BEHAVIOUR OF PCC AND RCC CYLINDERS UNCONFINED AND CONFINED BY UPVC AND HIGH PRESSURE UPVC

SYNDICATE ADVISOR: COL DR. HASSAN FAROOQ

SYNDICATE MEMBERS

NS ABDUL NAEEM (SYN LDR)

NS MUHAMMAD QASIM

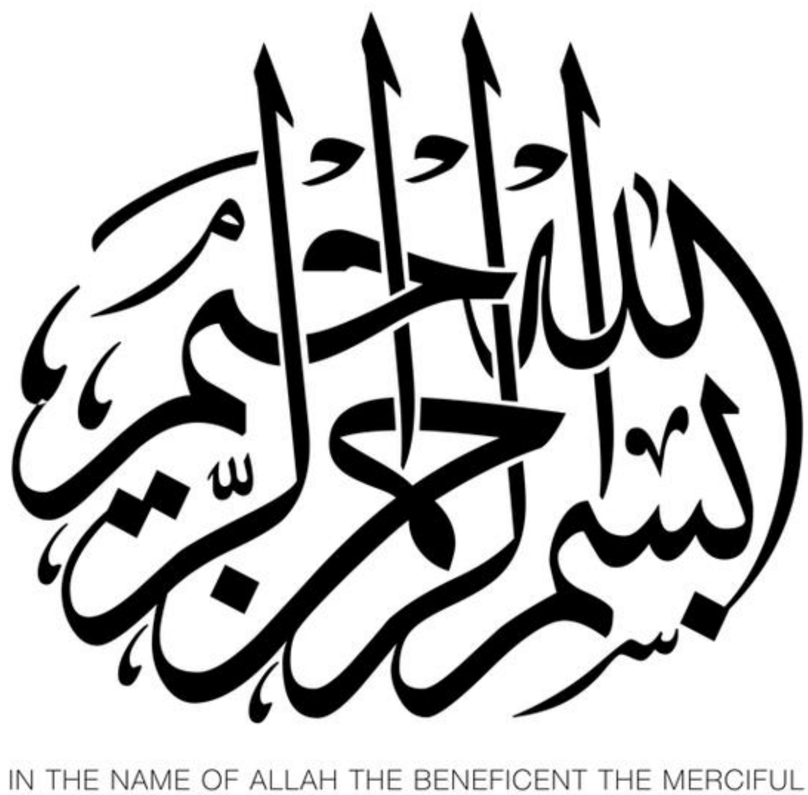
NS AHAD MUSTAFA

NS ASFAR NASIR KHAN

NS MUHAMMAD TALHA AYAZ

NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY

MILITARY COLLEGE OF ENGINEERING RISALPUR



This is to certify that the thesis titled

BEHAVIOUR OF PCC AND RCC CYLINDERS UNCONFINED AND CONFINED BY UPVC AND HIGH PRESSURE UPVC

Submitted by

NS ABDUL NAEEM (SYN LDR)	00000229317
NS MUHAMMAD QASIM	00000237937
NS AHAD MUSTAFA	00000207962
NS ASFAR NASIR KHAN	00000218245
NS MUHAMMAD TALHA AYAZ	00000229209

has been accepted towards the partial fulfillment of the requirements for the degree of

BACHELOR OF SCIENCE

In

CIVIL

ENGINEERING

Col Dr. Hassan Farooq

Associate Professor

Military College of Engineering

National University of Sciences and Technology

Risalpur, Pakistan

ACKNOWLEDGEMENTS

First and foremost, our gratitude goes to Allah Almighty, Who has granted us countless blessings.

We would like to express our deepest appreciation to Col. Dr. Hassan Farooq, our project advisor, who has consistently supported us and sought to provide us with the resources we required for our project. We learned a lot under his supervision and we could not have found a better mentor.

We are also grateful to the technical staff of the Structure Dynamics Lab particularly Engr. Huzaifa of Military College of Engineering, Risalpur Cantonment, for their assistance and cooperation.

The members of our family have been very crucial to us during this time and this would not be possible without the prayer and love of our parents who have been the driving force in all our endeavours.

Table of Contents

Contents

I. LIST OF TABLES

II. LIST OF FIGURES

III. ABSTRACT

The construction industry is always looking for cost effective ways to increase strength and durability of a structure. Steel and FRP based confinement have been used in the past but steel has a risk of strength degradation due to corrosion and FRP is not feasible because of high cost of manufacture.

This project proposes the use of UPVC as a confining jacket for concrete. The project focuses on the comparison of performance of plain and reinforced concrete unconfined, confined by different thickness UPVC and confined by canvas pipe. The thicknesses of the UPVC are . The specimens were tested on (CTM) Compression testing machine limited to 20% of ultimate strength. The machine applied axial load on the face of the cylinder. The results were recorded in the data logger attached with the machine. The results gave us loads with corresponding deformation. From the results, we determined the stress strain curve which provided us with the post peak behaviour of concrete. From the graphs, we found that the confined concrete has an improved strength from the unconfined concrete. The UPVC confined concrete had - times the strength of unconfined concrete. The post peak behaviour was also promising as we found that the confined concrete had improved durability as the concrete deformed at a lower rate than the unconfined concrete.

This project emphasizes on the potential of using UPVC as a confining material. It showed positive results in strength and durability and as it is less expensive than FRP and can withstand aggressive environmental and chemical attacks, it is a more feasible option. This project can be further researched by experimental testing on UPVC confined members i.e columns.

1. INTRODUCTION

1.1 BACKGROUND

Since the dawn of modern Civil Engineering and mass use of concrete, engineers have faced several challenges. Among them, appropriate removal of shuttering, bleeding of concrete, and protection of rebars from rust/corrosion have been one of the most prominent issues. The protection of rebars from corrosion is of greatest importance especially in the regions prone to extreme climatic agents. Reinforced Concrete, when exposed to these agents, begins to deteriorate over time, severely diminishing its physical and chemical properties. In Pakistan, this phenomena can be especially observed in construction along our coastal areas, such as Karachi, Pasni, Gwadar etc. Where several structures have collapsed or lost their integrity over time. As visible from the photos attached below, one of the most affected types of structures are partially-submerged pier columns.

Figure 1

Figure 2

It has been the focus of the researchers to minimize the exhaustion of general concrete ingredients and lessen the use of steel reinforcements. Several attempts have been made and practices have been altered but the main target of replacing and/or re-using concrete on a large scale is yet to be achieved.

Effective retrofitting and increasing concrete life by enhanced protective techniques can contribute to this regard. Recent studies used Fiber Reinforced Polymer (FRP) as a potential contender to provide additional reinforcement to Reinforced Concrete (RC) and as confinement. The results showed an increase in overall load-bearing capacity of the structures, protection against harmful environmental agents, reduced bleeding, and minimised use of shuttering. However, one of the negative aspects of usage of Fiber Reinforced Polymer (FRP), was lack of elasticity available- this coupled with brittleness of concrete, was a distressing blend. This meant that Fiber Reinforced Polymer (FRP) as confinement, never saw much use in the field. In modern times, there has been a lot of work in the development of synthetic polymers, namely Unplasticized Polyvinyl Chloride (UPVC). The UPVC has tremendous elasticity and strength increasing properties, which then utilised correctly can greatly help in eradicating the aforementioned shortcomings. However, since this is a considerably newer product, there has not been much research put into it, especially in the construction industry.

This literature shows use of UPVC as a confining element, significantly refines structural properties of concrete, by increasing its load-bearing abilities, as well as providing it with adequate elasticity, while diminishing the requirement of using shuttering.

1.2 PROBLEM STATEMENT

Construction industry is always looking for new ways and techniques to reduce cost and increase effectiveness. Steel Strips [1] and steel Jacketing [1-3] has been proved to be an effective method to increase both the axial compressive stress and the ductility of concrete thus making it ideal for new construction and retrofitting of rural structures. However, it poses a major con in the form of losing its confinement capacity and strength due to corrosion. It is also susceptible to weathering and chemical effects. Governments in several countries and various high-profile companies are investing to bring new products that are high performance and cost effective. Composite materials are now gaining interest in that regard and one of these composite materials is concrete filled steel tube, which has already been used widely as columns. The steel tubes pose the problem of corrosion which would reduce the effectiveness over longer periods under loading.

To counter this obstacle a search for a new material began. A relatively new method of using FRP (Fiber Reinforced Polymer) wraps and bonds, first proposed by Wolf, R., and Miessler, H.J [4], has become quite common. Researchers have proposed an even more effective method of utilizing FRP is in the form of FRP tubes [5]. It has its variations, depending upon requirements and conditions, in the form of concrete confined in normal PVC pipes reinforced with FRP hoops [6]. This method is more effective as the expensive FRP is used in comparatively less amount and thus eliminates the monetary strain.

FRP has its benefits but when a comparative study was made [7], it was found that the FRP hoops have reduced strain capacity and hence have an almost absolute chance of failing in shear. So in this project, we aim to provide an alternative material/s with the respective scope/limitation in usage. A detailed comparative study was conducted for both RCC (reinforced concrete cement) and PCC (plain concrete cement) encased in normal PVC, pressurized PVC and Canvas pipe. Stress-Strain relationship was drawn, and axial capacity was also compared.

PVC (Polyvinyl Chloride) has several applications in the construction field. It can be used in plumbing or encasing electrical wires. There has been a lot of research on PVC in regard to its longevity. Boersma and Breen (2005) concluded that the service life of high-quality PVC pipe should top 100 years [8]. The 100-year service life expectancy of a PVC pipe was confirmed by Burn in 2005 and Folkman in 2014 [9], [10]. PVC is inherently fire resistant and a good insulator.

According to Kuder et al, PVC as a stay-in-place formwork increases the flexural and compressive strength of the concrete [11]. This means that besides reduction of the construction cost due to no formwork being used, we are getting improved mechanical properties of the member.

UPVC (Unplasticized PVC) is a more rigid version of PVC that is used for water supply or drainage systems. Its thermal conductivity is less than 50% of steel. Its ability to resist environmental or weathering effects is excellent. It can be used for underwater piling or underwater columns. This was validated by Gupta and Verma (2016) when they submerged concrete filled UPVC in artificial sea water having 20 times more salt concentration than normal sea water for 6 months [12]. The results showed that there was no degradation in strength of the concrete, hence it improved the strength and durability.

Table 1: Typical costs of confining materials

Pipe size	**Material cost per meter length (Rs/m)**		
	Steel [13]	**FRP** [14]	**UPVC** [15]
2”	311.83	4555.30	251.25
3”	550.37	6294.07	351.25
4”	603.54	8047.21	502.5

1.3 PROJECT OBJECTIVES

1.3.1 OVERALL OBJECTIVE

To evaluate the performance of Plain concrete and Reinforced Concrete confined by simple UPVC, high pressure UPVC and Canvas pipe, when subjected to different types of loading conditions; specially those faced by an axially compressed structure.

1.3.2 DISTINCT OBJECTIVES

- To evaluate the behaviour of Plain and Reinforced Concrete confined by simple UPVC, and high pressure UPVC, under compressive axial loading, (A comparative study)

- To study the efficacy of Normal Pressure and High Pressure UPVC confined specimens on mechanical properties of concrete

1.4 JUSTIFICATION/RATIONALIZATION

From one research, it was concluded that approximately half of the cost of concrete work was of the formwork cost while the rest consisted of labour and materials. When the UPVC would be used as confining material, it would also act as long-lasting formwork which would reduce the expenditure appreciably.

Steel tubes and Fibre reinforced Polymer tubes also confines concrete but steel is susceptible to corrosion, weathering and chemical reactions which reduce its effectiveness while FRP is quite expensive to produce. The UPVC tube is a cost effective solution besides being resistant to environmental effects.

Even though steel has more strength than plastic (UPVC) . The plastic undergoes greater deformation under load, because it is elastic. UPVC pipes are lighter in weight than steel pipes. This is a beneficial quality as a light weight structure would require less manpower to erect it.

Currently, the construction industry seeks innovative materials or processes that will reduce the amount of resources required, finances spent, and labour engaged. The above-mentioned issues motivated this study, which aimed to provide answers to several of these complications by developing new building materials and solutions.

1.5 IMPORTANCE OF STUDY

In contrast to traditional reinforced concrete columns and steel columns using UPVC pipes, a more flexible and ductile form of column has been launched into the construction market. This Type of column will complement and/or enhance existing systems, alleviating the strain currently placed on traditional building materials. The end product is a composite section demonstrating better engineering capabilities in terms of strength and ductility. The end result is a composite section with improved technical properties like strength and the material's ductility. The absence of proper knowledge on a new product's performance is one of the most difficult parts of adopting new building methods. This study examines the behavioural characteristics of concrete-filled UPVC pipe under loading.

This study broadens the scope of concrete filled UPVC pipe being utilized as a structural member by measuring deformations under loads.

2. LITERATURE REVIEW

2.1 CONCRETE

Figure 3: Concrete

Generally concrete has three main ingredients namely:

1) Cement,

2) Fine aggregate,

3) Coarse Aggregate.

This is written in the order of the usual percentage that composes concrete. Concrete is one of the most consumed materials on earth after water [16]. This can also be estimated by the fact that 4.1 billion tons of cement, the smallest component of concrete, was produced in 2020 [17]. Cement production in Pakistan has been on a gradual rise for the last 25 years. From the graph by the State Bank of Pakistan, we can see that the production of cement in 2004 was less than 1000 thousand tonnes and it is now more than 4000 thousand tonnes.

Figure 4: Cement production from 2003 to 2020

For sustainability aggregates can and, in many cases, are made from recycled concrete. It may be used in place of primary materials. Some industrial waste products, for example slag and silica fume, can be used to make supplementary changes. Water is also one of the major components for the production of concrete. It is used during mixing and after setting, for curing. The number of days the concrete is cured, determines how much strength it will gain. For this project a '21 Day strength was achieved'. The strength of concrete is also determined by various other factors.

2.2 POLYMERS

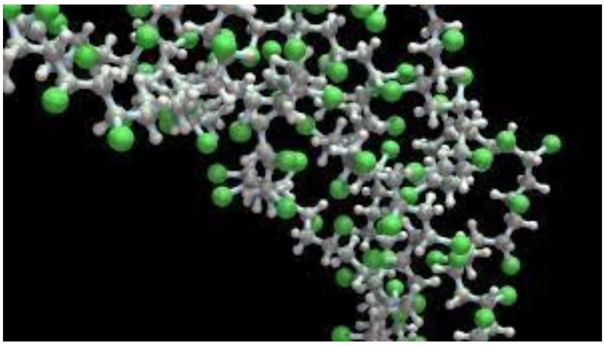


Figure 5: Polymer molecules

Polymers are compounds made up of long, recurring chains of molecules. Materials have different qualities based on the type of molecules bound and how they are joined.

The two main groups of polymerization processes are namely; thermosets and thermoplastic.

Thermoset and Thermoplastics are two distinct forms of polymers that differ in their heat reactions. Thermoset is a material that gains strength when it is subjected to heat, but may not be reshaped or heated once formed, whereas thermoplastics may be warmed, reshaped, and cooled without causing any chemical reactions. Because of these physicochemical qualities, thermoplastic materials have low melting temperature, but thermoset materials may withstand greater temperatures without changing their internal structure, thus providing greater structural integrity.

Thermoset plastic composites can fulfill the needs of a vast array of manufacturing materials at a cheap cost. Thermoset polymers increase thermal stability, chemical inertness, and structural stability. Thermoset parts thus, are broadly applied in a range of sectors, including the aerospace, medical, construction, and telecommunication, due to their exceptional physical and chemical stability, as well as exceptional durability and robustness.

2.2.1 PVC

Figure 6: PVC/UPVC pipes

Polyvinyl chloride (PVC) is one of the most commonly used thermoplastics in everyday life. PVC is available in both unplasticized and plasticized forms as well as in co-polymers. Unplasticized PVC (UPVC) is different from PVC because it does not have plasticizer. This plasticizer makes PVC soft while on the other hand, absence of it makes UPVC hard, tough, strong, stiff and abrasion resistant. UPVC also has the ability to be extremely transparent and does not ignite on its own. The corrosion resistant properties of UPVC were shown to be exceptional. UPVC has a thermal conductivity of 0.45 percent that of steel tube. This gives the concrete core a stable curing environment, allowing it to achieve better results and durability. UPVC tube has a life-span of greater than 60 years, and with the physical support of the concrete filled core, it may act as a shielding layer for the structure [11]. UPVC is generally used in manufacturing of small to large scale pipes for drinkable and non-drinkable purposes. Physical properties of UPVC pipes are displayed below.

Table 2: Physical Properties of UPVC pipes [33]

PARAMETER	VALUE
Density	1300-1450 Kg/m3
Elastic modulus	3380 Mpa
Flexural stiffness	65.5 Mpa
Poisson ratio	0.38
Ultimate tensile strength	27.5- 52 MPa
Breaking elongation	134%
Thermal conductivity	0.14 - 0.28 kcal/m.hroc
Service life	> 50 years

PVC that has been plasticized is normally more flexible than UPVC. It can be used to make frames for windows, pipes for drainage and drinking purposes, flooring, bags for storing purposes, among other things.

PVC pipes are widely used to distribute water and wastewater in civil engineering works. They are impenetrable by liquids and long-lasting. Their civil engineering project life cycle exceeds 50 years. [12].

Depending on the application, the pipes can be made in a variety of diameters and robustness. Because of their expected low load carrying ability, PVC pipes have been utilised in the building industry primarily for aesthetic purposes. PVC is non-corrosive, making it suitable for use in the erection of structures, especially those that are exposed to rusting. PVC material is famous for its low mass and density, which makes them simple to handle.

2.2.2 POLYMER COMPOUNDS

A synthesized structure is created by mixing up two or multiple elements that do not interact chemically. This results in a one-of-a-kind mix of enhanced properties that outperform the individual constituents. Plastic co-polymers, minerals, and wood may all be included in the above description which is more general. FRP composites are distinct from other synthesized elements in that the synthesized elements are molecularly distinct and mechanically separable. The constituent materials work together in bulk, but they retain their original shape. Composite materials' final properties are superior to constituent materials' characteristics.

2.2.3 DEVELOPMENT OF POLYMER COMPOUNDS WITH RESPECT TO CONSTRUCTION INDUSTRY

Humans have been using fibre composites in different forms since the start of civilization, e.g timber, paper and straw reinforced clay [20]. Reinforced concrete emerged as a new type of constructional synthesised material by 1900s. Fiber composite plastics, also known as fibre reinforced plastics (FRP), were developed in the middle of the twentieth century as a state-of-art and functional type of fiber synthesised material. This FRP material has high robustness and can withstand corrosive conditions [21]. As a result, it is strongly favoured by the aerospace and marine industries. The utilisation of FRP in constructing infrastructure has grown in popularity over the last two decades.

FRP is useful for structural repair because it is an efficient cure for chloride-induced corrosion of reinforced and prestressed concrete bridges [22]. FRP was once thought to be economically unfeasible, but recent developments in modern and automated production methods have reduced its cost and rendered it more competitive with other products [23].

Intensive research has been performed over the last decade to explore the properties of FRP as a modern construction material. Bavarian et al inspected the effect of rust-prone areas i.e. high presence of chlorine, wet, and hot/arid climate, on concrete samples jacketed with fiberglass and nanocellulose [24]. The results of the experiment revealed that sample size affects strength enhancement. It was observed that there was close to no decline in robustness or plasticity, according to the study. FRP has also been investigated in the present study of more extreme environmental effects such as cold climate, rapid cooling and heating, and excess of salt [25,26]. It was discovered that there was no significant loss of strength. Carbon fibres' characteristics have proved to be the most stable under such conditions. In terms of FRP's long-term behaviour, it has been proven that wrapping concrete beams in external carbon fibre will greatly reduce creep strains in the concrete [27,28].

2.3 CONFINEMENT OF CONCRETE COLUMNS

2.3.1 INTRODUCTION

It is certainly true that confining the concrete greatly enhances its strength and ductility, making it more robust and flexible to some extent [29,30]. Transverse strains are induced in an axially loaded concrete element, resulting in radial concrete expansion (Poisson's effect). Transverse strains are proportional to longitudinal strain under low loading conditions, which is associated by Poisson's coefficient, which ranges between 0.15 and 0.25 for concrete. Microcracking occurs in concrete after achieving a particular critical stress (approximately 75% of concrete strength), and lateral strains rapidly increase, resulting in significant lateral strains compared to a miniscule longitudinal strain. These small cracks progress to bigger cracks, which contribute to concrete rupture.

Confinement of concrete is linked to the utilisation of tensile-strengthening elements to limit the rise in transverse pressure. Confined concrete is in a triaxial compression stress when subjected to heavy loads. In this state, the concrete performs better in terms of strength and ductility than concrete that has been compressed uniaxially.

Since the early stages of structural concrete, the impact of confinement of concrete is thoroughly being studied. To determine the response of confined concrete, several confined concrete models have been developed. Concrete is more often than not claimed to be more responsive to axial pressure or load, instead of a better and more factual personation as more responsive to lateral confinement [31]. This explains why a confining member's stiffness enjoys a significant impact on action of confined concrete. [32].

By early 1900s, some experiments had been done to assess the increased strength of concrete due to confinement. Early experiments focused primarily on the active confinement, in which the hoop or spiral pressure was maintained consistent throughout the process of increasing pressure.

The lack of confinement and inadequate energy absorption potential is one of the several drawbacks of concrete structures, especially the axially loaded ones. [34].

All of these confinement approaches result in an inactive confinement, in which the confinement is governed by the sideways enlargement of the concrete [21]. The confining material creates a tensile hoop stress compensated by a consistent radial pressure that reacts against the concrete's lateral expansion as we see the rise in axial stress [35,36]. The concrete expands sideways when compressive forces are applied to a restricted column, which is limited by the confining material.

2.4 CONFINING CONCRETE BY LATERAL REINFORCEMENT

Richart, Brandtzaeg, and Brown [37] tested ‘passively' confined concrete in a series of experiments. The spiral reinforcement is forced against by extensive sideways deformations induced by high tensile stress in the concrete, and because the support of elastic parts is removed owing to a snapping action, spiral reinforcement provides the essential support. The concrete becomes more of a dynamic mass as the amount of activity increases, sustaining just as much stress as steel can offer sideways support.

The impact of spiral spacing was studied by Iyengar et al. [38]. From the research, it was deduced that sideways reinforcements provide restricting forces along the distinct lines that differ among these lines as well as the leftover space. Second, sideways reinforcement confinement is a consequence of lengthwise distortion.

Shanan et al. (2019) [39] discovered that increasing the volumetric proportion enhanced the strength and elasticity of restricted concrete, but that this gain did not persist, hence they proposed an area ratio of 0.040 as a maximum bound. It was also mentioned that the reinforcement's yield point isn't fully utilised for the confinement effect. The reinforcing configuration had no influence on load-bearing capabilities, and the elasticity of the material.

2.5 CONFINEMENT BY STEEL TUBES

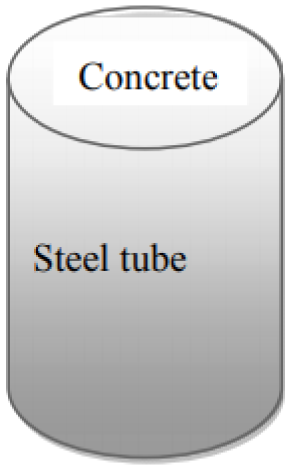


Figure 7: Concrete filled steel tube

Concrete restriction can also be accomplished by enveloping concrete in a tube made out of steel, as shown in Figure 7.

The steel tube behaves as lengthwise, lateral, and shear reinforcement, and also as the shuttering and a permanent concrete restricting cap. As a consequence, the tube's regional collapse is delayed [40]. Knowles and Park [41] carried out a chain of tests on steel tubes filled with concrete, with various slenderness ratios, determining that the tube's collapsing dictated the total failure of the composite section prior to the onset of the impact of restriction. To effectively use the tube's restricting features in the spiraling direction, it was proposed that the tube not be directly loaded in the lengthwise direction. Orito et al. [42] later confirmed this, discovering that unjoined concrete-filled steel tubes exhibited higher compressive strength than joined tubes. Prion and Boehme [43] conducted a study of testing on concrete core steel tubes. According to studies, the restricting effect is seen when the slenderness ratio is less than 12.

The goal of Liusheng, Siqi Lin, and Huanjun Jiang [44] was to figure out how to compute the inactive restriction of concrete core steel tubes (CFST). The restriction factor was shown to be a crucial element in axial load bearing capacity. The confinement factor was directly proportional to the degree of restricting force put by the steel tube to the concrete core.

Lin-Hai Han et al. (2005) [45] investigated the cyclic and noncyclic performance of Steel Tube Concrete Columns. They used 12 Steel Tube Concrete Columns, consisting of 6 square-sectioned columns and 6 circular-sectioned columns. Using the current codes, assessments are done with expected column strengths and flexural stiffness. Steel Tube Concrete Columns were discovered to have extremely high levels of energy dissipation and ductility, especially when subjected to severe axial loads. The energy dissipation capability of the circular-sectioned columns was significantly greater than that of the square-sectioned samples.

Y.-F. Li et al. (2005) [46] researched the constitutive model of concrete confined by steel rebars and steel jackets. They tested on 60 confined concrete cylinders. The test is done in order to obtain the stress-strain graph of the confined specimens. A model is then presented to explain the performance of steel confined concrete. It is observed from the experiments that various steel reinforcements have a positive effect on the compressive strength of confined concrete.

J.G Teng et al. [47] analysed the compressive behavior of Concrete Core Steel Tube columns with inner HSS spiral confinement. The addition of HSS (High Strength Steel) spiral confinement was proposed by the researcher. The new column is composed of a steel tube with concrete core being wrapped in HSS spiral reinforcement with a yield stress of well over 145 ksi. The results showed that this new type of column has higher ductility than those without the HSS spiral confinement, although the use of HSS would increase the steel percentage and would not be feasible.

2.5 CONFINEMENT BY FIBER REINFORCED POLYMER WRAPS

Since the early 1980's, fiber composites have been utilized for confinement of concrete. Fardis and Khalili [48] wrapped bi directional Fibre Reinforced Polymer (FRP) fabrics on 75 mm x 150 mm and 100 mm x 200 mm concrete cylinders. Different types of FRP fabrics were used. The specimens were tested under uniaxial compression. It was established that the ductility of concrete also increases alongside the strength when it is confined by FRP.

Practical application of Fibre Reinforced Polymer wrap shown below .

Figure 8: Application of Fibre Reinforced Polymer wrap

S.T. Smith, S.J. Kim and H. Zhang [49] researched on the performance and efficacy of fibre reinforced polymer wrap confining large concrete cylinders. They observed the development of interfacial failure between FRP and concrete at FRP rupture failure point.

2.6 CONFINEMENT BY FRP TUBES

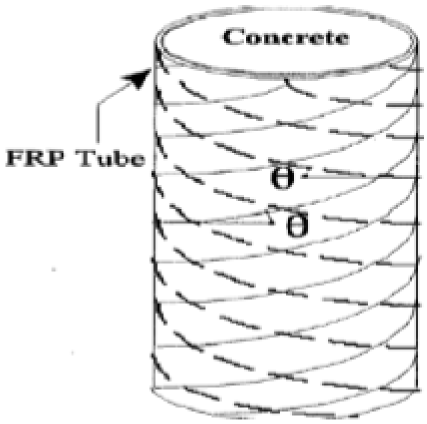


Figure 9: FRP confined concrete

During the 1990's Lahlou et al. [50], used two 50mm x 100mm fibre glass tubes filled with concrete, and discovered that there was not any worthwhile increase in the concrete strength. Mirmiran and Shahawy [51] suggested a CFRP tube as shown in the image. The tube acted as "shuttering" for the concrete filled in core, with longitudinal and hoop reinforcements provided. The tube also provided anti-corrosion properties to the concrete. The tube simply consisted of a filament-wound FRP tube with a concrete filled core. They suggested this CFRP tube system as columns for bridges or as pile splices.

The Florida Department of Transportation (FDOT) financed a chain of projects in order to analyze the behavior of the suggested CFFT. Various parameters were looked for in these projects, e.g., the loading type, the cross-sections, the bonds used, and the effective length. Kargahi [52] looked into the CFFT strength under uni-axial compressive loading. They tested 12 circular specimens, out of which 9 were CFFRPs tubes, and the other 3 were 150mm x 300mm PCC cylinders. Filament-wound polyester tubes were used, with a 75° winding angle (in respect to the longer axis of the tube). Three tubes of varying thicknesses were utilised. The results showed an increase in strength of concrete by 2.5x to 3x the unconfined strength. Several cylinder split tests were carried out to examine the improvement, if any, in the tensile strength of the FRP-confined concrete. It was found out that FRP tube considerably improves the performance of concrete in tension by containing instead of confining the cracked concrete. Another study was carried out to find the effect of ply thickness, the angle of winding, and the action on the confined strength of the column. The study was based on the confinement model proposed by Mander et al. [30]. It was found out that as we increase the thickness of the tube, the pure axial strength increases. A full composite action plays no part in the improvement of axial capacity of the column, however, it significantly improves the flexural capacity. Also, it was found that if we increase the fiber winding angle, the axial strength (pure) will decrease. The flexural capacity (pure) was noted to be maximum at 45° winding angle.

The bond effect was looked into by Mastrapa [53]. 32 composite cylinders measuring 150 mm x 300 mm were tested, 16 of which were wound in odd layers of S-glass fabric (1-7), and the other 16 samples were made by pouring concrete of the same batch into tubes of similar S-glass fabric, having similar layers. Tests were carried out in two groups. In the first group, multiple layer jackets were made periodically (layer by layer) with an overlap of approximately 20% of the cylinder perimeter. In the second group, the jacket consisted of a continued wrap of fabric which overlapped at approximately 30% of the cylinder perimeter. It was found out that a construction bond has close to no effect on a confined axially loaded concrete.

Pico [54] investigated 9 square FRP tubes (filled with concrete) measuring 150 mm x 150 mm x 300 mm, under uniaxial compression, in order to investigate the role cross-section of CFFT plays. Here, the concrete core and the FRP tube had no bond provided. Pico saw a slight increase in the strength, which was not dependent on the thickness of the jacket used. The most important parameter in managing the confinement was proven to be the product of the corner radius and the confining pressure.

El Echary [55] went over the effects of length-diameter and diameter-thickness ratios on how CFFT behaves. 24 circular CFFTs (Inner Dia of 145 mm) with 3 different thicknesses of tube (6, 10, and 14 layers) and 4 different lengths (300 mm, 450 mm, 600 mm, and 750 mm) were investigated. There was close to zero buckling seen. When results were analysed, it was found out that the eccentricity was maximum in the range of 10-12% of section width. There was no significant depletion in strength. It was analysed that upto length-diameter ratio of 5:1, there was no significant effect of slenderness.

Lately, several other models have been suggested by Fam [56] and Moran and Pantelides [57]. Most of these models build upon the straight-forward principle that the model stress-strain curve of FRP (concrete core). composite columns have an almost bilinear shape, as shown in the Figure 10 attached below.

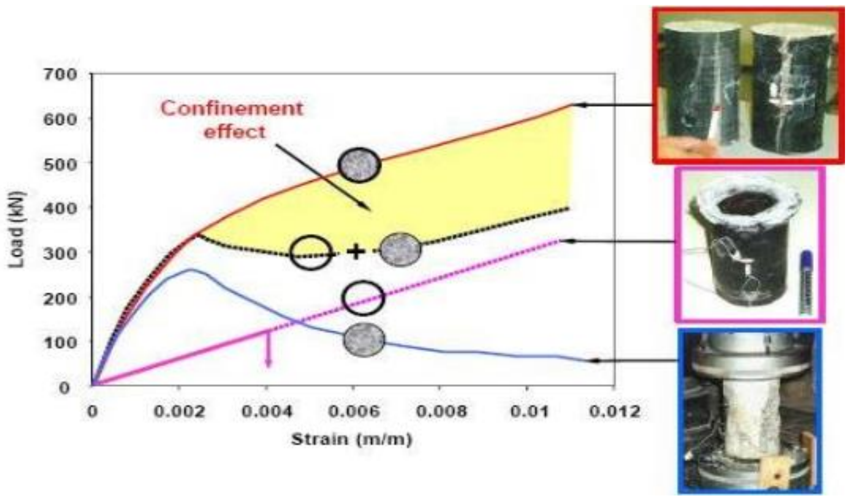


Figure 10: confinement effect on composite columns

As evident from the figure, the FRP (Fiber Reinforced Polymer) tube of a composite pile assists structurally to the pile by holding out some of the axial load, and by providing confinement to the concrete core. The main advantage of the provided confinement on the entire load carrying ability of a smaller dimension (length-wise), concrete core FRP (Fiber Reinforced Polymer) tubular element was studied by Fam and Rizkalla. As shown in the pictorial presentation attached above, the role of the composite end notably increases the load sharing ability of the two separate materials respectively. After this, the load-strain curve was thoroughly studied. It was noted that the curve begins to go off from the non-confined concrete curve in the region of the non-confined concrete total strength. It was noted that as soon as this stress level is reached, the concrete core begins to experience notable micro-cracking along with the greater expansion laterally. As a reaction to the concrete expansion, the FRP (Fiber Reinforced Polymer) jacket exerts a radially confined pressure, which ceaselessly grows in magnitude as a result of its linear properties of elasticity [56]. Another find was that the hoop tensile stiffness of the FRP shell determines the other gradient of the load-strain curve, and the ultimate peak strength is determined by the hoop tensile strength of the FRP shell.

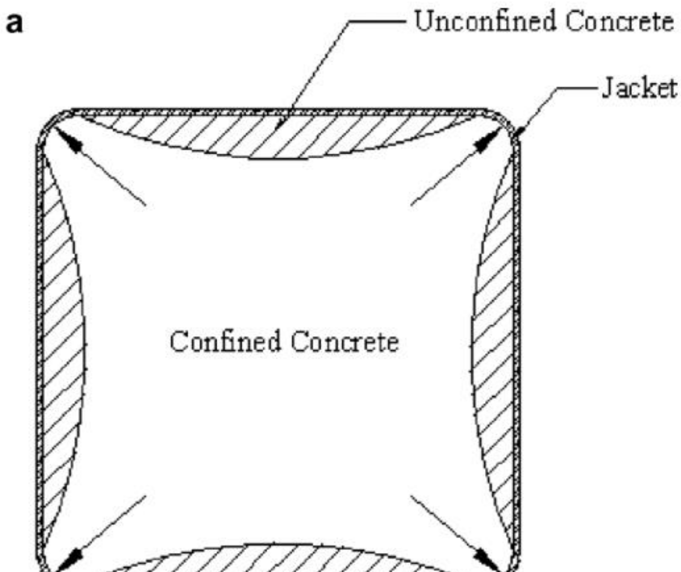


Figure 11: Confinement of concrete columns with FRP composite jackets [58]

Figure depicts how the confinement on a square member produces a concentrated confining stress around the corners, compared to uniform confining stress in a circular member.

2.7 CONFINEMENT BY PLASTIC TUBES

Carl Kurt [59] recommended using the PVC pipes with a concrete core that are readily accessible. According to the theoretical study, there was a contact between the concrete core and the plastic pipe, resulting in an increase in the concrete core's strength. The structural behaviour of the plastic pipe under a column load was similar to that of spiral reinforcement. The plastic pipe boosted the strength of the concrete core by about three fold the burst pressure of the pipe. Plastic-encased concrete demonstrated a 45° shear failure, both in the concrete core and in the plastic pipe, at a slenderness ratio of less than 20, due to a combination of axial compression and hoop tension in the pipe.The increase in concrete strength was not considerable due to Kurt's choice of a weak plastic substance. Nonetheless, his first findings suggested that concrete-filled PVC pipes may be a feasible column system for structures where being light-weighted is of importance.

As few academics and researchers have delved into this field, there is a lack of research and data on the usage of this form of composite section. Marzouk et al. [60] conducted initial testing on four PVC confined concrete column samples and two unconfined concrete columns and found that PVC tubes might be used as a viable confinement component. Marzouk et al. came to the following conclusions and recommendations based on his findings:

- The inclusion of PVC tubing offers concrete columns a degree of lateral confinement, which boosts the final compressive strength of the columns.
- The axial load-displacement relation shows that PVC tubes with concrete cores have a significant ductility. Before failing, the PVC tube works as a containment for the failed concrete filling and displays significant lateral distortion.
- As the slenderness ratio grows, the strength in compression of concrete filled PVC tube diminishes.
- Additional studies are needed to assess the strength of concrete core PVC tubes in compression, with a variety of slenderness ratios and tube diameters, as well as various concrete characteristics.

TGupta's most recent study [33] looked at UPVC pipes with concrete core and different diameters, such as 5.5 in, 6 in, and 9 in. The tubes were filled with three different concrete grades, namely: M20, M25, and M40. The following show the conclusions reached as a result of this research:

- The use of UPVC tubes to confine the concrete columns enhances their strength in compression, and positively affects the ductile properties of the column. The concrete strength and physical features of the tubes determine the increase in compressive strength and ductility of the columns.
- All the samples failed in shear.
- The results were similar to already established facts in prior research, only differing within the 5% range.
- Compressive strength of the concrete has a considerable impact on the load and compression curve after-crest behaviour. Due to increased fragility, the maximum value of the gradient of the curve increases with the strength of concrete.
- The gradient of the initial segment of the curve drops with reduction in concrete mix used.
- The tube D/t ratio influences the curve after-crest behavior; when the tube D/t ratio diwindles, the maximum value of the curve's slope dwindles as well.

However, since all the columns used had a fixed height of 20 inches, the effect of modifying the slenderness ratio was not examined.

Gathimba Naftary (2015) [61] in his thesis worked on the structural feasibility of concrete filled UPVC pipe by observing its behaviour under compressive loading. He tested on 144 specimens of which 72 were unconfined and 72 UPVC confined. The pipes were of varying outer diameters and varying thicknesses. He also used three different concrete mixes. From his tests, he concluded that mechanical bonds do not form between concrete and the pipe. He also came to the conclusion that compressive strength decreases with the increase in slenderness ratio. It was also observed that the lower the concrete strength and, as a result, the higher the ductility of the column specimen, the greater the column's energy absorption capacity.

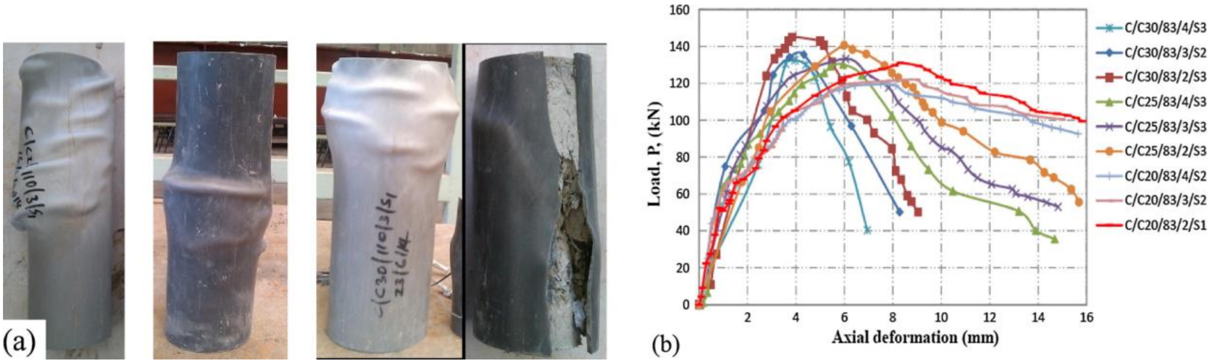


Figure 12: (a) typical failure modes (b) Load deformation curves for composite columns. [61]

Feng Yu et al. [62] did an experimental study on PVC-CFRP confined concrete columns under low cyclic loading. They used 8 PVC-CFRP confined reinforced concrete columns and 2 PVC confined concrete columns. These were divided into short and long columns as well. From the tests, it was observed that the ultimate bearing capacity of the columns increased as the axial compression ratio increased.

2.8 SUMMARY

From the few academics who have delved in this new field of composite building, it is clear that much knowledge on the usage of PVC pipes in composite column construction is absent. This is due to the fact that all of these researchers saw a lot of promise in this new construction material and explicitly expressed it in their results and suggestions. The new study looked at a number of variables that have previously escaped the attention of researchers. The study looked at the effects of tube diameters, heights, and concrete strengths on the composite columns' compressive strength, deformation, stress, and strain characteristics. After thorough research, it was found that UPVC, comparatively being a new technology, has a number of advantages if used as a confinement material. Following is a list of advantages we have gathered from what is explained before:

1. Lightweight as compared to steel and FRP and much easier to place and handle at site.
2. Quite economical and affordable to use in small and large scale projects resulting in a much better cost to benefit ratio in comparison to the alternative proposal or materials.

3. It has been observed that large scale curing of structures becomes quite tedious at times and requires the use of curing compounds or other applications. The confinement of concrete with UPVC automatically addresses this issue by significantly reducing the amount of evaporation and protecting the concrete from high temperatures, also addressing the issue of cracking.
4. Reduces the effect of corrosion on rebars by acting as an extra layer of protection.
5. Addresses the issue of infiltration of water into the concrete.
6. Negates the effects of Sulphur, Ammonia, and other harmful environmental agents.
7. Through research it has been found that UPVC pipes can last decades without degradation, thus addressing the issue of maintenance cost.

3. MATERIAL CHARACTERIZATION

3.1 STUDY SITE

This research was carried out within the premises of Military College of Engineering, NUST, Risalpur Cantonment, KPK, Pakistan. For testing purposes, the labs of the said institute were utilised.

3.2 RESEARCH OUTLINE

This study is conducted through laboratory experiments by testing the axial compressive strength of unconfined concrete (plain and reinforced) , concrete confined by UPVC pipe (plain and reinforced), concrete confined by high pressure UPVC pipe (plain and reinforced) and concrete confined by canvas pipe (plain and reinforced).

3.3 MATERIALS USED

1. Lawrencepur Sand: Lawrencepur sand is obtained from the Lawrencepur Quarry and is widely used in the Punjab province because of its exceptional quality and strength.
2. 5-16 mm Crush: We used Margalla crush that is acquired from Margalla query and easily available.

3. Portland Cement: Ordinary Portland Cement (OPC) was used for this study. It was manufactured by Bestway Cement Limited, Pakistan. The product conforms to local Pakistan Standards.
4. #3 rebars, #2 stirrups: Grade 40 steel. Manufacturer based in Gujranwala.
5. UPVC pipes available in the local market (normal and high pressure): used in drainage systems.
6. Canvas pipe : mostly used for transporting water.

Figure 13: specimens

3.4 MATERIAL PROPERTIES

3.4.1 FINE AGGREGATE

Figure 14: Lawrencepur Sand

We used Lawrencepur sand as Fine Aggregate. About 1000 g of sand was used as a sample to find the FM value. The sand was passed through the sieves (4.75 mm, 2.35 mm, 1.18 mm, 0.59 mm, 0.195 mm and 0.142 mm). The shaking was done for 2 minutes until no more of the sand passed through the sieve. The weight of each sieve was measured and recorded.

ASTM Requirement for FA

Sieve	% Passing
3/8"	100
#4	95-100
#8	80-100
#16	50-85
#30	25-60
#50	10-30
#100	2-10

Table 3: Gradation analysis of Fine Aggregate

S.no	Sieve no.	Sieve size (mm)	Weight Retained (g)	% Weight Retained	Cum Retained %	Cum Passing %
1	4	4.75	0	0	0	100
2	8	2.35	43	4.3	4.3	95.7
3	16	1.18	102	10.2	14.5	85.5
4	30	0.59	342	34.2	45.7	54.3
5	50	0.195	287	28.7	74.4	25.6
6	100	0.142	184	18.4	95.8	14.2
7	Pan	Pan	42	4.2	100	2.4

FM (FINENESS MODULUS) is calculated by the following equation:

$$FM = \frac{\sum(\text{Cumulative \% Retained on Standard Sieves of } 150\mu m \text{ or above})}{100}$$

3.4.2 COARSE AGGREGATE

3.4.2.1 RELATIVE DENSITY AND WATER ABSORPTION

1. APPARATUS USED:
    - Balance
    - Sample container
    - Water tank
    - Sieves
    - Oven

2. PROCEDURE:

Figure 15: Coarse Aggregate

A 2000 g sample of aggregate was obtained from the aggregate retained on the 4.75mm sieve. The retained aggregate was then washed so that the smaller aggregate is removed. The material is then dried in an oven at 110℃ till it has a constant mass (A). The aggregate is then cooled down at a temperature where it is easy to handle. After that, it is submerged in water for 24 hours. The sample is then dried to saturated surface dry (SSD) condition. The sample can be rolled in a towel and shaken side to side for this. The larger particles should be wiped separately by the towel until there is no visible water film. After weighing the sample in SSD (B), the sample is then placed in water and weighed again (C). After that, Dry the sample in the oven at 110℃ and then it is cooled by leaving it at room temperature for 1 to 3 hours. The sample is measured again.

$$\% \text{ Absorption} = \frac{B-A}{A} * 100$$

$$\text{Apparent Specific Gravity} = \frac{A}{A-C}$$

$$\text{Dry Bulk Specific Gravity} = \frac{A}{B-C}$$

$$\text{SSD Bulk Sp.Gr.} = \frac{B}{B-C}$$

3.4.3 CONCRETE

3.4.3.1 CONCRETE MIX DESIGN

Concrete mix design was calculated according to ACI Recommended Practice 211.1. A concrete mixture is developed in three stages: specifying, designing, and proportioning.

The steps should be taken in the order listed below:

- Establish task parameters, including aggregate qualities, maximum aggregate size, slump, w/c ratio, and admixtures.
- batch weight computation, and

- batch weight modifications depending on trial mix

Essential Points to Consider:

- Material prices are the most significant factor in determining the relative costs of various mixtures.
- Labour and equipment expenses are largely independent of mix design.
- Because cement is more costly than aggregate, it is obvious that the cement content should be kept as low as possible.

This may be done by

1. utilising the lowest slump that allows for handling,

2. using a proper coarse to fine aggregate ratio, and

3. utilising admixtures if necessary.

3.4.3.2 TRIAL MIX

The calculated amount was sufficient to make a trial mix which could be tested. The mix proportion was calculated to be 1:2:4. The mixing of concrete was done according to required procedure and laboratory guidelines. First, the dry mixing of coarse and fine aggregate was done while adding a small amount of water to account for absorption. Then cement was added to the mix and the remaining water was added until the mix reached adequate workability, and conformed to the desirable W/C ratio.

3.4.3.3 TESTS

a. **Slump test:**

Slump test is done on fresh concrete to find out the workability of concrete. It is also an approximate measure of its consistency. Slump can be determined by measuring the difference in height of mould and the settled concrete when the mould is lifted.

b. **Compressive strength test:**

The compressive strength of concrete samples is determined using this ASTM test method. The testing procedure is applying a compressive axial load to specimen at a rate that stays within a set range until failure is detected. The specimen's compressive strength is computed by dividing the max load achieved during the test by its cross-sectional area.

After the concrete was poured into the mould, the samples were kept at room temperature for 24 hours. After the 24 hours were over, the samples were placed in water for curing. The samples were tested for compressive strength after 3,7 and 28 days.

3.5 SPECIMEN

A total of 18 samples were casted in a cylindrical mold of dimension (6 in. x 12 in.). The samples included 3 unconfined plain concrete cylinder, 3 unconfined reinforced concrete cylinder, 3 UPVC (25 mm thickness) confined plain concrete cylinder, 3 UPVC (25 mm thickness) confined reinforced concrete cylinder, 3 UPVC (50 mm thickness) confined plain concrete cylinder, and 3 UPVC (50 mm thickness) confined reinforced concrete cylinder. The reinforcement consists of 6 #3 bars @ 3.25 in. c/c. with #2 circular stirrups @ 3.25 in. c/c.

Figure 16: Reinforcement

All the samples were casted with the same batch, on the same day, to ensure consistency. Fresh mix design, did not sit idle for more than half an hour- and was covered with a plastic sheet, to avoid any moisture absorbing.

To achieve the ultimate compressive strength of concrete, the samples were cured for 28 days before testing began.

The traditional method for casting of concrete samples was utilised for this study. The cylindrical moulds, measuring 6 in. x 12 in. had their inner surface first rubbed with lubricant- to prevent the concrete from sticking onto the mould surface. Then, the moulds were placed on a flat, dry surface, close to the curing site.

For the plain concrete samples; the fresh concrete was poured into the steel industry-standard moulds directly. And then an internal vibrator was used to consolidate the concrete. This was also accompanied by gentle hand rodding. Three equal layers of concrete were used, meaning the concrete was poured into the mould in three steps. Vibration and rodding, following each layer. The rodding was done 25 times for each layer. After this, the sides of the moulds were gently tapped to ensure no air pockets were left, and that the concrete completely filled the mould evenly. The top surface was cleaned and levelled with the help of a blade.

For the UPVC plain concrete samples (plain and reinforced), UPVC pipes were used as 'moulds', and the same methodology as mentioned above was followed.

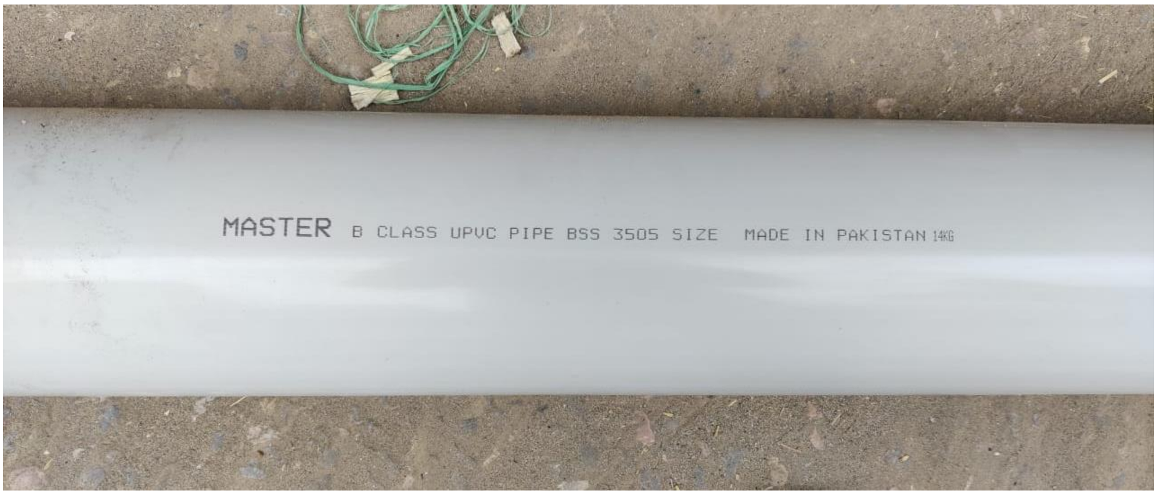


Figure 17: B class UPVC pipe

For the reinforced concrete samples, the rebar skeleton was inserted in the moulds (steel and UPVC), prior to the pouring of concrete. The rebar skeleton was suspended an inch above the bottom, with the help of threads- to ensure the 1 inch clear cover was maintained throughout the sample. Great care was taken to ascertain that there was no skew introduced.

The moulds were securely marked with the help of symbols and text to ascertain no mix-up during the testing phase.

After the casting, the samples were left unmoved at a safe space within the premises of PRC laboratory for 24 hours. Next day, the samples were moved to the curing tank and were cured for 28 days.

3.5.1 NOMENCLATURE

Table 4: Nomenclature

NAME	CODE	Area	Length	Diameter
PCC	PCC	27.57 in^2	304.5 mm	152.5 mm
RCC	RCC	27.57 in^2	304.5 mm	152.5 mm
UPVC (normal pressure)	UPVC-N	29.82 in^2	306.5 mm	153.5 mm
UPVC (normal pressure) Reinforced	UPVC-N-R	29.82 in^2	306.5 mm	153.5 mm
UPVC (high pressure)	UPVC-HP	29.82 in^2	307.0 mm	153.5mm
UPVC (high pressure) Reinforced	UPVC-HP-R	29.82 in^2	307.0 mm	153.5 mm

3.6 TESTING MACHINES

3.6.1 COMPRESSIVE TESTING MACHINE

The machine is Matest motorized concrete compression machines with servo-plus evolution. This machine is used to test the compressive strength of concrete and other materials. After the specimens were cured and dried, this machine was used to apply axial load on the face of the cylindrical specimens (top surface). The specimen was placed such that the axial load is applied through the centre of the specimen as to achieve a uniform stress distribution. The data was recorded in the data logger with it from where it was transferred to a USB device.

Figure 18: Compression Testing Machine

MACHINE FEATURES:

- Length 560 mm
- Width 590 mm
- Height 1280 mm
- Mass 80 Kg

3.6.2 ORIGIN PRO

The data was organized in Excel and then imported to OriginPro where the slopes of different curves were calculated using the tangent method. The area under the curve was also calculated using the software to get strain energy.

Figure 19: OriginPro by OriginLab Corporation

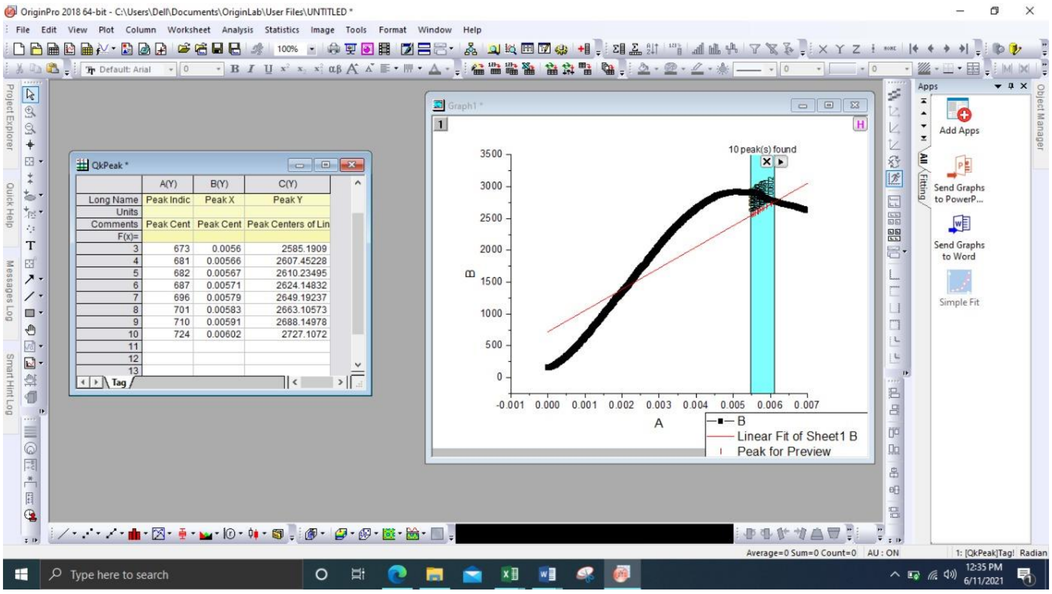


Figure 20: OriginPro homescreen

4. RESULTS AND DISCUSSIONS

4.1 MATERIAL PROPERTIES

4.1.1 FINENESS MODULUS OF AGGREGATE

The gradation curve of aggregate was plotted between sieve sizes in mm and percentage passing. The minimum and maximum values of passing percentage at each sieve size are also plotted.

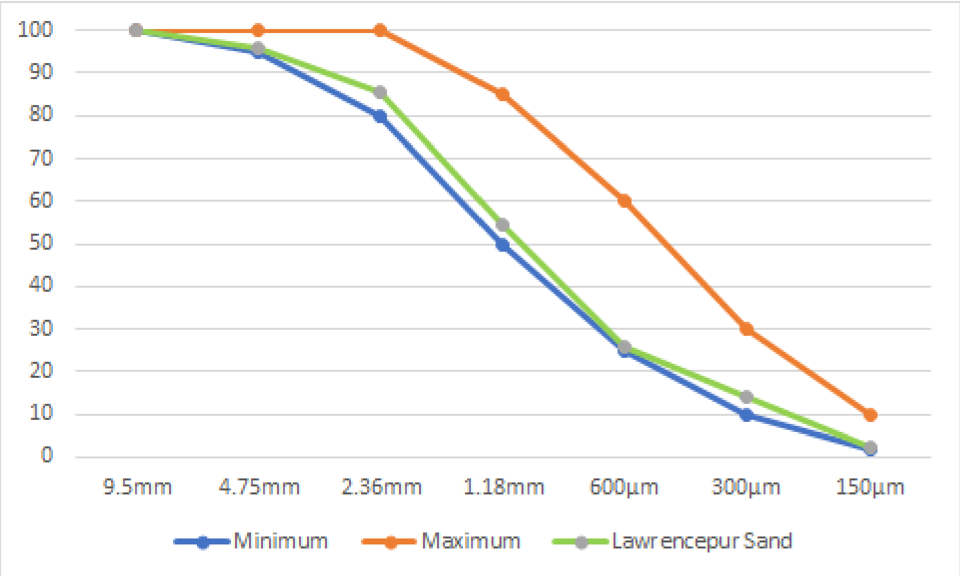


Figure 21: Gradation curve for fine aggregate

We can see from the graph that the curve of Lawrencepur sand that we used lies between the maximum and minimum curves. This means that the sand we used is acceptable and we would not need to mix it with other sand types.

The fineness modulus can be computed from the equation discussed above.

FM = 234.7/100 = 2.347

ASTM standard for fine sand ranges 2.3 - 3.1 .

The fine aggregates depend upon Fineness modulus as greater the value of FM, coarser the fine aggregates will be.

4.1.2 RELATIVE DENSITY AND WATER ABSORPTION

- FINE AGGREGATE:

Relative Density (Oven Dry) = 2.59

Relative Density (SSD) = 2.6

Apparent Relative Density = 2.62

Water Absorption % = 2.9

- COARSE AGGREGATE:

Relative Density (Oven Dry) = 2.65

Relative Density (SSD) = 2.67

Apparent Relative Density = 2.62

Water Absorption % = 0.95

Compressive strength = 25.4 MPa

The water absorbed was considered in calculation for concrete mix.

4.1.3 CONCRETE

DATA:

Table 5: Concrete Mix Data

s.no	Parameters	Values
1.	water content ACI 211.1 table 6.3.3	133.8 kg
2.	water cement ratio (ACI table 6.3.4(a))	0.65
3.	cement content	60 kg
4.	coarse aggregate content	240 kg
5.	fine aggregate content	120 kg
6.	compressive strength achieved	2300 psi

4.2 TEST RESULTS

4.2.1 BEHAVIOR NOTICED

It was observed that after a certain amount of load was applied, cracks started to develop in the concrete. While it was visible in the unconfined concrete, the confined concrete would show failure when the UPVC pipe would burst open due to concrete bursting. The failure that can be seen is pure compression failure which is due to the compressive force surpassing the capacity or ultimate compressive strength of the concrete cylinder. It was also observed in the UPVC confined concrete specimens that the UPVC provided confinement to the concrete by applying lateral stresses on the concrete surface which delayed the concrete failure by compression. In return, the concrete filled core provided the UPVC with the mechanical support, thus increasing the overall strength.

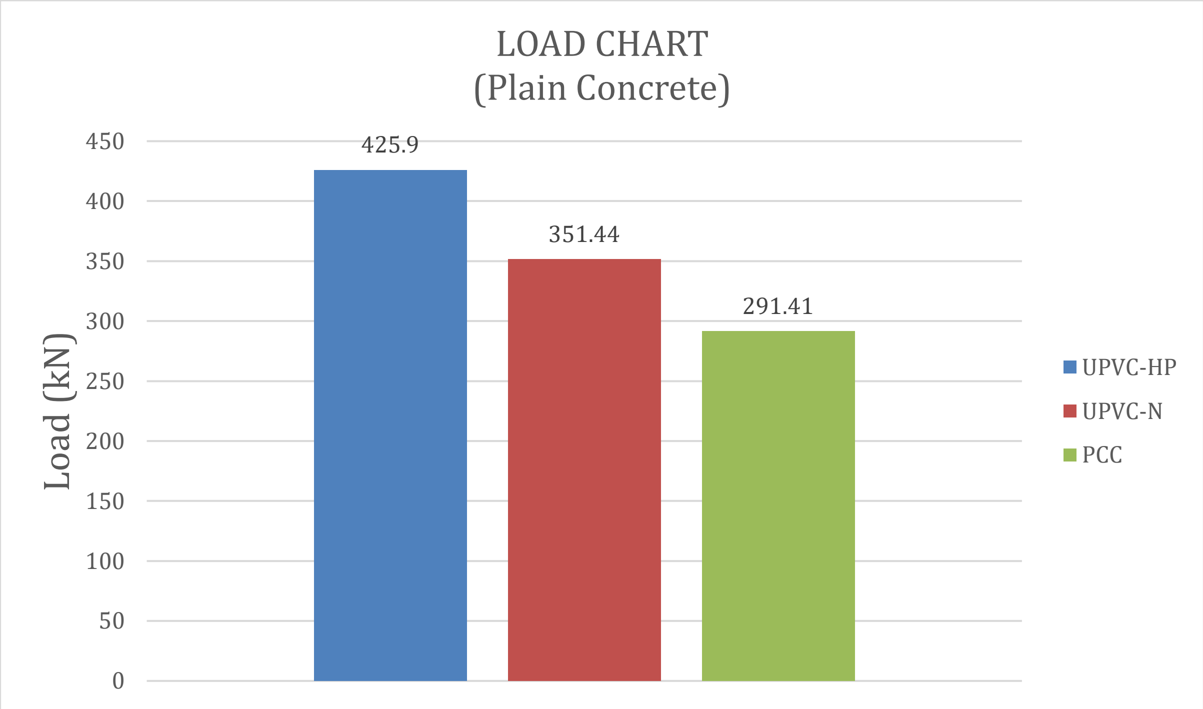
Figure 22: UPVC confined specimens failure

Bulging was detected in most of the confined specimens. From the figures, we can see that UPVC is confining the bulging of the concrete core, thus delaying the failure. This is a distinctive form of failure in concrete cylinders. We exceeded the ultimate compressive strength by 20%. When constant load was applied for more times than 20%, we found that the specimen was completely crushed. The bulging observed was consistent throughout the top, bottom, and middle of the cylinder, as visible in the photos attached above. There were minor cracks well dispersed throughout.

4.3 PARAMETERS COMPARISON/DISCUSSION

All the data taken in the following pages has been calculated by taking average values of the specimens.

4.3.1 LOAD



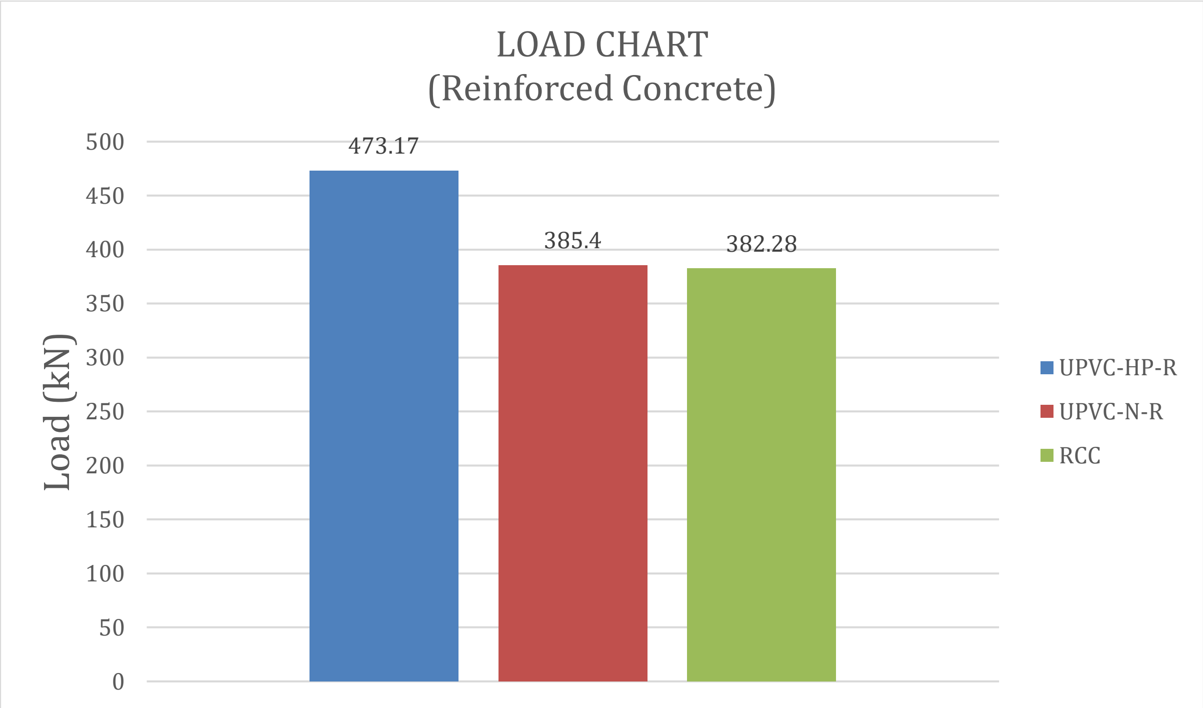


Figure A illustrates the load chart for PCC unconfined and confined (UPVC high pressure and UPVC normal pressure) specimens.

Figure B illustrates the load chart for RCC unconfined and confined (UPVC high pressure and UPVC normal pressure) specimens.

From Figure A,

As anticipated, the load carrying capability of unconfined PCC specimens was greatly outmatched by that of confined specimens. The increase in load carrying capability was substantial in UPVC-N confined specimen, where the overall load carrying capability was increased by 13.5% as compared to the unconfined specimen. It was noted, this increment was also reflected by the UPVC-HP confined specimen - where the increase in load carrying capability vis a vis UPVC-N confined specimen was an impressive 22% and against unconfined specimen was a significant 45 %. The maximum load carrying capability was observed in UPVC confined specimens where the maximum load carried was 426 kN. The corresponding values of the other tested specimens were observed to be 291.4 kN and 351.4 kN for unconfined and UPVC-N confined specimens respectively.

From Figure B,

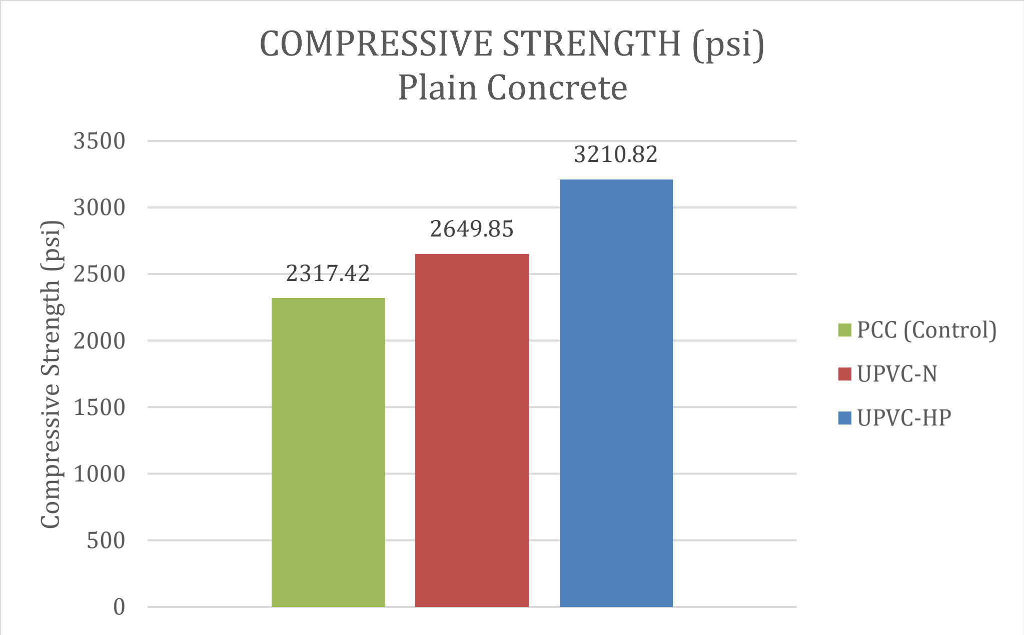
Unlike with PCC specimens, the increase in load carrying capability between unconfined RCC and UPVC-N-R confined specimens was not significant- with an increase of only 2%. The maximum increase in load carrying capability was showcased by UPVC-HP-R confined specimens, where the increase was 22%. The maximum load carrying capability here too was observed in UPVC-HP-R confined specimens, at 475 kN. The values of other tested specimens were 385 kN and 382 kN for unconfined reinforced and UPVC-N-R confined reinforced specimens respectively.

4.3.2 COMPRESSIVE STRENGTH

The compressive strength was achieved by the ratio between the Maximum Load Applied and the Cross Sectional Surface Area of the specimens.

$$\sigma_c = \frac{P}{A}$$

The Compression Testing Machine available at Military College of Engineering, NUST, Risalpur Campus also provided us with direct values for Compressive Strength. The data was exported out and Microsoft Excel was used to plot the following charts.



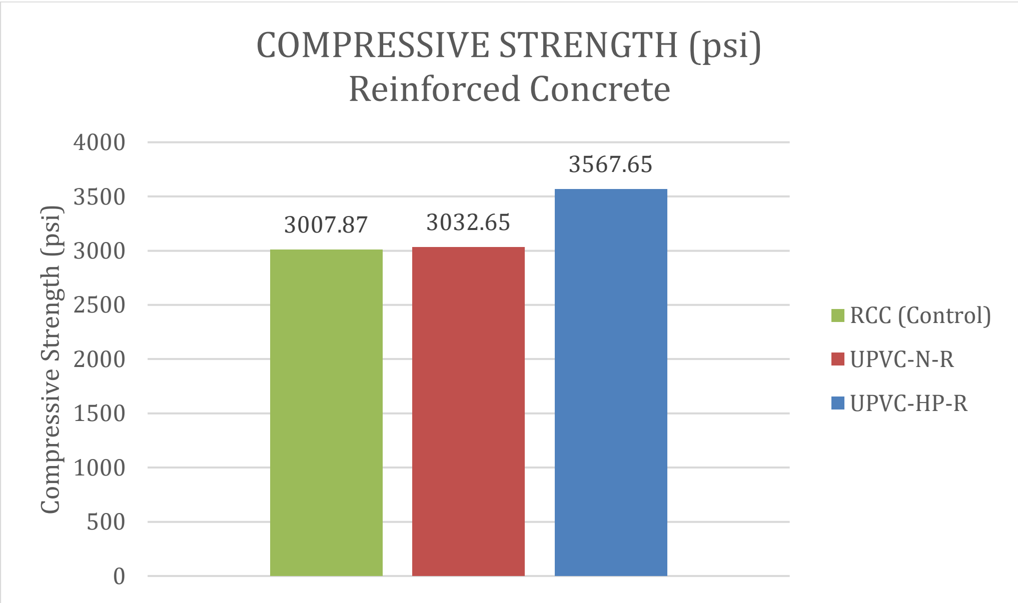


Figure C illustrates the compressive strength chart for PCC unconfined and confined (UPVC-HP and UPVC-N) specimens.

Figure D illustrates the compressive strength chart for RCC unconfined and confined (UPVC-HP-R and UPVC-N-R) specimens.

From Figure C,

The trend seen for compressive strength carried on from load bearing charts. The compressive strength of unconfined PCC specimens was considerably lower than that of confined specimens. Here, the increase in compressive strength from unconfined PCC specimens to UPVC-N confined specimens was calculated to be at 7.8%. While this is a substantial increase, the UPVC-HP confined specimens saw a much greater increase. The UPVC-HP confined specimens showed a striking 38.5% increase. Thus, the maximum compressive strength was shown by UPVC-N confined specimens, where it stood at 3211 psi. The compressive strength values for other tested specimens were seen to be 2317 psi and 2650 psi, for unconfined and UPVC-N confined specimens respectively.

From Figure D,

This chart shows compressive strength for RCC specimens. From the chart we can see there are mixed results. The UPVC-N-R confined specimens depicted a measly, but nevertheless, still a loss in compressive strength. Compared to unconfined RCC specimens, UPVC-N-R confined specimens lost their compressive strength by 0.85%. However, unlike UPVC-N-R confined specimens, the UPVC-HP-R confined specimens showed a reasonable increase in compressive strength, which clocked at 19%. Therefore, the maximum compressive strength achieved was by UPVC-HP-R confined specimens at 3568 psi. Compressive strength values for other tested RCC specimens were calculated to be 3007 psi and 3032.65 psi, for unconfined and UPVC-N-R confined specimens sequentially.

4.3.3 STRESS-STRAIN CURVE

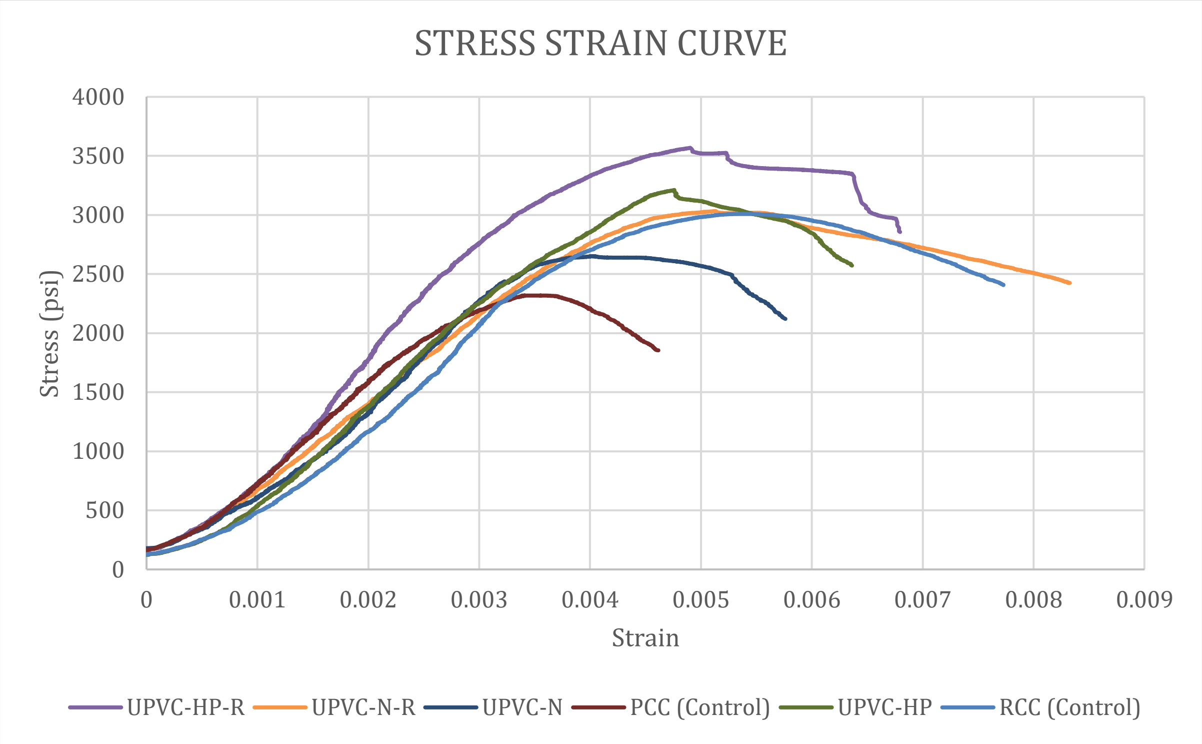


Fig E: Stress-Strain curve for all the specimens

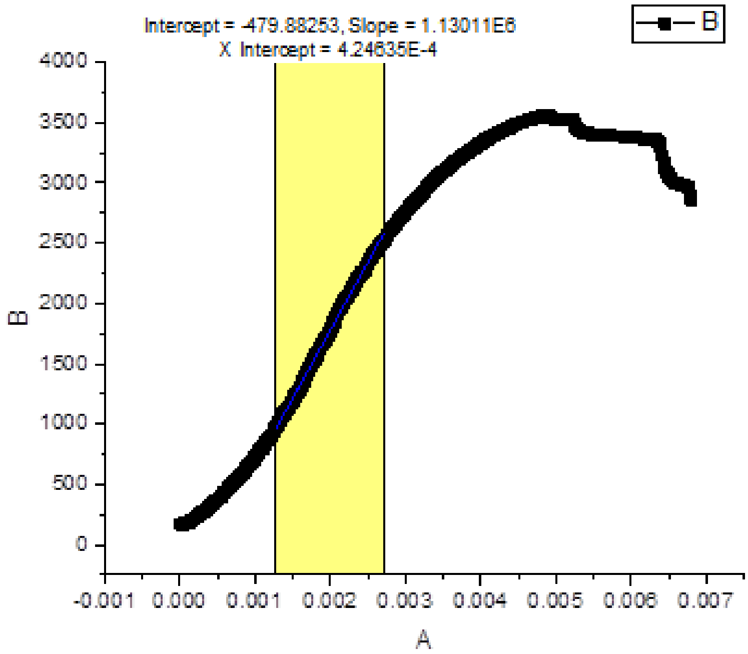
Figure E is representative of the performance of concrete when subjected to loading. The UPVC-HP-R can clearly be seen as having a clear edge over the others in terms of compressive strength, while UPVC-N-R shows good performance at post-peak. The PCC which is unconfined has the lowest compressive strength while UPVC-N performs slightly better . RCC (also unconfined) has the second best post peak performance. UPVC-HP-R and UPVC-HP both dominate in compressive strengths and have a slight effect on the post peak behaviour of concrete as well.

4.3.4 STRAIN ENERGY AND ELASTICITY

Strain energy is the energy absorbed by the material when certain load is being applied. The ability of a material to absorb energy is called toughness. Strain energy can be calculated by integrating the stress strain curve.

Modulus of Elasticity is the slope of the line between stress and strain. It shows the ability of the material to deform elastically before fracture. The modulus of elasticity usually increases with the increase in compressive strength.

UPVC-HP-R:



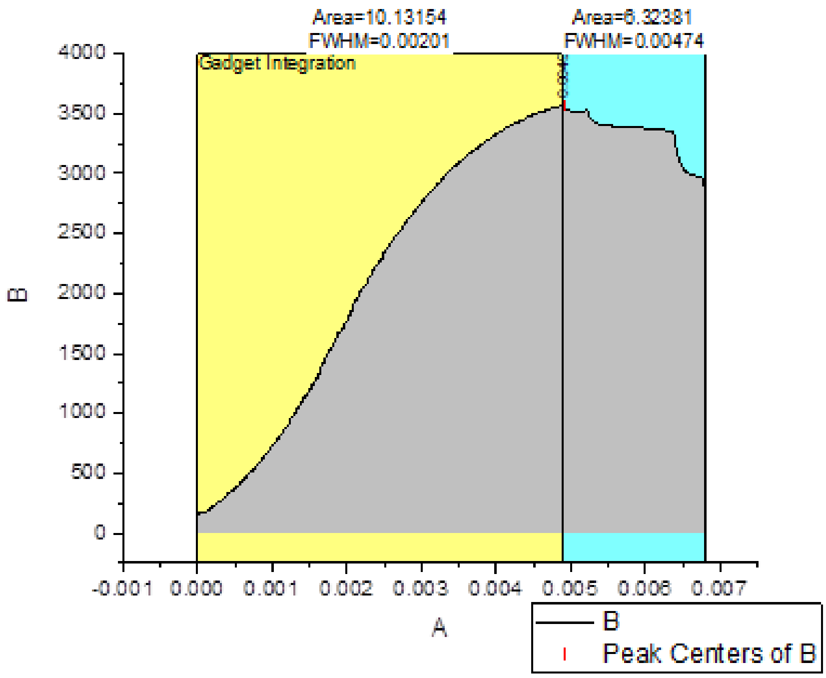
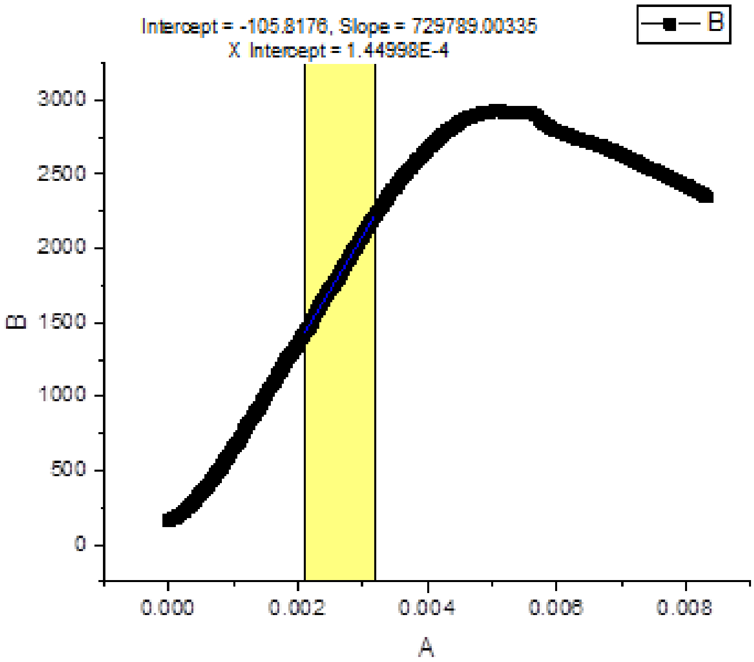


Fig F illustrates that slope value of UPVC-HP-R is 1.13 x 10^6 psi

Fig G illustrates that the area under the curve pre-peak is 10.132 and post-peak is 6.32 for UPVC-HP-R.

UPVC-N-R:



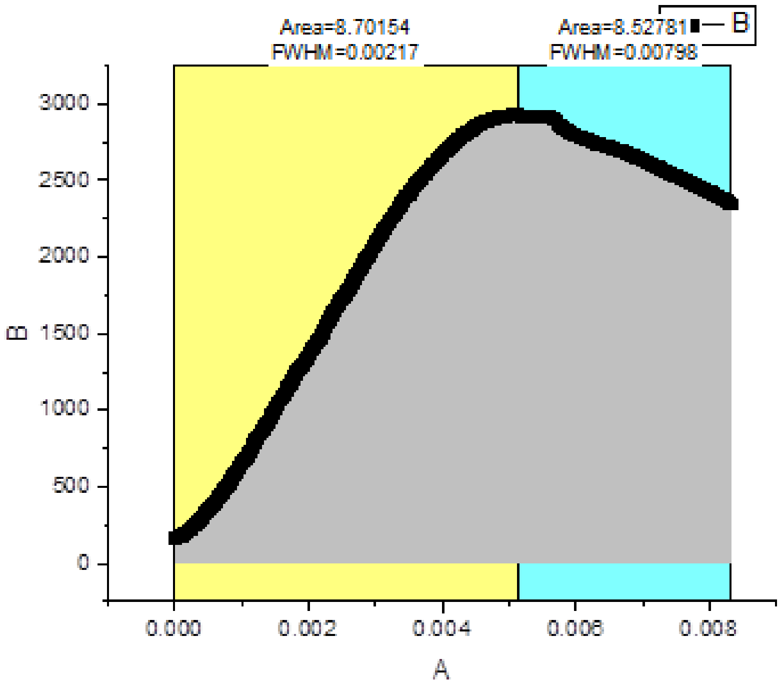
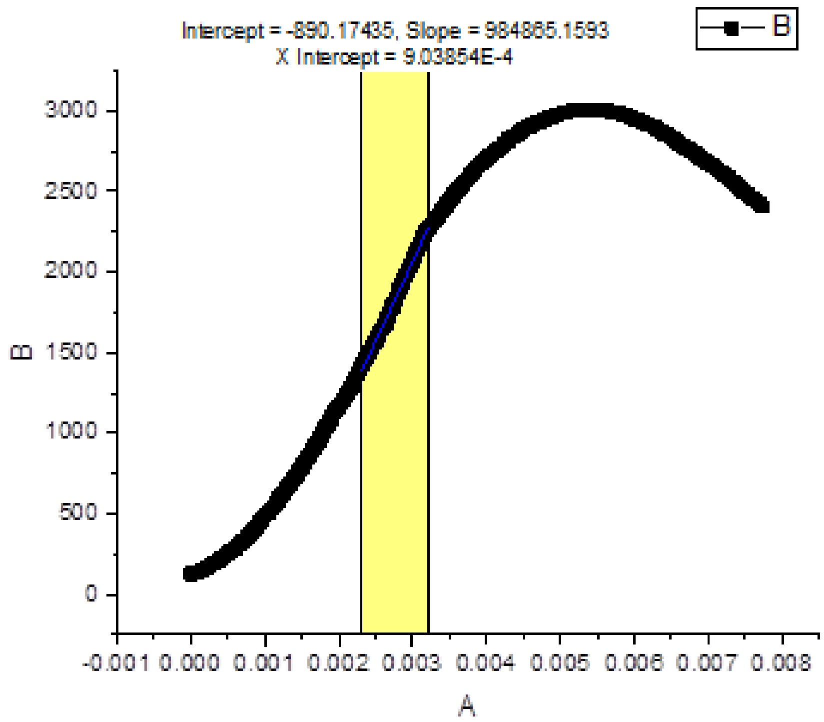


Fig H illustrates that the slope of UPVC-N-R is 0.73 x 10^6 psi.

Fig I illustrates that the area under the curve pre-peak is 8.7 and post-peak is 8.52 for UPVC-N-R.

RCC:



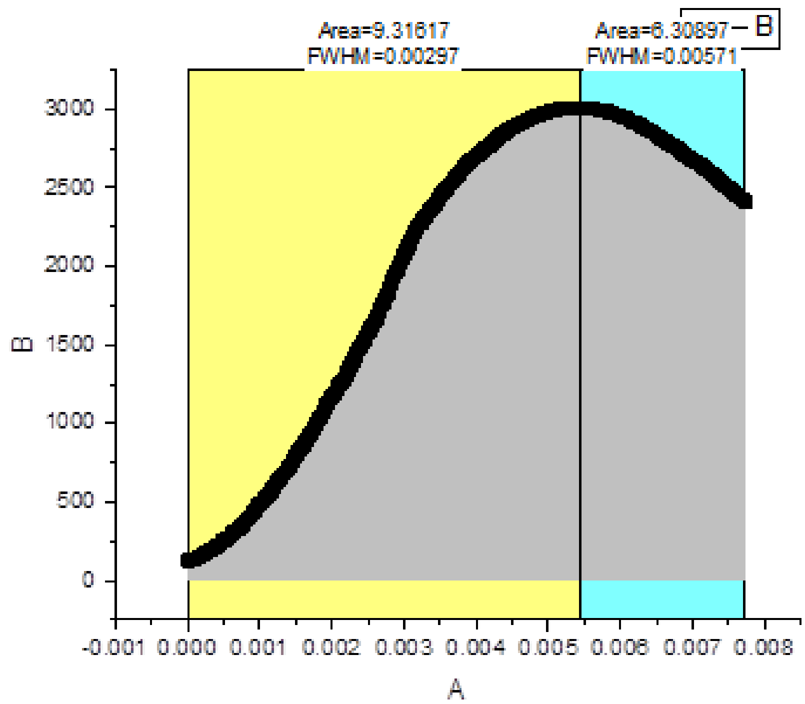


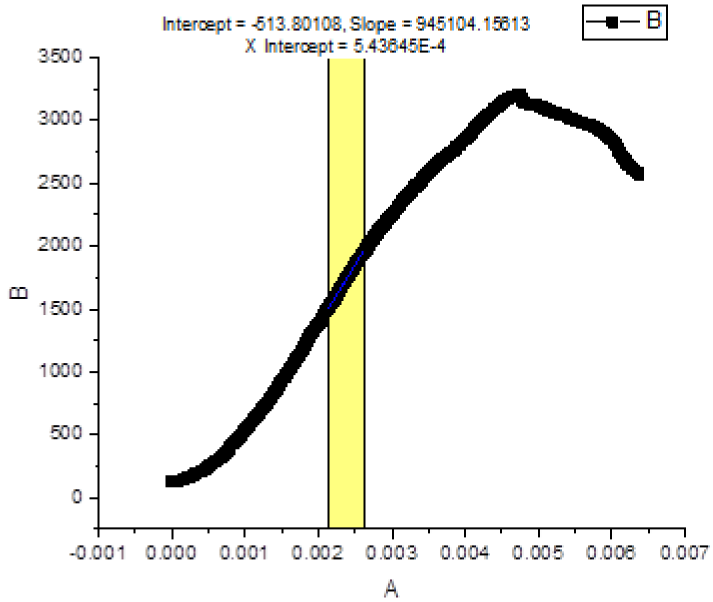
Fig J illustrates that the slope of RCC is 0.98 x 10^6 psi.

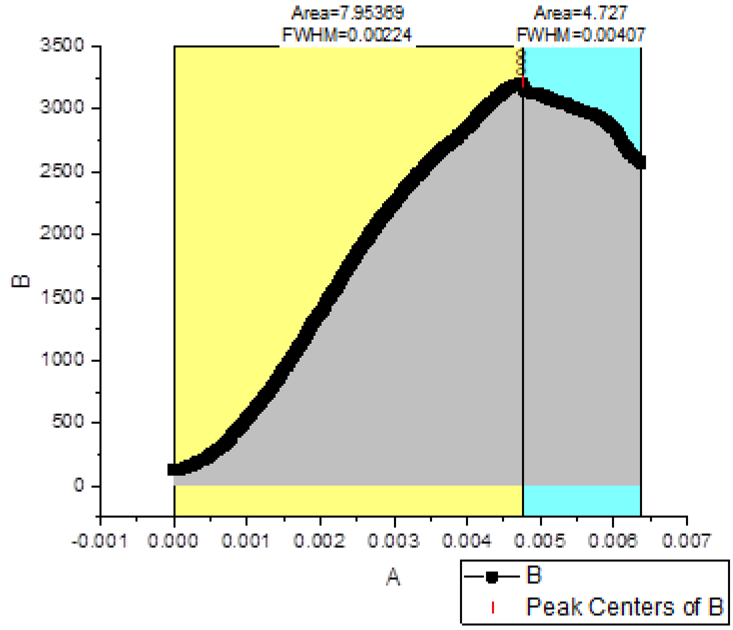
Fig K illustrates that the area under the curve pre-peak is 9.32 psi and post-peak is 6.3 psi for RCC.

The stress strain curve was plotted on Origin PRO. The software was used to find out the values of slope which would give modulus of elasticity and area which would give strain energy. We can see from Fig F that the slope or modulus of elasticity for UPVC-HP-R is 1.13 x 10^6 psi. This is quite a high value considering the values of the modulus of elasticity of concrete of other specimens. This means that UPVC-HP-R confined concrete is bearing greater stress with little change in strain. From the graph in Fig J that was imported from Origin PRO, we found that the slope/modulus of elasticity of RCC specimen is 0.98 x 10^6 psi. This means that its modulus of elasticity is more than UPVC-N-R. The elasticity is still less than UPVC-HP-R. The modulus of elasticity for UPVC-N-R is 0.73 x 10^6 psi.

The Fig G illustrates the area under the curve divided into two parts, pre-peak and post-peak. The area under the curve or strain energy is greater at pre-peak with a value of 10.14 psi for UPVC-HP-R, while the area under the curve at post peak is just 6.32 psi. This means that more energy was absorbed before reaching peak than after the peak strength was achieved. The area under the curve for RCC (Fig K) shows that it stored more energy than UPVC-HP-R before peak but UPVC-HP-R stored more energy post-peak. The pre-peak and post-peak strain energy values for UPVC-HP-R are almost equal giving it a symmetric shaped graph (Fig I). The post-peak strain energy of RCC is almost equal to UPVC-HP-R but it is important to note that both plastic confined specimens (UPVC-HP-R and UPVC-N-R) have a higher strain energy value than the unconfined specimen (RCC).

UPVC-HP:

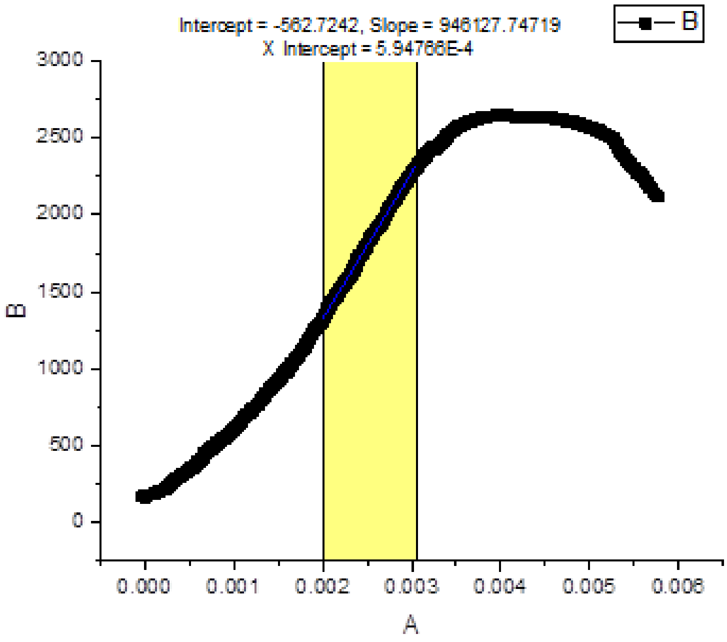




The Fig L illustrates that the slope of UPVC-HP is 0.945 x 10^6 psi.

The Fig M illustrates that the area under the curve pre-peak is 7.95 and post-peak is 4.727 for UPVC-HP.

UPVC-N:



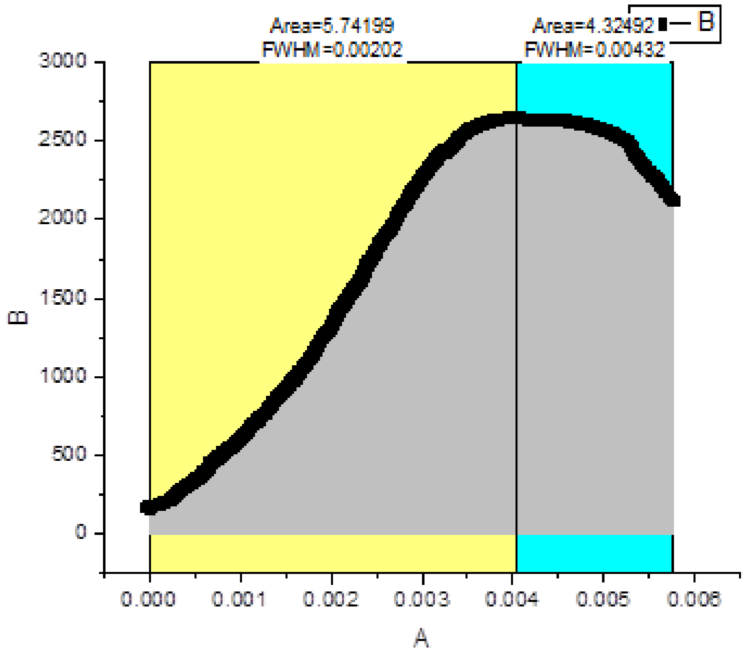
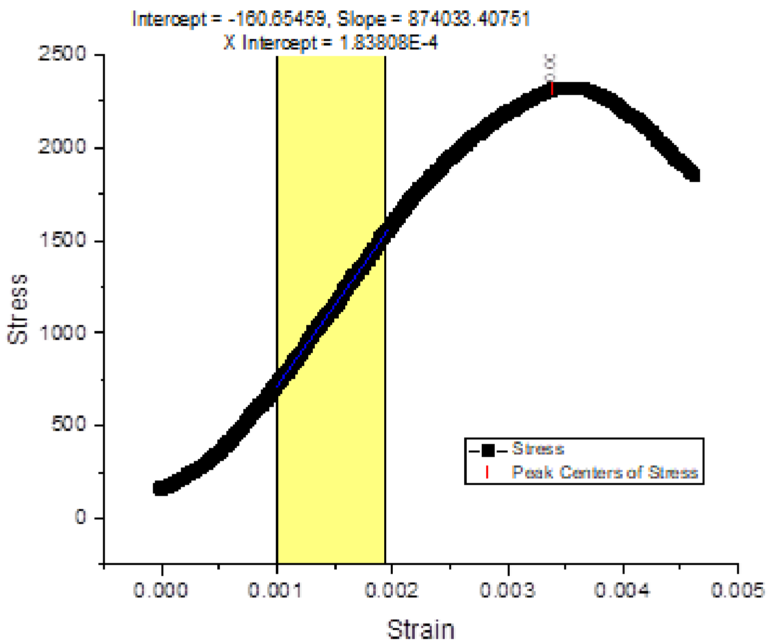


Fig N illustrates that the slope of UPVC-N is 0.946 x 10^6 psi.

Fig O illustrates that the area under the curve pre-peak is 5.742 and post-peak is 4.32 for UPVC-N.

PCC:



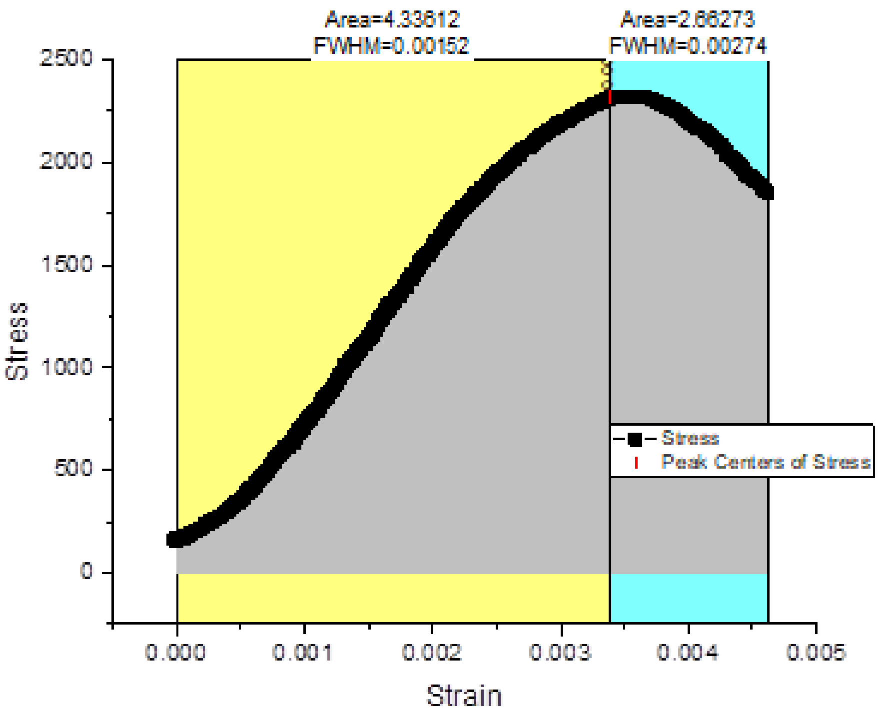


Fig P illustrates that the slope of PCC is 0.87×10^6 psi.

Fig Q illustrates that the area under the curve pre-peak is 4.336 and post-peak is 2.66 for PCC.

Fig L shows us the slope or modulus of elasticity of UPVC-HP which is 0.945 x 10^6 psi. This is almost equal to the elasticity of UPVC-N but greater than the elasticity of PCC. The values of elasticity for UPVC-N and PCC are 0.946 x 10^6 psi and 0.87 x 10^6 psi from Fig N and Fig P respectively. This means that elasticity of both plastic confined specimens is more than the unconfined specimen.

The strain energy value of UPVC-HP before peak is 7.95 (Fig M) which is greater than UPVC-N (5.74)(Fig O) and PCC (7.57) (Fig Q) before peak. The post peak behaviour shows that the plastic confined specimens (UPVC-HP and UPVC-N) have greater strain energy than the unconfined (PCC) i.e. UPVC-HP has a value of 4.727 post peak and UPVC-N has a value of 4.32 post peak while PCC only has a value of 2.39.

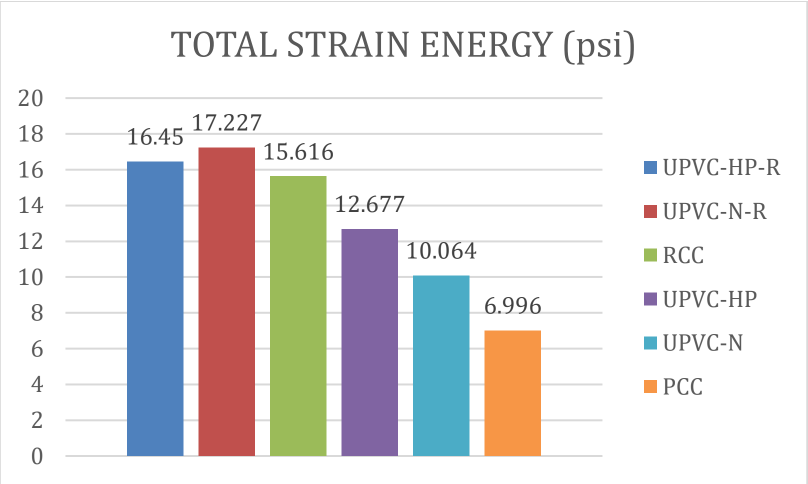


Fig R illustrates total strain energy of the specimens

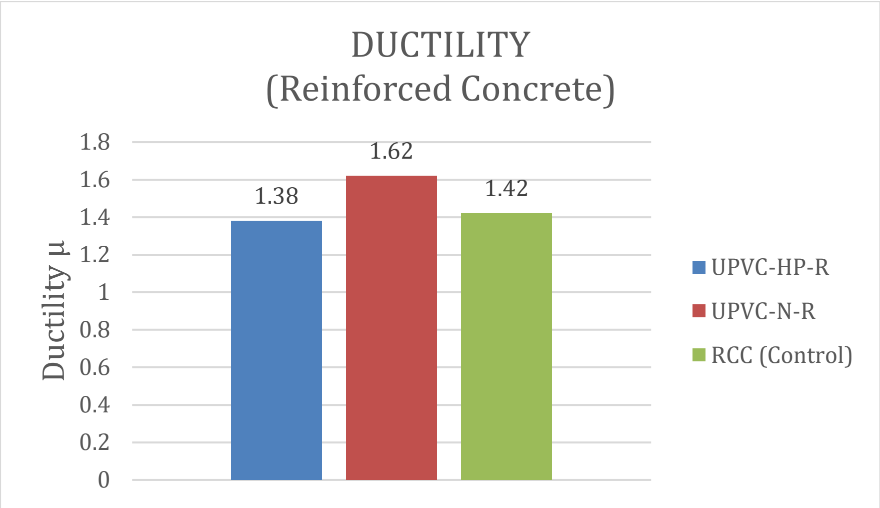
4.3.5 DUCTILITY

Ductility is an important parameter of any material. Concrete is a brittle material so work is done to make it ductile to extend its failure. Reinforcement is usually added in the concrete to increase its ductility

$$\text{Ductility factor } (R) = \Delta f / \Delta y$$

.

where Δf is the failure displacement, Δy is the yield displacement,



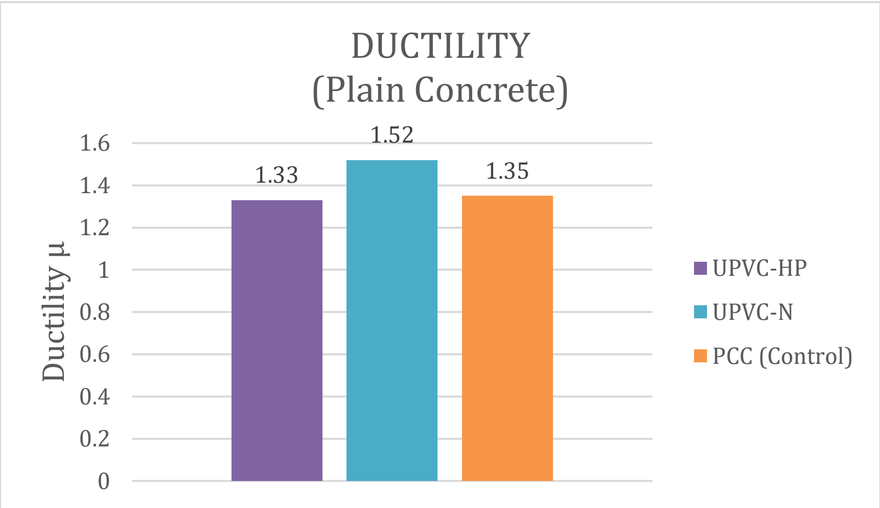


Fig S illustrates the ductility of specimens with reinforced concrete

Fig T illustrates the ductility of specimens with plain concrete

From Fig S, we can see that UPVC-N-R (normal pressure) has the highest ductility. The difference between UPVC-N-R and RCC is 14 %. While UPVC-HP (high pressure) has the lowest ductility among the three. This is because UPVC-HP has more thickness and is designed to be high strength where it could work in more aggressive environment, therefore it compromises on ductility.

From Fig T, we see the similar trend as UPVC-N (normal pressure) has the highest ductility value of 1.52 as compared to UPVC-HP with a value of 1.33. The PCC has a ductility of 1.35.

RCC has reinforcement which makes it more ductile than PCC. The UPVC-HP-R has less ductility than RCC and UPVC-N-R because the high pressure pipe makes it a little brittle. It is still more ductile than UPVC-HP because of the presence of the reinforcements.

5. CONCLUSION

In this study, we confined plain and reinforced concrete with normal pressure and high pressure UPVC pipes to compare their behaviour under axial compressive load. Stress strain relationship was developed and the curve was analysed and following conclusions were made:

i. UPVC high pressure reinforced concrete improved the axial compressive strength by 18% of unconfined reinforced concrete. UPVC high pressure had a 38.5% increase in strength compared to unconfined plain concrete. The concrete confinement by UPVC increases the period of compression failure at a constant load rate.

ii. UPVC normal pressure reinforced concrete only showed an increase of 0.85% against unconfined reinforced concrete. While UPVC normal pressure showed a 14 % increase in strength compared to unconfined PCC. This shows that in reinforced concrete, the normal pressure UPVC pipe does not improve strength compared to high pressure as UPVC normal pressure pipe does not increase the period of compression failure at a constant load rate.

iii. From this trend, we can conclude that reinforcement plays a more significant role in normal pressure UPVC than high pressure UPVC. The thickness of the UPVC normal pressure is less which decreases the effect of UPVC in compressive strength in reinforced concrete.

iv. High pressure UPVC is more rigid and has greater resistance to deformation but compromises its ductility for strength. Normal pressure UPVC is more ductile but its strength does not increase by a relative significant margin in reinforced concrete.

5.1 RECOMMENDATION

This study recommends that :

1. Normal strength UPVC is not very effective, and should not be studied further for increase in strength specially for RCC.
2. Further research should be carried out to study the behaviour of High Pressure UPVC confined members in depth with other variables.
3. Even greater strength UPVC pipes should be studied for confined members.

REFERENCES

[1] Farooq, H., Usman, M., Mehmood, K., Malik, M. S., & Hanif, A. (2018, September). Effect of steel confinement on axially loaded short concrete columns. In *IOP Conference Series: Materials Science and Engineering* (Vol. 414, No. 1, p. 012026). IOP Publishing.

[2] Furlong, R. W. (1967). Strength of steel-encased concrete beam columns. Journal of the Structural Division, 93(5), 113-124.

[3] Knowles, R. B., & Park, R. (1969). Strength of concrete filled steel tubular columns. Journal of the structural division, 95(12), 2565-2588.

[4] Wolf, R., & Miessler, H. J. (1989). HLV-Spannglieder in der Praxis. Erfahrungen Mit Glasfaserverbund Staben, Beton, 2, 47-51.

[5] Saafi, M., Toutanji, H., & Li, Z. (1999). Behavior of concrete columns confined with fiber reinforced polymer tubes. Materials Journal, 96(4), 500-509.

[6] Toutanji, H., & Saafi, M. (2002). Stress-strain behavior of concrete columns confined with hybrid composite materials. Materials and structures, 35(6), 338-347.

[7] Ismail, R., Rashid, R. S., Chan, W. C., Jaafar, M. S., & Hejazi, F. (2019). Compressive behavior of concrete cylinder fully and partially confined by carbon fibre-reinforced polymer (CFRP). Construction and Building Materials, 201, 196-206.

[8] Boersma, A., & Breen, J. (2005, April). Long term performance prediction of existing PVC water distribution systems. In 9th International Conference PVC.

[9] Burn, S., Davis, P., & Schiller, T. (2005). Long-term performance prediction for PVC pipes.

[10] Folkman, S. (2014, September). Validation of the long life of PVC pipes. In 17th Plastic Pipes Conference (pp. 1-9). The United States of America Chicago, Illinois.

[11] Kuder, K. G., Gupta, R., Harris-Jones, C., Hawksworth, R., Henderson, S., & Whitney, J. (2009). Effect of PVC stay-in-place formwork on mechanical performance of concrete. Journal of materials in civil engineering, 21(7), 309-315.

[12] Gupta, P. K., & Verma, V. K. (2016). Study of concrete-filled unplasticized poly-vinyl chloride tubes in marine environment. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 230(2), 229-240.

[13] BBJ Pipe Industries Pvt Ltd., “Pipes and Tubes”

[14] Litek Composites Corp., "Filament wound pipes" www.frpsupply.com

[15] Royal PVC Private Limited , “Pipes & Fittings”

[16] Gagg, C. R. (2014). Cement and concrete as an engineering material: An historic appraisal and case study analysis. Engineering Failure Analysis, 40, 114-140.

[17] World and U.S. cement production 2010-2020 (Published by M. Garside, Feb 15, 2021)

[18] Billmeyer, F., (1971) "Textbook of Polymer Science," 2nd ed., John Wiley and Sons, Inc., NY

[19] Thermoset vs. Thermoplastics - A Comparison of Materials, Advantages and Disadvantages (thomasnet.com)

[20] Illston J. M., (1994) "Construction Materials: Their Nature and Behaviour" UK. 1994-02-01. ISBN 0419154701/ 0-419-15470-01.

[21] Michel Sabri Samaan, (1997). "An analytical and experimental investigation of concrete-filled fiber reinforced plastics (FRP) tubes" PhD thesis, University of Central Florida, Orlando, Florida.

[22] Meier, U. (1996). "Composites for structural repair and retrofitting." Proc. 1st Int. Conf. Composites in Infrastructure, Tucson, AZ., 1202-1216.

[23] Seible, F. (1996). "Advanced composite materials for bridges in the 21' century." Adv. Composite Mater. in Bridges and Struct., El-Badry, M. M. (Ed.), CSCE, 17-30.

[24] Bavarian, B., Shively, J., Ehrgott, R, and Di Julio, R. (1996). "External support of c concrete structures using composite materials." Proc. 1st Int. Conf. Composites in Infrastructure, Saadatmanesh, H., and Ehsani, M. R., (Ed.), Tucson, AZ., 917928.

[25] Soudki, K A., and Green, M. F. (1996). "Performance of CFRP retrofitted concrete columns at low temperatures." Adv. Composite Mater. in Bridges and Struct., ElBadry, M. M.(Ed.), CSCE, 427-434.

[26] Karbhari, V. M., and Eckel, D. A. (1993). "Effect of a cold-regions-type climate on the strengthening efficiency of composite wraps for columns." Technical Report, University of Delaware Center for Materials, Newark, DE.

[27] Ligday, F. J., Kumar, S.V., and GangaRao, H. V. S. (1996). "Creep of concrete beams with externally bonded carbon fiber tow sheets." Adv. Composite Mater. in Bridges and Struct., El-Badry, M. M., (Ed.), CSCE, 513-518.

[28] Pelvris, N., Triantafillou, T. C. (1994). "Time-dependent behavior of RC members strengthened with FRP laminates." Journal of Struct. Engr., ASCE, 120 (3), 1016-1042.

[29] Ahmad, S.H. and S. P. Shah, 1982. “Complete Tri-axial Stress-Strain Curves for Concrete, Journal of Structural Division,” Proceedings of the American Society of Civil Engineering, ASCE,108 (ST4):728-742.

[30] Mander, J.B., M. J. N. Priestley and R. Park. 1988. “Theoretical Stress-Strain Model for Confined Concrete,” Journal of Structural Engineering, ASCE, 114:1804-1823. 58

[31] Pantazopoulou, S. J., and Mills, R. H. (1995)."Microstructural aspects of the mechanical response of plain concrete." ACI Materials J., 92 (6), 605-616.

[32] Mirmiran, A., and Shahawy, M. (1997a). "Behavior of concrete columns confined by fiber composites." J. Struct. Engr., ASCE, 123 (5), 583-90.

[33] Gupta, (2013):“Confinement of concrete columns with Unplasticized Poly-vinyl chloride tubes.”International Journal of Advanced Structural Engineering,. Available online at : http://www.advancedstructeng.com/content/5/1/19

[34] Schneider SP (1998)."Axially loaded concrete filled steel tubes."Journal of Structural Engineering 124(10):1125–1138.

[35] De Lorenzis, L. and Tepfers, R. (2001). “A Comparative Study of Models on Confinement of Concrete Cylinders with FRP

Composites.”Division of Building Technology, Work No.46, p.81, Publication:01:04, Chalmers University of Technology, Sweden

[36] Teng, J. G., Chen, J. F., Smith, S. T. and Lam, L. (2002). “FRP Strengthened RC Structures.” pp. 245, John Wiley and Sons Ltd., Chichester, UK.

[37] Richart, F. E., Brandtzaeg, A., and Brown, R L., (1929). "Failure of Plain and Spirally Reinforced Concrete in Compression." Engineering Experiment Station Bulletin No. 190, University of Illinois, Urbana, IL.

[38] lyengar, K. T. S. R, Desayi, R., and Reddy, K. N. (1970). "Stress-strain characteristics of concrete confined in steel binders." Magazine of Concrete Research (London), 22 (72), 173-184.

[39] M.A. SHANAN, A.H. EL-ZANATI, A.R. ANIS, AND G.METWALLY. (2019). Effect of confinement with lateral reinforcement on normal & high strength concrete columns.

[40] Gardner N. J. and Jacobson E. R., (1967).“Structural behavior of concrete filled steel tube.” American concrete institute Journal,404–413.

[41] Knowles, R. B., and Park, R., (1969). "Strength of concrete filled steel tubular columns." ASCE Journal of the Struct. Div., vol. 95, ST12, pp. 2565-2587.

[42] Orito, Y., Sato, T., Tanaka, N., and Watanabe, Y. (1987). "Study on the unbounded steel tube structure." Proc., Int'l Conf. Composite Construction in Steel and Concrete, ASCE, 786-804.

[43] Prion, H. G. L., and Boehme, J. (1994). "Beam column behavior of steel tubes filled with high strength concrete." Canadian J. Civil Engr., 21 (2), 207-218.

[44] Confinement Effect of Concrete-Filled Steel Tube Columns With Infill Concrete of Different Strength Grades https://www.frontiersin.org/articles/10.3389/fmats.2019.00071/full

[45] Han, L. H., Yao, G. H., Chen, Z. B., & Yu, Q. (2005). Experimental behaviours of steel tube confined concrete (STCC) columns. Steel and Composite Structures, 5(6), 459-484.

[46] Li, Y. F., Chen, S. H., Chang, K. C., & Liu, K. Y. (2005). A constitutive model of concrete confined by steel reinforcements and steel jackets. Canadian Journal of Civil Engineering, 32(1), 279-288.

[47] Teng, J. G., Wang, J. J., Lin, G., Zhang, J., & Feng, P. (2020). Compressive behavior of concrete-filled steel tubular columns with internal high-strength steel spiral confinement. Advances in Structural Engineering, 1369433220981656.

[48] Fardis, M. N., and Khalili, H. H. (1981). "Concrete encased in fiberglass-reinforced plastic."Journal of American Concrete Institute, 78 (6), 440-446

[49] Smith, S. T., Kim, S. J., & Zhang, H. (2010). Behavior and effectiveness of FRP wrap in the confinement of large concrete cylinders. Journal of Composites for Construction, 14(5), 573-582.

[50] Lahlou, K., Aitcin, P.C., and Chaallal, O. (1992). "Behavior of high-strength concrete under confined stresses." Cement & Concrete Composites, 14, 185-193.

[51] Mirmiran, A., and Shahawy, M. (1995). "A novel FRP-concrete composite construction for the infrastructure." Proc., Struct. Congress XIII, ASCE, Boston, MA, 1663-1666.

[52] Kargahi, M. (1995). "Fiber reinforced plastic (FRP) shell as external reinforcement for concrete columns." MS thesis, University of Central Florida, Orlando, FL.

[53] Mastrapa, J. C. (1997). "Effect of bonded and unbonded construction on confinement with fiber composites." MS thesis, University of Central Florida, Orlando, FL.

[54] Pico, O. (1997). "Confinement effectiveness of square FRP tubes in hybrid columns." MS thesis, University of Central Florida, Orlando, FL.

[55] El Echary, H. (1997). "Length effect on concrete-filled FRP tubes using acoustic emission." MS thesis, University of Central Florida, Orlando, FL.

[56] Fam, A., (2000). "Concrete-filled fiber-reinforced polymer tubes for axial and flexural structural members", PhD thesis, University of Manitoba, Canada.

[57] Moran, D.A., and Pantelides, C.P. (2002). "Stress-strain model for fiber-reinforced polymer confined concrete." J. Compos. Constr., ASCE, 6(4), 233-240.

[58] Youssef, M. N., Feng, M. Q., & Mosallam, A. S. (2007). Stress–strain model for concrete confined by FRP composites. Composites Part B: Engineering, 38(5-6), 614-628.

[59] Kurt, C. E., (1978). "Concrete filled structural plastic columns."Journal of the Structural Division, Vol. 104, No. 1, pp. 55-63

[60] Marzouck, M.,and Sennah, K., (2002). Concrete-filled PVC tubes as compression members: Composite Materials in Concrete Construction. Proceedings of the international congress "challenges of concrete construction" pp. 31-38

[61] Gathimba, N. K. (2015). Performance of UPVC pipe confined concrete columns in compression (Doctoral dissertation).

[62] Yu, F., Xu, G., Niu, D., Cheng, A., Wu, P., & Kong, Z. (2018). Experimental study on PVC-CFRP confined concrete columns under low cyclic loading. Construction and Building Materials, 177, 287-302.