BEHAVIOR OF RC BEAMS WITH RECYCLE AGGREGATE AS COARSE AGGREGATE REPLACEMENT WITH ADDITION OF STEEL FIBRES

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ABSTRAK

Kemampanan adalah satu kebimbangan menekan pada abad ke-21. pembangunan sosial di kebanyakan negara adalah meningkatkan kesedaran mengenai keperluan generasi masa depan dan undang-undang untuk melindungi kualiti masa kini dan masa depan kehidupan. Salah satu cabaran besar di negara-negara yang disebabkan oleh kuantiti yang semakin meningkat adalah pembinaan dan perobohan pelupusan sisa. Jadi, tujuan kajian ini adalah untuk menentukan kelakuan rasuk konkrit bertetulang yang dibina daripada agregat biasa (NA) dan agregat konkrit kitar semula (RCA), dan untuk menyiasat prestasi penambahan gentian keluli dalam kitar semula rasuk konkrit bertetulang. agregat dikitar semula telah dibuat oleh menghancurkan konkrit sisa makmal kiub ujian dan rasuk. Terdapat empat jenis campuran konkrit yang akan diuji; [1] Kawalan Campuran (NC), [2] 50% Recycled Concrete Agregat (RCA) Campuran, [3] 50% Recycled Concrete Agregat (RCA) + 1.0% Gentian keluli Campuran (RCA-SF1%), [4] 50 % Recycled Concrete Agregat (RCA) + 2.0% Gentian keluli Campuran (RCA-SF2%). Tujuan menambah gentian keluli di dalam campuran konkrit untuk mengawal pembangunan retak, meningkatkan kekuatan ricih muktamad, mengurangkan pesongan rasuk konkrit, dengan itu, dan juga meningkatkan interlock agregat dengan simen dalam campuran konkrit. Kesimpulannya, hasil kajian ini menunjukkan bahawa peningkatan menjanjikan beban membawa kapasiti, dikawal retak corak dan juga mod kegagalan rasuk konkrit bertetulang.

ABSTRACT

Sustainability is a pressing concern on the 21st century. Social development in most countries is raising awareness of the needs of future generations and legislations to protect the present and future quality of life. One of the major challenge in developing nations that due to its ever increasing quantities is construction and demolition waste disposal. So, the purpose of this study are to determine the behaviour of reinforced concrete beams that are constructed from normal aggregates (NA) and recycled concrete aggregates (RCA), and to investigate the performance of addition of steel fibres in recycled reinforced concrete beams. Recycled aggregates were made by crushing the waste concrete of laboratory test cubes and beams. There are four types of concrete mixtures that will be tested; [1] Control Mixture (NC), [2] 50% Recycled Concrete Aggregate (RCA) Mixture, [3] 50% Recycled Concrete Aggregate (RCA) + 1.0% Steel Fibres Mixture (RCA-SF1%), [4] 50% Recycled Concrete Aggregate (RCA) + 2.0% Steel Fibres Mixture (RCA-SF2%). The purpose of adding steel fibres inside concrete mixture as to control the crack development, increases the ultimate shear strength, decreasing the deflection of concrete beams, thus, and also enhancing aggregate interlock with cement inside concrete mixture. As conclusion, this study outcome suggests that the promising enhancement of load carrying capacity, controlled cracking pattern and also failure mode of the reinforced concrete beams.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

NA	Normal Aggregates
RCA	Recycled Concrete Aggregate
SF	Steel Fibres
RRCB	Recycled Reinforced Concrete Beams
RC	Reinforced Concrete
NC	Normal Concrete

CHAPTER 1

INTRODUCTION

1.1 Introduction of Study

Concrete is one of the most important materials that widely used in the construction works. The demand for the concrete as a construction material was very high in the past and will be continue in future. Concrete uses a significant amount of non-renewable materials and resources especially natural aggregates. But, nowadays, because of the shortage and increasing costs of construction materials, there is the need to explore and use alternative materials in construction. Thus, according to Puthussery (2016), in developed countries, the recycled concrete aggregates (RCA) are proposed to be used as a replacement to the normal aggregates (NA) in road and building construction. There are many benefits that can gain by using the recycled aggregates as the coarse aggregates replacement. One of them is it can reduce the need of landfilling while conserving the use of increasingly limited good quality normal aggregates. Furthermore, it is an eco-friendly construction materials and also can reduce the construction time and costs. This is because, for instance, the crushing concrete aggregate works can be done on site by using portable crushers rather than need to transport the concrete wastes in and out of the plant. Besides, according to Ahmad S Subaih (2005), he states that the strength of the concrete which are about 25MPa and 30MPa can be reached by making recycled aggregate as a replacement for coarse materials, hence, it is suitable for making the recycled concrete aggregates as one of the important elements in the construction materials.

There are many failure of a reinforced concrete beams. One of them is it can corrode easily because of the presence of steel inside the concrete. Water that contained inside the concrete mixture will react and cause the steel corrodes, hence, can make the beams lost its strength. Next, if the aggregates inside the reinforced concrete did not interlock properly, it can cause the weak bond between the steel and concrete. Thus, it will cause the cracking and deflections due to the shrinkage of the concrete.

Thus, in order to increase the strength of the reinforced concrete beams, the using of the steel fibre inside the concrete mixture is one of the ways. There are many reasons why it may be preferable to use the steel fibres in concrete mixtures. For example, the steel fibres are randomly distributed throughout the concrete volume at relatively small spacing and thus provide equal resistance to stresses in all directions. Next, it also can increase the resistance of the concrete from the crack formation and propagation. In addition, the increased resistance of the concrete cover to spalling and cracking helps to protect steel from corrosion, and hence, it is improve the structural durability. Last but not least, the steel fibre also significantly can reduce the construction time and costs, especially in an era of high labor costs and possibly even labor shortages.

1.2 Problem Statement

Nowadays, one of the major challenge in developing nations that due to its ever increasing quantities is construction and demolition waste disposal especially concrete waste. During the demolition and construction works, there are lots of concrete was abandoned, hence, the area of the landfilling to bury the concrete waste become increasing day by day. The using of recycled concrete aggregates is still one of the main construction materials rather than other materials for many years. Even though, this waste is been used which is not too comprehensive in the world of construction today. Limited information and knowledge of the performance in the concrete, effects on properties to the concrete and also lack of the research about the specific standards to the concrete structures are the reasons why the recycled concrete will be used only in some of the construction works.

Furthermore, the concrete wastes from construction works are increasing rapidly in number which can cause the increases in landfill areas. This can cause the ground and air pollutions that will cause in negative impact on our environment. Plus, the economy conditions of the countries will be affected as there are millions of dollar that need to remove the concrete waste from construction sites, transport the wastes to the landfill areas, and also need to perform many procedures just to bury the concrete wastes. As to preserve the non-renewable sources that will become limited on the future which is aggregates, one of the purpose of this research is using the recycled concrete aggregates as replacement of coarse aggregates, hence, can minimize the using of this source on the future.

1.3 Objectives of Study

The main objectives of this research are:

- To study the behavior of reinforced concrete beams that are constructed from normal and recycle concrete aggregates.
- To investigate the performance of steel fiber in recycled reinforced concrete beams.

1.4 Scope of Study

1) The scope of this study: To replace the coarse aggregates in the concrete mixture with 50% of recycled concrete aggregates.
2) Four types of reinforced concrete beam mixtures that will be tested;
    - Reinforced concrete beams with normal mix (NC)
    - Reinforced concrete beams with 50% replacement of recycled concrete aggregates (RCA)
    - Reinforced concrete beams with 50% replacement of recycled concrete aggregates with and addition of 1.0% steel fibre (RCA-SF1%)
    - Reinforced concrete beams with 50% replacement of recycled concrete aggregates with an addition of 2.0% steel fibre (RCA-SF2%)
3) The laboratory concrete test cubes were crushed to crush aggregates.
4) Maximum aggregate size: About 15-20 mm.
5) The concrete grade: Grade 30
6) Size of the beam samples: 150 x 200 x 1500 mm
7) Size of the mould of cube samples: 150 x 150 x 150 mm
8) The main reinforcement bar: 4H12
9) Type of shear links: H6-130
10) Admixture: Superplasticizer
11) Sieve analysis test; to check on the aggregate characteristics
12) Slump Test, Compressive Strength Test, Flexural Test

1.5 Significance of Study

The purpose of this study is to study the behavior of the reinforced concrete beams that are constructed from normal aggregates (NA) and recycled concrete aggregates (RCA). Therefore, some laboratory tests will be carried out as to determine the basic concrete properties such as compressive strength, workability and so on of the both types of concrete aggregates. Based on the result that we will obtain, we can determine whether the 50% of recycled concrete aggregates is suitable to be used as replacement of coarse aggregates in concrete beam mixtures.

Furthermore, it is an effort to value on sustainability which to protect the environment against negative impact derive from human. Thus, the replacement of coarse aggregates by using RCA more or less will help to be more economical solution to the main problem of waste concrete disposal in the landfill, plus the dumping of the laboratory concrete test cubes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, there are many studies on the concrete in expanding sources of the materials involved. One of the materials involved in the study is the aggregates. Recently, there are various types of aggregates has been produced. For example of the resulting aggregate consists of crushed glass, industrial waste, construction waste such as concrete and crushed bricks.

This research is supported with the related reading materials of the past studies about the recycle aggregate materials, which had been done as the references of this study. Many researchers have devoted their studies to determine the properties of the recycled aggregates, including the particle size distribution, density and water absorption and identifies the need to examine the porosity and possible chemical contamination of the aggregate.

Thus, this research focuses on the recycling of concrete waste as the replacement of coarse aggregate in concrete beam with an addition of steel fibre.

2.2 Recycled Aggregate

Recycled aggregate is obtained as a result of crushing and compressing, graded inorganic particles prepared from the materials that have been used in the construction and demolition debris or the laboratory test cubes. These materials resulted from destruction of buildings, bridges, roads and other concrete structures.

Recycled aggregate can be mixed, batched and transported in the same conditions as normal concrete. Special care is needed when using fine recycled aggregates. The recycled aggregates should be tested at several substitution rates as to determine optimal rate.

2.2.1 Properties of Recycled Aggregate in Concrete

There are some differences and variation of aggregate characteristics that contributes from the production of the natural aggregates (NA) and recycled concrete aggregates (RCA). RCA is made of natural aggregate coated with pieces of natural aggregate, cement paste residue, or just cement paste and some impurities. There is a general agreement that the amount of the cement paste has an important influence on the quality, physical and mechanical properties of the aggregates and as such has potential influence on the properties of reinforced concrete.

2.2.1.1 Shape and Size Distribution

In specific, the size of the coarse aggregate is an important characteristics that will affects the mechanical properties of the concrete. The shape and surface of the coarse aggregates can influence the strength of concrete by bringing the sufficient surface area for bonding with the paste or creating unfavourable high internal stress.

According to Tasong et al. (1998), the better bonding between the aggregate and cement paste in concrete mixture can be achieved by using the rough surface texture of the aggregate.

2.2.1.2 Specific Gravity

The specific gravity of waste concrete aggregates is much lower than normal aggregates (Prasad et al, 2007). The average specific gravity of the aggregates is normally varies between 2.6 to 2.8.

Hansen et al. (1983) found that the specific gravity decreases from 4.5% to 7.6% when compared with specific gravity of normal aggregates.

According to Topcu et al. (2004), the specific gravity of waste concrete aggregates were lower compared with normal aggregates as due to the certain proportion of mortar over these aggregates.

2.2.1.3 Water Absorption

Aggregates for concrete mixture can be in various moisture states such as air-dry, oven-dry, saturated-surface dry and wet. Water absorption of the aggregates is connected to its porosity and the amount of moisture absorbed by the minute pores present in the aggregate from its air-dry state to its saturated-surface dry state. Information of these property is essential for deciding the measure of water per cubic metre of concrete or keeping up a suitable water to cement ratio.

Hansen et al. (1983) concluded that the water absorption is about 8.7% for the material that is 4-8 mm in size, 3.7% for 16-32 mm size and the absorption capacity of recycled aggregate increased with a higher amount of adhered mortar. And according to Ravindraja (2000), he states that the recycled aggregate has the average value of the water absorption 6.35% while the natural aggregate has 0.9%. The quality and quantity of the adhered mortar are the main factors that can affects the absorption capacity of recycled aggregates. Thus, he concludes that recycled aggregates with adhered mortar have lower density and higher water absorption capacity compared with natural aggregates.

According to Gao et al. (2008), he states that the old testing approach for water absorption cannot give accurate results for recycled aggregates, which can cause errors in concrete mix design results. This is because due to the patches of the cement pastes that attached to the surface of the recycled aggregates will affects the water absorption in a manner different to normal aggregates. Thus, in order to get the rates of water absorption and corresponding soaking time, real-time assessment of water absorption is suggested to provide values of water absorption at different time-intervals. In addition, the proposed method can evade the removal of cement paste during the soaking and drying process of recycled aggregates sample. Hence, this approach are more accurate and proven to be a good alternative in measuring the genuine water absorption rate of recycled aggregate.

2.2.1.4 Bulk Density

Broadly, the saturated surface density of recycled aggregates is lower than the natural aggregates due to the low density of the mortar that sticked to the original aggregates. Also, it depends on the strength and size of the original aggregates.

According to the Hansen et al. (1983), he states that the recycled concrete aggregates have a higher density and the saturated surface density depends on the type of the crushing machine and energy used. And Hansen (1985) concludes that the density changes with the size of the aggregates and the amount of adhered mortar to the aggregate, which means the concrete is grinded with the same type of the machine and same load applied.

Tam et al. (2008) mentioned that the cement mortar density of around 1.0 to 1.6 mg/m^3 less than the natural aggregates at around 2.6 mg/m^3. Thus, the lower the density of demolished concrete samples, the higher contents of the cement mortar will be. The density of demolished concretes have range between 2269 kg/m^3 to 2432 kg/m^3.

2.2.1.5 Workability

The concrete structures made of the recycled aggregates need more 5% water than normal concrete in order to achieve the same workability (Hansen et al, 1983) and (Ravindrajah et al, 1985). And Hansen (1986) states that the recycled aggregates in production of concrete must be used in a condition of near saturation point as to decrease the absorption capacity.

According to the Malhothra (1978) and Kumar Roy et al. (1988), they stated that the workability of the recycled concrete aggregate can be maintained with the normal aggregates if the addition of more 5% to 8% of water to the recycled concrete aggregates. Topcu et al. (1997) investigates that the slump value decreases if the waste concrete aggregate increases. The slump values for the normal aggregates are 100 mm while 75 mm for waste concrete aggregates. This is because of the higher presence of cement paste debris that can make the water content in the mixture decreases, hence, the workability of the concrete also decreases.

The problem of workability in concrete mixture become higher by using the recycling concrete aggregates (Topcu et al, 2004). In specific, by using 50% recycled aggregates can gives more effects on the problem of workability.

2.2.1.6 Water to Cement Ratio

Tavakoli et al. (1996) concluded that the normal concrete have higher water to cement ratio compared with the concrete that made of 100% recycled aggregate. When the water to cement ratio is same, the compressive strength of concrete made with 100% recycled aggregates were lower.

2.2.1.7 Density and Air Content

According to the Hansen (1985), he states that the natural air content of recycled concrete aggregate may be quietly higher than normal concrete aggregates. But it is certainly possible to produce recycle concrete aggregate in the laboratory with no significant increase in air content compared with normal mix.

The unit weight of the recycled concrete aggregates is 2235 kg/m^3 while for the normal concrete aggregates is 2370 kg/m^3. This shows that the unit weight of recycled aggregates is much lower compared with normal concrete aggregates.

2.3 Steel Fibres

Using of steel fibres in reinforced concrete structures are quite demanding and developed through extensive research and development work during the last two decades. It has already found and proven to be a reliable construction materials having superior performance characteristics compared to normal concrete. Over past few decades, fibre reinforced concrete beams has been given due attention by the researchers (Syed Mohsin, 2012). According to Susetyo (2011), by adding the steel fibres into the concrete mix can significantly increase the ductility of concrete and post-cracking toughness. Plus, he also states that the addition of steel fibres also can increase the tensile strength and reduce the spacing and crack width of the reinforced concrete structures.

2.3.1 Properties of Steel Fibres

The stiffness, strength and the ability of the fibres to bond with the concrete are important fibre reinforcement properties. According to the Vasudev.R (2013), steel fibres have higher strength and also modulus of elasticity. The mechanical properties of steel fibres also does not affected by the long term loading. In certain environment conditions such as high temperature, the use of stainless steel fibres may be proposed. There are many grades of stainless steel, available in fibre form, respond somewhat differently to exposure of elevated temperature and potentially corrosive environments.

2.4 Superplasticizer

In order to increase the workability of the concrete, the using of superplasticizers will be needed in concrete mixture. This is because, by using superplasticizer in concrete mix can reduce the amount of water without affects the workability of the concrete (Reddy et al., 2015). The using of superplasticizer also economical as the cost effects on them is less than the cost of cement saved.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Concrete is one of the general material used in building construction material. It is an artificial stone obtained by mixing aggregates, cement and water and allowing the product to cure for hardening. Its main ingredients are cement and water, which react with each other chemically, to form another material having useful strength. The strength of concrete depends upon the quality of its ingredient, their relative quantities, and the manner in which they are mixed, compacted and cured. It is possible to produce concrete of different specifications for various purposes by suitably adjusting the proportions of cement, aggregates and water. In this research, the concrete grade will be used is Grade 25.

Reinforced concrete is a composite materials made of concrete and steel bar. Plain concrete possesses high compressive strength but little tensile strength. Reinforcing steel possesses high strength both in tension and compression. In reinforced concrete, steel provides the tensile strength and the concrete provides the compressive strength. So, this combination will provides high utility and versatility.

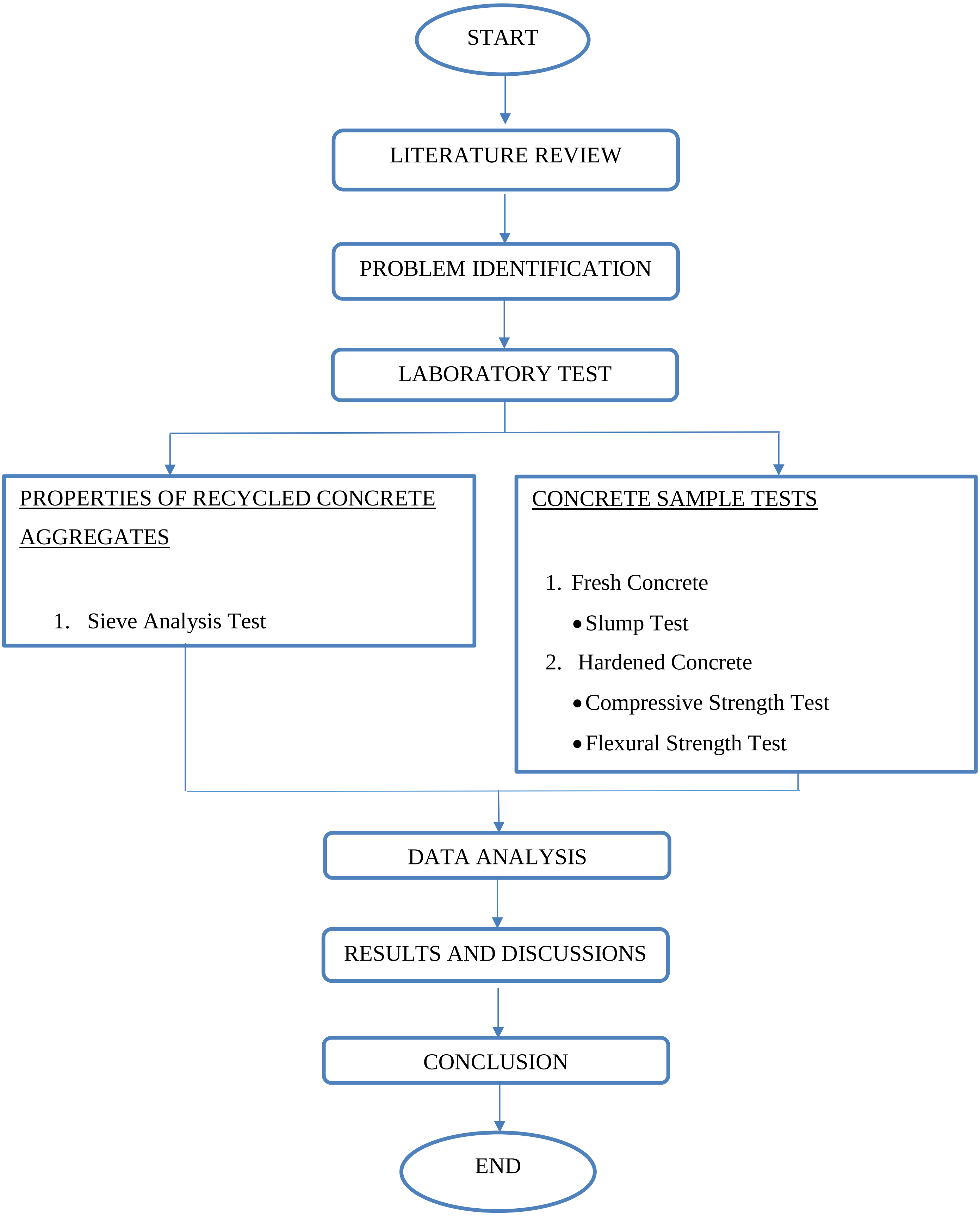

Figure 3-1: Methodology Flow Chart

3.2 Laboratory Work Methodology

The procedures of the laboratory works can be divided into four stages. The first one involved the preparation of materials for concrete samples, standard testing methods and design of concrete mix grade 30 according to standard Department of Environmental (DOE), United Kingdom. The materials that need to prepare for example Ordinary Portland Cement (OPC), aggregates, recycled concrete aggregates (RCA), water and superplasticizer. Next, the sieve analysis test need to be carried out as to get the exact aggregates size that will be used in this study.

After that, the concrete mix part was run after the preparation of all concrete materials. The size of the beam specimens were 150 x 200 x 1500 mm while the cube samples size were 150 x 150 x 150 mm. In order to measure workability of the concrete, the slump test was carried out right after the concrete mixing works. Next, all the concrete samples were taken out from their mould and followed by curing works that according to the ASTM C 192 for 7 and 28 days.

After 7 and 28 days of curing, the next stage of methodology is the destructive test of the beam specimens. The compression test need to carry out in order to determine the compressive strength of concrete samples. This test was done based on the BS 1881-116:1983. While the flexural test of the concrete beam is carried out as to investigate the flexural strength of the beam specimens after 28 days of curing. This test is based on the BS 1881: Part 118 and ASTM C 78-02. A total of 24 cubes and 4 beam samples had been cast and tested for compressive and flexural strength test.

For the last stage, data collecting and analysis were carried out after all the testing have been done. All the data need to be processed in order to get the value for compressive and flexural strength for normal mix and concrete mix that made from RCA. Next, the comparison of mechanical properties of both concrete were made.

3.3 Materials Preparation

All the concrete materials that will be used in this study are as follows:

3.3.1 Ordinary Portland Cement (OPC)

Cement is produced by burning together, in a definite proportion, a mixture of siliceous (silica), argillaceous (alumina) and calcareous (lime) materials in partial fusion, at a temperature of 1400 to 1450 °C. Then, the material that called as clinker is obtained. This clinker is cooled and then ground to the required fineness to get cement. Ordinary Portland Cement (OPC) is usually used for the general construction works. It has a medium rate of strength development and heat generation. It also has sufficient resistance to drying, shrinkage and cracking, but is less resistant to the chemical attack. So, in this study, the "YTL Orang Kuat OPC" type of cement will be used for the concrete mix works.

Figure 3-2: YTL Orang Kuat OPC cement

3.3.1.1 Chemical Composition of OPC

Lime, silica, alumina and iron oxide are the main important raw materials for manufacturing cement. Depending upon the wide variety of raw materials used in the manufacture of cement, its oxide components vary widely. The main oxide components of Ordinary Portland Cement (OPC) and their composition are given in Table 1.1:

Table 3-1: Oxide composition of OPC cement

Oxide	Content (%)
CaO	59-64
SiO_2	19-24
Al_2O_3	3-6
Fe_2O_3	1-4
SO_3	1-3
MgO	0.5-4
Alkalis	0.2-1.3

When water is mixed with cement, the chemical processes of hydrolysis and hydration occur simultaneously during the reaction of cement and water. Hydrolysis is the process of change of a compound of cement into others as a result of chemical action of water. While hydration is the process of the combination of cement with water. As a result of hydration, setting and hardening of cement takes place.

Fine grinding increases the rate of hydration and hydrolysis of cement which result in the early development of strength, though the ultimate strength is not affected.

3.3.2 Aggregates

A mixture of only cement and water is costly and possesses low strength and shrinks unacceptably on drying. In order to reduce the cost and modify such properties as the strength and drying shrinkage of the hardened mass, it is usual to introduce insoluble non-cementitious particles described as aggregates.

Aggregates are classified as coarse aggregates and fine aggregates based upon their sizes. Coarse aggregate is material which passes through 80 mm sieve and retained on a 4.75 mm sieve. It may be uncrushed gravel if it results from the natural disintegration of rock, crushed stones or gravels if it is produced by the crushing hard stone or gravel respectively. While fine aggregates is the material which passes through 4.75 mm sieve and retained on 75 micron sieve. It may be natural sand if it results from the natural disintegration of rock or crushed stone sand or gravel sand if it is produced by crushing hard stone or gravel respectively. Particles between 0.06 mm and 0.002 mm are classified as silt and particles of size smaller than 0.002 mm as clay. Silt and clay are unwanted particles and should be removed from aggregates used in concrete mixture. In this study, the maximum size aggregates that will be used is 20 mm. Below are the table of the aggregate sizes and their applications:

Table 3-2: British Standard maximum aggregate sizes with applications

Nominal maximum size (mm)	Application
40	Mass concrete, road construction
20	General concrete work, including reinforced and pre-stressed concrete
10	Thin sections, screeds over 50 mm thickness
5	Screeds of 50 mm thickness or less

Figure 3-3: Coarse Aggregates

Figure 3-4: Fine Aggregates

3.3.3 Recycled Aggregates

The using of recycled aggregates can reduce the environmental impact and slow the huge consumption of natural resources used for concrete production. Generally, this recycled aggregates we can get from the demolition of the construction structures and the waste of concrete cubes and beams from the laboratory, later on processed and used as recycled aggregates in the mixture. In this study, the using of 50% recycled aggregates will be used as replacement of coarse aggregates for concrete mixture purpose. The wastage of concrete cubes and beams from laboratory tests will be crush by using the Jaw Crusher machine and processed to get the coarse aggregates. Maximum the range size of aggregates that will be used is 15-20 mm.

Figure 3-5: Collecting of RCA samples process

Figure 3-6: Jaw Crusher

Figure 3-7: RCA after crushing process

3.3.4 Water

Water is one of the main components in concrete mixture. It chemically reacts with cement (hydration) to produce the desired properties of concrete. Mixing water is the quantity of water that comes in contact with cement, impacts slump of concrete and is used to determine the water to cement ratio of the concrete mixture. Strength and durability of the concrete is controlled to a large extent by its water to cement ratio.

Besides its quantity, the quality of mixing water used in the concrete mixture has important effects on fresh concrete properties such as setting time and workability and it also has important effects on the strength and durability of hardened concrete.

3.3.5 Steel Reinforcement Bar

Reinforcement bar or rebar is one of the important elements that need and widely used in the construction of reinforced concrete. Rebar is commonly used as tensioning device to reinforced concrete in order to help hold the concrete in a compressed state. Concrete is very strong in compression state, but virtually without strength in tension. Thus, the rebar will be cast into it to resist the tensile loads. Rebar's surface is often patterned to form a better bond with the concrete.

The commonly used types of steel reinforcement are mild steel, medium tensile steel and high yield strength deformed bars. High yield strength deformed bars has deformations on the surface, which inhibit longitudinal movement of the bar relative to the concrete that surrounds it. So, in this research, the high yield (Y) type with diameter 12 mm of reinforcement bar will be used as the main reinforcement bar, while the round type (R) with diameter 6 mm.

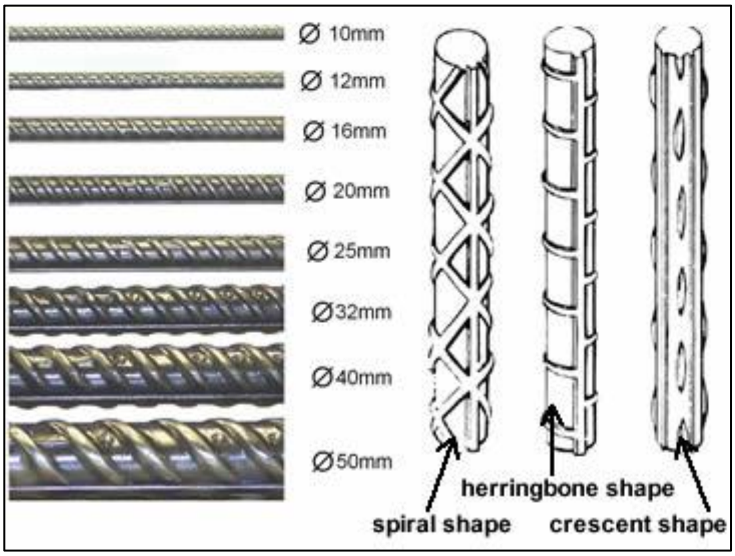

Figure 3-8: Diameter of rebar and type of bond

Source: http://www.pcwirestrand.com/pcwirestrand/deformed-steel-bar.html

3.3.6 Admixtures

In this study, the type of admixture that will be used is superplasticizer. Superplasticizer can be used to enhance the concrete early strength and also reduce the water content up to 30%. Sika ViscoCrete 2100 by Sika brand will be used in this study as the superplasticizer.

3.3.7 Steel Fibres

Normal unreinforced concrete is brittle with a low tensile strength and strain capacity. The function of adding steel fibres distributed randomly is to fill the cracks in the composite. Steel fibres are mixed into the concrete mixture that can provide an alternative to the provision of conventional steel bars in some applications. Fibres are generally used in concrete mixture as to manage the plastic shrink cracking and drying shrink cracking. Many types of steel fibres are used for concrete reinforcement. Round fibres are the one of the major type that widely used and it has a diameter ranges from 0.25-0.75 mm.

Figure 3-9: Steel Fibres

3.3.7.1 Steel Fibre Properties

The properties of the steel fibres that will being used in this study are as follows:

Table 3-3: Properties of Steel Fibres

Fibre Properties	Steel Fibres
Length (mm)	60.0
Shape	Hooked End
Size/Diameter (mm)	0.75
Aspect Ratio	60
Density (kg/m^3)	7850
Young's Modulus (GPa)	210
Tensile Strength (MPa)	532

3.4 Preparation of Reinforced Concrete Beams

The preparation of the concrete mixture for the testing on the beams are as follows:

3.4.1 Concrete Mix Design

The concrete mix design is a process of selection of suitable materials and amount such as cement, aggregates, water and superplasticizer. The calculation process that involved in the mix design are selection of target water to cement ratio and free water content, determination of total aggregate and cement content depends on the grade of the concrete.

For this study, the grade of all concrete samples are 30 N/mm^2 and the design is based on the standard Department of Environmental (DOE). There are four types concrete mixtures that will be done and labelled as follows; [1] Control Mixture (NC), [2] Concrete mix made from 50% recycled concrete aggregate (RCA) as replacement coarse aggregate (RCA), [3] Concrete mix made from 50% RCA with addition of 1.0% Steel Fibres (RCA-SF1%), [4] Concrete mix made from 50% RCA with addition of 2.0% Steel Fibres (RCA-SF2%). The concrete mix proportions and design are as follows:

Table 3-4: Concrete Mix Design

	NC	RCA	RCA-SF1%	RCA-SF2%
Cement (kg/m^3)	245.21	245.21	245.21	245.21
Water (kg/m^3)	137.93	137.93	137.93	137.93
Fine Aggregates (kg/m^3)	643.68	643.68	643.68	643.68
Coarse Aggregates (kg/m^3)	904.21	459.77	459.77	459.77
Recycled Aggregates (kg/m^3)	0.0	459.77	459.77	459.77
Superplasticizer (L/m^3)	5.0	5.0	5.0	5.0
Steel Fibres (kg)	0.0	0.0	0.60	1.08

3.4.2 Detailing of the Reinforced Concrete Beams and Cross Section

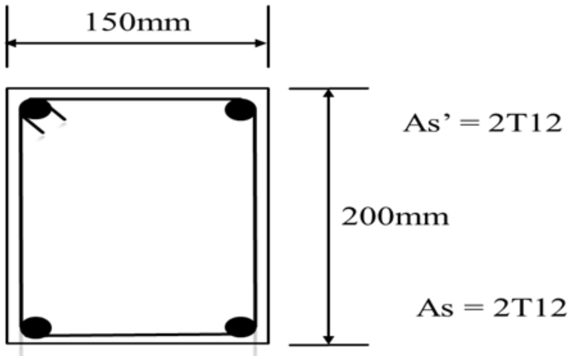

Figure 3-10: RC beams cross sections

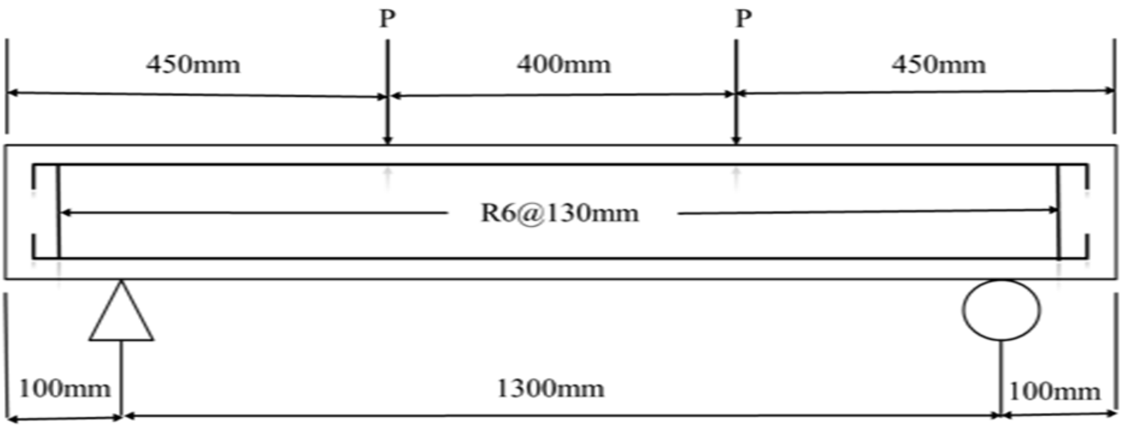

Figure 3-11: RC beams detailing and load arrangement

3.4.3 Mixing and Casting Process

There are four sets of concrete mixture proportions, the table of concrete mix shown in Table 3-4 will be used in the study. The type of steel fibres that will be used is the hooked end type with a length of 60 mm and a diameter of 0.75 mm were added into the mixtures. The beams were designed as rectangular (150 x 200 mm) with 1500 mm length as shown in Figure 3-11 and Figure 3-12. Two tensile steel bars with diameters of 12 mm (2H12) and (3H12) for compression and tension respectively. While for the shear reinforcement, they will installed with round steel bars of 6 mm diameter at 130 mm centre to centre. All the designs and calculations are referring to the Eurocode 2. There are no use of formwork for this concreting works as will use the mould with the size of 150 x 200 x 1500 mm that are laboratory provided.

The oil and grease should be applied on the surface of the beam and cube moulds as to prevent the concrete attached at the surface of the moulds, thus provide the smooth surface of the concrete samples as shown in Figure 3-14. The concrete mixture machine as shown in Figure 3-15 and poker vibrator as shown in Figure 3-16 will be used during the casting process as to ensure all the concrete mix and compact very well, respectively.

After mixing works process, the preparation of slump for slump test was prepared. The slump test processes are shown as in Figure 3-17. A layer of concrete was placed about 1/3 of the depth of the mould for the first layer. The concrete then was tamped by using tamping rod about 15 times. Next, the second layer of the concrete will be poured about 2/3 of the mould depth and tamped for 15 times. For the last layer, the mould was filled until full with the concrete and tamped again for about 15 times. The top of the mould later should be touch up until flat and the height of the slump can be measured after the mould removed.

Figure 3-12: Installation of rebar

Figure 3-13: Apply oil at surface of mould

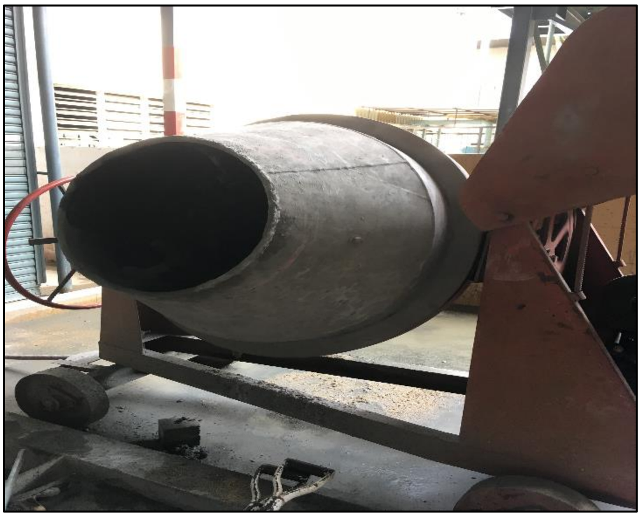

Figure 3-14: Concrete Mixture Machine

Figure 3-15: Compaction Process

Figure 3-16: Slump Test Flow Process

3.4.4 Curing

Curing is the process that to ensure the constant of moisture and water of the concrete samples to complete hydration process. In this study, water curing was used accordance to the ASTM C192. The wet burlap coverings as shown in Figure 3-18 will be placed on the top of the beam samples right after the samples were removed from mould. While the concrete cube samples will be placed inside the water tank. This process of curing was continued until the time of testing.

Figure 3-17: Wet Burlap Coverings

3.5 Laboratory Tests

The laboratory tests on the reinforced concrete beams are as follows.

3.5.1 Slump Test

The purpose of the concrete slump test is to determine the workability of the concrete mixture at the laboratory or construction sites during the progress of work. The slump test will be follow based on the standard ASTM C 143/ C143M-05. Usually, the concrete slump value is used to indicate the water-cement ration, but there are various factors including properties of materials, mixing methods, dosage, admixtures and many more that will affects the concrete slump value.

Before the test begin, a 300 mm high concrete frustum cone prepared under the standard condition is allowed to subside. The slump of reduction in height of the cone is taken to be a measure of consistency of the mixture. There are some procedures to perform this test.

First of all, fill the concrete mixture into the cone about 3 layers and each layer is tamped 25 times by using rounded end steel rod. Then the moulds are held firmly against its base. Immediately but slowly lifted the cone vertically. Next, the mould is placed beside the concrete specimen and the decrease in height.

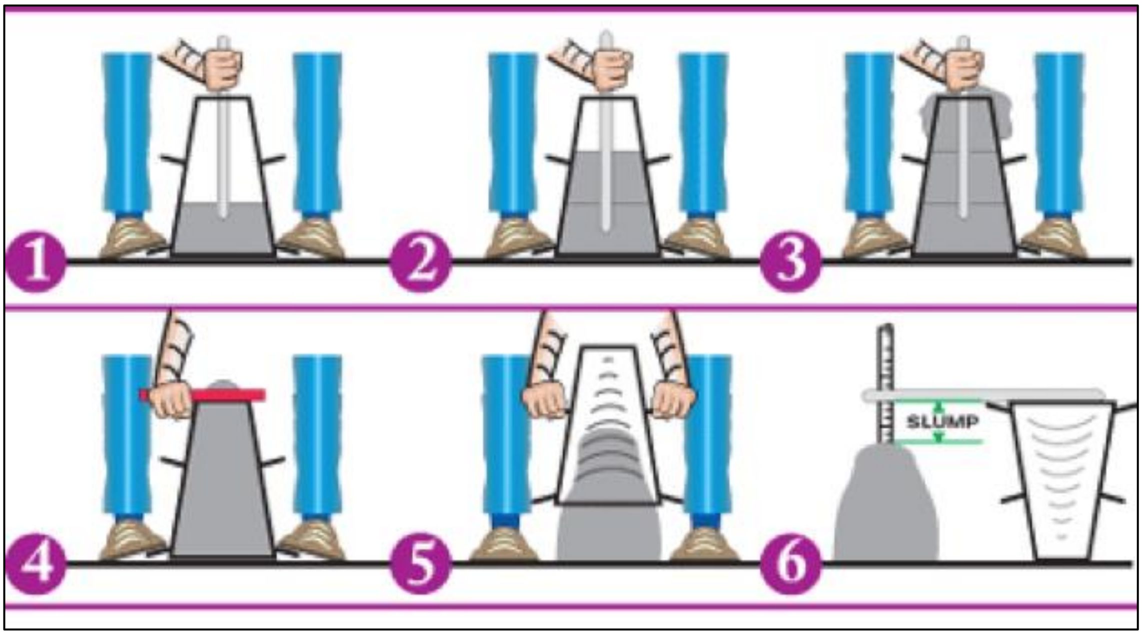

Figure 3-18: Slump Test Procedures
(Source: https://mastourreadymix.wordpress.com/tag/concrete-slump-test/)

There are four types of slump in this test, which are true slump, zero slump, shear slump and collapse slump. Thus, in this research we only consider for the true slump.

- True slump – The only slump that can be measured in the test. The measurement is taken between the top of the cone until the top of the concrete after the cone has been removed.
- Zero slump – It indicates a very low water-cement ratio, which will results in dry mixes.
- Shear slump – Indicates the result is incomplete, and the concrete need to be retested.
- Collapse slump – Indicates that the water-cement ratio is too high as the concrete mix is too wet.

Figure 3-19: Concrete Slump Test Results

3.5.2 Cube Compressive Strength Test

The compressive strength test is based on the BS 1881: Part 116. The purpose of this test is to determine the compressive strength of concrete cube specimens. Six cubes with 150 x 150 x 150 mm size is used to make the test specimens. This cube must have true dimension and the surface must be smooth. The cube must tight before being used as to ensure that there is no water leaking from the concrete mixtures. Next, the inner surface of the cubes must covered with the grease or mineral oil in order to make that there is no concrete stains left on the cube surfaces. The procedures of the cube test are as follows:

Figure 3-20: Cube Samples Preparation

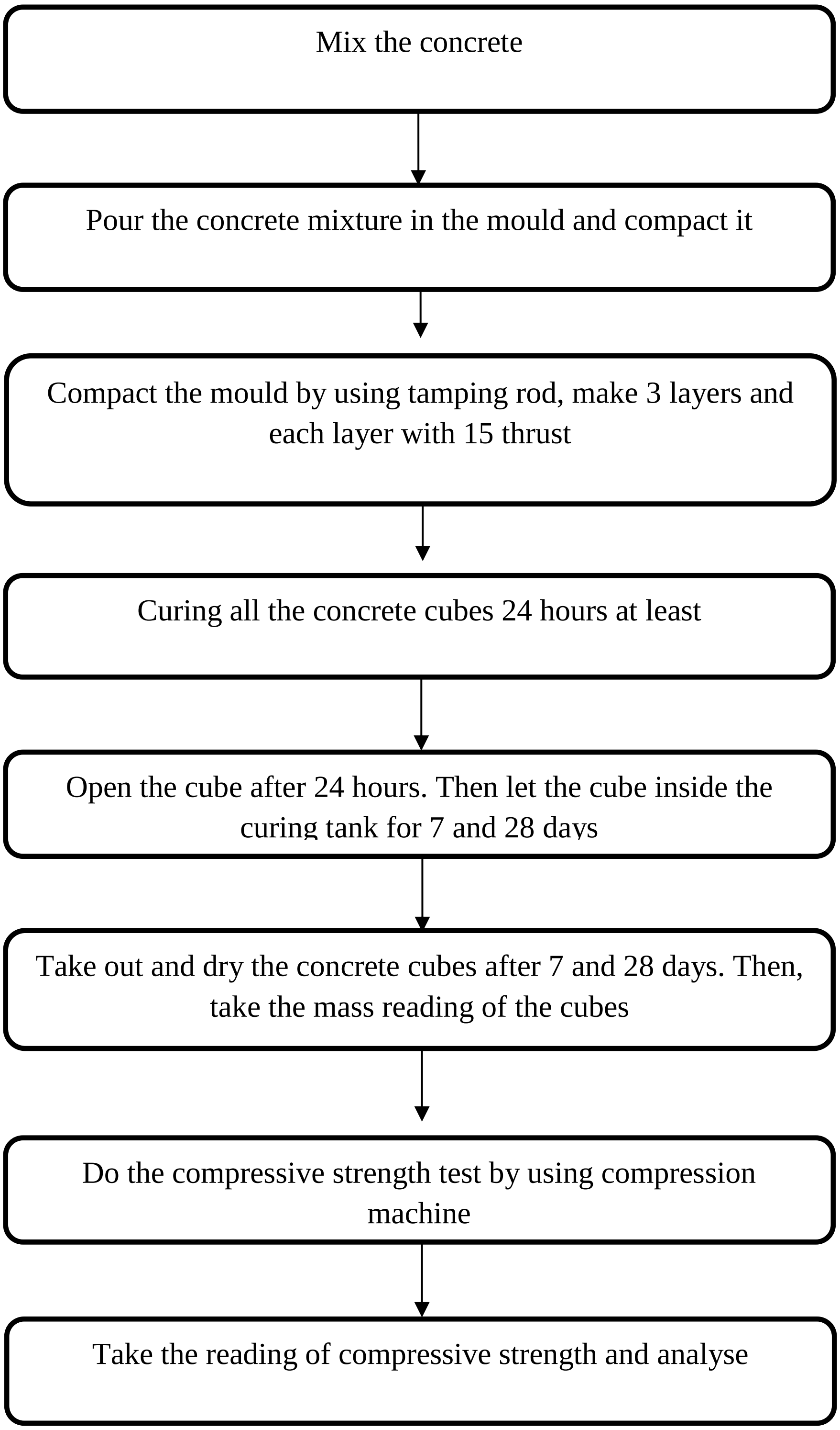

Figure 3-21: Cube Test Procedures

3.5.3 Flexural Strength Test

The purpose of this flexural test is to measure the tensile and flexural strength of the beams to resist failure in bending. This test is based on the standard BS 1881: Part 118 and ASTM C 78-02.

Next, the loading system was centred in relation to the applied force. The set-up of the beam loading and arrangement is shown in Figure 3-11. The load was applied at the centre of the concrete beams and applied at a constant rate about 0.1 N/mm^2 until the beam reach its cracking point.

Figure 3-22: Flexural Test setup

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The experimental data and outcomes were discussed and analysed for each testing and samples. All the laboratory test data were analysed to study about the strength and mechanical properties of the recycled concrete aggregates with addition of steel fibres compared to the normal concrete. The analysis will be presented by using the graph and table. This study is very important as a guideline for any recommendation and future research.

4.2 Results and Discussions of Workability Tests

In this study, the slump test was conducted for the workability test. The slump test was carried out immediately after concreting works done. Table 4-1 and Figure 4-1 shows the results of all slump test for all samples.

Table 4-1: Slump Test results of All Samples

No of Samples	Concrete Types	Height of Slump (mm)	Type of Slump
1	NC	100.0	Shear
2	RCA	84.0	Shear
3	RCA-SF1%	86.0	Shear
4	RCA-SF2%	92.0	Shear

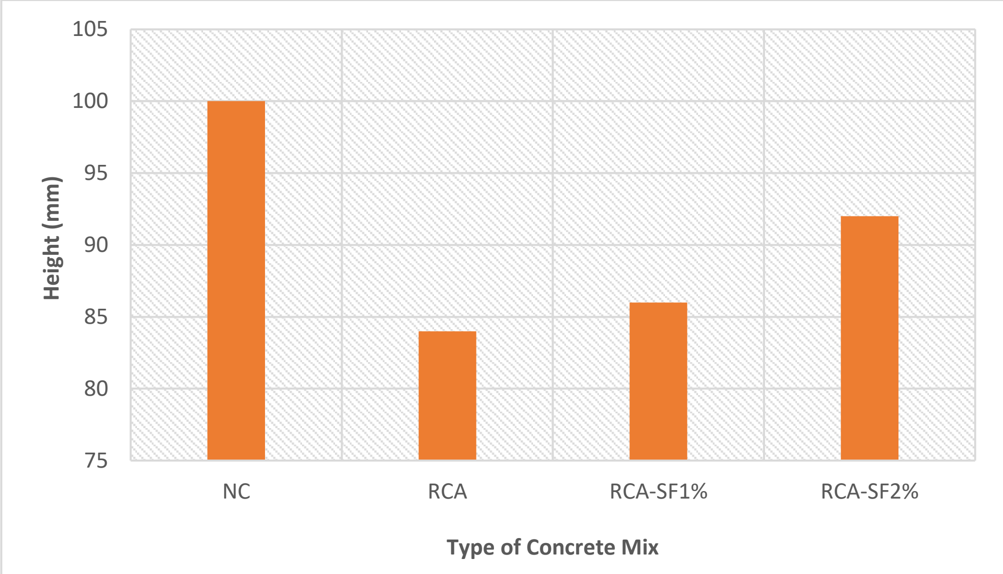

Figure 4-1: Difference of Height of all Slump Test Samples

The height of slump samples that using RCA are much lower compared to the NC mix is because inside the recycled concrete aggregate, it still has a particle of cement or dust adhere that attached to the aggregate, as it can cause absorbs more water than normal aggregates. The workability of the concrete will decreases as the content of RCA inside concrete mix increases. Thus, the using of steel fibres can increase the workability of the RCA concrete mix.

The workability of the concrete can be determined by the type and height of the slump itself. The higher the height of the slump, the concrete has higher workability. As to achieve the same slump, workability and water-cement ratio as in normal concrete, the amount of water reducer or the paste content should be increased. As a conclusion, from Figure 4.1, we can conclude that, by increasing the volume of steel fibres used inside RCA concrete mix, the height of slump will also increases.

4.3 Results and Discussions of Compressive Strength

The objective of this test is to determine the compressive strength of the samples which was to fulfil one of the objectives of this study. This test was conducted on the 7 and 28 days with the standard water curing. The loading rate is 6.80 N/mm^2 / minute as accordance to the BS 1881-116:1983 test method. The compressive strength results are as follows:

Table 4-2: Compressive Strength of NC

Number of Samples	**Compressive Strength (N/mm^2)**	
	7 Days	**28 Days**
1	47.51	55.24
2	44.65	34.43
3	44.22	48.71
Average	**45.46**	**46.13**

Table 4-3: Compressive Strength of RCA

Number of Samples	**Compressive Strength (N/mm^2)**	
	7 Days	**28 Days**
1	32.49	33.38
2	30.01	34.90
3	34.00	38.97
Average	**32.17**	**35.75**

Table 4-4: Compressive Strength of RCA-SF1%

Number of Samples	Compressive Strength (N/mm^2)	
	7 Days	**28 Days**
1	41.09	42.24
2	40.05	45.09
3	39.32	42.90
Average	**40.15**	**43.41**

Table 4-5: Compressive Strength of RCA-SF2%

Number of Samples	Compressive Strength (N/mm^2)	
	7 Days	**28 Days**
1	41.12	46.38
2	32.23	45.64
3	40.49	45.78
Average	**37.95**	**45.93**

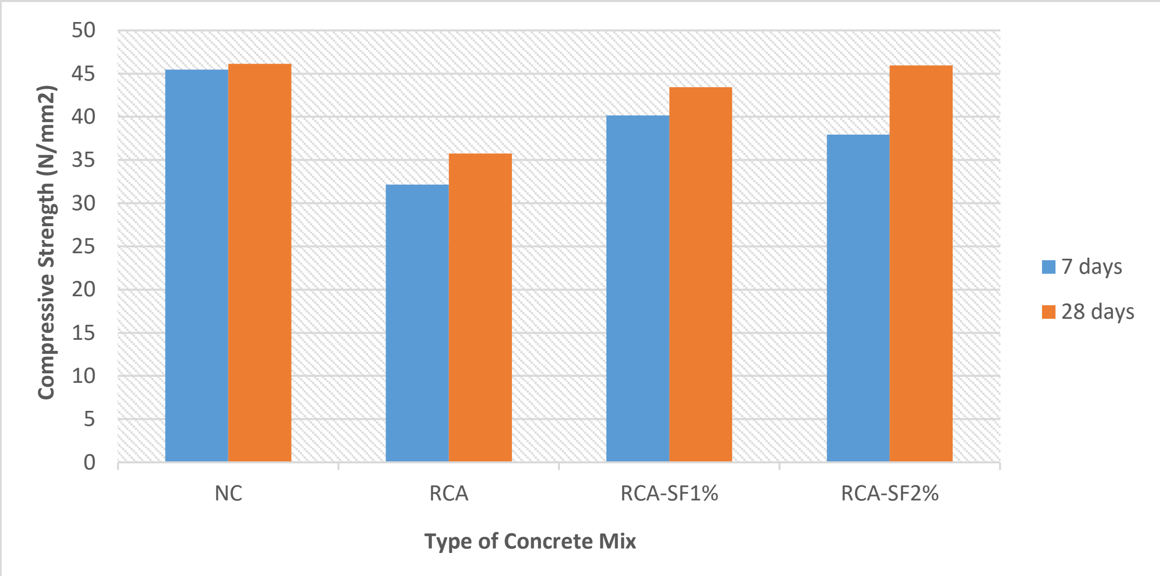

Figure 4-2: Compressive Strength of All Concrete Mixtures

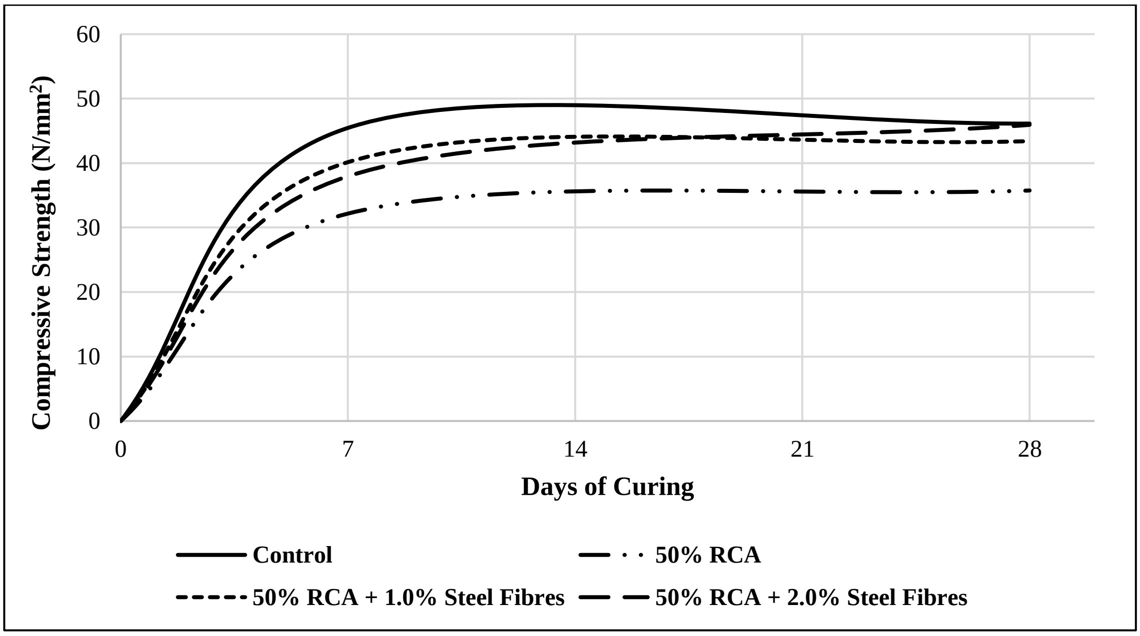

Figure 4-3: Comparison of Compressive Strength for All Mixtures

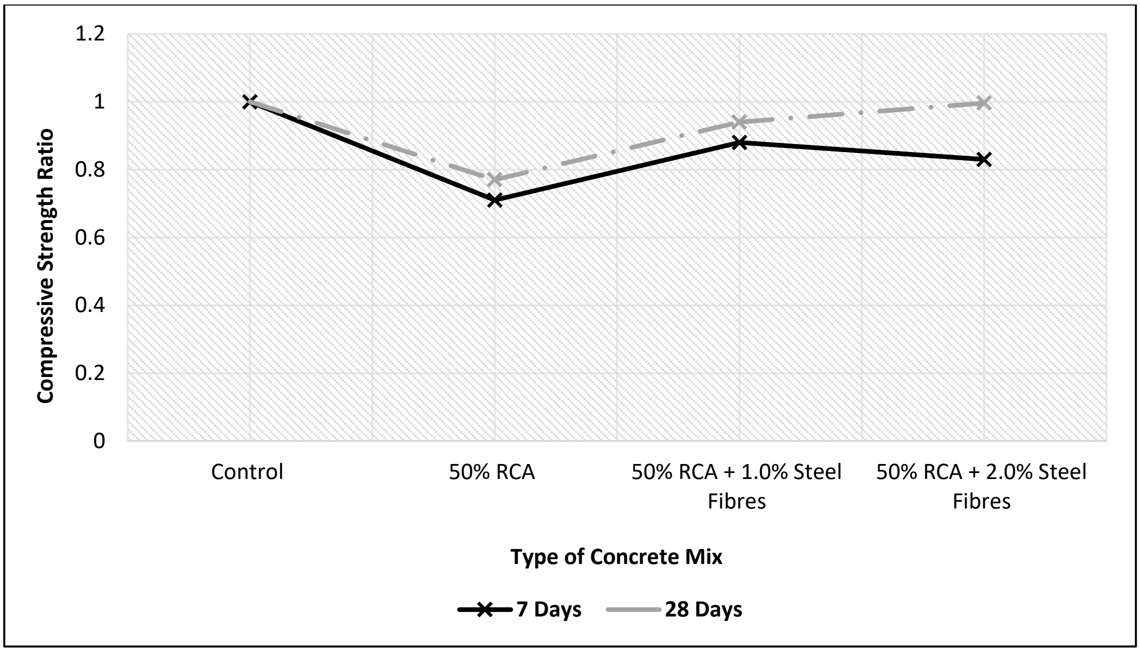

Figure 4-4: Compressive Strength Ratio to Control Mix

Based on Figure 4-2 and Figure 4-3 above shows that the comparison of compressive strength with different concrete mixture for 7 and 28 days. As can be seen that when the concrete age is increasing, the compressive strength value of the concrete also increasing. For 7 and 28 days of curing, the NC mixture shows the highest compressive strength values among other mixtures, which are 45.46 N/mm^2 and 46.13 N/mm^2 respectively.

Next, the addition of recycled concrete aggregate (RCA) into the concrete mixture as the replacement of coarse aggregate can be the main reason why the compressive strength of concrete is slightly decreased, which is about 32.17 N/mm^2 and 35.75 N/mm^2, respectively for 7 and 28 days of curing. By adding more amount of steel fibres inside the concrete mixture, it can helps by increasing the compressive strength of 50% replacement of RCA's concrete. This can be seen, by adding 2.0% of steel fibres have higher compressive strength on 28 days compared to the RCA-SF1.0% beam sample. This is because, during the compressive test, steel fibres acting as the reinforcement inside the concrete, hence, it can make the delay and increase load carrying capacity of the concrete.

As conclusion, the addition volume of steel fibres can helps the recycled reinforced concrete beams become stronger and gives higher strength, as it can reduce the transversal deformation of specimens, hence, will increase their compressive strength.

4.4 Results and Discussions of Flexural Strength Test

4.4.1 Load vs Deflection Graph

The flexural strength of all concrete beams were determined after 28 days of curing. In this test, the standardized four bending point loading method was applied to the concrete beams until the beam specimens break or crack. The standard used for this experiment are BS 1881:Part118 and ASTM C 78-02. The purpose of this testing was to determine the flexural strength of the beams which was to fulfil one of the objectives of this study. The results of flexural test obtained are as follows:

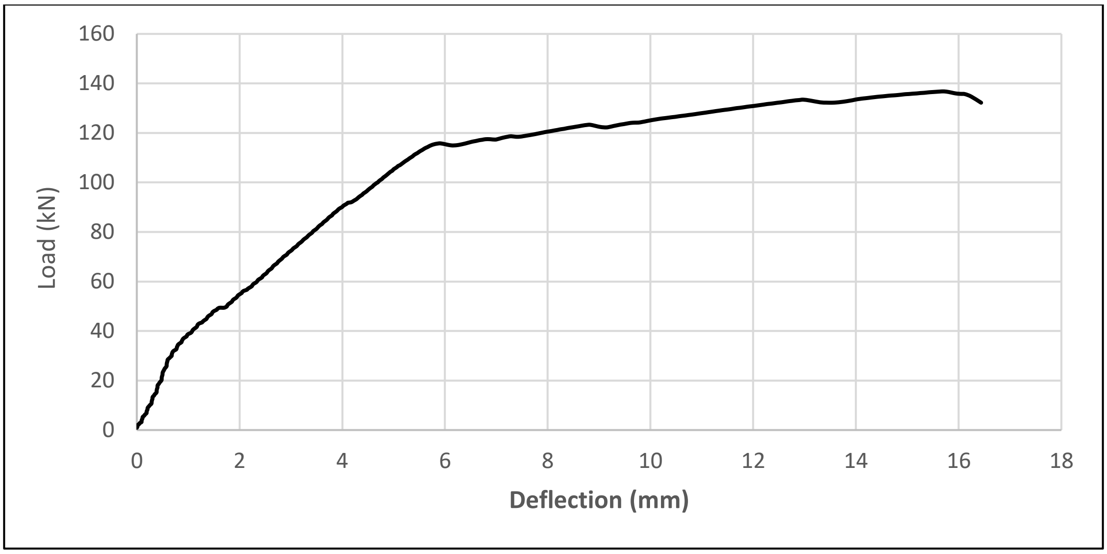

Figure 4-5: Load vs Deflection of NC mix

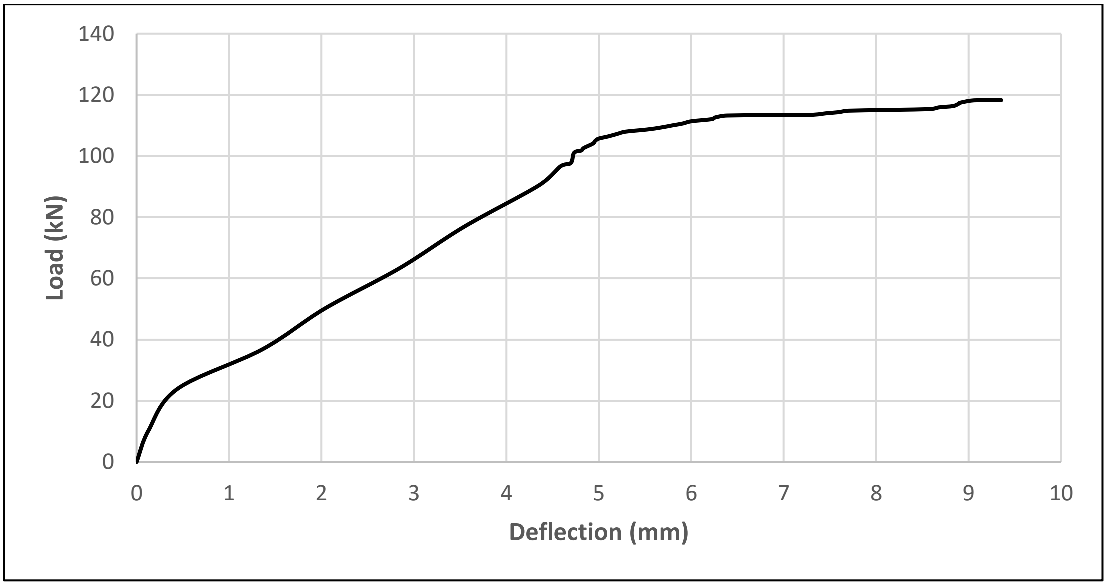

Figure 4-6: Load vs Deflection of RCA mix

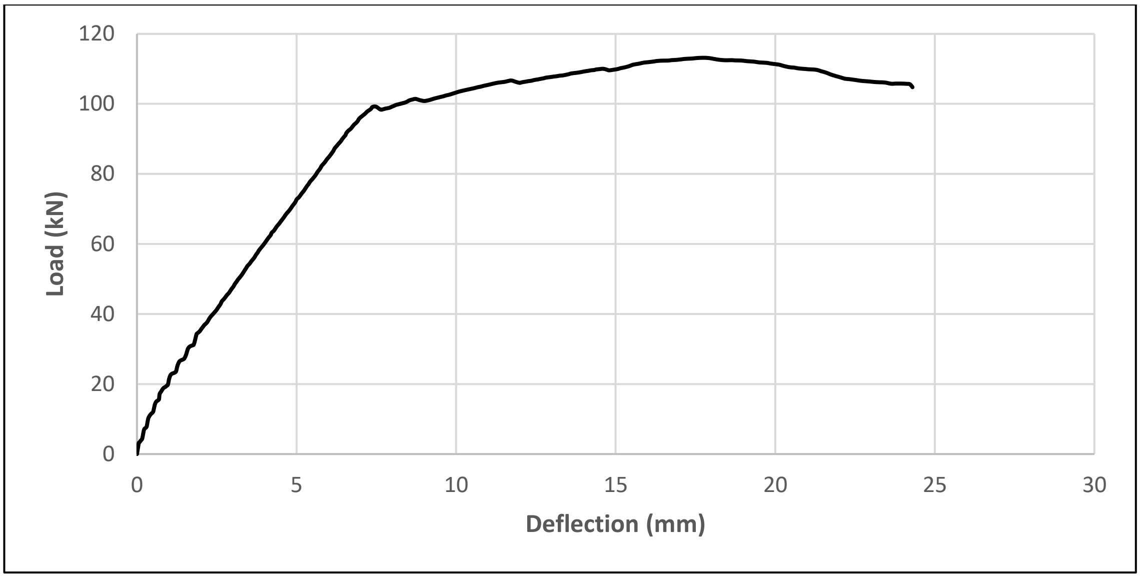

Figure 4-7: Load vs Deflection of RCA-SF1% mix

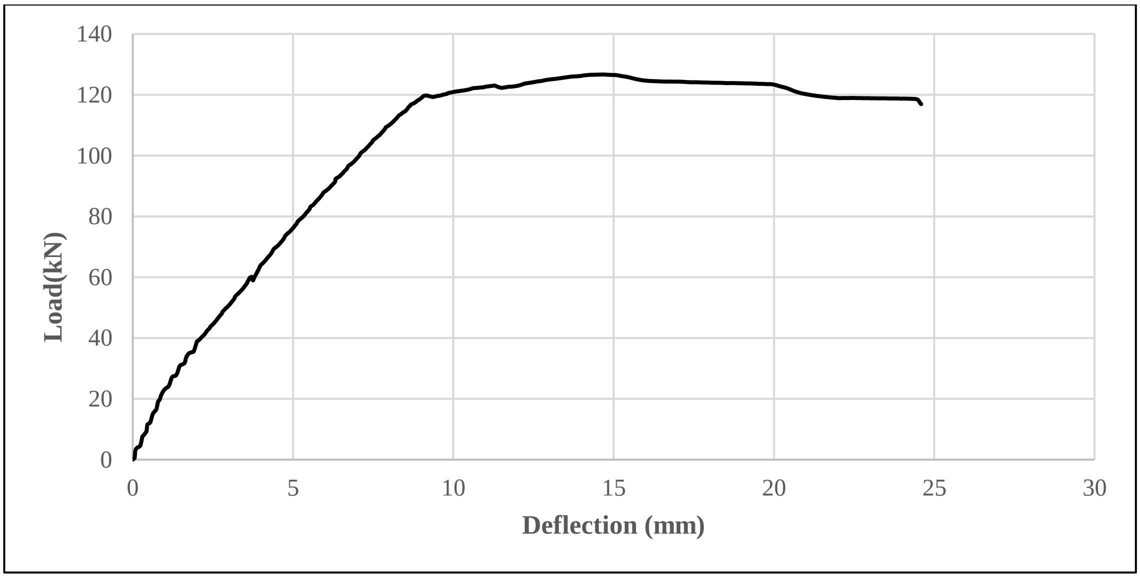

Figure 4-8: Load vs Deflection of RCA-SF2% mix

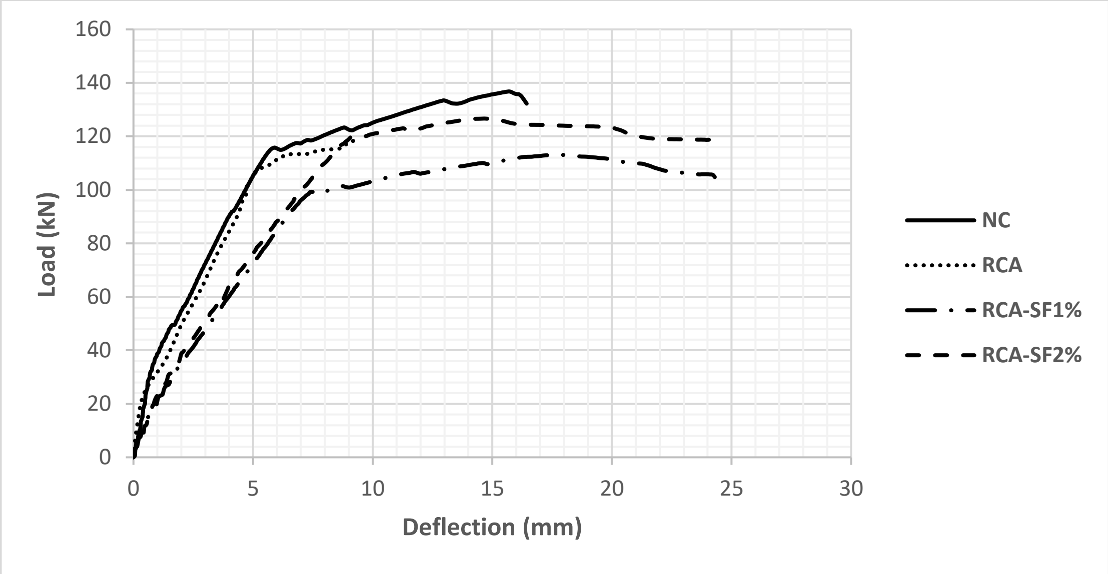

Figure 4-9: Comparison of Flexural Strength of All Concrete Beam Samples

From Figure 4-5 to Figure 4-8 above shows that the load versus displacement graph for every type of concrete specimens. While the Figure 4-9 shows that the comparison of flexural strength for all concrete mixtures. This is because of the replacement of recycle concrete aggregate (RCA) can influences the flexural strength. The low of flexural strength obtained is caused by the weak bonding between the aggregates and cement paste. In addition, the RCA absorbs huge amount of water compared to the normal aggregates also one of the factors that can affects low flexural strength of concrete beam samples. Apart from that, the segregation inside concrete mixture that can cause the performance of its mechanical properties become weaker is also one of the main factors the reduction of flexural strength.

Based on Figure 4.9 above, there are some parameters that can be obtained, which are longitudinal reinforcement yields in tension state (P_y) and its yield deflection (δ_y), the maximum load-carrying capacity (P_{max}) and its maximum deflection (δ_{max}), the ultimate load (P_u) and its corresponding deflection (δ_u), and lastly the ductility ratio (μ) that can be found as $\mu = \delta_u / \delta_y$. In addition, the control mixture is taken as standard measures for comparison purposes.

Table 4-6: Analysis from Flexural Test Result

Type of Mix	NC	RCA	RCA-SF1%	RCA-SF2%
P_y (kN)	115.40	105.661	93.464	106.413
δ_y (mm)	5.784	4.996	6.75	7.66
P_{max} (kN)	136.78	118.275	113.035	126.597
δ_{max} (mm)	15.716	9.167	17.967	14.764
P_u (kN)	132.22	79.918	105.798	117.29
δ_u (mm)	16.437	11.987	23.98	24.562
$\mu = \frac{\delta u}{\delta y}$	2.84	2.399	3.55	3.21

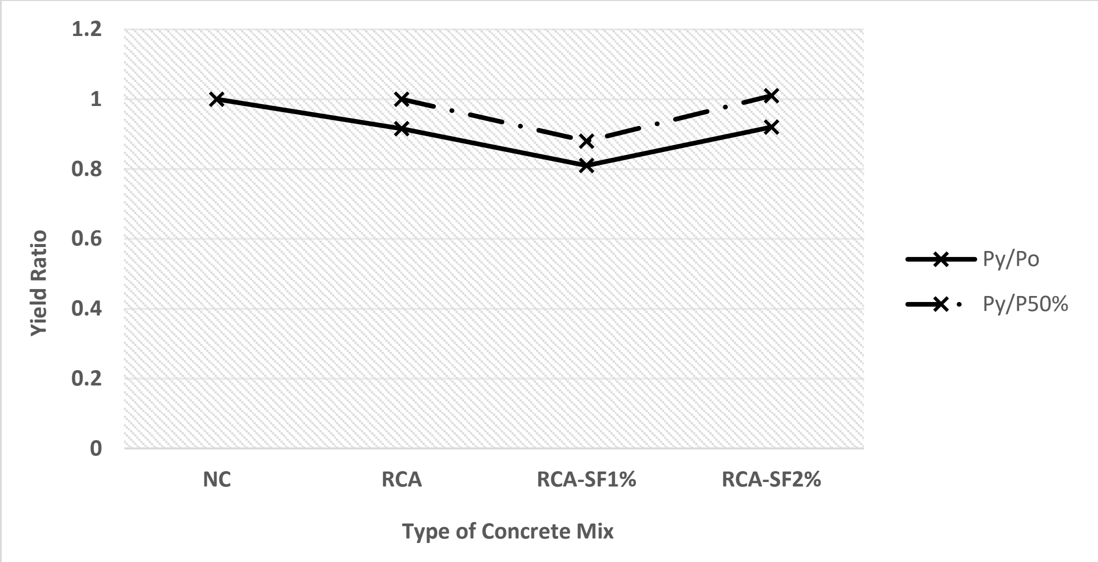

Figure 4-10: Graph Yield Load Ratio vs Concrete Mixtures

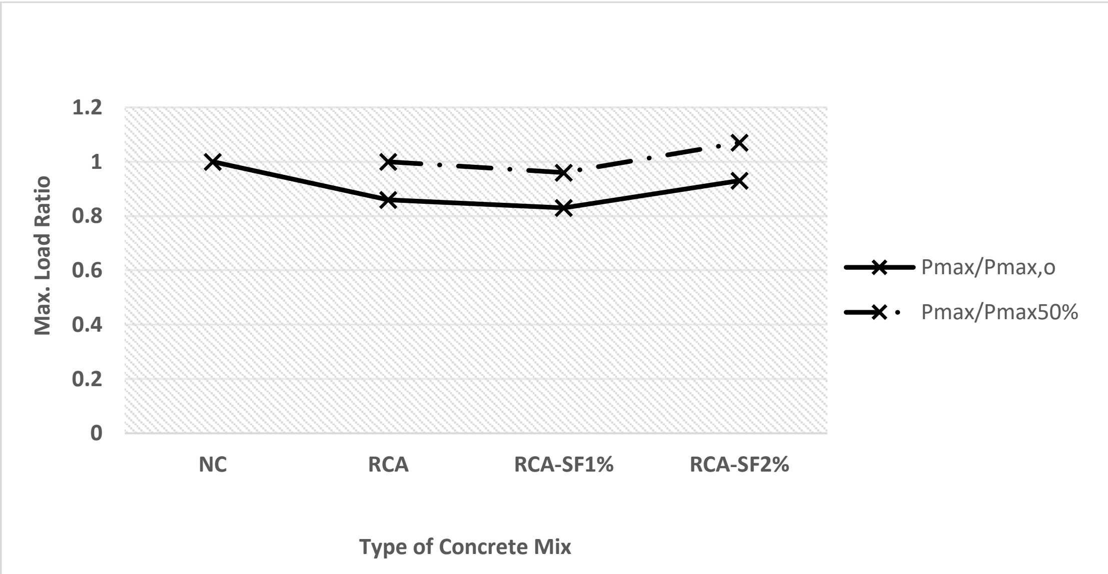

Figure 4-11: Graph Maximum Load Ratio vs Concrete Mixtures

From the analysis, the NC beam shows that the highest strength compared to the RCA concrete samples while the RCA-SF1% beam shows the lowest load carrying capacity. But, different with RCA-SF2%, it shows the better result compared with RCA-SF1% as the strength of the concrete increases when the fibre content also increases. But, different result for RCA beam, the flexural strength of the RCA beam is higher than RCA-SF1% beam. This is because of due to the some error such as different quality and grade of RCA used for both beams will produce different and unexpected result. Plus, the segregation occurred on the RCA-SF1% beam also one of the cause why their strength became lower than RCA beam. This problem happened when the water to cement ratio is high and excessive vibration works of concrete that can cause low of flexural strength.

While, based on Figure 4-10 and Figure 4-11, they both shows the yield and maximum load ratio against the concrete mixtures with different percentage of steel fibres used. As we can see, there were slightly decrease at the RCA-SF1% specimen before going upward when adding the volume of steel fibres to 2%. This is because, during the mixing process of RCA-SF1%, most of the steel fibres did not pulled out and distributed well inside the concrete mixture, hence, caused getting the lower flexural strength.

Apart from that, another reason that affects the flexural strength of the RCA-SF1% beam which is show that it is lower than RCA beam because of the recycled concrete aggregate (RCA) itself. During the process of selecting and crushing of RCA, the RCA may have different quality, which may consist of some others composite materials that can affect the strength of the RCA beams.

Besides, the duration of beam curing also may affect the strength of RCA beams. The RCA beams had been cured with different duration. For this experiment, NC and RCA had been cured with water fully 28 days, while for RCA-SF beams had been cured with water only 7 days, and air curing for another 21 days. As to get the better result, all of the beams should need to cure with standardized duration.

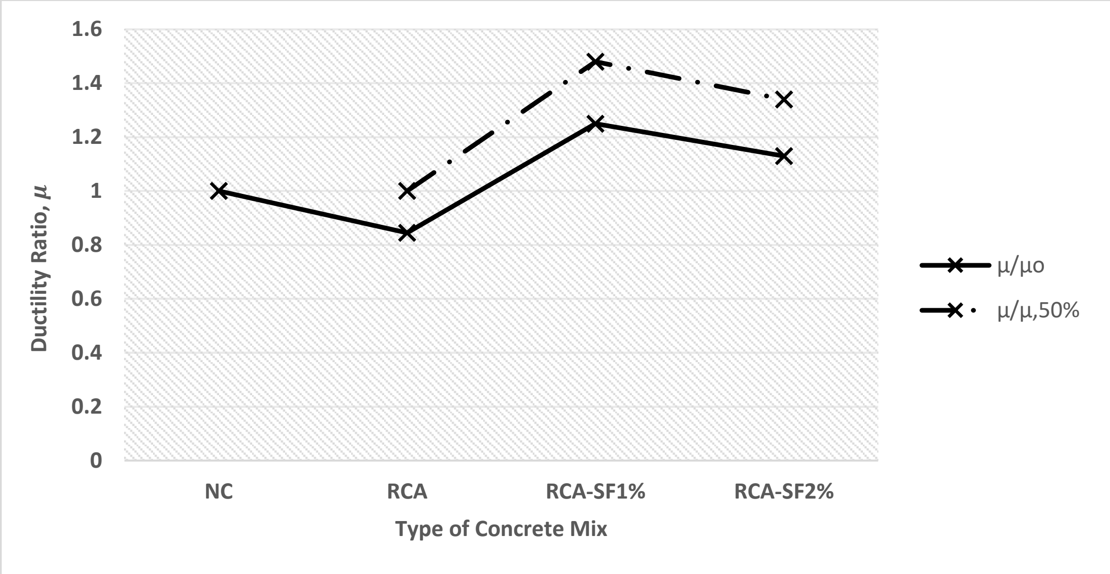

Figure 4-12: Graph Ductility Ratio, μ vs Concrete Mixtures

Based on Figure 4-12 above, it can be seen that, the RCA-SF1% had reach the higher ductility compared to the other type of concrete mixtures. Previous studies show that the ductility of the beam will be increases with the increasing volume of steel fibres used. But for this present study, there were a slightly decrease in terms of ductility on RCA-SF2% specimen due to the problem of using RCA. For this reason, the RCA that being used, especially for RCA-SF2% beam may have lower concrete grade and quality rather than RCA-SF1%, hence, it can affects the decreasing of the beam ductility. Besides, the RCA that being used for RCA-SF1% beam may have some other composite materials that can increase flexural strength, which may affect the sudden increase of the ductility.

4.4.2 Cracking Pattern and Failure Mode

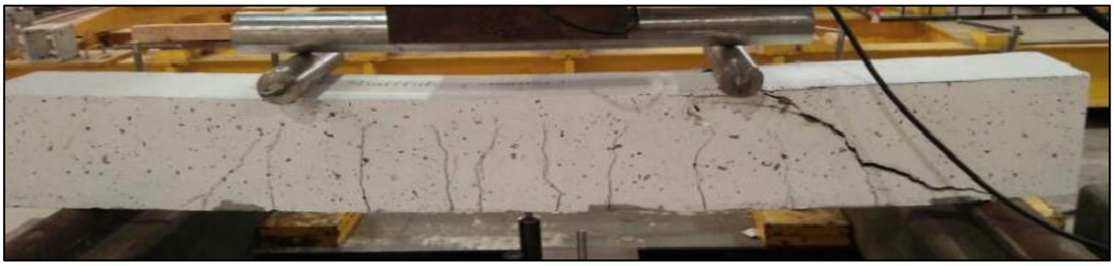

Figure 4-13: Cracking Pattern of NC beam

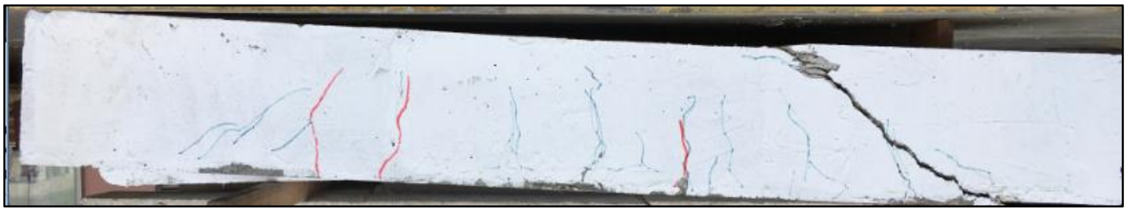

Figure 4-14: Cracking Pattern of RCA beam

Figure 4-15: Cracking Pattern of RCA-SF1% beam

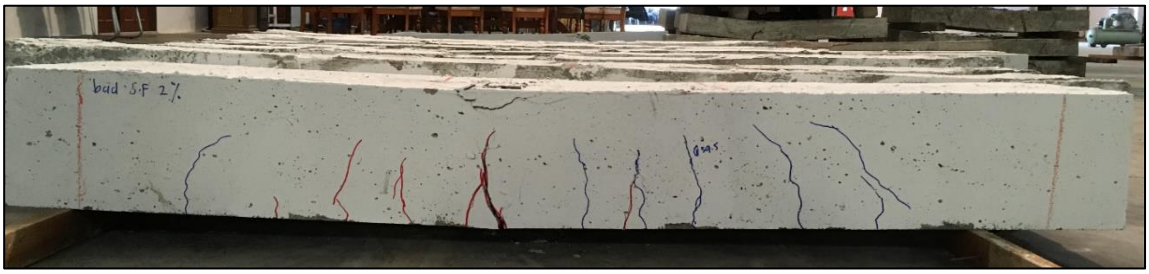

Figure 4-16: Cracking Pattern of RCA-SF2% beam

Table 4-7: Failure Mode and 1st Crack Load

Concrete Mixtures	Failure Mode	1st Cracking Load (kN)
NC	Bending- shear	NA
RCA	Bending- shear	NA
RCA-SF1%	Bending	42.8
RCA-SF2%	Bending	59.5

Figure 4-13 to Figure 4-16 show that the cracking pattern for each concrete mixtures after the flexural test. From the figures, it proves that most of the beams experienced the cracking propagation at the area of mid-span between the loading and beam support. It can concludes that all control concrete beam samples, which are NC and RCA sample, failed in bending-shear mode. While, when adding the steel fibres inside the concrete mixtures, the failure mode for other recycled reinforced concrete beams become bending mode. Plus, the crack propagation become less and not obvious when adding steel fibres inside the RCA concrete mixtures, 1.0% and 2.0% of steel fibres respectively. This is because, by adding steel fibres, it can reduce the crack width and deep as the steel fibres generally distributed inside the concrete beam, thus, can increase the strength of recycled reinforced concrete beam itself.

Apart from that, different duration and type of beam curing are also one of the main reasons which influence the strength of beams. The beam curing should be standardized for all of the concrete beams, thus, the better results can be obtained. Based on the Table 4-7, it shows the 1st cracking load and the failure mode of the concrete specimens. It can concludes that, by adding the steel fibre inside concrete mixtures, the recycled reinforced concrete beams can sustain higher load that needed for getting the first cracking on the beam surface. However, there are no results for both control specimens due to the some technical problems and human errors.

4.5 Conclusions

The replacement of coarse aggregate by using RCA did not help to improve the strength but the strength is still nearly with each other. All of the compressive strength values for all concrete mixture had surpass the mix design strength due to the some factors that influenced such as, the cement mechanical properties itself, the curing method of concrete samples and also the quality of aggregates. RCA have a lower quality compared to the normal aggregates because during the crushing process, the particle of cement still adhere at the aggregate, so the aggregate are not clean as normal aggregate. This particle of cement can affects the mix of concrete because it absorbs more water, hence the concrete have a lower workability.

Apart from that, RCA did not mixed properly with normal aggregate and mortar in concrete mixture. This can cause the segregation problems in concrete. The segregation of concrete can be defined as separation of the fresh concrete components that can cause a non-uniform mix. That means, this implies on the separation on the coarse aggregate from mortar, and will cause the strength of concrete decrease.

In conclusion, the replacement of coarse aggregate by using 50% of RCA and addition of steel fibres show the good strength and performance as the compressive and flexural strength is not far from the normal concrete. Plus, all the compressive and flexural strength of all concrete mixtures had achieved the strength greater than mix design strength.

CHAPTER 5

CONCLUSION

5.1 Introduction

The main objectives of this study are to study the behaviour and performance of steel fibre reinforced concrete that made up from normal and recycled concrete aggregates. In this chapter will discuss about the conclusion that referring to all the laboratory testing on previous chapter, Chapter 4.

5.2 Conclusions

Based on the result discussed and presented, it shows that the performance of recycled concrete aggregates (RCA) as the replacement of coarse aggregates inside the concrete mixture is not as good as using the natural aggregates, not only in terms of its mechanical properties, but also other requirements that related to the production of this concrete type.

Correspondingly, the strength of all the RCA beam samples have a slightly reduced compared to the normal concrete (NC) mixture, but still surpass the range of design grade which is 30 MPa. This is because of the RCA problems in the matter of its different concrete grade used and other composite elements in the RCA, thus, it affects the trend of RCA beams in terms of flexural strength.

In addition, different duration and type of beam curing is also one of the main reasons which influence the strength of the beams. The beam curing should be standardized for all of the beams, so that the better results can be obtained.

In conclusion, it can proves that the performance of using RCA as coarse aggregates replacement is not good enough as natural aggregates, even though the steel fibres had been concerned and used in this experiment as to improve the strength of the RCA beams. It can be seen that the concrete strength mainly depends on the RCA quality.

5.3 Recommendations

In order to improve the skills, behaviours, methods and processes, the recommendations are very important. There are some recommendations for the further study in the future based on the laboratory testing and studies that had been conducted. The recommendations are as follows:

a) Perform more mechanical testing such as sieve analysis test, creep and shrinkage, and water absorption test as to find more about the mechanical properties of the concrete that made from RCA and normal aggregates.
b) The addition of number days of curing such as on 14, 45 and 90 days in order to get more accurate and precise data of the compressive and flexural strength.
c) Use other type or brand of the “YTL Orang Kuat” Ordinary Portland Cement (OPC) as by using this type of cement, the higher of compressive strength will be obtained compared to the target strength.
d) Use the same type and quality of RCA as to obtain better results.
e) The beam curing should be standardized for all concrete beams.

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APPENDIX A

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: Control 1 (NC) Sample

DAYS: 7 days

DATE: 8th February 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm^2)	Compressive Strength (N/mm^2)
1	7.865	1/2/2017	7	150	150	1069	22500	47.51
2	7.932	1/2/2017	7	150	150	1005	22500	44.65
3	7.948	1/2/2017	7	150	150	995	22500	44.22

- Length x Width = Surface Area
- Compressive Strength (N/mm^2) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: Control 1 (NC) Sample

DAYS: 28 days

DATE: 1st March 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm^2)	Compressive Strength (N/mm^2)
1	7.705	1/2/2017	28	150	150	1243	22500	55.24
2	7.924	1/2/2017	28	150	150	775	22500	34.43
3	7.858	1/2/2017	28	150	150	1096	22500	48.71

- Length x Width = Surface Area
- Compressive Strength (N/mm^2) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: RCA 50% Sample

DAYS: 7 days

DATE: 8th March 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm^2)	Compressive Strength (N/mm^2)
1	7.942	1/3/2017	7	150	150	925	22500	41.12
2	7.933	1/3/2017	7	150	150	725	22500	32.23
3	7.916	1/3/2017	7	150	150	911	22500	40.49

- Length x Width = Surface Area
- Compressive Strength (N/mm^2) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: RCA 50% Sample

DAYS: 28 days

DATE: 29th March 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm²)	Compressive Strength (N/mm²)
1	7.897	1/3/2017	28	150	150	1044	22500	46.38
2	7.945	1/3/2017	28	150	150	1027	22500	45.64
3	7.879	1/3/2017	28	150	150	1030	22500	45.78

- Length x Width = Surface Area
- Compressive Strength (N/mm²) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: RCA-SF1% Sample

DAYS: 7 days

DATE: 15th March 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm^2)	Compressive Strength (N/mm^2)
1	7.592	8/3/2017	7	150	150	731	22500	32.49
2	7.595	8/3/2017	7	150	150	675	22500	30.01
3	7.686	8/3/2017	7	150	150	765	22500	34.00

- Length x Width = Surface Area
- Compressive Strength (N/mm^2) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: RCA-SF1% Sample

DAYS: 28 days

DATE: 5th April 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm²)	Compressive Strength (N/mm²)
1	7.649	8/3/2017	28	150	150	751	22500	33.38
2	7.730	8/3/2017	28	150	150	785	22500	34.90
3	7.721	8/3/2017	28	150	150	877	22500	38.97

- Length x Width = Surface Area
- Compressive Strength (N/mm²) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: RCA-SF2%

DAYS: 7 days

DATE: 22nd March 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm^2)	Compressive Strength (N/mm^2)
1	7.897	15/3/2017	7	150	150	925	22500	41.09
2	7.869	15/3/2017	7	150	150	901	22500	40.05
3	7.852	15/3/2017	7	150	150	885	22500	39.32

- Length x Width = Surface Area
- Compressive Strength (N/mm^2) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack

CONCRETE CUBE COMPRESSIVE STRENGTH TEST

TITLE: RCA-SF2%

DAYS: 28 days

DATE: 12th April 2017

Sample Mark	Weight (kg)	Date of Mix	Sample Age (days)	Sample Length (mm)	Sample Width (mm)	Load (kN)	Length x Width (mm^2)	Compressive Strength (N/mm^2)
1	7.923	15/3/2017	28	150	150	950	22500	42.24
2	7.926	15/3/2017	28	150	150	1014	22500	45.09
3	7.828	15/3/2017	28	150	150	945	22500	42.90

- Length x Width = Surface Area
- Compressive Strength (N/mm^2) = Load x 1000 / Surface Area
- Type of Failure : N = Normal Force, T = Tensile Crack