DEVELOPMENT OF SUSTAINABLE CONCRETE WITH INCORPORATION OF GFRP BARS

FINAL YEAR PROJECT UG 2017

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This is to certify that the

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Dedications

To

Our Advisor Dr. Musaad Zaheer Nazir Khan

& Our Parents

ABSTRACT

As the world is moving towards sustainability the goal was to make sustainable concrete and for this purpose, The recycled aggregate was used as an alternative to natural aggregate and an optimum quantity was taken and silica fume to achieve the high-performance concrete strength concrete. Recycled aggregate replacement in range of 10%-30% was taken along with 7% silica fume to achieve a high-performance sustainable concrete. It was observed that concrete silica fume enhanced the cooperative strength of concrete. There was a minimum decrease in concrete strength after 20% RCA substitute and this was then selected as the optimum formulation. The sustainable concrete formulation was employed to cast concrete beams of two different spans namely 750 and 1500 mm were integrated with GFRP rebars. The experimental testing of the beams under three-point bending were carried out and subsequent analysis was performed. The 1500 mm span beam failed in flexure and shear whereas the 750mm beam failed in pure shear both then following FRP rupture. The failure modes indicated by Abaqus software were in line with experimental values. The research was then extended to model the beams in ABAQUS . An investigation on the effect of reinforcement ratio and size of reinforcement was studied. It was observed that an increase in reinforcement ratio led towards concrete crushing failure whereas a decrease in GFRP reinvestment size resulted in FRP rupture. The ABAQUS software predicted the strength of the beam with great accuracy. A detailed cost analysis was performed that concluded that the effect of using RCA and GFRP bars in concrete resulted in 9.1% savings in cost of concrete. Moreover, use of RCA tends to reduce the cost of concrete by 5.42% and its combined use with GFRP rebars increases savings up to 6.20%.

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CHAPTER 1

INTRODUCTION

1.1 General

In the previous decade, Construction Industry has been pushed to pursue an extra durable, lighter, better strength, environmentally pleasant material i.e., Glass Fiber Reinforced Polymer Rebar to recognize a superior structural layout incorporation, good mechanical properties, and prolonged carrier life of a structure. GFRP rebar's are making a breakthrough in Structure Engineering because of its non-corrosive properties which allow it to be used anywhere, where there is water common occurrence like dams, water tanks, bridges, seawalls etc. this will help in longevity of the structure and allow it to stay in much finer condition. [1] GFRP rebar have excellent fatigue resistant making it great for large load situation such as roads, bridges. In contrast to steel, GFRP have low thermal conductivity that is why they can be used in nuclear power plants or anywhere where power can be subject to concrete. GFRP rebar weighs 70 times lighter than steel and possess a higher tensile strength. GFRP rebar are engineered to have strong bond with concrete and can maintain a cosmetically attractive structure with good flexural strength. [2] One of the prime concerns of steel reinforced members is gradual maintenance over time whereas FRP reinforced member do not require so. FRP being highly economical eventually result in reduction in life cycle cost of structure over a longer period. Another major concern with steel reinforced member is Carbon Footprint. According to air quality report 2020, Pakistan is the second most polluted country of the world. Case study that focused on the footprint of carbon for FRP induced in a pedestrian bridge present in a marine environment and for its assessment against a conventional prestressed concrete bridge. It became discovered from this situation that the usage of FRP integrated bridge results in a lower CO_2 emission through a total of 26% for the duration of the material production and construction duration. [3]

1.2 Objectives

- To develop a sustainable concrete mix by utilizing RCA
- To test beams experimentally to determine deflection in GFRP reinforced RCA Concrete
- To model the behavior of GFRP reinforced beams and carry out a parametric study

1.3 Drawbacks of Conventional Steel

Steel reinforcement albeit reliable and ductile has certain disadvantages associated towards it:

- Corrosion of reinforcement. As the steel corrodes, concrete begins to crack and spall. This deterioration can be mitigated by incorporating GFRP rebar's in Concrete
- Steel rebar's are heavier in weight whereas GFRP weighs 70% lighter than steel
- Durability of reinforcement.
- Steel has low critical temperature that is why they shows Lower resilience at Elevated temperature.

1.4 Recycled Coarse Aggregate (RCA)

Crushed concrete aggregates also called as recycled coarse aggregates are fragments of demolished concrete buildings. Recycled Coarse Aggregate is the aggregate that comprises both the natural aggregate and mortar paste; hence the property of RC aggregate not only depends upon the natural aggregate properties but also depends on and incorporates the quantity and quality of mortar paste attached. Incorporation of recycled coarse aggregate has brought about a tremendous change in the world of sustainable concrete production. Use of crushed concrete from demolished buildings not only reduces the cost but also benefits the environment and also diminishes the carbon footprint. Based on research it is generally accepted that around **20-30%** of NCA can be replaced with RCA, without changing the properties of the concrete in an excessive manner.

1.5 Silica Fume

Silica Fume is used as a partial substitute for cement. Silica Fume lowers concrete permeability. Increases strength and durability. Refines the shape of the pores. Silica pozzolan concrete reduces the pores in the concrete mix as well as improves the mix composition to yield greater strength than normal concrete mix. Furthermore, the compressive and flexural strength of silica pozzolan concrete is greater than normal concrete. [4]
The sturdiness of silica pozzolan concrete is more prominent than normal concrete. The resistance to the freeze and thaw actions as well as resistance to chemical action is greater in the case of silica pozzolan concrete when compared to normal concrete. The scenario of segregation of mix and bleeding of concrete mix is quite lower in silica pozzolan concrete as compared to normal concrete mix.

1.6 Glass Fiber Reinforced Polymer Bars

GFRP bars although new are a more environmentally friendly alternative compared to steel. They consist of Glass fiber embedded in a polymer or plastic matrix. Fibers go in longer dimension of bar, and they are surrounded by theses polymers. In cross section they consist of (60-70%) fiber and (30-40%) of polymer binder that helps hold the fibers together.
Advantages of GFRP rebar’s are as follows:

- High Strength
- Light weight
- Corrosion Resistant
- Chemical Resistance
- Lower Thermal Conductivity
- Durability
- Amazing Lifespan
- No maintenance cost
- Environmentally Friendly

CHAPTER 2

LITERATURE REVIEW

2.1 Glass Fiber Reinforced Plastic

2.1.1 Historical Background

In the beginning of the 20^{th} century rapid development and use of composite material was taking place. The driving forces for such innovation were the use of light-weight materials having high strength for military vehicles. The extremely high theoretical strength of glass fibers was being discovered in the 1940s and the industries were trying to know that how this composite material can be utilized to solve the problems posed by the military's demands. As the world progressed, further applications for glass fiber reinforced plastics rapidly grew, and in the present this material is being used in the aerospace industries, automotive applications, marine environment, and construction ventures.

2.1.2 Composition of GFRP

GFRP is a material which has a composite nature and consist of glass fibers as well as matrix polymers. Vinyl ester, epoxy resins, or thermosetting polymer resin is used for the polymer matrix. Resin which is utilized brings resistance of environmental and chemical nature to the GFRP. Fibers of glass improve the strength of the composite material; the fibers present can be arranged randomly or are aligned conveniently. Common category of glass fiber utilized for GFRP is E glass, which is referred as Alumino.Boro-silicate glass. For protection against acidic corrosion E-CR-glass is used which is referred to as Electrical/Chemical Resistance glass.

2.1.3 Advantages of using GFRP

Glass Fiber Reinforced Plastics have numerous advantages over conventional steel reinforcements in the construction industry. GFRP bars show electromagnetic neutrality, have high strength to weight ratio, and are easy to handle, cut, and process which ultimately reduces the overall cost of construction. Moreover, the critical temperature for GFRP bars is higher as compared to steel which portrays better performance of GFRP bars in case of fire. GFRP is considered to be a material which is durable, has good and long-life expectancy, usually used for a broader range of applications in different industries.

Furthermore, there exist multiple methods for repairing or preventing the corrosion in steel reinforcements of various concrete structures. But these different procedures are expensive, and their effectiveness in the long run is doubtful. An innovative procedure to resolve the issue of corrosion in steel reinforcement is the inculcation of GFRP bars instead of the steel reinforcement. This is a cheaper and an effective method to eliminate the corrosion factor in concrete construction.

2.1.4 Applications of GFRP

GFRP has many uses and applications in civil structures and construction industry. Engineers and contractors are taking interest in the applications of GFRP as many countries are inculcating GFRP reinforcement in different structures. Due to the technical attributes of various composite material, they exhibit excellent performance enhancement when inculcated in restoration and upgradation works as well as when used in seismic strengthening of various structures. Prominent examples of GFRP reinforcement in the construction industry are:

- In a case study, GFRP bars extended the life of an RC water tank structure up to 100 years compared to steel RC tanks.
- Moreover, in a paper dedicated to extending bridge service life, the working life of concrete slabs reinforced with steel was estimated to be about 25 years while it increased to about 75 years when the slabs were reinforced with GFRP reinforcement.

- GFRP can be utilized for controlled structural collapse which is quite fruitful when demolition of structures needs to be carried out; this eventually can help mitigate risks to surrounding infrastructure.
- GFRP can also be useful for preserving structures that are rendered unstable due to natural disasters.

2.2 Recycling of Concrete

2.2.1 Historical Background

During World War II, destruction to the infrastructure in Europe occurred at a massive scale. It became necessary to call for construction of new infrastructure in the region. With this call came two most challenging tasks to the establishments. How the required material for construction was to be procured at such a short notice and what was to be done with the debris and demolished material accumulated due to wide scale destruction of infrastructure? [5] Hence using recycling techniques at that time saved both the raw material and space. Even today, immense construction waste is produced each year from control demolished structure sites and from collapsed structures due to natural calamities. Concrete waste disposal poses a serious environmental problem. This consequently leads to recycling of concrete to create a sustainable environment.

Figure 2.1 Disposal of Construction Wastes

2.2.2 Recycled Aggregate

Recycled Aggregate (RCA) is the coarse aggregate that consists of both the original aggregate and cement mortar on its surface; two interfacial zones (ITZs) are present in it when used for making concrete.

RCA can be obtained from demolished concrete structure sites, concrete pavement or laboratory tested concrete samples. Hence, the concrete formed by inculcating coarse aggregate from sites of structural demolition and debris is known as sustainable concrete or recycled concrete; the properties of recycled concrete are different and better from conventional concrete in certain categories.

2.2.2.1 Advantages of using RCA

The many advantages of using RCA are as follows: -

- The absence of naturally acquired coarse aggregate (NCA) and the continuous hike in prices for landfill activities have given rise to the utilization of RCA in concrete structures. [6]
- The source of natural aggregate is often far away from the place of construction, and this becomes tiresome for contractors hence they prefer to utilize RCA instead of NCA. [7]
- Waste generated due to demolishing of different structures as well as the waste generated due to collapsing of structures due to natural disasters causes grave concerns for the environment. The issue of effective waste disposal needs to be resolved. Hence, RCA plays the role of the savior. RCA when utilized in concrete structures ultimately ends the crisis of waste disposal due to demolitions and collapsing of structures. [8]
- Properly processed Recycled Concrete Aggregate is utilized for freshly prepared concrete for different infrastructure projects. It is also used in structural grade concrete and in the production of bituminous concrete. [9]

2.2.2.2 Problems associated with RCA

Recycled Concrete Aggregate produced by the demolition and collapsing of concrete structures and from crushing old concrete portrays properties that seem to be inconsistent due to varying composition of water cement ratio or the composition of cement in the originally prepared concrete. Quantity of Recycled Concrete Aggregate is usually lower than NCA. The density of Recycled Concrete Aggregate is lower as compared to NCA and the former has more water absorption value as compared to the latter due to cement mortar attached to its surface. This cement mortar makes the former aggregate porous than natural aggregate. [10] Workability of Concrete Aggregate is less as compared to natural aggregate when same amount of water content is considered, this is more visible when 50 percent replacement is carried out. Content of air in the concrete prepared with Recycled Concrete Aggregate is slightly higher (5 percent) than the one formed natural aggregate, when replacement is 100 percent. The variance in air content is mainly due to difference in porosity of the aggregate material. [11]

2.2.3 Sustainability

Sustainability acquirement in this era of construction industry is a big challenge not only for the policy makers of any government but it is a grave concern for the construction sector as well.

In the 21st century majority of the countries are pursuing a sustainable society by incorporating the agenda of sustainable development goals. Now, the construction industry is a big hindrance in this motive as the construction sector utilizes 50 percent of nature's resources and also utilizes 40 percent of this as energy while generating a staggering 50 percent of worlds total waste material, this is quite alarming. [12]

Recycled Coarse Aggregate is a sustainable option in all aspects including economy, environment, and social perspective.

Figure 2.2 Aspects of Sustainable Development

Economical aspect:

- By using Recycled Coarse Aggregate (RCA), cost for quarrying of aggregate is reduced and the need for blasting is eliminated.
- Transportation costs of material from quarry site to the construction sites is considerably reduced.
- Use of Recycled Coarse Aggregate reduces charges for landfilling of material.

Environmental aspect:

- Using Recycled Coarse Aggregate for the purpose of construction, environmental issues such as global warming and climate change will be tackled and minimized as this helps in preservation of natural resources.
- It also helps in eliminating air and noise pollution which is produced by blasting and transportation at quarry sites.
- Recycled Coarse Aggregate also provides viability for preservation of non-renewable natural resources.

Sociological aspect:

- The social benefits of sustainable construction include improvements in the quality of life, health, and well-being.

2.3 Silica Fume

2.3.1 Advantages of silica fume

It is a fine powder like substance of high density; is a famous pozzolan material which is utilized to maximize strength of concrete. Silica fume also consist of a peculiar chemical composition which eventually makes it perfect for being incorporated as an additional material in concrete. This pozzolan also significantly helps in maximizing the property of hardness in concrete; this makes the pozzolan a perfect additive for creating good bonds between all the different components to manufacture a compact structure. Silica pozzolan has the quality of uniqueness in maximizing the hardness of concrete because of the advantage of having a higher density. Concrete poses some problems in the form of coarser material present in it which leads to segregated mix and multiple pores; this is due to absence of proper bonding between the different constituents. This eventually reduces the properties of concrete like ductility, hardness of concrete, and durability of concrete as well. To mitigate these problems, silica fume is utilized which effectively fills the gaps and pores which leads to a mix having higher density. Furthermore, synergistic effects are achieved for recycled concrete and natural concrete by incorporating silica fume and glass fiber reinforcement. Finally, the incorporation of Silica fume incorporation yields better strength of bond between binder material and fibers; this also improves the dispersion of glass fiber.

2.3.2 Applications of silica fume

The utilization of this pozzolan material in concrete is a popular practice for the production of High Strength Concrete. Moreover, Silica fume has a specific gravity of 2.2 which is lighter than cement, Silica fume enables the mix designer to get a lighter concrete with same or higher strength, increases the bonding between the paste of cement aggregate; increases viscosity of mix which prevents the potential floating of some types of lightweight aggregates.

Furthermore, study has shown, addition of a certain percentage of silica pozzolan, mainly 10 percent, as a replacement of cement in concrete increases the physical and mechanical attributes of Concrete Aggregate.

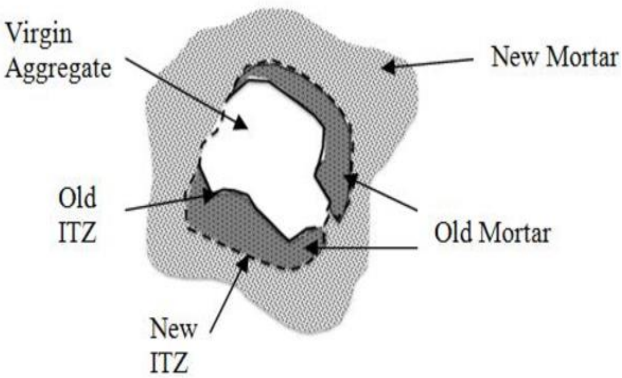


Figure 2.3 Silica Fume with Recycled Concrete Aggregate

2.3.3 Problems incorporating silica fume

This pozzolan enhances the strength utilization of concrete, however this also increases brittleness of concrete which eventually decreases the fiber reinforcement confinement effectiveness. Furthermore, fiber reinforcements confinement can portray a monotonous upward moving stress strain curve, this curve exhibits strength loss initially at the region of transition. In addition, Increased strength of concrete as well as increase in brittleness which happens due to the addition of silica pozzolan to the mix of concrete, these strength losses are more significant for concretes containing silica fume.”

2.4 Water Reducing Agent

2.4.1 Super Plasticizer

ASTM C 494 refers to superplasticizers as “water-reducing, high range admixtures”, classifying them as Type F admixtures or when retarding effect is induced, Classified as Type G admixtures. Super Plasticizers (SP) are inculcated into the concrete mixture during concrete mixing to improve the workability of concrete at lower water/cement ratios. SP are chemical admixtures which increase the workability of cementitious systems at low mixing water contents and are therefore considered to be essential for durability of structures.

2.4.2 Mechanism Action of Superplasticizer

In the Cement Pastes, major clinker phases of cement are C2S, C3S, C3A & C4AF, usually aluminate phases (C3A and C4AF) have positive charges and silicate phases (C2S and C3S) have negative charges. This causes a rapid clotting of the cement grains in the fresh cement paste and concrete. When the SP is added to concrete along with mixing water, the SP polymer molecules bind on the surface sites of cement grains especially on aluminate phases and decrease surface potential which become negative for all major phases of cement. The electrostatic repulsive forces are thus created between cement grains. This is the mechanism by which the agglomeration is prevented.

CHAPTER 3

MATERIAL AND EXPERIMENTAL METHODOLOGY

3.1 Materials

The materials utilized in developing a sustainable concrete mix are mentioned below along with the properties the Glass Fiber Reinforced Polymer Bars that have been incorporated as reinforcement for the concrete beams. A detailed experimental program of all the materials is also tabulated. .

3.1.1 Cement

Fauji Ordinary Portland Cement of grade 53 (Type I) was utilized for all the casting regimes. The cement's properties were conforming to the ASTM standard of C150 / EN 196-1. The properties of cement have been determined keeping in view the guidelines prescribed by ASTM and have been displayed in the table below.

Table 3.1 Properties of Cement

Properties	Standard	Values	Temperature
Initial Setting Time (min)	ASTM C191	45	22
Final Setting Time (min)	ASTM C191	225	22
Specific Gravity	ASTM C188	3.15	24
Blaine's Fineness (cm^2/g)	ASTM C204-07	3124	24

3.1.2 Sand

The fine aggregate used for the casting of concrete was obtained from Quarry site at Lawrencepur. The sieve analysis was performed in accordance with ASTM C136 and a fineness modulus of 2.44 was attained which falls well in the range of 2.2-3.2 as prescribed by ASTM

Table 3.2 Properties of Sand

Properties	Standard	Values
Bulk Specific Gravity	ASTM C128-07a	2.497
Water Absorption	ASTM C128-07a	1.006%
Bulk Specific Gravity (Oven Dried)	ASTM C128-07a	2.36
Fineness Modulus	ASTM C 136	2.44

The gradation curve of Fine Aggregate is shown below. The D_{50} was around 595 microns.

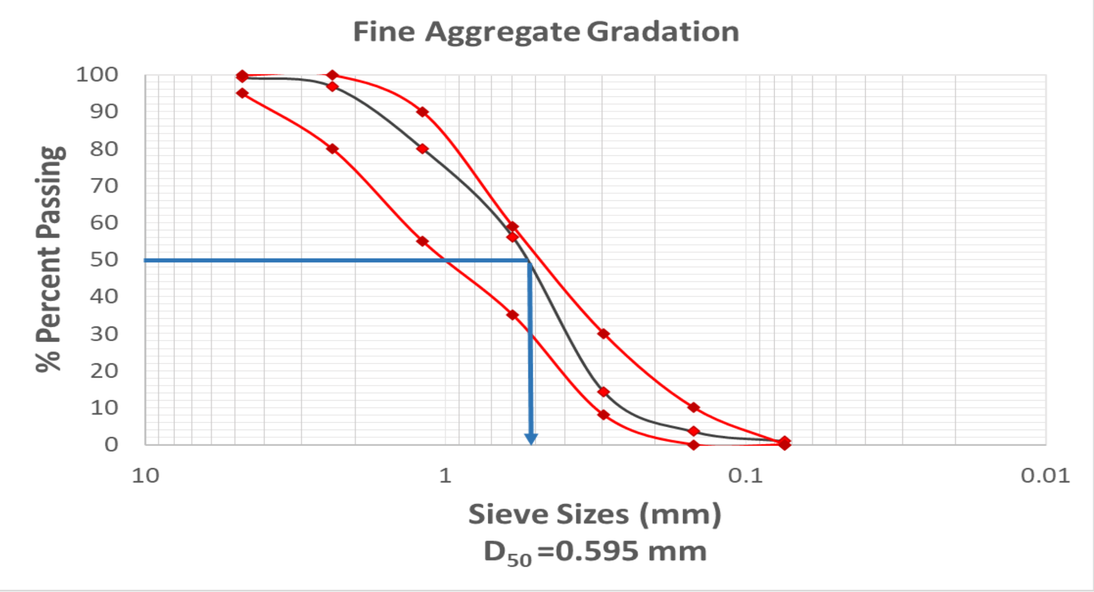


Figure 3.1 Fine Aggregate Gradation Curve

3.1.3 Coarse Aggregate

Coarse aggregates form a significant part of concrete and affect many aspects of concrete including its strength and durability. Two major types of aggregates have been utilized in this research which include Recycled Aggregate Concrete and Virgin Coarse Aggregate. Their properties have been discussed below.

Figure 3.2 Coarse Aggregate (Left) and Recycled Coarse Aggregate (Right)

3.1.4 Virgin Coarse Aggregate

The natural aggregates used in this study have been obtained from Margalla Crush. Necessary tests were carried out to determine aggregate properties including sieve analysis, crushing value and other tests in accordance with ASTM specifications.

The Gradation Curve of the natural coarse aggregate is shown below here with maximum size around 16 mm and D_{50} around 9.5 mm.

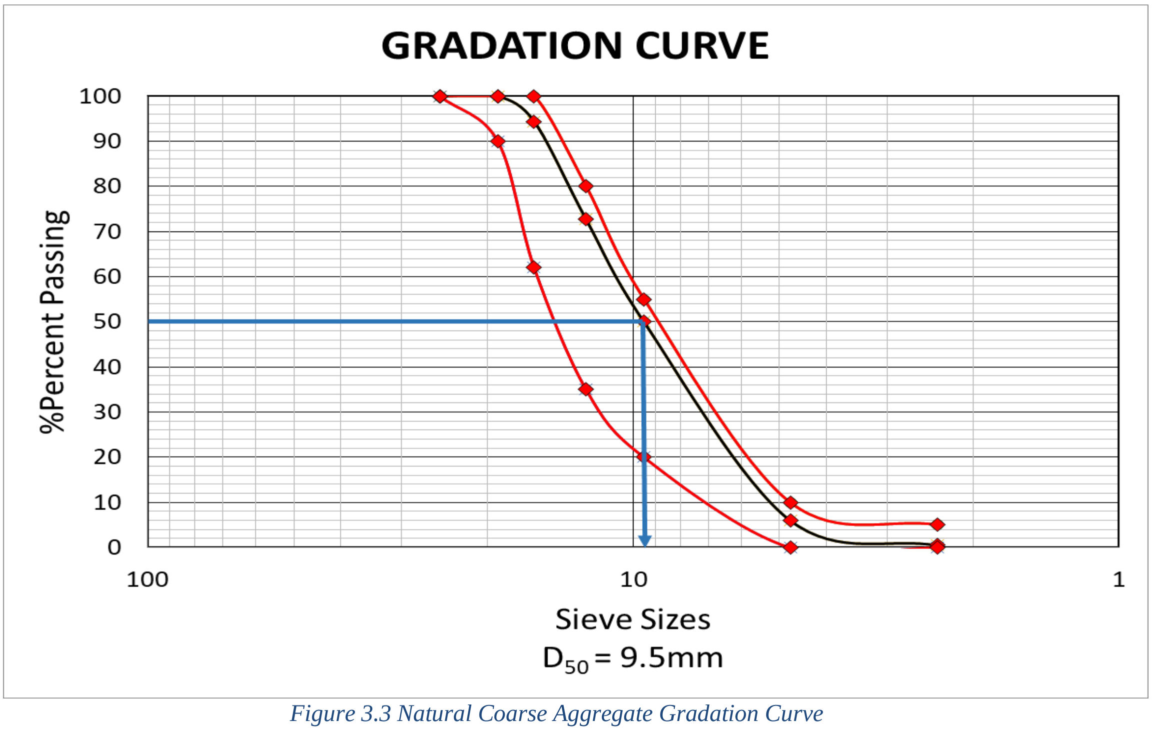


Figure 3.3 Natural Coarse Aggregate Gradation Curve

The properties of the aggregates have been summarized in the table below:

Table 3.3 Properties of Coarse Aggregate

Properties	Standard	Values
Specific Gravity (SSD)	ASTM C-127	2.68
Water Absorption (Virgin Aggregate)	ASTM C-127	0.40%
Specific Gravity (Oven Dried)	ASTM C-127	2.44
Crushing Value	BS-812	25.5%

3.1.5 Recycled Coarse Aggregate

Recycled coarse aggregate of the same original source i.e., Margalla crush was utilized as replacement of the virgin aggregates in this research. The concrete samples from where the was Recycled coarse aggregate was extracted were taken from Structures Lab of NICE in the form of crushed concrete cylinders and cubes with each sample averaging over 3500 psi strength.

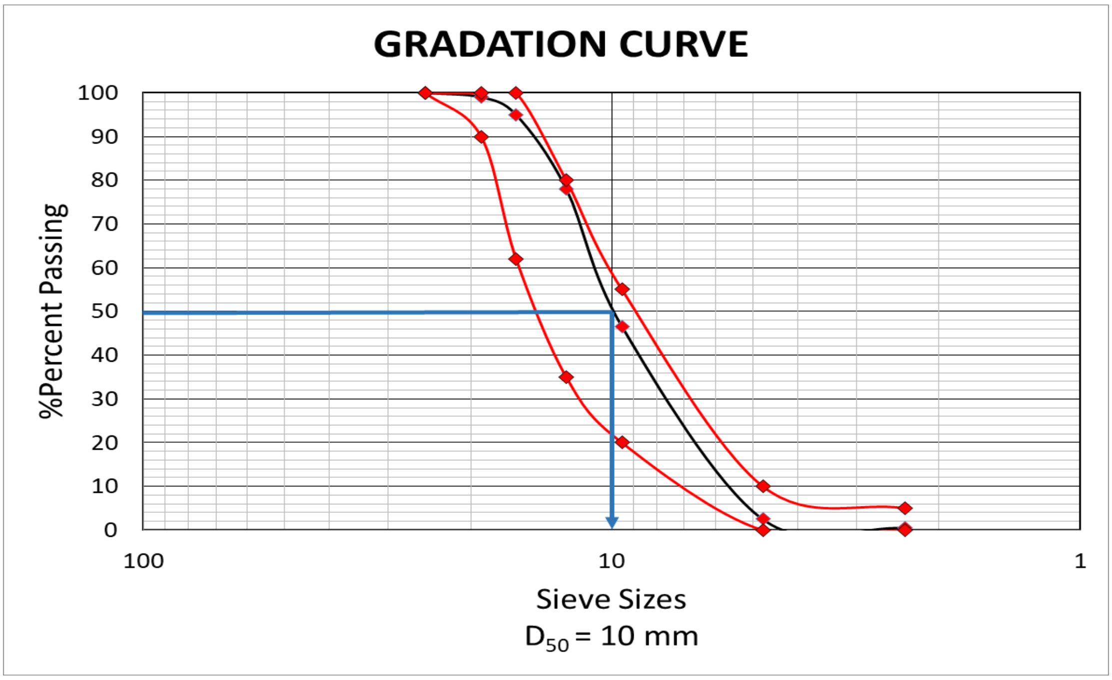
Figure 3.4 Recycled Coarse Aggregate

This Recycled Coarse Aggregate serves as useful material for optimizing the process of concrete construction since it tends to reduce the amount of overall waste that is generated by consuming already discarded concrete.

A total of 60 concrete cubes and cylinders were crushed manually to obtain the required amount of RCA needed throughout the research program. The aggregate tests of sieve analysis and gradation were also performed in accordance with ASTM standards.

The gradation curve of coarse aggregate is shown here with maximum size around 16 mm and D_{50} around 10 mm.

Figure 3.5 Recycled Coarse Aggregate Gradation Curve



The properties of Recycled Coarse Aggregate have been summarized below as:

Table 3.4 Properties of Recycled Coarse Aggregate

Properties	Standard	Values
Specific Gravity (SSD)	ASTM C-127	2.63
Water Absorption (Recycled Aggregate)	ASTM C-127	5.490%
Specific Gravity (Oven Dried)	ASTM C-127	2.54
Crushing Value	BS-812	25.24%

3.1.6 Silica Fume

Silica Fume is obtained as a result of manufacturing of basic silicon and alloys incorporating silicon, iron and other materials and is produced as a side product. Silica fume particles are very finely produced ball-shaped particles that have very significant effects on the mechanical and material characteristics of concrete.

MasterRoc® MS 610 [13] was used throughout the experimentation program which was obtained from BASF manufacturers. The recommended dosage of Silica Fume is between 5-15% of cement mass as specified by BASF.

Table 3.5 Properties of Super Plasticizer

Admixture	MasterRoc MS 610
Appearance	Grey Powder
Density	0.55 - 0.7 kg/l
Chloride Content	<0.1%

3.1.7 Super Plasticizer

In this report Expanplast* SP-568[14] as processed by EXPANCHEM company has been incorporated as Super Plasticizer. It conforms to ASTM and EN standards for a liquid SP. Its recommended dosage ranges between 0.5% to 2% of by mass of cement (binder material). However, incorporating various parameters such as concrete materials, on job conditions and other factors variation is acceptable during trail mixes based upon best engineering judgement.

The properties of Expanplast* SP-568 [14] have been summarized below:

Table 3.6 Properties of Super Plasticizer

Admixture	**Expanplast* SP-568**
Appearance	Brown liquid
Specific gravity	1.195 @ 20°C ± 0.005
Water soluble chloride	NIL
Alkali content	Typically, less than 5 mg. Na_2O equivalent / liter of admixture

3.1.8 Mixing Water

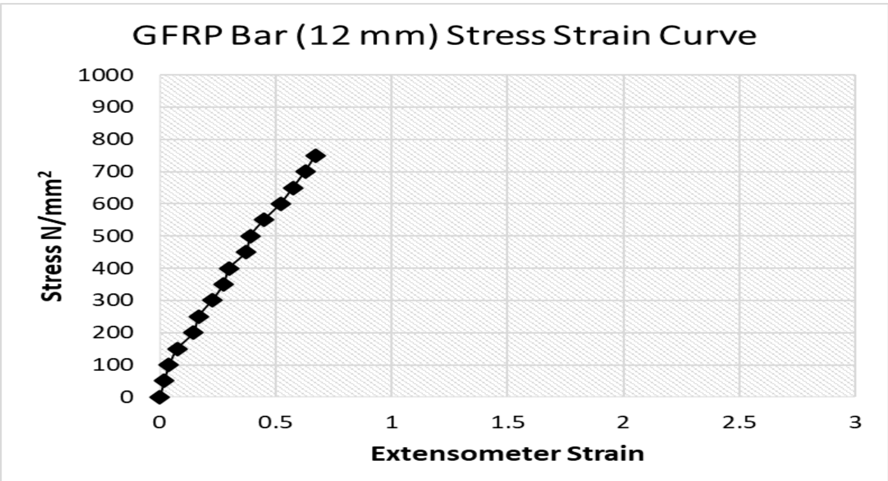
Ordinary tap water available in NICE structure's lab was utilized as water for all the concrete batching throughout the experimentation phase and the water's temperature was normally within the range of 20-26°C.

3.1.9 Glass Fiber Reinforced Polymer Bars

The GFRP bars that were incorporated into the sustainable concrete mix were ordered from T-ROD international Pvt Ltd. The GFRP bars of 12 mm were used throughout the research phase.

The stress versus extensometer strain curve for the bars was plotted and is shown below. The GFRP bars had an Ultimate Tensile Strength of 850 MPa (123300 psi).

Figure 3.6 Stress-Extensometer Strain Curve for GFRP Bars



The properties of the GFRP bars have been summarized in the table below:

Table 3.7 Properties of GFRP bars

Properties	Standard	Values
Bar Diameter	-	12mm (#4)
Ultimate Tensile Strength (MPa)	ASTM D7565	850
Modulus of Elasticity (GPa)	ASTM D7205	48

3.2 Experimental Methodology

In order to develop a sustainable concrete using recycled concrete aggregate and silica fume a list of formulations were prepared to ensure adequate amount of testing and accurate results. In the first set of formulations the amount of Silica Fume was varied between 3-7% as cement replacement by mass and the concrete demonstrating the highest compressive strength was taken into consideration.

In the subsequent formulations the percentage of silica fume yielding the highest compressive was kept unchanged and the amount of Recycled Coarse Aggregate as replacement of natural aggregate was incorporated in concrete in percentages between 10%-30%. The amount of Recycled coarse aggregate was not increased beyond 30% since an increase in percentage of RCA beyond 30 % tends to significantly affect the concrete compressive strength. The formulations have been summarized below.

The nomenclature in a particular concrete formulation is defined as “Number1-NC-Number2”. Here the “Number1” refers to the amount of silica fume used as cement replacement, “NC” refers to the concrete and the “Numner2” refers to the amount of RCA as natural aggregate replacement. For example, for the formulation “7C20”, here the number “7” characterizes the amount of silica fume utilized as cement replacement and ”20” symbolizes the amount of RCA used as natural aggregate replacement.

Nomenclature and Notation	Cement	Water	Silica Fume	Coarse Aggregate	Recycled Coarse Aggregate
Normal Concrete-**NC**	1	0.38	-	2.05	-
NC with 3% Silica Fume-**3NC**	0.97	0.38	0.03	2.05	-
NC with 5% Silica Fume-**5NC**	0.95	0.38	0.05	2.05	-
NC with 7% Silica Fume-**7NC**	0.93	0.38	0.07	2.05	-
7NC with 10 % RCA as Coarse aggregate-**7NC10**	0.93	0.38	0.07	1.845	0.205
7NC with 20 % RCA as Coarse aggregate-**7NC20**	0.93	0.38	0.07	1.64	0.41
7NC with 30 % RCA as Coarse aggregate-**7NC30**	0.93	0.38	0.07	1.435	0.615

Table 3.8 Details of formulations

A total of 66 concrete cylinders were casted 12 for the normal concrete and 9 for each of the subsequent formulation.

3.2.1 Concrete Mix Design (CMD):

The CMD used for the purpose of experimentation was finalized using ACI 211.1 guidelines. A design strength of 4200 psi was selected the properties of all the concrete constituents were utilized for the preparation of the final concrete mix.

In order to satisfy the concrete mix requirements as specified by ACI 211.1 (slump, mixing water, maximum permissible water etc.) several trial mixes were performed. In the trials the water cement ratio was initially varied between 0.40-0.45 but the slump requirements were not met and therefore superplasticizer was then incorporated in various dosages to achieve the required slump. For this purpose, the water cement ratio was therefore restricted up to 0.38 with 0.8% as superplasticizer as percentage of cement mass. The following table shows the details of the concrete mix design.

Sample	Cement	Sand	Aggregate	Water
Concrete	**1**	**1.56**	**2.05**	**0.36**

Table 3.9 Concrete Mix Design Details

3.2.2 Mixing Regime

The mixing regime as per ASTM standards was utilized for preparation of concrete specimens. Concrete pan mixer was utilized for casting of concrete specimens. The mixing regime has been summarized below in the following table.

Step 1	Cement, sand, aggregate and all the other materials were weighed as per mix proportions.
Step 2	Cement, Silica Fume, sand, and aggregates were placed in the mixer and slowly mixed.
Step 3	Add about 80% of water to the dry mix and mix the concrete constituents.
Step 4	Now add SP in remaining water and mix thoroughly again.
Step 5	The prepared concrete was placed into the molds
Step 6	The prepared molds were then placed on a shake table to properly compact the specimens and the surface was levelled with a trowel.

Table 3.10 Step by Step procedure for concrete casting

Figure 3.7 Casted Concrete Cylinders to be placed for curing

3.2.3 Curing

After the concrete cylinders were removed from there molds and labelled to ensure proper documentation. The concrete mixes were then placed inside water tanks for the purpose of curing. The temperature of the water tank was kept at 25°C. The concrete specimens were then periodically taken out from the tanks after 7, 14 and 28 days to conduct testing.

3.2.4 Beam Design

For incorporation of GFRP rebars in the sustainable concrete mix, a beam cross section of an appropriate span had to be selected. For this purpose, a beam cross-section was selected that was to incorporate the 12mm GFRP rebars. For this purpose, two different types of beams were tested to ensure both the shear as well as flexure failure of the GFRP rebars in concrete.

A similar concrete mix was utilized for casting both the beams. This concrete mix was prepared after casting and testing the concrete formulations that gave out the best results. Therefore, the concrete formulation of “7NC20” that contains 7% silica fume as cement replacement and 20% RCA as coarse aggregate replacement was used as the concrete mix for casting of beams.

The beam cross sections were selected as per ACI 440.IR-15 [15] that deals with FRP reinforced members. The span length was varied to study the effect of the GFRP reinforced RCA concrete beam in shear as well as flexure.

The selected cross section was 140mm by 230mm and the span length was varied between 750 mm and 1500 mm.

3.2.4.1 Behavior of GFRP reinforced RCA concrete in shear

At the time of this study the only 12 mm GFRP bars were available, and they were utilized for casting the beam specimens. Two beams of span 750 mm were reinforced with 2-12mm GFRP bars (reinforcing area of 226.2 mm^2) as main reinforcement while 2-12mm GFRP rebars were utilized as compression reinforcement. Wooden mold of internal dimensions 140 x 230 x 750 was used for casting of concrete.

Figure 3.8 Casted Concrete Beam of 750mm

The beam's reinforcement was limited to longitudinal reinforcement since GFRP stirrups were not available. The cross section has been displayed below:

Figure 3.9 (a) Beam of 750 mm span with reinforcement area of 226.2 mm^2

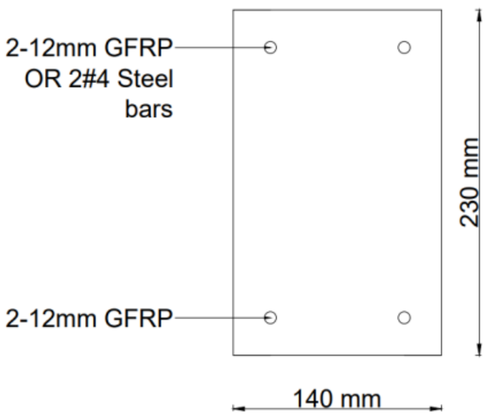


Figure 3.9(b) Cross Section of Beam of 750 mm span

3.2.4.2 Behavior of GFRP reinforced RCA concrete in Flexure

For flexure the span length was increased up to 1500 mm and the similar cross section beam was then casted. The reinforcement area was again set at 226.2 mm^2 as the main reinforcement was not changed except for changing the span length. A wooden mold of inner dimensions 140 x 230 x 1500 was used.

Figure 3.10 Casting of Concrete beam of span 1500 mm

The cross section has been displayed below:

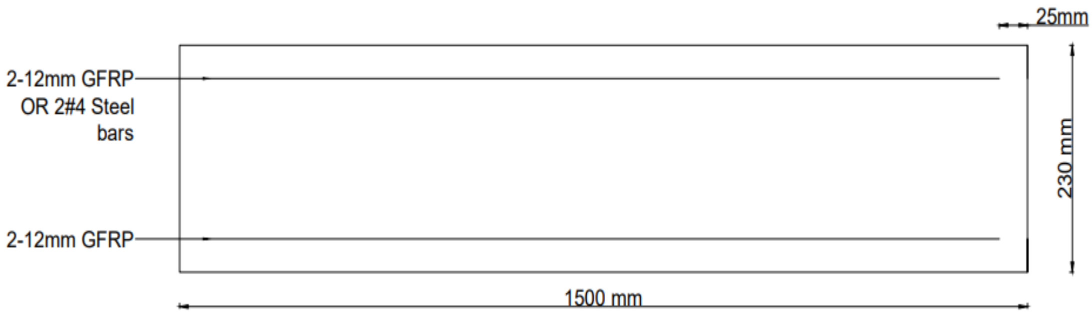


Figure 3.11(a) Beam of 1500 mm span with reinforcement area of 226.2 mm^2

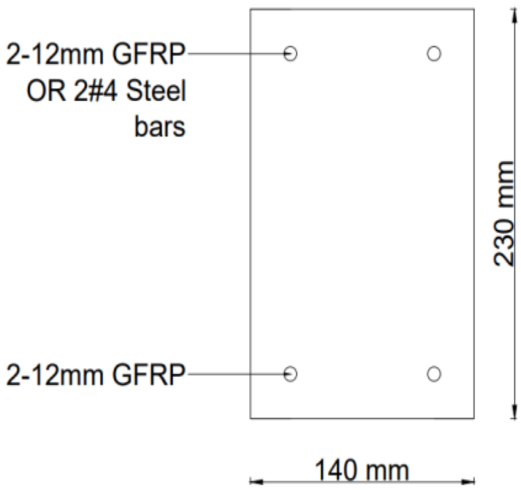


Figure 3.11(b) Cross Section of Beam of 1500 mm span

Table 3.11 Beam specifications

Beam Notation	Diameter of Bar (mm)	No. of Bars	b (mm)	h (mm)	A_f (mm^2)	f'_c (MPa)	ρ_f
750-12	12	2	140	230	226.2	48.5	0.0078
1500-12	12	2	140	230	226.2	48.5	0.0078

3.2.4.3 Testing Methodology for Beams

Both of the beams were tested under 3-point loading test in the reaction chamber in NICE shed. The test setup is shown in the figure below:

Figure 3.12 Test Setup

As can be seen load was applied at the center and an LVDT was attached at the center to measure the midspan deflection.

For the 1500 mm beam load was applied on a simply supported clear span of 1290 mm while for the shorter 750 mm beam load was applied on a clear span of 540 mm. Load was applied until either the concrete failed, or the bars ruptured.

3.3 Beam Modelling Parameters

3.3.1 Simplified Concrete Damaged Plasticity

In order to obtain the plastic behavior of concrete we referred to literature and used the findings to establish values for concrete's compressive as well as tensile strength beyond the cracking stage. According to Milad Hafezolghorani et. al. [15] the cocnrete's elastic and plastic behaviour can be modeled by a more rudimentary form of Concrete Damaged Plasticity Model. This model makes use of the hardeneing and softening variables for determining the post crack beahviour. For this purpose two variables of indicated by $\varepsilon_c^{pl,h}$ and $\varepsilon_t^{pl,h}$. Both of these were furhter used to determine the post cracking compressive stress through the following equations[15] :

$$\sigma_c = (1-d_c)E_0\left(\varepsilon_c - \varepsilon_c^{pl,h}\right)$$

$$\begin{cases} \varepsilon_c^{in,h} = \varepsilon_c - \dfrac{\sigma_c}{E_0} \\ \varepsilon_c^{pl,h} = \varepsilon_c - \dfrac{\sigma_c}{E_0}\left(\dfrac{1}{1-d_c}\right) \end{cases}$$

$$\varepsilon_c^{pl,h} = \varepsilon_c^{in,h} - \frac{d_c}{(1-d_c)}\frac{\sigma_c}{E_0}$$

Similarly for the purpose of concrete's tensile strength beyond the cracking phase the following equations were used:

$$\sigma_t = (1-d_t)E_0\left(\varepsilon_t - \varepsilon_t^{pl,h}\right)$$

$$\begin{cases} \varepsilon_t^{ck,h} = \varepsilon_t - \dfrac{\sigma_t}{E_0} \\ \varepsilon_t^{pl,h} = \varepsilon_t - \dfrac{\sigma_t}{E_0}\left(\dfrac{1}{1-d_t}\right) \end{cases}$$

$$\varepsilon_t^{pl,h} = \varepsilon_t^{ck,h} - \frac{d_t}{(1-d_t)}\frac{\sigma_t}{E_0}$$

3.3.2 Damage Parameters

The concrete's damage parameters which included damage in tension as well as damage in compression were calculated based upon the concrete's compressive and tensile strength beyond the cracking phase using the equations derived in the research.

$$d_c = 1 - \frac{\sigma_c}{\sigma_{cu}}$$

And for tension the damage parameter was determined by:

$$d_t = 1 - \frac{\sigma_t}{\sigma_{t0}}$$

It should be noted here that for the development of simplified concrete damaged plasticity model for our case the ultimate stress (Yield stress) was selected by us which was taken to be as 48.5 MPa. The second most important parameter was tensile strength of concrete whose value for our formulation of 7NC20 was 5.52 MPa.

3.4 ABAQUS BEAM MODELLING PARAMETERS

3.4.1 ABAQUS OVERVIEW

ABAQUS is one of the software for finite element analysis. Due to its wide collection of resources and elements, as well as its capacity to be adapted for 1, 2, and 3-D scenarios, ABAQUS has become popular in teaching and research institutes. ABAQUS was created by Hibbit, Karlsson and Sorensen and later acquired by Dassault Systemes Simulia.Corporation (DSS) [16].

ABAQUS/CAE, ABAQUS/Standard, and ABAQUS/Explicit are the three core products of the ABAQUS product portfolio.

ABAQUS/CAE is an FEM based graphical software that permit users to build, analyze, and assess the results of the FEM based model all in one spot by taking help from a customized graphical interface (GUI). Users can develop geometries by playing with the Graphical User Interface (GUI) and by including drawing models such as CAD models for meshing in ABAQUS/CAE. From here on researchers can perform analysis on the models and explain the findings using many visualization choices.

ABAQUS/Standard employs solution approaches that are well suited to constant and slow-paced Dynamic Simulations.

For the purpose of this research ABAQUS v6.14 has been utilized to model and study the behavior of all the beam formulations.

3.4.2 Modelling the Compressive Nature of Concrete

The elastic response of concrete can be ascertained by performing the ASTM test of C649 and determining the stress-strain relationship of concrete. However, for the post stress-strain behavior, specialized equipment is required to determine for analyzing the plastic behavior. For this reason, literature was referred to determine the compressive strain beyond the cracking phase as have been mentioned earlier and a simplified concrete damage plasticity model [15] was used. The Kent and Park Model for confined and unconfined concrete was used for compression behavior [17].

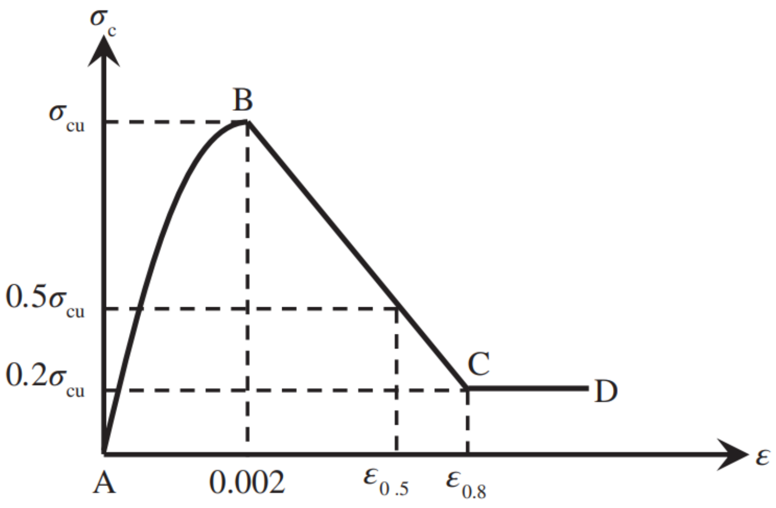


Figure 3.13 Kent and Park Model for concrete

The elastic response was recorded by performing the test for Elastic modulus while a spreadsheet function incorporating the formulae [15] is employed to produce the post stress-strain behavior.

3.4.3 Modelling the concrete's Tensile Behavior

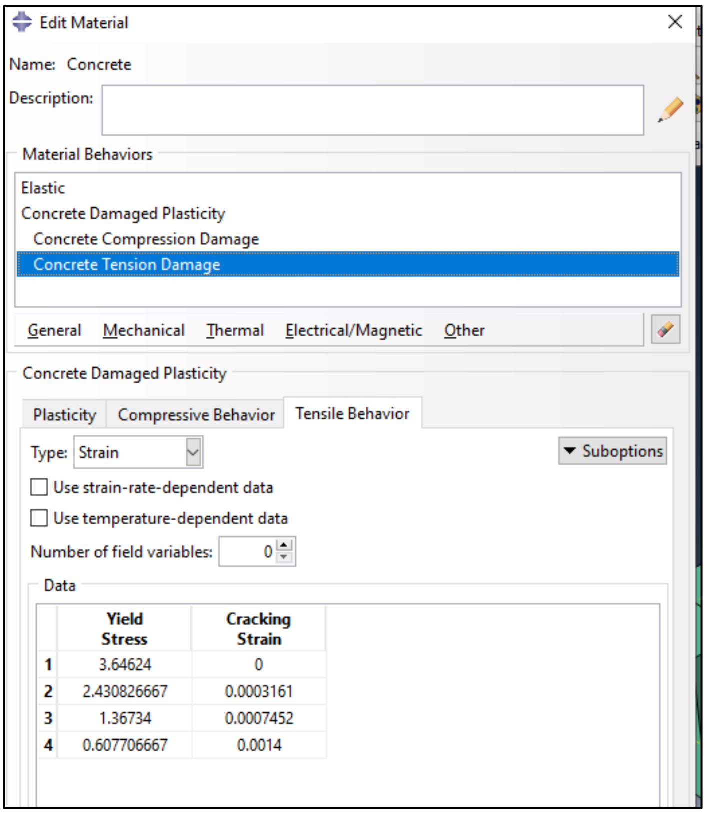


Figure 3.14 Concrete Tension Damage

The tensile strength of concrete is naturally in range between 8%-12% of the concrete's compressive strength. There are various experimental assessments to determine the tensile strength of the concrete which include splitting tensile strength, direct tension test and the prism test or modulus of rupture test. For the purpose of this research the splitting tensile strength was determined using experimentation and it was then used to determine the tensile behavior of concrete and then accurately model it in ABAQUS.

Therefore, a modified tension stiffening curve as proposed by Said M. Allam[18] has been utilized to determine the post-cracking tensile behavior. The following curve has been used:

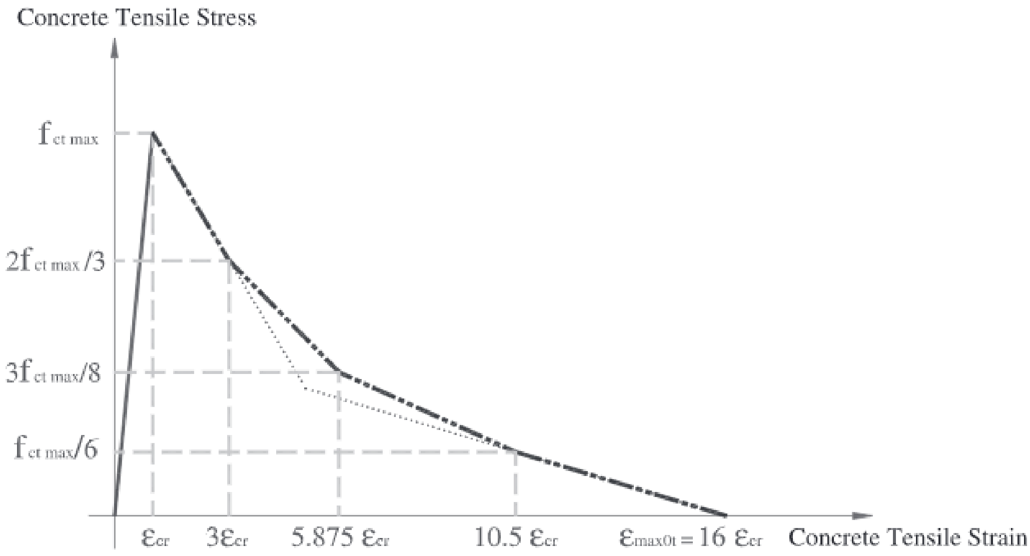


Figure 3.15 Modified tension softening curve [18]

Tension stiffening refers to the capacity of the concrete to bridge among cracks to transmit tension, a fact that aids in the controlling of a constituent's deformation and the enlargement of cracks. To incorporate this phenomenon into modeling, ABAQUS requires researchers to input a post-peak reaction of the concrete specimen in tension in order to model the interlinkage between the reinforcement and the concrete specimen. For this research tensile stress has been determined as function of cracking strain from the modified tension stiffening curve [18] to introduce in the FEM model of ABAQUS.

3.4.4 Concrete Modulus of Elasticity (CME)

ASTM recommends a method for determination of elastic modulus by means of performing the experiment for Elastic Modulus according to ASTM C469. This test prescribes an accurate method of determining the Elastic Modulus. The modulus elasticity (ME) of concrete is impacted by a range of parameters, comprising of compressive strength of the concrete, aggregate, and mortar characteristics, and loading rate. To evaluate the ME of concrete, various relationships have been developed. For concrete with varying densities between 1500 and 2500 kg/m3, ACI 318-19 has also proposed the following equation to be used when the experimental data is lacking:

Ec =57000 $\sqrt{f'c}$ For Psi

Or Ec =4700 $\sqrt{f'c}$ For MPa

3.4.5 Poisson Ratio (υ):

One of the important material parameters required for defining the concrete properties inside of ABAQUS/CAE is the Poisson's ratio. The Model code 2010 specifies the Poisson's ratio of concrete to be in the range of 0.15 - 0.26 which is reaffirmed by most of the research as well [20,21]. This limit corresponds to the compressive stresses in range from between -0.6 f_{ck} and 0.8 f_{ck}. Here "f_{ck}" represents the compressive strength of concrete which is arbitrarily determined as $f'c$ -1.6MPa [19]. For this study, the Poisson's ratio of 0.20 has been selected for all the beam simulations.

3.4.6 GFRP bars' Modulus and Tensile Strength

GFRP bars belong to a family of FRP composites. Being brittle in nature these bars have a sudden disadvantage as compared to steel that undergoes yielding prior to failure. However, to define the material properties of the GFRP bars we must introduce the Tensile Modulus and Ultimate strength to model their elastic behavior. For this purpose, the values of modulus and tensile strength have been taken from table 3.7 to introduce the material parameters of GFRP bars. The diameter has been varied between 10 mm – 16mm.

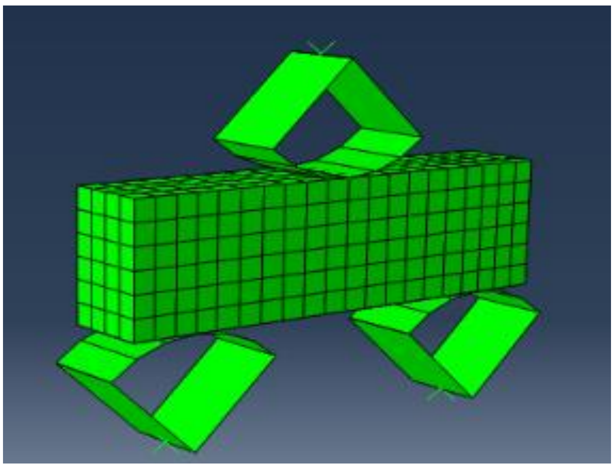


Figure 3.16 FEM model of 750 mm beam

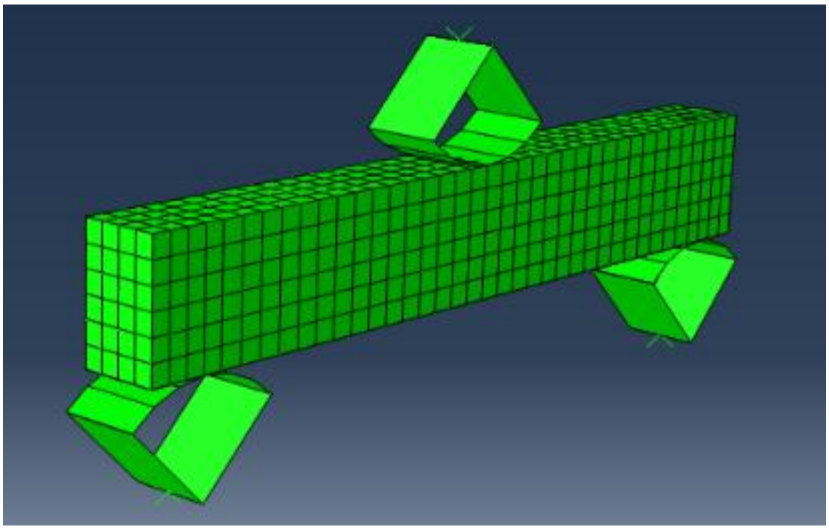


Figure 3.17 FEM model of 1500 mm beam

3.5 CONCRETE BEAM MODELLING

The beams cross sections were finalized using ACI 440.IR-15. Two 12mm GFRP Rebar's ordered from T-ROD International were used as main reinforcement and 2-12 mm GFRP rebar's have been employed as compression reinforcement. Beam with span of 750mm and 1500 mm were being modelled on Abacus Software. Materials perimeters imported in ABAQUS software include young's modulus, poissons's ratio, Dilation angle, Eccentricity etc.

3.5.1 Beam parts and Section assignment

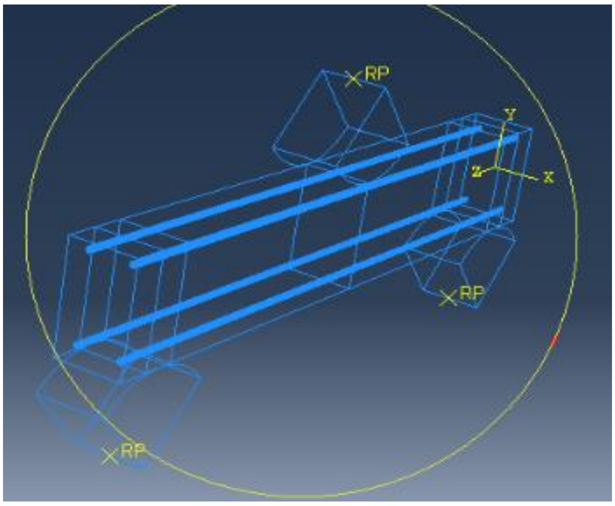


Figure 3.18 Model of beam with reinforcement incorporated

Using the ABAQUS's interface, each beam's geometry was modelled in 3-D. The model is built by developing components, which are then connected to form the final model. Each element is a separate piece of geometry with its own "Section." A section is a collection of data on the features of a part or a segment of a part. This section's attributes are determined by the type of part being under consideration. So, every piece of material is given a unique name and is not associated with any one particular section. As a result, the user can designate a specific content to as many sections as needed. To clarify, the technique for assigning properties to a part is as follows:

1. Creating the material
2. Creating the section
3. Assigning material properties to respective section
4. Assigning section to respective component

The beam model can be divided into two parts:

- The concrete section
- GFRP reinforcement

Rectangular geometry of beam made up of the concrete was the initial component. The GFRP Reinforcement was the second part. Each part was built separately, with section and material parameters assigned, before being assembled to form the final mode. A Homogenous solid section was employed for defining properties of concrete parts.

Concrete Element Section

Due to the vast element library provided. This section contains an explanation of the elements used to model concrete. The "family" of an element defines the geometry it adopts. As illustrated here, the following group of elements can be introduced into the software:

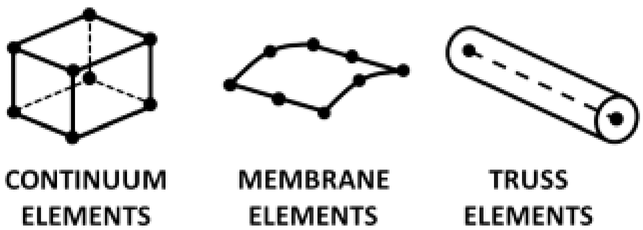


Figure 3.19 Element Families [16]

In this study Continuum elements are used for Finite modelling of concrete since the concrete beams are rectangular in nature and so we have used these elements since they increase efficiency of analysis [**22**].

3.5.2 Beam Boundary Condition

The figure shows the boundary conditions for thee beams which have been displayed as 1,2 and 3 each referring to a separate directional axis. "1" represents the directions that occur in a direction out of plane. "2" represents the directions that are perpendicular to the longitudinal direction and "3" is the direction that is along the longitudinal direction. Simply supported beams were used to test the beams. The loading was controlled by employing a constant displacement rate. All this was incorporated to analyze the post cracking response of the beams.

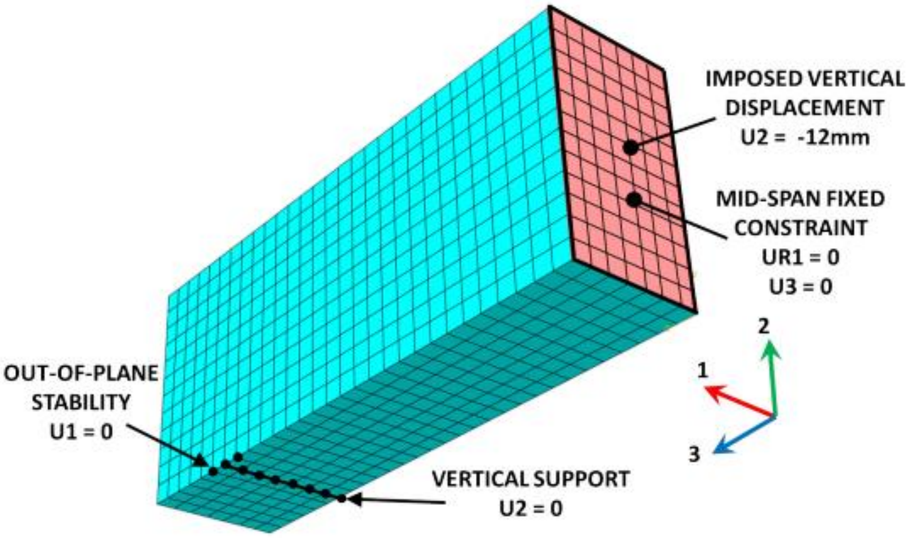


Figure 3.20 Element Families [22]

3.5.3 Time step incrementation

One or more analysis "steps" must be defined before analysis may begin. Variations in the model's loading and boundary conditions, variations in the interactivity among sections in the created beam model, change in examination technique, and other alterations that may happen during evaluation are all captured in the sequence of stages.

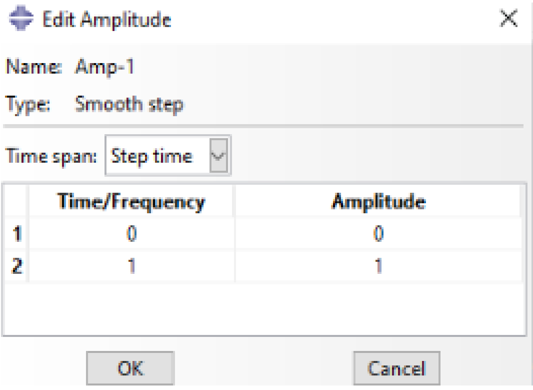


Figure 3.21 Time Step Increment

3.5.4 GFRP reinforcement modelling

There are two basic methods for the provision of reinforcement to the concrete i.e.

- Separate 1-D truss components
- Reinforced membrane sections of smeared nature

3.5.4.1 FE modelling of Damage in Concrete

The concrete when loaded, more than the elastic region and its plastic strains are introduced, successive un-loading of this respective concrete will result in a reduced as well as disrupted elastic modulus. Consequently, for precision of the concrete damage modelling parameters, the damage parameters d_t and d_c holds utmost importance. Now we have already discussed the method for determining the damage parameters in the previous section using the formulae described by Said M. Allam [18].

3.5.4.2 Plasticity Modelling (PM)

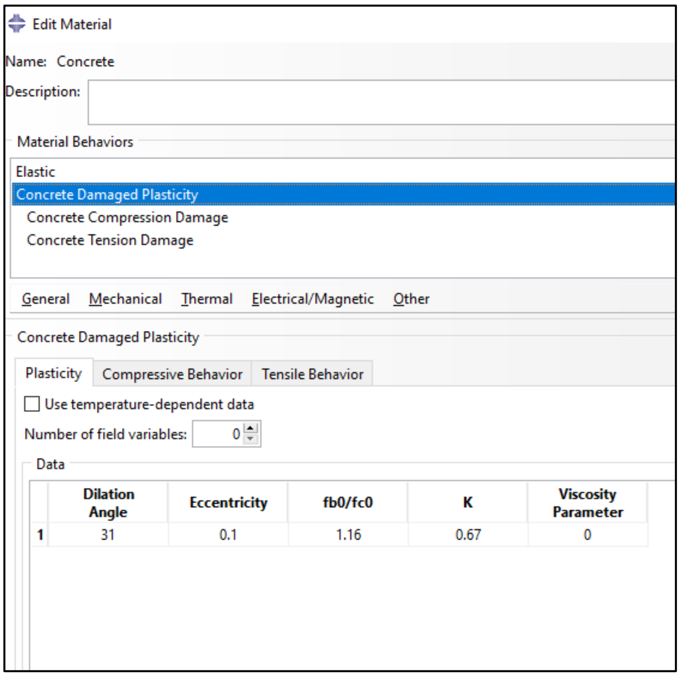


Figure 3.22 Material Parameters

Five factors that influence Plastic behavior of concrete are dilation angle, f_{bo}/f_{co}, K_c, and coefficient of viscosity are used to govern plastic behavior for a Concrete Damaged Plasticity Model. The yield function is directly influenced by the parameters f_{bo}/f_{co} and K_c. For the purpose of this research, the default of 1.16 was utilised for f_{bo}/f_{co} in which "f_{bo}" represents the initial-equibi-axial compressive yield stress" f_{co}" represents the initial-uniaxial compressive yield stress. For all beam simulations, the value of 0.6667 was applied for K_c which is the factor that defines the structure of the collapse inside the deviatoric plane. The goal of this part is to look at how these factors, affect the modelling of beams without stirrups.

3.5.5 Dilation Angle (DA)

The DA is an important characteristic parameter used to govern the plastic flow potential CDP Model. At high confining pressures, this angle represents the tendency of plastic flow potential. Literature suggests that smaller dilation angles of around 10 degrees resulted in relatively brittle beam failure, whereas larger angles of degree greater than 40 resulted in more ductile responses with greater peak loads [23]. The dilation angle has been selected as 31 degrees for both the uni-axial tension and compression in this research for all the beam simulations. This value has been selected keeping in view the model proposed by Lee, J. and Fenves, G. (1998) [24]. The general specified by various researchers is between 30-40 degrees.

3.5.6 Mesh Refinement

The mesh refinement is an important parameter and the mesh size that yielded the best results whilst engaging minimum resources was selected. Mesh patterns are important since they directly govern the amount of accuracy, and precision the model will have.

CHAPTER 04

EXPERIMENTAL TESTS AND RESULTS

4.1 Compression Strength of Cylinders

The cylinders of 100 mm by 200 mm for all the formulations were tested under compression and the results have been displayed below:

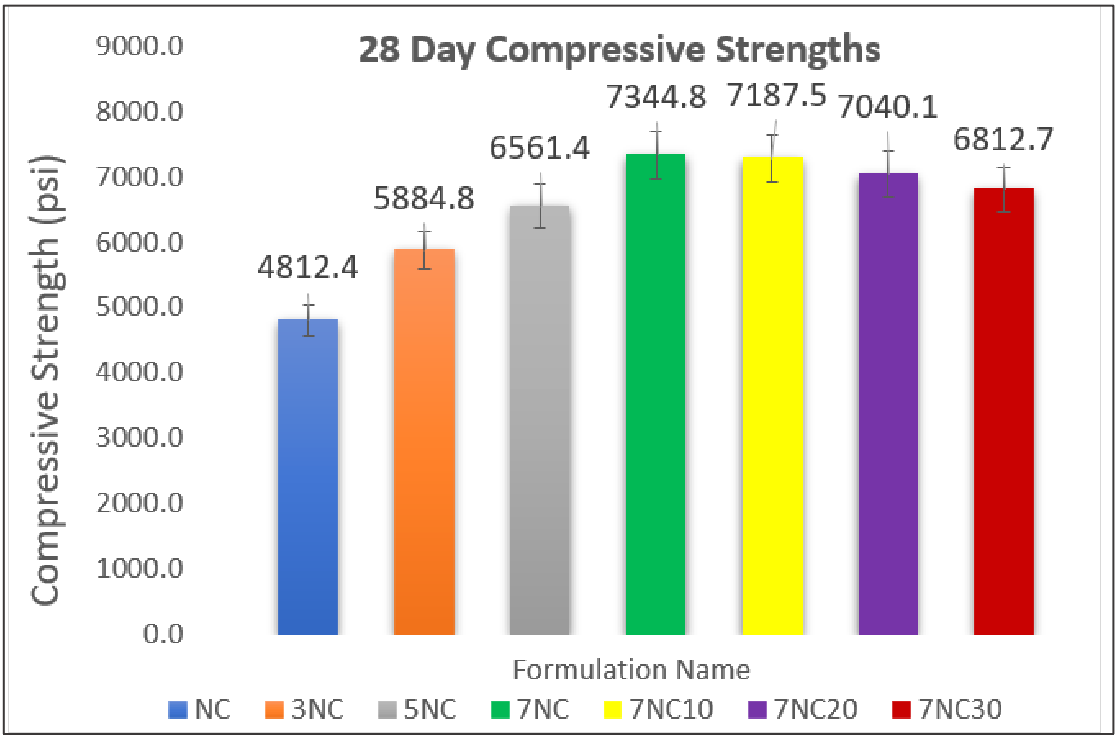


Figure 4.1 Compressive strengths of Cylinders

As can be seen that the concrete gains strength upon the addition of Silica Fume as an admixture and a high strength concrete is achieved for the formulation of 7NC. A compressive strength of 7344.8 psi is achieved for a period of 28 days. The strength of concrete decreases upon the addition of Recycled coarse aggregate as replacement of natural aggregates as can be seen by the strengths of 7NC10, 7NC20, 7NC30.

For the formulation of 7NC20 the decrease in strength from the 7NC one was 4% and for the 7NC30 one it was around 7.3%. Since, 7NC20 offers greatest replacement of natural aggregates with minimal decrease in strength therefore it was taken as the concrete for casting of beams.

In the following tables the compressive strength of 7NC10, 7NC20 AND 7NC30 for 7, 14 and 28 days have been recorded

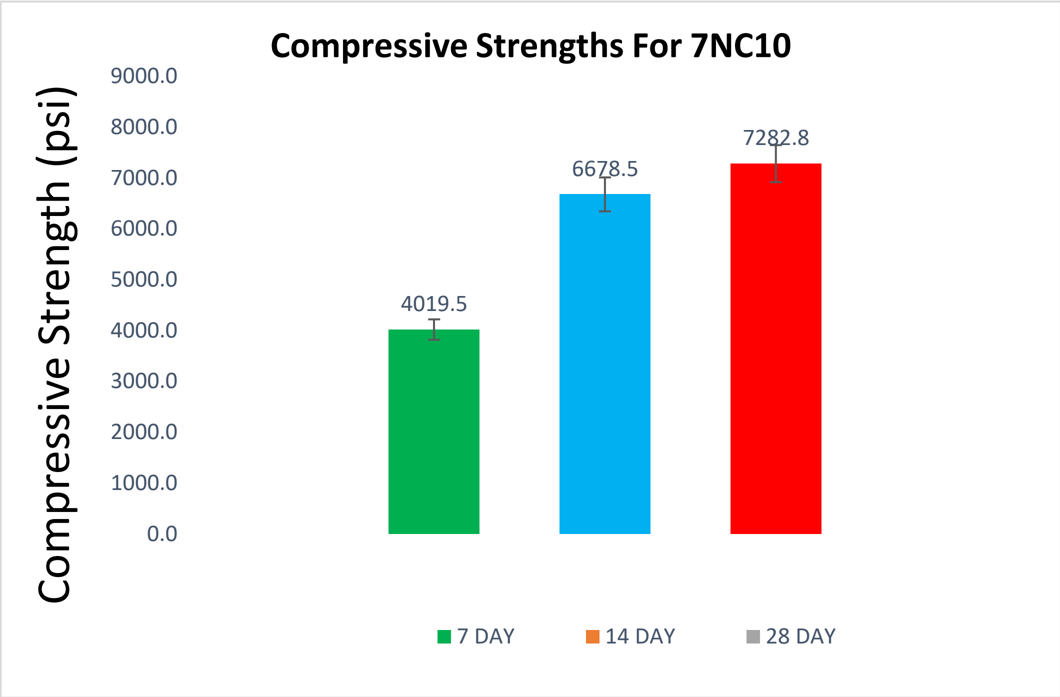


Figure 4.2 Compressive strengths for 7NC10

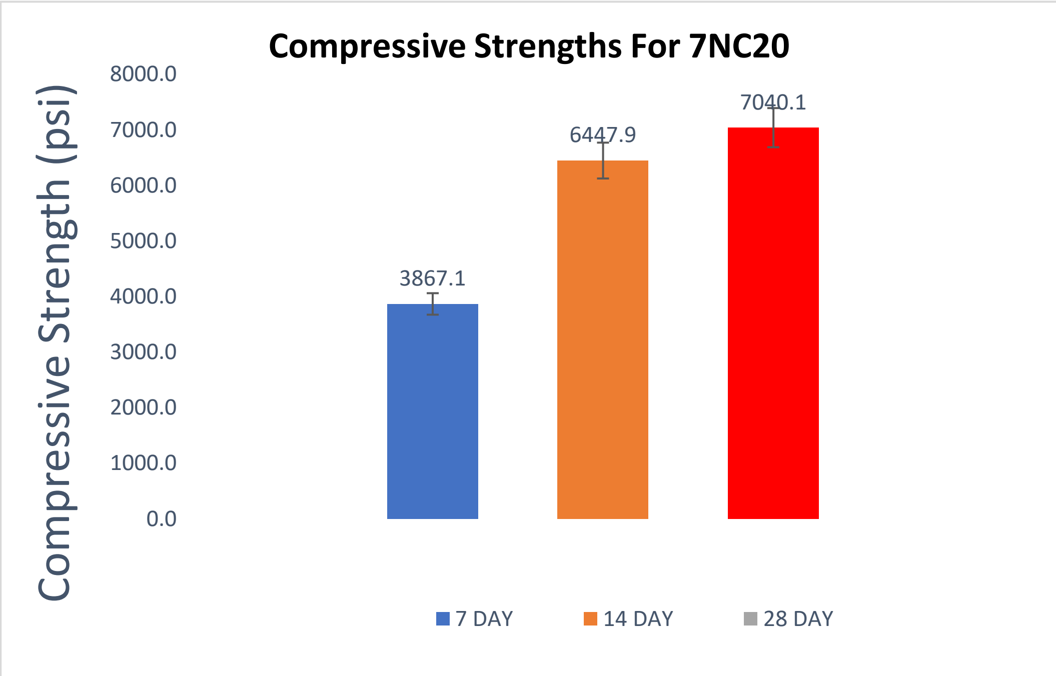


Figure 4.3 Compressive strengths for 7NC20

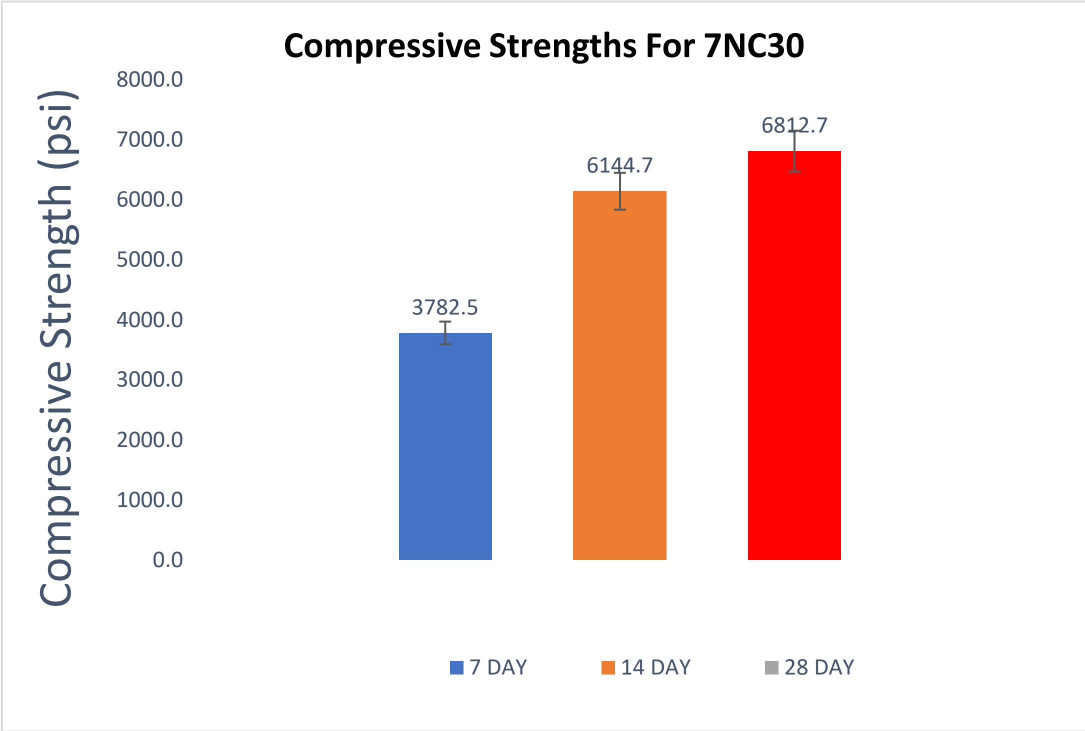


Figure 4.4 Compressive strengths for 7NC30

4.2 Behavior of beams reinforced with GFRP bars

4.2.1 750 span beams

The beam of span 750 mm failed in shear failure since the shear stirrups were not provided. The beam initially failed in shear failure followed by the rupture of the FRP bars. The ultimate load for the beam was 143.85 KN. The failure of the beam is shown in the figure:

Figure 4.5 Failure of GFRP reinforce 750 mm span beam

4.2.1.1 Load Deflection Curve

The LVDT was utilized to determine the maximum deflection and the plot the corresponding load deflection curve.

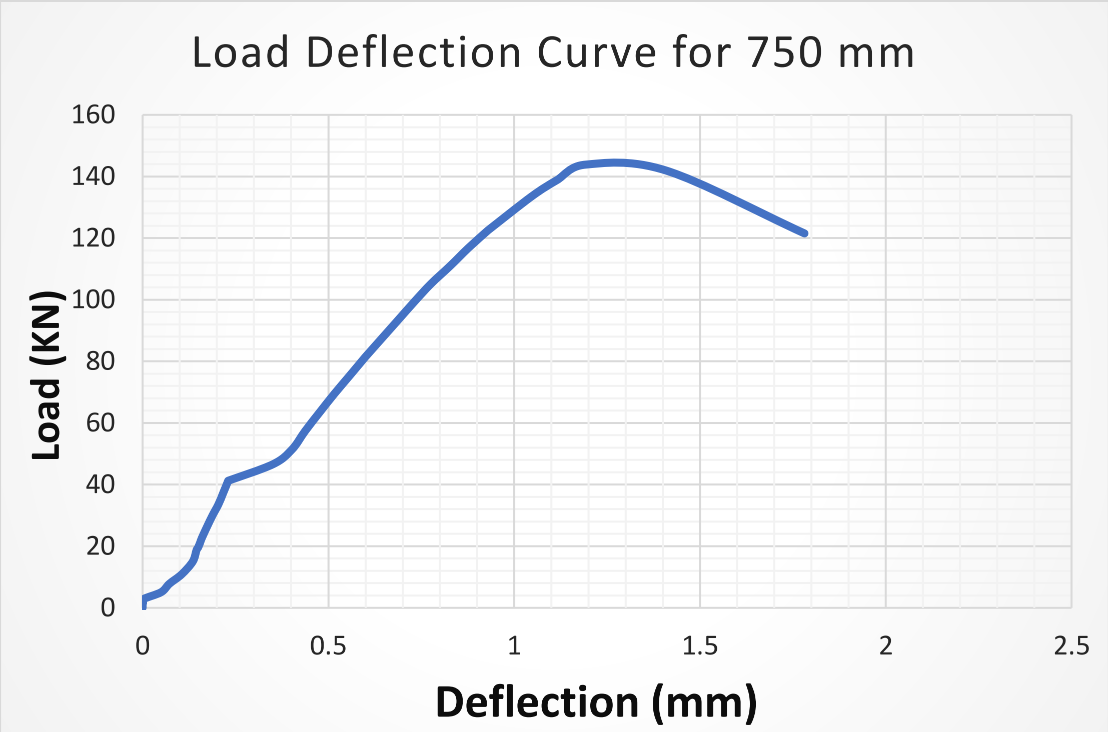


Figure 4.6 Load deflection Curve for 750mm

4.2.2 1500 Span Beam

The bigger span beam failed with the occurrence of multiple flexure cracks and greater amount of deflection at the midspan. The beam's ultimate failure was characterized by appearance of multiple flexures as well as flexure-shear cracks that lead to the failure of the beam.

Figure 4.7 Load deflection Curve

The ultimate load for this beam came out to be 62.05 KN. The load deflection curve has been plotted below:

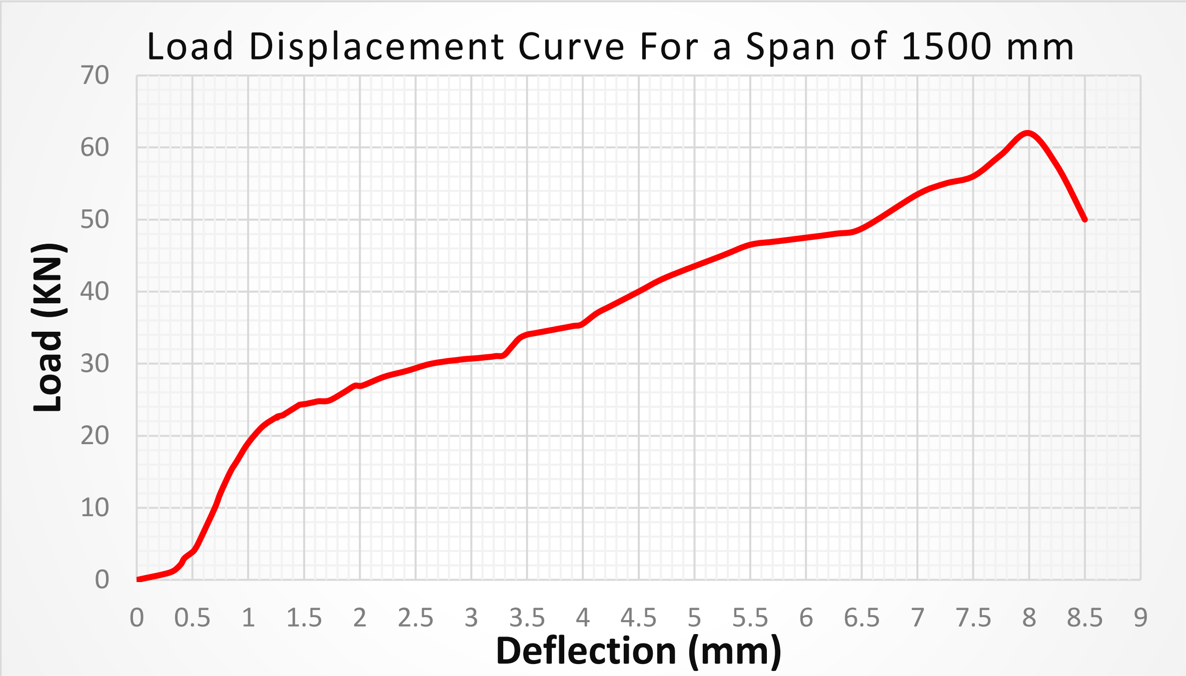


Figure 4.3 Load deflection Curve for 1500 mm

4.3 ABAQUS Model

4.3.1 750 mm Beam

Now the beams were modeled in ABAQUS to sufficient accuracy and the results were then compared to determine the accuracy of the ABAQUS model. It was observed that the ABAQUS model predicted the ultimate loads with sufficient accuracy. The failure modes for the 750 mm beam as predicted by the software are shown here:

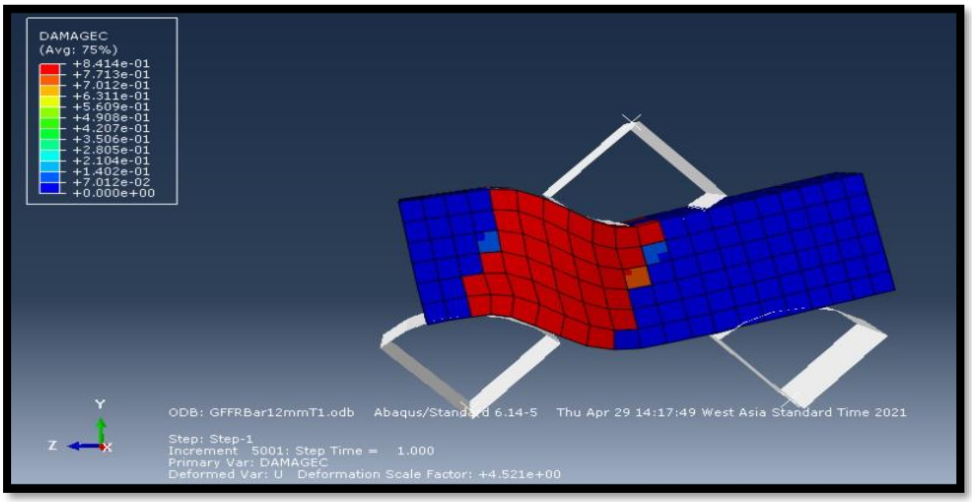


Figure 4.7(a) Damage in Compression

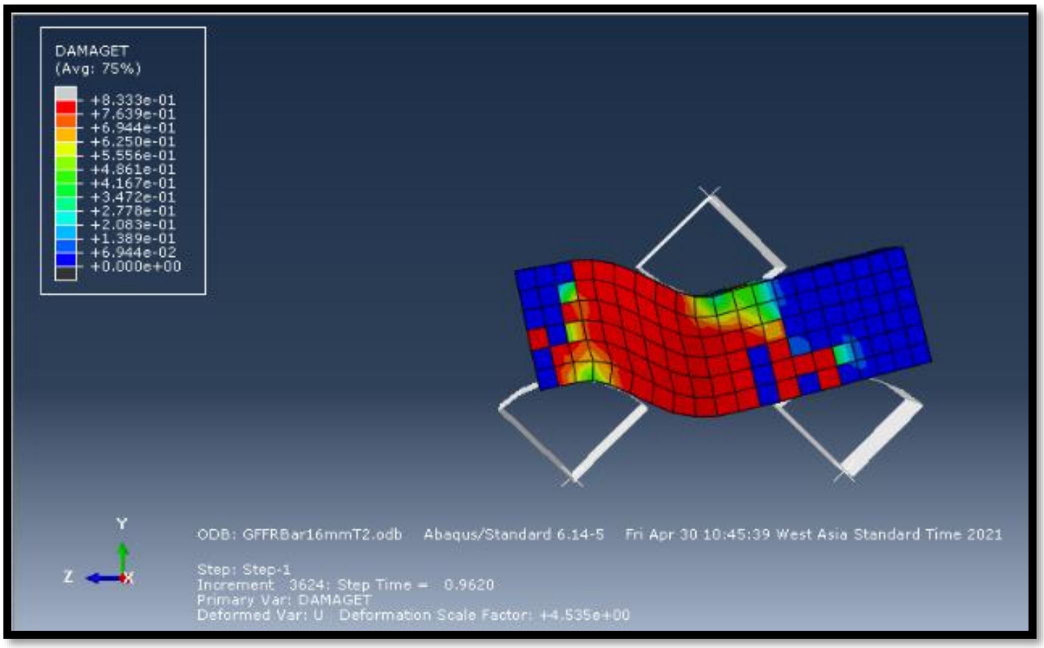


Figure 4.7(b) Damage in Tension

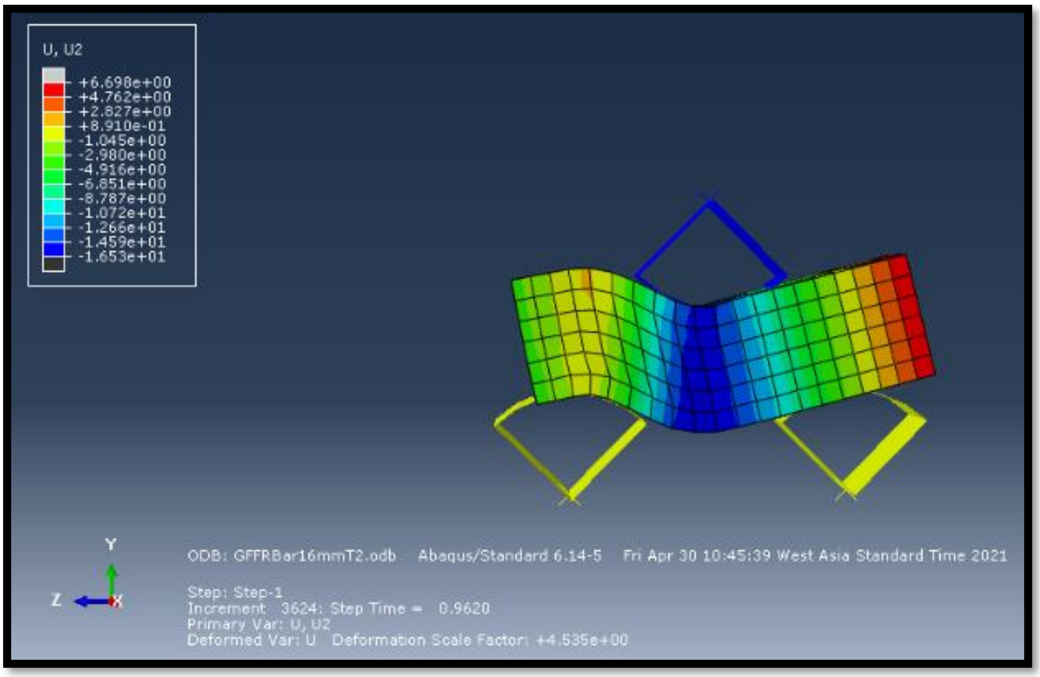


Figure 4.7(c) Vertical Deflection U2

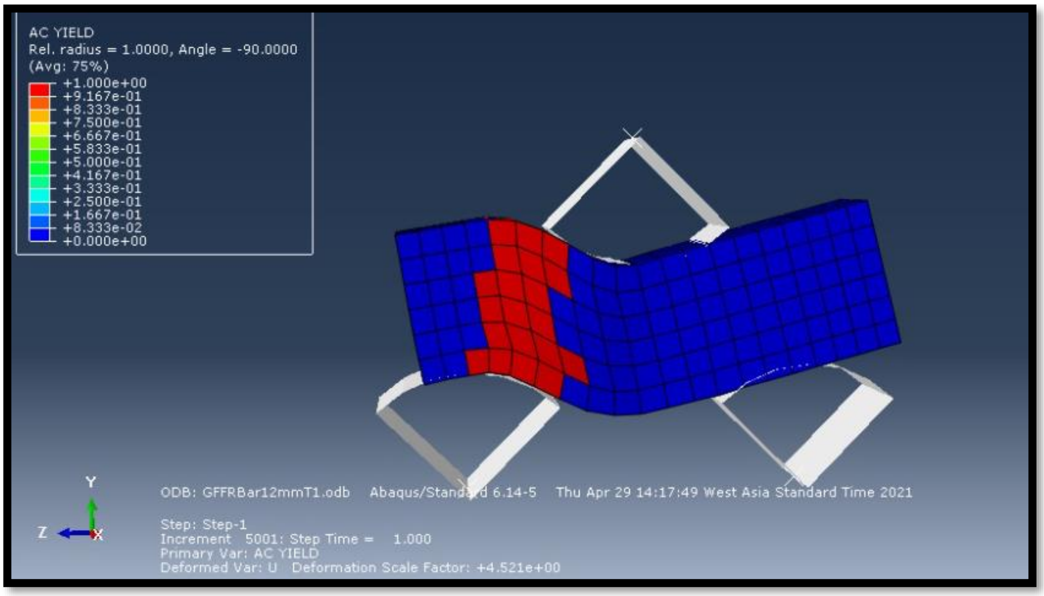


Figure 4.7(d) AC Yield of the 750mm beam

The load deflection curve for the 750 mm span has been plotted and its comparison with the experimental data has been shown:

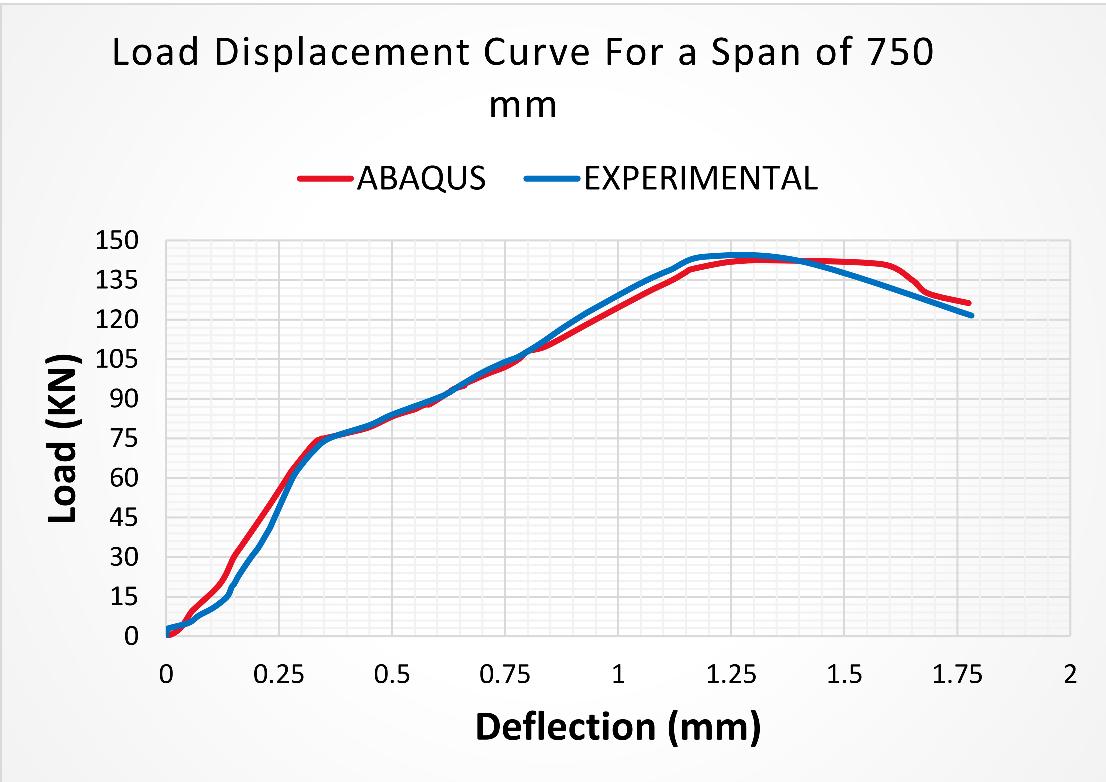


Figure 4.8 Load displacement Curve of 750 mm

The similar ABAQUS model was used for the purpose of determining behavior of different diameter GFRP bars in concrete. The following load deflection curves were obtained for beams with bar size of 10mm (A_f =157 mm^2) and 16 mm (A_f =402 mm^2).

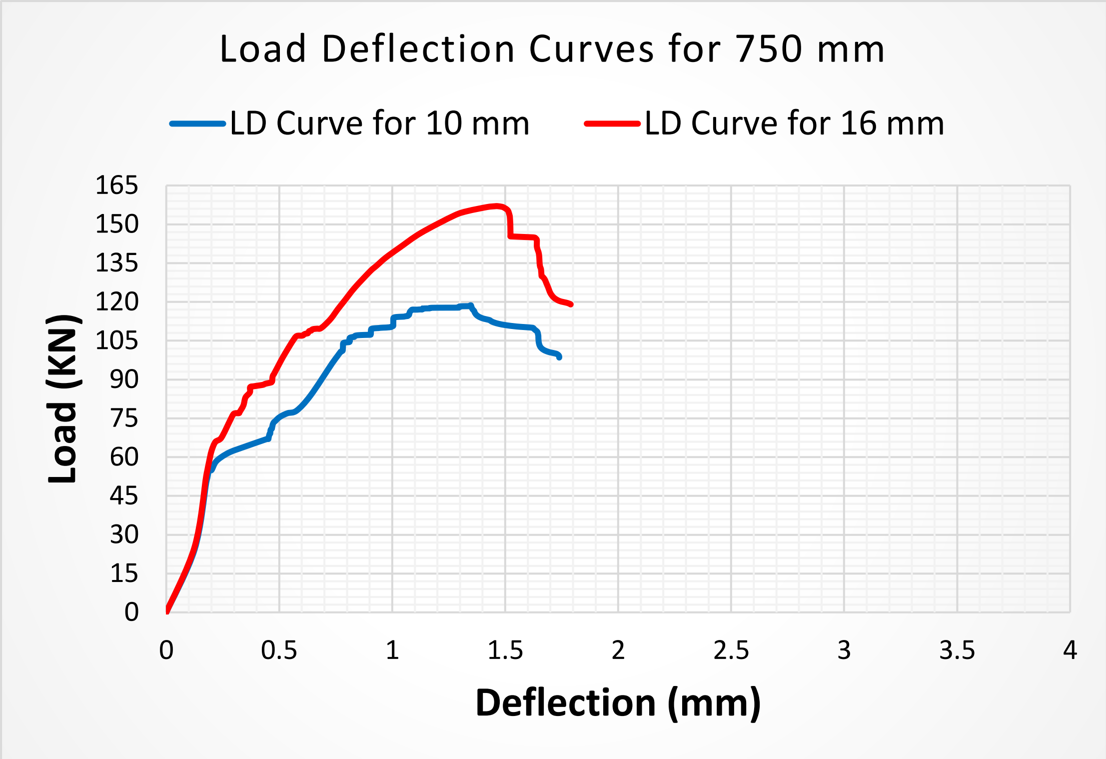


Figure 4.9 Load deflection Curves for 750 mm

4.3.2 1500 mm beam

In a similar manner in order to draw a comparison between the 1500 mm experimentally tested and the one prepared in the ABAQUS model the value of ultimate loads and modes of failure were compared. The failure modes for 1500-12 beam have been shown here:

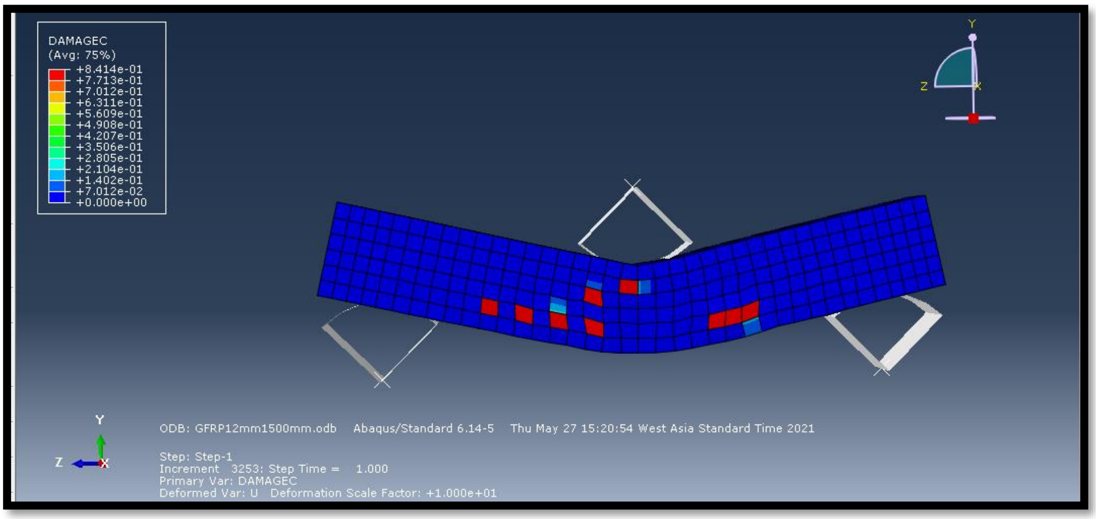


Figure 4.9(a) Damage in Compression for 1500 mm beam

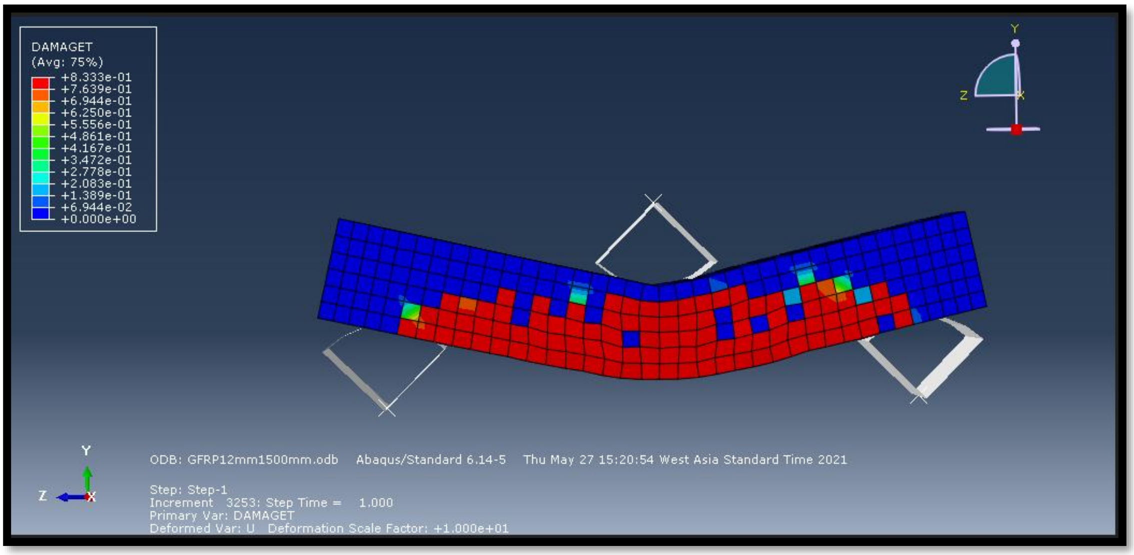


Figure 4.9(b) Damage in Tension for 1500 mm beam

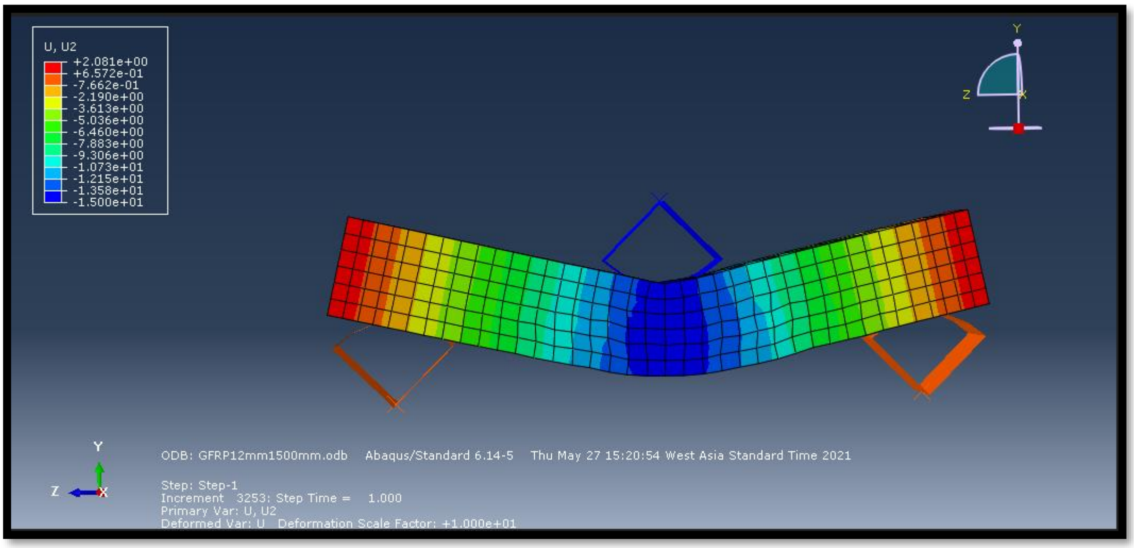


Figure 4.9(c) Vertical Deflection U2 for 1500mm beam

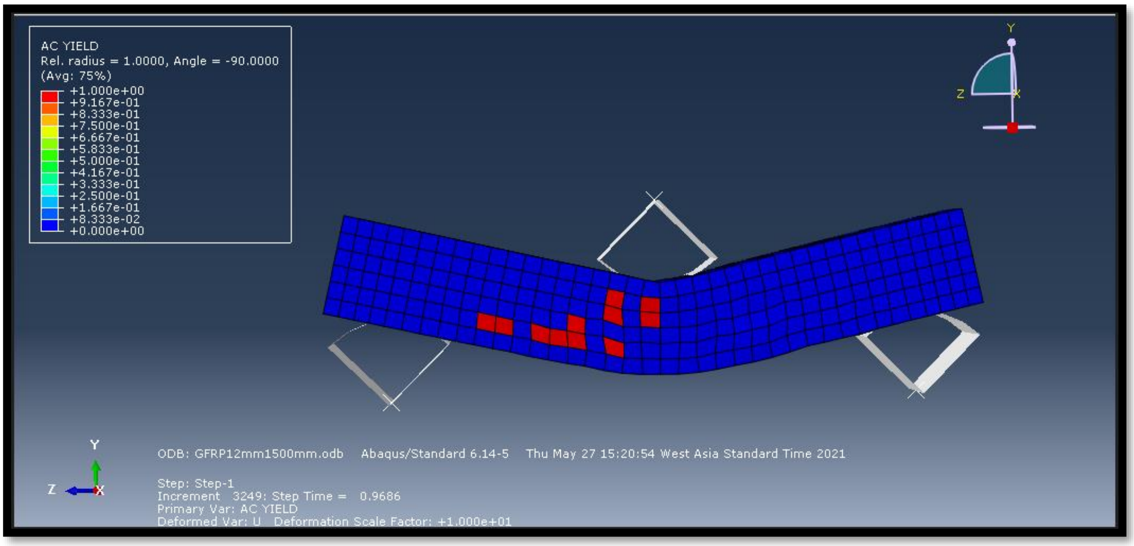


Figure 4.9(d) AC Yield of the 1500mm beam

The following load deflection curves were obtained:

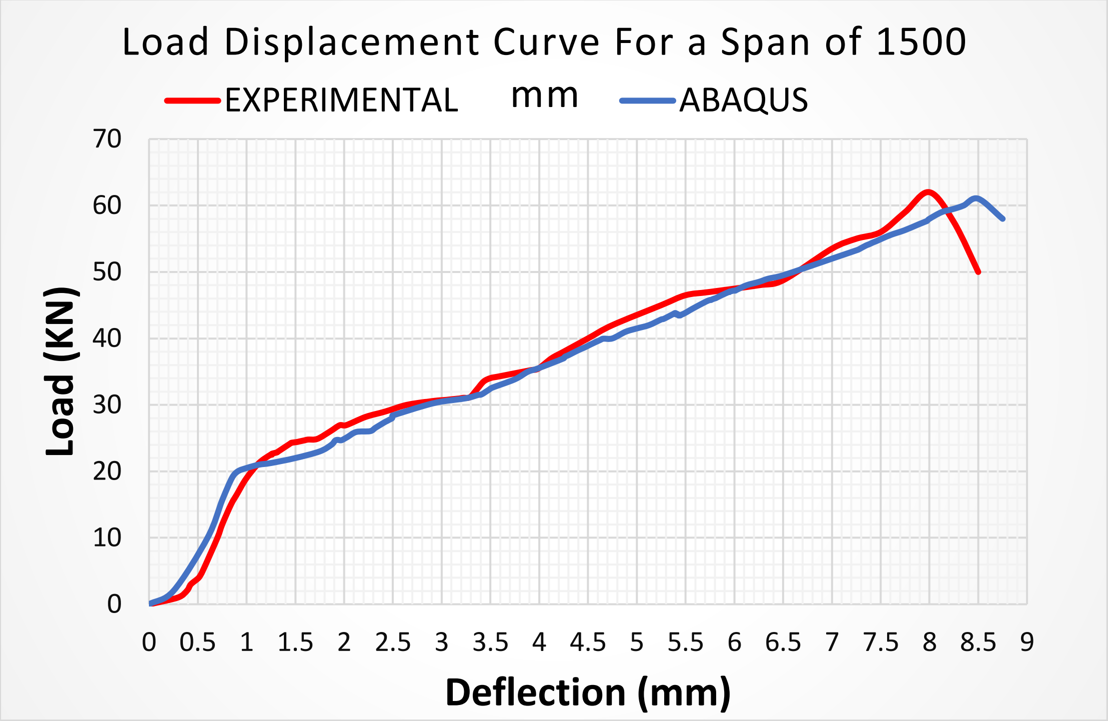


Figure 4.10 Load deflection Curve for 1500mm span

As can be seen that ABAQUS results are in line with the experimental data. Therefore, this Model was further utilized to model the behavior of different diameter bars in the 1500 mm beam. The plot for beams with bar size of 10mm (A_f =157 mm^2) and 16 mm (A_f =402 mm^2) are shown below:

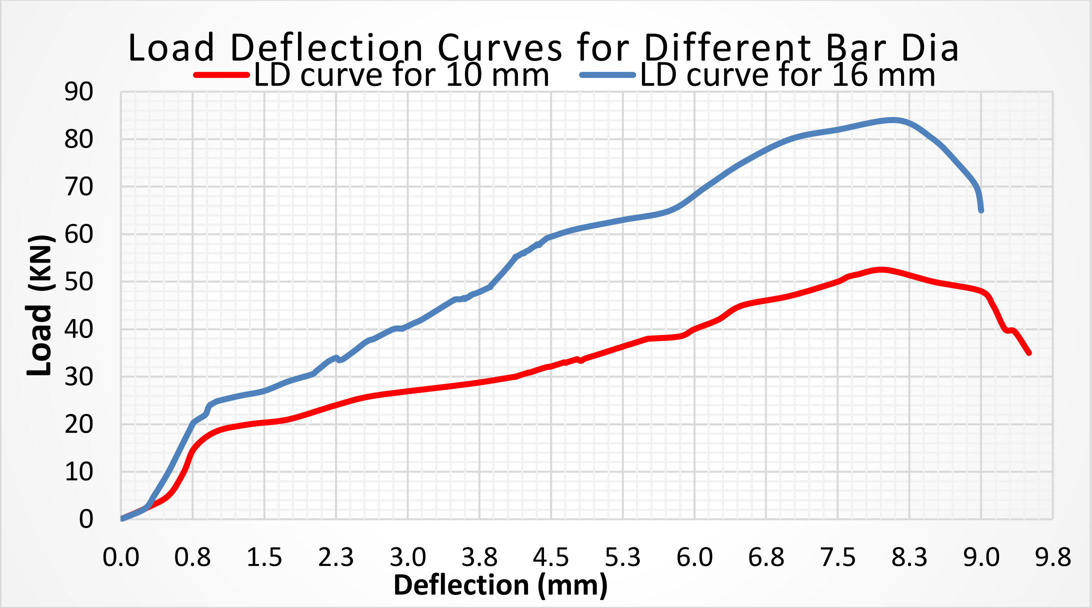


Figure 4.12 Load deflection Curve for 1500mm span

The details of the results for both the beams have been displayed in the table below:

Table 4.1 Beam properties

Beam Notation	**Diameter of Bar (mm)**	**Experimental Ultimate Load (KN)**	**ABAQUS Model (KN)**	**Percentage Difference**
750-12	12	143.85	142.65	0.8%
1500-12	12	62.015	61.025	1.6%

4.4 Cost Comparison

A detailed cost comparison was performed taking into the account that the concrete composition of 7NC20 yielded favorable results. So, a detailed cost analysis has been carried out to determine how much does the replacement of Natural Aggregates with Recycled Coarse Aggregate affects the concrete cost. In the following lines the details have been summarized. The cost comparison has been carried out on three different levels. These include determining the effect RCA, GFRP bars and RCA and GFRP bars combined would have on cost of concrete.

4.4.1 Recycled Coarse Aggregate Concrete Cost Analysis

For this purpose, prices were calculated for a normal concrete cube and another one with RCA as replacement of Natural Aggregates. The following table summarizes the details:

Table 4.2 Cost Comparison with NA

Concrete with Natural Aggregates				
MATERIAL QUANTITES			MARKET RATE	PRICE (PKR)
ITEM	QUANTITY	UNIT		
Cement	363.12	kg	Rs 620/bag	4502.73
Sand	609.11	kg	Rs 10/kg	6091.11
Natural Aggregate	800.43	kg	Rs 9/kg	7203.91
Silica Fume	27.33	Kg	Rs 105/Kg	2869.85
Total	Rs 20667.60			

Concrete with RCA				
MATERIAL QUANTITES			MARKET RATE	PRICE (PKR)
ITEM	QUANTITY	UNIT		
Cement	363.12	kg	Rs 620/bag	4502.73
Sand	609.11	kg	Rs 10/kg	6091.11
Natural Aggregate	640.35	kg	Rs 9/kg	5763.12
RCA	160.09	kg	Rs 2/Kg	320.18
Silica Fume	27.33	Kg	Rs 105/Kg	2869.85
Total	Rs 19547.00			
Savings of 5.42% can be visualized				

Table 4.3 Cost Comparison RCA

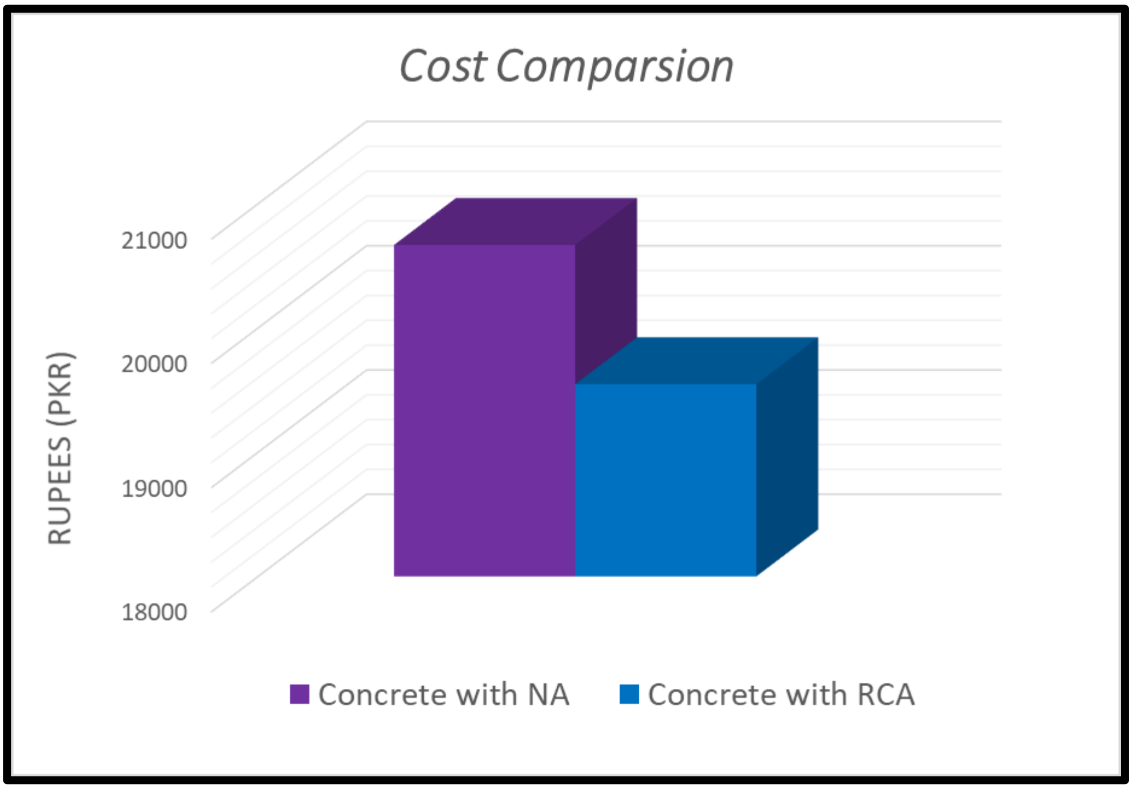


Figure 4.13 Cost Comparison between NA and RCA

4.4.2 GFRP reinforced concrete beam analysis

For analyzing the cost of GFRP rebars in concrete we calculated the equivalent costs of utilizing GFRP reinforcement as a replacement of Steel reinforcement in a concrete beam of size 140 x 230 x 1500 as used in this research. The GFRP bars were of size 12 mm and its price was specified by the supplier. The following tables summarizes the cost analysis:

Table 4.4 Cost Comparison Steel

7NC20 Beam with Steel				
MATERIAL QUANTITES			MARKET RATE	PRICE (PKR)
ITEM	QUANTITY	UNIT		
Cement	17.54	kg	Rs 620/bag	192.93
Sand	29.42	kg	Rs 10/kg	294.20
Natural Aggregate	30.93	kg	Rs 9/kg	278.36
RCA	7.73	Kg	Rs 2/Kg	15.46
Silica Fume	1.320	Kg	Rs 105/Kg	138.62
Steel	0.004393	Ton	Rs 140000/ton	860.94
Total	Rs 1780.35			

Table 4.5 Cost Comparison GFRP

7NC20 Beam with GFRP				
MATERIAL QUANTITES			MARKET RATE	PRICE (PKR)
ITEM	QUANTITY	UNIT		
Cement	17.54	kg	Rs 620/bag	192.93
Sand	29.42	kg	Rs 10/kg	294.20
Natural Aggregate	30.93	kg	Rs9 /kg	278.36
RCA	7.73	Kg	Rs 2/Kg	15.46
Silica Fume	1.320	Kg	Rs 105/Kg	138.62
GFRP	5.6	meter	Rs 134/meter	750.4
Total	Rs 1670.00			
Savings of 6.20% can be visualized				

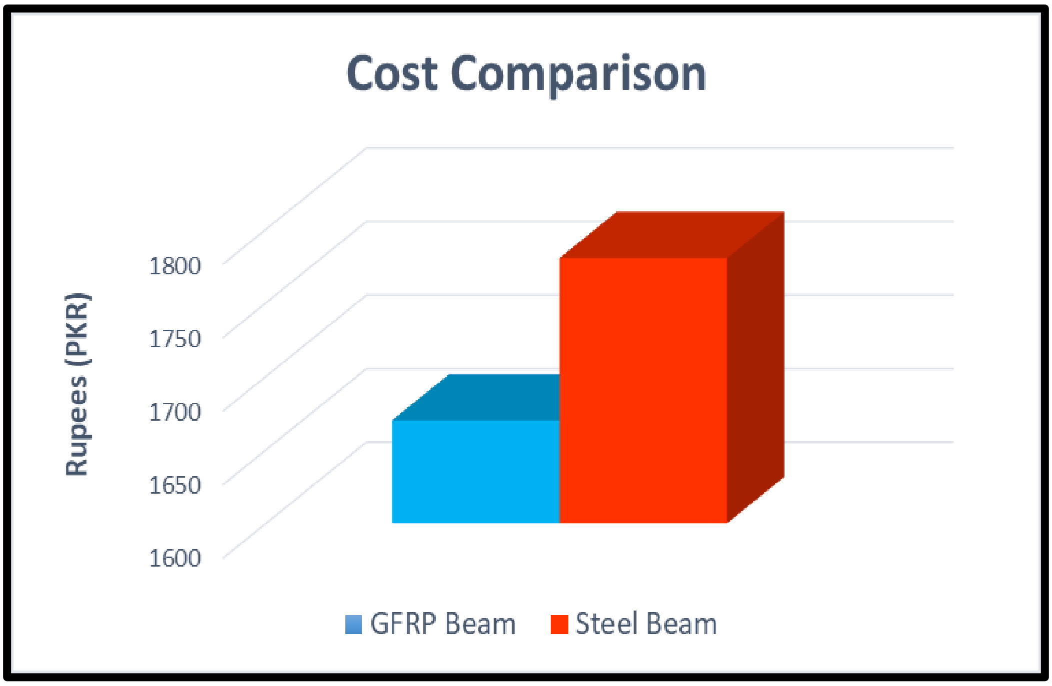


Figure 4.14 Cost Comparison between GFRP and Steel

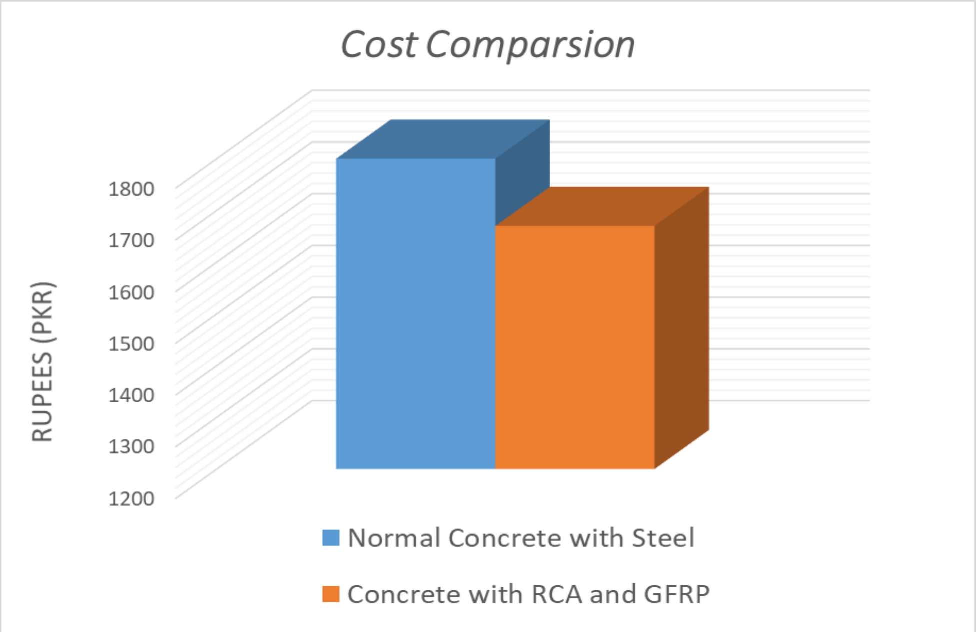
4.4.3 GFRP reinforced RCA concrete beam analysis

In this case the effect of using both GFRP and RCA has been studied on the cost of concrete.

7NC Beam with Steel				
MATERIAL QUANTITES			MARKET RATE	PRICE (PKR)
ITEM	QUANTITY	UNIT		
Cement	17.54	kg	Rs 620/bag	192.93
Sand	29.42	kg	Rs 10/kg	294.20
Natural Aggregate	38.66	kg	Rs 9/kg	347.94
Silica Fume	1.320	Kg	Rs 105/Kg	138.62
Steel	0.004393	Ton	Rs 140000/ton	860.94
Total	Rs 1834.63			

7NC20 Beam with GFRP				
MATERIAL QUANTITES			MARKET RATE	PRICE (PKR)
ITEM	QUANTITY	UNIT		
Cement	17.54	kg	Rs 620/bag	192.93
Sand	29.42	kg	Rs 10/kg	294.20
Natural Aggregate	30.93	kg	Rs9 /kg	278.36
RCA	7.73	Kg	Rs 2/Kg	15.46
Silica Fume	1.320	Kg	Rs 105/Kg	138.62
GFRP	5.6	meter	Rs 134/meter	750.4
Total	Rs 1670.00			
Savings of 9.1% can be visualized				

Figure 4.15 Cost Comparison between GFRP and Steel



CHAPTER 5

CONCLUSIONS

- The incorporation of silica fume maximized the compressive strength of concrete.
- There was a minimum decrease in concrete strength after 20% RCA replacement.
- Use of RCA tends to reduce the cost of concrete by 5.42%.
- Furthermore, incorporation of GFRP increases savings up to 6.20%.
- For the incorporation of GFRP and RCA in a concrete beam savings of up to 9.1% can be visualized.
- The 1500 mm span beam failed in flexure and shear whereas the 750 mm beam failed in pure shear, both then following FRP rupture.
- The failure modes predicted by ABAQUS software were in line with experimental values.
- Finally, an increase in reinforcement ratio led towards concrete crushing failure whereas a decrease in GFRP reinforcement size resulted in FRP rupture.

RECOMMENDATIONS

- The proposed concrete mix should be tested under various durability tests.
- Further tests employing FRP stirrups needs to be carried out to r investigate the behavior of the beams.
- Moreover, the prepared concrete mix should be tested with steel rebar’s to draw a comparison.
- The experimental program should be further extended to check the feasibility of CFRP, BFRP and AFRP bars in RCA concrete mix.

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