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TECHNOLOGY AND INNOVATION

PERFORMANCE OF SELECTED WASTE MATERIALS AS AGGREGATES IN CONCRETE

This Thesis submitted to the Pan African University, Institute of Science, Technology and Innovation, in partial fulfilment of the requirement for the award of the degree of Master of Science in Civil Engineering (Structural Engineering Option) of the Pan African University 2016.

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Declaration

I declare that this thesis is my original work and has not been submitted to any educational institution or University for the award of a certificate. Therefore, the materials quoted in this thesis, which are not mine have been duly acknowledged.

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Dedication

To all those who lead monotonous lives, in the hope that they may experience at second hand the delights and dangers of adventure.

Acknowledgement

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Abbreviations

ACI	American Code Institute
ASTM	American Standard of Testing and Materials
BS	British Standard
CAC	Conventional Aggregates Concrete
CaO	Calcium Oxide / Lime
CC	Coarse Ceramic Tiles Aggregates
CG	Coarse Glass Aggregates
CO_2	Carbon (IV) oxide
CRT	Coarse Rubber Tyres Aggregates
FC	Fine Ceramic Tiles Aggregates
FE	Finite element
FG	Fine Glass Aggregates
FRT	Fine Rubber Tyres Aggregates
GC	Glass Concrete
HDPE	High Density Polyethylene
IS	Indian System
JICA	Japan International Cooperation Agency
NCAC	Non-conventional Aggregates Concrete
RCAC	Reinforced Conventional Aggregates Concrete
RNCAC	Reinforced Non-Conventional Aggregates Concrete
RTC	Rubber Tyres Concrete
SI	International System
W/C	Water/Cement Ratio

Abstract

Waste materials have many unfavourable effects on the environment which are deleterious to the human. The high cost of construction materials demands another suitable substitute. Due to the poor recycling of waste materials, engaging the waste materials in the construction represent process has many benefits especially, on the environment, economy, and health. In this study, waste materials such as glasses, ceramic tiles, and rubber tyres that have been used for many decades were tested, prioritized, and used as aggregates in concrete. In addition, the research reveals the influence of the respective waste materials namely glass, ceramic tiles, and rubber tyres on the concrete whether hardened or fresh concrete. This research looks at the differences between the British Standard (BS) and the American Code Institute (ACI) methods in the mix design of concrete and concrete properties of the non-conventional aggregates concrete and compares it with the normal concrete. Moreover, this research explores the mechanical properties of the reinforced non-conventional aggregates concrete. Also, the crack patterns of the reinforced non-conventional concrete illustrates experimentally. To do this, a finite element model was prepared. the results demonstrated that ceramic tile and fine glass aggregates are suitable as for concrete. It was also concluded that sand and gravel should not be replaced more than 50% and 25% respectively. The Finite Element Model and the laboratory experiments have an acceptable degree of corroboration.

Chapter One

Introduction

1.1 Background to the study

Reinforced concrete is a common material in the construction of structures around the world. Usually, the constituent materials for production of the concrete consist of aggregates, cement, and water. For a high - quality concrete, the ratio of aggregates should constitute about three - fourths of the total volume of concrete (Malhotra, 1996). There are requirements for the other materials as well. Therefore, the required performance of the concrete cannot be achieved without having proper design of constituent materials in concrete.

Currently, world cities generate about 1.3 billion tonnes per year of solid waste materials. This volume is expected to increase to 2.2 billion tonnes by 2025. Waste generation rates will more than double over the next twenty years in lower income countries. Globally, solid waste management costs will increase from today's annual $205.4 billion to about $375.5 billion in 2025. Cost increases will be most acute in low income countries, and lower-middle income countries (Lagerkvist, 2010).

In addition, Africa alone contributes 5% of the global waste materials. Although 5% contributions from Africa may seem to be a much smaller quantity, it is a significant amount based on the overall amount of the world's wastes. 54% consists of inorganic materials made up of paper, glass, plastic, metal, and others with 17%, 5%, 10%, 4%, and 18% respectively. The remaining 46% consist of organic waste materials, and it includes foods and agricultural wastes (Thompson, 2012).

In Kenya, the environment is highly polluted due to the various types of garbage resulting from the different sources. Based on Kasozi & Harro, (2010) study, the garbage in Nairobi consists of 58.6% Biodegradable, 11.9% Papers, 15.9% Plastics, 1.9% glass, 2% Metal, and 9.7% others. JICA report that, the garbage includes 1% leather, 2% rubber, 2.7% ceramic and soil, and 6.7% Grass/Wood. ("JICA Strategy

Paper on Solid Waste Management," 2014). JICA estimated the total garbage generated each day in Nairobi is 1530 tonnes of which 82.8% (1266.84 ton/day) come from households. In 1999, the population of residents in Nairobi was 2,143,254 persons with an average capita residential garbage generation rate of 0.59kg per day for each person. Recycling of the garbage is one way of solving this problem, but very few countries have been carrying out this, with most using of landfills to get rid of the waste materials. Similarly, Kenya has been using landfills, with the main dumpsite for the majority of the wastes from Nairobi dumped at the Dandora dumpsite (Baud *et al*., 2004) and (Kasozi & Harro, 2010). It is significant to appreciate the fact that in Kenya as well as other developing countries, solid waste in mainly collected and disposed in open dumpsites. Therefore, utilizing these waste materials can provide a good substitute for conventional materials, and decrease the cost of construction.

The economy of Kenya is growing at a very high rate and because of this it has resulted into the progression of construction projects. Most of these projects include construction of buildings such as malls, apartments, car parking structures and many others. Other such projects include the construction of roads, airports, bridges (on highways and the standard gauge railway spanning from Kenya, through Uganda to Rwanda and South Sudan) and many others. The construction sector in 2014 contributed a massive 4.8% of the total economy in Kenya and 4.5% in 2013 with a higher projection for 2016 (Budget Brief Regional Economic Highlights, 2016)

The study of these waste products as non-conventional construction materials is greatly required as it will be a guide to ascertain whether these may be used as alternative materials. The merits of the use of these materials are vast and will have a great impact on reduction of costs on the economy, as such resources may be diverted to other paramount sectors and also will reduce the pollution of the environment. The production of crushed aggregates in the construction quarries leads to the release of large quantities of carbon dioxide gas into the atmosphere during the manufacturing process which is unsafe for the environment (Faculty of Engineering, Civil & Team, 2016).

1.2 Problem statement

Construction cost has been rising due to increase in the cost of materials and there is a need to come up with substitute materials which are cheaper but when applied provide structurally safe structures. On one hand, the disposal of garbage has many repercussions. For instance, poor disposal may be unhealthy and lead to disease outbreak such as cholera. It may also be dangerous to domestic animals.

In a similar manner, the wastes are a nuisance to the environment; such as plastics reduce the fertility of soil and will stay in the soil for very long periods as they do not decompose. They may also impede the flow of water in cases where the solid waste particles are big sizes. As such they affect the environment in many different ways that will be put right or the implications reduced if used as alternative construction materials. The impacts of waste to the environment, especially non-biodegradables such as plastics and rubber tyres cannot be overstated. Land quality is compromised by the presence of wastes. Blocked drainage systems and overflowing/burst sewers are sources of diseases that wreak havoc to human health with abandon. The consumer is paying heavy medical bills for diseases which would have been kept at bay if wastes were properly disposed.

On the other hand, the process of the manufacture or preparation of the conventional materials such as aggregates, sand and others entails crushing of rocks and boulders. This results into the propagation of large amounts of carbon dioxide as already discussed in the background of the study. As is well known, the carbon dioxide emission to the atmosphere affects the ozone layer resulting into the current predicament that the world is facing called global warming. Global warming is a hypothetical severe increment in Earth's temperatures, with disastrous environmental consequences to humans, animals, and plants (Soon, Baliunas, Robinson, & Robinson, 1999).

In fact, the high percentage of waste materials in Kenya (1266.84 ton/day) is unprecedented and unacceptable, especially, glass, metals, and rubbers which can recycle perfectly. Furthermore, poor disposal of garbage has an effect on the general appearance, and it reduces the crawling green. Moreover, the recycling of waste materials in Nairobi is insufficient (Kasozi & Harro, 2010). Hence, these problems aforementioned have to be under consideration, and treat it seriously.

In addition, modelling of reinforced non-conventional aggregates concrete (RNCAC) is limited in comparison with reinforced conventional aggregates concrete (RCAC). Especially, in terms of flexure, cracks patterns, and stress – strain relationship. The normal aggregates have less elasticity in comparison with waste materials which have no chemical effects on the concrete. Hence, it leads to lower nonlinearity in the concrete elements. This unsatisfying elasticity in the concrete is one of the problems of this study.

1.3 Study justification

The use of solid waste materials to produce structural concrete could alleviate the problem of waste Disposal.

The main target of this study is to provide a good solution to the disposal of inorganic waste materials by using them in producing concrete. Therefore, that will reduce the cost accordingly, and it will help in the disposal of garbage. Also, the pollution that comes from the waste materials will reduce, and the environmental risks which come from the manufacturing of the normal aggregates will also be less.

The propagation of harmful gases from the process of crushing aggregates and manufactured cement has to be curbed. More research is needed to find suitable substitute construction materials necessary to reduce infections related to waste, and protect the environment. In addition, this study will give a list of waste materials sorted in order of priority for use in concrete making. The properties of the non-conventional aggregates concrete (NCAC) have to be studied sufficiently, and compared with the normal concrete. It is therefore justifiable to find means of utilizing waste materials in concrete instead of the conventional aggregates.

Furthermore, a model of RNCAC can be applied in Finite Element program to provide the linear and nonlinear behaviour when it is subjected to a static load. That model can also serve to predict the cracks patterns, maximum stresses, maximum strains, and other forces like bending moment and shear. Thus, it can be exploited and developed in further studies. Also, it can validate the experimental results for both RNCAC and RCAC behavior. However, the new generation of the structures demands high resistance with superior capability to sustain heavy loads. Finally, this study should help in the recycling process and the disposal problem.

1.4 Objectives

1.4.1 General objective

The main objective of this research is to investigate the performance of selected waste materials as aggregates in structural concrete.

1.4.2 Specific objectives

1) To identify which of the selected waste materials can be used as alternative aggregates for concrete production.
2) To investigate the influence of glass, ceramic tiles, and rubber tyres on both the mix design and the concrete properties.
3) To apply a Finite Element Model (FEM) in characterising the structural behaviour of non-conventional aggregates concrete.

1.5 Research questions

1) What is the best among the selected waste materials to be used as alternative aggregates in concrete?
2) What is the influence of the selected waste materials on the mix design and the concrete properties?
3) How does FEM analysis of structural concrete made form RNCAC and RCAC respond?

1.6 Scope

The main scope of this study is to investigate the utilization of glass, ceramic tiles, and rubber tyres as aggregates as structural concrete for the construction Industry. This research is aimed to give preference in using the glass, ceramic tiles, and rubber tyres. Thus, the characteristics of glass, ceramic tiles, and rubber tyres were tested individually. Using the waste materials influenced concrete properties such as; mix design proportions, concrete density, workability, compressive, splitting tensile, and flexural strengths. As a result, it gave a very good reason to examine the characteristics of concrete. It is therefore necessary to carry out a comparison between the normal concrete and the modified concrete. As a matter of emphasis, the compressive strength study was done using both BS and ACI method.

In addition, the linear and non-linear behaviour was obtained by apply a Finite Element model using ANSYS. Cracks patterns, maximum load, and maximum displacement were also obtained. ANSYS results were compared with experiment results.

Chapter Two

Literature Review

2.1 Theoretical background

Traditionally, aggregates consist of fine and coarse components. Fine and coarse aggregates can be obtained naturally or crushed (F. Chen & Richard, 2003). In other words, aggregates are a granular material gained from treating natural materials (BS EN 12620, 2002). Because aggregates represent form 60 to 80% of concrete volume, it characterizes the hardness of the concrete. (Nawy, 2005). Aggregates that are retained in sieve No. 5mm is known as coarse aggregates, and aggregates that passed sieve No. 5mm or have sizes less than 5mm is fine aggregates (Kong & Evans, 1978). The shape of surface and the physical properties affects the strength of concrete.

The surface of aggregates provides the bond between the cement paste and aggregates. It could also hold the water of the subsequent hydration reactions (Neville, 1981). Aggregates should be clean, hard, and it did not react chemically with cement (Wilson & Kosmatka, 2011).

The characteristics of aggregate appear in many properties such as; particles size distribution, particle shape, surface texture, unit weight, specific gravity, density, absorption, and surface moisture (Wilson & Kosmatka, 2011). Additionally, the resistance to freezing, dry wetting properties, shrinkage, strength, resistance to acid, thermal properties, and fire resistance represent a major part for determining the quality of aggregates (ASTM C33 /C33M-16, 2000).

The uncrushed smooth and rounded coarse aggregates lead to lower strengths than the crushed aggregates, although the workability will be more (MacGinley & Choo, 1990).

In case of the nominal maximum size of the coarse aggregates for reinforced concrete are normally 20 mm. the maximum size of aggregate depends on the dimensions and the spacing between the reinforcement steel bars. The good practice ensures that the maximum size of the aggregates is not more than 25% of the minimum thickness of the member and the cover. By contrast, the workability concerning the size of the aggregates should be reasonable (Kong & Evans, 1978).

According to (Kong & Evans, 1978), the strength of aggregates has no effects on the strength of the bond between the cement paste and aggregates. The strength of concrete does not depend only on the strength of aggregates, but also on the surface characteristics (BS 812: Part 2, 2002). As a result, the primary purpose of aggregates is to provide the strength and the specific surface. The recommended strength of aggregates is above 100 N/mm^2.

Aggregates properties have an influence on the workability in two ways. First and foremost, the particles size distribution, and it is normally determined by sieve analysis test. Second, is the nature of aggregates particles, and it considers the shape, porosity, and surface texture of aggregates (Wilson & Kosmatka, 2011).

2.2 Selected waste materials

In this research, some selected waste materials such as glass, ceramic tiles, and rubber tyres were suggested to replace the normal aggregates. From the theoretical aspects, density of glass, ceramic tiles, and rubber tyres affect the concrete density and the mix design proportions. The physical and mechanical properties of selected waste materials give strong motivation to use it as aggregates. Glass, ceramic tiles, and rubber tyres were used as aggregates lastly in many studies. In the following clauses, the theoretical and experimental background were demonstrated.

2.2.1 Ceramic Tiles

Theoretically, ceramic tiles originally were manufactured from clay. (ASTM C373-88, 2006) classified the ceramic tiles into categories depends on the water absorption. Impervious, which has 0.5 % or less water absorption. Vitreous, with water absorption 0.5%, but not more than 3%. Semi-vitreous, which has more than 3.0%, but less than 7.0%. Non-vitreous, with water absorption more than 7.0 % (ASTM C373-88, 2006) and (ASTM C650-04, 2004). Other properties were checked according to ASTM

C373-88 such as scratch hardness. ASTM usually tests the breaking strength, chemical resistance, and abrasion resistance.

Taylor et al., (2015), compared ceramic tiles with normal aggregates. The water absorption of the ceramic tiles was 0.55%, while sand was 2.24%, and gravel was 0.23%. The density also was checked, it is 2.4 for ceramic aggregates, 2.83 and 2.64 for sand and gravel respectively. Obviously, the density of the ceramic tiles aggregates is close to the normal aggregates (Taylor et al., 2015). Moreover, the resistance of fragmentation of the ceramic tiles aggregates is 0.55, and it is 0.23 for the gravel. It also indicates that the ceramic tiles aggregates are suitable for using as aggregates (Taylor et al., 2015).

Experimentally, Poon & Chan, (2007), summarized the details of a building called *Wetland Park* in Hong Kong. Wetland Park was constructed from concrete made from recycled brick and ceramic tiles. The building consumed approximately 14,300 m^3. A study was needed to investigate the possibility of using this waste in concrete. Normal sand was replaced by 20% to 100% depending on the class of concrete. Results showed that slightly decrease in the density of hardened concrete. The compressive strength also decreased, and the modulus of elasticity was less than the control.

Senthamarai & Manoharan, (2005), used ceramic tiles as gravel in concrete. They recommended that ceramic tiles can be used as coarse aggregates. Although, the compressive, splitting tensile, and flexural strengths were slightly lower than the normal concrete strengths. Ceramic tiles properties are nearly similar to the conventional aggregates. In their study, an attempt was made to find the suitability of ceramic wastes as a possible substitute for conventional crushed stone coarse aggregates. Thus, the properties of aggregates were compared. Results indicate that the workability of ceramic tiles concrete did not change, and the strengths are similar to the control.

In addition, Taylor et al., (2015) studied the replacement of gravel by coarse ceramic tiles with particles size ranged from 12.5mm to 4mm. Mix design proportions showed that the amount of aggregates increased, when the recycled aggregates replaced.

While the quantity of cement – water did not change. Results showed that the replacement of ceramic tiles as gravel has no negative effects on the mechanical properties of concrete.

Hemanth Ch et al., (2015), replaced partially the sand and gravel by 10% and 20% fine and coarse ceramic tiles respectively. Aggregate tests confirmed that the coarse ceramic tiles have more impact factor, but less specific gravity than the gravel. Meanwhile, fine ceramic tiles are almost having the same specific gravity of the sand. Results demonstrated that the strength and workability increased, when the fine and coarse ceramic tiles were used. Kamal and B. Krishna R. (2014), also found that gravel can be replaced by coarse ceramic tiles aggregates partially in concrete. The strength did not affect, when gravel replaced by up to 40%.

A. M. Mustafa Al Bakri1 et al., (2013), investigated the strength of concrete with ceramic waste as a replacement of coarse aggregates in concrete. Results showed that the concrete which contains recycled ceramic waste aggregates achieved the strength levels between 80 to 95% compare to the control.

Ceramic tiles have been employed consequently in architecture throughout history: The Great Wall of China, the dome of Florence Cathedral and the Chrysler building in New York are just some examples. Furthermore, due to their many aesthetic possibilities, ceramic materials are frequently used for surfacing, whether on walls (cladding) or floors (flooring), and both outdoors (walls, roofs and paths) and indoors (kitchens and bathrooms).

2.2.2 Glass

Mechanically, the density of glass is 2500 kg/m^3, with compressive strength of 1000 N/mm^2. Its Young' modulus is 70 Gpa, and Lateral contraction coefficient is 0.22. The linear thermal expansion is 9 x 10-6 m/Mk.

Glass has been used increasingly in the last few years (Dalloul, 2013). Furthermore, many of the studies investigated the replacement of glass in concrete. Shayan, (2002), stated that glass is inappropriate for the alkali-silica reaction. As a result, pulverizing the glass and used as pozzolanic materials. Their recommendation was that 30% of the cement can be replaced by the pulverizing glass. At that replacement, the concrete gave compressive strength more than the normal gravel (Shayan, 2002).

Siam & Al-qedra, (2007), summarized that the waste glass used as coarse and fine aggregates with 0.4 w/c ratio. Compressive strength was 385 kg/cm^2 and 400 kg/cm^2 for coarse and fine glass replacement respectively compared to 300 kg/cm^2 for normal concrete. The flexural strength was enhanced, and a slight reduction in the splitting tensile strength.

Batayneh, Marie, & Asi, (2008), studied the use of glass, demolished concrete, and ground plastic in concrete. Sand and gravel were replaced by up to 20%. The density and the workability decreased with increase in the waste amount. compressive strength improved, when the fine glass was used. But when ground plastic was used, the compressive and splitting tensile strength decreased.

Suganthy, Chandrasekar, & K, (2013), replaced the sand by fine glass aggregates. Glass type HDPE was used (High Density Polyethylene). Replacement percentages were; 0% ,25%, 50%, 75%, and 100%. Results illustrated that when the quantity of glass was less, the strength was also less, But the difference was not substantial. Therefore, their research recommended that the pulverized plastic can be adopted as sand up to 25% replacement.

M. Iqbal Malik et al., (2013) substituted the sand by waste fine glass. Sand were replaced by fine glass weight at 10%, 20%, 30% and 40%. Results demonstrated that permissibility of using waste glass powder as partial replacement of the sand up to 30% by weight.

Vijayakumar, Vishaliny, & Govindarajulu, (2013), used glass powder as cement in concrete at replacement percentages; 10%, 20%, 30% and 40%. From the results the glass powder can be used as cement.

2.2.3 Rubber Tyres

(Grinys, Sivilevi, & Daukšys, 2012) and (Neil & Senouci, 1994) used rubber tyres as sand partially in concrete. Results showed that the strength and density of rubberized concrete decreased. (Batayneh et al., 2008) addressed that the compressive strength and splitting tensile strength were reduced, when the sand was replaced. In spite of, it complied with the requirements of lightweight concrete. This research would emphasize this point, where the applicable applications of this concrete can be used.

Grinys et al., (2012) used rubber as sand. Results showed increase in the splitting tensile, and they retained that increase to the adhesion between the cement paste and rubber particles. Although, the compressive and splitting tensile strengths were less than the control, the absorption of the plastic energy is higher. The density of concrete decreased, when the amount of rubber increased (Neil & Senouci, 1994). Otieno, (2015) found out that the compressive strength decreased, when rubber tyres aggregates replaced partially the gravel. Hence, the use of rubber tyres has not been recommended in the structures, where high compressive strength is required.

Batayneh et al., (2008) replaced also the sand by crumb rubber tyres. Their main observation in the mixture was the volumetric percentage of rubber tyres. Compressive strength, splitting tensile strength, and workability decreased, when rubber tyres replaced the sand. Other authors studied the rubber in self-compact concrete, and it helped in binding the rubber phases (Bignozzi & Sandrolini, 2006).

Lu, Chang, & Maw, (2015) referred the drop in the strength to the local imperfections in the cement hydration. Experiment showed that rubber disturbed the water transfer to generate waterways. Thus, the bond between the cement paste and rubber particles was not sufficient (Lu et al., 2015).

2.2.4 Other Used Waste Materials

Other waste materials were used in concrete. Recycled aggregates from the concrete used before also has an excellent impact, when its utilization in concrete (Wilson & Kosmatka, 2011). Yehia, Rashwan, Assaf, & Samee, (2014) prove that 20% of recycled concrete aggregates were improved flexure performance of the reinforced concrete beam.

The Coconut shell, sisal fibre, and PET plastic in concrete as aggregates, the lengths of these materials were; the Coconut shell is ¾ in (19.05 mm), sisal fibre is 3/8 in (9.525mm), and the PET plastic is 6 in (152.4 mm). Results showed that; the coconut shell is suitable as aggregates, but the concrete contains sisal fibre did not give the specific compressive strength. Moreover, adequate compressive strength observed, when the PET plastic used (Watkins, 2014). Also, the plastic bottles were made from polyethylene terephthalate (PET), and it has been used for a long time in concrete partially or wholly. It showed a perfect results, and it is very useful in concrete as sand (Konin, 2011).

In addition, the concrete debris, PVC scrap, and leather waste used partially in concrete 25MPa. The weight, compressive strength and workability were checked and compared with conventional concrete. Compressive strength increased in the lightweight concrete, when the concrete debris replaced entirely and partially. Although, the workability was affected slightly. The leather waste did not do well in concrete, and it gave zero compressive strength, when it employed as fine aggregates (Puri, Kumar, & Tyagi, 2013).

Industrial wastes have a part in the endeavouring to discover valuable waste materials in concrete mix. The slag (crystallized & granular) produces by-products from the industries used as aggregates applying Taguchi's Approach for Optimization. The replacement of the gravel alone showed that 5% of the slag increased the compressive strength by 7% compare with the control. Additionally, the replacement of fine aggregates alone and both fine and coarse aggregates demonstrated 30% to 50% (Nadeem & Pofale, 2012).

The pulverized plastic was utilized in concrete instead of fine aggregates. The plastic has seven types and any type has its own recycling rate. The High-Density Polyethylene (HDPE) is obtainable, and it has more density than the other types. The density of pulverized plastic is 460 kg/m^3 with 0.46 specific gravity. Results gave more strength than the normal concrete. It increased from 3 to 3.2 N/mm^2 at 7 days, and from 4 to 6.5 N/mm^2, when the replacement was 25% and above (Suganthy et al., 2013).

Evangelista & Brito, (2007), investigated reuse of fine recycled concrete aggregates. The original concrete (OC) is the concrete that crushed and obtained the fine recycled aggregates. Recycled sand gave suitable grading in comparison with the normal sand. Results showed that when the added percentage is up to 30%, the strength did not change significantly. Splitting tensile strength and modulus of elasticity decreased, when the percentage of replacement increases. The abrasion resistance increases with the replacement of normal sand by recycled sand.

Moriconi, (2003), made use of fly ash in concrete. W/C ratio was 0.6 for control, and 0.3 for recycled concrete. Compressive strength, tensile and bond strength were good in comparison with the control. The stiffness of the recycled concrete is less than the normal.

Yehia et al., (2014), investigated the performance of RC – beams made from recycled aggregates using non-traditional admixture. The admixture that was used is waste from vegetable oil industry with different added percentages (0%, 20%, 30% and 40%). Eight beams were cast with a cross section of 120mm x 300mm x 2800 mm. Beams were tested under four points static load. Other tests like deformation characteristics, modulus of elasticity, and toughness were conducted. Results showed that the vertical deflection was reduced, while the modulus of elasticity and toughness were improved. Thus, the research recommended was that the recycled concrete can be used, but with not more than 20% replacement.

Ergun, (2011), used the red mud in concrete with 5%, 10%, and 15% replacement of the cement. When the cement was replaced by 5% chromite industry waste and 5% red mud, the compressive strength was the same, and the workability did not effect.

Katz, (2003), checked the recycled aggregates from hydrated old concrete. 100% replacement of the normal aggregates substituted by recycled aggregates. From experiment, it observed that the recycled aggregates which crushed at different ages were nearly similar. The grading of the aggregates, water absorption, bulk-specific gravity, bulk density, cement content, and crushing value were the same for the different ages of crushing. The strength of recycled concrete was less than the conventional concrete, when the replaced percentage was 100%. But it increased when the percentage was lower. Strength of concrete made from recycled aggregates after 3days was better than the recycled aggregates after 28 days.

Arulrajah, Piratheepan, Bo, & Sivakugan, (2012), investigated the use of recycled crushed brick, recycled normal aggregates, and crushed rock for pavement sub-base uses. Laboratory tests were conducted on mixtures of 10%, 15%, 20%, 25%, 30%, 40%, and 50% crushed brick blended with recycled concrete aggregates or crushed rock. From the results, it was suggested that up to 25% crushed brick could be safely added to recycled concrete aggregates and use pavement sub-base applications.

Ankit J Patel et al., (2014) and A. V. Sai et al., (2014) replaced the cement by quarry dust and Metakaolin. Metakaolin is a DE hydroxylated form of the clay mineral kaolinite. The study found that 25% of the partial replacement is beneficial for the concrete without loss in the strength of concrete. Concrete made of 25% replacement of cement with quarry dust as constant, 2.5%, 5.0%, 7.5%, 10.0%, 12.5% of Metakaolin. Results showed that the quarry dust and Metakaolin can be used partially instead of cement.

The partial replacement of cement in concrete by use of waste materials such as steel Slag. They have studied that aggregates occupy 70 – 80 percent of the volume of concrete (Subramani & Ravi, 2015).

Yerramala, (2014), investigated the use of poultry waste in concrete through the development of concrete contains eggshell powder (ESP). Cement was replaced by 5 – 15% of ESP. at 5% replacement of the eggshell powder (ESP), the strength was greater than control concrete and indicates that 5% ESP is an optimum content for maximum strength. They have resulted that addition of fly ash along with ESP was beneficial for improving the performance of concrete. Raval, Patel, & Pitroda, (2013), studied the replacement of (OPC) cement by ceramic waste powder accordingly in the range of 0%, 10%, 20%, 30% 40%, & 50% by weight, and they got better results.

Lakshmi & Nagan, (2010), used non-biodegradable waste such as electronic waste as coarse and fine aggregates. Coarse aggregates were replaced by percentage ranging from 0% to 30%. Compressive, splitting tensile, and flexural strengths increased, electronic wastes were utilized as aggregates.

Christy & Tensing, (2010), investigated the replacement of cement by Class-F fly ash at 0%, 10%, 20%, 25% and 30% replacement. Strength increased due to these replacements. They concluded that fly ash class-F can be effectively used in masonry with compressive strength of the brick unit ranges between 3-20 N/mm^2.

Muthusamy, Sabri, Resources, & Razak, (2012), made concrete mixes containing 0%, 5%, 10%, 15%, 20%, 25% and 30% cockle shell as aggregates. Workability and compressive strength were conducted. Results showed that replacement of appropriate cockle shell content able to produce workable concrete with satisfactory strength. Integration of 20% cockle shell improved the strength of concrete.

Suman, Saxena, & Arora, (2015), studied the use of rice husk ash as cement, and ceramic tiles as coarse aggregates. Results gave effectiveness of use ceramic tiles as coarse aggregates by partially 20%, 30%, 50%. Also, cement was replaced by rice husk ash with 10%,15% and 20% without influence the strength.

Finally, glass and ceramic tiles were highly encouraged to use as aggregates. Numerous studies demanded more investigation on the glass and ceramic tiles. Although, the rubber tyres reduced the strength, it has a high wear resistance. Which makes it interested to use in different ways.

2.2.5 Research gap

This study establishes the technical viability of utilising a composite waste materials consisting of a combination of glass, ceramic tiles, and rubber tyres as a potential eco-concrete material. Many of the studies have investigated the performance of individual waste materials. i.e. the composite waste material. This research therefore intends to further establish the performance of a composite of two or more of the identified waste materials as course and fine aggregates in concrete.

This study established the priority of using glass, ceramic tiles, and rubber tyres in concrete instead of normal aggregates. As a result, the combination of waste materials influences the mix design proportions, and the concrete properties as well. Here, design mix of concrete was done according to both DOE and ACI, and concrete tests were carried out according to BS and ACI. Thus, the comparison between the two methods for these types of concrete have not been covered fully.

Accordingly, the structural behaviour of the modified reinforced concrete is also represented a research gap. Modelling of reinforced conventional concrete was done, and many studies were conducted. The model of the reinforced concrete which contain the selected waste materials was not done before.

Some limitations face the study to establish the objectives. The method of preparing the rubber tyres to be as coarse aggregates takes time and effort. Also, the lack of the literature on the model of non-conventional concrete limited the study.

Chapter Three

Materials and Methods

3.1 Materials preparation and properties

3.1.1 General

The experimental program under this research was carried out at the structural laboratory of Jomo Kenyatta University of Agriculture and Technology in 2016. This chapter presents the type of materials that were used. It also contains the scientific methodology that was followed for; testing the used materials, conducting the proposed experiments, and modelling the chosen structural element. The work plan of the experiment and the research method were demonstrated.

3.2 Materials

In this research, the material that were used consist of cement paste (cement and water), and the filler materials (aggregates). Aggregates consist of coarse and fine aggregates which are usually gravel and sand. For the cement paste, Ordinary Portland Cement (OPC) class 32.5R and clean potable water were used. In addition, waste materials such as; glass, ceramic tiles, and rubber tyres were used as aggregates, replacing gravel and sand.

3.2.1 Conventional aggregates

Conventional aggregates are gravel and sand. Gravel that was used is crushed stone with maximum size of 20mm. River sand was used as fine aggregates. Sand has maximum particles size of 5.0mm. Gravel and sand passed sieve No. 20mm and sieve No. 5 were used. After sieving the gravel, it was washed once. Therefore, all clay and other deleterious materials were removed.

3.2.2 Glass

Glass which was used throughout this research is tough material naturally transparent. It has been used in windows and doors with maximum thickness of 1.0 cm. It is made mainly from sand (silicates) and an alkali (Lenntech, 1998). It is cooled rapidly forming, and other materials are contributing to manufacture it such as; Soda Ash (sodium carbonate Na2CO3), limestone (calcium carbonate), and dolomite.

3.2.3 Ceramic tiles

Ceramic tiles are inorganic substances obtained from different raw materials. Principally, clay which are stabilized by firing at temperatures between 700°C to 1800°C depending on the final product desired, acquiring a stony consistency in the process. The chemical composition of tiles materials can vary considerably and hence they produce different properties (Taylor et al., 2015). They also have a high melting point, are aseptic, do not transmit odours or bacteria and require little maintenance. Due to these properties, ceramics are considered an extremely useful building material. Ceramic tiles that were used in the study are broken ceramic. It was brought from a ceramic company.

Ceramic tiles have different mechanical properties that depend on the type of ceramic. E.g. the ceramic which is commonly used in buildings, has a young’s modulus between 350 – 670 GPa. Most of the typical ceramic tiles have young’s modulus 450 GPa, Poisson’s ratio 0.126, and shear modulus of 182 GPa (A. A. Wereszczak et al., 0000 EDITED).

3.2.4 Rubber tyres

Rubber normally has a tensile strength ranged between 10 to 21.5 MPa, and the elongation at break is from 101 to 789%. Its flexural strength and flexural modulus ranges between 10 – 25.4 and 278 – 1154 MPa respectively. Tensile impact strength is 144 to 577 kg/m^2, and it has hardness between 28 – 42. (Puşcă, Bobancu, & Duţă, 2010). The polymer of rubber tyres is called Polybutadiene, and it has an extreme wear resistance. The high elasticity in the polybutadiene presented consisted positive aspect of using it as aggregates.

3.3 Materials test

Aggregates and waste materials were tested to evaluate their properties. These tests were done according to specific standards as mentioned in the following clauses. For a purpose of using them in mix design.

3.3.1 Particle size distribution

The particle size distribution was conducted for both coarse and fine aggregates. This test was done by using the grading sieve analysis according to (BS 812-103/1, 2000) and (BS 812-103/2, 2000). BS 812-103.1&2 need (BS 812-102, 2000) to determine the used sample for test. BS 812-103.1 indicated two methods to determine the particle size distribution. First method is washing and sieving. It is the preferred method, when aggregate may contain clay or other materials. Second method is dry sieving.

3.3.2 Moisture content

Moisture content was carried out according to BS 812-100, (2000) is the mass of water which can be removed from an aggregates, usually by heating at 105^{o}C, expressed as a percentage of the dry mass. The procedure of obtaining the moisture concrete was provided in BS 812-109, (2002). This procedure is suitable for both fine and coarse aggregates. The BS described three methods to determine the moisture content; oven-drying method (definitive method), the high temperature method, microwave-oven method for fine aggregates only. Here, oven-drying method was implemented.

3.3.3 Concrete density

BS 812: Part 2, (2002) describes the determination of the particle density, water absorption, bulk density. Therefore, in this research, these tests were carried out according to BS 812: Part 2 (2002). The code described these tests for fine aggregates which is having 10.0mm nominal sizes and smaller, and coarse aggregates which have nominal size between 40mm and 5mm.

3.3.4 Impact factor and crushing value

Aggregates impact factor (AIV) gives a relative measure of the resistance of aggregates to sudden shock or impact as described in (BS 812-112, 2004). The impact factor was determined for coarse aggregates passing at 14.0mm and retained on a 10.0mm test sieves. There are two methods, one in which the aggregates were tested in a dry condition, and the other in a soaked condition. Here, it was obtained by using the aggregates in a dry condition. On the other hand, the aggregates crushing value (ACV) described in (BS 812-100, 2002). It gives a relative measure of the resistance of aggregates to crush under a gradually applied compressive load. It was also recommended for aggregates passing a 14.0mm and retained on a10.0 mm test sieve. Thus, AIV and ACV were not obtained for the fine aggregates.

3.3.5 Fineness modulus

Fineness modulus (FM) is determined from sieve analysis test. It was used in mix design especially in ACI method. FM is the sum of the cumulative percentage retained on the sieves; 150, 300, 600ɥm, 1.15, 2.36, 5.0mm divided by 100. Fineness modulus usually calculated for the fine aggregates rather than coarse aggregates. Typical values between 2.3 – 3.0, and it has an effect on the workability (Neville, 1981).

3.4 Mix design

The process of determining the required properties of a concrete mixture is called mix design. These properties may include; fresh concrete properties (e.g. workability), mechanical properties of hardened concrete (e.g. strength and durability), and the boundaries of particular components of the concrete (Wilson & Kosmatka, 2011).

Many factors affecting the quality of concrete such as; type of cement, w/c ratio, strength and cleanliness of the aggregates, interaction between the aggregates and the cement paste, adequate mixing of the components. These components have a specific percentage of the total volume. Aggregates have a considerable contribution in quantity. It depends on the size of aggregates. Apparently, aggregates increase from 59% to 75% of the total volume of concrete. Hence, it is quite important. The mix design of concrete should be a balance between economy and requirements for place-ability, strength, durability, density, and appearance.

In this study, the mix design methods which were applied are DOE method and the (ACI 211.1-91, 1997). Concrete mix was designed for four main components; cement, water, sand, and gravel. Thus, no admixtures or cementitious materials have utilized. ACI 211.1-91 recommended that trial batches in the laboratory should be conducted, to check the first assumed proportions.

3.5 Experimental plan

The laboratory experiment of this research consists mainly of three phases. First phase includes two groups, and second phase includes three groups, while third phase includes two groups. Fig. 3.1 illustrates the experimental plan.

3.5.1 First phase

First phase is to cast the normal concrete (control). It has two groups, group one is to test compressive strength (according to BS and ACI), splitting tensile, and flexural strengths. Group two is to cast beams with 1000.0mm span, and 200 x 200mm cross-section.

3.5.2 Second phase

Second phase generally is to replace the gravel and sand in the glass, ceramic tiles, and rubber tyres (GCR). It contains three groups. Group One is to replace 50% of the sand alone by the selected waste materials. This replacement of sand was done for each waste material separately. Group two is similar to group one, but with replacing gravel instead of sand. Group three is to replace both sand and gravel by glass, ceramic tiles, and rubber tyres at different percentages; 25%, 50%, 75%, and 100%.

3.5.3 Third phase

Third phase is a blending stage. The optimum percentages that gave better strength was picked. After determining the best percentage to mix the waste materials together, the compressive, splitting tensile, and flexural strengths were tested, and this is group one. Group two is to test the beams which were made from the selected concrete in group one.

Testing compressive strength was done using cubes and cylinders. Splitting tensile and flexural strengths were conducted using only the BS. Therefore, the comparison between the two methods was confined in compressive strength.

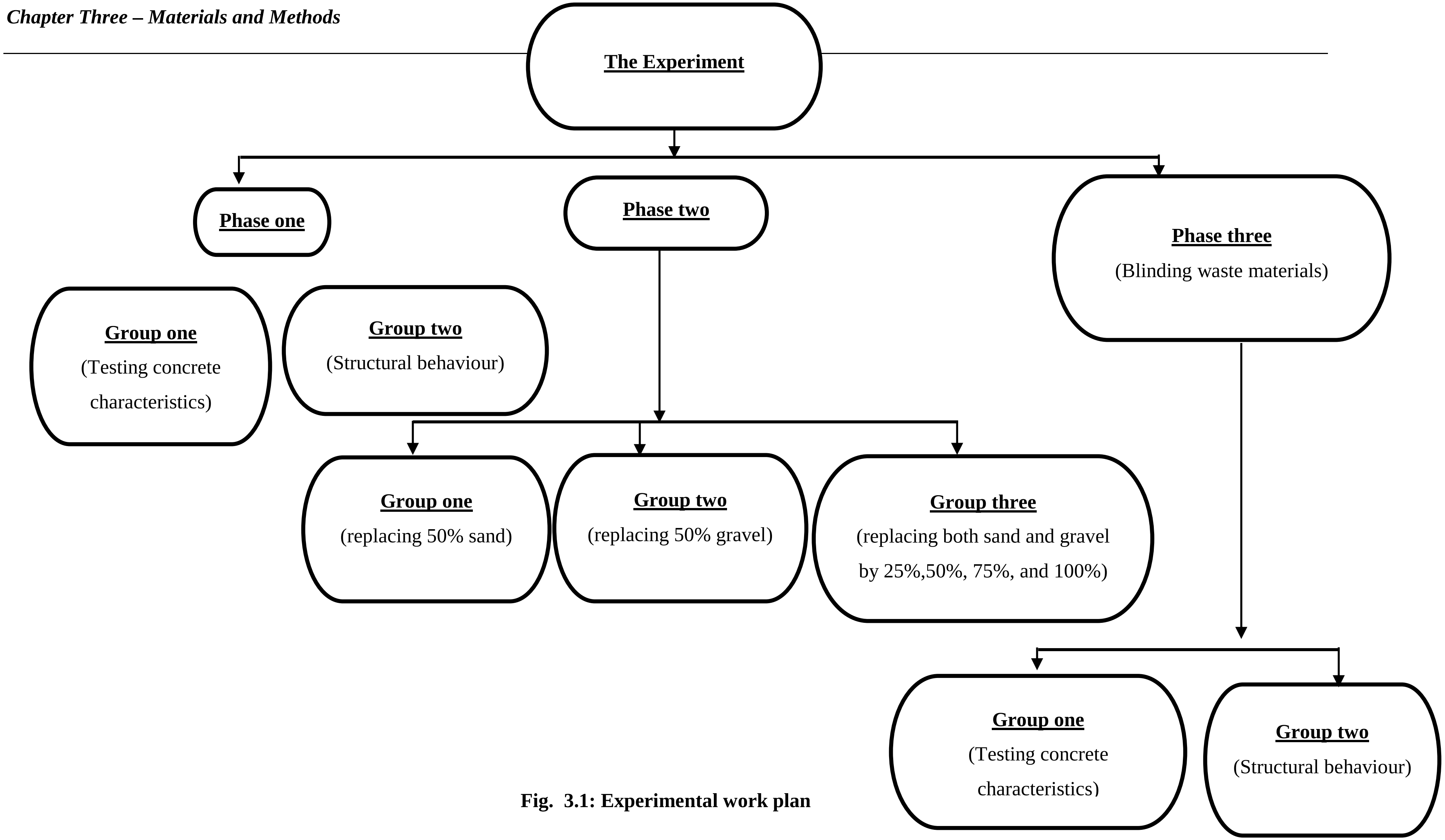


Fig. 3.1: Experimental work plan

3.6 Preparing the waste materials

Prior testing the glass, ceramic tiles, and rubber tyres, proper preparation of the selected waste materials was carried out to ensure usability. Glass and ceramic tiles as in Fig 3.2 and 3.3 were crushed manually. After crushing, sieve No. 20mm and No. 5mm were used to separate the fine and coarse aggregates. Rubber tyres as in Fig. 3.4 was cut manually using scissors to obtain coarse particles.

Fig. 3.2: Fine and Coarse Ceramic Tiles Aggregate

Fig. 3.3: Fine and Coarse Glass Aggregate

Fig. 3.4: Fine and Coarse Rubber Tyres Aggregate

3.7 Modelling reinforced concrete beams

3.7.1 Experimental test

Four beam samples were cast for each type of concrete as mentioned in phase three. Reinforced concrete beams were to subjected to three point-load. In addition, strain gauges were attached on the beams at specific locations to record the strain; at the bottom and at the top fibre of the beam; on both sides of the beams in the high shear region. LVTD was fixed at the middle of the beam to record the maximum vertical displacement. Load cells were used in order to apply the load gradually. Fig. 3.5 shows the experimental set up for a beam.

Fig. 3.5: Simple Supported Beam Subjected to Three-point Load

3.7.2 Finite Element model

The ANSYS finite element program (Ansys, 2012), was utilized in this study to simulate the behavior of experimental beams. Concrete was modelled as solid65 as in Fig. 3.6.

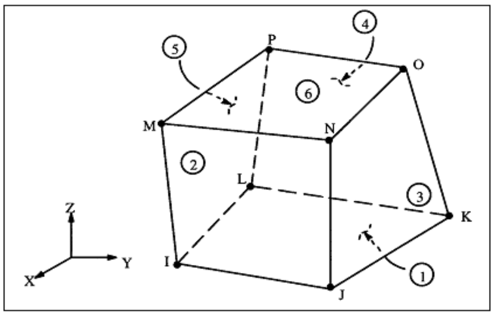


Fig. 3.6: Solid65 – 3D Reinforced Concrete

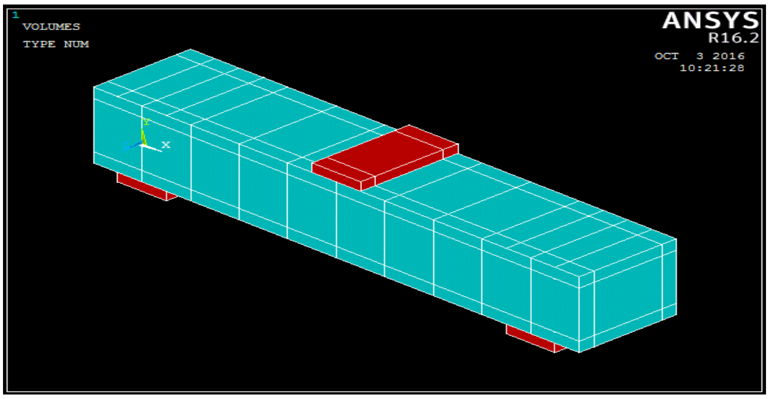


Fig. 3.7: 3D Beam Model

Solid65 has eight nodes with three degrees of freedom at each node translations in the nodal x, y, and z directions. It is capable of plastic deformation, cracking in three directions, and crushing. The geometry and node locations for this element type illustrates in Fig. 3.7.

The steel reinforcement was modelled by using link8. The element must define two nodes at the end as in Fig. 3.8.

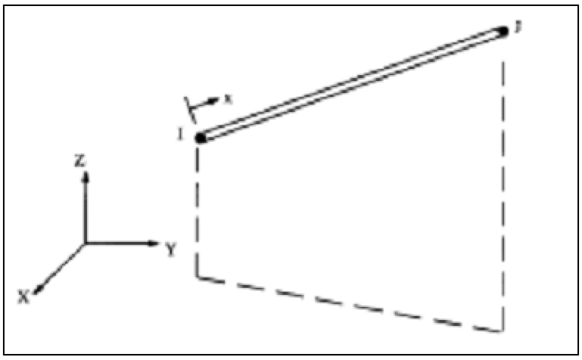


Fig. 3.8: Steel Reinforcement Element, Link8 with Two Nodes

Solid185 was used to model the two simple supports at the bottom. The element has 8 nodes, and each node has three degrees of freedom in three dimensions x, y, and z. The geometry and the nodes locations are similar to solid65.

3.7.3 Materials properties

3.7.4 Concrete

Applying a FEM using ANSYS obtained more data on the behaviour of the concrete. Concrete is a brittle material, and it does not get that much of elasticity as in the steel. The tensile strength of concrete ranged between 8 – 15% of the compressive strength which is not advantageous (Jack C. McCormac *et al.*, 2006). Concrete model needs a full stress-strain curve. Thus, it covers the nonlinear behavior of the concrete. The typical stress – strain curve of the concrete illustrates in Fig. 3.9 (Bangash, 1989). The linear line in the graph using the modulus of the elasticity (E_c), and w_c is varying from 1500 – 2500kg/m^3.

$$E_c = w_c^{1.5}(0.043)\sqrt{f_c^{`}}$$

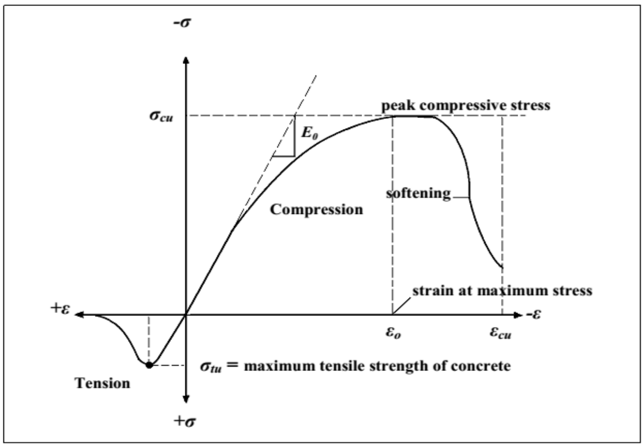


Fig. 3.9: Typical Stress – Strain Curve of Concrete

The first part of the curve, and up to about 30% of the ultimate strength $f_c^{`}$, it can be considered essentially linear. After it reaches the maximum strength, the curve descends into a softening region the peak compressive stress point. In tension, the concrete is linear up to maximum tensile strength.

Modulus of elasticity of the concrete was obtained experimentally for the different types of concrete. And it served as input in ANSYS. Nonlinear region was modelled as multilinear. The uniaxial compressive stress – strain relationship for concrete was used. It has been obtained by the numerical expression (Desayi, P. and Krishnan, 1964). Equation 3-2 and 3-3 were used. Also, Hooke's law equation 3-4 was used to represent the stress – strain curve as in Fig. 3.10 (Timoshenko & Goodier, 1986).

$$f = \frac{E_c \varepsilon}{1+\left(\frac{\varepsilon}{\varepsilon_o}\right)^2} \quad \ldots\ldots\ldots\ldots \text{(3-2)}$$

$$\varepsilon_o = \frac{2f_c^{`}}{E_c} \quad \ldots\ldots\ldots\ldots \text{(3-3)}$$

$$\varepsilon_o = \frac{f}{E_c} \quad \ldots\ldots\ldots\ldots \text{(3-4)}$$

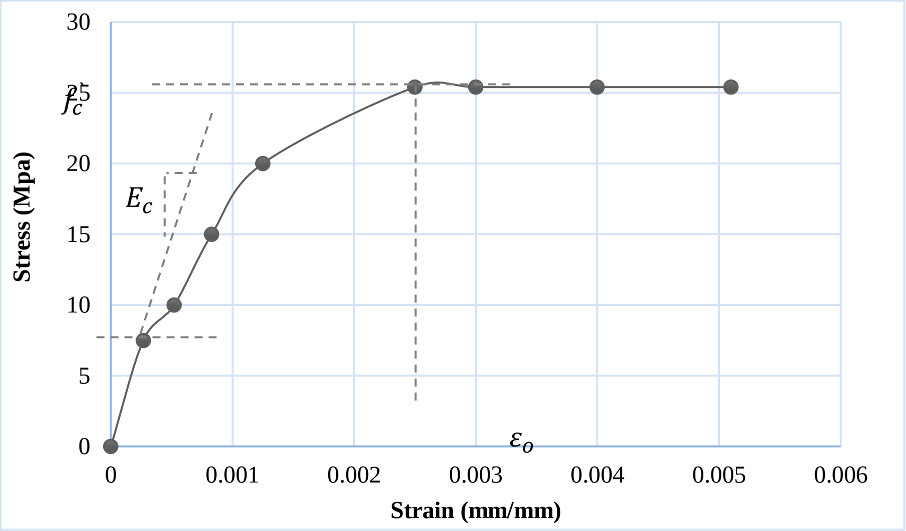


Fig. 3.10: Simplified Stress – Strain Relationship of Concrete

Where:

f = stress at any strain ε.

ε = strain at stress f.

ε_o = strain at the ultimate strength $f_c^{`}$.

In addition, ANSYS required other input data for modelling the concrete such as; ultimate uniaxial tensile strength (modulus of rupture, f_r), Poisson's ratio (ν), and shear transfer coefficient (βt). modulus of rupture can be obtained from equation 3-5 (Ohbuchi & Obikawa, 2001).

$$f_r = 0.7\sqrt{f_c^{`}} \text{ (MPa)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(3-5)}$$

Poisson's ratio of concrete varied from 0.18 - 0.2. Shear transfer coefficient denotes forms of the crack face. Its value ranged between 0.0 - 1.0. Zero value means smooth cracks, and 1.0 indicating rough cracks (Ansys, 2012). The βt value that was used in several studies of modelling reinforced concrete is between 0.05 and 0.25 (Ohbuchi & Obikawa, 2001).

3.7.5 Steel reinforcement and support plate

The steel reinforcement that was used in the experiment is Grade 60. Modulus elasticity is 200,000MPa, and Poisson's ratio is 0.3. For the finite element model, steel reinforcement assumed to be modelled as elastic-perfectly plastic material (Bilinear). Thus, the yield stress of the steel f_y is 460 MPa. (Timoshenko & Goodier, 1986) gave the stress – strain curve of the steel as Fig. 3.11 shows.

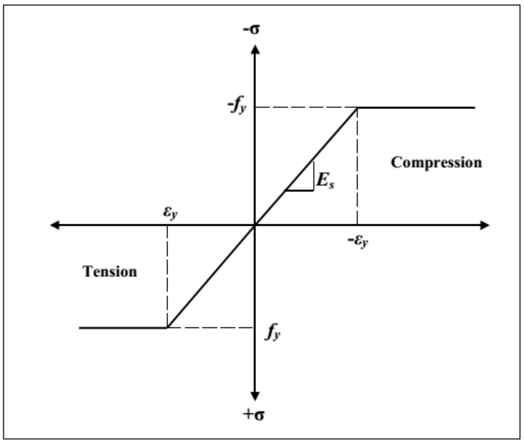


Fig. 3.11: Stress – Strain Curve of Steel Reinforcement

Steel plates were used as support shown in Fig. 3.7, and it was modelled as in Fig. 3.11. It is assumed to model as linear elastic materials with elastic modulus of 200,000MPa, and Poisson's ratio of 0.3. Therefore, it could be given more stress distribution on the contact area between the concrete and the plate. Table 3.1, summarized the materials properties that were used in ANSYS.

Table 3.1: Summary of Materials Properties for Concrete

Concrete type	**E_c (MPa)**	**f'_c (MPa)**	**f_r (MPa)**	**ν**	**βt**
Control	21515	25.4	3.53	0.2	0.2
Type A	20186	24.61	3.473	0.2	0.2
Type B	22178	25.28	3.52	0.2	0.2
Type C	24653	23.17	3.37	0.2	0.2

3.7.6 Finite element discretization

This step in ANSYS called meshing, it discretizes the beam into small elements depending on the required accuracy. More number of elements gave more accurate results. (Ohbuchi & Obikawa, 2001) performed a comparison between the ANSYS and the SAP2000 program. That comparison showed that when the number of elements increased, the accuracy of the results increased. This step also signs the defined materials to each element. In this model, the beam was discretized into elements as in Fig. 3.12 with size of 50mm.

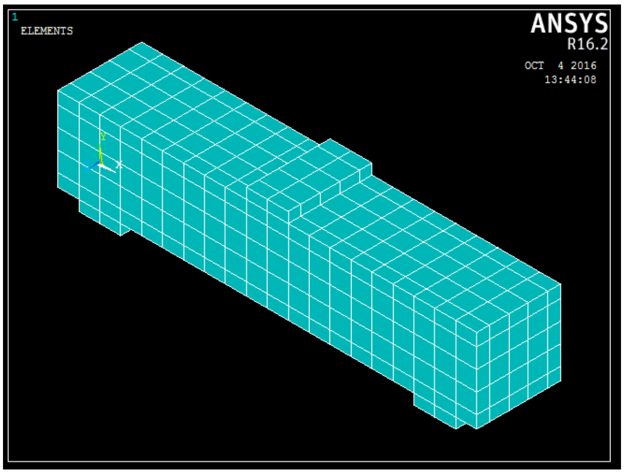


Fig. 3.12: Discretized 3D Beam into elements

3.7.7 Loading and boundary conditions

After meshing the beam and sign the defined materials, the volumes, lines, and nodes were merged. Thus, any replicate in the model which can influence the solution was removed. This step followed by applying the load and boundary conditions.

Concentrated loads (20,000 N) were implemented in each node at the middle of the beam. So, the total load on the beam will be the summation of the applied load at the nodes. Supports were assumed to be hinge at one support and a roller at the other support. Hinge support singed by stopping the displacement in x, y, and z, while roller support signed by stopping the displacement in the longitudinal axis of the beam (x axis in our model). Fig. 3.13 shows the boundary conditions and the load.

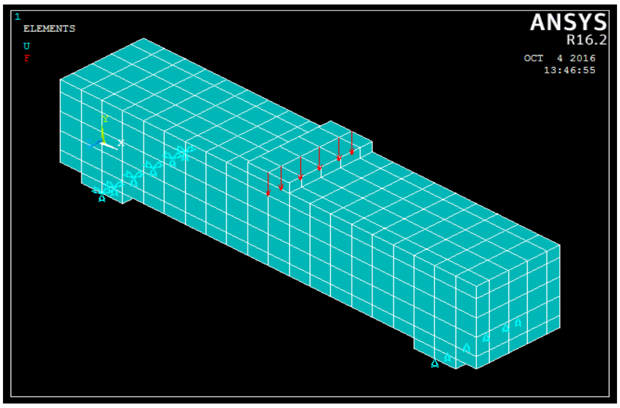


Fig. 3.13: Beam Loading and Boundary Conditions

3.7.8 Solve the model

The solution of the model was formed to obtain the linear and nonlinear solution. Normally, the total load was divided into load steps. The load is increasing incrementally at each next step until the beam fails. The program allows one to select the number of iterations at each sub-step. ANSYS uses Newton Raphson equilibrium iterations for upgrading the model stiffness at each load step. Here, the assumed maximum number of equilibrium iterations per step load is 20. For time control, the time at the end of load step is the maximum applied load (20,000 N). Number of sub-step was considered 25. Maximum and minimum load step is 1000 and 5000 respectively.

Chapter Four

Results and Discussion

4.1 Introduction

This chapter presents the results, analysis, and discussion of the laboratory results. Results were obtained from different tests and for different materials were carried out are presented. Fine and coarse aggregates of both conventional and waste materials aggregates were tested such as; Particle size distribution, dry- rodded and loss-rodded density, specific gravity, water absorption, impact value, crushing value, and moisture content were also presented in this chapter. Concrete mix design proportions were done according to DOE and ACI method. Tests of the characteristics of concrete were also illustrated. Finally, results which were obtained from the modelling of the beams using ANSYS.

4.2 Particle size distribution

Sieve analysis was done for sand to examine the grading of particles. Gravel, fine glass, coarse glass, fine ceramic, fine rubber tyres, and coarse rubber tyres were sieved. Sieve analysis test normally provides the distribution pattern of aggregates sizes in generally. The fineness modulus and the passing percentage of sieve No. 600.0ɥm were obtained from sieve analysis test. These two factors were used in the mix design of the concrete mixes.

4.2.1 River sand

River sand was used in this research. Before testing, the sample passed sieve No. 10.0mm, to ensure that there are no particles have size more than 10.0mm. Fig. 4.1 showed the results of sieve analysis test of the sand.

From Fig. 4.1, sand has a good size distribution. The curve is grading perfectly between the limits. However, both sand and gravel satisfied the grading requirements which were specified by BS 822: 1992. The size distribution of the aggregates has a huge effect on the workability and the strength. Fineness modulus of the sand was calculated as described by (Neville, 1981). It was obtained from sieve analysis test as described in Table 4.1. In addition, the passing percentage of sieve No. 600 ɥm was 45.3%.

Table 4.1: Sieve Analysis Results for Sand

Sieve Sizes (mm)	Wt. Retained	Wt. Retained%	Wt. Cum.	% Cum Rt.
10	1	0.1	0.1	0.01
5	24	2.4	2.5	0.25
2.36	45	4.5	7	0.70
1.7	54	5.4	12.4	1.24
1.2	145	14.5	26.9	2.69
0.6	278	27.8	54.7	5.47
0.3	314	31.4	86.1	8.61
0.15	118	11.8	97.9	9.79
Pan	21	2.1	-	
Sum			2.88	

$$\mathrm{F.M} = \frac{\mathrm{sum.\ of\ cumulative\ weight\ retained}}{100}$$

$$\mathrm{F.M.} = \frac{0.1 + 2.5 + 7 + 12.4 + 26.9 + 54.7 + 86.1 + 97.9}{100} = 2.88\ \%$$

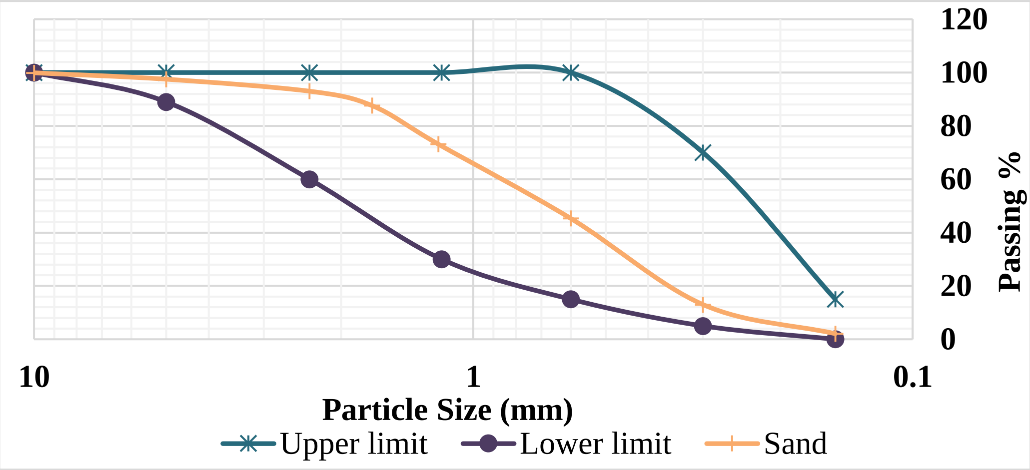


Fig. 4.1: Grading Curve of The Sand

BS 882:1992 specified requirements which were represented in limits. Grading curve of the sand has to be between the upper and lower limits. Hence, it can produce a good concrete. Sand met the requirements as showed in Fig. 4.1.

4.2.2 Gravel

Gravel was sieved, and the results illustrates in Fig. 4.2. A sample of 1000g weight was washed before testing. Thus, clay and any other materials were removed. The size distribution of the gravel was acceptable as Fig 4.2 shows. The gravel gave 68.8 passing percentage of sieve No. 20 mm, and the upper limit at that point was 70%. However, the gravel curve was placed between the required limits.

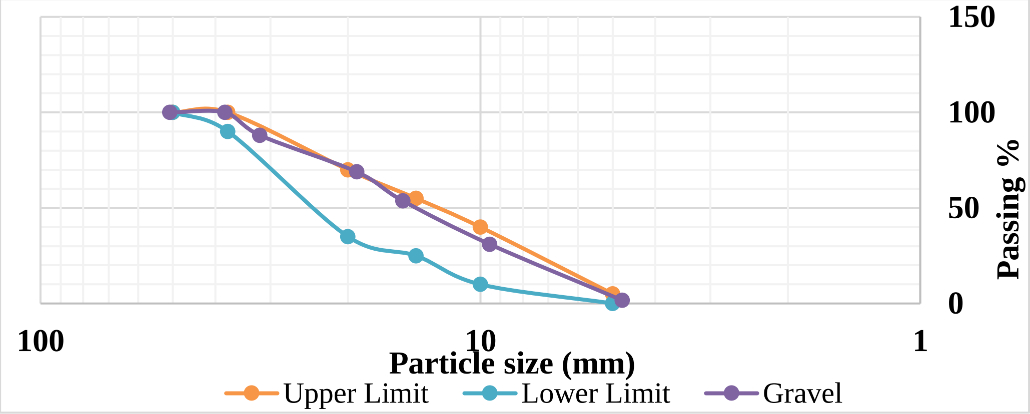


Fig. 4.2: Grading Curve of The Gravel

4.2.3 Glass

The preparation of fine and coarse glass aggregates was described in clause 3.5. Fig. 4.3 showed the size distribution of fine glass aggregates. Glass aggregates satisfied the requirements, when the grading curve located between the upper and lower limits. Fig. 4.3 can provide the fineness modulus and the percentage passing of sieve No. 600ɥm. The fineness modulus is 3.41 and the passing percentage of sieve No. 600ɥm is 37.5%. Fineness modulus of the glass is slightly higher than the fineness modulus of the sand. The passing percentage is a smaller amount than the sand. The grading curve of coarse glass aggregates was described in appendix A1.

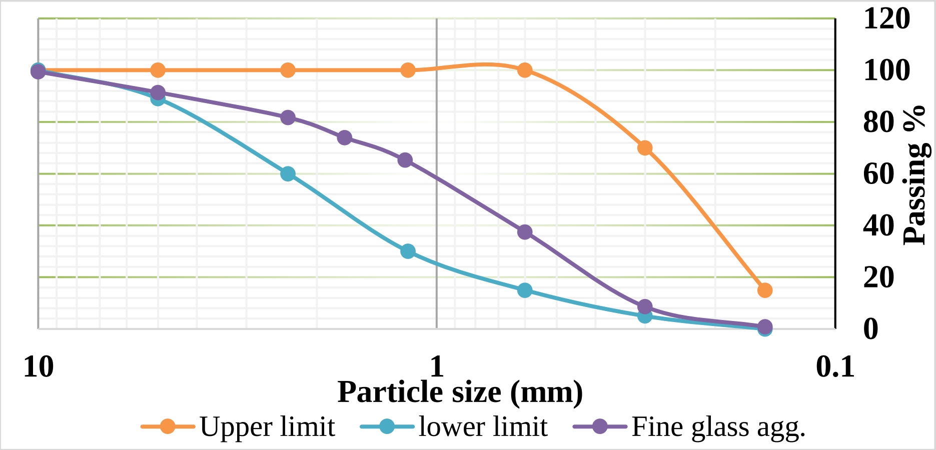


Fig. 4.3: Grading Curve of Fine Glass Aggregates

4.2.4 Ceramic tiles

Fig. 4.4 shows the size grading of the fine ceramic tiles particles. Fine ceramic tiles aggregates satisfied the BS 822: 1992 grading requirements. Fig. 4.4 shows that fine ceramic tiles curve lies between the upper and lower limit. Sieve analysis test provided the fineness modulus of, and it was 3.22. The passing percentage of sieve No. 600ųm was 39.9%. The fineness modulus of fine ceramic aggregates is a slightly higher than sand, but lower than the fineness modulus of fine glass aggregates. The percentage passing of sieve No. 600ųm of fine ceramic is less than the sand and higher than the fine glass aggregates. The coarse ceramic tiles aggregates grading was attached in the appendix A2.

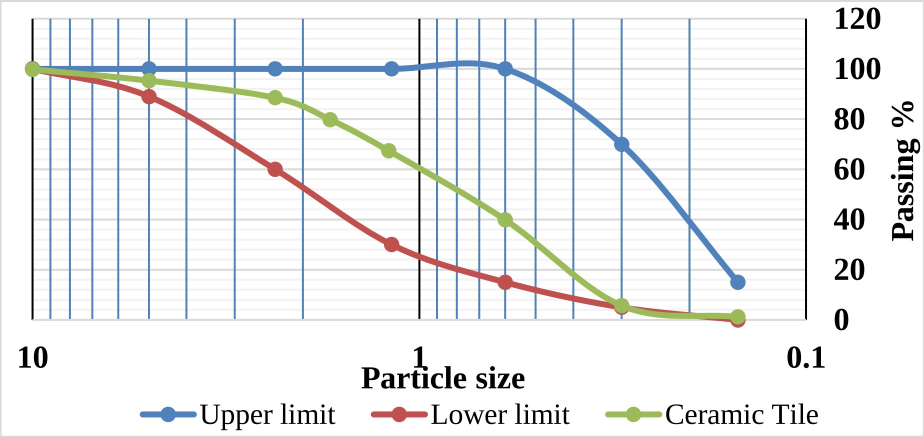


Fig. 4.4: Grading Curve of Fine Ceramic Tiles Aggregates

That change in both fineness modulus and passing percentage of sieve No. 600ɥm of the fine glass aggregates and fine ceramic tiles aggregates appeared because of the sand is uncrushed, while glass and ceramic were crushed. However, glass and ceramic aggregates tests values are still acceptable.

4.2.5 Rubber tyres

The fine rubber tyres aggregates were sieved, and the sieve analysis results are illustrated in Fig. 4.5. Fine rubber particles showed a good grading. Rubber aggregates curve satisfied the requirements. The fineness modulus of rubber aggregates is 3.86, and the passing percentage of sieve No. 600ɥm is 15.3%.

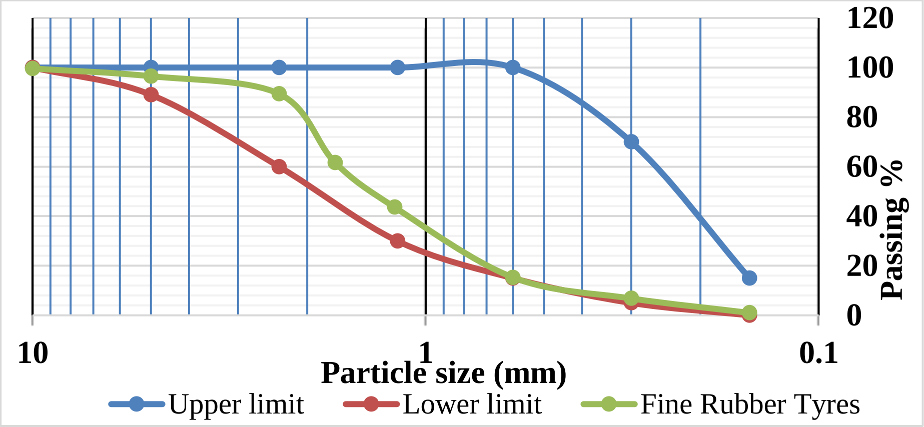


Fig. 4.5: Grading Curve of Fine Rubber Tyres Aggregates

The fineness modulus of rubber aggregates was very low in comparison with the sand, fine glass, and fine ceramic tiles aggregates. This difference in the fineness modulus between the types of aggregates will be having a big effect on the amount of fine rubber aggregates in the mix design. Sieve analysis result of the coarse rubber particles was provided in appendix A3. The properties of the aggregates are summarized in Table 4.1.

ASTM C294 specified a recommended value of the dry-rodded density (Bulk density), and it was ranged between γ_b = 1500 – 1680 kg/m^3 as showed in Table 4.1.

Fig. 4.6 and Fig. 4.6 illustrates the dry-rodded density of the coarse and the fine aggregates respectively. The values of Dry-rodded density of gravel, sand, coarse

Table 4.1: Summary of The Aggregates Properties

Tests	Sand	Gravel	FG	CG	FC	CC	FRT	CRT
Dry-rodded density (kg/m^3)	1521	1578	1457	1479	1482	1508	674	706
Dry-loss density(kg/m^3)	1504	1545	1417	1447	1464	1450	621	678
Fineness modulus (%)	2.88	–	3.41	–	3.22	–	3.86	–
Crushing value (%)	–	28.4	–	42.3	–	21.0	–	0.02
Impact value (%)	–	10.27	–	31.0	–	11.1	–	0.04
Specific gravity (kg/m^3)	2.4	2.68	2.54	2.72	2.16	2.53	1.4	1.1
Water absorption (%)	1.7	1.47	1.64	1.44	0.86	0.55	–	–
Sieve analysis, 600mm passing percentage (%)	45.3	–	37.5	–	39.9	–	15.3	–

ceramic, coarse glass, fine ceramic, and fine glass are acceptable. But the dry-rodded and the loss-rodded density of the rubber aggregates are very low. The dry-rodded density results indicate that the weight of glass and ceramic aggregates is almost the same as the gravel.

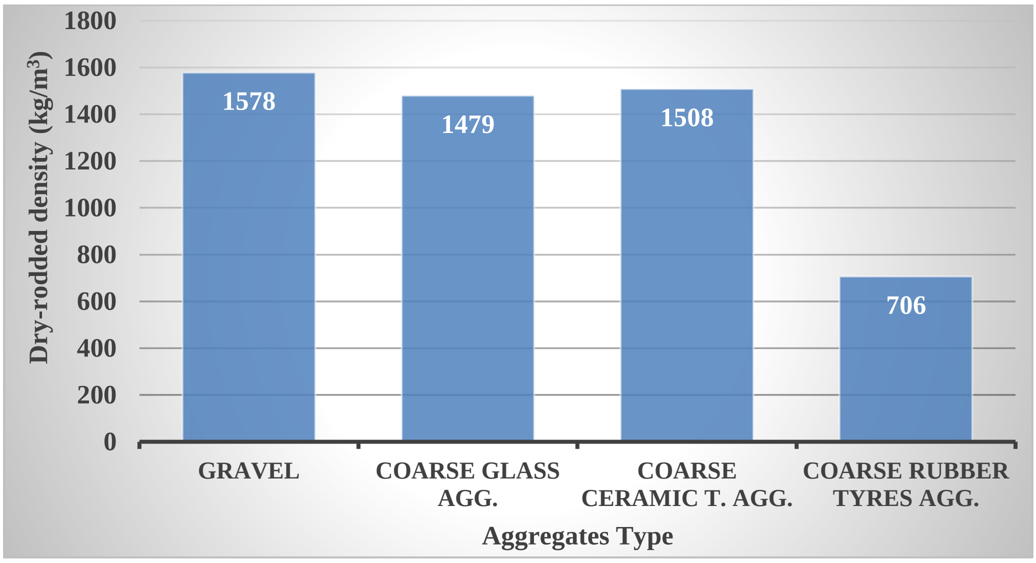


Fig 4.6: Dry-rodded Density of Coarse Aggregates

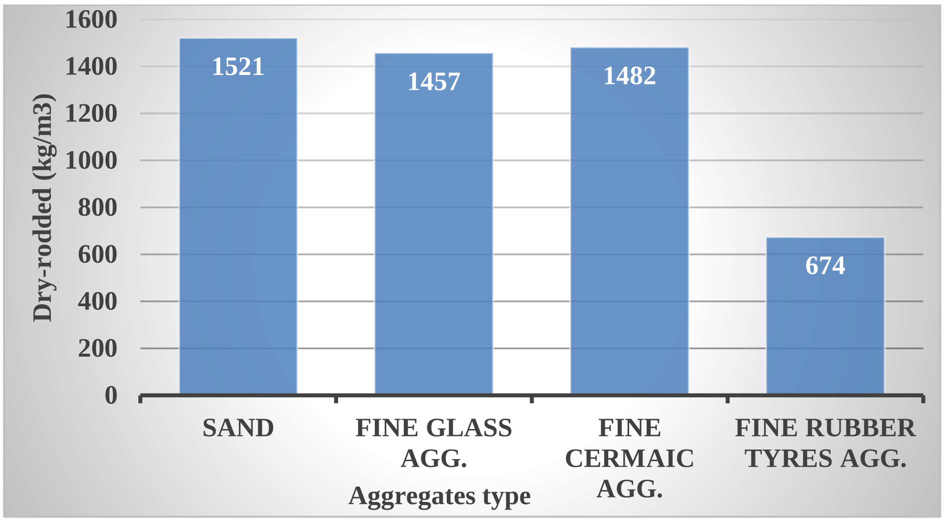


Fig 4.7: Dry-rodded Density of Fine Aggregates

The results of aggregate crushing value (ACV) and aggregate impact value (AIV) of the coarse aggregates were showed in Fig. 4.8 and Fig. 4.9 respectively. ACV and AIV are varying from one type of aggregates to another. BS 812-112 stated that if the AIV is more than 30%, the results should be treated with caution. The AIV of gravel and ceramic tiles satisfied the requirements, but the AIV of glass is more than 30.1% which is undesirable. Rubber tyres aggregates has no value of AIV and ACV, because the ductility of rubber aggregates is high.

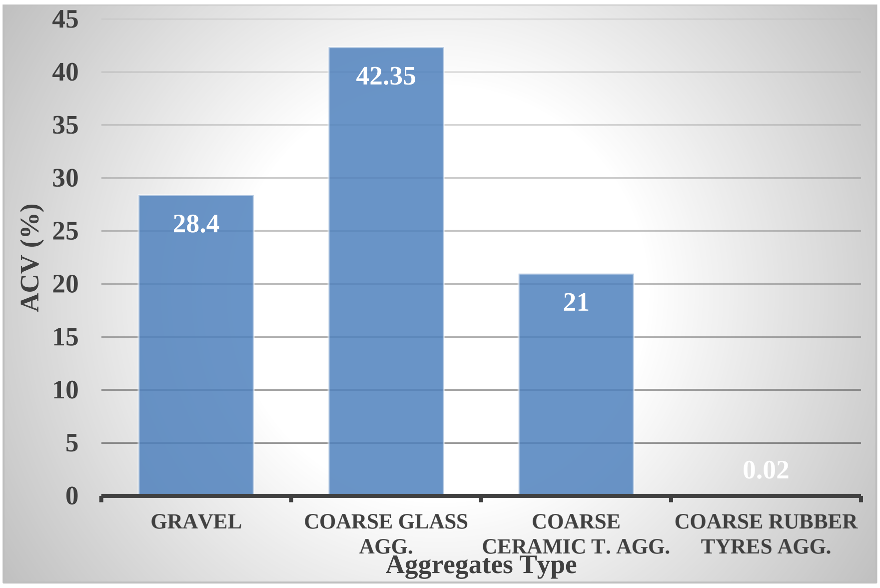


Fig 4.8: Aggregates Crushing Value

According to Indian Standard, IS: 2386 (Part IV) - 1963, if the Aggregate Crushing Value (ACV) is more than 30%, aggregates should be classified as weak aggregates. ACV of the gravel and coarse ceramic tiles was less than 30% which is ok. But ACV of the glass aggregates was less than 30%. AIV and ACV gave advantage for the coarse ceramic aggregates than coarse glass aggregates and rubber tyres aggregates. In other words, coarse ceramic tiles aggregates are significantly similar to the normal gravel.

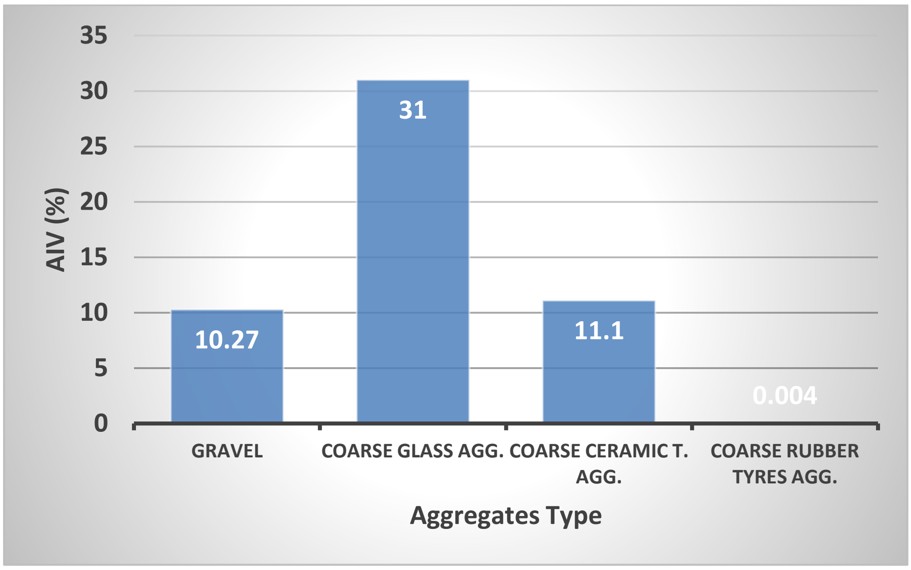


Fig 4.9: Aggregates Impact Value

Normally, specific gravity of the fine and coarse aggregates is between 2.4 - 3.0 kg/m^3. Fig. 4.10 and Fig. 4.11 shows the specific gravity of the fine aggregates and the coarse aggregates respectively. Sand, gravel, glass aggregates, and ceramic tile aggregates have suitable values of specific gravity, while the rubber tyres have the lowest value.

Sand, gravel, and glass aggregate have almost the same value of water absorption. Ceramic tiles aggregates have less value of water absorption compare with the rest, and it shall affect the amount of water in the mix design.

In fact, the rubber tyres aggregates did not give values for any test that required oven. From what we observed, rubber tyres particles lose its consistency inside the oven.

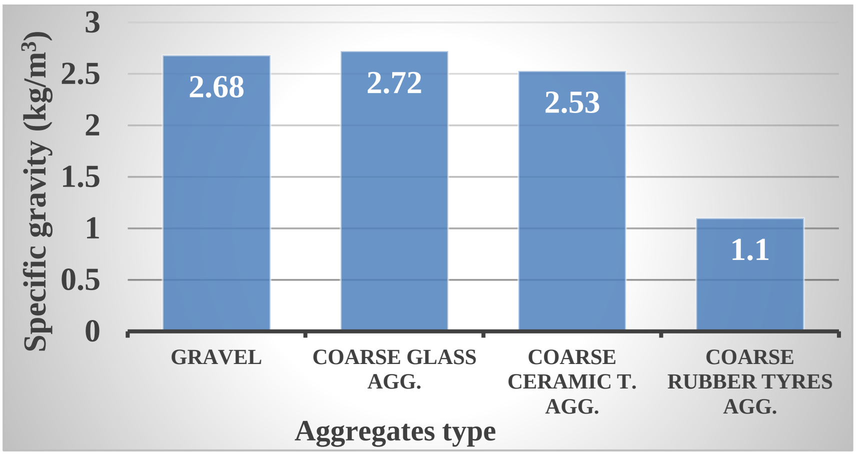


Fig. 4.10: Specific Gravity of Coarse Aggregates

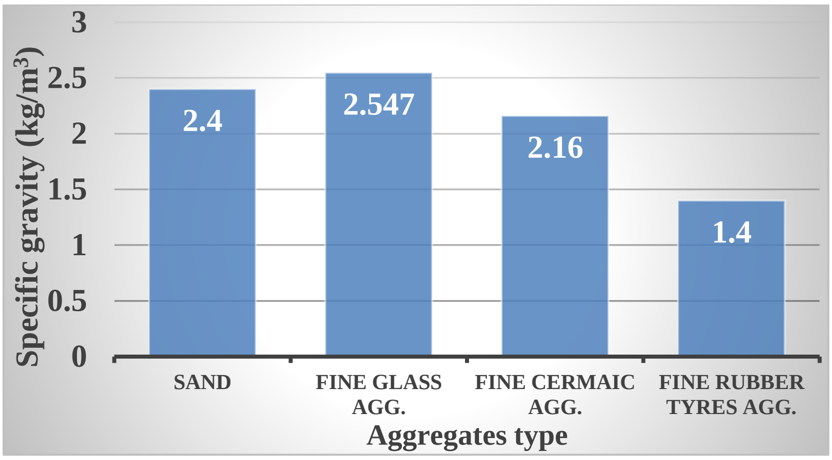


Fig. 4.11: Specific Gravity of Fine Aggregates

4.3 Mix design proportions

Finding a perfect mix design is not possible, because the used materials vary in many aspects. Thus, mix design of concrete is an intelligent guess based on various relationships. In this study, DOE and ACI methods were used in mix design. Trial samples are highly required. Therefore, after preliminary tests, trail samples were cast to control the w/c ratio and materials proportions. Adjacent was needed to be done according to the preliminary results. Mix design was done for glass and ceramic tiles individually as illustrates in Table 4.2. The rubber properties did not fit into the mix design charts and tables. As a result, it was substituted volumetrically the normal aggregates. The w/c ratio for both DOE and ACI method was 0.58, and the maximum coarse aggregates size was 20.0mm. The slump was assumed to be between 30 – 60mm and between 25 – 100mm for DOE and ACI method respectively.

Table 4.2: Mix design proportions according to DOE and ACI methods

Normal concrete (kg/m^3)				
Method	**Water**	**Cement**	**Fine Aggregates**	**Coarse Aggregates**
DOE	178	403	754	1138
Mix Ratios	0.45	1	2	3
ACI	200	440	685	960
Mix Ratios	0.45	1	1.6	2.2
Glass concrete (kg/m^3)				
Method	**Water**	**Cement**	**Fine Aggregates**	**Coarse Aggregates**
DOE	245	441	953	855
Mix ratios	0.6	1	2.2	2
ACI	215	430	520	890
Mix ratios	0.5	1	1.21	2.1
Ceramic tiles concrete (kg/m^3)				
Method	**Water**	**Cement**	**Fine Aggregates**	**Coarse Aggregates**
DOE	207	357	955	785
Mix ratios	0.6	1	2.7	2.2
ACI	215	430	520	890
Mix ratios	0.5	1	1.21	2.1

Table 4.2 is shown the mix design proportions for both DOE and ACI methods. DOE method gave less quantity of water than the ACI method, especially the w/c ratio did not change in both methods. The quantity of the water affected the cement quantity. The aggregates proportions of DOE method are more than the aggregates proportions of ACI method. The quantity of water in the mix was adjected based on water absorption and moisture content of various aggregates.

In DOE method, mix design of glass concrete and ceramic concrete is different. Glass aggregates properties influenced the proportions of the mix, and ceramic aggregates as well. Glass concrete needs more water than both ceramic concrete and normal concrete. But the difference in the aggregates proportions in glass concrete and ceramic tiles concrete is not significant.

That difference in the proportions of aggregates in both methods retained to the factors which determine the quantity e.g. specific gravity, fineness modulus, and passing percentage of sieve No. 600ɥm. Usually, DOE method uses the passing percentage of sieve No. 600.0um, and ACI method uses the fineness modulus of the fine aggregates. The coarse aggregates quantity was determined according to the amount of fine aggregates in both methods. Mix design proportions of glass concrete and ceramic concrete did not differ in ACI method.

4.4 Testing program

As mentioned in chapter three, the experiment has three phases, each phase consists of groups as shown in Fig. 3.1. First phase includes the normal concrete (control) without any added waste materials aggregates. Second and third phase comprise the waste materials aggregates.

4.4.1 First phase

First phase has two groups, group one is for testing the properties of the control concrete. In this stage, cubes of size 150x150x150mm and cylinders of size 150mm dimeter 300mm height were cast for testing the compressive strength according to BS and ACI respectively. In addition, splitting tensile strength and flexural strength were tested using cylinders and beams according to the BS. Beams of size 150x150x550 mm dimensions were used to determine the flexural strength. Group two in this phase is for testing the structural behavior such as deflection, cracks pattern, stresses, and strains by casting beams of size 200x200x1000mm.

Table 4.3: Results of Group One in First Phase

Test	**Cubes**	**Cylinders**
Density (kg/m^3)	23.3	23.6
Slump (mm)	27.8	65
	7 days	**28 days**
Compressive strength (MPa) Cubes Cylinders	 19.03 18.03	 25.42 25.14
Splitting tensile strength (MPa)	1.7	2.65
Flexural strength (MPa)	2.6	3.87

Concrete class 25MPa should give 67% of the ultimate strength in 7 days. Which is 16.75 MPa for cubes and 14.24 MPa for cylinders. The compressive strength of the cubes and cylinders are 19.03MPa and 18.03MPa respectively after 7 days curing, which are acceptable. Group two results in this phase were mentioned in the third phase. For the purpose of comparing them with other beams' results.

4.4.2 Second phase

Phase two was created to present the replacement of sand and gravel by the waste materials aggregates. The samples in this stage were cured for 7 days, and it contains three groups. In group one, 50% of the weight of sand was replaced by fine waste materials. Group two, 50% of the weight of gravel was replaced by coarse waste materials aggregates. Results of group one and group two were summarized in Table 4.4.

Table 4.4: Results of Group One and Two in The Second Phase

Concrete Type	**Test**	**Cubes**		**Cylinders**	
		50 %(S)	**50 %(B)**	**50 %(S)**	**50 %(B)**
GC	Density (kg/m^3)	23.62	23.85	23.29	23.29
	Slump (mm)	51	45	85	81
	Compressive Strength (MPa)	14.02	11.77	13	10.5
CC	Density (kg/m^3)	23.96	25.46	23.46	23.15
	Slump (mm)	45	57	67	71
	Compressive strength (MPa)	19.65	16.62	17.05	14.78
RTC	Density (kg/m^3)	22.12	21.19	20.26	18.69
	Slump (mm)	25	21	45	55
	Compressive strength (MPa)	4.15	4.09	2.62	2.47

Table 4.4 illustrates the density, slump, and compressive strength of glass, ceramic tiles, and rubber tyres concretes according to both BS and ACI methods. The density of glass concrete and ceramic concrete did not vary significantly compare to the control concrete. But the density of rubberized concrete decreased marginally.

About the glass concrete, the slump increased from 27.8mm to 51mm and 45mm in BS method, and increased from 65mm to 85mm and 81mm in ACI methods. The slump increased by approximately 50% in BS method, and increase by 20% in ACI method. Fine glass aggregates increased the slump more than the coarse glass aggregates in both BS and ACI. Surface of glass particles is smoother than the normal aggregates. From the mix design, the amount of fine glass aggregates is more than the coarse glass aggregates. As a result, fine glass concrete gave more slump than the coarse glass concrete.

Compressive strength of glass concrete decreased from 19.03Mpa to 14.02MPa and 11.77MPa in BS method, and it decreased from 18.03MPa to 13Mpa and 10.5MPa in ACI method. These values of strength were not sufficient in comparison with the control. When the fine glass aggregates replaced, the strength dropped by nearly 25% in BS and ACI methods. While it decreased by approximately 40%, when coarse glass aggregates were used. As a result, the fine glass aggregates have more ability to give better strength than the coarse glass aggregates.

In addition, the ceramic concrete gave very good results of density, slump, and compressive strength. The density of ceramic concrete increased slightly. The slump increased from 27.9mm to 45mm and 57mm in BS method, and it increased from 65mm to 67mm and 71mm in ACI. The slump generally did not increase significantly as long as it is still within the assumed ranged.

The strength of ceramic concrete increased slightly from 19.03MPa to 19.65MPa, when fine ceramic aggregates were utilized. It decreased from 19.03MPa to 16.62MPa, when coarse ceramic aggregates used in BS. These values of strength achieved the required strength. In ACI method, the strength decreased from 18.03Mpa to 17.05MPa, when fine ceramic aggregates were used. While it dropped from 18.03MPa to 14.78MPa, when the coarse ceramic aggregates were used. However, the strength achieved the requirements, and it is satisfactory.

When rubber aggregates were used, the density of the concrete decreased by 5 - 15% in both methods. The slump was reduced from 27.9mm to 25mm and 21mm in BS method, and from 65mm to 45mm and 55mm. Rubberized concrete gave the lowest strength among the others. Strength decreased significantly, and concrete loss up to 80% of its strength in BS method, and up to 85% in ACI method.

Group three in this stage exhibited the replacement of both fine and coarse aggregates in different percentages as described in chapter three. Table 4.5 and Table 4.6 illustrates the result of the density, slump, and compressive strength of the cubes and cylinders correspondingly.

The density of glass concrete did not vary significantly in both BS and ACI method. Slump of glass concrete is increasing with increase in the amount of glass aggregates. In BS method, slump increased slightly, but in ACI method, it increased by approximately 10%.

Compressive strength decreased with increase in the amount of the glass aggregates in concrete in both BS and ACI method. Strength decreased from 19.03MPa to 17.55MPa, 14.42MPa, 10.41MPa, and 9.7MPa, at replacement percentage 25%, 50%, 75%, and 100% respectively for BS method. The cylinders gave strengths; 16.4MPa, 12.03MPa, 10.70MPa, and 8.26MPa at replacement percentages 25%, 50%, 75%, and 100%. Fig. 4.12 shows how the strength of the glass concrete decreased, when the waste glass aggregate replaced more than 50% of the normal aggregate, the strength decreased significantly. Up to 25%, the glass concrete gave a good strength, But with increase in the quantity of glass aggregates, the strength was affected considerably.

Table 4.5: The Density, Slump, and Compressive Strength Results of The Cubes.

Concrete Type	**Test**	**Replaced percentages**				
		0 %	**25 %**	**50 %**	**75 %**	**100 %**
GC	Density (kg/m^3)	23.30	23.62	23.95	23.28	23.26
	Slump (mm)	27.9	31.2	32	35	41
	Compressive strength (MPa)	19.03	17.55	14.42	10.41	9.7
CC	Density (kg/m^3)	23.30	23.55	22.81	21.69	22.69
	Slump (mm)	27.9	35	31	20	15
	Compressive strength (MPa)	19.03	20.7	17.83	16.32	14.05
RTC	Density (kg/m^3)	23.30	19.95	17.35	14.51	13
	Slump (mm)	27.9	25	18	10	8
	Compressive strength (MPa)	19.03	2.5	2.2	1.9	1.6

Ceramic concrete density decreased slightly compare to the density of control in both BS and ACI methods. The slump of the ceramic concrete was decreasing with increase in the ceramic aggregates in both methods. The strength of ceramic concrete was reasonable even at high replacement of fine and coarse ceramic tiles aggregates. The strength of ceramic concrete was more than the control strength between 5 to 25 %, and started decreasing with increase in the replacement percentage as illustrates in Fig. 4.13.

Table 4.6: The Density, Slump, and Compressive Strength Results of The Cylinders.

Concrete type	**Test**	**Replaced percentages**				
		0 %	**25 %**	**50 %**	**75 %**	**100 %**
GC	Density (kg/m^3)	23.6	23.10	23.20	23.07	22.83
	Slump (mm)	65	71	75	81	88
	Compressive strength (MPa)	18.03	16.4	12.03	10.70	8.26
CC	Density (kg/m^3)	23.6	23.12	22.44	22.44	22.18
	Slump (mm)	65	29	54	57	61
	Compressive strength (MPa)	18.03	17.6	14.75	13.54	12.72
RTC	Density (kg/m^3)	23.6	19.71	17.98	16.09	14.69
	Slump (mm)	65	57	45	27	19
	Compressive strength (MPa)	18.03	2.7	1.45	0.87	0.6

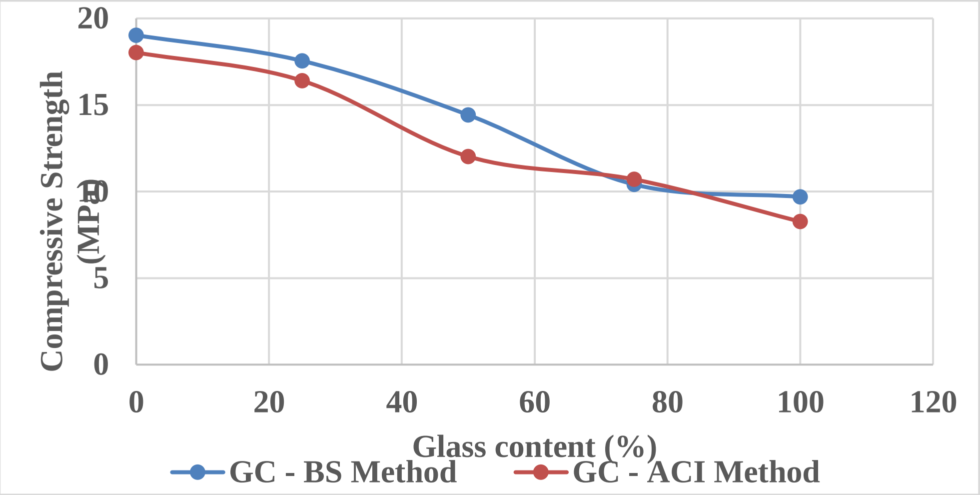


Fig. 4.12: Compressive Strength of Glass Concrete

Generally, the density of rubberized concrete decreased by 15%, when the added percentage of rubber tyres increase. In addition to that, there was slight change in the slump from 0% to 25% replacement, but the rest changed significantly. The highest replacement of rubber, the lower the workability. The rubberized concrete has very low strength in comparison with the normal concrete in both methods.

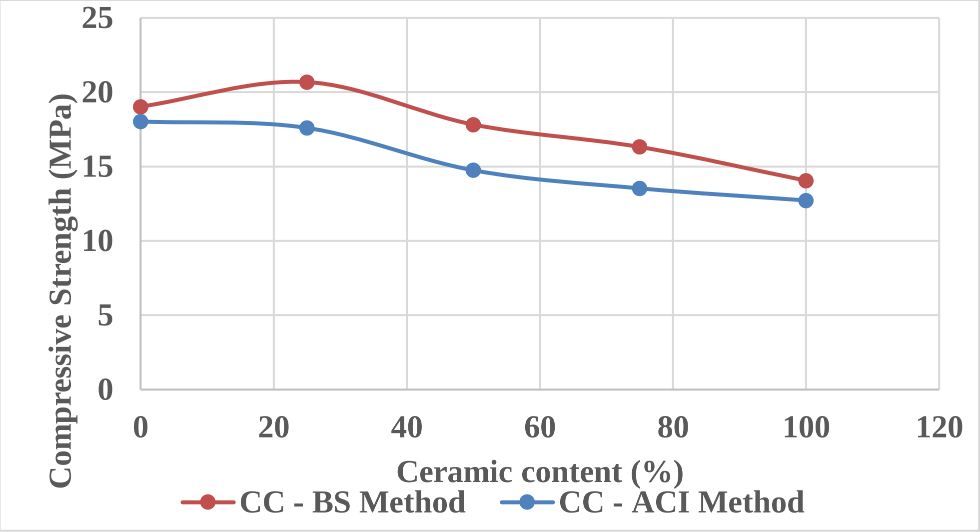


Fig. 4.13: Compressive Strength of Ceramic Concrete

In Fig. 4.14, It is obvious that there is a big drop in the curve between the 0% and 20% replacement. The strength was changing slightly after the 25% replacement for both methods.

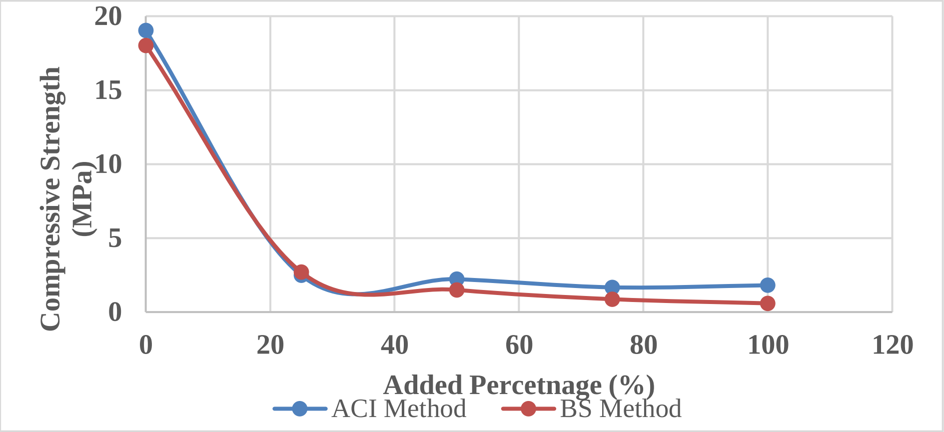


Fig. 4.14: Compressive Strength of Rubberized Concrete

Rubber tyres concrete shown high resistance of compression failure. Also, it has high resistance of wear. Those characteristics is suitable for footpaths. At lower replacement, the strength was about 5 MPa which it could be enough. Also, it could be used in sports field especially in tennis field, and others such as; Basketball and Volleyball. Where the high compressive strength is not required. Fig. 4.15 shows that the higher replacement of sand and gravel the higher concrete ductility.

Table 4.7: Flexural Strength and Splitting-Tensile Strength of Rubberized Concrete

Test	Control	Rubberized concrete
Flexural strength (MPa)	3.5	1.22
Splitting tensile strength (MPa)	2.61	1.4

In addition, sand and gravel were replaced by 50% of fine and coarse rubber aggregates to check the splitting tensile and flexural strengths. Table 4.7 illustrates that the flexural strength is 1.22 MPa, while the splitting tensile strength is 1.4.


(a) **(b)**

Fig. 4.15: Specimens failure pattern for compressive strength test, (a) Specimen with high amount of rubber tyres (b) Specimen with lower amount of rubber.

The flexural strength dropped by 65% of the control, and the splitting tensile strength reduced by approximately 50% in comparison with the control. It was observed that at ultimate failure of the specimens, the shape of the specimens remains generally intact. This is noted as seen in Fig. 4.16. The cohesiveness of rubberized concrete increases with increase in the amount of rubber tyres. Furthermore, the samples still coherent after repeating the compressive strength test many times. That extreme elasticity produces high resistance of crashing.

Fig. 4.16: Specimens failure pattern, (a) Beam Failure under Flexural Test (b) Splitting Tensile Strength Test

4.4.3 Third phase

This phase mainly depends on the results of the second phase. Rubber aggregates were dropped in this stage, because it did not provide convincing strength. But it has a high elasticity which gives the concrete a different used opportunity.

According to second phase results, the replacement percentages for blending the glass and ceramic tiles aggregates together were determined. Results showed that when coarse glass aggregates were used instead of the gravel, the strength is weak. Therefore, it was also dropped in this phase. Coarse ceramic aggregates gave a good strength, and it could be better at lower replacement percentage. Fine glass and fine ceramic aggregates can be also use as sand, while they gave better results. Therefore, the blending percentages based on those results. The percentages that were chose to replace the sand and the gravel are as follow;

- Type A: 25 % F Glass + 25 % F Ceramic + 50 % Sand + 100 % Ballast.

- Type B: 25 % F Glass + 25 % F Ceramic + 50 % Sand + 25 % C Ceramic + 75 % Ballast.
- Type C: 50 % F Ceramic + 25 % C Ceramic + 50 % Sand + 75 % Ballast.

Table 4.8: Results of Group One in The Third Phase.

<table>
<tr><th colspan="3">Type A</th></tr>
<tr><th>Test</th><th>7 days</th><th>28 days</th></tr>
<tr><td>Compressive strength (MPa)</td><td>18.86 (19.029)</td><td>24.611(25.421)</td></tr>
<tr><td>Splitting tensile strength (MPa)</td><td>1.671(1.7)</td><td>2.51 (2.65)</td></tr>
<tr><td>Flexural strength (MPa)</td><td>3.56 (2.6)</td><td>4.303 (3.87)</td></tr>
<tr><th colspan="3">Type B</th></tr>
<tr><th>Test</th><th>7 days</th><th>28 days</th></tr>
<tr><td>Compressive strength (MPa)</td><td>17.657(19.029)</td><td>25.28(25.421)</td></tr>
<tr><td>Splitting tensile strength (MPa)</td><td>1.63 (1.7)</td><td>2.43 (2.65)</td></tr>
<tr><td>Flexural strength (MPa)</td><td>3.119 (2.6)</td><td>4.012 (3.87)</td></tr>
<tr><th colspan="3">Type C</th></tr>
<tr><th>Test</th><th>7 days</th><th>28 days</th></tr>
<tr><td>Compressive strength (MPa)</td><td>17.867 (19.029)</td><td>24.55(25.421)</td></tr>
<tr><td>Splitting tensile strength (MPa)</td><td>1.6(1.7)</td><td>3 (2.65)</td></tr>
<tr><td>Flexural strength (MPa)</td><td>2.594 (2.6)</td><td>3.98 (3.87)</td></tr>
</table>

Table 4.8 showed the results of the concrete types that were assumed. Compressive, splitting tensile, and flexural strengths tests were conducted at 7days and 28 days. In Table 4.8, the control values were indicated in brackets, thus, any test can be compared.

Compressive strength of the three types of the concrete met the requirements, and the results are acceptable at 7 and 28 days. Splitting tensile strength for the three types of concrete are adequate. Splitting strengths were 1.67MPa, 1.63MPa, and 1.6MPa for type A, type B, and type C respectively at 7days. Splitting strength of modified concrete is slightly less than the control, but their values are still satisfactory. Concrete type C achieved splitting strength of 3MPa which is more than the control at 28days. Flexural strength of the three types of the concrete were great in comparison with the control.

4.4.3.1 Experimental beam results

The beams were cast to check the structural behavior of the different types of concrete. The results represent group two in phase three. The three types of concrete were used to cast beams; this is for purpose of testing the structural behaviour. The vertical defection, applied load, strains at shear points, and strain at the center were measured. Also, modulus of elasticity was tested. The LVDT was used to measure the deflection at the center of the beam, while the load cell was used to apply the vertical load. Fig. 4.17 shows how the experiment was setup and failure under load.

Fig. 4.17: Test of the Beam Under Three-Point Load

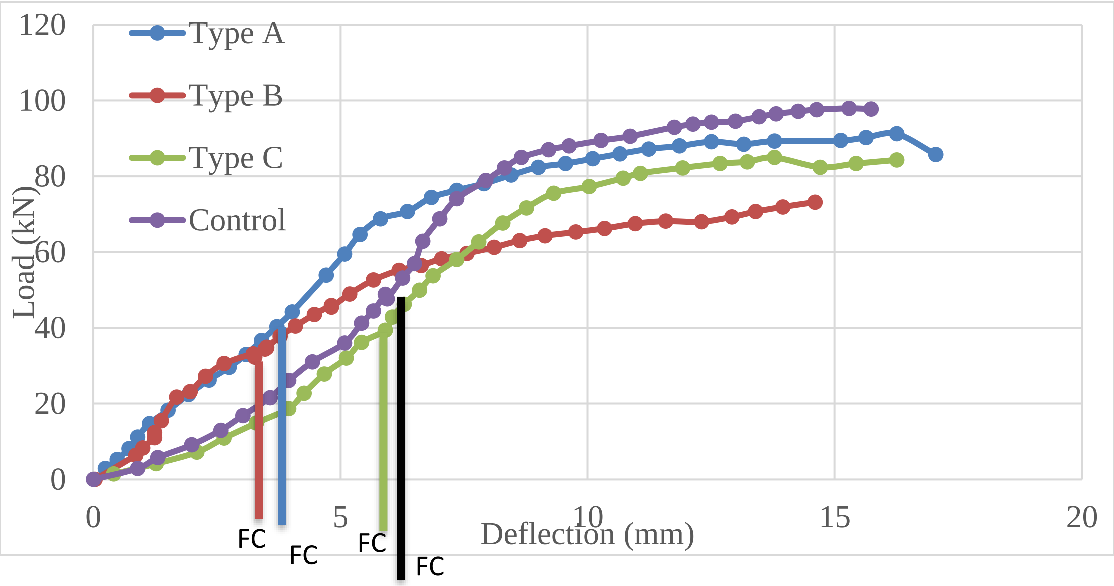


Fig. 4.18: Load-Deflection of all types of beams

Fig. 4.18 showed the load – deflection for all types of beams, control beam and type C concrete beam were obtained more displacement, when the subjected load between 0 and 40 kN than type A and type B. The variation between the curves in Fig. 4.18 are not significant, and lines in Fig 4.18 indicate the first crack that happened in beams. Type B concrete beam cracked before the others, and at a smaller amount of deflection. Meanwhile type A and type B beams start cracking at almost the same load, but at different deflections. Type A concrete started was cracked before concrete type B. Obviously, the control beam sustains more load with more deflection compare to the other beams, and it indicates that the normal concrete can sustain more load in the elastic region than the other materials. Obviously, control and Type C beams cracked at higher load than other beams types, which it gave concrete type C an advantage.

4.4.4 Finite element model

This section captures ANSYS program results, and followed by the comparison with the laboratory results. Beams were cast which were made from the three types of concrete and normal concrete. As aforementioned, beams were subjected to three-point load. Data were collected from sixteen beams. The main target is to determine the load-deflection of all types of beams, and compare the created materials with the control. Maximum strain was also determined, and the modulus of elasticity as well. Some data were used in the simulation e.g. the modulus of elasticity and ultimate compressive strength, and were shown in Table 3.1. Modelling of the materials was done as mentioned in clause 3.6.1. Meshing the beams and the size of the element was illustrated in clause 3.6.1.4, and the solution setup was done according to clause 3.6.1.5.

4.4.4.1 Load – deflection curve

The normal concrete was used to make control beams. Ultimate compressive strength was 25.42MPa and the modulus of elasticity was 21515 N/mm^2. Fig. 4.19 showed the load-deflection of the control beam from ANSYS and the experiment. ANSYS gave perfect elastic behaviour up to approximately 30% of the ultimate compressive strength. The stress-strain curve was obtained from stress - strain curve predicted based on the individual material properties determined experimentally. The perfect elastic in the graph was affected by the input stress-strain curve, while the experiment did not provide that perfect elastic behaviour at the beginning of the curve.

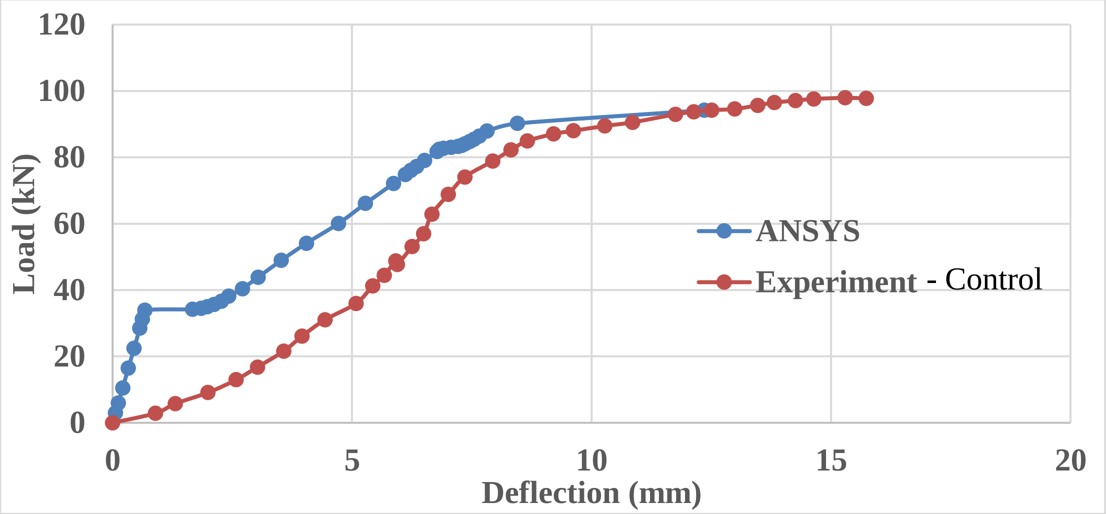


Fig. 4.19: Load-Deflection of Control Beam

The simulated beam (ANSYS curve) gave lower deflection at lower load, but beam from experiment started deflecting more at lower load. The variation in the two curves at the beginning is significant. However, at load 94.5kN the two curves are conservative.

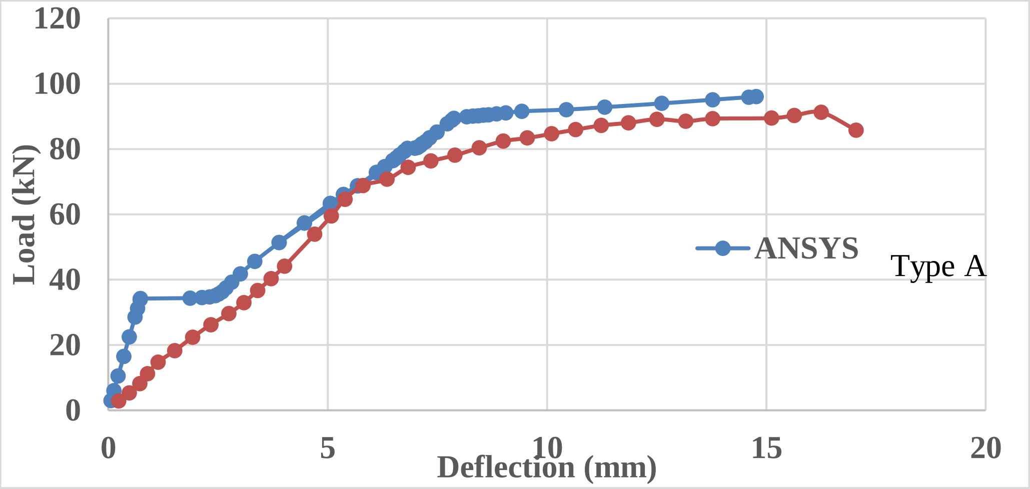


Fig. 4.20: Load-Deflection of Type A Beam

Concrete Type A as in Fig 4.20 showed better behaviour compared the control. Generally, ANSYS differed slightly than the laboratory results. The experiment gave more deflections at lower load compared to ANSYS.

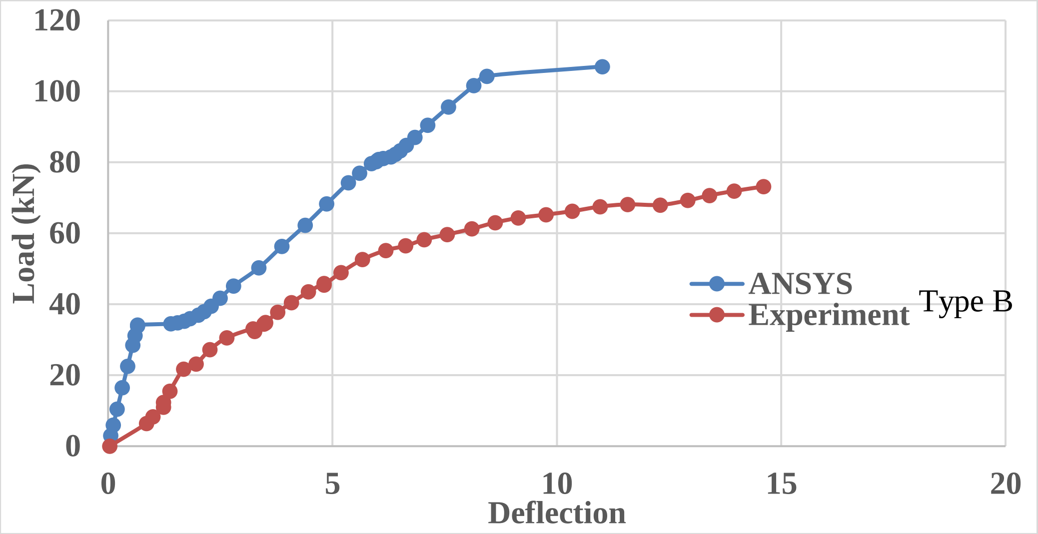


Fig. 4.21: Load-Deflection of Type B Beam

Fig. 4.21 illustrates the results of type B beam. ANSYS and experiment results disagreed significantly, but the behaviour generally is very similar. ANSYS gave more load with less displacement compared to concrete Type B and Type C as in Fig. 4.22.

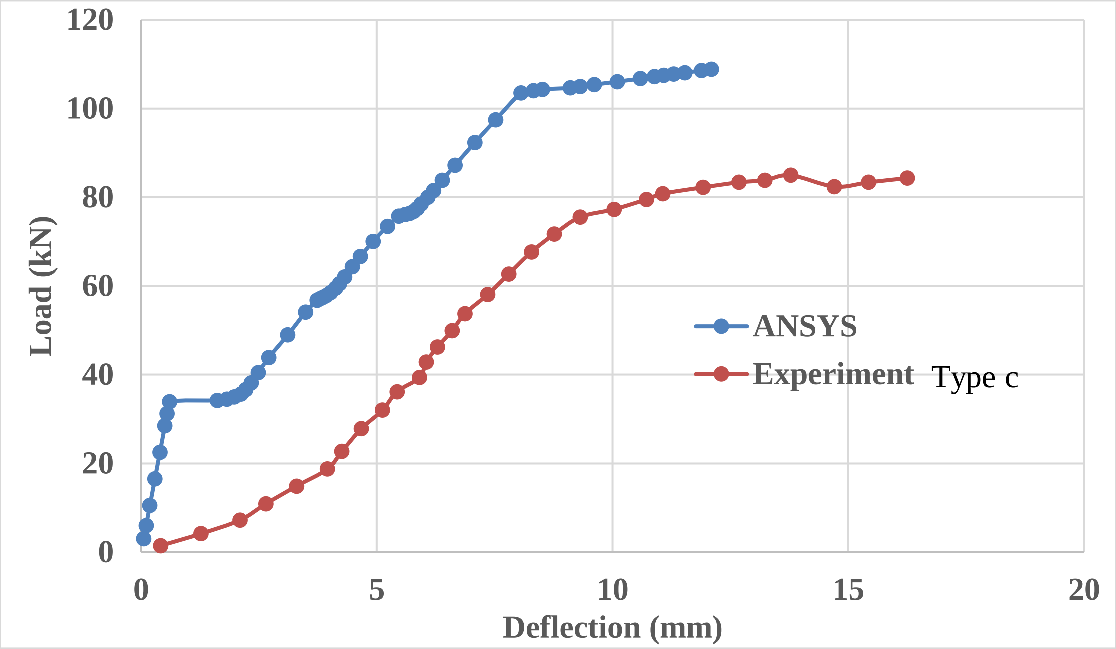


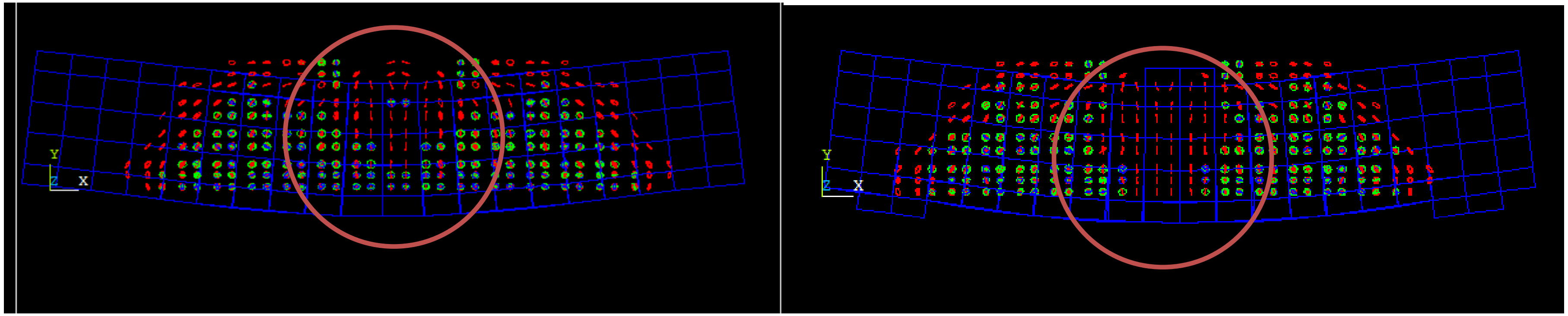
Fig. 4.22: Load-Deflection of Type C Beam

Finally, ANSYS model gave comparable results. In fact, many factors affected the simulation. The model of concrete was assumed to be theoretically described, and controlled by the modulus of elasticity. The values of modulus of elasticity that were obtained experimentally for each material, and it is not that accurate. Furthermore, the modulus of elasticity was assumed to be equal in the whole section, and that assumption was not exactly true, but it was uncontrollable. Thus, the best estimate for the modulus of elasticity was used. In addition, steel reinforcement was assumed to be yielded in the whole reinforced section, which was not also accurate.

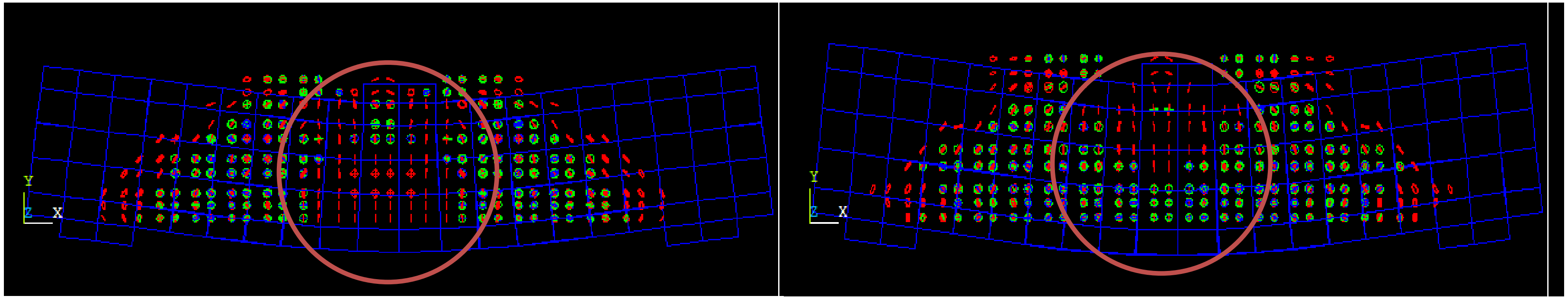
4.4.4.2 Crack pattern of beams

Fig 4.23 and 4.24 show the crack pattern which was obtained from both ANSYS program and the laboratory experiment. Generally, the crack pattern did not appear similar in pattern and direction. Cracks pattern was shown in Fig 4.23. The degree of severity of the crack was described by type of the colour, e.g. the cracks increased, when the colour of the small circular is changing from red to green and from green to blue. Control beam and type C beam showed almost the same behaviour of cracks.

The severe cracks in the control beam and type C beam occurred continuously at the bottom fibres. In type A and B beams, severe cracks have a gap at the centre of the beam, and that is what happened in the experiment.



(a) Control Beam (b) Beam Type A



(c) Beam Type B (d) Beam Type C

Fig 4.23: Cracks Pattern of Different Types of Beams, ANSYS

(a) Control Beam (b) Beam Type A

(c) Beam Type B (d) Beam Type C

Fig. 4.24: Cracks Pattern of Different Types of Beams, Experiment

4.4.4.3 Stress – Strain Curve

Three cubes of different types of concrete were tested after 28 days. The modulus of elasticity was obtained from the experimental stress – strain curve of each type. Different types of concrete were compared with the theoretical stress – strain curve.

4.4.4.3.1 Normal concrete

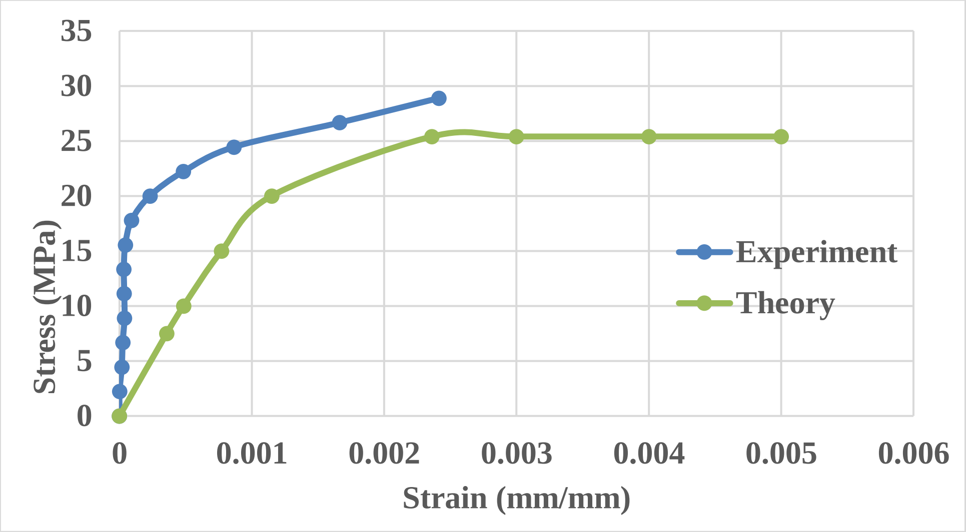


Fig. 4.25 Stress – Strain Curve of The Control

The stress – strain curve of the control was shown in Fig. 4.25. The first part of the curve (up to $0.7{*}f_c^{`}$) was used to determine the optimum modulus of elasticity. The modulus of elasticity of the normal concrete is 21515 MPa. Fig. 4.25 showed that the difference in strains increased more dramatically from approximately $0.3f_c^{`}$ up to the ultimate stress.

4.4.4.3.2 Concrete Type A

The stress – strain curve of concrete Type A showed in Fig. 4.26. The modulus of elasticity of concrete Type A is 20186 MPa. The stress – strain curve of the experiment is higher than the theory which gave an advantage to concrete Type A. Fig. 4.26 showed that the difference in strains from the beginning increased more significantly.

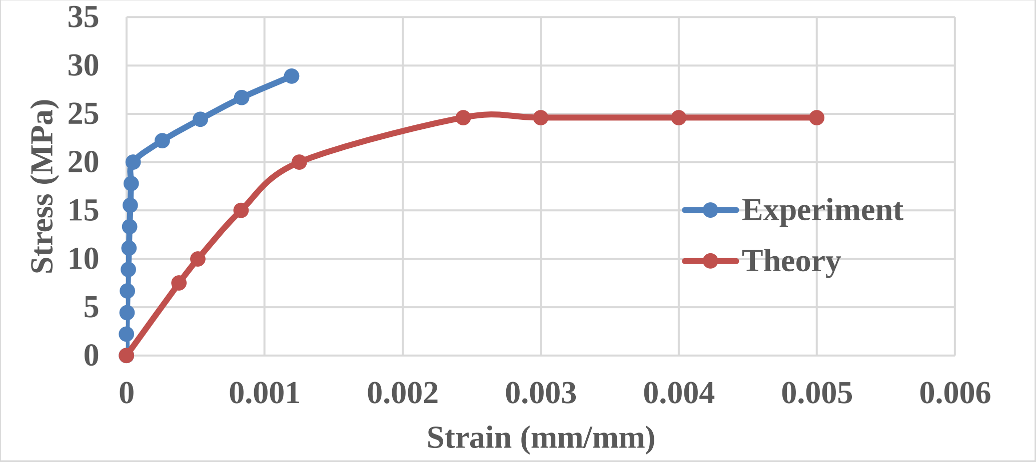


Fig. 4.26 Stress – Strain Curve of Concrete Type A

4.4.4.3.3 Concrete Type B

The stress – strain curve of concrete Type B was shown in Fig. 4.27. The modulus of elasticity of concrete Type B is 22178 MPa. The stress – strain curve of the experiment is higher than the theory which gave an advantage to concrete Type A. Fig. 4.27 showed that the difference in the strains increased more with increase in the stresses, although, the experiment failed early. Concrete Type B did not reach the ultimate strain.

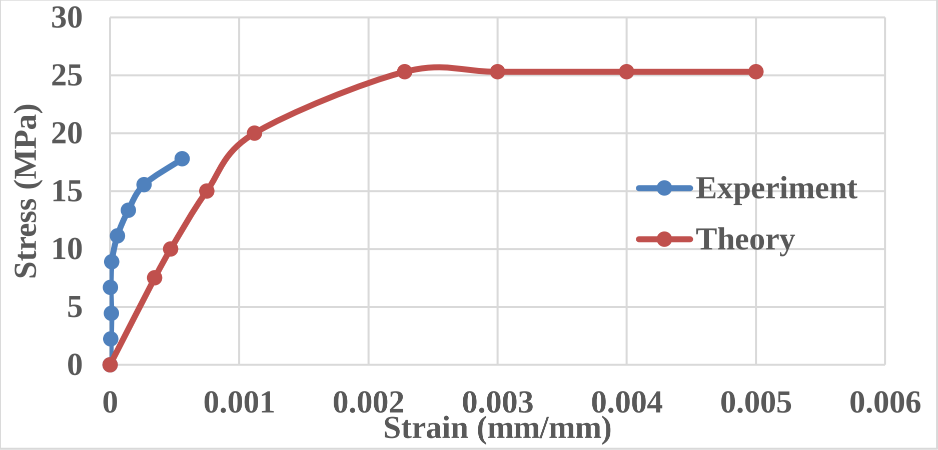


Fig. 2.27: Stress – Strain Curve of Concrete Type B

4.4.4.3.4 Concrete Type C

The stress – strain curve of concrete Type C was shown in Fig. 2.28. The modulus of elasticity of concrete Type C is 24653MPa. The stress – strain curve of the experiment is higher than the theory which gave an advantage to concrete Type C. Fig. 4.28 showed that the difference in the strains increased more significantly from approximately $0.3f_c^{`}$ up to ultimate strain, but generally it is reasonable.

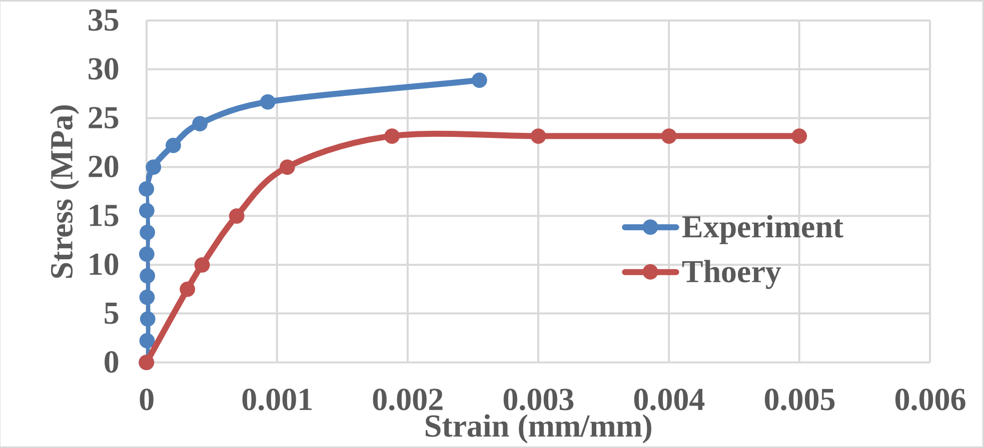


Fig. 4.28: Stress – Strain Curve of Concrete Type C

4.1 Cost analysis

As a matter of fact, the use of waste materials in concrete instead of normal aggregates should bring financial benefits. Three identities should be used to evaluate, materials cost, labour cost, and equipment cost. If crushing of aggregates is done by machine, the labour cost considers equal for both normal aggregates and waste materials. The equipment cost is likewise equal to both aggregates. Table 4.9 showed the materials cost, and how the use of waste materials can cut down cost. Obviously, using concrete Type A saved 20% of the price of normal concrete. Concrete Type B and C saved 35% of the normal concrete. These percentages were huge, and it influences the cost of the project significantly, especially, the big project.

Table 4.9: Cost Analysis of Using Waste Materials as Aggregates in Concrete

Used materials	Concrete type			
	Control	Type A	Type B	Type C
Sand (Ksh)	1508	754	754	754
Gravel (Ksh)	2276	2276	1707	1707
Glass aggregates (Ksh)	0.0	0.0	0.0	0.0
Ceramic aggregates (Ksh)	0.0	0.0	0.0	0.0
Total	3784.0	3030.0	2461	2461
Saving (%)	0	20	35	35

The values in Table 4.9 were calculated for one meter cubes of concrete. The cost of one tone (1000 kg) of both sand and gravel is 2,000 KSH according to Kenyan market.

Chapter Five

Conclusion and Recommendations

4.2 General

This chapter presents conclusions and recommendations of the research results. Outcomes lied on the analysis and discussion of the results that have mentioned in the previous chapter. Also, it clarifies weaknesses and areas of further research. Recommendations were mentioned to imply this research in a better way in real life.

4.3 Conclusion

Many tests were conducted for the properties of inorganic waste materials as aggregates, for a purpose of use in concrete. Particles size distribution, dry-rodded, loss-rodded density, aggregate crushing value, aggregate impact value, water absorption, and specific gravity were tested. These tests were conducted for fine and coarse aggregates, fine and coarse ceramic tiles aggregates, and fine and coarse rubber tyres aggregates. Sand and gravel were tested as well. The following conclusions were draw;

i. In this study, it is proposed “to identify which of the selected waste materials can be used as alternative aggregates for concrete production”. From the results, ceramic tile aggregates can be applied as either fine or coarse aggregates. Fine glass aggregates also have suitable results. ACV of the coarse glass was 42.3%, and AIV was 31.0% which are both more than 30%. Rubber tyres aggregates gave ACV and AIV of 0.02% and 0.004% respectively which are very low results in comparison with other aggregates. Therefore, fine glass, ceramic tiles, and coarse ceramic tiles could be acted as normal aggregates under mentioned conditions.

ii. Furthermore, the second objective was of this research was “to investigate the influence of glass, ceramic tiles, and rubber tyres on both the mix design and the concrete properties”. Therefore, Compressive strength was 17.55MPa and 20.7MPa for glass concrete and ceramic concrete at 25% replacement, and as it was discussed early in chapter four. It was concluded that sand should not be replaced by fine glass and fine ceramic tiles aggregates more than 50%. Also, the gravel should not replace more than 25% by coarse ceramic tiles aggregates. For these replacement, the strength of the concrete was not much affected.

iii. The fine glass, fine ceramic, and coarse ceramic aggregates were blended up to 50% replacement for fine aggregates, and up to 25% replacement for coarse aggregates. Based on the results, it concluded that the fine glass, fine ceramic, and coarse ceramic can be blended and used as specifically mentioned replacement.

iv. In addition, rubber aggregates can be used as normal aggregates either sand or gravel, where high strength is not needed. Rubberized concrete showed high elastic energy, which gave it an advantage than the normal concrete. Wear resistance increased highly by increasing the amount of the rubber aggregates in concrete. This study concludes that rubberized concrete can be used in the construction industry such as; landscaping, sports field ground, architectural finishing, and other engineering applications where normal strength is not needed.

v. Beams were made from chosen waste materials were cast to check the structural behaviour. ANSYS was used to simulate these beams. The results (refer to Figures 4.18, 4.19, 4.20, and 4.21) were not giving a good agreement with the test results, and the simulation gave the load -deflection curve somehow close to the experimental load – deflection curve.

vi. The use of waste materials instead of normal aggregates has financial benefits, and it saves approximately 20% to 30% of the amount of suggested budget in the construction materials.

4.4 Recommendation

This research was conducted based on materials' results that have been mentioned in the previous sections. Any type of glass and ceramic tiles waste can be used without significant change in the results and rubber tyres as well. From this research, the following recommendations were set for further studies.

i. This study did not consider the effect of the durability. The used waste materials were not natural, and re-producing them may affect their characteristics with time. Waste materials should not contain any organic materials and clay. The fine glass and ceramic tiles aggregates can provide more rough surface, and therefore, the strength may increase.
ii. The method of papering the waste materials was recommended to be developed to reduce the consumed time and effort.
iii. The research recommended that sand should not be replaced by fine glass and fine ceramic tiles aggregates more than 50%. Also, the gravel should not replace more than 25% by coarse ceramic tiles aggregates.
iv. Rubberized concrete was recommended to be used in the construction industry such as; landscaping, sports field ground, architectural finishing, and other engineering applications where normal strength is not needed.
v. In fact, many factors affected the simulation results of concrete beam which was made from inorganic waste materials. The model of the concrete was assumed to be theoretically described, and controlled by the modulus of elasticity. The values of modulus of elasticity that were obtained experimentally for each material were not that accurate. Furthermore, the modulus of elasticity was assumed to be equal in the whole beam element, and that assumption was not exactly true but it is uncontrollable. Thus, the best estimate for the modulus of elasticity was used. The steel reinforcement was assumed to reach yield strength in the whole reinforced section, which was not also accurate. Therefore, for a better solution, the above assumptions should be considered.

References and Bibliography

--. (2002). *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*. *American Concrete Institute*. USA.

--. (2014). JICA Strategy Paper on Solid Waste Management. (2014).

Arulrajah, A., Piratheepan, J., Bo, M. W., & Sivakugan, N. (2012). Geotechnical characteristics of recycled crushed brick blends for pavement sub-base applications. *Canadian Geotechnical Journal*, *49*(7), 796–811.

ASTM C373-88, S. (2006). C373-88 (2006)“Standard test method for water absorption, bulk density, apparent porosity and apparent specific gravity of fired whiteware products.” *ASTM International, West Conshohocken, PA*.

ASTM C650-04. (2014). *Standard Test Method for Resistance of Ceramic Tile to Chemical Substances*. *ASTM*. USA.

Batayneh, M., Marie, I., & Asi, I. (2008). Promoting the use of crumb rubber concrete in developing countries. *Waste Management*.

Bignozzi, M., & Sandrolini, F. (2006). Tyre rubber waste recycling in self-compacting concrete. *Cement and Concrete Research*, *36*(4), 735–739.

Bobancu, Ş., & Duţă, A. (2010). MECHANICAL PROPERTIES OF RUBBER-AN OVERVIEW. *Bulletin of the Transilvania University of Brasov*, *3*(52).

British-Standard-Institution. (1985). BS 812-103.1 Part 103: Methods for determination of particle size distribution � Section 103.1 Sieve tests, 13.

British-Standard-Institution. (1989). BS 812-103.2 Part 103: Methods for determination of particle size distribution � Section 103.2 Sedimentation test, 13.

British-Standard-Institution. (1990). BS 812-100 Part 100: General requirements for apparatus and calibration, 18.

British-Standard-Institution. (1990). BS 812-102 Part 102: Methods for sampling, 12.

British-Standard-Institution. (1990). BS 812-109 Part 109: Methods for determination of moisture content, 13.

British-Standard-Institution. (1990). BS 812-110 Part 110: Methods for determination of aggregate crushing value (ACV), 12.

British-Standard-Institution. (1990). BS 812-2:1995 Part 112: Methods for determination of aggregate impact value (AIV), 15.

British-Standard-Institution. (1993). BS 812-2:1995 Part 2: Determination of density and porosity. *Advanced Technical Ceramics. Monolithic Ceramics. Gerneral and Textural Properties.*, 1–16.

British-Standard-Institution. (2013). BS EN 12620 2013 Aggregates for concrete, 60.

Choo, B., & MacGinley, T. (2002). *Reinforced concrete: design theory and examples*. CRC Press.

Chou, L. H.Lu, C. K., Chang J. R., & Lee, M. T. (2007). Use of waste rubber as concrete additive. *Waste Management & Research*, *25*(1), 68–76.

Christy, C., & Tensing, D. (2010). Effect of Class-F fly ash as partial replacement with cement and fine aggregate in mortar. *Indian Journal of Engineering & Materials*, *17*, 140–144.

Dahlén, L., & Lagerkvist, A. (2010). Pay as you throw: strengths and weaknesses of weight-based billing in household waste collection systems in Sweden. *Waste Management*, *30*(1), 23–31.

Dalloul, K. (2013). Study of the Effect of Crushed Waste Glass as Coarse Sand and Filler in the Asphalt Binder Course. *(Doctoral Dissertation, The Islamic University of Gaza).*

Desayi, P., & Krishnan, S. (1964). Equation for the stress-strain curve of concrete. *Journal Proceedings*, *61*(3), 345–350.

Ehia, A. H., Rashwan, M. M., Assaf, K. A., & el Samee, K. A. (2014). Improvement of Performance for RC Beams Made from Recycled Aggregate by Using Non-Traditional Admixture. *World Academy of Cience, Engineering and Technology, International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, *8*(6), 668–673.

Eldin, N., & Senouci, A. (1993). Rubber-tire particles as concrete aggregate. *Journal of Materials in Civil Engineering*, *5*(4), 478–496.

Evangelista, L., & Brito, J. De. (2007). Mechanical behaviour of concrete made with fine recycled concrete aggregates. *Cement and Concrete Composites*, *29*(5), 397–401.

García-González, J., & Rodríguez-Robles, D. (2015). Ceramic ware waste as coarse aggregate for structural concrete production. *Environmental Technology* , *36*(23), 3050–3059.

Gere, J. M., & Timoshenko, S. (1986). *Theory of Elasticity 2nd ed*. Grupo Editorial Iberoamérica.

Grinys, A., Sivilevičius, H., & Daukšys, M. (2012). Tyre rubber additive effect on concrete mixture strength. *Journal of Civil Engineering*, *18*(3), 393–401.

Kasozi, A., & Blottnitz, H. von. (2010). Solid Waste Management in Nairobi: A Situation Analysis. *Report for City Council of Nairobi, Contract for UNEP*, 59.

Kong, F., & Evans, R. (2013). *Reinforced and prestressed concrete*. Springer.

Konin, A. (2011). Effect of plastic waste content on Physico-Mechanical properties of flexible pavements. *International Journal of Civil & Structural Engineering*, *2*(1), 382–394.

Kosmatka, S., Kerkhoff, B., & Panarese, W. (2011). *Design and control of concrete mixtures*. Portland Cement Assoc.

KPMG Kenya Budget Brief 2016. (2015). *2016 Budget Highlights "Consolidating Progress Towards A Brighter Medium Term."* Niarobi.

Lakshmi, R., & Nagan, S. (2010). Studies on concrete containing E plastic waste. *International Journal of Environmental*, *1*(3), 270.

Lee, H. (2015). *Finite element simulations with ANSYS workbench 16*. SDC publications.

Malhotra, V., & Mehta, P. (1996). *Pozzolanic and cementitious materials* (Vol. 1). Taylor & Francis.

Mesci, B., Çoruh, S., & Ergun, O. (2011). Use of selected industrial waste materials in concrete mixture. *Environmental Progress &*, *30*(3), 368–376.

Mohammed, N., & D, P. A. (2012). Utilization of industrial waste slag as aggregate in concrete applications by adopting Taguchi's approach for optimization. *Open Journal of Civil Engineering, 2012*.

Moriconi, G. (2007). Recyclable materials in concrete technology: sustainability and durability. *Sustainable Construction Materials and Technologies, UK*, 11–13.

Muthusamy, K., & Sabri, N. (2012). Cockle shell: a potential partial coarse aggregate replacement in concrete. *International Journal of Science, Enviroment and*, *1*, 260–267.

Nawy, E. G. (2005). *Reinforced concrete a fundamental approach 5 th*.

Neville, A. M. (1981). *Properties of concrete Pitman*. *Green Technolog*. California: SAGE Publications, Inc.

Ohbuchi, Y., & Obikawa, T. (2003). Finite element modeling of chip formation in the domain of negative rake angle cutting. *Journal of Engineering Materials and Technology*, *125*(3), 324–332.

OTIENO, O. (2015). STRENGTH CHARACTERISTICS OF RUBBER DERIVED CONCRETE (RUBCRETE). *University of Nairobi*.

Poon, C., & Chan, D. (2007). The use of recycled aggregate in concrete in Hong Kong. *Resources, Conservation and Recycling*, *50*(3), 293–305.

Puri, N., Kumar, B., & Tyagi, H. (2013). Utilization of Recycled Wastes as Ingredients in Concrete Mix. *Journal of Innovative Technology and Exploring Engineering (IJITEE*, 2278–3075.

Rajora, V., & Sidhu, G. (2013). Effect of Partial Replacement of Fine and Coarse

Aggregate (10mm) with Ceramic Waste on the Properties of Concrete. *International Journal of Science and Research (IJSR)*, *5*(8).

Raval, A., Patel, I., & Pitroda, J. (2013). Ceramic Waste: Effective Replacement Of Cement For Establishing Sustainable Concrete. *International Journal of Engineering Trends and Technology (IJETT)*, *4*(6).

Senthamarai, R., & Manoharan, P. (2005). Concrete with ceramic waste aggregate. *Cement and Concrete Composites*, *27*(9), 910–913.

Shayan, A. (2002). Utilisation of waste glass products in concrete. *Municipal Engineering in Australia*, *29*(4).

Siam, A. (2007). Properties of Concrete Mixes with Waste Glass. *(Doctoral Dissertation, The Islamic University of Gaza)*.

Soon, W., Baliunas, S. L., Robinson, A. B., & Robinson, Z. W. (1999). Environmental effects of increased atmospheric carbon dioxid. *Energy & Environment*, *10*(5), 439–468.

Stone, R. (2011). A Remedy at Last for the Ailing Ganges? *Science*, *332*(6028), 412–413.

Subramani, T., & Ravi, G. (2015). Experimental Investigation Of Coarse Aggregate With Steel Slag In Concrete. *IOSR Journal of Engineering*, *5*(5), 64–73.

Suganthy, P., & Chandrasekar, D. (2013). Utilization of pulverized plastic in cement concrete as fine aggregate.

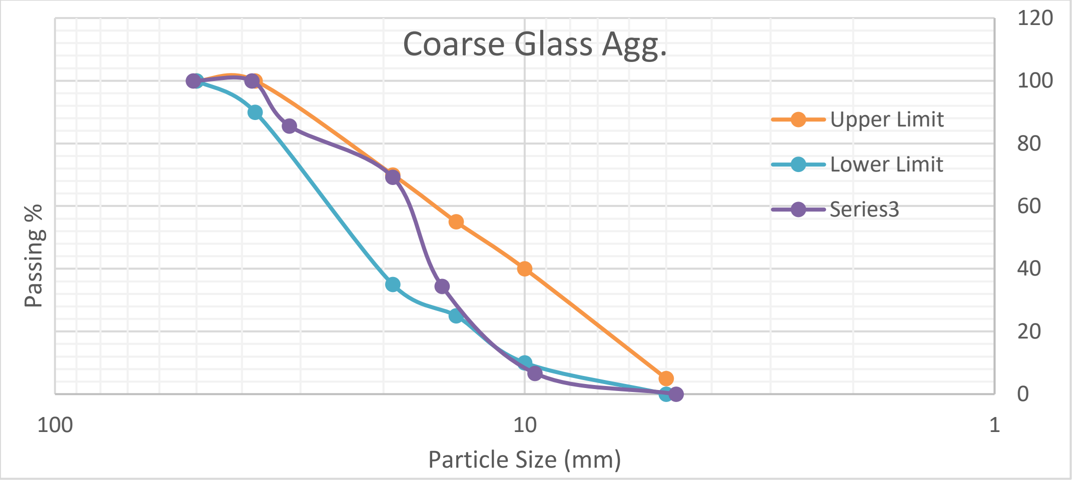
Suman, A. K., Saxena, A. K., & Arora, T. R. (2015). Assessment of Concrete Strength using Partial Replacement of Cement for Rise Husk Ash - Google Scholar. *International Journal of Soft Computing and Engineering (IJSCE)*, 2231–2307.

Vijayakumar, D., & Vishaliny, M. (2013). Studies on glass powder as partial replacement of cement in concrete production. *International Journal of Emerging Technology and Advanced Engineering*, *3*(2), 153–157.

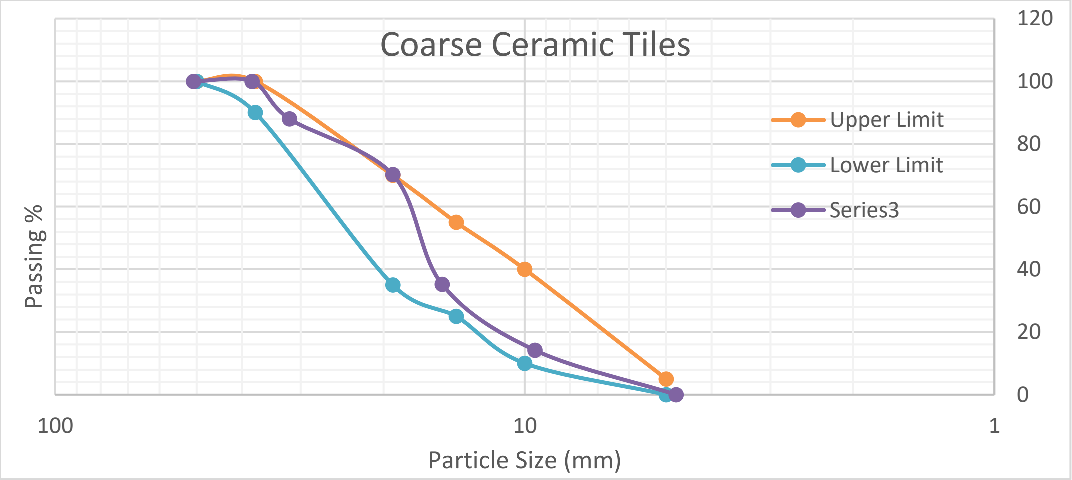
Yerramala, A. (2014). Properties of concrete with eggshell powder as cement replacement. *Indian Concrete Journal*, *94*.

Appendix

APPENDIX 1 Coarse aggregates size distribution

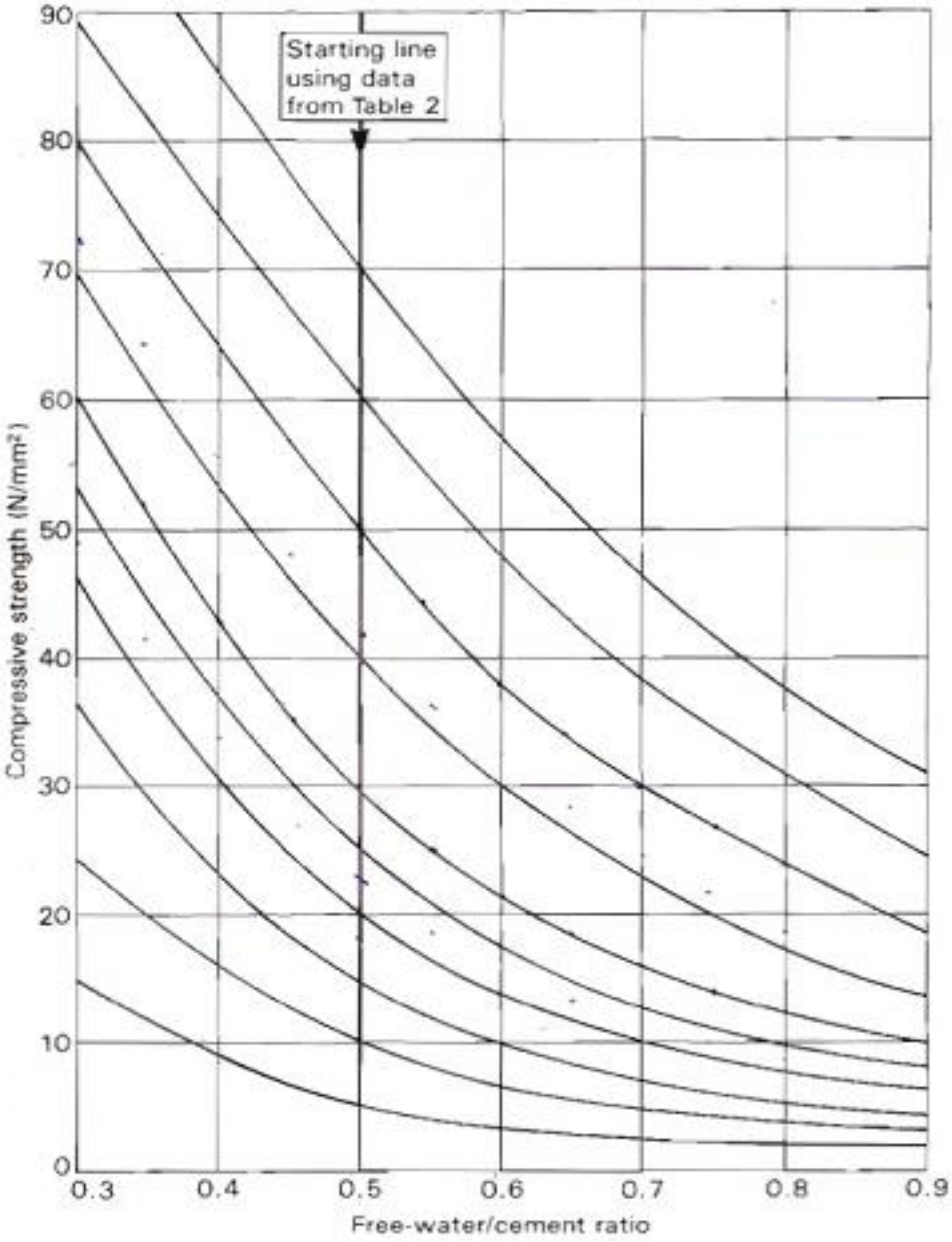


A1: Grading Curve of Coarse Glass Aggregates



A2: Grading Curve of Coarse Ceramic Tiles Aggregates

APPENDIX 2 Concrete mix design curves



B1: Relationship between the compressive strength and the water/cement ratio

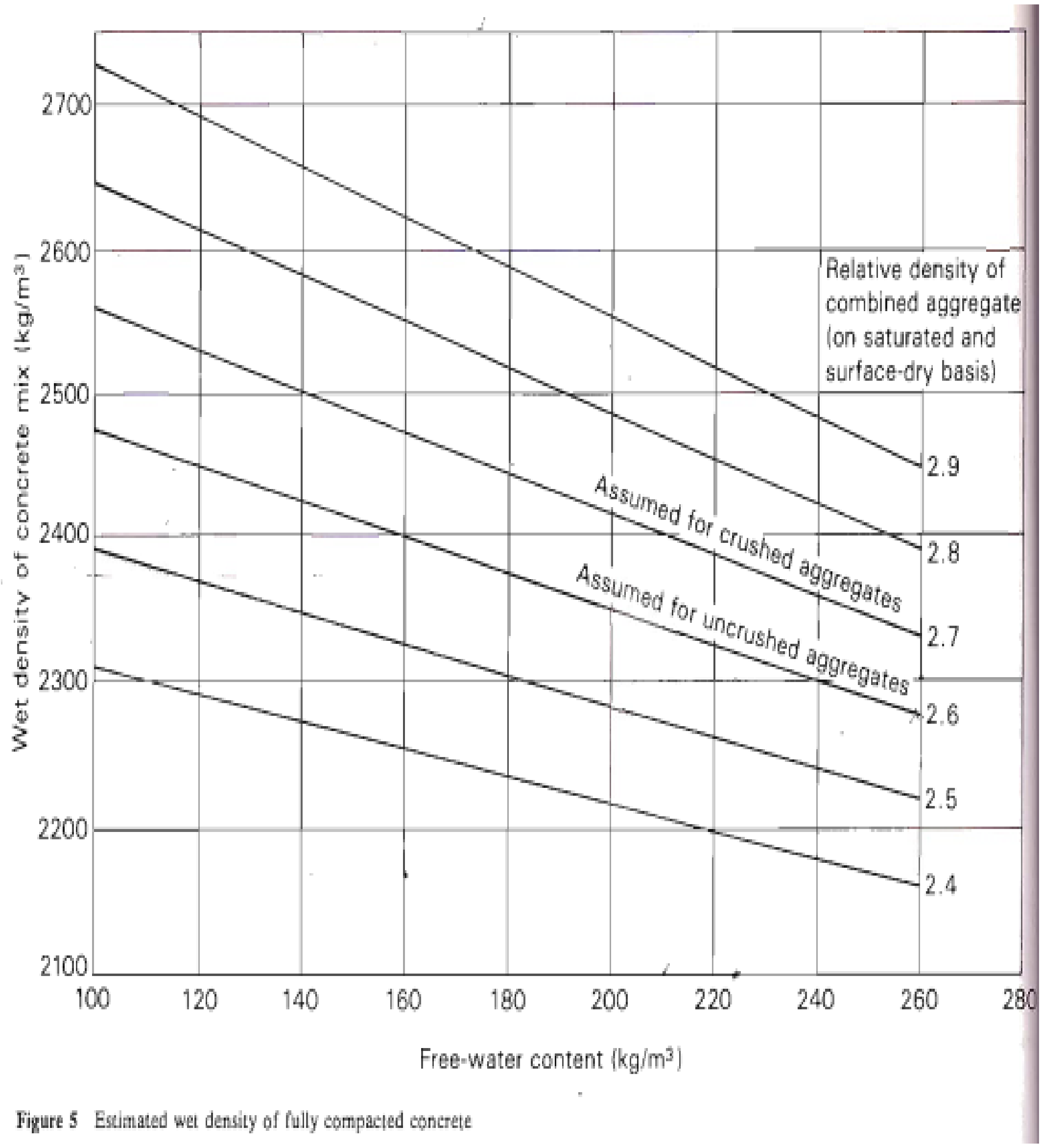


Figure 5 Estimated wet density of fully compacted concrete

B2: Relationship between the free-water content and the wet density of concrete mix

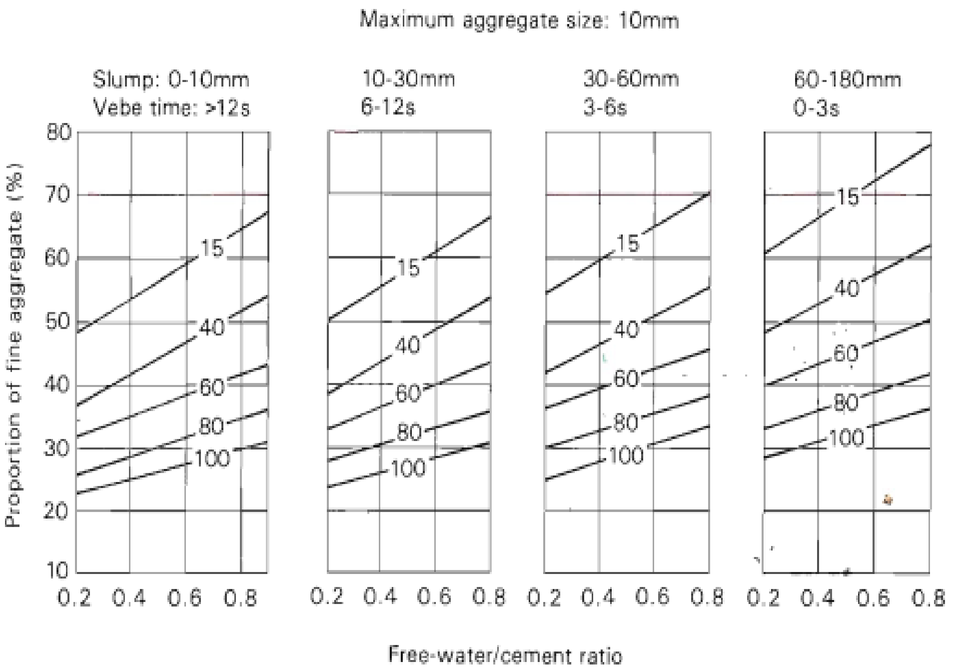
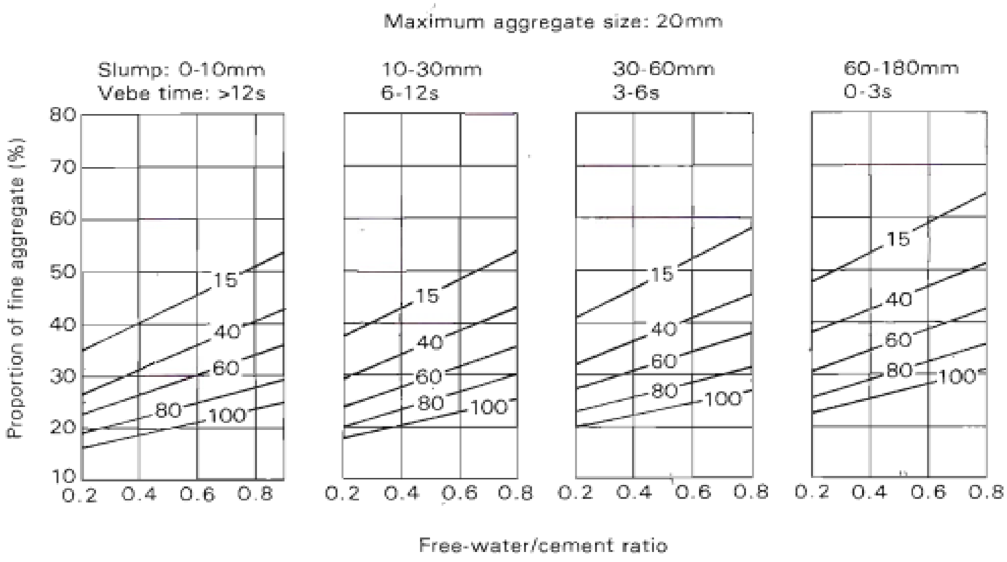
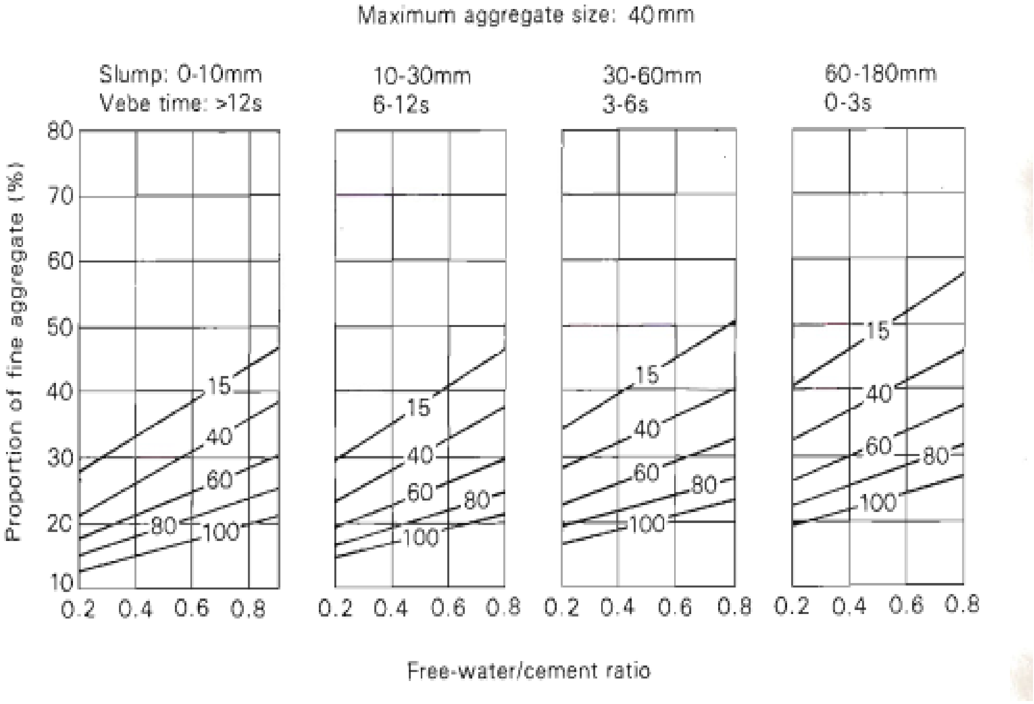


Figure 6 Recommended proportions of fine aggregate according to percentage passing a 600 μm sieve

B3: Free-water/ cement ratio and the proportion fine aggregates for maximum size 10 mm



B4: Free-water/ cement ratio and the proportion fine aggregates for maximum size 20 mm



B5: Free-water/ cement ratio and the proportion fine aggregates for maximum size 40 mm