. Size: The size of recycled bricks should be of required size in order for it to pass through the sieve i.e. crushed or fine (Szilagyi and Terec, 2013),

iii. Shape: Recycled brick should be uniform in shape for proper mixing and sharp straight right angle edges (Palmer and Griscom, 2013),

iv. Hardness: A good recycled brick after reuse should be sufficiently hard (Smol et al., 2015),

v. Soundness: A good recycled brick should give a sound when struck with another brick (Lawrence and David, 2010),

vi. Crushing Strength: The crushing strength of recycled brick should not be less than $3.5N/mm^2$ (Jayaraman, 2014),

vii. Durability: A quality recycled brick should be able to resist the effects of weathering e.g. rain, temperature etc. (Riveiro et al., 2011),

viii. Water Absorption: A quality recycled brick should not absorb water more than 20% of its dry weight when soak in water for 24hrs (Pavia, 2009).

Table 4.2.1 below shows the physical property requirement in the specification of recycled bricks

		Minimum Compressive Strength, psi (Mpa)		Maximum Cold Water Absorption (%)		Maximum 5hrs boiling Absorption (%)		Maximum Saturation Coefficient	
		5 brick average	Individual	5 brick average	Individual	5 brick average	Individual	5 brick average	Individual
ASTM Specification and Classification									
C62 (Building Brick)	SW	3000 (20.7)	2500 (17.2)			17.0	20.0	0.78	0.80
	MW	2500 (17.2)	2200 (15.2)			22.0	25.0	0.88	0.90
	NW	1500 (10.3)	1250 (8.6)			No Limit	No Limit	No Limit	No Limit
C216 (Facing brick)	SW	3000 (20.7)	2500 (17.2)			17.0	20.0	0.78	0.80
	MW	2500 (17.2)	2200 (15.2)			22.0	25.0	0.88	0.90
C652 (Hollow bricks)	SW	3000 (20.7)	2500 (17.2)			17.0	20.0	0.78	0.80
	MW	2500 (17.2)	2200 (15.2)			22.0	25.0	0.88	0.90
C902 (Pedestrian & Light traffic paving)	SX	8000 [4000][1] (55.2) [(27.6)][1]	7000 [3500][1] (48.3) [(24.1)][1]	8.0 [16.0][1]	11.0 [18.0][1]			0.78	0.80
	MX	3000 (20.7)	2500 (17.2)	14.0	17.0			No Limit	No Limit
	NX	3000 (20.7)	2500 (17.2)	No Limit	No Limit			No Limit	No Limit
Number in brackets are for molded brick and apply provided the requirements for saturation coefficient are met									

Table 4.2.1: Physical Properties in Brick Specifications (Borchelt et al., 2006)

4.2.2. Chemical Properties of Recycled Brick in Concrete

Recycled brick have the ability to react with lime in the presence of moisture to form hydraulic products (Godts et al., 2014). When a brick is been prepared, clay or other suitable earth is moulded to desired shape after it is subjected to several processes. When the brick is dried, shrinking and cracking should not occur because the clay use for the brick mainly contain silica and alumina which are mixed in a proportion that the clay becomes plastic when water is added to it. The materials also contain some small proportions of iron, lime, manganese, sulphur, etc. and the proportions of this ingredient are as follows.

Silica	50-60%
Alumina	20-30%
Lime	10%
Magnesia	<1%
Ferric oxide	<7%
Alkalis	<10%

Reference: (Maharaj et al., 2014).

Water: During the curing of bricks, water should not exceed 20% of it dry weight when immersed in water for 24hours and the crushing strength should not be less than $10N/mm^2$.

<u>Function of Various Ingredients</u>

1. Silica: Silica helps the bricks to maintain it shapes and imparts durability and also prevent shrinkage. During burning, excess of silica makes the bricks weak and brittle. Therefore, silica is added to decrease shrinkage in burning and also to increase the refraction of low alumina clay. A larger percentage of sand in clay is undesirable (Maharaj et al., 2014),
2. Alumina: If Alumina is present in excess of the specified quantity, it produces cracks in bricks on drying. Alumina absorbs water and renders the clay plastics. Clay that has high exceeding Alumina content is likely to be very refractive (Maharaj et al., 2014),
3. Magnesia: Magnesia affects the colour and makes bricks to be yellow. In burning, magnesia causes the clay to soften at a slower rate (Maharaj et al., 2014),
4. Iron: The oxide of iron constitutes less than 7% of clay and their properties is that it improves permeability and durability, it also gives the clay a red colour on burning when excess oxygen is available and a dark brown when the oxygen is not sufficient. The presence of ferric oxide gives it a dark blue colour. Iron lower the fusion point of the clay especially if present as ferrous oxides and also gives strength and hardness (Maharaj et al., 2014),

5. Lime: Lime usually constitutes less than 10% of clay. The effects of lime in bricks are as follows:
    i. It reduces the shrinkage on drying,
    ii. It causes silica in clay to melt on burning and thus helping it to bind,
    iii. Red brick are obtained on burning at considerably high temperature more than 800°C and buff burning bricks are made by increasing the lime content,
    iv. Excess lime causes the bricks to melt, thereby making it loose shape,
    v. Lime lowers the fusion point in carbonated form, (Maharaj et al., 2014).

Table 4.2.2 and 4.2.3 below shows the properties and chemical composition of recycled brick materials.

Table 4.2.2: Properties of recycled brick materials (Jankovic et al., 2012)

Fraction	0/4	4/8	8/16
Particle density (kg/m^3)	1618	1758	1611
Compacted density (kg/m^3)	1216	1011	1010
Loose density (kg/m^3)	1017	907	850
Water absorption (%)	21.8	21.2	20.1
Water absorption after 30’ (%)	17.7	17.1	17.4

Table 4.2.3: Chemical Composition of recycled brick materials (Jankovic et al., 2012)

Chemical Composition (%)	Clay brick powder
Silicon dioxide (SiO_2)	50.91
Iron Oxide (Fe_2O_3)	8.97
Aluminum oxide (Al_2O_3)	15.29
Calcium oxide (CaO)	12.70
Magnesium oxide (MgO)	4.06
Sulphur trioxide (SO_3)	0.20
Loss on Ignition (LOI)	6.41

4.3. Manufacture of Concrete with Recycling Brick Addition.

Recycling of brick materials is one of the materials that have been widely used in construction materials instead of using wood, sand, concrete and other waste materials. Recycled brick have high resistance to atmospheric condition, easy access of it deposit near the earth surface, low price and geochemical purity (Konta et al., 1995). Fired clayed brick is classified as one of the demolition waste materials in buildings or house renovation, which is usually, disposed in most construction places. The uses of this type of construction waste materials help to replace the natural aggregates in concrete mixtures. Some previous research shows that the utilization of recycled waste bricks has been conducted to study the feasible use of waste bricks as construction materials (Poon et al., 2005).

Monteiro et al. (2003) carry out some research on the effect of ground clay brick to replace cement mass. During this research, the ground clay brick meet the strength activity requirement of ASTM in mortar and effective in suppressing the alkali-silica reaction expansion in mortar. In two years after Gutovic et al. (2005) reported the strength development of autoclaved OPC clay bricks blend, where different varieties of clay bricks were used.

According to Poon et al. (2006), the optimum compressive strength was achieved at 50% mass recycled clay brick addition. He now studied the result indicated from the incorporation of recycled clay bricks which shows reduce in density, compressive strength, and tensile strength of the paving blocks. In 2007, research was carried out by examining the possibility of using recycled bricks as materials for coarse and fine aggregate for a new concrete (Kenai et al., 2007).

From the result, it was shown that it is possible to manufacture concrete containing recycled bricks (Coarse and fine) with characteristics similar to that of natural concrete provided that the percentage of the recycled materials is limited to 25% and 50% for the coarse and fine aggregates, respectively.

Moreover, according to the research carried out by Akhtaruzzaman and Hasnat (1983) using burnt brick as a coarse aggregate in concrete, their findings was based on the mechanical properties of brick aggregate concrete and it was shown that there is a possibility to achieve concrete of high strength using recycled brick as a coarse aggregate. However, Khaloo (1994) used crushed clinker as coarse aggregate and it was shown that there is a 7% loss in the compressive strength when compared with normal aggregates and this decrease in strength also lead to 9.5% decrease in the unit weight of the crushed bricks.

4.3.1. Criteria for Selection of Recycled Bricks to be used in Concrete

Brick selection is usually made according to certain application in which the brick is used. Selection for bricks helps to ensure durable brick work which meet the performance specification. In the production of concrete using recycled bricks as materials, the selection of the recycled bricks depends on the availability of the materials in the construction location and also the transportation network have to be considered (Alvarez et al., 1994).

The standard for brick entails the classification and the specific uses of the bricks according the performance. The criteria for performance of the requirement for bricks include durability, strength and aesthetics. There are certain international standard publish by ASTM regarding to the selection of brick and this standard is widely accepted. These standards are reviewed always in order to give necessary information regarding to the selection of bricks (Borchelt et al., 2006). All of the building code used in the United States referred to ASTM standard for bricks while in Canada, Canadian building codes for bricks are prepared by the Canadian Standards Association (CSA) which the uses is similar to the ASTM building codes for bricks. Table 4.3.1 below shows the specification for bricks

Table 4.3.1: Specification for bricks (Borchelt et al., 2006)

Title for Specification	ASTM Designation	CSA Designation
Building Brick	C62	-
Facing Brick	C216	A82
Hollow Brick	C652	A82
Thin Veneer Brick unit made from Clay or Shale	C1088	-
Pedestrian and Light Traffic Paving Brick	C902	-
Heavy Vehicular paving Brick	C1272	-
Ceramic Glazed Structural Clay Facing Tile, Facing Brick and Solid Masonry Units	C126	-
Glazed Brick, Singled Fired	C1405	-
Firebox Brick, Residential Fireplaces	C1261	-
Chemical Resistant Masonry Units	C279	-
Sewer and Manhole Brick	C32	-
Industrial Floor Brick	C410	-

ASTM: American Society for Testing and Materials, CSA: Canadian Standard Association

4.3.1.2 Test Materials and Equipment that are observed in previous studies

i. Bulk density of fresh concrete,
ii. Bulk density of hardened concrete,
iii. Workability of slump test immediately after mixing and also 30mins after mixing,
iv. Air content,
v. Wear resistance at 28days,
vi. Water absorption at 28days,
vii. Splitting tensile strength at 28days,
viii. Compressive strength at 28days,
ix. Modulus of elasticity at 28days,
x. Flexural strength at 28days,

4.3.2 Criteria for Proportioning (Mix design) observed to be used in previous studies

The design of concrete mixes using recycled crushed brick as a coarse aggregate can also be done in the same way as normal conventional aggregates. The only difficulties that may arise is that crushed brick aggregate absorbs a large amount of water thereby affecting the workability compare to conventional concrete i.e. crushed bricks is a very porous materials. According to Hansen (1992), he explains that crushed bricks must be saturated totally before use in the production of concrete in order to prevent the concrete from being dehydrated. He also shows that the absorption of crushed bricks is approximately between 22 and 25% by weight relating to the dry state of the materials. From Hansen test result, it was revealed that after 30mins of immersing crushed bricks in water, it become totally saturated. In particular, if the crushed bricks are immersed in water for 24hours, there is an increase of about 2% water absorption.

However, Khaloo (1994) assumed the pre-wetting of recycled clay bricks is not important. He supports his idea that mixing fine and coarse aggregates together with cement for 1-2 minutes before adding water to the mix and later add the water to the absorbs aggregates for a period of 2minutes and lastly continue to mix for another 3-4mins.

Moreover, Neville (1995) does not approve pre-wetting for any aggregate considering the fact that the aggregates particles can be coated easily with cement paste thereby preventing opening of water for saturation to occur. Therefore, the sufficient water to cement ratio is higher than having full absorption of water by the aggregate.

Furthermore, Bairagi et al. (1990) works on the advancement of the design mix policy for recycled concrete aggregate and his work shows the use of recycled concrete as a materials in new aggregate, which reveal that crushed concrete and crushed bricks have similar properties and therefore crushed bricks should have similar properties with crushed concrete. Another investigation was carried out by Schulz (1988) on the use of recycled masonry as aggregate in new concrete, and he stated that water absorption is very important for the design mix of concrete. He also explain that the water content and the total water absorption of recycled aggregate have to be considered before use if the aggregate is being soaked earlier.

In conclusion, Schulz recommended that pre-soaking is the only definite way to satisfy the workability level and achieved the desired water cement ratio. In summary, from the above reports, it was shown that the more favorable water contents, the better workability of the concrete mixes and this can be achieved using crushed brick as a coarse aggregate, thereby leading to a way of producing better concrete.

4.3.3 Mixing, Compacting and Curing of Brick Concrete observed in previous studies

Concrete failures are associated with several reasons, which are the properties of materials used, mix designs, compaction, curing procedures, placing etc. There are many misinterpretations about the period of curing of concrete particularly when we refer to site conditions. On many occurrences, it was found that the curing period of concrete elements, brickworks, plastering etc. is left to the discretion of the site staff. Unsuitable curing is considered as one of the important reasons for concrete failure in column, slabs, beams, pavements etc. Crushed brick concrete usually has better cohesion and rigidity qualities than conventional materials or granular base materials from natural sources.

4.3.3.1 Curing applications observed in previous studies

Curing is the process of regulating the degree and duration of moisture loss from concrete to assure a consecutive hydration of Portland cement after concrete have been placed and completed in its final position. During curing, consistent temperature should be maintained throughout the concrete depth to prevent thermal shrinkage cracks. Curing of concrete perform a major function in establishing the microstructure and pore structure of concrete. Curing of concrete means preserving moisture inside the body of concrete throughout the early ages and ahead in order to promote the desired properties in terms of strength and durability (Weiss et al, 2012). Moreover, according to Yahia (2006), he narrate the curing of recycling concrete as a method that involves the combination of certain condition such as temperature, humidity and time that helps to improve the cement hydration immediately after the placement of concrete mixture into the formwork. Furthermore, American Concrete Institute defined internal curing as the supplying of water throughout freshly placed cementitious mixtures using reservoirs, via pre wetted light weight aggregates that readily releases water as needed for hydration or to replace moisture lost through evaporation of self desiccation (Weiss et al., 2012). In order to have a better knowledge about Recycled brick aggregate absorption capacity, further research has to be conducted. According to Weiss et al. (2012) on water absorption test for recycled bricks aggregate and virgin aggregate types, from his research, it was shown that the absorption rate of recycled brick aggregate is between 9-15%, while the water absorption rate of granite is 10%, which shows that the absorption rate of recycled crushed brick is large enough to produce internal curing within the sample. In general, it was concluded that recycled brick aggregate absorption capacity is more than three times of normal aggregate because most of the water absorption is taking place inside the pores of the recycled crushed aggregate mortar which surround the original aggregates. There are several reasons to cure recycled brick aggregate in concrete and they are shown below.

i. Improved Durability of Concrete: The durability of concrete is affected by amount of factors such as absorptivity, permeability, and porosity. If a recycled bricks aggregate is cured using a required standard, it will reduce drying shrinkage cracks, thermal, and making the concrete more water tight thereby preventing moisture from coming into the concrete and thereby increasing its durability (Aslan, 2014),
ii. Concrete Strength gain: An increase in the strength of concrete increase with age as moisture and encouraging temperature is present for cement hydration (Jo et al., 2015),
iii. Improved microstructures: The material properties of recycled bricks are related to the microstructure. When recycled bricks aggregate is cured with the aid of cement hydration reaction in order to increase and produce calcium silicate hydrate gel which binds the aggregate together and makes the concrete denser which decreases its porosity and enhances the mechanical and physical properties of concrete (Marthong and Marthong, 2015),
iv. Enhanced Serviceability: A recycled brick as aggregate in concrete that is allowed to dry quickly will undergo an early age shrinkage. If the concrete is not cure properly, it will contribute to the weakness and dusty surface of the concrete making it to have a poor abrasion resistance (Medina et al., 2012),
v. Duration of Curing: Duration of curing of concrete depends on the type of cement used, grade, concrete strength, shape and size of the concrete and the mix proportion etc (Ajay et al., 2012),
vi. Water Curing: When recycled bricks are used in the production of fresh concrete, water curing should be done by spraying water over the concrete surface thereby

making the concrete surface remains moist continuously and helping it to prevent the moisture on the body of concrete from evaporating and provide much strength to the concrete (Medina et al., 2012).

$$2(CaO)_3(SiO_2)+6H_2 \longrightarrow (CaO)_3(SiO_2)3(H_2O)+3Ca(OH)_2 \qquad \text{(iv)}$$

C-S-H gel

$$2(CaO)_3(SiO_2)+4H_2O \longrightarrow (CaO)_3(SiO_2)_2 3(H_2O)+Ca(OH)_2 \qquad \text{(v)}$$

C-S-H gel

4.3.3.2 Workability of Brick Concrete observed in previous studies

According to Mulheron and Mahony (1988), they compared the use of two recycled aggregates i.e. crushed concrete and recycled bricks, from their findings, it was shown that concrete containing crushed concrete as a coarse aggregate had a much lower workability than the control concrete containing natural gravel as the coarse aggregate. When recycled bricks are use as a coarse aggregate in concrete, it produces concrete mixes of similar workability to that of the control. From there outcomes, it was concluded that the individual aggregate particles were less abrasive and rounder than the crushed concrete aggregate and that the texture and shape of the aggregate particles helps in controlling the workability of the fresh concrete.

Moreover, deVries (1993) also shows that recycled brick aggregate are more angular in shape, and also has higher water absorption than that of fresh concrete made with gravel. However, Orchard (1993) shows that when recycled brick aggregate is used as a materials, dust content must be considered because it causes decrease in workability. He further explained that additional water should be added to the concrete mix in order to increase the workability. it was obvious that there is strength loss, if the reduction in strength is limited to about 5%, and the maximum amount of dust which may be allowed will range from 5% of the total aggregate content for low workability with a coarse grading and 10% for low workability with a fine grading and to 20% for a mix having high workability with a fine grading.

In particular, Hansen and Narud (1983) carried out a research on trial mixes using crushed concrete as a coarse aggregate. Despite the fact that there is a different aggregate to crushed brick, but there is a similarity that pervious aggregates require more water during mixing. Later he reported that the workability of recycled brick aggregates decreases with time after mixing compare to the workability of normal aggregates. Furthermore, Ravindrarajah (1987) shows that the use of different types of coarse aggregates has little control on initial workability but a decrease in workability with time is far greater when using pervious aggregates. In conclusion, Hansen and Narud (1983) report that the water absorption use by recycled brick aggregate after mixing has little effect on the strength because recycled aggregates always have a much higher coefficient of water absorption than natural aggregates.

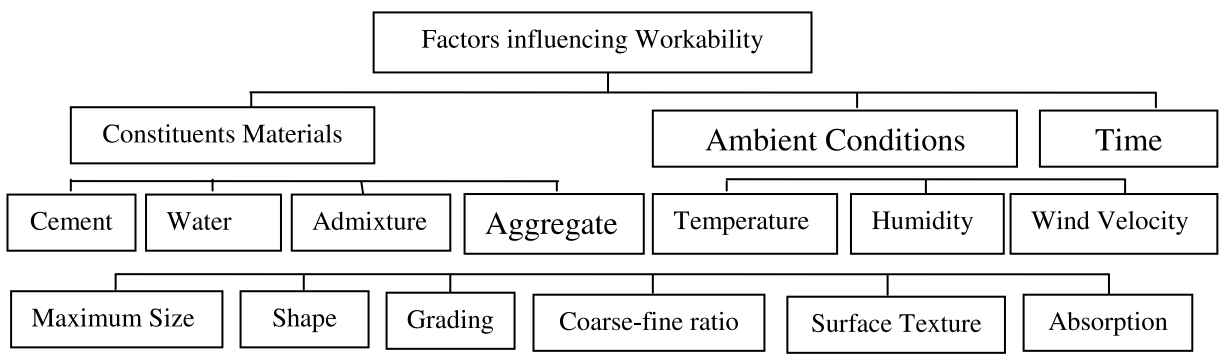


Figure 4.3: Factors Affecting Workability of Fresh Concrete

4.4 Compressive Strength of Brick Materials in Concrete Observed in Previous Studies

Compressive strength test is used to determine the failure stress of the test specimens under uniaxial compression. Recycled bricks differ in compressive strength due to the different qualities of raw materials and methods of firing. The Compressive strength can range from 3.5MPa for NFP to greater than 50MPa for face bricks. The Compressive strength of concrete cannot surpass the strength of the important part of the aggregate contained within, despite the fact that it is very hard to determine the strength of the individual particles. In fact, aggregate strength characteristics normally have to be obtained by indirect test, such as crushing strength of the brick samples, crushing value of the bulk aggregate, impact test and the performance studies of aggregate in concrete.

According to Akhtaruzzaman and Hasnat (1983), there reports on concrete cubes exhibits that compressive strength of between 22N/mm^2 and 42N/mm^2 at 28days for crushed clay brick aggregates concrete, the water to cement ratio exhibiting the main influence on strength, produced concrete using crushed bricks aggregates with water-cement ratio of between 0.54 and 0.88. Later on, there result was compared with that of Khaloo (1994) who produced concrete of between 26N/mm^2 and 41N/mm^2 using different proportion of crushed bricks.

However, Zakaria and Carbrera (1996) produced concrete which contain crushed brick as a coarse aggregate and they found out that crushed brick aggregate concrete had a comparably lower strength at early ages than normal concrete and this was later associated to the features of the higher water absorption of crushed brick aggregate compare with gravel which was use as the control aggregate. De Brito et al. (2005) account 13MPa at 28days strength when the coarse aggregate was replaced with crushed brick whereas Khalaf and DeVenny (2004) accomplished high strength concrete of 67MPa at 28days.

Moreover, Khatib (2005) make use of fine crushed brick aggregate in concrete and it was proved that 25% brick replacement has the same 90 day strength as that of the control. The strength gain between 28 and 90 days was assigned to the Pozzolanic action provided by the very fine portion of the brick. Similarly, from a current study by Debieb and Kenai (2008), there reports shows that 5-10% strength reduction for 25% fine brick aggregate replacement and for full aggregate replacement, the reduction is 30%. Depending on the strength of the brick source and other concrete specification, a broad area of compressive strength can be obtained. From Mansur et al. (1999) reports, it was shown that 40-70MPa cube strength with different water-cement ratio crushed bricks. Furthermore, there investigation also found that crushed brick aggregate concrete had a relatively greater strength at later ages which they ascribed to the Pozzolanic effect of the finely ground portion of the brick aggregate.

CHAPTER FIVE
USING PVC AS A RECYCLED MATERIALS IN CONCRETE

5.1 Theoretical Background for recycled PVC as a material in concrete

In distinction to the word plastic, it means constituents which have plasticity or whatever that is produced in a soft state and used in a solid state is known as plastic. Plastics are originated from the petrochemical produced of fossil oil and gas. In the course of production of plastics, energy is essential which utilizes supplementary amount of fossils fuels (British Plastic Federation, 2008). Waste plastic utilization has sufficiently grown in all part of the world and in recent years, waste plastic have been created in a considerable amount of quantities.

Nowadays, plastic waste has now been a serious threat to the environment (i.e. both human and other living organisms). According to the post consumer packaging account in Portugal, out of 40% of their total domestic waste, 10-14% of it consists of plastics waste (Magrinho et al., 2006). Another example was in United States in 1996, it was shown that about 12% of Municipal solid waste was made up of plastics (Siddique et al., 2008). The plastic industry has developed extraordinarily and since the creation, it was shown that plastic have a very large advantage in construction because of it lower cost, easy to assemble, durability and low weight when compare to many other materials (Andrady and Neal 2009; Thompson et al. 2009a). The substitution of sand with plastic aggregates helps to advance some properties of the concrete because plastic has a good abrasion behavior, high toughness, high heat capacity and low thermal conductivity. The used of waste plastic as a materials in concrete helps to reduce the dead weight of concrete, thereby lowering the risk of earthquake to the structures and it also assist in designing earthquake resistant building (Akcaozoglu et al., 2010).

Moreover, a journal by plastic Europe (2008b), from their discovery, it was shown that polymer production was estimated to be 260 million metric tonnes per annum in year 2007 and these polymers comprises of thermoset plastic (Plastics that cannot be melted by heating), thermoplastics (Plastic which can be melted for recycling in plastic industry), adhesive and coatings etc.

However, plastic waste cannot be released in the landfill because it has larger size and the rate of deterioration is very slow. The best explanation for plastic recycled waste is to use it to produce fresh materials like aggregate in concrete, thereby giving it ecological and economic advantages. Plastics as aggregates are produced by separating plastics mechanically and processing the waste. Mechanical recycling of plastic is the recycling methods whereby the recycling materials are conducted mechanically (e.g. screening, grinding, and sieving).

Similarly, Fisher (2003) shows that plastic recycling is complicated and sometimes confusing due to the large range of recovery activities and recycling. These activities include four classifications which are the primary, secondary, tertiary and quaternary. The primary is also known as close loop recycling or a mechanical processing into products with equivalent properties, secondary as downgrading recycling or mechanical reprocessing into products requiring lower properties, tertiary as feedstock's recycling or the recovery of the chemical constituents and quaternary is known as valorization or the recovery of energy (Song et al., 2009). The table 5.1 below shows the terminology of plastic recovery activities.

Table 5.1: Terminology used in different types of plastic recycling and recovery

(Song et al., 2009)

ASTM D5033 definitions	Equivalents ISO 15270 (draft definition)	Other equivalent terms
Primary recycling	Mechanical recycling	Close-loop recycling
Secondary recycling	Mechanical recycling	Downgrading
Tertiary recycling	Chemical recycling	Feedstock recycling
Quaternary recycling	Energy recovery	Valorization

5.1.1. Standards for Concrete Made with recycled PVC Aggregate Materials.

Nowadays, there are two provisional recycled PVC standards, namely the first one is called "PS1" for smaller diameters pipe and the other called "PS 8" for larger diameter pipes. These standards assist the use of recycling materials and in general, it helps to demonstrate how to make PVC pipes with recycled contents. PS 1 normally require a minimum of 5% recycled content, this 5% minimum is not meant for technical discussion but for some aims such as government in which they have unique procedure on buying recycled materials. In concise form what the finding is telling us about is that if a suppliers said is pipes is of ASTM standards PS 1 and the buyer want to have assurance on that the supplier did not just put 0.01% recycled materials into the pipes and later saying all the pipes is made with a recycled materials, so the 5% minimum is there to secure that pipes containing recycled materials really do contain it (Lisa, 1995). Recycled plastic are subjected to some elementary process, which are listed below.

i. Segregation process: Plastic waste collected from various sources must be separated from other waste and the maximum thickness should be of 60 micron,
ii. Cleaning process: Waste plastic must be cleaned and dried in order to remove contaminant from it before using for concrete production,
iii. Shredding process: Waste plastic must be shredded or cut into smaller pieces and later the different plastic waste can be mixed together,
iv. Collection process: The plastic waste retaining 2.36micron is collected and used for construction purpose.

Moreover, Siddique et al. (2008) made some declaration that the advancement of advanced building materials using recycled plastics is necessary to both the plastic recycling and construction industries. Due to the inadequacy of sand in construction industry, plastic waste are used in replacement of sand as a fine aggregate in concrete and using plastics waste as a materials in concrete helps to reduce disposal concerns. Collection of plastic waste is readily available and the possibility is much. From previous test using plastic waste as a replacement of sand by 10%, 20%, 30%, 40% and 50% in concrete, the plastic waste having small quantity of coarse grained particles of size 3.5mm to 4.5mm were used and the properties of the plastic waste were determined in the laboratory (Adnan, 2012). There are different kinds of Plastic waste used as aggregate for fiber in cement mortar or filler in concrete after treating it mechanically, these includes PVC pipe, polycarbonate, thermosetting plastics, mixed plastic waste etc. (Albano et al., 2009). Table 5.1.1 below shows the properties of plastic waste used as replacement of sand in concrete.

Table 5.1.1: Properties of Plastic Materials (Albano C et al., 2009)

Sr. No.	Property	Types of Plastic waste used		
		PE	PP	PVC
1	Density(Kg/m^3)	910 to 925	946	1380
2	Specific gravity	0.92	0.90	1.2
3	Melting Point	105^o to 115^o	85^o to 145^o	100^o to 260^o

PE- Polyethylene, PP- Polypropylene, PVC- Polyvinylchloride

5.1.2. Use of Waste PVC Waste in Concrete

i. Recycled PVC is used to produce a good quality of precast concrete (Rebeiz, 2007),
ii. Plastic waste is used as fillers in road construction (Eldin and Senouci, 1992),
iii. Polythene terephthalate (PET) is used as an aggregate substitute in concrete mix (Marzouk et al., 2006),
iv. The use of recycled plastic as a coarse aggregate helps to improves thermal properties of concrete mix (Elzafraney et al., 2005),
i. Thermoset plastic as sand replacement helps to check the practicability of the use,
ii. Plastic waste is used as materials in the production of plastic roads (Siddique et al., 2008),
iii. Waste thermal plastic is use as admixtures to the concrete cement for construction industry (Correia, 2011),
iv. Plastic waste is used as partial replacement of inorganic aggregates in concrete application thereby reducing the dead weight of the structures,
v. Thermosetting recycled plastics as a lightweight material is mainly used in Thailand for the construction of exterior and interior walls of building in most cases where the walls are not design for lateral loads (Panyakapo, 2007).

5.1.3. Advantages of Waste Plastic in Concrete

i. It has lighter weight than other materials (Barnes et al., 2009),
ii. Durability and not easy to fail (Borsellino et al., 2009),
iii. Extreme versatility and ability to be modified to meet specific technical needs (Guo et al., 2009),

iv. Ability to combine with other materials like adhesives (Mali, 2014),
v. Excellent thermal and electrical insulation properties (Polanský et al., 2014),
vi. Lesser production cost compare to other materials (Barnes et al., 2009),
vii. Reduction in solid waste thereby having better use of the land than landfills (Mazhindu et al., 2012).

5.1.4. Disadvantages of Waste Plastic in Concrete

i. Plastic has low bonding properties thereby reducing the strength of the concrete such as flexural, compressive and tensile strength (Saikia and de-Brito, 2012),
ii. The disposal of plastics also contributes to the effect on the environment (Barnes et al., 2009),
iii. Most plastics are non-biodegradable, so they may require a long time for them to disintegrate once they are landfills (Thompson et al., 2009).

5.2 Materials Properties of Recycled PVC in Concrete

5.2.1. Physical Properties of Recycled PVC in Concrete

i. Recycled plastic have a good chemical resistance (Claessens et al., 2013),
ii. Hardness: Plastic is made up of strongly bond together particles that make it hard to break (Saikia and de-Brito, 2012),
iii. Not easily biodegradable/Durability: This properties show that plastic can be used as an inert matter in cement matrix (Thompson et al., 2009),
iv. High heat resistance (Polanský et al., 2014),
v. Lightness: Plastics is very light in terms of weight (Barnes et al., 2009),
vi. Low linear dilation coefficient (Mali, 2014),
vii. Versatility: Plastics can be used in many areas of the industries; this makes it an economical attractive choice (Guo et al., 2009).

5.2.2. Mechanical Properties of Recycled PVC in Concrete

The mechanical properties of recycled PVC in concrete are Elasticity Modulus (EM), Ultimate Tensile Strength (UTS), and Percent Elongation to Fracture (% Elong.)

i. Treating plastic chemically and coating plastics with slag and sand powder can advance the mechanical accomplishment of concrete by developing the between cement paste and plastic aggregates (Choi et al., 2008),
ii. Recycle PVC has high stability and mechanical properties,
iii. The mechanical properties of recycled PVC improves with an increase in molecular weight, but decrease with temperature increasing,
iv. The flexible PVC elastic is 1.5-15MPa. However elongation at break is up to 200%-450%. PVC friction is ordinary, the static friction factor is 0.4-0.5, and the dynamic friction is 0.23,
v. The elastic modulus of PVC can reach 1500-3000MPa,
vi. Abrasion: Plastic mainly show excellence performance under abrasive conditions,
vii. Creep Modulus: The creep modulus or stress/strain relationship for PVC must be examined in the framework of the rate or the duration of loading and the temperature,
viii. Long Term Tensile Strength: PVC pipe are developed to have long term tensile strength, the long term hydrostatic design basis for PVC is two or more times greater than other thermostatic pipe materials.

5.3. Manufacture of Concrete with Recycled PVC Addition from Previous Studies.

According to analysis that was conducted on the utilization of waste plastics as materials in concrete, it was shown that plastic can be used in distinct applications but attempt has been done to investigate the use of plastic as aggregate in concrete and asphalt (Siddique et al., 2008). However, different journals and papers have been published on the use of recycled plastics as aggregate in concrete and it was shown that recycled plastics has more advantages by using it as a materials for asphalt production than normal concrete.

Moreover, manufactures of recycled plastic aggregate primarily rely on the concrete mix proportion. The mix proportion of recycled plastics aggregate concrete will depend on the percentage replacement of the coarse aggregate by recycled plastic aggregate. Close to 20% of replacement level of should be substitute with coarse plastic aggregate. The higher the replacement of plastics as a coarse aggregate, the increase in water demand for a given workability. At higher aggregate replacement level, modification should be made to the aggregate proportions thereby accounting for the shape, grading and texture of the plastic recycled aggregate; the quantity of admixture may also be adjusted. The use of water reducing or superplasticising admixtures helps to maintain the strength of the concrete required. An increase in the demand for water will be dependent on the recycled plastic aggregates and its properties. Different types of waste plastic are used in concrete manufacturing and such plastics are polyvinyl chloride (PVC) pipe Kou et al. (2009), Polyethylene terephthalate (PET) bottle Albano et al. (2009); Akcaozoglu et al. (2010); Choi et al. (2005); Kim et al. (2010), high density polyethylene (HDPE), Naik et al. (1996), shredded plastic waste Al-Manaseer and Dalal (1997); Ismail and Al-Hashmi (2008), thermosetting plastic (Panyakapo and Panyakapo, 2008).

Furthermore, majority of waste plastics use as aggregate in different studies came from container waste or plastic bottles. Mostly, plastic bottles are grinded in the laboratory with the aid of a grinding machine and then sieved to get a suitable size fraction. In addition, plastic waste with suitable size is collected from a plastic waste treatment plant. In most studies, treatment of plastic waste was done by heating, melting followed by mixing other materials using different techniques.

According to Akcaozoglu et al. (2010), he used granules from shredded PET bottle waste as an aggregate which were supplied from commercial company. The bottles were obtained by picking up waste PET and then washing and mechanically crushing them into granules. However, from Frigione (2010) studies, waste PET aggregate used was manufactured from PET bottles waste and is not washed and not separated due to the basis of the colour. From research, in order to prepare WPET aggregate, PET bottle waste with a thickness of 1-1.5mm was grinded in a blade mill to the size of 0.1-5mm and later the resulting particles were separated using sieve into a similar size grading compare to that of natural sand. From Kou et al. (2009) research, he produced PVC plastic granules by grinding scraped PVC pipes into small granules with about 95% passing the 5mm sieve. Choi et al. (2009) prepared an aggregate by mixing granulated waste PET bottle with powdered river sand at 250^{o}C, after air cooling the mixture, he screened the prepared aggregate and remaining powdered sand fraction using 0.15mm sieve. In year (2005), Choi et al. also prepared another types of plastic based aggregate by mixing it with powdered blast furnace slag with granulated waste PET bottle at a temperature of 250^{o}C.

5.3.1. Criteria for Selection of PVC from Previous Studies

From numerous research, the criteria for selection of materials were based on the major property of waste plastic aggregates and they are size grading which was generally done by standard sieving methods (Batayneh et al., 2007; Ismail and Al-Hashmi 2008; Kou et al., 2009). Moreover, Albano et al., (2009) use a different approach to estimate the size distribution of plastic aggregate and from his approach; he measured the sizes of plastic aggregate by a means of an electronic magnifying glass and the average particles size was determined using a software application. Furthermore, other aggregates properties, such as specific gravity, bulk density, water absorption were also evaluated. Although the procedure they used for adoption was not specified but standard procedure for natural aggregate can be used. Similarly, some other properties of plastic aggregates such as compressive and tensile strength, decomposition temperature, elastic modulus were also reported. In fact, some studies shows that parameters such as initial degradation temperature and melt flow index which may assist in the evaluation of fire behavior of concrete containing plastic waste, thermal conductivity, heat capacity were also determined.

5.3.1.1 Test Materials and Equipment observed to be used in Previous Studies

From various reports, several types of plastic waste were use as aggregate, since the basis of this aggregate is different from normal conventional aggregate i.e. the first is organic and the other one is inorganic which shows big differences in the properties from the observation. Albano et al. (2009) studied the benefit of polyethylene terephthalate (PET) as aggregate and he compared it with other types of plastic aggregate using the replacement of fine natural aggregate to be ≤4mm and for coarse natural aggregate to be ≥4mm using similar fraction of PET. From numerous studies, the incorporation of plastic aggregates shows an increase in slump value (Al-Manaseer and Dalal, 1997). According to them, the increase of slump concrete mixes is due to the incorporation of plastic aggregates due to the presence of free water in the mixes with plastic waste than the normal aggregate, since plastic aggregates can absorb water during mixing unlike natural aggregate.

However, the incorporation of plastic aggregates generally decreases the density of the resulting concrete due to the lightweight natures of the aggregates (Kou et al., 2009; Choi et al., 2005). From Ismail and Al-Hashmi report, it was shown that the fresh density of concrete with 10, 15, and 20% plastic aggregates as a replacement of fine aggregates tends to decrease by 5, 7 and 8,7% respectively. Moreover, from Saikia and de-brito (2010) studies, it was observed that there is a reduction of the density of fresh concrete with increasing volume of PET aggregates that is incorporated.

5.3.2. Criteria for Proportioning (Mix design) observed to be used in previous studies

The method of appointing suitable ingredients of concrete and deciding their relative amount, with the aim of producing a concrete of appropriate durability, strength and workability as economically as feasible is known as concrete mix design. The proportioning of ingredient of concrete is conducted by the appropriate performance of concrete in two states which are the plastic and the hardened states. Provided that the plastic states are not workable, it cannot be correctly placed and compacted. As a result of this, the property of workability becomes of basic importance. The compressive strength of hardened concrete which is mainly deliberated on to be an indication of its other properties rely primarily upon the quality and quantity of cement, water and aggregates, batching and mixing, placing, compaction and curing. The requirements for concrete mix design of waste plastics are as follows.

i. The minimum compressive strength required for structural consideration (Nataraja et al., 1999),
ii. The enough workability necessary for full compaction with the compacting equipment available (Kabora, 2014),
iii. The utmost water-cement ratio and/or least cement content to give adequate durability for the specific site conditions (Blissett and Rowson, 2012),
iv. The highest cement content to avoid shrinkage cracking due to the temperature cycle in mass recycled concrete (Blissett and Rowson, 2012).

Factors to be considered for Waste Plastic Mix Design

i. The grade designation giving the strength characteristics requirement of recycled plastic aggregates in concrete (Providakis et al., 2013),
ii. The workability of plastic recycled concrete for satisfactory placing and compaction which is connected to the dimension and structure of division, number and spacing of reinforcement and method used for transporting, placing and compacting (Pacheco et al., 2012),
iii. The type of cement used helps to influence the proportion of growth of compressive strength of recycled plastic aggregate in concrete (Saikia and de-Brito, 2012),
iv. The cement content should be limited for cracking, shrinkage and creep (Saikia and de-Brito, 2012),
v. Required standard (Eurocode 2 or EN 206) of plastic aggregates should be used in concrete (Silva et al., 2014).

5.3.3 Mixing, Compacting and Curing of PVC Concrete observed in previous studies

5.3.3.1 Curing

Curing is the method that includes the conservation of an appropriate moisture content and temperature in concrete for suitable period of time instantly after placing and finishing so that desired properties of concrete are achieved. After all, concrete produce a lot of heat because of the reaction between water and cement (hydration), and curing should be done properly in order to avoid cracking because of excess expansion of the particles. Therefore, pouring involves discharging of water to cool the surface of concrete and also covering to reduce loss of water through evaporation and consequence of hydration. Curing and making of concrete test specimen is done in the laboratory under accurate control of materials and test conditions using concrete that can consolidate vibration or roding.

According to Al-Negheimish (1988), he explained that the curing characteristics of recycled PVC (exotherm and shrinkage) are very important. He further his research by saying for precast component, low shrinkage is more important because excessive shrinkage affect the dimension of the structures thereby making their assembling, demolding more difficult. Furthermore Rebeiz (1998) explain that the shrinkage strains are measured during the polymerization device, and as the ultimate shrinkage of the PVC system using a weight aggregate to resin ratio of 4 to 1 is about three times higher than the one corresponding to the PVC system using a weight aggregate ratio of 9 to1. The reason for this is because of the huge amount of resin which is susceptible to shrinkage in a low aggregate to resin ratio. Most shrinkage in PVC system occurs in first eight hours after mixing and stops after twenty four hours.

5.3.3.2 Workability observed in previous studies

Workability of concrete is specified as the ease in which concrete can be blended, conveyed, deposited and finished easily without segregation, Slump test is used widely at site. The mould of slump test is a frustum cone of 305mm high and it is generally controlled per ASTM C 143-78. After the concrete is filled into the cone, it is lifted gently and then unsupported concrete will slump, the reduction in height of the concrete is called slump. According to Koehler and Fowler (2003), it was discussed that the major factor to check in concrete is its workability. Workability has a wide range from very low, having a slump of 0-25mm which is applied for vibrated concrete in large sections to high workability of slump from 100-180mm for section with congested reinforcement.

However, Al-manaseer and Dalal (1997) decide on the slump of concrete mixes made with plastic aggregates, from their reports, it shows that there was an increase in slump when the plastic aggregate were added to concrete. Concrete with 50% plastic replacement of aggregates had a higher cone slump than that without plastic aggregates. Their conclusion was that plastic aggregates did not absorb or add any water to the concrete mix. Due to the non absorbing water characteristics of plastic concrete containing plastics aggregates had more free water in the mix hence increasing the slump. The slump is used to measure the workability or consistency of fresh concrete mix, since it is a substantial property, the slump mix of plastic aggregates was shown from the following research.

Similarly, Ismail and Al-Hashmi (2008) works on two parallel view on the workability behavior of concrete containing plastic aggregate and from there reports, it was shown that there is a lower value of fresh concrete due to the incorporation of several types of plastic aggregates than the conventional concrete mix and additional further increment of plastics aggregates also lower the slump value. From numerous researches, the reason for the lower slump value is due to the concrete mix containing plastic aggregates which have angular plastic sizes and sharp edges.

Moreover, Choi et al. (2005) reports shows that the influence of polyethylene terephthalate (PET) waste bottles as light aggregates (WPLA) on the workability of concrete. From their reports, they used a water cement-ratio proportion of 45%, 49%, and 53% and the replacement ratio of WPLA were 0%, 25%, 50% and 75% by volume of fine aggregate. From their accounts, it was shown that PET bottles light weight aggregates concrete slump value increase with an increase in water to cement-ratio and the replacement ratio. The increase in workability represent 52%, 104%, and 123% comparing to that of normal concrete at water-cement ratio of 45%, 49% and 53% respectively. They therefore concluded that it was because of the spherical and smooth shape and the non-absorption characteristics of the waste PET bottle lightweight aggregate (WPLA).

Furthermore, Al- Manaseer and Dalal (1997) shows that an increase in slump value due to the incorporation of plastic aggregates is due to the presence of more free water in the mixes containing plastic than in the concrete mix containing natural aggregates since plastic aggregates cannot absorbs water during mixing unlike natural aggregates. Table 5.3 below shows the cone slump test result.

Table 5.3: Cone Slump test result (Al-Manaseer and Dalal, 1997)

Plastic Aggregates (%)	Workability of W/C 0.5
0	55
10	45
30	50
50	50

5.4 Compressive Strength of PVC as Materials in Concrete

Compressive strength is defined as the measured maximum resistance of the concrete or mortar specimen to an axial load, usually expressed in Psi (Pounds per square inch) at an age of 28days. The addition of waste plastic extremely changes the hardened properties of concrete. According to Choi et al., (2009); Akcaozoglu et al., (2010), the compressive strength of concrete and cement mortar is an important property. The addition of recycled plastic waste as aggregate decreases the compressive strength of resulting concrete and mortar. The compressive strength behavior of concrete and mortar with PET as fine and coarse aggregate in concrete have a low bond strength between the surface of plastic waste and cement paste as well as the hydrophobic nature of plastic waste which can inhibit cement hydration reaction by restricting water movement thereby causing low compressive strength of concrete with plastic aggregates. Akcaozoglu et al., (2010) investigated the use of shredded waste polyethylene terephthalate (PET) bottle granules as lightweight aggregates in mortar preparation using two types of binders: NPC and a 50:50 mixture of BFS and NPC, he found that the compressive strength of mortar with PET aggregate is higher for the NPC-BFS binder than for NPC only.

However, Batayneh et al. (2007) observed a reduction in the compressive strength of concrete due to the addition of plastic waste as a partial substitution of fine aggregates and it was shown that from up to 20% replacement, compressive strength show a sharp reduction up to 72% of the original strength and for 5% replacement, the compressive strength drops to 23%. From all these findings, it was shown that the factors that may be responsible for low compressive strength of plastic as aggregates in concrete are the very low bond strength between the surface of the plastic waste and cement paste, the hydrophobic nature of plastic waste which can inhibit cement hydration reaction by restricting water movement. Table 5.4 below shows the reduction in compressive strength of cement mortar and concrete (28-day) due to the substitution of natural aggregates by plastic aggregates.

Moreover, according to a research carried out in India on the use of recycled PVC as materials in concrete, it was shown that the compressive strength of PVC materials decreased when used as replacement with natural aggregates and later on there is a increase in compressive strength when natural aggregates were replaced with recycled PVC materials but the characteristics strength was achieved successfully.

Furthermore, another compressive strength test carried out in India by Raghatate, it was shown that the compressive strength of concrete produce with recycled plastics goes on reducing with increase in percentage of recycled plastic and the rate of reduction in compressive strength is very low. He later concluded that the compressive strength of concrete containing recycled plastics is affected by increasing the addition of plastics aggregate which lead to a decrease in compressive strength after 28days.

Table 5.4: Reduction in Compressive Strength of Cement Mortar and Concrete.

Reference	Types of Substitution	Reduction in Compressive Strength for Substitution level (%) of									
		3	5	10	15	20	30	45	50	75	100
Batayneh et al. (2007)	Fine/PET		23			72					
Frigione (2010)	Fine/PET		<2								
Hannawi et al. (2010)	Fine/PET Fine/PC	9.8 6.8		30.5 27.2		47.1 46.1			69 63.9		
Kou et al. (2009)	Fine/PVC		9.1		18.6		21.8	47.3			
Saikia and de Brito (2010)	Fine Flakes/PET Coarse Flakes/PET Fine Pellet/PET	13.8 28.3 12.2	28.5 47.9 14.6	41.8 64.4 22.4							

Table 5.4.1: Compressive strength of various types of concrete (Nitish et al., 2013)

S/N	Type of concrete	Average Compressive Strength (KN/m^2)		
		7 Days	14 Days	28 Days
1	PVC	19.48	20.67	28.72
2	100% Debris as coarse aggregates	19.97	23.67	31.28
3	50% Debris + 50% coarse aggregates	20.58	21.17	32.37
4	25% Debris + 75% coarse aggregates	21.58	27.20	33.14
5	10% PVC + 90% coarse aggregates	17.97	19.57	26.76
6	5% PVC + 95% coarse aggregates	19.76	20.94	28.87

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 General Conclusions

Recycling and reuse of construction wastes and other waste materials have been found to be an applicable explanation to the problems of dumping debris in the landfills and it also helps to reduce the shortage of conventional aggregates. The use of recycled materials as aggregate in concrete proves to be important beneficial construction materials in terms of technical, environment and economical value. Recycled materials as aggregate exhibit approximately crushing and impact values, lower bulk density, and higher water absorption as compared to natural aggregate. There are several reliable applications for using recycled materials in construction. However, more research should be make for application of recycled concrete by modifying our design codes, specifications and procedure for use of recycled aggregate as a materials in concrete.

6.2 Conclusions on Selected Materials

6.2.1. Glass

- The use of recycled glass, most especially fine waste glass as materials in concrete helps to increase the workability of concrete,
- Recycled glass increased the durability measured by water test i.e. since waste glass does not absorb water, the mix will provide a better strength in lower w/c ratio,
- Recycled waste glass also decreases the unit weight of concrete,
- The modulus of elasticity of recycled glass depends on the compressive strength and unit weight of concrete,
- The use of waste glass as materials for concrete manufacture will help to reduce construction material cost and also the amount of waste glass in landfill.

6.2.2. Bricks

- The higher the crushed bricks substitution, the higher the water cement ratio,
- Recycled bricks as materials in concrete also increase the compressive strength and durability of concrete,

- Recycled bricks influenced the hardened properties of concrete,
- Concrete prepared with recycled bricks show similar behaviour in terms of moisture content against curing age with conventional aggregates,
- The water-cement ratio of recycled bricks as materials in concrete increased as the percentage replacement increased

6.2.3. PVC

- The use of recycled PVC as materials in concrete results in the formation of lightweight concrete,
- Recycled PVC has a considerable decrease in compressive strength and flexural strength,
- Recycled PVC as less reduction in workability of concrete, and also a decrease in unit weight of concrete,
- Recycled PVC has low water absorption rate,
- The use of waste PVC as materials for concrete manufacture will help to reduce construction material cost and also the amount of waste PVC in landfills.

The research on recycled materials from available information gathered from different sources in TRNC, has shown that North Cyprus is still lacking vivid information on how to develop and use recycled aggregates as a replacement of conventional aggregates in concrete production. It was observed that there is no clear and systematic information available from the authorities on the amount of waste from demolished structures and their disposal, there is a lack in the codes, a lack in the organization of handling the wastes, contradictory information were also given by different authorities and no construction industries in North Cyprus practicing the use of recycled materials as a replacement of aggregates in concrete.

6.3. Conclusion on Properties of Recycled Materials in Concrete Manufacturing

6.3.1. Glass Particle Size Range: During the course of this research, the particle size of glass materials used by different researchers is as follows:

- Barbieri et al. (2001) using ASTM standards used a particle size range of <2.0mm and >0.0625mm,

- Federio and Chidiac (2001), used a particle size range of 75µm,
- Shayan and Xu (1999) used a particle size of 12mm-4.75mm for Coarse aggregate, 4.75mm-0.15mm for fine aggregate and <10µm for glass powder,
- Dumitru et al. (2010) used size of 3mm-0.3mm during his course of research.

Percentage of Recycled Glass added to Concrete: During the course of this study, the percentage of recycled glass materials added to concrete by different researchers is as follows:

- Barbieri et al. (2001) added 25%, 50% 75% and 100% of recycled glass materials as aggregates for concrete manufacture,
- Ganiron and Ucol-Ganiron (2013) added 25%, 50%, 75% and 100% of recycled glass materials as aggregates for concrete manufacture,
- Shayan and Xu (2004) added 30% of recycled glass powder as fine aggregates for concrete manufacture,
- Sagoe et al. (2001) added 5-30% of recycled glass materials as aggregates for concrete manufacture,
- Umar et al. (2002) added 10%, 20%, 30% , 40% and 50% of recycled glass materials as aggregates for concrete manufacture,
- Shetty (2007) used glass materials as aggregates for concrete manufacture in the proportion of 20%, 40%, 60%, 80% and 100% respectively,
- Dumitru et al. (2010) added 30%, 45% and 60% of recycled glass materials as aggregates for concrete manufacture,
- Kou and Poon (2009) added 15%, 30% and 45% of recycled glass materials as aggregates for concrete manufacture.

Water/Cement Ratio: During the course of this study, the water/cement ratio of recycled glass materials added to concrete by different researchers is as follows:

- Poutos, and Nwaubani (2013) used a w/c ratio of 0.50 when adding 100% glass as replacement for concrete manufacture,

- Tavakoli and Soroushian (1996) used w/c ratio of 0.55-0.65 added to recycled glass for concrete manufacture,
- Husni (2005) used w/c ratio of 0.265 for coarse glass aggregates and 0.195 for fine aggregates.

Expected Compressive Strength Range: During the course of this study, the compressive strength of recycled glass materials as aggregates in concrete by different researchers are as follows:

- Ganiron and Ucol-Ganiron (2013) results for compressive strength are 10.96MPa, 11.60MPa, 12.08MPa, and 10.12MPa,
- Smith (2009) result for compressive strength using recycled glass aggregates materials of 100% in concrete is 103.4MPa,
- Husni (2005) values for compressive strength of recycled glass for concrete manufacture are 29.4MPa for coarse glass aggregate, 31.2MPa for fine glass aggregates.

Flexural Strength: During the course of this study, the information on flexural strength of recycled glass materials in concrete by different researchers are as follows:

- According to Federio and Chidia (2001), he explain that the chemical composition of recycled glass materials as well as the shape of the aggregates use are mainly influenced by the flexural strength,
- Parl et al. (2004) explains that concrete containing waste glass shows a decreasing tendency in flexural strength with an increased in mix ratio of the waste glass,
- Topcu and Canbaz (2004), Ling et al. (2011) and Batayneh, et al. (2007) also explain that the flexural strength have tendency to decrease with an increase in waste glass content as coarse aggregates in the mixtures.

Workability: During the course of this study, the information gathered on workability of recycled glass materials in concrete by different researchers are as follows:

- According to Schwarz (2008), he explain that glass aggregates improves the workability of fresh concrete,
- Meyer et al. (2001) also explain that the strength of coarse glass in concrete mix is affected by the increase in water cement ratio.

6.3.2. Bricks

Particle Size Range: During the course of this research, the particle size of bricks materials used are as follows:

- According to ASTM standard, crushed clay bricks are materials of aggregate size 0.075mm-50mm.

Percentage of Recycled Bricks added to Concrete: During the course of this study, the percentage of recycled bricks materials added to concrete by different researchers are as follows:

- Poon et al. (2006) added 50% of recycled bricks materials as aggregates for concrete manufacture,
- Kenai et al. (2007) added 25% and 50% of coarse and fine recycled bricks materials as aggregates for concrete manufacture,
- Khatib (2005) use fine crushed bricks aggregate of 25% replacement as materials for concrete manufacture,
- Debieb and Kenai (2008) reports also used 25% fine bricks materials as aggregates replacement for concrete manufacture.

Water/Cement Ratio: During the course of this study, the water/cement ratio of recycled bricks materials added to concrete is as follow:

- According to Akhtaruzzaman and Hasnat (1983) they use a w/c ratio between 0.54 and 0.88 in preparing crushed bricks aggregate materials in concrete.

Expected Compressive Strength Range: During the course of this study, the compressive strength of recycled bricks materials as aggregates in concrete by different researchers are as follows:

- Borcheit et al. (2006) results for compressive strength of recycled bricks are 10.3MPa, and 20.7MPa,
- According to Akhtaruzzaman and Hasnat (1983) from their report, it was shown that the compressive strength of recycled bricks aggregates materials is between 22MPa and 42MPa,
- Khaloo (1994) results on compressive strength of recycled bricks ranges from 26MPa and 41MPa using different proportion of crushed bricks,
- De-Brito et al. (2005) results on compressive strength of crushed bricks as materials in concrete is 13MPa,
- Khalaf and DeVenny (2004) reports on compressive strength is 67MPa when they used crushed bricks as aggregates replacement for concrete manufacture,
- Mansur et al. (1999) reports on compressive strength of recycled bricks as materials in concrete ranges from 40MPa-70MPa.

Flexural Strength: In this study, there is no information on Flexural strength of using recycled bricks as materials for concrete manufacture.

Workability: During the course of this study, the information gathered on workability of recycled bricks materials in concrete by different researchers are as follows:

- Hansen (1992) explain that crushed bricks absorb a large amount of water thereby affecting the workability compare to normal concrete,
- Mulheron and Mahony (1998) explain that concrete containing crushed bricks aggregates as coarse materials had much lower workability compare to conventional concrete,
- Orchard (1993) explain that dust content in recycled bricks decreases the workability, therefore more water should be added to the concrete to increase the workability,
- Hansen and Narud (1983) reported that the workability of recycled brick aggregate decreases with time after mixing compare to that of normal concrete,
- Ravindrarajah (1987) explains that the use of different types of coarse bricks aggregates decreases the workability.

6.3.3. PVC

Particle Size Range: During the course of this research, the particle size of PVC materials used is as follow:

- According to Adnan (2012) report on recycled PVC materials the particle size they use ranges from 3.5mm-4.5mm.

Percentage of Recycled PVC added to Concrete: During the course of this study, the percentage of recycled PVC materials added to concrete by different researchers is as follows:

- Adnan (2012), added 10%, 20%, 30%, 40%, and 50% of recycled PVC materials as aggregates for concrete manufacture,
- Ismail and Al-Hashmi (2008) added 10%, 15% and 20% plastic aggregates as a replacement of fine aggregates for concrete manufacture,
- Al-manaseer and Dalal (1997) use 50% plastic aggregates as replacement for concrete manufacture,
- Choi et al. (2005) reports also used 25%, 50% and 75% PVC materials as aggregates replacement for concrete manufacture,
- Batayneh et al. (2007) uses 5% and 20% plastic aggregates replacement for concrete manufacture,
- Frigione (2010) added <5% plastic aggregates as a replacement of fine aggregates for concrete manufacture,
- Hannawi et al. (2010) added 3%, 10%, 20% and 50% of recycled PVC materials as aggregates for concrete manufacture,
- Kou et al. (2009), added 5%, 15%, 30% and 45% of recycled PVC materials as aggregates for concrete manufacture,
- Saikia and de-Brito (2010) added 3%, 5% and 10% of recycled PVC materials as aggregates for concrete manufacture.

Water/Cement Ratio: During the course of this study, the water/cement ratio of recycled PVC materials added to concrete is as follows:

- According to Al-manaseer and Dalal (1997), they use a w/c ratio 0.54 in preparing PVC aggregate materials in concrete.

Expected Compressive Strength Range: During the course of this study, the compressive strength of recycled PVC materials as aggregates in concrete by different researchers are as follows:

- Batayneh et al. (2007) results for compressive strength of recycled PVC are between 23MPa-72MPa,
- According to Frigione (2010) report, it was shown that the compressive strength of recycled PVC aggregates materials is <2MPa,
- Hannawi et al. (2010) results on compressive strength of recycled PVC ranges from 6.8MPa-69MPa,
- Kou et al. (2009) results on compressive strength of recycled PVC as materials in concrete is between 9.1MPa-47.3MPa,
- Saikia and de-Brito (2010) reports on compressive strength of recycled PVC as materials in concrete ranges from 3MPa-64.4MPa.

Flexural Strength: In this study, Saikia and de Brito (2012) reports on recycled PVC shows that plastic has low bonding properties thereby reducing the flexural strength.

Workability: During the course of this study, the information gathered on workability of recycled PVC materials in concrete by different researchers are as follows:

- According to Koehler and Fowler (2003), it was discussed that the major factor to check in concrete is the workability,
- Al-manaseer and Dalal (1997) explain that concrete there is an increase in slump when plastic aggregates are added to concrete,
- Ismail and Al-Hashmi (2008) reports shows that there is a lower value in workability due to the incorporation of several types of plastic aggregates.

Table 6.3: Properties of Recycled Materials used in Concrete Manufacturing

Properties when used in concrete	Materials Glass	 Bricks	 PVC
Particle size range	Coarse glass aggregate 12mm-4.75mm Fine glass aggregate 4.75mm-0.15mm Glass powder <10µm	4.75mm – 38.1mm	3.5mm-4.5mm
Percentage added to concrete	5– 80%	25- 50%	3 - 75%
w/c range	0.195-0.65	0.30-0.90	0.5-0.74
Expected Compressive Strength Range	10.12-103MPa	3.5- 70MPa	2-72MPa
Flexural strength	1-8MPa	No information on Flexural Strength has been found in the articles studied	PVC has low bonding properties thereby reducing the flexural strength
Workability	Recycled glass improves the workability of fresh concrete compared to normal concrete	Recycled bricks have low compressive strength compared to Normal concrete	PVC have less reduction in workability compared to normal concrete

Note that during the course of this research, no information has been found on the unit weight, fire resistance and thermal properties of concrete made with recycled glass, bricks and PVC, within the references covered during the course of this research.

6.4 Recommendations

1. Waste and recycling management plans should be developed for construction project in TRNC prior to the start of work in order to sustain environmental, economic, and social development principles,
2. A standard should be generated i.e. code so as to follow this standard as a guidelines for civil engineering practices
3. A comparison between the cost of natural and recycled aggregate should be considered in the project management plans, taking into consideration the availability of this materials, and location where to get them,
4. A comparison should be carried out on the test between conventional concrete and recycled concrete so as to have knowledge and also distinguish between the strength of concrete made with recycled and conventional aggregate which will serves as a guidelines for similar practices in future,
5. There should be an organization owned either by the government or private, which will be monitoring and coordinating the waste materials and it disposal in TRNC, thereby having idea or information on where to get all this materials when needed.
6. It is also recommended that concrete with recycled materials of lower strength should be used in civil engineering applications, especially in non-structural applications, mostly where lower strength up to 25MPa is usually required, thereby contributing to the reduction of cost of the materials in concrete production,
7. Future studies should be carried out on unit weight, fire resistance and thermal properties of concrete made with recycled glass, bricks and PVC.

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