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Mechanical properties of Recycled Concrete with Forta Ferro Fibers

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إقـــرار

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Mechanical properties of Recycled Concrete with Forta Ferro Fibers

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نتيجة الحكم على أطروحة ماجستير

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الخواص الميكانيكية للخرسانة المعادة التدوير باستخدام ألياف فورتا فيرو

Mechanical properties of Recycled Concrete with Forta Ferro Fiber

وبعد المناقشة التي تمت اليوم الأربعاء 11 صفر 1436هـ، الموافق 2014/12/03م الساعة الواحدة ظهراً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*/** قسم **الهندسة المدنية – تصميم وتأهيل المنشآت**.

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

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DEDICATIONS

To My Parents, brothers, sisters, to my wife and my son Ahmed.

To my friends, and to whom I belong.

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ABSTRACT

Owing to the shortage of space for land reclamation in Gaza Strip, it is difficult to dispose tons of construction and demolition waste generated daily from construction activities and destroying of building during Israeli campaigns in addition to the huge amount of ex-settlements destroyed buildings. Adoption of recycled aggregate from concrete waste thus becomes a burning issue.

The main goal of this research is to obtain concrete mixes with optimum replacement of natural aggregate with recycled aggregate considering Forta Ferro Fibers to ensure the actual ductility of concrete.

Different trial mixes were used to obtain the acceptable hardened properties of fiber reinforced concrete with recycled aggregate by using a recognized manufacturer mineral cement, Aggregates (Recycled, Natural), Forta Ferro Fibers (FF Fiber), Quartz sand, water in addition to superplastisizers.

To determine those properties, experimental work has been carried out. Three batches of concrete have been cast: one with no fibers and the remaining with two different volume fibers fractions of 0.5% and 1.0% with different percentage of recycled aggregates 0.0% ,50% and 100%. Concrete specimens (cubes, cylinders and beams) have been cast to determine the mechanical behavior such as compressive, tensile, flexural strength and load - deflection relationships.

Test results have showed that fibers cause decrease in the compressive strength insignificantly, while the replacement of natural aggregate by recycled aggregate (RA) causes the decrease in the compressive strength but it is still above the target strength. However, Splitting tensile strength due to fiber addition increased about 10% to 30% of the original. Split tensile strength at 28'days is 48% higher than 7 day's strength using 1.0% FF Fiber. It is clear that the indirect tensile test indicates that it decreases when the percentage of recycled aggregate (RA) increases. On the other hand, it is observed that a general gradually increases trend in the flexural strength when using 0.5% to 1.0% FF Fiber. However, the concrete reinforced with Forta Ferro Fibers (FF Fiber) has showed more ductile behavior compared to the plain concrete.

الملخص

كما هو معروف فان قطاع غزة يعانى من صغر المساحة، وضيق الأماكن اللازمة لطرح حطام المباني الناتج عن عمليات البناء، والمباني التي هدمها جيش الاحتلال الصهيوني، والمباني التي هدمت في المحررات؛ وبالتالي جعل موضوع استغلال الركام المعاد تدويره موضوعا ذا أهمية عالية.

ان الهدف الرئيسي من هذا البحث هو الحصول على الخلطات الخرسانية مع الاستبدال الأمثل للركام الطبيعي بركام معاد تدويره، مع الاخذ بعين الاعتبار ألياف فورتا فيروا لضمان ليونة فعلية للخرسانة.

وقد استخدمت خلطات تجريبية متنوعة للحصول علي خصائص مقبولة من الخرسانة المسلحة ذات الالياف، والتي تحتوي علي ركام معاد تدويره وتتكون من: اسمنت، وركام (طبيعي- معاد تدويره)، وألياف الفورتا فيروا، ورمل طبيعي، وماء، واضافات، ولتحديد هذه الخصائص تم عمل ثلاث خلطات من الخرسانة الأولى بدون ألياف، والباقي بنسب مختلفة من الالياف وهي: (0,5% -0,1%) بالإضافة الي نسب مختلفة من الركام المعاد تدويره: (0% -50% 100%). فقد تم صب عينات خرسانية (مكعبات – اسطوانات - احزمة)؛ لتحديد الخواص الميكانيكية للخرسانة مثل قوة الضغط ، وقوة الشد، وقوة الانحناء، والعلاقة بين القوة والانحناء.

وقد اظهرت نتائج الفحوصات أن استخدام الألياف يسبب نقص في قوة الضغط للخرسانة بصورة ضئيلة، في حين استبدال الركام المعاد تدويره يقلل قوة الضغط، ولكن كانت دائما فوق القوة المستهدفة. ومع ذلك فان قوة الشد تزداد بإضافة الالياف من 10% الي 30% وكذلك قوة الشد تكون عند 28 يوم اعلي ب48% من قوة الشد عند 7 ايام وذلك باستخدام نسبة الالياف 1%، في حين أن زيادة نسبة الركام المعاد تدويره يقلل من قوة الشد، ومن الناحية الأخرى لوحظ أن هناك زيادة في قوة الانحناء عند استخدام الركام المعاد تدويره في المرحلة التي تكون فيه نسبة الألياف ما بين 0.5% و1%، كما أن الخرسانة المسلحة ذات الألياف أكثر مرونة من الخرسانة العادية.

ABBREVIATIONS

ACI	American Concrete Institute**.**
ASTM	American Society for Testing and Materials.
FF Fiber	Forta Ferro Fibers.
FR Concrete	Fiber Reinforced Concrete.
NA	Natural aggregates.
RA	Recycled aggregates.
W/C	Water / Cement ratio.

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Chapter (1)

Introduction

1.1 General Background:

Concrete is well known as a brittle material when subjected to normal stresses and impact loading especially, with its tensile strength being just one tenth of its compressive strength. It is only common knowledge that concrete members are reinforced with continuous reinforcing bars to withstand tensile stresses, to compensate for the lack of ductility and is also adopted to overcome high potential tensile stresses and shear stresses at critical location in a concrete member.

Even though the addition of steel reinforcement significantly increases the strength of the concrete, the development of micro-cracks must be controlled to produce concrete with homogenous tensile properties. To improve such weaknesses of the material, numerous studies on fiber reinforced concrete have been performed,*(Ballouy et al, 2009).*

The production of demolition and construction waste has been increasing at a gradual rate in recent years, *(Fraternali, et al., 2011).* The amount of landfill available to contain this material has been decreasing, and the need to find appropriate disposal locations has been of increasing concern. The most effective way to reduce the waste problem in construction is agreed in implementing reuse, recycling and reduced the use of a construction material in construction activities, *(Poon et. al., 2006).*

According to the Ministry of Public Works, Israel’s offensive on Gaza (2014) has caused over $5 billion of damage to homes and infrastructure in the Strip. Some 10,000 homes have been completely destroyed, and 30,000 homes partially destroyed, (MPWH, 2014)

The damage to Gaza’s infrastructure from the current conflict is more severe than the destruction caused by either of the last two Gaza wars, according to the United Nations Relief and Works Agency (UNRWA) and other organizations. The fighting has displaced about a fourth of Gaza’s population. Nearly 60,000 people have lost their homes, and the number of people taking shelter in UNRWA schools is nearly five times as many as in 2008-2009, (UNRWA, 2014)

In 1978, FORTA Corporation introduced the concept of three-dimensional synthetic fiber reinforcement to the construction market worldwide. One of the successful early product applications was the use in a wide variety of air-placed concrete projects. The FORTA family of standard synthetic fibers has enjoyed widespread use since that time in both dry-mix and wet-mix applications, such as bridge deck toppings, lake and reservoir linings, and artificial rock and waterscape projects. In these instances, these standard-grade synthetic fibers were used in relatively low dosages (approximately 0.1% by volume) to reduce temperature and shrinkage-related cracking, reduce rebound, and increase toughness and long-term durability, *(FORTA Corporation manual, 20014).*

With regard to the advantages of replacing reinforcement and using recycled aggregate and merging them together to get more improvement in the construction field.

The combination of recycled construction and demolition waste, synthetic fibers and binder creates an unusual fiber concrete; new composite, which offers a wide field of possible use in construction industry, The idea to add fibers to a concrete mixture with recycled aggregate may change material properties of such concrete, improve behavior, bring about new types of applications and enables saving sources of natural aggregate, *(Vytlaicova, 2011).*

1.2 Statement of the Problem:

On one hand, the usage of concrete with recycled aggregate in construction applications has been increasing worldwide and will make an impact in Gaza strip due to the limited land area available for construction and the fast growing population and demolition waste generated daily from construction activities and destroying of building during Israeli campaigns. On the other hand, the use of fibers as a solution to develop concrete with enhanced flexural and tensile strength, which is a new form of binder that could combine Portland cement in bonding with cement matrices.

This research presents an experimental investigation of fiber reinforced concrete made from construction and demolition waste – recycled aggregate – with and without fibers. This work is aimed at developing and testing mechanical properties (Compressive strength, Tensile splitting strength, Flexural strength) of concrete with RA.

1.3 Aim and objectives:

This research aims at obtaining concrete mixes with optimum replacement of recycled aggregate with natural aggregate considering synthetic fiber to ensure the actual ductility of concrete.

In order to achieve the aim of the current study, the following were set:

1- Produce concrete mix with optimum RA content and synthetic fibers.
2- Study the behavior of concrete mix under compression, tension and flexure.
3- Finding the optimum mix proportions.
4- Draw recommendations for the local industry to use RC according to the research findings.

1.4 Methodology:

To achieve the objectives of this research, the following tasks will be executed:

1. Conducting a literature review about recyclable building waste and synthetic fibers.
2. Selection of suitable local available materials required, including cement, Aggregates (Recycled, Natural), FF Fiber, Quartz sand, water in addition to superplastisizers.
3. Determine mix design using FF Fiber , with different percentages “i.e. 0%, 0.5%, 1%”and using recycle aggregate with different percentages.
4. Performing physical and mechanical laboratory tests on samples.
5. Analysis of results, and recommendations.

1.5 Thesis Layout:

This thesis is consisted of five chapters arranged carefully to make it clear and understandable. This section presents a brief description of these chapters.

Increasing the concrete strength and growing problem of production of RA in Gaza Strip is presented in ***Chapter (1).*** In this chapter, General Background, problem statement, the objective of work, and the methodology followed in the study are given.

General background about Recycled Concrete and FF Fiber is given in ***chapter (2)***. The goal of this literature review is to build an understanding of the developments in the field of fiber reinforced concrete, recycled aggregate and recycled aggregate in Gaza Strip.

chapter (3) reviews the materials were used and mix design, then discusses types of laboratory tests, standards, adopted procedures, materials properties, curing condition and schedules of the testing program.

chapter (4) discusses the results and analysis of all experimental results obtained from the testing procedures.

The conclusions derived from experimental results are presented in ***Chapter (5)***. Finally the recommendations for further studies on this subject will be provided in this chapter.

Chapter (2)
Literature Review

2.1 Recycled aggregate:

2.1.1 Historical background:

Construction and demolition waste (C&DW) constitutes a major portion of total solid waste production in the world, and for the present most of it is used in landfills. The most effective way to reduce the waste problem in construction is agreed in implementing reuse, recycling and reduced the use of a construction material in construction activities. Application of recycled materials in the building industry is important for sustainable development and keeping of primary sources of each country. There is whole range of applications of recycled materials for civil engineering structures and it's necessary seek the other possibility in re-use of those building materials whose live-span has been finished, *(Vytlačilová, 2011).*

When existing structures are destroyed or renovated, the debris of their demolition exists. This can be applicable to all structures including both residential and nonresidential in addition to all public works projects such as streets, highway, bridge and dams after demolitions of structures takes place. It results in the waste materials or what is usually referred to as debris. This contains all types of buildings. The demolition debris contain things like asphalt, metals, concrete and so many other materials used in construction. *(Dave et al., 2007).* According to Park T. (2003), Demolition debris are caused by the remnants of destroyed houses and concrete pavements rehabilitation projects.

Recycling and reusing of rubbles from demolished buildings is not a new concept. Since several countries have been using crushing's wastes to produce aggregate for a number of years, the produced aggregate has mainly been limited to such a low level as it is used as pipe bidding, site fill, sub base or as a capping layer. Concrete buildings, made of crushed brick, have been known since early Roman era. An early example is the concrete channel of Eiffel water supply to Cologne. In this structure, the binder is a mixture of lime and crushed brick dust or other pozzolans of the time *(Khalaf & DeVenny, 2005)*

In Germany, during the reconstruction period after the Second World War, it was necessary to satisfy an enormous demand for building materials, and to remove the rubble from the destroyed cities. The quantity of this rubble in German towns is estimated at about 400 to 600 million cubic meter. Using this rubble does not only reduce site cleaning costs, but also fulfills the need for building material. Similarly in United Kingdom, national demand for aggregate has risen steadily since the Second Word War because of the urgent need for houses, as well as the need for a new network of roads. The consumption of crushed rock and sand in the United Kingdom in 1992 was 240 million ton, obtained mainly by quarrying and *dredging (Kalaf & DeVenny 2005)*

Within the European Union, the C&D wastes come to at least 180 million tons per year. Roughly 75% of the wastes is disposed to landfills, despite its major recycling potential. However, the technical and economic feasibility of recycling has been proven, thus enabling some Member States (in particular Denmark, The Netherlands and Belgium) to achieve recycling rates of more than 80%.On the other hand, the South European countries recycle very little of their C&D waste. In Italy, every year more than 20 million tons of C&D wastes are produced. They are mainly constituted of debris coming from demolished structures made of masonry or reinforced concrete. At present, only 10% of this material is recycled and the exceeding part is disposed of in landfills for inert materials since it is illegally disposed of by other means *(Corinaldesi & Moriconi, 2008).*

The quality of concrete made from recycled aggregate is generally lower than that of concrete made from natural aggregate. The main reason for this is that recycled aggregate with its higher water absorption capacity has a porous mortar matrix around the natural aggregate and hence develops an inferior bond, *(Imamoto, et al.,2009)*

Although of low quality of recycled aggregate, recycled aggregates have long been used in the construction industry, however, due to lack of suitable specifications, their use is being limited to the low grade applications. Undoubtedly, suitable quality recycled aggregates may be used successfully in higher grade applications such as structural concrete. Recent international advances in the drafting of specifications now provide good guidance on the quality control of recycled aggregates and their use in higher grade applications, *(Poon et al., 2007).*

Many studies were constructed on recycled aggregate concrete all over the world, and locally in Gaza Strip these studies included the behavior of recycled aggregate concrete in fresh and hardened case.

2.1.2 Recycled Aggregate in Gaza Strip:

Gaza strip is one of the most density populated places in the world with an area of 365 km². It has a population of 1.416 million inhabitants. In any country in the world, the demolition debris is considered as an environmental problem as well as it could have economic benefits based on local factors. So a lot of studies and researches have been done all over the world on the recycling of those debris and their usage in aggregate production. Gaza strip was suffering during the last decay from the Israeli incursions and military actions, which produced damaged buildings and infrastructure, *(Rustom, 2005).*

There are no studies on construction and demolition waste generation rates in Gaza Strip. However, the international available data does allow predicting the amount of construction and demolition waste generated yearly in Gaza Strip is around 0.5 ton per capita per year. So we can assume generation rate of construction and demolition waste in Gaza Strip is around 0.5 ton per capita per year and since the population of Gaza strip is around 1.5 million, so there will be 0.75 million ton generated per year in Gaza strip in normal situations, *(*Al-Riyati, *2005).* Three main sources of construction and demolition waste are in Gaza Strip:

1. Construction and demolition waste generates from new construction sites, structure renovation, structure demolition road repair sites, razing of buildings, and broken pavement. A survey by the Islamic University of Gaza in 2002 indicated that more than 1 million m^3 of construction and demolition wastes are distributed over 21 main sites in Gaza Strip, *(Rustom, 2007).*

2. Construction and demolition generates from destroying buildings due to Israeli military actions. The number of houses was destroyed during Israeli military actions is shown in (Table 2-1) according to Ministry of Public Works and Housing in Gaza Strip (MPHW).

Table 2-1: Number of destroyed houses in Gaza Strip.

Year	Rafah	Khan-Youns	Middle Area	Gaza	Jabalia &North Area
2012	132	64	33	12	28
2008	1455	649	202	45	197

3. Huge quantities of construction and demolition was generated as a result of destroying Israeli settlement during the withdrawal from Gaza Strip .

The problem of construction and demolition wastes has appeared obviously at the beginning of the year 2005, after the withdrawal of Israeli occupation and the rapid continuous campaigns of destroying buildings and infrastructure in Gaza Strip. This problem began to increase and became urgent to the extent that it has become phenomenon worth of studying in order to find the suitable solution .This problem became complex at Al-Aqsa Intifada 2001 when the Israeli air force attacked all public buildings and Palestinian Authority Headquarters in the Gaza Strip. After the Israeli withdrawal from Gaza settlements in 2005, and as a result of the Israel policy that destroyed all residential, industrial and public buildings in these settlements, huge quantities of waste have been crouching everywhere . This new quantity added a big quantity of RA to the existing locally dumped. The history of Gaza demolition wastes' problem didn't stop at this point, but it opened a new stage at the end of the years 2008 and 2009, when Israel waged war on Gaza population. This war extended to about 22 days of continuous destruction of public, residential and also industrial building. According to Palestine Central Bureau of Statistics Estimation, 22000 buildings were subject to complete and partial destruction, about 15 % of all Gaza buildings.

Fifty-two days after the start of Operation Protective Edge on June 8/2014, a three-day cease-fire was announced, and renewed again. However, the end of the war will reveal a reality that may be harsher than the war itself. The Gaza Strip, a small densely populated area, is perhaps the only place in the world that suffered three devastating wars requiring extensive reconstruction three times in seven years.

Although the assessment of the losses has yet to actually begin because of the continuing military operations, initial statistics issued by international and governmental institutions are shocking. These figures are expected to double with the start of the assessment of the losses in the field. According to statistics from the Ministry of Public Works in Gaza, it will take two decades to rebuild the thousands of houses destroyed during Israel’s assault on Gaza. This is in addition to the destruction of roads, water and electricity systems, household items, identification papers, photos and certificates, as well as dozens of factories, mosques, schools, health clinics, hospitals and sewage plants.

According to the Ministry of Public Works, Israel’s offensive on Gaza (2014) has caused over $5 billion of damage to homes and infrastructure in the Strip. Some 10,000 homes have been completely destroyed, and 30,000 homes partially destroyed.

The damage to Gaza’s infrastructure from the current conflict is more severe than the destruction caused by either of the last two Gaza wars, according to the United Nations Relief and Works Agency (UNRWA) and other organizations. The fighting has displaced about a fourth of Gaza’s population. Nearly 60,000 people have lost their homes, and the number of people taking shelter in Unrwa schools is nearly five times as many as in 2008-2009.

The disposal of construction and demolition wastes in Gaza Strip is one of the challenging problems; due to the scarcity of open lands and the limited size of municipal dumping sites to accommodate large quantities of debris and unprocessed construction wastes. The random and uncontrolled disposal of construction and demolition wastes creates several open dump sites.

2.2 Fiber Reinforced Concrete (FR Concrete):

FR Concrete is a concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers each of which lend varying properties to the concrete. In addition, the character of fiber-reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities, *(Ballouy et al, 2009).*

Evidence of fiber reinforcement has been traced back to the ancient Egyptian times. Organic straw fibers were added to adobe to increase the strength and durability of the clay brick. Horsehair was also used for brittle materials in early times *(ACI Committee, 2002).* It was noticed as early as these times that fibers could bridge the gaps in fractured ceramic materials. Although such fibers are still in use today for some applications, organic fibers are typically limited to developing nations. Fiber technology has come a long way since biblical times. Fibers are now being added to concrete used in bridge and parking decks, slabs and pavements because of the ability of fibers to improve toughness, or ductility, of concrete, ,*(Majdzadeh, 2006).*

With synthetic concrete reinforcement Products from FORTA Corporation, it could control cracking and add long-term durability to a wide variety of concrete applications. Since FORTA's beginning in 1978, it Corporation a worldwide leader in synthetic fiber research and development. From a single grade of fiber, FORTA has expanded its product line to include an entire family of reinforcement fibers, each tailored to specific applications and demands of the international concrete community, *(www.forta-ferro.com, 2014).*

Since 1993, another generation synthetic fibers have been developed with improved performance benefits that affect the structural properties of the concrete itself. These synthetic fibers have begun to play an important role in the shotcrete market by enhancing toughness and durability while offering a safer and easier alternative to conventional reinforcing steel. Again, there is no standard definition describing these synthetic fibers, but an easily understood and typically used term is to describe these fibers as macro fibers due to their larger cross section compared to the 1978 first generation, synthetic fibers. Again, the measured difference in cross section by some boundary or threshold has not been standardized, *(Ballouy et al, 2009).*

2.2.1 Fiber types:

Several different types of fibers, both manmade and natural, have been incorporated into concrete. Use of natural fibers in concrete precedes the advent of conventional reinforced concrete in historical context. However, the technical aspects of FR Concrete systems remained essentially undeveloped. Since the advent of fiber reinforcing of concrete in the 1940's, a great deal of testing has been conducted on the various fibrous materials to determine the actual characteristics and advantages for each product.

Several different types of fibers have been used to reinforce the cement-based matrices. The choice of fibers varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organic such as cellulose or sisal to natural inorganic asbestos. Currently the commercial products are reinforced with steel, glass, polyester and polypropylene fibers. The selection of the type of fibers is guided by the properties of the fibers such as diameter, specific gravity, young's modulus, tensile strength…..etc and the extent these fibers affect the properties of the cement matrix *(Clarke, et al., 2007).*

There are numerous fiber types available for commercial and experimental use. The basic fiber categories are steel, glass, synthetic, and natural fiber materials. Table (2-2) gives a list of properties and common applications of various fiber reinforced concrete types presented by ACI 544 *(ACI Committee, 2002)*.

Table 2-2: Various fiber types, properties, and applications.

Fiber Type	Categories	Properties	Current Industry Applications
Steel	• Cold-Drawn Wire • Cut Sheet • Melt-Extracted: • Crimped-End • Flattened-End • Deformed	• Improved flexural toughness • Impact resistance • Flexural fatigue endurance • Static and Dynamic tensile strength • Energy absorption	• Flat slabs on grade subject to impact loads • Shotcrete applications • Hardened military structures • Tanker docks • Airport Pavements • Dams and vaults
Glass	• Borosilicate(E-Glass) • Soda-Lime-Silica(A-Glass) • Alkali Resistant(AR-Glass)	• Light Weight • Economic • Strength reduction due to long term exposure to elements • Shape versatility	• Architectural cladding and facades • Thin section applications • Electrical Utility Products • Building restoration • Fire protection • Asbestos replacement

Table 2-2:Table continue.

Synthetic	• Acrylic • Aramid • Carbon • Nylon • Polyester • Polyethylene • Polypropylene	• High Ductility while maintaining integrity • Impact Resistance • Crack distribution and control • Increase flexural fatigue strength • Ductile compressive failure • Low water absorption • High ignition temperatures	• Slabs on grade • Floor Slabs • Stay in place forms • Tunnel linings • Boat hulls • Scaffold boards • Pool construction • Precast units.
Natural	• Wood fibers • Flax • Bamboo • Coconut • Elephant grass • Sugar cane, etc...	• Lower durability • Fibers swell from moisture • Increased tensile and flexural strength • Increased toughness	• Roof shingles • Pipes • Siding planks • Thin cement wall/roof sheets • Low income housing • Gas and water tanks

- **Synthetic fiber:** Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. SNFRC utilizes fibers derived from organic polymers which are available in a variety of formulations. Fiber types that have been tried in Portland cement concrete based matrices are: acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. For many of these fibers, there is little reported research or field experience, while others are found in commercial applications and have been the subject of extensive reporting*(ACI Committee, 2002).*

With the development of synthetic fiber, synthetic macro-fiber -fiber's diameter is larger than 0.1mm is defined as macro fiber-*(CECS, 2004)* has been used widely in civil engineering. Due to some limitations of steel fiber, macro synthetic fiber could be a better solution for enhanced performance, such as facilitate light weight concrete structure, high corrosion resistance; better residual (post-cracking) flexural strength, smaller crack width and improved performance in impact, abrasion along with more of a leveled surface than traditional steel fiber reinforced concrete,*(Majdzadeh, 2006).*

The number of synthetic fiber suppliers has grown in recent years, giving contractors a wide range of fiber products from which to choose. The primary types of synthetic fibers commercially available in the United States are polypropylene, polyester, and nylon. Though the fibers within each type come in various lengths, thicknesses, and geometries, synthetic fibers provide similar benefits when used as secondary concrete reinforcement. Table (2-3) shows typical properties of the various synthetic fibers. Most synthetic fibers also have excellent acid, alkali, mildew, and salt resistance, are non-corrosive, and have low thermal conductivity.

Table 2-3: Typical Properties of Synthetic Fibers

Fiber	Type	Specific gravity	Length (inches)	Tensile strength (psi)	Young's modulus (ksi)
Polypropylene	Fibrillated	0.91	¼-2½ (or graded)	80-110	500-700
Polypropylene	Monofilament	0.91	½-¾	40-100	500-700
Polyester	Monofilament	1.34	¾-2	80-170	1450-2500
Nylon	Monofilament	1.16	¾-2	130	750

Several fiber materials in various sizes and shapes have been developed for use in FR Concrete. Among these fibers, the polypropylene has been one of the most successful commercial applications. The common forms of these fibers are smooth-monofilament and have triangular shape. Polypropylene fibers have some unique properties that make them suitable for reinforcement in concrete. The fibers have a low density, are chemically inert and non-corrosive, *(Patel et al, 2012).*

Polypropylene: Of the synthetic fibers available in the United States, polypropylene is the most widely used in ready mixed concrete *(Hasan et al., 2011).* Polypropylene fibers are hydrophobic, so they don't absorb water and have no effect on concrete mixing water requirements. They come as either fibrillated bundles or monofilaments. To produce fibrillated fibers, manufacturers extrude the polypropylene in sheets that are stretched and slit. The result is a mesh of interconnected fiber strands rectangular in cross section. Manufacturers cut the strands to specified lengths and separate them into bundles. Fiber lengths range from 1⁄4 to 21⁄2 inches . When added to concrete during mixing, the fibrillated fibers open into a network of linked fiber filaments that mechanically anchor to the cement paste, Figure (2-1). One manufacturer offers a graded fibrillated fiber having various lengths, sizes, and fibrillation patterns. The graded fibers reportedly disperse more thoroughly into all areas of the cement paste during mixing. Monofilament fibers are fine, cylindrical strands that separate during mixing. Because monofilament fibers are smooth and have a small surface area, they don’t anchor into the cement matrix as well as fibrillated fibers. With fibrillated fibers, cement paste penetrates into the network of fiber filaments resulting in better mechanical anchoring to the concrete. Research shows that lower volumes of fibrillated fibers than of monofilament fibers are needed to improve the post-cracking load- carrying capacity and ductility of concrete *(Majdzadeh et al., 2006).* Some manufacturers recommend using monofilament fibers for relatively short-term benefits, such as plastic shrink- age crack control during the first few hours after concrete placement.

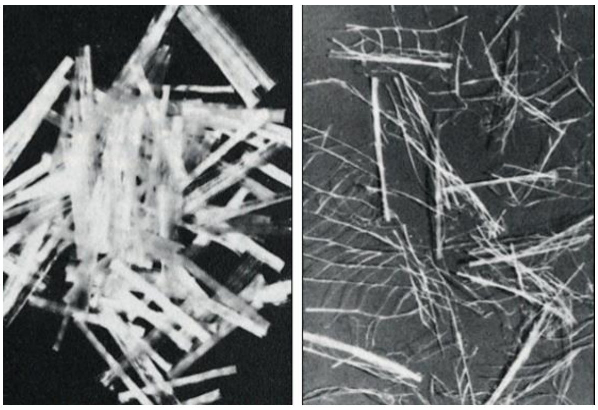


Figure 2-1: Fibrillated polypropylene fibers (left) consist of interconnected fiber strands that open during mixing (right). Fiber-reinforced versus conventionally reinforced concrete.

2.2.2 Forta Ferro Fibers (FF Fiber):

Forta Ferro is an easy to finish, color blended macro synthetic fiber, made of 100% virgin copolymer/ polypropylene consisting of a twisted bundle non-fibrillating monofilament and a fibrillating network fiber. Figure (2-2), yielding a high-performance concrete reinforcement system. Forta Ferro is used to reduce plastic and hardened concrete shrinkage, improve impact strength, and increase fatigue resistance and concrete toughness. This extra heavy-duty macro synthetic fiber offers maximum long-term durability, structural enhancements, and effective secondary/temperature crack control by incorporating a truly unique synergistic fiber system of long length design, *(FORTA Corporation manual, 20014).*

FF Fiber is non-corrosive, non-magnetic, and 100% alkali proof.This patented fiber is actually a blend of two fibers:

2. a standard fibrillated polypropylene fiber to reduce and control shrinkage and temperature cracking, and
3. a very heavy-duty twisted-bundle monofilament fiber made of a strong synthetic copolymer, to increase load-transfer and post-crack performance. This pre-blended fiber is typically used in long lengths (2-1/4") and in high dosages (5 to 30 lbs./cubic yard) to affect a higher replacement level of reinforcing steel than standard synthetic fibers. Forta Ferro, which means "Strong As Steel", is also extremely user friendly, having gained a reputation as the best mixing and finishing fiber of its kind in the industry, *(www.forta-ferro.com, 2014).*.

Figure 2-2: Forta Ferro Fibers.

FR Concrete is a concrete mix containing water, cement, aggregate and discontinuous fibers of various shapes and sizes.
According to Bentur & Mindess (2006), fibers have been used as reinforcement for quite some time now. Asbestos was the first material widely used in the beginning of the 20th century. Man-made fibers produced from steel, glass, synthetics, asbestos and natural fibers such as cellulose, sisal and jute, are examples of materials that are used in FR Concrete today. Unreinforced concrete is as known, a brittle material with high compressive strength but low tensile strength. Therefore, concrete requires reinforcement. The most known method has been, using ordinary continuous reinforcing bars in order to increase the load carrying capacity in the tensile and shear zones. Fibers that are short materials randomly spread in the concrete mix, are however discontinuous. Fibers do not increase the (tensile) strength remarkably, but due to their random distribution in the mix, they are very effective when it comes to controlling cracks. As a result the ductility of fiber reinforced members is increased. Fibers can also be used in thin and complex members where ordinary reinforcement cannot fit.

2.3 Interaction between fibers and matrix:

Many detailed analytical predictions and models have been developed in the interaction of fiber-matrix stress transfer and crack bridging, as well as analysing the shear stresses that develop across the fiber-matrix interface. Most of the models were done by simulate analytical solution on fiber-matrix interaction, which based on a simple pullout geometry shown in Figure (2-3). These analytical models involves the shear stress and frictional stress which developed between the fiber and cement matrix, offering predictions on the efficiency of short, randomly oriented fibers in the concrete matrix. The effectiveness of fibers in the mechanical properties of the fiber reinforced concrete is influenced in two ways:

• Processes where load is transferred from the cement matrix to the fibers, and
• The bridging effect of the fibers in the concrete when the concrete cracks.

The stress transfer effects must be considered in both pre-cracking case and post cracking case for the brittle FR Concrete, as the processes of stress transfer are different in these two cases. Such understanding of mechanisms for the stress transfer permits the prediction of stress/strain curve on the fiber reinforced composite, the mode of fracture and a basis for developing performance on the composite with the modification of the interaction of fiber-cement matrix, *(Mein, 2004).*

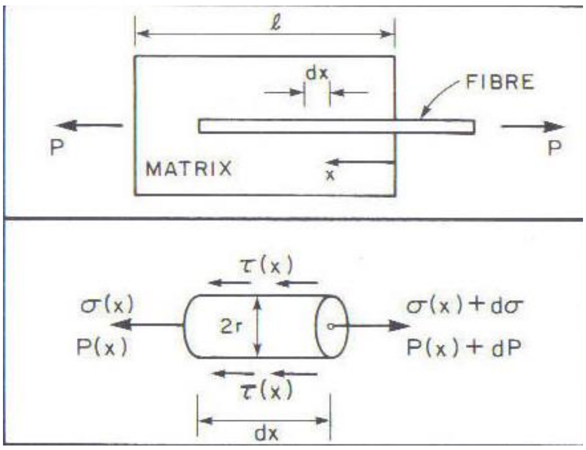


Figure 2-3: Pullout geometry to simulate the interaction between fiber and cement

The behavior of FR Concrete, varies with composition and can have a softening or hardening behavior, see Figure (2-4). Post crack hardening allows multiple cracks before failure while in post crack softening there is a reduction of strength after the first crack allowing no further cracks, *(Banthia N. and Gupta, 2006).*

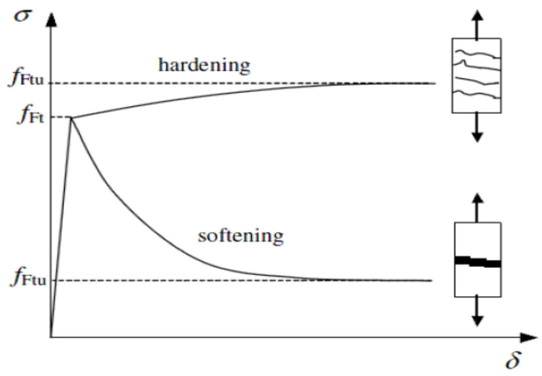


Figure 2-4: Post cracking behavior of FR Concrete in tension.

2.4 Recycled Concrete with FF Fiber:

Concrete with aggregate from recycled materials, which enables saving sources of natural aggregate, is considered to have generally worse mechanical properties than common concrete. But the idea to add fibers to a concrete mixture with recycled aggregate may change material properties of such concrete, improve behavior and bring about new types of applications. FR Concrete with recycled aggregate can be considered as optimal structural concrete for various applications. The approach to design of fiber concrete with recycled aggregate is defined by the method, or the philosophy, of the design, whose flow is shown in Figure (2-5).

While in the case of ordinary, or plain, concrete the material characteristics are defined by its application, which is reflected in the composition of fresh concrete (way 1), in the case of fiber concrete this process is its complete opposite (way 2). The composition is given in advance and subsequently its properties are proofed and its applicability in building industry sought. The general procedure of testing of composites mostly follows the economic criteria (cost minimization) with respect to simplicity of technology and possible applicability in practice, which would contribute to the building sustainability. The advantage of the wide grading curve of the used recycled aggregate is apparent in the design of fiber concrete.

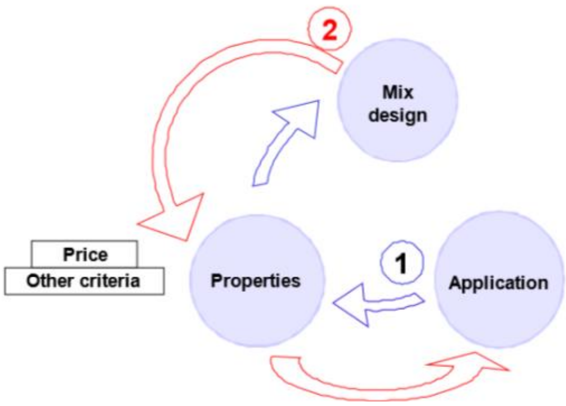


Figure 2-5: Philosophy of the design of fiber concrete with recycled aggregate.

The design can be based only on determination of the density of the compacted recycled aggregated regardless to its saturation, and the remaining components can be just added. The amount of cement should ensure the bond between the fibers and the recycled aggregate, and the amount of fibers should ensure the required uniaxial tensile strength. The amount of water should be decided according to workability requirements. The mix composition is based on the following principles*: (Vytlačilová, 2011).*

- recycled aggregate of wide grading curve (a single grade, e.g. 0/32 mm),
- constant-minimum amount of binder (cement),
- weight of fibers according to the requirement of fiber concrete properties,
- amount of water according to required workability.

2.5 Advantages and Disadvantages of FR Concrete:

Fibers, which are randomly distributed throughout the concrete, can overcome cracks and control shrinkage more effectively. These materials have outstanding combinations of strength and energy absorption capacity. In general, the fiber reinforcement is not a substitution for conventional steel reinforcement. The fibers and steel reinforcement has their own role in concrete technology. Therefore, many applications in which both fibers and continuous reinforcing steel bars can be used together, *(Mein, 2004).*

However, fibers are not efficient in withstanding the tensile stresses compare to conventional steel reinforcement. But, fibers are more closely spaced than steel reinforcement, which are better in controlling crack and shrinkage. Consequently, conventional steel reinforcement used to increase the load bearing capacity of concrete member; fibers are more effective in crack control, *(Fang, 2010).*

Due to these differences, there are particular applications that fibers reinforced are advance than conventional steel reinforcement. These include:

- Fibers comprise as ‘primary reinforcement’, in which the conventional steel reinforcement cannot be utilized. The fiber concentrations are comparatively high in thin sheet materials, normally exceeding 5% by volume, acts to increase in toughness and strength of mortar or concrete.
- Fibers can be components to withstand locally high loads or deformations, which applies to structures like precast piles, precast walls, blast resistant structures or sewer tunnel and linings.
- Applications that control cracks persuaded by temperature and humidity, such as pavements and slabs, where fibers offered as ‘secondary reinforcement’.

The uses of steel bars and wire mesh require unnecessary labor and material costs for structure concrete. With replacement of randomly distributed short fibers as an alternative reinforcement, will significant reduce both labour and material costs, greatly increase construction and project time, *(Patel et al, 2012).*

Benefits of using fibers-reinforced concrete are:

- Increase impact and shatter resistance, fatigue endurance and shear strength of concrete.
- Requires no special equipments to install reinforcement.
- Increase crack resistance, long-term ductility, energy absorption capacity and toughness of concrete.
- Reduce labor and material costs in concrete applications.
- Provides multi-directional concrete reinforcement.
- Compatible with admixtures, all types of cement and concrete mixtures.
- Reduce plastic shrinkage and crack width formation.

Restrictions and limitations of using fiber-reinforced concrete are:

- Control crack as result of external stresses.
- Reduction in curling and creep.
- Justification for a reduction in the size of support columns.
- Higher structural strength development.
- Replacement of any moment for structural steel reinforcement.
- Decreasing the thickness of slab on grade.

Although short fibers cannot replace conventional steel reinforcement, they create supplementary reinforcement use to achieve increase in strength, higher ductility, greater shrinkage, crack control, fatigue, impact and abrasion resistance. However, development and advances in technologies has led to the discovery of more effects for fibers behavior and mechanical properties of concrete, *(Mein, 2004).*

As mention above, polypropylene fibers reduce or relieve internal forces by blocking microscopic cracks from forming within the concrete. The main disadvantage associated with the fiber reinforced concrete is fabrication. The process of incorporating fibers into the cement matrix is labor intensive and costlier than the production of the plain concrete. The real advantages gained by the use of FR Concrete overrides this disadvantage, *(Brown et al., 2002).*

Chapter3
Materials And Experimental program

3.1 Introduction:

This chapter provides a description of the laboratory study performed in this work. All of the tests were performed over a span of approximately 4 months, starting with trial concrete batches in January to April 2014, followed by a preliminary investigation and concluding with the main experimental program. All work was performed in the Structural Laboratories - soil and material laboratory at IUG and consulting center for quality & calibration. This chapter comprises the experimental program and the constituent materials used to produce of recycled Concrete with FF Fiber associated with this research work.

The properties of several constituent materials used to produce recycled Concrete with FF Fiber are also discussed such as moisture content, unit weight, specific gravity and the grain size distribution. The test procedures, details and equipment used to assess concrete properties are illustrated in the following sections which summarized in chart (3 -1).

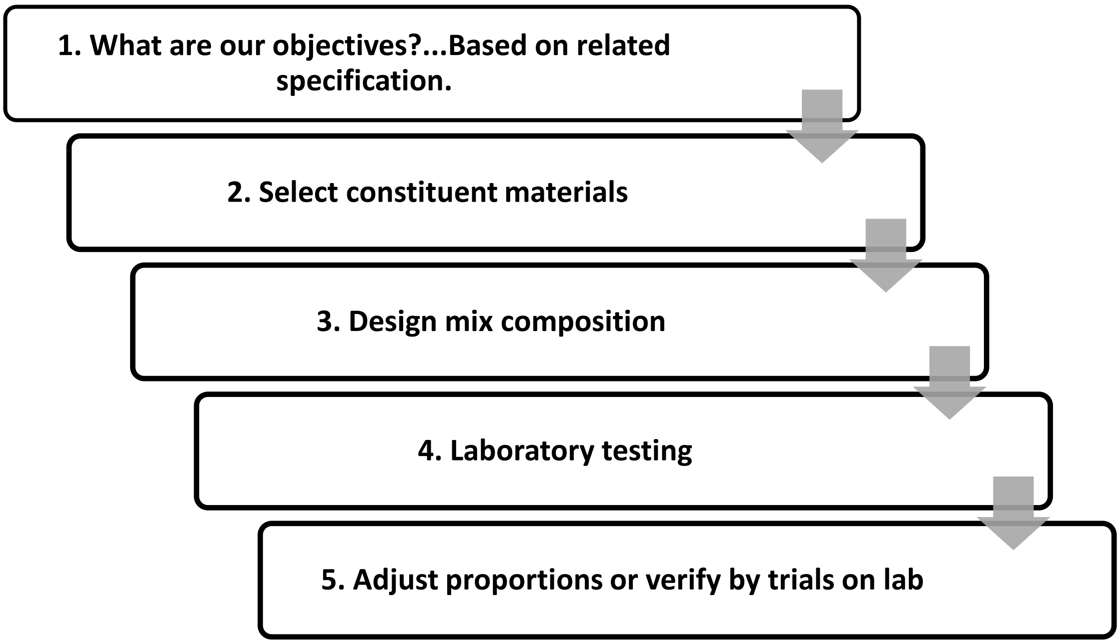


Figure. 3-1: Outline of chapter (3).

3.2 Experimental program:

As mentioned in chapter one the aim of this research is to produce RA with FF Fiber using local available materials. The test program adopted to achieve this objectives is summarized in Figure (3-2). Three batches of concrete have been cast: one with no fibers and the remaining with two different volume fractions fibers of 0.5% and 1.0% with different percentage of recycled aggregates 0.0% ,50% and 100%. Concrete specimens (cubes, cylinders and beams) have been cast to determine the mechanical behavior such as compressive, tensile, flexural strength and load - deflection relationships. As shown in Figure (3-2), a total of 189 specimens tested: 81 cubes of size 100×100×100 mm for compressive strength test, 81 cylinders of size 150mm diameter and 300mm height for tensile strength test and 27 of 150mm x 150mm x 600mm beam for flexural strength test. All of specimens with three different percentages of RA volume fractions, such as 0%, 50% and 100% tested, at an age of 7 days, 14 days and 28 days for each batch.

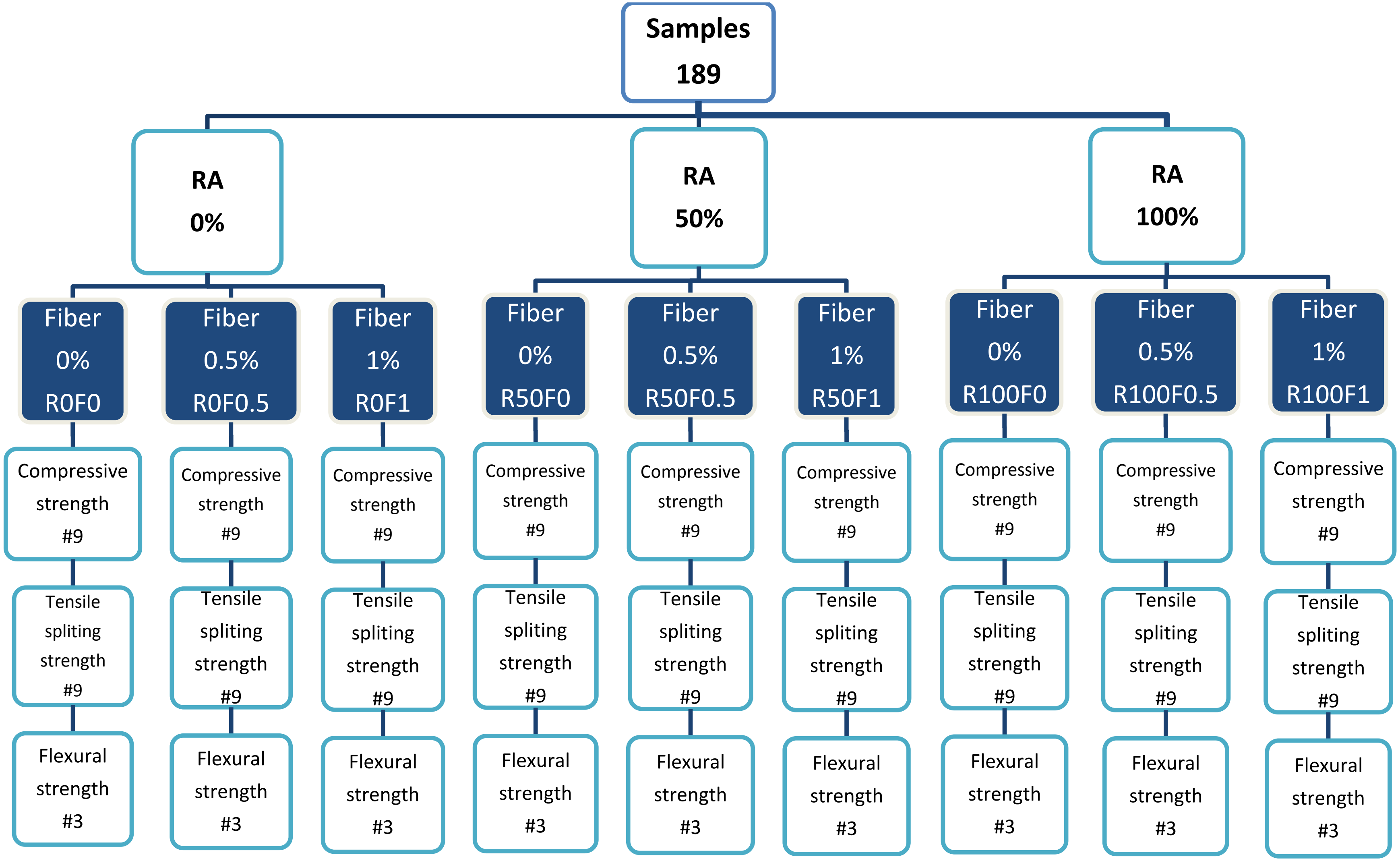


Figure 3-2: Test Program.

3.3 Characterizations of Constituent Materials:

Concrete is a composite material composed of course granule material (the aggregate or filler) embedded in hardened matrix of material (the cement) that fills the space between the aggregate particles and glues them together. Aggregate can be obtained from many different kinds of material, although we mostly make use of the materials of natural common rocks, but recycled aggregate can also be considered as another source of aggregate.

The materials used in this research include ordinary Portland cement, Aggregates (Recycled, Natural), FF Fiber, Quartz sand, water in addition to superplastisizers, are used to ensure suitable workability. FF Fiber used to improve the strength and ductility. Proportions of these constituent materials have been chosen carefully in order to optimize the packing density of the mixture.

3.3.1 Cement:

Cement paste is the binder in recycled Concrete with FF Fiber that holds the aggregate (coarse, fine, micron fine) together and reacts with mineral materials in hardened mass. The property of sample depends on the quantities and the quality of its constituents. Because cement is the most active component and usually has the greatest unit cost, its selection and proper use is important in obtaining most economically the balance of properties desired of mixture. In this research ordinary Portland Cement CEM I 42.5R brought from Egypt is used, because of unavailability of other types of cement in Gaza during performing these tests. The cement met the requirements of ASTM C 150 specifications. The results of physical and mechanical analyses of the cements are summarized in Table (3-1) along with the requirements of relevant ASTM specifications for comparison purposes.

Table 3-1: cement characteristics according to the manufacturer sheets.

Type of test		Ordinary Portland Cement	
		Results	ASTM C 150
Setting time (Vicat test) hr : min	Initial	1 hr 30 min	> 60 min
	Final	4 hr 40 min	< 6 hrs 15 min
Mortar compressive strength (MPa)	3-Days	20.7	Min. 12
	7-Days	35.3	Min. 19
	28-Days	48.6	No limit
Blain Fineness (cm2/gm)	-	3005	Min. 2800
Water demand	-	27.5 %	No limit

3.3.2 Aggregates:

Aggregate is relatively inexpensive and strong making material for concrete. It is treated customarily as inert filler. The aggregate used in this study can be divided into two types based on its source as natural aggregate and recycled aggregate.

3.3.2.1 Aggregate types:

- **Natural Aggregate:** Crushed limestone were used as course aggregate (Foliya, Adasiya, Simsimiya) with the maximum nominal size as shown below according to the local market size classification.
- **Fine aggregate**: The sandy dunes, which are considered as the source of sand, are spread along the Gaza Strip, especially in Rafah, Khan Younis and Bait Lahya . Sand was tested for physical properties.
- **Recycled aggregate:** It is looks like natural aggregate. However, recycled aggregate has many physical properties that vary from those of natural aggregates. In general, crushed concrete particles are more angular and have a rougher surface texture than natural aggregate. particles with roughly textured, angular shape and elongated particles require more water to produce workable concrete than smooth rounded compact aggregate. The lightweight, porous cement mortar attached to recycled concrete aggregates causes crushed concrete aggregates to have a lower specific gravity and higher water absorption than comparatively sized natural aggregates.

3.3.2.2 Aggregate properties:

The most important aggregate properties which needed to prepare concrete mixes are:

A. Specific gravity:

The density or specific gravity of an aggregate is defined as the ratio of the mass of solid in a given volume of sample to the mass of an equal volume of water at the same temperature. The specific gravity is clustered under three different conditions namely bulk, apparent and saturated specific gravity. The bulk specific gravity is where the specific gravity of the aggregate is determined under the natural environment. The apparent specific gravity is determined after the aggregate is oven dried for 24 hours. The saturated specific gravity is determined when the aggregate is under the saturated condition. The specific gravity of an aggregate gives valuable information on its quality and properties and it is seen that the higher the specific gravity of an aggregate, the harder and stronger it will be. Table (3-2) illustrates the specific gravity value for all natural coarse aggregate and Recycled aggregate which used in the preparation of concrete mixes. As we note the density of the recycled aggregates is lower than the one of natural aggregates, because of the fact that the cement paste remains stuck at the grains and because there are some impurities of lower density, as asphalt or bricks . The determination of specific gravity of coarse and fine aggregate was done according to ASTM C 127 and ASTM C128 respectively.

B. Absorption:

The water absorption is defined as the absorption rates of water by aggregate. It is determined by measuring the increase in mass of an oven dried sample when immersed in water for 24 hours. The ratio of the increase in mass of the sample, expressed as a percentage. The absorption rate not only affects the bond between the aggregate and cement paste but also the specific gravity of the aggregate. When the water absorption of the aggregate is higher, it will decrease the workability of fresh concretes.

The water absorption is the physical property of recycled aggregate which shows more difference with the natural aggregate as shown in Table (3-2). The absorption rate produces the effect of having to control the mix proportions of water content and to maintain water-cement ratio constant. That means, in concrete design, the higher absorption raises the issues of workability and water demand.

Table 3-2: Physical property of Natural and recycled aggregate.

Natural Aggregates				Recycled aggregate
Foliya	Adasiya	Simsimiya	Sand	
Specific Gravity				
2.579	2.598	2.615	2.576	2.402
Absorption				
1.7	1.5	2.0	0.7	3.6
Fine Materials Content (less than 75 µm)				
1.797	2.087	2.719	0.193	1.1
Bulk Density				
1.384	1.343	1.354	1.266	1.384

C. Grading and sieve analysis:

The sieve analysis of aggregate includes the determination of coarse and fine aggregate by using a series of sieves. The size of aggregate particles differs from aggregate to another, and for the same aggregate the size is different. ASTM C136 procedure was used to determine the sieve analysis of coarse and fine aggregate, *(ASTM C136, 2004).*

Table (3-3) and (3-4) show the sieve grading of the three types of Natural coarse and fine aggregates and Recycled aggregate.

Table 3-3: Aggregates Gradation (Sieve Analysis) of Natural and recycled aggregate.

Sieve No.	Sieve Opening Size (mm)	***Foliya:*** Max Size 25 mm	***Adasiya:*** Max Size 14 mm	***Simsimiya:*** Max Size 10 mm	Recycled aggregate
		Passing%			
1 1/2"	37.5	100.0	100.0	100.0	100.0
1"	25	100.0	98.7	100.0	100.0
3/4"	19	90.9	89.8	100.0	100.0
1/2"	12.5	45.3	35.9	97.7	52.4
3/8"	9.5	6.3	6.0	91.9	2.5
#4	4.75	2.2	1.1	20.9	0.2
#8	2.36	2.2	1.0	4.9	0.2
#16	1.18	2.1	1.0	2.3	0.2
#30	0.6	1.8	1.0	1.3	0.2
#100	0.15	0.4	0.3	0.5	0.1
pan	0	0.0	0.0	0.0	0.0

Table 3-4: Aggregates Gradation of sand (Maximum Size 0.600 mm).

Sieve No.	Sieve Opening Size (mm)	Passing%
# 8	2.36	100.0
#16	1.18	99.7
#30	0.600	95.7
#50	0.300	46.3
#150	0.150	1.3
pan	0.000	0.0

(a) (b)

Figure (3-3):Texture comparison between coarse natural aggregate and coarse recycled a) Natural coarse aggregate b)Recycled coarse aggregate.

Comparison between coarse recycled and coarse natural aggregate:

Figure (3-3) and Tables(3-2,3-3) indicated that:

1. Recycled aggregate has rough – textured, angular and elongated particles where natural aggregate is smooth and rounded compact aggregate.
2. Recycled aggregate is well graded as natural aggregate.
3. The water absorption capacity of coarse recycled aggregate is 3.6% which is more than natural coarse aggregates.

The difference is due to cement paste adhered to aggregate and some kinds of impurities in recycled aggregate .The rough – texture, angular and elongated particles require more water than the smooth surface which increase the capacity of water absorption .The void content will increase with the angular aggregate which decrease the dry density of coarse recycled aggregate.

3.3.3 Forta Ferro Fibers (FF Fiber):

FF Fiber has been tested by scores of agencies, laboratories, and testing facilities in a wide variety of performance areas, such as toughness, impact resistance, flexural strength, and residual strength, Table (3-5) shows the hysical property of FF Fiber.

Recommended dosage rate of Forta Ferro is 0.2% to 2.0% by volume of concrete (3 to 30 lbs. per cubic yard) added directly to the concrete mixing system during, or after, the batching of the other ingredients and mixed at the time and speed recommended by the mixer manufacturer (usually four to five minutes).

Table 3-5: Physical property of Forta Ferro.

Materials	Virgin Copolymer/Polypropylene
Form	Monofilament/Fibrillated Fiber System
Specific Gravity	0.91
Tensile Strength	83-96 ksi. (570-660 MPa)
Length	2.25" (54mm), 1.5" (38mm)
Color	Gray
Absorption	Nil
Acid/Alkali Resistance	Excellent

3.3.4 Water:

Drinkable water was used in all concrete mixtures and in the curing of specimens.

3.3.5 Superplastisizers:

Supe Flow B.D. is a hydroxylated polymer blended with lignosulphonic acid family it can be used with all types of Portland cement and/or blast furnace slag cements with fly ash, pozzolan, fillers fume-silica etc…

However, the rate of addition is in the range of 0.6-1.0 Kg/100kg of Cement, The technical data for Super Flow are shown in Table (3-6). Full data details are presented in Appendix II

Table 3-6: The technical data for Super Flow (source: from supplier)

Form	Brown liquid
Specific Gravity	1.18 (=/-0.01) kg/dm3 a 200 C.
pH	7(+/-1)
Freezing Point	-20 C approx.
Chloride content	Nil

3.4 Mix Design of recycled Concrete with FF Fiber:

Concrete is the basic engineering material used in most of the civil engineering structures. Its popularity as basic building material in construction is because of, its economy of use, good durability and ease with which it can be manufactured at site. The ability to mould it into any shape and size, because of its plasticity in green stage and its subsequent hardening to achieve strength, is particularly useful.

The process of determining required and specifiable characteristics of a concrete mixture is called mix design.

Concrete mix design is defined as the appropriate selection and proportioning of constituents to produce a concrete with pre-defined characteristics in the fresh and hardened states, *(IS 10262, 2009).*

Characteristics can include: (1) fresh concrete properties; (2) required mechanical properties of hardened concrete such as strength and durability requirements; and (3) the inclusion, exclusion, or limits on specific ingredients. Mix design leads to the development of a concrete specification.

Mixture proportioning refers to the process of determining the quantities of concrete ingredients, using local materials, to achieve the specified characteristics of the concrete. A properly proportioned concrete mix should possess these qualities:

1. Acceptable workability of the freshly mixed concrete

2. Durability, strength, and uniform appearance of the hardened concrete

3. Economy

Understanding the basic principles of mixture design is as important as the actual calculations used to establish mix proportions, *(Kosmatka et al., 2003).*

3.4.1 Material properties:

With the available data, such as particle density, water absorption, proportion of aggregates, water/cement ratio, aggregate/cement ratio and target strength, the calculation of mix quantities can be obtained. In this research standard design procedure starting with determining the amount of aggregates required using the other parameters such as densities of fine and coarse aggregates in SSD condition, volume ratio of fine aggregate to the total aggregate, then determination of the cement content for a target design compressive strength.

After that water content to be determined according to the selected water/ cement and assumed air content, using the total absolute volume equation.

Then determination of the superplasticizer dosage based on the calculated total cement content.

3.4.2 Mixing procedure was according following steps:

1) Adding 40 % of superplasticizer to the mixing water.
2) Placing all dry materials (cement, quartz sand, course aggregate and FF Fiber) in the mixer pan, and mixing for 2 minutes.
3) Adding water (with 40% of superplasticizer) to the dry materials, slowly for 2 minutes.
4) Waiting 1 minute then adding the remaining superplasticizer to the mixture for 30 seconds.
5) Continuation of mixing as the changes from a dry powder to a thick paste.

After final mixing, the mixer is stopped, turned up with its end right down, and the fresh homogeneous concrete is poured into a clean plastic pan.

The casting of all specimens used in this research completed within 20 minutes after being mixed. All specimens were cast and covered to prevent evaporation, *(Karmout, 2010).*

Fibers can be added with the coarse and fine aggregate at the batch plant or to the central or truck mixer at the jobsite. If adding the fibers with other mix ingredients, no extra mixing time is needed.

If adding the fibers to mixed concrete, agitate the concrete an additional 3 to 7 minutes as recommended by ASTM C 94 to disperse the fibers thoroughly.

Typical values of dosage rates call for fibers to be added as a percentage volume, with rates ranging from 0.2% to 2.0%.

3.4.3 Curing:

Once the specimens were cast and finished, they were allowed to sit for about two to three hours in open air to commence the setting process. The specimens were covered with one or two layers of wet burlap and left overnight. On the next day, the modulus of rupture prisms and panel specimens were removed from their moulds and again placed in curing basin for the next six days. Cylinders were also demoulded and placed in a curing chamber located in the soil lab at the IUG (see Figure 3-4) at 100% relative humidity for the next six days. On the seventh day after casting, all of the specimens were uncovered and left to cure to maturity in ambient conditions.

Figure 3-4: Test curing basin.

3.5 Equipment and testing procedure:

Once the mix job was done, the concrete specimens were then prepared by pouring the concrete into 150mm diameter x 300mm large cylindrical moulds, 100mm x 100mm x 100mm cubic moulds and 150mm x 150mm x 600mm beam moulds. In total there were three batches for each type of fiber corresponding to the various fiber volume dosages (0.5% and 1.0%) and one control batch with no added fibers. This shows grand total of 189 concrete specimens, which include nine cylindrical specimens, nine cubic specimens and three beam specimens for each concrete mix batch. The Figure (3- 5) shows the moulds for specimens.

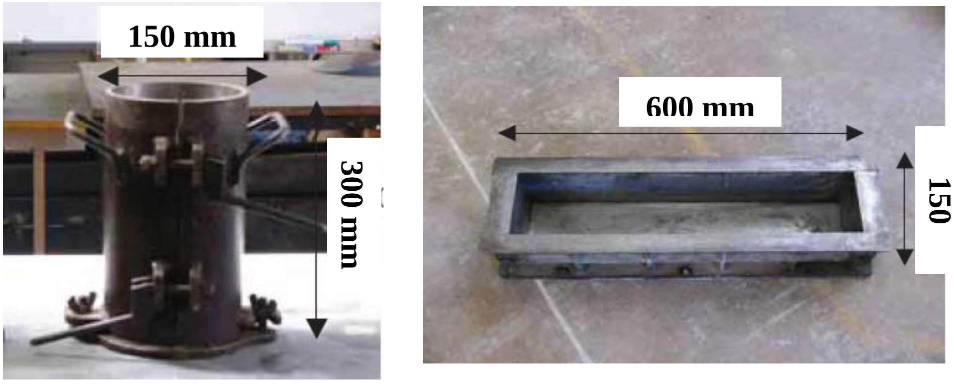


Figure 3-5: moulds for specimens.

Before any fresh concrete was poured into the concrete moulds, all concrete moulds must be cleaned from the existing concrete stain and diesel oil was applied inside and around the moulds. The fresh concrete was placed into the mould with the scoop and vibrated with an immersion vibrator. Once the concrete moulds were filled, the surface of the concrete was leveled with a lever.

The specimens were demoulded after 24 hours of casting and curing in steel moulds. Thereafter, the demoulded specimens were marked for identification and kept submerged in a curing tank at a temperature (27° ± 2°C) till the age of testing.

3.5.1 Hardened properties testing:

It is important to understand the properties of concrete as they indicate the potential qualities to this purpose. Nevertheless, characteristics of concrete strength and durability should not consider as essential material properties.

Such factors like specimen geometry and preparation, temperature, loading rate, moisture content, and type and method of testing will affect the mechanical behaviour. Majority of these properties of concrete were used in laboratory work, and especially in research, where it is based to the knowledge of the influence on these tests and the measured property is important. Hardened properties tests can categorise to destruction and non-destructive tests, which permit repeated test on the same

specimen, making potential study of change in properties with time. The tests conducted for this project are destructive test.
This section 4.3.1 mainly deals with the hardened property test of FR Concrete. Each test and methodology was outlined and discussed. The test procedure to measure the hardened property of FR Concrete in this project was according with AS1012.3, and these methods include:
• Compressive strength test.
• Tensile strength test.
• Flexural strength test.

3.5.1.1 Compressive strength test:

Compressive strength of a concrete is a measure of its ability to resist static load, which tends to crush it. Most common test on hardened concrete is compressive strength test. It is because the test is easy to perform. Furthermore, many desirable characteristic of concrete are qualitatively related to its strength and the importance of the compressive strength of concrete in structural design. The compressive strength gives a good and clear indication that how the strength is affected with the increase of fiber volume dosage rate in the test specimens.

A total of 81 cubes of size 100×100×100 mm with three different percentages of Recycled aggregate with three different percentages of Forta Ferro fiber volume fractions, such as 0, 0.5, and 1.0 % are tested, as shown in Figure (3-6).

The specimen was placed in the testing machine (between the two platens) then the axis of the specimens was carefully aligned. The upper platen was lowered down to the capped specimen so that uniform bearing is obtained. Finally the maximum force was read from the testing machine meter and the reading was recorded. The compressive strength of the specimen was obtained by through the maximum load form the meter over the cross sectional area of the specimen.
The compressive strength of concrete can be calculated using the following formula:

$$f'_c = \frac{P \times 1000}{A} \qquad \text{Eq. (3-1)}$$

Where:
f'_c = Compressive strength of concrete (MPa).
P = Maximum load applied to the specimen in kN.
A = Cross sectional area of the specimen (mm^2).

Figure 3-6: Compression test specimens (100x100x100mm)

3.5.1.2 Indirect tensile strength test:

The split tension test is an indirect way of measuring the tensile strength of concrete. These tests were performed with Cylinder Testing Machine. The test method involves applying a diametric, compressive force along the length of the cylindrical specimen. The stress distribution, shown in Figure (3-7), along the plane of the applied load has a high compressive stress at the extreme fibers, but rapidly changes to a nearly uniform tensile stress in the transverse direction over the remaining cross section.

The testing of specimens in pure tension is very difficult and usually determines by indirect mean, applying tension in the form of splitting.

Concrete specimens for indirect tensile test were 150mm diameter and 300mm height. The specimens were placed with its axis horizontal, between the platens of a compression-testing machine. The apparatus set up was shown in Figure (3-7). Load was applied until the specimen fails in its vertical diameter. The splitting test is simple to conduct and gives more consistent results than other tension tests. It is believed that the strength obtain by splitting test is nearer that the true tensile strength of the concrete than modulus of rupture.

The task of this test was performed to find the increase and differences of strength according the increasing percentage of fiber in the concrete.

The concrete cylinder will crack, but will refrain from completely shattering as load is continuously added past the first crack. The fibers should bridge the gap that is created by the load and assist the concrete in supporting additional load. It is also expected that unless the fibers severe or pullout, that the concrete specimen will not completely separate into two or more discrete segments, but rather maintain some integrity.

At failure, the maximum applied load, the type of failure, and the appearance of the concrete are recorded and a calculation for splitting tensile strength is performed. The indirect tensile strength of concrete is calculated using the following formula:

$$f'_{ct} = \frac{2P \times 1000}{\pi \times L \times D} \quad \text{.......Eq. (3-2)}$$

Where:

f'_c = Indirect tensile strength of concrete (MPa).

P = Maximum load applied to the specimen in kN.

L = Length of the specimen in mm.

D = Diameter of the specimen in mm.

Figure 3-7: A typical setup of indirect tensile test.

3.5.1.3 Flexural strength Test:

Flexural strength of a concrete is a measure of its ability to resist bending. Flexural strength can be expressed in terms of 'modulus of rupture'. Concrete specimens for flexural strength were cross sectional area of 150mm width with 150mm depth and length of 700 mm concrete beam. The center point loading device is adjusted so that its bearing edge is at exactly right angles to the length of the beam and parallel to its top face as placed, with the center of the bearing edge directly above the center line of the beam and at the center of the span length as shown in Figure (3-8). The load contacts with the surface of the specimen at the center. If full contact is not obtained between the specimen and the load applying or the support blocks so that there is a gap, the contact surfaces of the specimen are capped.

The specimen is loaded continuously and without shock at until rupture occurs. Finally, the maximum load indicated by the testing machine is recorded.

The flexural strength of the beam, Fr (in MPa), can be calculated by using the following equation:

$$F_r = \frac{3P \times L}{2B \times D} \quad \text{......Eq. (3-3)}$$

Where:
P = maximum applied load indicated by the testing machine;
L = span length;
B = average width of specimen, at the point of fracture;
D = average depth of specimen, at the point of fracture).

All beam specimens were tested after 28 days from casting. Three beams were tested for each patch, the mean values of the specimens were considered as flexural strength of the beam.

Figure 3-8:Flexural strength test machine.

Chapter 4
Experimental test results and discussion

4.1 Introduction

This chapter focuses on discussion and analysis of results obtained from the experimental program. The experimental tests were carried out to obtain the mechanical properties and behavior of fiber reinforced concrete and study the effect of using FF Fiber and RA on the mechanical behavior including compressive strength, indirect tensile strength and flexural strength of the concrete.

4.2 Trial Mixes

The mix design used for this research was based on a sample mix design prepared by researcher. Table (4-1) shows one cubic meter ingredient of the best results obtained mixture of recycled Concrete and FF Fiber. All mixtures details and average results are presented in appendix (A).

Table 4-1: One cubic meter components of mixture.

Recycled aggregate %	0.0%	50%	100%
Cement (Kg)	349	349	349
Course Aggregate (Kg)	1389	1226	1131
Sand (Kg)	498	604	649
Water (Kg)	185	197	206
Water/Cement Ratio	0.45	0.45	0.45
Superplastisizers (L)	2.5	2.5	2.5

A data spreadsheet was created to take a given amount of concrete, increase the total concrete by 10% for losses during mixing, and along with a predetermined fiber dosage as a percent by volume, calculate total weights of coarse and fine aggregates, water, and fibers. The amount of concrete needed is shown in Table (4-2).

Table 4-2 Required concrete volume for one sample mix.

	Cubic	Cylinder	Beam
Number of Specimen	9	9	3
Volume of Single (cubic meter)	0.001	0.005	0.013
Total Volume (cubic meter)	0.009	0.045	0.039
Total Volume x 1.1 (cubic meter)	0.0099	0.0495	0.0429
Total Volume x 1.1 (cubic meter)	0.1		

The batch weights, in Table (4-3), were then calculated for a fiber dosage of 0.5% using batch proportions and specific gravities:

Table 4-3 Required weight and volume for each mix component

Recycled aggregate 0.0% & Fiber Dosage 0.5%		
Total Volume: 0.1 cubic meter		
Component	**Weight (Kg)**	**Volume (m3)**
Cement	34.6	0.023
Course Aggregate	138.9	0.053
Sand	49.8	0.019
Water	18.5	0.0185
Forta Ferro	0.455	0.0005

Recycled aggregate 50% & Fiber Dosage 0.5%		
Total Volume: 0.1 cubic meter		
Component	**Weight (Kg)**	**Volume (m3)**
Cement	35.3	0.024
Course Aggregate	122.6	0.047
Sand	60.4	0.023
Water	19.7	0.019
Forta Ferro	0.455	0.0005

Recycled aggregate 100% & Fiber Dosage 0.5%		
Total Volume: 0.1 cubic meter		
Component	**Weight (Kg)**	**Volume (m3)**
Cement	35.7	0.024
Course Aggregate	113.1	0.047
Sand	64.9	0.024
Water	20.6	0.02
Forta Ferro	0.455	0.0005

With the weights of each component, the concrete was ready to be mixed. The mixing process was performed in two steps. After dampening the mixing drum, the sand and aggregate were added to the drum and then the fibers were added at a rate slow enough to ensure good distribution of fibers and to minimize clumping. The aggregates and fibers were mixed thoroughly before the second set of materials was added. Once the fibers were well distributed the cement, water and super plasticizer were added to the mix.

4.3 Testing Results

The experimental results for all tests performed in this research will be discussed on the following sections.

4.3.1Effect of using RA:

4.3.1.1 Compressive strength test results:

A total of 81 cubes of size 100×100×100 mm with three different percentages of RA volume fractions, such as 0%, 50% and 100% tested, as shown in Figure (4-1) three cubic tests at an age of 7 days, three cubic at an age of 14 days and three at 28 days for each batch. Results show the compressive strength test and the changes in the compressive strength for each type of specimen. Full details of results are presented in Appendix I.

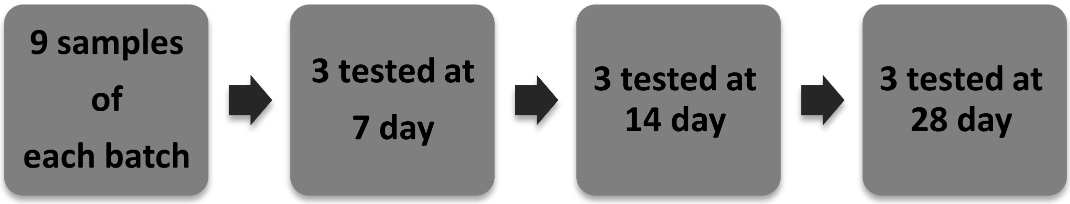


Figure 4-1: Compressive strength evaluation chart of concrete cube specimens.

The compressive strength of concrete is affected by the aggregate properties, the bond that is developed when concrete hardens is the aggregate-paste bond, which is both physical and chemical. The presumption is that recycled aggregate concrete might develop an even weaker chemical bond with cement paste, as the chemical composition of the aggregate is different from those of commonly used natural aggregates and the re-bonding of some elements in cement paste residue can take place. With replacement of recycled aggregate the compressive strength has decreased but was always above the target strength. This gives a conclusion that recycled aggregate concrete is not less important than normal concrete.
Figure (4-2) shows the influence of recycled aggregate in concrete mixes, optimum results was obtained using zero recycled aggregate but the concrete specimen with 100% RA had the lowest compressive strength which was only 32.5MPa, it is around 12.6% drop when compared to control concrete specimen. The strength of recycled aggregate concrete was lower than the natural aggregate concrete for the same targeted compressive strength concrete this agree with results obtained by *Abu Shaban, (2012).*

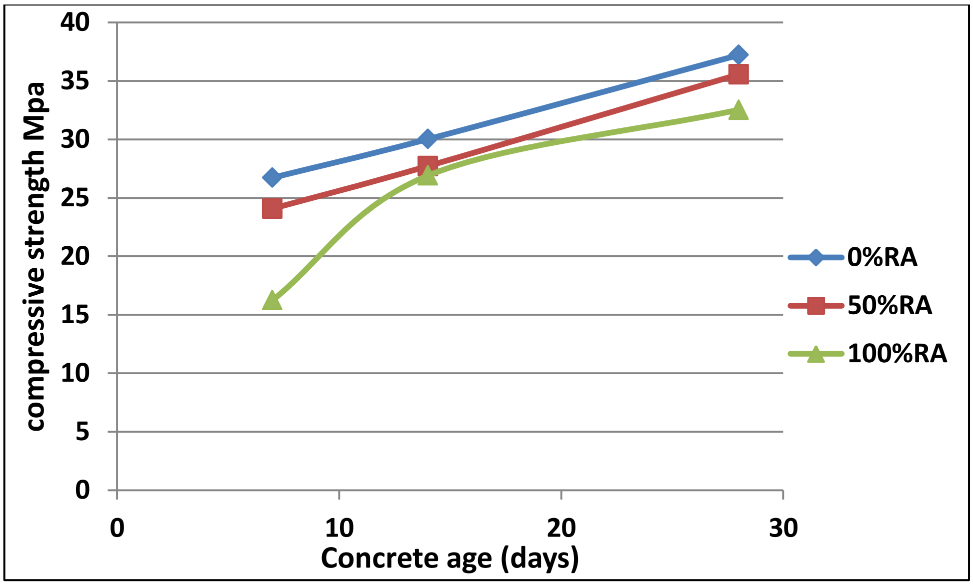


Figure 4-2: The variation of mean compressive strength (no fiber mix) with age for different percentage of RA.

The decrease of compressive strength due to increase of recycled aggregate percentage can be explained as follows:

- The recycled aggregate is covered with hardened cement paste, which is very weak layer ,so the compressive strength of recycled aggregate itself is weak .
- The hardened cement paste on recycled aggregate is high in water absorption ,consequently no enough residual water is present to complete all the quantity cement reaction .
- The shape of recycled aggregate concrete prevent sliding due to compaction, this leads to not good compaction ,consequently not well compacted concrete.
- The existence of cement paste layer on recycled aggregate prevent integration of all aggregate ,and prevent enough bond between recycled aggregate and new cement paste .
- There was some impurities in the recycled aggregate like wood, glass, bricks………..etc. which affect the bond in general adversely, *(Abed,2009).*

4.3.1.2 Indirect Tensile Strength Test:

All batches discussed before in the experimental program were prepared, cured, and tested for tensile strength at 7, 21 and 28day as shown in Figure (4-3),. Immediately after prepared cylinders, the specimens were covered to prevent water evaporation.

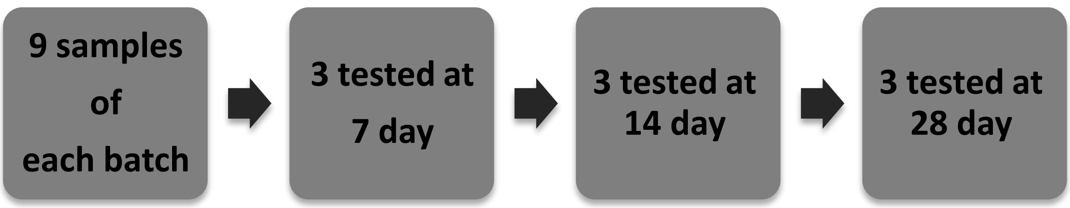


Figure 4-3: Tensile Strength evaluation chart of concrete cylinders specimens for each batch.

The split tensile test indicates a decreasing trend of split tensile strength at both 7, 14 and 28 days of curing, when the percentage of recycled aggregate is increased. A graphical representation of reduction in tensile strength of concrete is shown in Figure (4-4). The concrete specimen with 100% RA had the lowest tensile strength, which was only 2.96MPa. It is around 21% drop when compared to control concrete specimen.

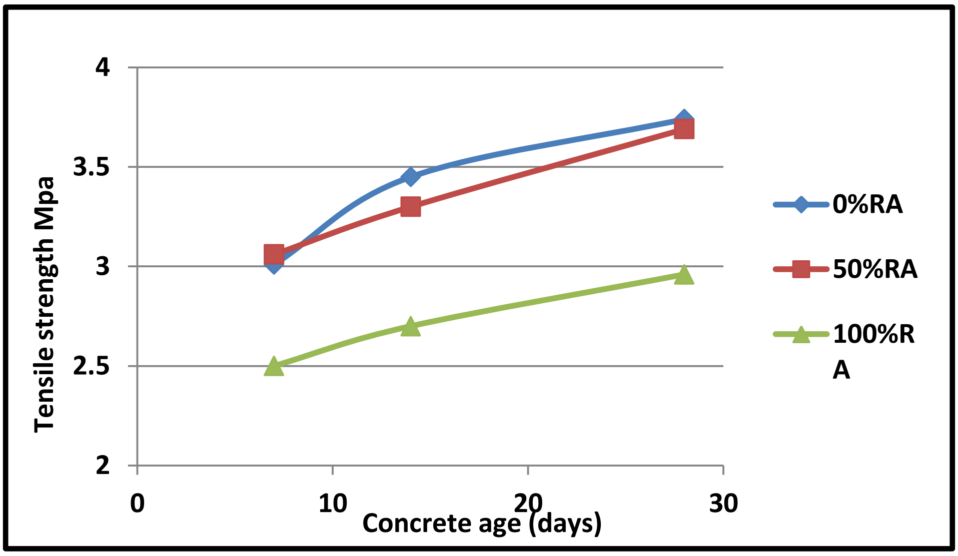


Figure 4-4: The variation of splitting strength (no fiber mix) with age for different percentage of RA.

It is observed that the failure is not only through the interface but also through the recycled aggregates. The split tensile strength of RA reduces with the increase in amount of RA. The split tensile strength of RA with replacement of 50%, 100% of RA was less than split tensile strength of control batch. Results agree with that of previous research of *Abu Shaban, (2012).*

4.3.1.3 Flexural strength Test:

A total of 27 of 150mm x 150mm x 600mm beam with three different percentages of RA volume fractions, such as 0%, 50% and 100% tested as shown in Figure (4-5). Flexural strength results of specimens are included in Table (4-7), The flexural strength trend on all FF Fiber varies when the percentage of FF Fiber and recycle aggregate increased as shown below.

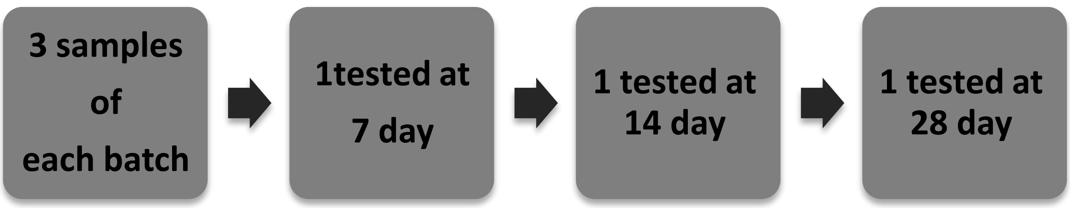


Figure 4-5: Flexural strength evaluation chart of concrete beam specimens for each batch.

The results show that the concrete specimens with more replacement of recycled aggregate have the lowest flexural strength when compared to the concrete specimens with less recycled aggregate. Figure (4-6) shows a graphical representation of reduction in flexural strength for different percentage of RA. There is a drop in flexural strength of 3% and 12% for the concrete specimens with 50% and 100% RA respectively. The same justifications of compressive strength versus percent of recycled aggregate , is valid for flexural strength. Results agree with that of previous research of *Abu Shaban, (2012).*

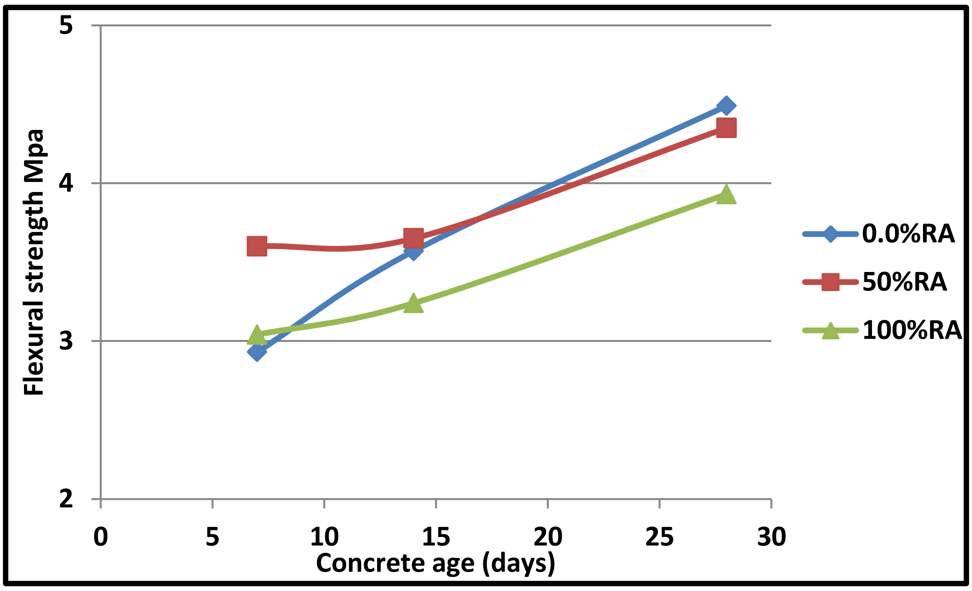


Figure 4-6: The variation of flexural strength (no fiber mix) with age for different percentage of RA.

4.3.2 Effect of using FF Fiber:

4.3.2.1 Compressive strength test results:

Three different percentages of FF Fiber volume fractions, such as 0, 0.5 and 1.0 tested. The results of compressive strength test shows that the compressive strength did not increase when the percentage of FF Fiber increased, this can be attributed to the fact that the FF Fiber in the concrete mixture reduce the cohesion with other aggregates, resulting in reducing the mechanical properties of the mix. Table (4-4) below shows the average compressive strength recorded during the test and the strength difference in percentage for all mix batches compared to control batch noted that compressive strength decrease from 32.5, 28.9 to 23.6 MPa when the percentage of FF Fiber increased from 0.0%, 0.5% to 1.0% respectively at 28 days with 100% RA.

Results agree with results obtained by *Vytlačilová (2011)*, where results showed that compressive strength decrease from 20.20, 19.73 to 17.87 MPa when the percentage of FF Fiber increased from 0.0%, 0.5% to 1.0% respectively at 28 days.

Table 4-4: Summary of compressive strength test results (MPa) and the percentage difference.

	Days	0.0% Fiber	0.5% Fiber	Percentage difference	1.0% Fiber	Percentage difference
0.0 %recycled aggregate	7	27	24	11%	23	15%
	14	30	29	3%	28	7%
	28	37	32	14%	30	19%
50 %recycled aggregate	7	24	23	4%	19	21%
	14	28	24	14%	25	11%
	28	35.5	27	24%	28	21%
100 %recycled aggregate	7	16	16	0%	15	6%
	14	27	22	19%	20	26%
	28	32.5	29	11%	23	29%

Figure (4-7,8,9) below shows a graphical representation of average compressive strength for concrete containing no FF Fiber and concrete containing different amounts of FF Fiber and recycled aggregate.

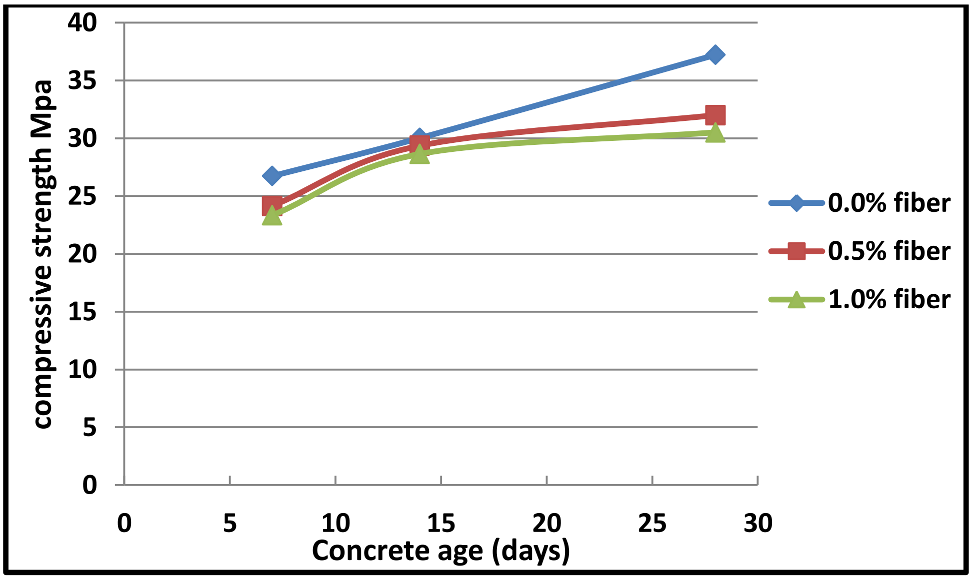


Figure 4-7: Effect of using FF Fiber on compressive strength using 0.0% recycled aggregate.

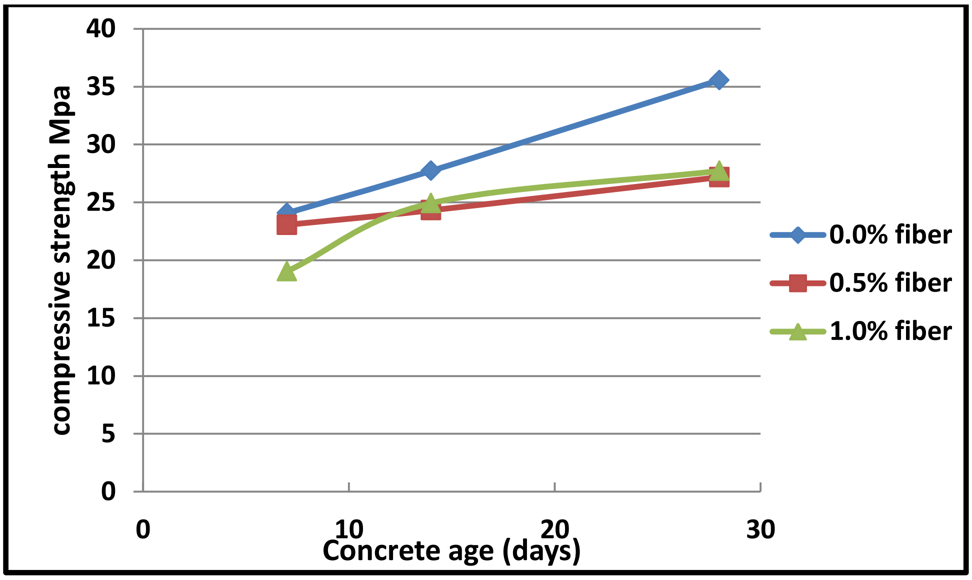


Figure 4-8: Effect of using FF Fiber on compressive strength using 50% recycled aggregate.

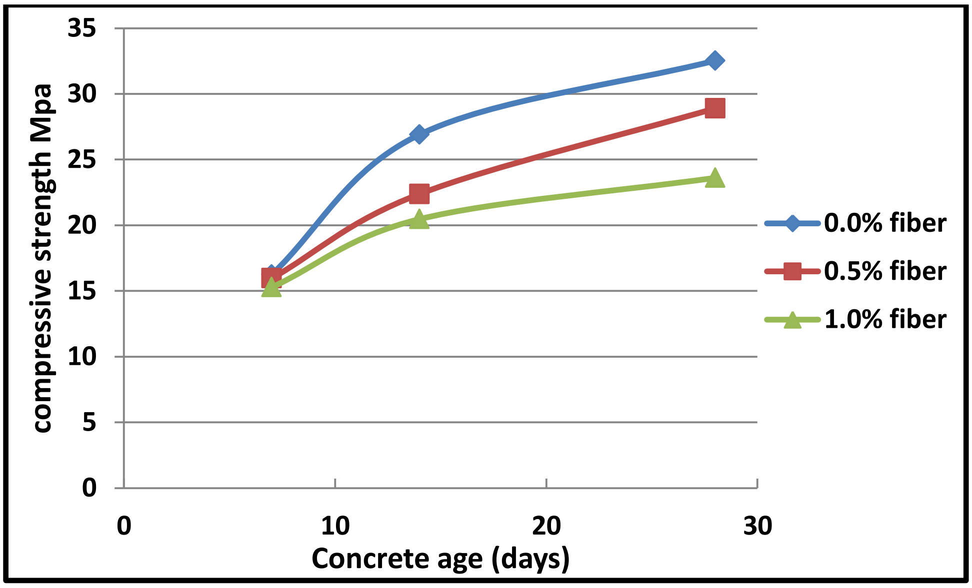


Figure 4-9: Effect of using FF Fiber on compressive strength using 100% recycled aggregate.

More importantly, the mode of failure was reported as an extremely ductile at all FF Fiber dosages as shown in Figure (4-10), instead of the conventional brittle and sudden failure. This advantage of enhanced ductility and unique failure mode is naturally a very valuable feature to designers and builders. It is clear that the FF Fiber are located in the width of formed crack and creating the connection bridges. The characteristic of FF Fiber prevent the separation of concrete pieces after cracking.

Figure 4-10: The mode of failure for compressive strength specimens.

4.3.2.2 Indirect Tensile Strength Test:

The tensile strength of FF Fiber reinforced concrete increased in indirect tensile strength test when the percentage of FF Fiber increased. Table (4-5) shows the average indirect tensile strength recorded during the test for all mix batches and the increase in tensile as a percentage compared with mix with no FF Fiber. Figure (4-8) below shows a graphical representation of average indirect tensile strength for concrete containing no FF Fiber and concrete containing different amounts of FF Fiber, Full test data details are presented in Appendix I

Table 4-5: Average indirect tensile strength for each batch (MPa) and percentage difference.

	Days	0.0% fiber	0.5% fiber	Percentage difference	1.0% fiber	Percentage difference
0.0 %recycled aggregate	7	3.01	2.96	1.7%	3.06	1.6%
	14	3.45	3.69	6.5%	4.04	14.6%
	28	3.74	4.20	11%	4.53	17%
50 %recycled aggregate	7	3.06	2.78	10%	3.01	1.7%
	14	3.3	3.45	10%	3.34	7%
	28	3.69	3.99	7.5%	4.01	8%
100 %recycled aggregate	7	2.50	2.68	7%	2.92	14%
	14	2.7	2.79	12%	3.65	33%
	28	2.96	3.54	16%	4.05	27%

It is clear that the use of FF Fiber improves the splitting strength in the range of 10% to 30%, based on the FF Fiber content and the amount of recycled aggregate. Table (4-5) shows that splitting strength increases gradually as FF Fiber content increases 17% for 0.0 % recycled aggregate, 8% for 50% recycled aggregate and 27% for 100

%recycled aggregate, The optimum FF Fiber content for splitting strength is found to be 4.5 MPa. At 7 and 14 days specimens results achieved about 70 % and 90 % of the 28-day strength respectively, as shown in Figures below. This can be attributed to the strong bond between FF Fiber and cement paste, which leads to higher increase the early strength of concrete.

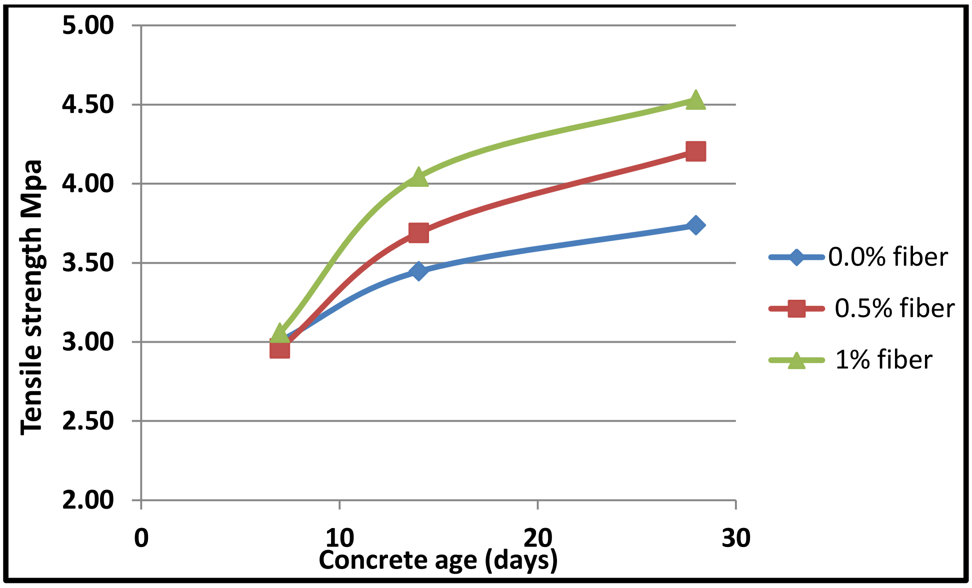
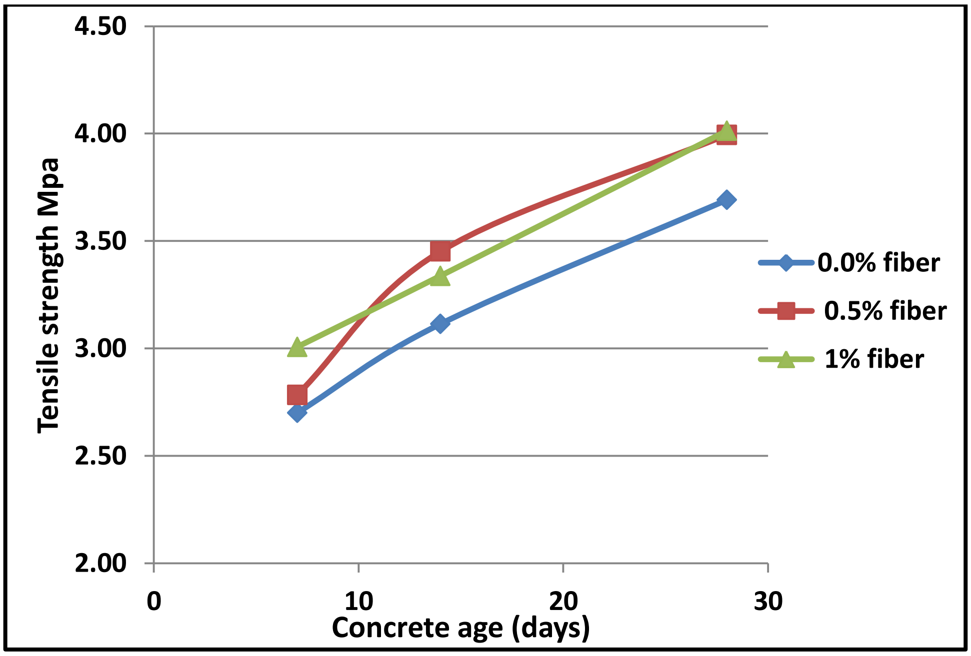


Figure 4-11: Effect of using FF Fiber on indirect tensile strength with 0.0% recycled aggregate.



4-12: Effect of using FF Fiber on indirect tensile strength with 50% recycled aggregate.

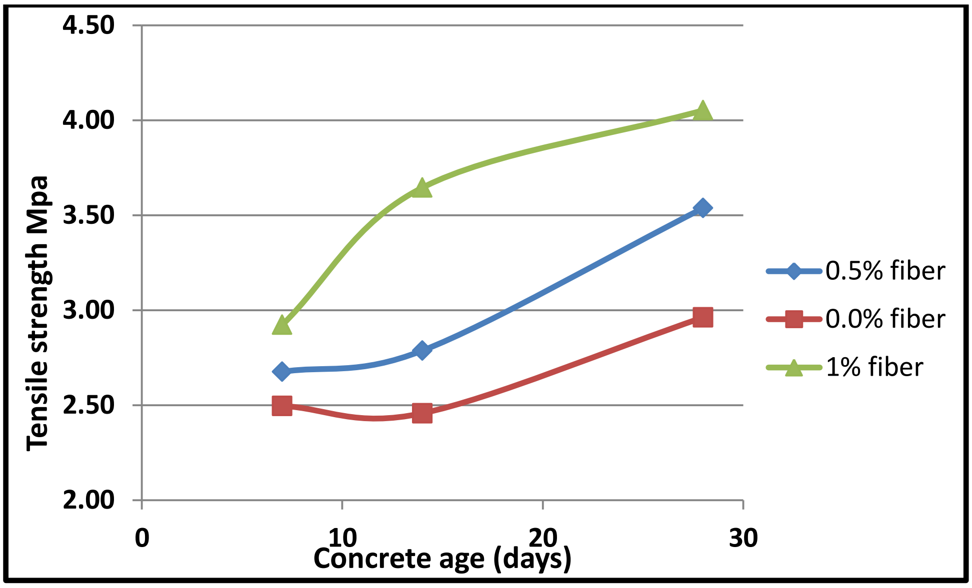


Figure 4-13: Effect of using FF Fiber on indirect tensile strength with 100% recycled aggregate.

Figures (4-11), (4-12) and (4-13) showed that the indirect tensile test results have an increasing trend of average tensile strength for all percentage of FF Fiber reinforced concrete when the FF Fiber volume dosage rate increased. It shows that the increasing trend of tensile strength is different from the compressive strength's trend. This increase in tensile strength was due to the nature of binding of FF Fiber available in concrete. When the reinforced concrete was force to split apart in the tensile strength test, the load was transferred into the FF Fiber as pullout behavior when the concrete matrix began to crack where it exceeded the pre-crack state. The control batch specimens containing no FF Fiber failed suddenly once the concrete cracked, while the fiber reinforced concrete specimens were still intact together. This shows that the FF Fiber reinforced concrete has the ability to absorb energy in the post-cracking state. Results agree with results obtained by *Vytlačilová (2011)*, where results showed that indirect tensile strength increase from 1.58 to 1.7 MPa when the percentage of FF Fiber increased from 0.0% to 1.0% respectively.

Enhancement in split tensile strength is expected with increasing the fiber proportion since the plane of failure is well defined (diametric). The higher the number of fibers bridging on the diametrical splitting' crack, the higher would be the split tensile strength. Non-fiber specimens tested for ' splitting tensile strength typically split into two or more sections at failure as shown in Figure (4-14). These tests are performed until failure and the maximum load is recorded.

Figure 4-14: Splitting Tensile Strength Tests Results for Plain Concrete.

Although the FR Concrete cylinders split down at vertical diameter of the specimen as do the plain concrete cylinders, the FR Concrete specimens do not fully break apart due to the presence of FF Fiber as shown in Figure (4-15).

Figure 4-15: Splitting Tensile Strength Test Results for FR Concrete.

4.3.2.3 Flexural strength Test:

The results showed that the use of FF Fiber improves the flexural strength in the range of 16%-26% based on the fiber content. Table (4-6) shows that the flexural strength increases slowly at FF Fiber content from 0.0% to 1.0%. This is due to contribution FF Fiber to undertake the tensile load before fracture of the samples. In addition, the existence of FF Fiber delays the growth of micro cracks and thereby improving the ultimate tensile stress capacity.

Table 4-6: The flexural strength of the fibrous and non-fibrous mixes (Mpa).

	Days	0.0% fiber	0.5% fiber	1.0% fiber
0.0 %recycled aggregate	7	2.93	3.68	3.28
	14	3.57	4.04	3.80
	28	4.49	4.12	4.51
50 %recycled aggregate	7	3.60	3.25	3.39
	14	3.65	3.48	3.80
	28	4.09	3.07	4.20
100 %recycled aggregate	7	3.04	2.64	3.03
	14	3.24	2.81	3.15
	28	3.93	2.98	4.08

Figures (4-16),(4-17) and (4-18) show the details of flexural strength for concrete for different replacement of recycled aggregate, with no FF Fiber, 0.5% and 1.0% additions. There is a various in flexural strength of fibrous concrete at all percentage replacements of recycled aggregate as compared to no FF Fiber concrete. A decreasing trend of flexural strength happens when the FF Fiber volume dosage rate less than 0.5%, but, an increasing trend of flexural strength developed for 0.5% to 1.0% FF Fiber volume dosage. However, all recycle aggregate percent tends to have similar behavior of the flexural strength, where an average of 4.51 Mpa for 1.0% FF Fiber reinforced concrete.

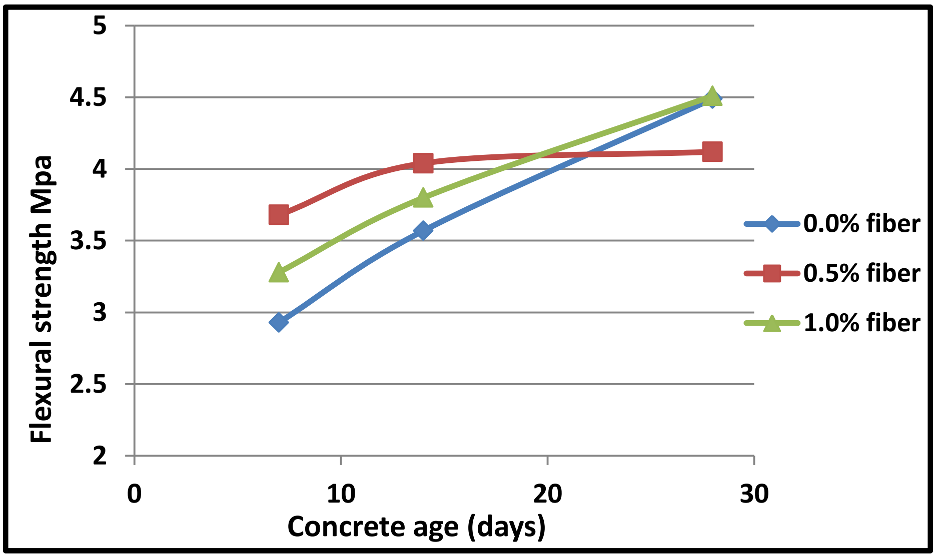


Figure 4-16: Effect of using FF Fiber on flexural strength using 0.0% recycled aggregate.

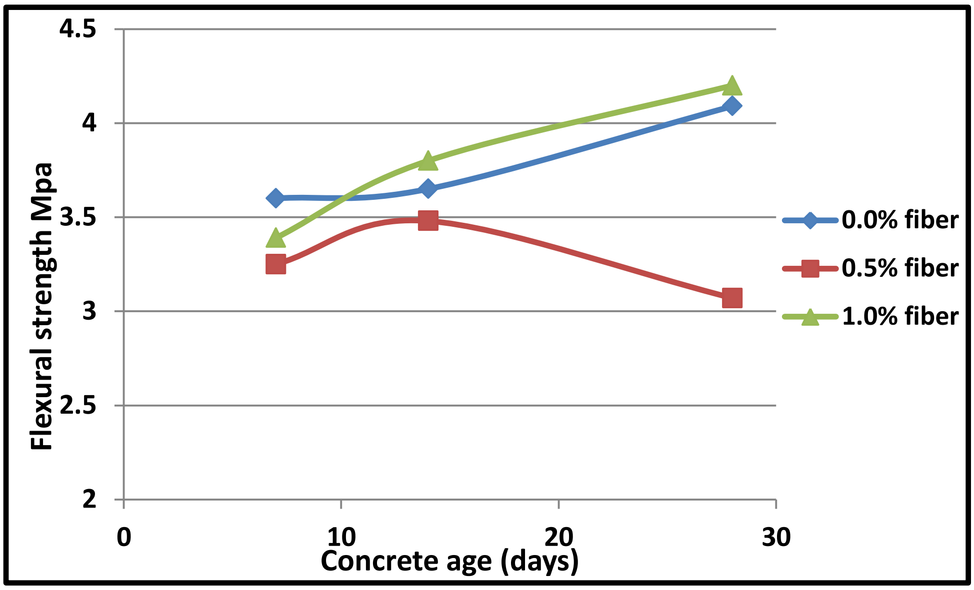


Figure 4-17: Effect of using FF Fiber on flexural strength using 50% recycled aggregate.

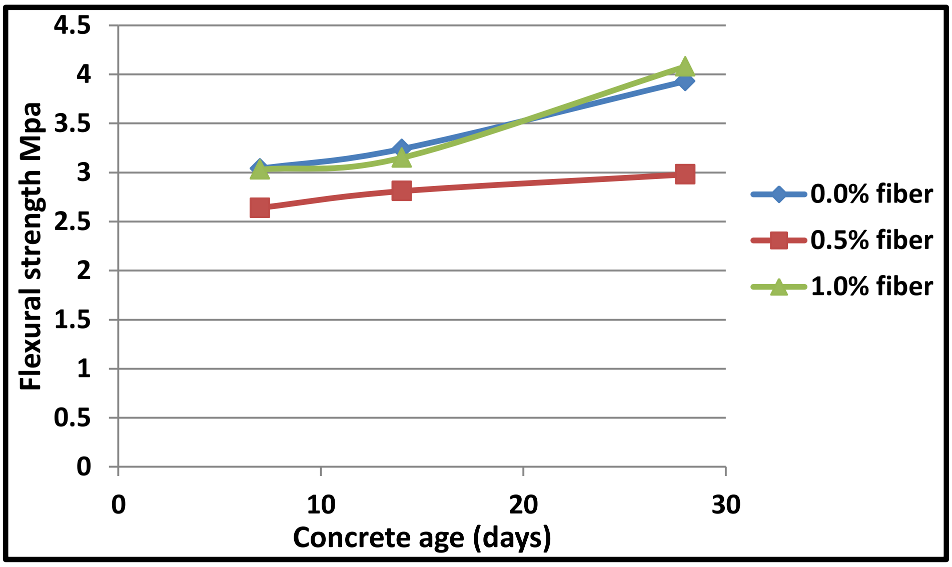


Figure 4-18: Effect of using FF Fiber on flexural strength using 100% recycled aggregate.

In general, a high degree of variability was exhibited by the specimens tested. The location of the crack had a large effect on the cracking load and the post-cracked peak load. The closer the crack was to the mid-span of the specimen, the higher the cracking and peak loads in the two point bending condition.

The Figure (4-19) showed the flexural strength of the concrete corresponding to the increase in the amount of FF Fiber applied to the concrete. First it indicated that decrease of flexural strength were occurred as the FF Fiber content was increased, then increase of flexural strength were occurred as the FF Fiber volume dosage rate was increased. Furthermore, it shows the general upward trend in the flexural strength from 0.5% to 1.0% stage for all amount of recycled aggregate. When FF Fiber was added into the concrete, it shows that the concrete has the ability to carry more strength compare to control batch concrete. Results agree with results obtained by *Vytlačilová (2011)*, where results showed that flexural strength was 2.09, 1.81 and 2.16 MPa when the percentage of FF Fiber increased from 0.0%, 0.5% and 1.0% respectively.

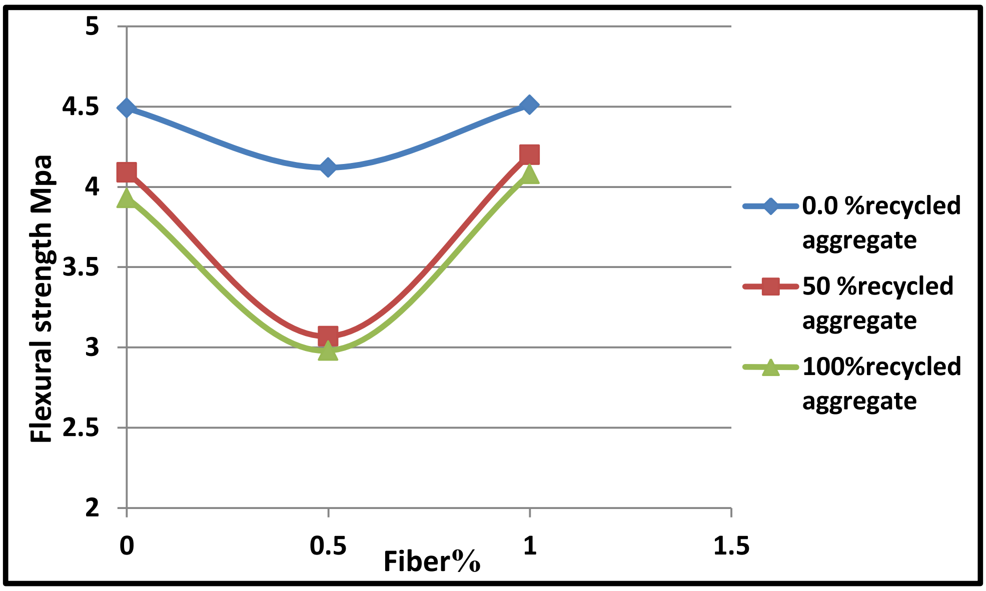


Figure 4-19: Variation of Flexural strength after 28 days.

The concrete specimens containing no FF Fiber were cracked and failed in brittle condition when it reached the ultimate strain in the concrete. However, FF Fiber reinforced concrete also cracked at ultimate strain, but it is capable to carry the load well after the crack developed on the concrete. This indicates that the fiber recycled concrete has the ability to hold on the crack of the concrete and preventing the concrete beam to fall apart. Figure (4-20) showed the crack developed in concrete containing no FF Fiber and FR Concrete. The test showed that the FR Concrete beams were still intact together. The addition of FF Fiber to the mix controlled the abrupt opening of the failure crack. In all cases, the FR Concrete specimens exhibited an ability to carry residual flexural loads after first cracking and the load-carrying capacity decreased steadily and gradually as the crack continued to open. The load-deflection curves for the test sets are presented in Figure (4-21), Full test data are presented in Appendix I.

Figure 4-20: The mode of failure for flexural strength specimens.

4.3.3 Load - Deflection relationship

It is obvious from the results that the curvature ductility directly related to the FF Fiber volume concentration as shown in Load – Deflection diagrams of tested specimens with RA. Volume of ductility of composites is evident in presented figures of Load – Deflection Diagrams for 0,5% and 1,0% FF Fiber. The new material has higher tensile strength and ductility and improves behavior of the structural element in comparison to ordinary concrete.

Table 4-7: Load – Deflection table for 100% Natural Aggregates - 28 day Results.

0.0% FF Fiber		0.5% FF Fiber		1.0% FF Fiber	
Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
0	0	0	0	0	0
4.6	0.28	4.6	0.5	4.6	0.5
6.9	0.5	6.9	0.7	6.9	0.7
9.2	0.6	9.2	0.9	9.2	0.9
13.8	0.73	11.5	1.1	11.5	1.1
16.1	0.9	13.8	1.32	13.8	1.32
18.4	1	16.1	1.5	16.1	1.5
20.7	1.1	18.4	1.68	18.4	1.68
23	1.26	20.7	1.9	20.7	1.9
27.4	1.40	23.0	2.1	23.0	2.1
33.67	1.46	27.4	2.3	27.4	2.3
-	-	30.9	2.6	30.9	2.6
-	-	-	-	33.82	2.7

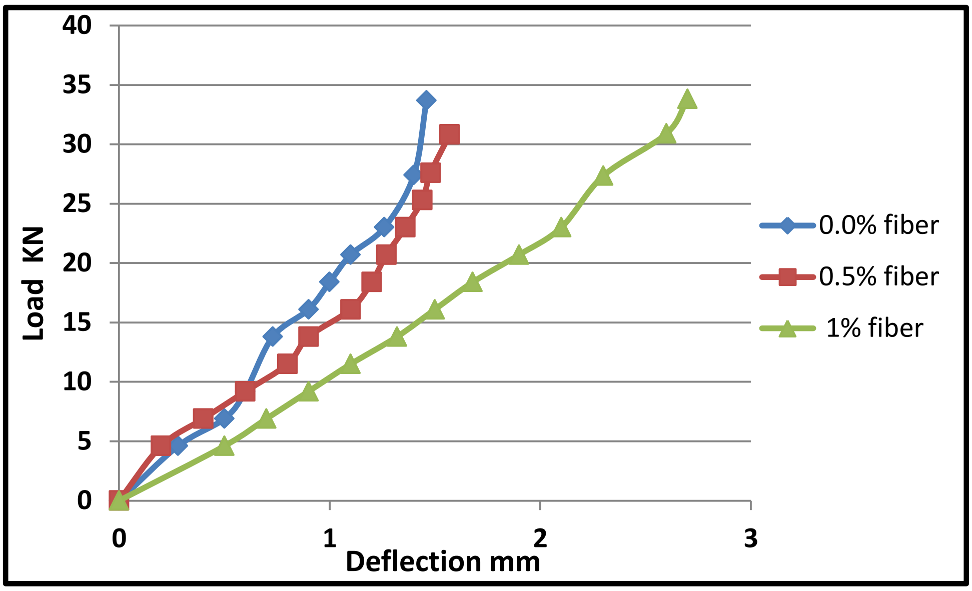


Figure 4-21: Load – Deflection curve for 100% Natural Aggregates - 28 day Results.

Table 4-8: Load – Deflection table for 50% Natural Aggregates - 28 day Results.

0.0% FF Fiber		0.5% FF Fiber		1.0% FF Fiber	
Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
0	0	0	0	0	0
4.6	0.20	4.6	0.21	4.6	0.20
6.9	0.33	6.9	0.4	6.9	0.41
9.2	0.43	9.2	0.56	9.2	0.55
11.5	0.52	11.5	0.71	11.5	0.63
13.8	0.59	13.8	0.88	13.8	0.80
16.1	0.72	16.1	1.01	16.1	0.95
18.4	0.76	18.4	1.1	18.4	1.07
21.62	0.79	20.7	1.19	20.7	1.18
23.8	0.83	22.33	1.5	23.0	1.25
25.4	0.86	-	-	25.3	1.34
27.7	0.91	-	-	28.5	1.47
30.3	0.97	-	-	31.5	1.50
32.6	1.03	-	-	-	-

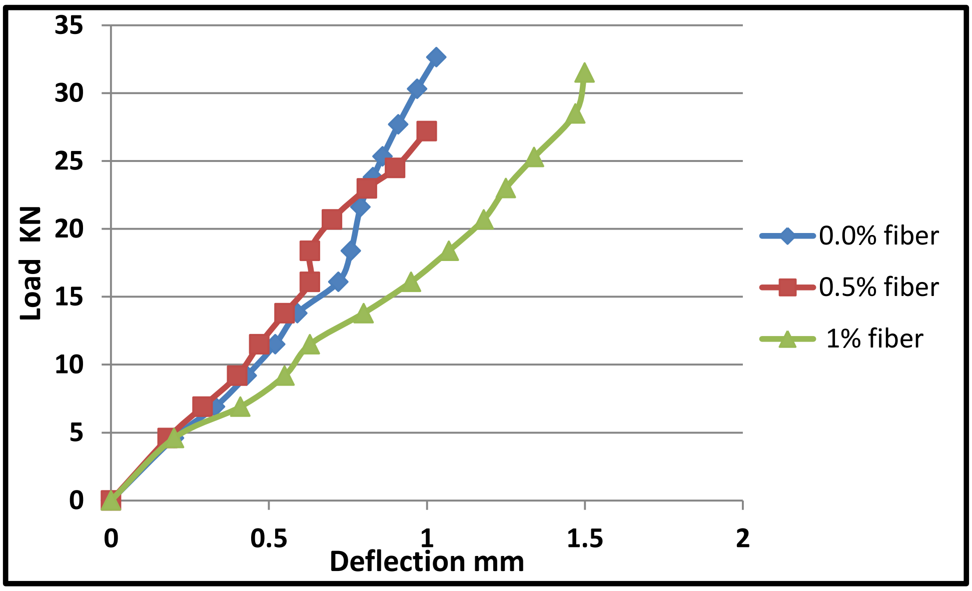


Figure 4-22: Load – Deflection curve for 50% Natural Aggregates - 28 day Results.

Table 4-9: Load – Deflection table for 0.0% Natural Aggregates - 28 day Results.

0.0% FF Fiber		0.5% FF Fiber		1.0% FF Fiber	
Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
0	0	0	0	0.0	0
4.6	0.19	4.6	0.21	4.6	0.23
6.9	0.29	6.9	0.4	6.9	0.47
9.2	0.4	9.2	0.56	9.2	0.65
11.5	0.47	11.5	0.71	11.5	0.86
13.8	0.52	13.8	0.88	13.8	1.00
16.1	0.64	16.1	1.01	16.1	1.13
18.4	0.7	18.4	1.1	18.4	1.31
20.7	0.82	20.7	1.19	20.7	1.54
23.0	0.94	22.33	1.5	22.33	1.7
25.3	1.27	-	-	24.7	1.9
27.6	1.50	-	-	28.3	2.00
29.5	1.7	-	-	30.6	2.2

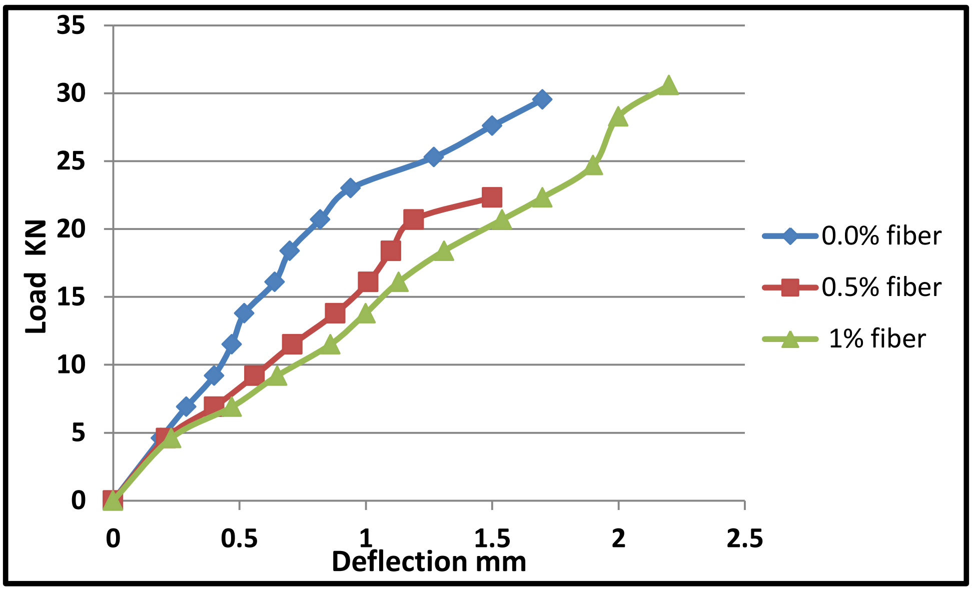


Figure 4-23: Load – Deflection curve for 0.0% Natural Aggregates - 28 day Results.

It is obvious from the results that the curvature ductility directly related to the FF Fiber volume concentration as shown in Load – Deflection diagrams of tested specimens with recycled aggregate. Volume of ductility of composites is evident in above presented figures of Load – Deflection Diagrams for 0,5% and 1,0% FF Fiber. The new material has higher tensile strength and ductility and improves behavior of the structural element in comparison to ordinary concrete.

The load-deflection curve for specimen with high FF Fiber volume fraction was elastic-plastic with a transition zone. No significant drop in the load was observed after first crack. The specimen shows large numbers of fine cracks before failure. After cracking, the FF Fiber play major role in deformation. It was observed that the performance of both concrete types (with and without FF Fiber) is very similar until first crack load is reached. The curve for concrete without FF Fiber finished when the specimen showed the first crack. However, FF Fiber specimen allows much higher strain and is able to resist increasing loads after the first crack.

Chapter 5
Conclusions and recommendations

This chapter was set out to draw conclusions on the properties tests where it is used to assess the mechanical properties of FR Concrete. Moreover, the achievement of the project objectives (scopes) set at beginning of the research was also achieved. Finally, recommendations for further studies were suggested with the usage of the fibers in concrete to study its mechanical properties in more details.

5.1 The project achievements are as follows:

- In this work, the review for research of current usage to the use of fibers in the concrete was done sectors, such as constructions, industries, previous research and investigation.
- Batches of concrete mixes with 189 sample were tested, which included the 3 percentage of recycled aggregate (0.0%, 50% and 100%) with various fiber volumes (0.0% 0.5%, and 1.0%) .
- Most importantly, this research found that the fibers have large influence on the mechanical properties of concrete, especially on the workability, indirect tensile strength and flexural strength. It was found that the fibers have moderately increased the flexural strength and tensile strength.
- By the completion of this research, considerable experience was acquired in the handling, application, testing of the specimens and analyzing of the test result.

5.2 Conclusion:

This research undergoes on the use of fibers in structural concrete altering the mechanical properties of the concrete. It shows that effects of several volume of fibers and several percentages of recycled aggregate may involve and varies workability, indirect tensile strength and flexural strength.

The results of the experiments proved an unambiguously positive influence of the synthetic fibers. From the analysis of the mechanical-physical properties and behavior of composites, the following preliminary conclusions can be drawn:

- Aggregate waste material can be recycled and experiments testify that utilization of recycled concrete with fibers in every-day life is possible. It is useful without plasticizer and other admixtures. Suitable technology of construction material recycling could be considered an easy alternative for future applications. The recycling of this waste will reduce environmental damages caused by incorrect disposal, extend the useful life of landfills and preserve finite natural resources.

- In all trial mixtures, where the W/C was constant and equal to 0.45, no segregation was observed and all mixtures were homogenous and fibers were well distributed through every batch.
- The presence of fibers in concrete improves the failure mode of material. It is found that the failure mode of plain concrete is mainly due to spalling, while the failure mode of fiber concrete is bulging in transverse directions.
- Compressive strength of material did not increase when the percentage of fiber increased. With replacement of recycled aggregate the compressive strength has decreased but was always above the target strength.
- Strength enhancement in splitting tensile strength due to fiber addition varies from 10% to 30%. Split tensile strength at 28'days is approximately 19% higher than 7 day's strength.
- Indirect tensile test indicates a decreasing trend of indirect tensile strength when the percentage of recycled aggregate increased.
- During the test it was visually observed that the fiber recycled concrete specimen has grater crack control as demonstrated by reduction in crack widths and crack spacing. The flexural strength increases with increasing fiber content.
- Flexural strength decreases as the percent of recycled aggregate increases and the flexural strength is well proportioned to compressive strength .

As the concrete is a fundamental material in the field of construction engineering, the improvement of its mechanical properties by the addition of this fiber will certainly increase the use of this composite material which will offer more strong and durable structures in the future and will open a new era in the field of construction materials. RA with FF Fiber may be suitable mainly for newly built road and water management earth structures with a limited appearance and occurrence of cracks (consolidation of slopes, embankments, dam crest trenches) and also for road pavement layers, layers of industrial floors and multipurpose halls, for the construction of diverse utility services, parking places, sports grounds etc.

5.3 Recommendation for further studies:

In order to determine whether fibers can partly or entirely substitute ordinary reinforcement, more full scale tests with considerable amounts of fibres are needed. Experiments on strain hardening materials should also be considered, if fibers are to entirely replace ordinary reinforcement.

Studies are continuing with the aim of obtaining more information about concretes made with RA and reinforced with FF Fiber. This will show more definitive trend of the effect of the level of replacement primary aggregates on the properties concretes. The experimental results indicate that it is viable to produce concrete made with recycled concrete or masonry aggregates as full replacement of natural aggregate suitable for structural concrete.

Further investigations were highly recommended and should be carried out to understand more mechanical properties of fiber reinforced concrete. Several recommendations for further studies are mentioned below:

- The problem on the workability of the fresh fiber reinforced concrete can be reduced by adding chemical admixture such as superplasticiser, silica fume or blast furnace slag. Hence, with high workable fresh concrete can demote the quick stiffening effects from the fibers.
- More investigations and laboratory tests should be done to study the mechanical properties of fiber reinforced concrete. Such application of fibers was recommended in testing concrete slabs, beams and walls or conducting more tests such as abrasion, impact, blasting, shatter, shear or creeping of concrete.
- The combination of short fibers may tend to provide more efficient mechanical properties of structure. Further investigation can be carried out by combination of different types of short fibers into the concrete mix.
- To widen the use of fiber reinforced concrete, different or more complicated geometry of fiber can be used to investigate the effects of short fibers in the concrete through fresh and hardened properties.

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APPENDIX I

Results

Table 1: Compressive strength test results (Kg/cm²) for 0.0 %recycled aggregate.

	0.0% fiber				0.5% fiber				1% fiber			
	1	2	3	average	1	2	3	average	1	2	3	average
7day	271.3	259.7	270.7	267	237	245	242.3	241.4	252	230.4	217.3	233.2
14day	306.3	301	293.3	300	281.5	305.9	293.2	293.5	274.8	291.9	292.5	286.4
28day	371.1	368.2	377.1	372	324.2	318.4	317.4	320.0	312.1	299.6	303.6	305.1

Table 2: Compressive strength test results (Kg/cm²) for 50 %recycled aggregate.

	0.0% fiber				0.5% fiber				1% fiber			
	1	2	3	average	1	2	3	average	1	2	3	average
7day	239.2	237.7	245.5	240.8	235.3	226.7	229.9	230.6	192.7	192.3	186.2	190.4
14day	282.2	278.1	271.3	277.2	243.2	238.3	248	243.2	249.2	250	248.7	249.3
28day	365.4	348	353.4	355.6	270.3	280.8	264.1	271.7	266.9	285.3	279.3	277.2

Table 3: Compressive strength test results (Kg/cm²) for 100 %recycled aggregate.

	0.0% fiber				0.5% fiber				1% fiber			
	1	2	3	average	1	2	3	average	1	2	3	average
7day	157.4	164.8	165.1	162.4	157.9	151.4	169.4	159.6	148.8	155.2	154.4	152.8
14day	274.9	265.8	266.5	269.1	231	222	218.4	223.8	202.7	202.3	209	204.7
28day	316.1	322.2	337.6	325.3	283.1	293.2	290.7	289.0	240.6	227.8	239.9	236.1

Table 4: Indirect tensile strength test results (MPa) for 0.0 %recycled aggregate.

	0.0% fiber				0.5% fiber				1% fiber			
	1	2	3	average	1	2	3	average	1	2	3	average
7day	222.2	203.5	211.8	2.77	210	209.6	207.9	2.96	215	230.8	202.8	3.06
14day	229.6	269.4	231.6	3.45	260.1	266.7	255.5	3.69	303.4	270	284.1	4.04
28day	260.8	264.5	267.1	3.74	298.3	288.1	305	4.20	322.6	314.4	323.8	4.53

Table 5: Indirect tensile test results (MPa) for 50 %recycled aggregate.

	0.0% fiber				0.5% fiber				1% fiber			
	1	2	3	average	1	2	3	average	1	2	3	average
7day	210.8	224.7	213.9	3.06	193.7	199.2	197.3	2.78	202.2	215	220.4	3.01
14day	220.4	227.3	212.6	3.11	238.5	247.9	245.5	3.45	230.6	238.6	238.6	3.34
28day	258.8	252.2	271.8	3.69	293.2	283.2	270.6	3.99	289	276.1	285.9	4.01

Table 6: Indirect tensile test results (MPa) for 100 %recycled aggregate.

	0.0% fiber				0.5% fiber				1% fiber			
	1	2	3	average	1	2	3	average	1	2	3	average
7day	188	180.6	198.9	2.68	173.5	175.5	180.4	2.50	214.7	198	207.1	2.92
14day	200.6	202.8	187.8	2.79	176.5	170.6	174.1	2.46	260.2	257.5	255.5	3.65
28day	239.4	254.3	256.5	3.54	215.9	202.9	209.4	2.96	288	289	282.4	4.05

Table 7: Load – Deflection for 100% Natural Aggregates.

7 day Results		14 day Results		28 day Results	
Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
0.0% Fiber					
0	0	0	0	0	0
4.6	0.2	4.6	0.19	4.6	0.28
6.9	0.3	6.9	0.24	6.9	0.5
9.2	0.35	9.2	0.32	9.2	0.6
11.5	0.4	13.8	0.43	13.8	0.73
13.8	0.45	16.1	0.55	16.1	0.9
16.1	0.5	18.4	0.64	18.4	1
18.4	0.65	20.7	0.67	20.7	1.1
20.7	0.8	23	0.74	23	1.26
22	0.92	26.8	0.78	27.4	1.40
-	-	-	-	33.67	1.46
0.5% Fiber					
0	0	0	0	0	0
4.6	0.2	4.6	0.15	4.6	0.5
6.9	0.4	6.9	0.28	6.9	0.7
9.2	0.5	9.2	0.39	9.2	0.9
11.5	0.58	11.5	0.51	11.5	1.1
13.8	0.65	13.8	0.6	13.8	1.32
16.1	0.74	16.1	0.69	16.1	1.5
18.4	0.82	18.4	0.74	18.4	1.68
20.7	0.9	20.7	0.82	20.7	1.9
23	0.98	23.0	0.85	23.0	2.1
25.3	1.05	25.3	0.96	27.4	2.3
27.6	1.12	27.6	1.02	30.9	2.6
-	-	30.3416	1.100	-	-
1.0% Fiber					
0	0	0	0	0	0
4.6	0.18	4.6	0.25	4.6	0.2
6.9	0.31	6.9	0.47	6.9	0.4
9.2	0.42	9.2	0.6	9.2	0.6
11.5	0.53	13.8	0.7	11.5	0.8
13.8	0.63	16.1	0.82	13.8	0.9
16.1	0.71	18.4	0.89	16.1	1.1
18.4	0.8	20.7	1.07	18.4	1.2
20.7	0.88	28.5	1.57	20.7	1.27
23	0.95	-	-	23.0	1.36

24.5	1.08	-	-	25.3	1.44
-	-	-	-	27.6	1.48
-	-	-	-	30.82	1.570
-	-	-	-	33.82	1.6

Table 8: Load – Deflection for 50% Natural Aggregates.

7 day Results		14 day Results		28 day Results	
Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
0.0% Fiber					
0	0	0	0	0	0
4.6	0.13	4.6	0.2	4.6	0.20
6.9	0.25	6.9	0.4	6.9	0.33
9.2	0.35	9.2	0.58	9.2	0.43
11.5	0.42	11.5	0.73	11.5	0.52
13.8	0.51	13.8	0.88	13.8	0.59
16.1	0.6	16.1	1	16.1	0.72
18.4	0.65	18.4	1.11	18.4	0.76
20.7	0.69	20.7	1.21	21.6	0.79
23	0.77	23.0	1.29	23.8	0.83
25.3	0.84	25.03	1.36	25.4	0.86
26.9	0.86	26.7	-	27.7	0.91
-	-	27.4	-	30.3	0.97
-	-	-	-	32.6	1.03
0.5% Fiber					
0	0	0	0	0	0
4.6	0.25	4.6	0.2	4.6	0.18
6.9	0.34	6.9	0.33	6.9	0.29
9.2	0.42	9.2	0.47	9.2	0.40
11.5	0.5	11.5	0.51	11.5	0.47
13.8	0.5	13.8	0.63	13.8	0.55
16.1	0.58	16.1	0.72	16.1	0.63
18.4	0.65	18.4	0.81	18.4	0.63
20.7	0.73	20.7	0.9	20.7	0.70
24.38	0.78	23	0.97	23.0	0.81
-	-	25.3	1.04	24.5	-
-	-	26.1	1.07	27.2	-
1.0% Fiber					
0	0	0	0	0	0
4.6	0.15	4.6	0.6	4.6	0.20
6.9	0.32	6.9	0.8	6.9	0.41
9.2	0.43	9.2	1	9.2	0.55

11.5	0.57	11.5	1.1	11.5	0.63
13.8	0.66	13.8	1.15	13.8	0.80
16.1	0.77	16.1	1.2	16.1	0.95
18.4	0.86	18.4	1.3	18.4	1.07
25.4	0.95	20.8	1.38	20.7	1.18
-	-	28.5	1.4	23.0	1.25
-	-	-	-	25.3	1.34
-	-	-	-	28.5	1.47
-	-	-	-	31.5	1.50

Table 9: Load – Deflection for 0.0% Natural Aggregates.

7 day Results		14 day Results		28 day Results	
Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)	Load (KN)	Deflection (mm)
0.0% Fiber					
0	0	0	0	0	0
4.6	0.2	4.6	0.23	4.6	0.19
6.9	0.4	6.9	0.37	6.9	0.29
9.2	0.5	9.2	0.48	9.2	0.4
11.5	0.67	11.5	0.6	11.5	0.47
13.8	0.8	13.8	0.7	13.8	0.52
16.1	0.9	16.1	0.77	16.1	0.64
18.4	0.95	18.5	0.85	18.4	0.7
20.7	1.03	21.2	0.92	20.7	0.82
22.8	1.1	22.2	0.95	23.0	0.94
-	-	24.3	1.1	25.3	1.27
-	-	-	-	27.6	1.50
-	-	-	-	29.5	1.7
0.5% Fiber					
0	0	0	0	0	0
4.6	0.16	4.6	0.19	4.6	0.21
6.9	0.31	6.9	0.29	6.9	0.4
9.2	0.43	9.2	0.4	9.2	0.56
11.5	0.55	11.5	0.47	11.5	0.71
13.8	0.65	13.8	0.52	13.8	0.88
16.1	0.76	16.1	0.64	16.1	1.01
18.6	0.85	18.4	0.7	18.4	1.1
19.7	1.18	20.7	0.82	20.7	1.19
-	-	21.2	1.09	22.3	1.5
1.0% Fiber					
0	0	0	0	0.0	0
4.6	0.22	4.6	0.21	4.6	0.23
6.9	0.43	6.9	0.4	6.9	0.47

9.2	0.6	9.2	0.56	9.2	0.65
11.5	0.75	11.5	0.71	11.5	0.86
13.8	0.82	13.8	0.88	13.8	1.00
16.1	0.92	16.1	1.01	16.1	1.13
18.4	1.03	18.4	1.1	18.4	1.31
22.724	1.25	20.7	1.19	20.7	1.54
-	-	23.6118	1.28	22.33	1.7
-	-	-	-	24.7	1.9
-	-	-	-	28.3	2.00
-	-	-	-	30.6	2.2

APPENDIX II

Superplastisizers

Super Flow B.D.

Supe Flow B.D. is a hydroxylated polymer blended with lignosulphonic acid family.

USES :

Super Flow B.D. can be used with all types of Portland cement and/or blast furnace slag cements with fly ash, pozzolan, fillers fume-silica etc…

However the diversity of these cements is such that site trials will ensure the best results.

For other cements our Technical Department should be consulted as a precaution.

Super Flow B.D. is mainly used in the following fields:

- Ready-mix concretes
- Highly-reinforced concretes
- Industrial floors
- Prestressed concretes
- Heavy precast concretes

ADVANTEGES:

- Flowing concrete is obtained from concretes with a dry or plastic consistency without adding water.
- Important water reduction is obtained while concretes keep the same workability.
- Setting time, shrinkage remains practically unchanged.
- Optimization of cement content to get desired mechanical strengths.
- Safe with prestressed concrete.

STANDARDS:

Super Flow B.D complies with many standards including:

- ASTM C494 Type B&D.
- BS 5075 part 1 and part 3.
- NF P 18103, 18333 and 18336.

SPECIFICATIONS:

Form: brown liquid

Specific Gravity: 1.18 (=/-0.01) kg/dm3 a 200 C.

pH: 7(+/-1)

Freezing Point: -20 C approx.

Chloride content: nil

PROPERTIES:

- FRESH CONCRETRE

Thanks to its dispersing action on the cement and other fine particles contained in concrete, Super Flow B.D. is used to produce flowing concretes.

When concrete composition has been correctly determined, there is no segregation.

Conversely, high water reductions can be obtained at equal workability.

- HARDENED CONCRETES

The mechanical strengths of flowing and primary concretes are not changed as a result of using **Super Flow B.D.**

Increased mechanical strengths: increases of over 30% can be obtained when water is reduced at equal workability.

CEMENT SAVINGS

The physico-chemical properties of **Super Flow B.D**. allows he user to optimize the cement content when a specified mechanical strength is requested.

DIRECTIONS FOR USE

- DOSAGE

Site trails should be conducted to determine the best dosage for the purpose under site conditions.

However, as a guide, the rate of addition is in the range of 0.6-1.0 Kg/100kg of Cement.

- Other Parameters for Use

The composition of the concrete to be fluidified has to be established carefully; the grain size range must contain more fines than in the standards concretes and be of the concrete type.

PACKAGING

1000 liter bulks.

STORAGE

The quality is guaranteed for 18 months from the manufacturing date, provided the product is kept sealed in its original packaging.

The storage temperature should exceed 00 C.

TECHNICAL ASSISTANCE

Our company can, when requested by one of our representatives, provide technical consulting and on-site assistance More technical data and guidance can be given on request.

Information contained in this document is given to the best of our knowledge and based on extensive testing. In no event can it be considered as a warranty, involving our liability incase of misapplication. A trial before application will ensure that the product conforms to the required conditions for use.

Chloride: Nil means no chloride has been introduced in the product and the chloride content in inferior to 0.1%. Our specialists will assist in solving any difficulties encountered by the user.

Precautions

- Health and Safety instructions

Super Flow B. D. is non-toxic. Any splashes on the skin shouldbe washed immediately with water. Splashes on the eyes should be washed immediately with water and medical advice should be sought.

- Fire

Super Flow B.D. is nonflammable.

APPENDIX III

FORTA-FERRO®

FORTA®

FACT-DATA©

MANUFACTURER

FORTA CORPORATION, 100 Forta Drive, Grove City, PA,
U.S.A., 16127-6399
TELEPHONE: 1-800-245-0306, (724) 458-5221;
FAX: (724) 458-8331; **www.forta-ferro.com**

GENERAL DESCRIPTION

FORTA-FERRO® is an **easy to finish**, color blended macrosythetic fiber, made of 100% virgin copolymer/ polypropylene consisting of a twisted bundle non-fibrillating monofilament and a fibrillating network fiber, yielding a high-performance concrete reinforcement system. **FORTA-FERRO®** is used to reduce plastic and hardened concrete shrinkage, improve impact strength, and increase fatigue resistance and concrete toughness. This **extra heavy-duty** macrosynthetic fiber offers maximum long-term durability, structural enhancements, and effective secondary/temperature crack control by incorporating a truly **unique synergistic fiber system** of long length design. **FORTA-FERRO® is non-corrosive, non-magnetic, and 100% alkali proof!**

APPLICATIONS

FORTA-FERRO® is mainly used with performance concrete applications such as industrial floors, bridge decks, shotcrete, loading docks, precast products – anywhere that steel reinforcement reduction or replacement is the objective. Contact FORTA Corporation for design assistance.

INSTALLATION

Recommended dosage rate of **FORTA-FERRO®** is **0.2% to 2.0% by volume of concrete** (3 to 30 lbs. per cubic yard) added directly to the concrete mixing system during, or after, the batching of the other ingredients and mixed at the time and speed recommended by the mixer manufacturer (usually four to five minutes).

PHYSICAL PROPERTIES

Materials	Virgin Copolymer/Polypropylene	Color	Gray
Form	Monofilament/Fibrillated Fiber System	Acid/Alkali Resistance	Excellent
Specific Gravity	0.91	Absorption	Nil
Tensile Strength	83-96 ksi. (570-660 MPa)	Compliance	A.S.T.M. C-1116
Length	2.25" (54mm), 1.5" (38mm)	Compliance	A.S.T.M. D-7508

AVAILABILITY

FORTA-FERRO® can be purchased from FORTA Corporation or an authorized FORTA® products distributor, dealer or representative.

PACKAGING

Convenient incremental pound or kilogram mixer-ready bag packaging.

WARRANTY

FORTA® products are warranted to be free of defects in material and meet all quality control standards set by the manufacturer. FORTA Corporation specifically disclaims all other warranties, express or implied. The exclusive remedy for defective product shall be to replace the product or refund the purchase price. No agent or employee of this company is authorized to vary the terms of this warranty notice. FORTA Corporation has no control over the design, production, placement, or testing of the concrete products in which FORTA® products are incorporated, and therefore FORTA Corporation disclaims liability for the end product.

U. S. Patent Nos. 6,753,081 and 7,168,232. Additional patents pending.

FORTA Corporation's technical recommendations regarding synthetic fiber characteristics are based on years of engineering research and scores of concrete projects. FORTA® has developed a simple "4-C's" formula to help the specifier choose the right fiber for any concrete project application. By making a decision with each of the **FORTA® "4-C's"** categories – Configuration, Chemistry, Contents, and Correct Length–specifiers are assured of obtaining the desired fiber performance level for a given project. The following 4-C's formula specification has been prepared to accommodate the stated reinforcement objective for this FORTA® product grade.

REINFORCEMENT OBJECTIVE: To inhibit plastic and settlement shrinkage cracking prior to the initial set, and to reduce hardened concrete shrinkage cracking, improve impact strength, and enhance concrete toughness and durability as an alternate secondary/temperature/structural reinforcement.

DIVISION – CONCRETE
SECTION – CONCRETE REINFORCEMENT
SUB-SECTION – SYNTHETIC FIBROUS REINFORCEMENT

Synthetic fibrous reinforcement shall be used in the areas denoted in plans, and shall comply with the following fiber characteristics:

1. **Configuration – Fiber should be a macrosynthetic synergistic combination of a twisted-bundle non-fibrillating monofilament and a fibrillating network fiber system.**
2. **Chemistry – Fiber shall be made of 100% virgin materials in the form of fully-oriented copolymer/polypropylene, gray in color.**
3. **Contents – Fiber shall be used at a rate of ___% by volume of concrete, resulting in a dosage of ___pounds per cubic yard [i.e. 0.2%, 3.0 lbs. / cu. yd; 0.33%, 5.0 lbs. / cu. yd; 0.5%, 7.5lbs. / cu. yd; etc]**
4. **Correct Length – Fiber Length shall be ¾", 19mm; 1 ½", 38mm, 2 ¼". 54mm.**

Compliance: Fibers shall comply with A.S.T.M. C-1116 "Standard Specification for Fiber Reinforced Concrete and Shotcrete" and A.S.T.M. D-7508 "Standard Specification for Polyeolefin Chopped Strands for Use in Concrete". The approved product is FORTA-FERRO® macrosynthetic fiber as manufactured by FORTA Corporation, Grove City, PA, U.S.A. Phone: 1-800-245-0306 or 1-724-458-5221; Fax: 1-724-458-8331.

FORTA®

FORTA Corporation
100 Forta Drive, Grove City, PA 16127-6399 U.S.A.
1-800-245-0306 or 1-724-458-5221
Fax: 1-724-458-8331
www.forta-ferro.com

MADE IN U. S. A.

FORTA®, FORTA-FERRO®, and FORTA® are registered trademarks of FORTA Corporation

APPENDIX IV

Job Mix Design of Concrete

Client: م. عبد الرحمن ابو جياب

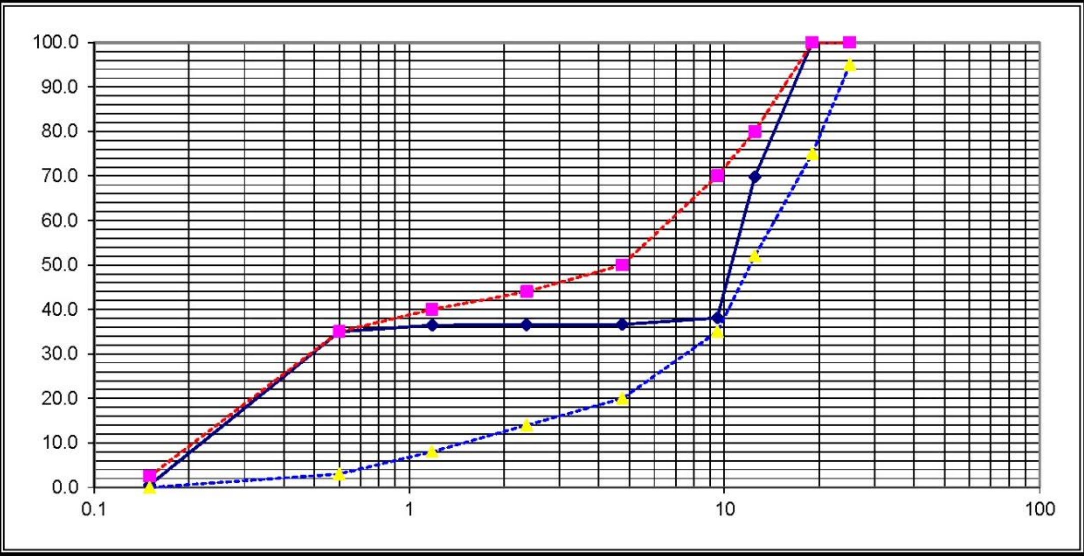
Date: 20/01/2014

Rquierments:		
Mix grade	B-	300
Minimum cement contenet	(Kg	330
Max Water cement ratio		0.45
Max cement content	(Kg)	400
Air Entrained		No
Trial Aggregate Quantity		1649

Design Parameters:	
Design target strength	40.2 Mpa
Design W/c	0.45
Design Agg/C Ratio	5.0
Target Concrete Density	2.400 g/cm^3
Slump:	Medium

	Aggregate					Water	Cement	Retarder	Total m^3
	1"	5/8"	3/8"	Sand	Total				
%	21.2	21.2	21.2	36.5	100.0				
Quantity	377	377	377	649	1780	161	357	3.0	2346
S.G	2.402	2.402	2.402	2.576	2.463	1	3.15	1.18	2.347
Volume	157.0	157.0	157.0	251.9	722.8	161	113.4	2.57	1.00
Water Absorption	3.6	3.6	3.6	0.7		45			
				mixing water		206			

Sieve size	1"	5/8"	3/8"	Sand	All in Agg	Sieve opening (mm)	Job mix	Max	Min
1"	100.0	100.0	100.0	100.0	100.0	25	100.0	100	95
3/4"	100.0	100.0	100.0	100.0	100.0	19	100.0	100	75.0
1/2"	52.4	52.4	52.4	100.0	69.8	12.5	69.8	80	52.0
3/8"	2.5	2.5	2.5	100.0	38.1	9.5	38.1	70	35.0
No. 4	0.2	0.2	0.2	100.0	36.6	4.75	36.6	50	20.0
No. 8	0.2	0.2	0.2	100.0	36.6	2.36	36.6	44	14
No. 16	0.2	0.2	0.2	99.7	36.5	1.18	36.5	40	8
No. 30	0.2	0.2	0.2	95.7	35.0	0.600	35.0	35	3.0
No. 100	0.1	0.1	0.1	1.3	0.5	0.150	0.5	2.5	0.0



Mix grade B- 300 Trial mix 100% Recycled Aggregates

trial mix	1"	5/8"	3/8"	Sand	Water	Cement	Additive
For 1.00 m^3 (kg)	377	377	377	649	206	357	2.6 Litre
For 0.03 m^3 (kg)	11.31	11.31	11.31	19.47	6.18	10.72	77 CC

Job Mix Design of Concrete

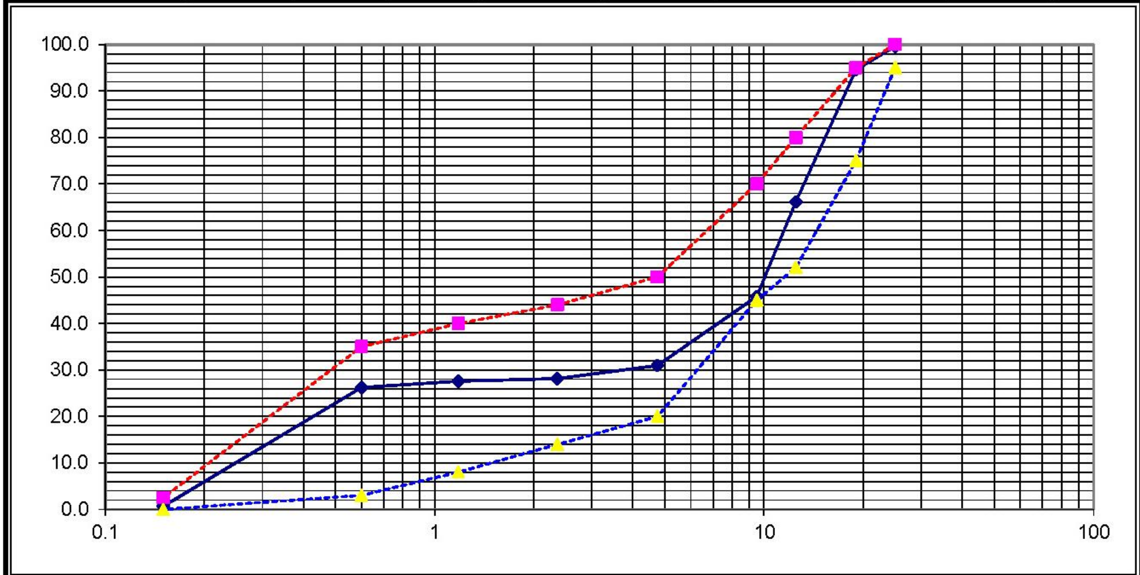
Client: م. عبد الرحمن ابو جياب **Date:** 20/01/2014

Rquierments:		
Mix grade	B-	300
Minimum cement contenet	(Kg	330
Max Water cement ratio		0.45
Max cement content	(Kg)	400
Air Entrained		No
Trial Aggregate Quantity		1649

Design Parameters:	
Design target strength	40.2 Mpa
Design W/c	0.45
Design Agg/C Ratio	5.0
Target Concrete Density	2.400 g/cm³
Slump:	Medium

	Aggregate					Water	Cement	Retarder	Total m³
	1"	5/8"	3/8"	Sand	Total				
%	28.1	28.1	17.3	26.4	100.0				
Quantity	531	530	327	498	1885	157	350	3.0	2422
S.G	2.579	2.598	2.615	2.576	2.590	1	3.15	0.91	2.423
Volume	205.7	204.1	124.9	193.1	727.9	157	111.0	3.27	1.00
Water Absorption	1.7	1.5	2.0	0.7		27			
				mixing water		184			

Sieve size	1"	5/8"	3/8"	Sand	All in Agg	Sieve opening (mm)	Job mix	Max	Min
1"	100.0	98.7	100.0	100.0	99.6	25	99.6	100	95
3/4"	90.9	89.8	100.0	100.0	94.6	19	94.6	95	75.0
1/2"	45.3	35.9	97.7	100.0	66.2	12.5	66.2	80	52.0
3/8"	6.3	6.0	91.9	100.0	45.8	9.5	45.8	70	45.0
No. 4	2.2	1.1	20.9	100.0	30.9	4.75	30.9	50	20.0
No. 8	2.2	1.0	4.9	100.0	28.1	2.36	28.1	44	14
No. 16	2.1	1.0	2.3	99.7	27.6	1.18	27.6	40	8
No. 30	1.8	1.0	1.3	95.7	26.3	0.600	26.3	35	3.0
No. 100	0.4	0.3	0.5	1.3	0.6	0.150	0.6	2.5	0.0



Mix grade B- 300 Trial mix 100% Natural Aggregates

trial mix	1"	5/8"	3/8"	Sand	Water	Cement	Additive
For 1.00 m³ (kg)	531	530	327	498	184	350	3.3 Litre
For 0.03 m³ (kg)	15.92	15.91	9.80	14.93	5.53	10.49	98 CC

Job Mix Design of Concrete

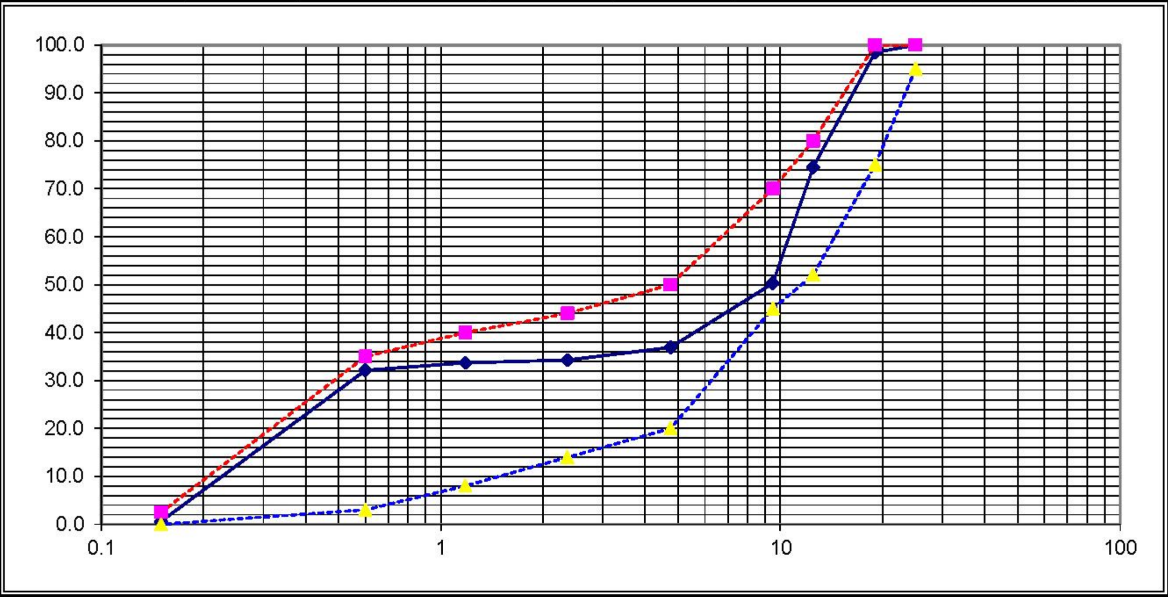
Client: م. عبد الرحمن ابو جياب **Date:** 20/01/2014

Rquierments:		
Mix grade	B-	300
Minimum cement contenet	(Kg	330
Max Water cement ratio		0.45
Max cement content	(Kg)	400
Air Entrained		No
Trial Aggregate Quantity		1649

Design Parameters:	
Design target strength	40.2 Mpa
Design W/c	0.45
Design Agg/C Ratio	5.0
Target Concrete Density	2.400 g/cm^3
Slump:	Medium

	Aggregate					Water	Cement	Retarder	Total m^3
	1"	5/8"	3/8"	Sand	Total				
%	16.8	33.5	16.7	33.0	100.0				
Quantity	307	613	306	604	1830	159	353	3.0	2383
S.G	2.579	2.402	2.615	2.576	2.522	1	3.15	1.18	2.384
Volume	119.0	255.2	117.0	234.4	725.7	159	112.2	2.55	1.00
Water Absorption	1.7	3.6	2.0	0.7		38			
				mixing water		197			

Sieve size	1"	5/8"	3/8"	Sand	All in Agg	Sieve opening (mm)	Job mix	Max	Min
1"	100.0	100.0	100.0	100.0	100.0	25	100.0	100	95
3/4"	90.9	100.0	100.0	100.0	98.5	19	98.5	100	75.0
1/2"	45.3	52.4	97.7	100.0	74.5	12.5	74.5	80	52.0
3/8"	6.3	2.5	91.9	100.0	50.3	9.5	50.3	70	45.0
No. 4	2.2	0.2	20.9	100.0	36.9	4.75	36.9	50	20.0
No. 8	2.2	0.2	4.9	100.0	34.2	2.36	34.2	44	14
No. 16	2.1	0.2	2.3	99.7	33.7	1.18	33.7	40	8
No. 30	1.8	0.2	1.3	95.7	32.1	0.600	32.1	35	3.0
No. 100	0.4	0.1	0.5	1.3	0.6	0.150	0.6	2.5	0.0



Mix grade B- 300 Trial mix 50% Natural Aggregates Recycled

trial mix	1"	5/8"	3/8"	Sand	Water	Cement	Additive
For 1.00 m^3 (kg)	307	613	306	604	197	353	2.5 Litre
For 0.03 m^3 (kg)	9.21	18.39	9.18	18.12	5.90	10.60	76 CC