Improvement in the compressive behavior of RC column by encasing in HDPE (High density polyethylene) tubes

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By

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This thesis is dedicated to my family.

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Abstract

In this paper, the investigation of a new column type is presented, specifically Column confined with HDPE and stirrups (CHS) and column confined with HDPE only (CH) columns. The first set of columns are confined with HDPE externally and steel stirrups internally and concrete filled in the core area, while the second set of columns is confined only with HDPE externally. A number of axial compression tests were conducted on CHS, CH, and control columns, and characteristics such as the thickness of HDPE (high density polyethylene) tubes, the diameter of the column, and the availability of stirrups were studied. The test findings indicate that the concrete-filled HDPE tube columns increase peak stresses by up to 170 percent and have outstanding ductility, while the inner steel stirrup confinement system offers effective confinement for CHS. The HDPE-confined columns demonstrated superior compressive strength, energy absorption, and compressive toughness compared to the control columns. The deformation behaviour of concrete in CHS with HDPE is somewhat less than in CH with HDPE alone. The unique column shape is well suited for maritime structures, bridges, and subterranean structures where a novel supporting system is required to have both a high deformation capacity and a high-water resistance.

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Abbreviation

HDPE High density polyethylene.

RC Reinforced concrete.

CH Cconcrete filled HDPE Reinforced concrete column without Stirrups.

CHs Cconcrete filled HDPE Reinforced concrete column with Stirrups.

LVDT Linear variable displacement transducer.

CHAPTER 1

1 INTRODUCTION

1.1 GENERAL

External confinement was effectively used for the concrete columns to enhance their strength and ductility, and to rehabilitate them from degradation caused by a variety of factors. Concrete-filled steel tubes were adopted in early constructions for some of the reasons indicated above. The high expenditure of corrosion maintenance, low fire resistance, and the excessive weight of the tubes are the main drawbacks of this approach[1]. Finite study has been conducted to better understand the axial compressive behaviour of concrete-filled plastic pipes [2]. It was found that PVC pipe confinement had no influence on the compressive strength of concrete. Furthermore, the restriction from plastic pipe increases ductility. External confinement device of fiber-reinforced polymer (FRP) has been used to increase the compressive strength of concrete-filled plastic pipes, since it has recently been found that FRP confinement is useful in enhancing the strength and ductility of concrete [3], [4][5][6] . It has been demonstrated that FRP tubes and FRP wraps in the form of FRP discontinued rings or continuous jackets may offer adequate confinement to concrete [7][8][9]. equivalent to the confinement of FRP, Yu et al [10]. It was discovered that concrete-filled plastic tubes with no reinforcement perform much worse than concrete filled FRP PVC composite pipes internally strengthened with a steel section. PVC-FRP tube exhibits a spectacular improvement in ductility, according to previous mechanical property research [11][12]. Zhang and Hadi's [13] research on geopolymer concrete piles (GCPs) with FRP-PVC- confined concrete (FPCC) core has led to the conclusion that the use of FRP-PVC composite pipe significantly improves the mechanical performance of GCPs.

Fakhariar and Chen [14], studied the compressive behavior of concrete-filled FRP-PVC pipes, while Jiang et al. [15] created a nonlinear finite element model to simulate the axial compressive behavior of thin CCFPTs. On the other hand, the final wrap of plastic wrap often has a tensile strength that is much higher than that of traditional FRPs [14], [15]. [e.g., Carbon FRP (CFRP), Glass FRP (GFRP)]. In practice, this means that the FRP-plastic (with and without internal steel wire reinforcement) confined concrete typically reaches its final state when the FRP explodes, at the expense of the plastic's material properties (however, the plastic may experience fracture failure due to the explosive failure of the FRP explosion and the sudden reduction in captivity from the FRP). The strength and ductility of RC components enhanced with conventional FRPs might be much lower than those FRPs with a substantial rupture strain (LRS) since the ultimate state of concrete with FRP confinement is often connected to the tensile strength of the FRP [16][17][18]. To address this issue, researchers have developed a novel kind of FRP composites with a high rupture strain (or "LRS FRP composites" for short). It has recently gained a lot of traction in the academic and engineering sectors all around the globe. When compared to regular FRP composites with constrained concrete, LRSFRP composites are expected to deform much better. High ductility is a hallmark of concrete-filled SRTP tube columns, and the outer FRP confinement system reliably contains CFFSCs [19]. When compared to CFFSCs using carbon FRP, the expansion of concrete in polyethylene terephthalate FRP CFFSCs is different. Most modern urban drainage systems employ either high-density polyethylene (HDPE) or polyvinyl chloride (PVC) pipes. This is due to the superior performance and low price of HDPE and PVC.

Table 1.1 Nomenclature

Nomenclature	
fc'_0	Compressive strength of concrete.
ε_{co}	Axial strain at the concrete's maximum stress.
$f_{c'1}$	Yield Stress
ε_{c1}	Yield point Strain
$f_{c'2}$	Ultimate axial stress of column.
ε_{c2}	Ultimate Axial strain of column.
f'_{c3}	Fracture axial stress of column (at 80% peak load).
ε_{c3}	Axial strain at fracture stress of column (at 80% peak load).
f_{Lh}	Lateral confining pressure provided by HDPE.
E_H	The elasticity modulus of HDPE.
t_f	HDPE tube thickness.
d	The HDPE tube's inner diameter.
H	Height of the column.
D	The HDPE tube's outside diameter.
S_f	Space between steel rings (stirrups).
m	the number of columns specimens.
Ec	The elasticity modulus of an unconfined concrete column.
f_c	Concrete strength.

Table 1.2 Specifications of test specimens

Specimens	D (mm)	E_H (GPa)	t_f (mm)	f'_{c1} (Mpa)	ϵ_{c1}	Peak stress (Mpa)	ϵ_{c2}	f'_{C3} (Mpa)	ϵ_{c3}	E (Mpa)
CONTROL-200	200	_	0	30.76	0.00276	32.27	0.0030	25.8	0.0032	10500
CONTROL-110	110	_	0	28.8	0.00224	29.88	0.0023	23.9	0.0024	12693
16-CHS-200	200	63.28	19.2	46.10	0.00637	57.69	0.0195	46.1	0.0271	10857
12-CHS-200	200	63.28	15.5	40.93	0.00454	46.44	0.0125	37.1	0.0186	11600
10-CHS-200	200	63.28	12.55	34.39	0.0027	39.13	0.0081	31.3	0.0184	15145
16-CHS-110	110	63.28	10.55	46.53	0.00341	51.38	0.0082	41.1	0.0215	15138
12-CHS-110	110	63.28	8.6	38.95	0.00313	45.93	0.0058	36.7	0.0164	15390
10-CHS-110	110	63.28	7	32.6	0.00244	42.13	0.0126	33.7	0.0200	17759
16-CHS-200	200	63.28	19.2	35.43	0.00319	41.28	0.0109	33.0	0.0200	14406
12-CHS-200	200	63.28	15.5	34.15	0.00213	40.72	0.0071	32.5	0.0157	15738
10-CHS-200	200	63.28	12.55	32.11	0.00408	37.90	0.0077	30.3	0.0139	10433
16-CHS-110	110	63.28	10.55	38.11	0.00426	44.35	0.0095	35.4	0.0215	11286
12-CHS-110	110	63.28	8.6	34.15	0.00386	39.36	0.0091	31.4	0.0141	10451
10-CHS-110	110	63.28	7	28.51	0.00282	38.54	0.0084	30.8	0.0177	12918

Plastic pipes have been used as a protective sheath for concrete in order to enhance its longevity, owing to their exceptional resilience. In recent times, a number of studies have been conducted to investigate the axial compressive behaviour of columns made of concrete-filled plastic pipes [1]. If we were to compare PVC to other types of protective techniques or materials, we would find that it has several benefits. These advantages include a good resistance to corrosion and a greater capacity for elongation. Furthermore, when the PVC pipes are expanded to their maximum capacity, they effectively contain the core concrete. However, to date, no research has been undertaken on the use of concrete-filled high-density polyethylene (HDPE) columns.

An experimental program on the axial compressive behavior of HDPE-confined concrete was carried out as part of an effort to get a more comprehensive understanding of the performance characteristics and confinement processes of concrete that was confined with HDPE (with or without lateral reinforcement). Results of test are presented in detail. The impacts of HDPE pipes, HDPE pipe thickness, lateral steel (with or without stirrups), and column diameter were thoroughly explored. Sixteen design-oriented columns were cast to investigate the fracture axial stresses and related strains of concrete confined with HDPE.

Columns are critical structural members that are subjected to primarily axial forces with or without the moment, and their failure results in the collapse of a structure. When a weight is applied to a column, it shortens longitudinally and expands laterally. When the stresses approach 70% of the column strength, the lateral expansion becomes more evident. When the maximum axial load is applied, the concrete crushes and the longitudinal reinforcement buckles outwards. Engineers in practice and design give special attention to the confinement of columns, the durability of modern reinforced concrete structures, and their protection from harsh conditions. The use of HDPE tubing for encasing concrete and its steel reinforcement is one way that may be used for the purpose of providing confinement as well as protection. The current understanding as well as the possibilities of using HDPE tubing in construction and civil applications are talked about here. However, the published literature on this technique of concrete confinement is just getting started, and the quantity of the data and associated information on its development and use is limited, and it has a tendency to be dispersed both in study and in practice. In HDPE tube encased concrete, the tube serves multiple purposes, including providing lateral confinement, enhancing ductility, preventing any moisture loss necessary for the setting and hydration of fresh concrete, eliminating the time-consuming and expensive curing process, eliminating shuttering, casting of prefabricated columns, protecting concrete from thermal changes, and making column impermeable by closing the surface pores. These functions are in addition to the primary function of the tube, which is to confine the concrete core and the surrounding aggregate. As a permanent formwork for fresh concrete, the tube can confer a protective cover to concrete, preventing the cover from spalling, in substructures that come into contact with soil (pile), marine environment (bridge columns and piers), as well as in a variety of light structural applications and constructions, such as houses, residential, agricultural, and industrial buildings.

1.2 PROBLEM STATEMENT

Confinement of columns is one of the key issues in construction industry. One of the key challenges in the construction industry is the strength and durability of reinforced concrete columns under severe environmental conditions. The load of whole building act on column so the durability of building depends on column. Circular (RC) columns are frequently used in bridges as piers and piles of foundation because they are simple to construct, have a pleasant look, and give equivalent strength qualities in all directions under wind, flood, and seismic loads. Loss of load-carrying capacity in bridge columns and piles is a serious problem globally, most of the time it is due to confinement failure. additionally, the corrosion of steel reinforcement in concrete bridges and underground column subjected to de-icing salts and/or aggressive environments constitutes the major cause of structure deterioration, leading to costly repairs and rehabilitation as well as a significant reduction in service life. Estimates indicate that the billions of dollars spent annually to repair and replace bridge substructures such as pier columns and marine piling systems (National Association of Corrosion Engineers International). Problems related to expansive corrosion and enhancement of column strength could be resolved with help of concrete filled HDPE reinforced concrete (CH) tubes so protecting the steel reinforcing bars from corrosion-causing agents and increased the ductility of column.

1.3 RESEARCH OBJECTIVES

This study's primary objective is to investigate the enhancement of column peak stress, column ductility, column elastic modulus, column energy absorption, and column stress strain behavior. The study's objectives include:

- To study the efficiency of HDPE encasement in improving the compressive behavior of columns
- To determine the optimum in improving the columns strength, ductility stiffness and energy absorption.
- To evaluate the suitable diameter of column which have optimum properties.
- To investigate the effect of stirrups for column.

1.4 RESEARCH SIGNIFICANCE

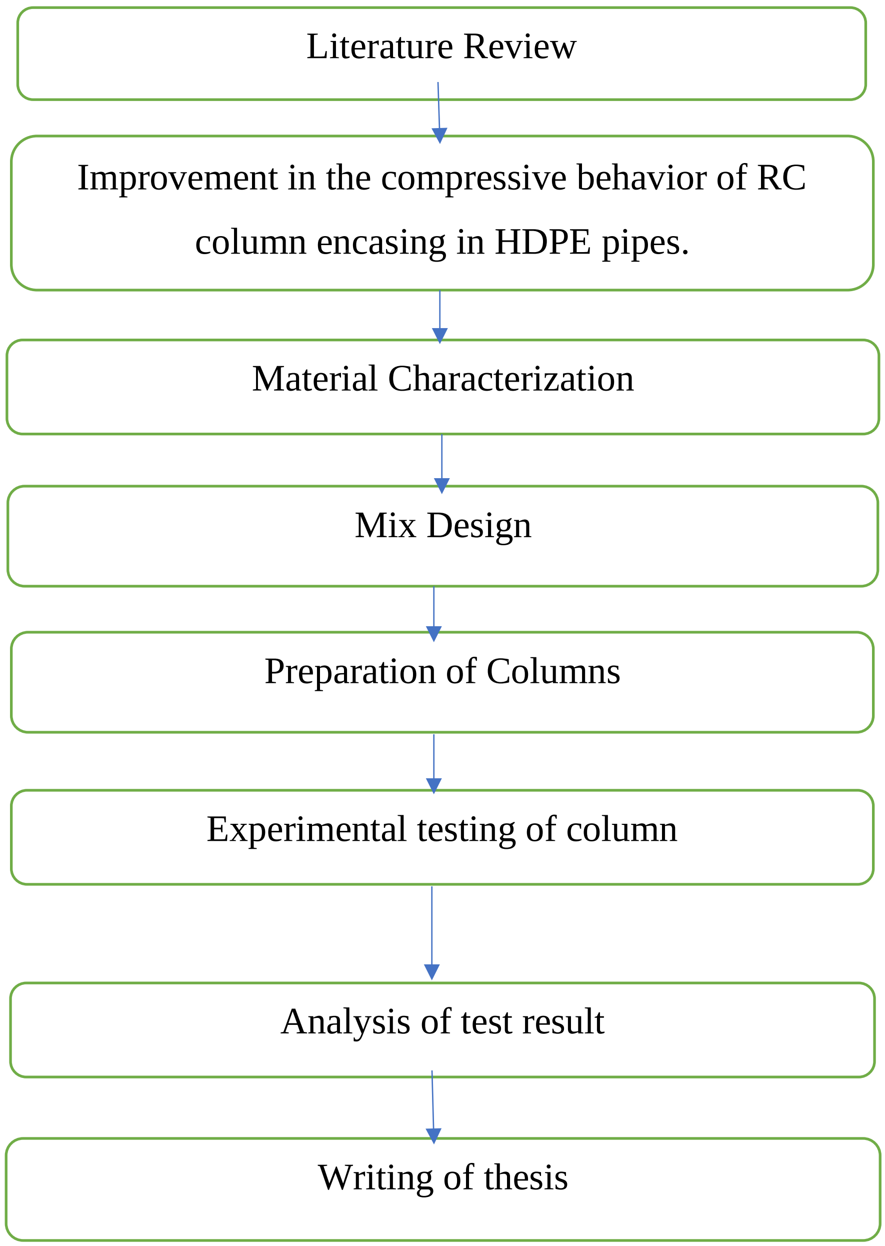
The influence of PVC and steel tubes on CFST (concrete filled steel tubes) and CFPT (concrete filled PVC tubs) strength is well documented, and there is plenty of test data for pvc and steel tubes in the literature. The possible characteristics of concrete-filled HDPE must be investigated. Although there is sufficient test data for PVC and steel tubes in the literature, the capacity of HDPE to enhance the ultimate strength, stiffness, energy absorption, and ductility of concrete filled HDPE reinforced concrete (CH) columns (with or without Stirrups) is yet unknown.

1.5 SCOPE OF THE STUDY

The purpose of this research is to enhance the tensile strength and ductility of columns. Both steel and pvc tubes increase column strength and ductility, but the pvc tubes exhibit only a small increase in strength and ductility while the steel tubes increase both column strength and ductility. Corrosion is a problem with steel tubes; HDPE is utilized to combat this issue. The purpose of this study is to compare the compressive strength, stress-strain response, elastic modulus, compressive toughness, strain ductility, and energy absorption of HDPE confined columns to those of RC columns used as a reference. The formulations were evaluated based on HDPE thickness, column diameter, and availability of stirrups.

1.6 RESEARCH METHODOLOGY

Flow chart of research methodology is given below:



CHAPTER 2

2 LITERATURE REVIEW

2.1 GENERAL

In any structure, a column is the most fundamental structural element. Any structure's load is transferred from the slab and beam to the foundation. along with its ornamental function, it must be dependable and efficient under load. columns are sometimes referred to as compression members because they support the weight of beams, ceilings, and arches. They must, however, be designed to withstand buckling while carrying lateral wind and seismic stresses. Short or stub columns, intermediate columns, and long or thin columns are the three primary types of columns. any form of it may be employed in any size, depending on the load circumstances. For many years, composite columns have been employed in the building sector with considerable success. This is because composite column systems are superior to their non-composite competitors, which include reinforced concrete (RC) and steel. or wooden supports; there are several factors that went into the decision to choose a composite column rather than, say, wood pillars. various materials have different qualities. Tubes made of steel and fiber-reinforced polymer in concrete encased columns, the most typically employed restricting material has been construction. Steel, on the other hand, is prone to corrosion, particularly when used in harsh environments, while fiber reinforced polymer requires a more costly manufacturing process. This study developed a new form of concrete-filled composite column in which concrete was confined with a high-density polyethylene (HDPE) plastic tube.

2.2 WHAT IS CONCRETE

Concrete is the predominant composite material used in the construction sector. Visualizing a world devoid of concrete is a formidable challenge. Concrete is formed by combining cement (or an other cementitious material), water, coarse aggregates (such as gravel or crushed stone), fine aggregates (such as sand), and/or admixtures. In the local vicinity, an abundance of these components may be readily obtained. The use of recycled concrete aggregates as a replacement for primary resources is a viable option. Incorporation of fly ash, slag, silica fumes, and several other waste materials derived from diverse sectors is a potential practice in contemporary building projects. The transformation of the liquid into a solid state occurs when it is placed into molds and allowed to undergo a curing process. The strength of concrete increases with time due to chemical reactions occurring between water and cement, resulting in the hardening of the material. Concrete strength, durability, and other features are affected by the properties of its component materials, the mixture composition, the compaction technique, and other elements used during installation, compaction, and curing.

2.3 CONCRETE MIX DESIGN

Concrete mix design involves selecting the proper ingredients such as cement, water, coarse aggregate, and sand, as well as any admixtures, and determining the relative amounts of these ingredients to achieve the desired level of strength, workability. , and sustainability in the finished product. Concrete in its freshly mixed stage is famous for having a workability that is regarded as an essential quality. When the material has reached the stage of being hardened, compressive strength and durability become very important qualities.

2.3.1 FACTORS CONSIDERED IN MIX DESIGN

2.3.1.1 GRADE OF CONCRETE

This tells how strong the concrete needs to be in general. Depending on how well quality control can be done on-site, the concrete mix must be made for a desired mean strength that is higher than the characteristic strength.

2.3.1.2 TYPE OF CEMENT

The selection of cement type significantly influences the pace of development of concrete's compressive strength and its capacity to withstand severe environmental conditions. The building of reinforced concrete often makes use of Ordinary Portland Cement (OPC) and Portland Pozzolanic Cement (PPC), which are both forms of Portland cement.

2.3.1.3 AGGREGATE TYPE AND GRADE

The bond between the matrix and aggregate particles, and thus the concrete's strength, is significantly affected by the surface texture of the concrete. This is because the concrete's workability is affected by the particles' shapes. When compared to concrete made with uncrushed aggregates, concrete made with crushed aggregates is less pliable but more durable. This is due to the angular particles and severe surface roughness seen in crushed aggregates. It has been shown that the quantity of cement needed to get a certain water-cement ratio is inversely proportional to the aggregate size. Typically, nominal aggregate sizes of 20 millimetres or smaller are considered appropriate.

2.3.1.4 WATER / CEMENT RATIO

The kind of cement that is used is what determines the minimum water-to-cement ratio that is necessary for a certain strength.

2.3.1.5 WORKABILITY

How thoroughly concrete can be poured and compacted depends on the size and shape of the section to be concreted and the amount of free water available for the cement to hydrate in.

2.3.2 METHODS FOR CONCRETE MIX DESIGN

The primary mix design approaches used in various nations are based on empirical correlations and the application of charts and graphs resulting from significant experimental research. The approaches widely used in the sector include the American Concrete Institute (ACI) methodology and the British Research Establishment (BRE) method. Nevertheless, it is crucial to acknowledge that this particular research only used the ACI technique.

2.3.2.1 METHOD OF ACI MIX DESIGN

The sand FM and dry-rodded coarse aggregate bulk density are used to calculate the sand and coarse aggregate percentages, respectively. As a consequence, this technique considers the actual voids in compacted coarse aggregates that must be filled with fine aggregates, cement, and water. This method is ideal for creating air-entrained concrete since it generates separate tables for the two types of concrete. Aggregate sizes up to 150 mm may have their water and sand content precisely measured using this technology. That's why this method is ideal for making plum concrete. It also provides separate estimates for coarse aggregates of 12.5 and 25 millimeters in size. The problems with this strategy are as follows: -

1. It calculates coarse aggregate ratios for sand with FM values ranging from 2.4 to 3.0. As a result, ultra-fine aggregates with FM greater than 3.2 are excluded.
2. The specific gravity of concrete components is not employed to estimate the density of new concrete in this approach. IS (Indian Standards) and British mix design approaches both connect the plastic density or yield of concrete to its components' specific gravity.

3. According to this approach, the density of freshly produced concrete ranges from 2285 kg/m3 for coarse particles with a diameter of 10 mm to 2505 kg/m3 for coarse aggregates with a diameter of 150 mm. The plastic density of new concrete, specifically for 20- and 10-mm down particles, has a range of 2400 to 2600 kg/m3 throughout several nations. The cement content tends to be elevated when weight estimations are derived from specified densities.
4. The distinction between natural (uncrushed) aggregates and crushed stone aggregates, as well as the impact of aggregate surface flakiness and roughness on sand and water content, are all ignored by the ACI method.
5. There is no particular procedure for blending 10 mm and 20 mm aggregates in the ACI method.
6. The fine aggregate content cannot be changed to accommodate for variations in cement content. As a result, for a specific combination of components, the sand % may be the same in both richer and leaner blends.

2.4 HIGH DENSITY POLYETHYLENE (HDPE) TUBES

HDPE raw material is used to make HDPE lines. This material is hard to break and can be burned at high temperatures. HDPE pipes and tubes are often used in drinking water lines, gas lines, sewage lines, and irrigation systems because they last a long time and don't rust. There are also extrusion lines [20]. High density polyethylene (HDPE) is a common option for geotechnical applications because of its light weight, corrosion resistance, and low cost. It has been employed in potable and wastewater transportation geomembranes and pipes. Gas distribution networks are made of medium density polyethylene, which is more durable but less resistive. HDPE replaces concrete and steel in water ducts. While HDPE is one of the strongest polymers, it has a lower fracture toughness than commercial alloys. In comparison to metals and concrete, it also has poor strength and stiffness, which is somewhat countered by its light weight (specific strength). HDPE is used in small and medium-sized pipes that carry drinking water and work under mild pressure. [21]. When compared to the traditional ones that have been utilised in the past, HDPE has several benefits. Here are a few such examples: They don't need cathodic protection systems, they last a long time, they don't need extra anti-corrosion coatings on the inside or outside, the smooth interior surface gives them great hydraulic qualities that stay the same over time, and they are good for the environment. They cost little to keep up and are easy to build, which saves time and money. When high pressures are needed, it is very helpful to have a good cover. The way the joints are built lets them change angles, so they can change directions without needing special parts. Compared to concrete or metal tubes, the weight is less. Since only a few links are needed and the tubes can be put up quickly, they can be made very long. Because the materials used are thermally stable, they don't change in quality when the temperature changes. Pipes that are sold don't smell, don't taste good, aren't dangerous, and aren't affected by chemicals or weather. Prices are dropped, making sure that delivery is quick and cheap. Pipes that are traded are odorless, tasteless, non-toxic, and resistant to the effects of chemicals or weather. Pipes age slowly. For example, plastic pipes can be used in a 50-year setup as long as the manufacturer's recommended pressures and temperatures are met [22].

2.5 REINFORCED CONCRETE COLUMNS CONFINEMENT

2.5.1 INTRODUCTION

It is well understood that confinement enhances the ductility and strength of concrete [23]. Transverse stresses are produced for an axially loaded concrete part, leading to radial concrete expansion (Poisson's effect). Poisson's coefficient, which for concrete generally ranges from 0.15 to 0.25, links the transverse stresses and longitudinal strain inversely under light loading circumstances. The material will begin to microcrack once it reaches a critical stress, which is typically anywhere between 60% and 80% of the concrete's strength. As a result, transverse strains rapidly develop, resulting in enormous transverse strains for relatively minor longitudinal strain. These little fractures develop into larger ones that eventually cause the concrete to break apart.

The use of tensile-strengthening materials to control the growth of transverse strain is associated with the confinement mechanism of concrete. When confined concrete is loaded heavily, it enters a tri-axial compression stress state. When subjected to axially compression, concrete outperforms its uncompressed counterpart in terms of both strength and ductility.

Since the beginning of structural concrete, researchers have been interested in the ways in which confinement influences concrete. There have been a number of different confinement models devised to assist in the prediction of how confined concrete will behave. Although the term "pressure-sensitive" is sometimes used to describe concrete, "restraint-sensitive" is a more appropriate descriptor for this material [24]. This explains why the stiffness of the confining element has such a significant impact on the behaviour of confined concrete and gives an explanation for why this effect is so significant [25]. Furthermore, the use of a confinement model is subject to several limitations that vary according on the cross-sectional shape and stress conditions.

By the turn of the century, some studies had been done to assess the increased strength of concrete owing to confinement. Early experiments focused on the 'active' state of confinement, in which the confining pressure was kept constant during the loading process. Considered investigated the tri-axial behaviour of 80 mm x 300 mm mortar cylinders with continuous hydraulic pressure providing lateral confinement. A relationship was created to estimate the compressive strength of restricted concrete, using the outcomes of conducted experiments.

$$f'cc = k\, lf'co + .4\, 8fr \qquad (2.1)$$

The variables f'cc and f'co represent the compressive peak stresses experienced by confined and unconfined concrete, respectively. The constant kl falls between the range of 1 to 1.5, while fr denotes the lateral confining pressure. Richart, Brandtzaeg, and Brown [26] looked through these results further for concrete cylinders. They subjected cylinders made of normal-weight concrete (100 mm in diameter and 200 mm in height) to continuous hydraulic pressure while concurrently subjecting them to axial compressive stress till failure. Concrete's limiting strength was defined as follows:

$$f'_{cc}=f'_{co}+k_c f_r \quad (2.2)$$

For the experiments they did, the average confinement coefficient, kc, was 4.1. Lack of confinement and limited energy absorption capacity are two flaws in concrete columns [27]. Concrete columns can be restrained using the following methods:

1. steel ties or spirals for lateral reinforcement.
2. steel tube-encased concrete.
3. wrapping with exterior fibre composite.
4. concrete encased with fiber composite tubes.
5. concrete encased in plastic tubes (a novel technique).

All of these methods of confinement produce a 'passive' condition in which the confining influence is defined by the lateral expansion of the concrete core [28]. The concrete wants to expand laterally as the axial tension rises, but the confining material resists this with a constant radial pressure [29]. When subjected to axial compression, a confined column experiences lateral expansion of the concrete. However, the presence of a confining medium restricts this expansion, thereby preventing further expansion of the concrete. The effectiveness of a material in concealing concrete is measured by how well it works to contain the concrete. Compressive strength of concrete in confined spaces (f'.cc) divided by compressive strength of concrete in unconfined spaces (f'.co) is the mathematical expression.

2.5.2 CONFINEMENT WITH LATERAL STEEL REINFORCEMENT

Richart, Brandtzaeg, and Brown [30] carried out a number of tests to investigate the characteristics of 'passively' confined concrete. Concentric compression testing was conducted on a set of 23 circular concrete columns, with dimensions of 250 mm x 1000 mm apiece. The columns were enveloped by helical mild steel reinforcements, characterised by a pitch measurement of 25.4 mm. The range of spiral diameters observed was between 3.2 mm and 9.5 mm. Equation 2.2, which was initially calculated for "active" confinement, was used to calculate the confined compressive peak stress f'cc with a confinement coefficient of 4.1. Based on the greatest stress found in the steel spirals, the hoop tension was calculated to estimate the confinement pressure fr. Thus

$f\mathrm{r} = 2\mathrm{fsy}\ \mathrm{ds/D}$……………………………………………………………………… (2.3)

Where: Confining spirals' yield stress is represented here by fsy.

The limiting spirals' diameter is denoted by the symbol ds.

D stands for the column's internal space's diameter.

On the other hand, the effect of spiral spacing was not taken into account.

The impact of spiral spacing was studied by Iyengar et al. [31]. A number of standard-weight concrete cylinders with spiral reinforcement were tested under concentric compression. Spiral pitch varied from 30 mm to 98 mm, and the specimens measured 100 mm 200 mm. The other samples varied in size from 150 to 300 millimeters with spiral pitches from 30 to 118 millimetres. If the facts hold, equation 2.1 may explain spiral confinement's strength gains using a confinement coefficient of 4.6 instead of 4.1. Revisions to the confining pressure fr formula are indicated in equation 2.4[31].

$$fr = \frac{2Asp\ fsy}{D\ Ssp} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.4)$$

A sp is cross-sectional area of spiral

f sy is spiral stress at yielding.

S sp is spiral pitch.

Column inside diameter is D.

2.5.3 CONFINEMENT THROUGH STEEL TUBES

As shown in Figure 2.1, there is also the option of using steel tubes to enclose the concrete, which is still another method of concrete confinement. The steel tube serves as a shear, longitudinal, and transverse reinforcement in the structure. In addition, it acts as formwork and a continuous jacket for the concrete within the enclosure. However, concrete delays tube buckles locally [32]. Knowles and Park [33] tested concrete-filled steel tubes with varied slenderness ratios. They found that most of the time, the failure of the hybrid column was caused by the tube breaking before confinement could take effect. It was suggested that the tube shouldn't be loaded right away in the lengthwise direction. This would allow the tube's ability to contain in the circular direction to be used to its fullest. Orito et al [34], finally proved this to be true when they found that unbonded steel tubes filled with concrete had a higher axial compression strength than bonded tubes. This was a comparison made between the two types of tubes. number of experiments were carried out by Prion and Boehme [35] using circular steel tubes that had been

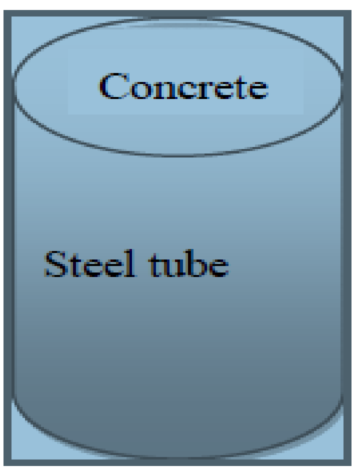


Fig. 2.1 concrete filled steel tube.

filled with concrete. The confinement effect has been reported to become apparent at a slenderness ratio of less than 15, where L and D are the length and diameter of the column, respectively. A shear collapse of the concrete core was determined to be the mechanism of failure for short columns (L/D 15). Over the past two decades, structural steel tubes have been the focus of much study for concrete confinement. As a consequence, a large body of literature [36], [37] has been produced as a result of these studies. in the preceding two decades, and as a direct consequence, a large body of literature [36], [37] is now accessible.

2.5.4 CONFINEMENT WITH FRP TUBES

The behavior of the proposed CFFT has been extensively studied through a series of research projects funded by the Florida Department of Transportation (F D O T). The aforementioned studies examined various factors including the type of stress, cross-sectional properties, bonding characteristics, and the impact of length. In this study, Kargahi [38] examined the strength of the CFFT (Carbon Fiber Fabric Tube) when subjected to uni-axial compression. 12 circular columns were utilized for testing purposes, consisting of nine tubes made of carbon fiber reinforced polymer (CFFRP) and three plain concrete cylinders measuring 150 mm x 300 mm. The study utilized filament-wound tubes made of E-glass/polyester material. These tubes were wound at a specific angle of 75° with respect to the longitudinal axis of the tube. There were three distinct tube thicknesses provided. Based on some observations, it has been observed that the compressive strength of concrete exhibits an increase ranging from 2.5 to 3.5 times when compared to unconfined concrete. In order to investigate the methods by which the tensile strength of FRP-confined concrete may be improved, a sequence of split-cylinder experiments were undertaken. The FRP tube was shown to enhance the behaviour of the concrete portion under stress by enclosing rather than limiting the fractured concrete. Parametric study was also done on how the limited strength of the column changed with changes in board thickness, winding angle, and composite action. The work was based on the model made by Mander et al [39]. The pure axial strength of the tube was shown to be improved by tube thickness. Instead of increasing the axial capacity of the column, the presence of full composite action improves the column's flexural capacity. Additionally, the pure axial strength decreases as the fiber winding angle rises. At a winding angle of 450, the pure flexural capacity reaches its maximum.

Lahlou et al [40] In the early 1990s, they looked at two 50 mm x 100 mm fibre glass tubes to study how confinement affected high-strength concrete. The axial orientation of the fibers prevented a significant improvement in concrete strength. The CFFRP tube suggested by Mirmiran and Shahawy [41] is depicted in Figure 2.2. The tube served as a mold for the concrete, a longitudinal reinforcing hoop, and a protective casing against corrosion. The tube also served as a longitudinal hoop for added strength. As can be seen in Figure 2.2, the structure's primary component is a filament-wrapped FRP tube filled with concrete. The concrete-filled steel tube is analogous to this carbon fiber reinforced plastic tube, abbreviated as CFST. It was recommended that the CFFRP tube system be used for the bridge columns and pile splicing.

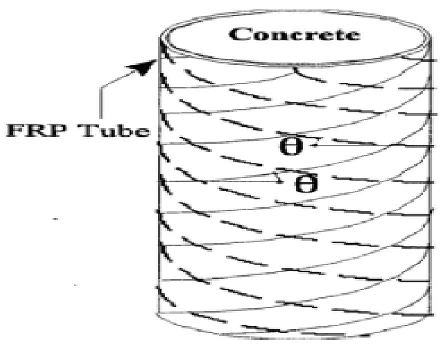


Fig 2.2 concrete filled FRP tube.

Mastrapa [42] did some research on the bond effect. There was a total of 32 composite cylinders measuring 150 mm × 300 mm that were put through the testing process. Fifty percent of the cylinders were enveloped in either one, three, five, or seven layers of Sglass fabric, and the other fifty percent were put into tubing composed of identical Sglass fabric with an equivalent number of layers. Two separate testing groups were performed. The Series 1 multi-layer casings were built up layer by layer, with the connection making up around 17% of the cylinders' radii. A single length of cloth was wound around a cylinder to create the Series 2 coat, and the resulting overlap made up around 32% of the garment's overall diameter. The effects of construction bond on axially laden confined concrete were revealed to be insignificant. Pico [43] investigated how the CFFT cross section affected the axial compression of a total of nine square concrete-filled FRP tubes with dimensions of 150 millimeters by 150 millimeters by 300 millimeters. The FRP tube that held the concrete core had no connection to the core itself. No matter how thick the jacket, a little improvement in strength was seen. The product of the corner radius and the confining pressure has been identified as the most important parameter for attaining efficient control in the context of confinement. El Echary [44] conducted a study on the impact of the length-to-diameter (L/D) and diameter-to-thickness (D/t) ratios on the behavior of circular CFFTs. The study involved a total of 24 CFFTs with a diameter of 145 mm. These CFFTs were categorized into three groups based on their tube thickness, which included 6, 10, and 14 layers. Furthermore, the CFFTs were categorised into four distinct categories according to their respective lengths, namely 300 mm, 450 mm, 600 mm, and 750 mm. During the testing, no buckling was seen. The highest eccentricity, according to the test findings, was within 10-12 percent of the section width. There was no discernible loss of strength. Slenderness effects were shown to be minimal up to an L/D ratio of 5:1.Fam [45], Fam and Rizkalla [46], Moran and Pantelides [47], Shehata et al. [48], and Becque et al. [49] have recently offered alternative models.

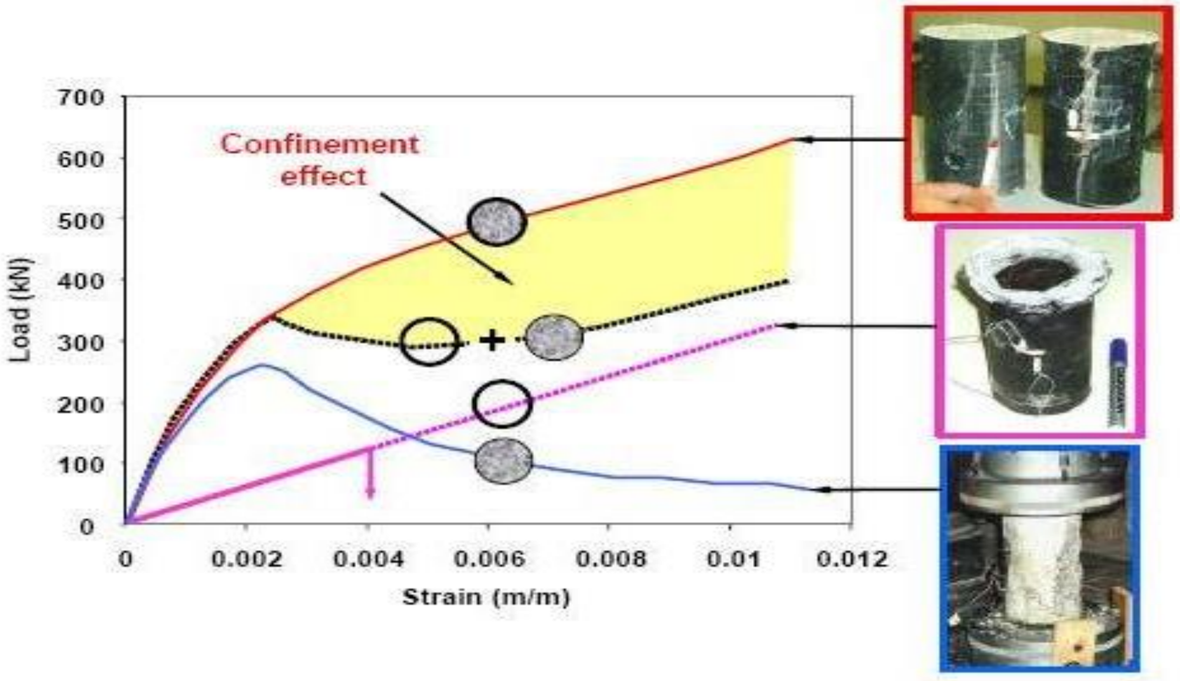


Figure 2.3 FRP tube confinement effect [46]

The bulk of these models are based on the basic fact that the stress-strain behaviour of concrete-filled FRP composite columns may be effectively described by a bilinear curve as depicted in figure 2.3.

Figure 2.3 shows how the FRP tube of a composite pile resists axial load and confines the concrete core [46]. We investigated how confinement improves the load bearing capability of a short, concrete-filled FRP tubular component. This shows that the composite stub's capacity is substantially higher than the two components. In the unconfined concrete strength area, the load-strain curve deviates. Microcracking and lateral expansion begin in the concrete core at this stress level. In response to the concrete's rising lateral expansion over time due to its linear elastic properties, the FRP shell exerts a radial restricting pressure [45]. The ultimate peak strength is determined by the hoop tensile strength of the FRP shell, which is defined by the second slope of the load-strain curve.

2.5.5 CONCRETE CONFINEMENT USING PLASTIC TUBES

Commercially accessible PVC pipes with a concrete core were proposed by Kurt C. E.[50]. In theory, the strength of the concrete core could potentially increase as a result of contact with the plastic tubing. The structural response of the plastic pipe under a column load was found to be comparable to that of spiral reinforcement. by around 3.2 times the pipe's rupture pressure, the plastic pipe increased the concrete core's strength. The observed behavior of plastic-encased concrete with a slenderness ratio below 20 indicates a shear failure at a 45° angle. This failure occurs in both the concrete core and the plastic pipe due to the combined effects 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. Despite this, his first research revealed that a column system made of concrete-filled PVC pipes would be practical for lightweight construction. Few scholars [50]–[54] explored this issue since there is a lack of literature and data on the use of this kind of composite column. Marzouk et al. [50] performed initial investigations on two unconfined concrete columns and four PVC-confined concrete column specimens, and he discovered that PVC tubes would work well as a confinement medium. In Table 2.3, the study's results are summarized.

Table 2.3 Properties and strength of the specimen [50]

SPECIMEN NUMBER	PIPE THICKNESS (mm)	CONCRETE CORE DIAMETER (mm)	HEIGHT (mm)	COMPRESSIVE AXIAL RESISTANCE (kN)
1	3	100	758	287
2	3	100	562	291
3	3	100	416	311
4	N/A	100	416	265
5	3	100	270	318
6	N/A	100	270	287

Based on their results, they came to the following conclusions and recommendations:

1. The use of PVC tubes gives excellent lateral confinement to concrete columns, increasing their ultimate compressive strength.
2. The connection between axial load and displacement demonstrates the ductility characteristics of PVC tubes filled with concrete. Before experiencing failure, the tube functions as a means of containing the deteriorating concrete core and exhibits significant lateral displacement.
3. A concrete-filled PVC tube's compressive strength decreases as its slenderness ratio rises.

Future research on the compressive strength of concrete-filled PVC tubes will require to examine a wide range of slenderness ratios, tube diameters, and concrete parameters. Different concrete mixes: M20, M25, and M40. The following was the conclusion reached because of this research:

1. Concrete columns become stronger and more ductile when enclosed in UPVC tubes. Strength and ductility increase with concrete strength and tube geometry.
2. All the specimens failed in a shear type failure pattern.
3. Previous models in the literature predicted that UPVC would have a confining effect, and the results were only slightly different (by 6%).
4. The post-peak behaviour of the load compression curve is affected by the compressive strength of the concrete. Because of brittleness, the slope of the curve rises as concrete strength increases.
5. As the grade of the concrete drops, so does the slope of the bends' onset portion.
6. The absolute amplitude of the slope of the curve decreases as the tube diameter/thickness

ratio decreases, affecting its post-peak behavior.

7. However, as the height of each column was set at 500 mm, the effects of changing the slenderness (height-to-diameter) ratio were not examined.

Gupta's most recent study [51] looked at concrete-filled UPVC pipes with different sizes, such as 140 mm, 160 mm, and 200 mm. The tubes were filled with three Confinement with HDPE tubes. Kurtoglu [55] suggested using HDPE pipes with a concrete core that are readily accessible commercially. Load-strain behavior was examined to ascertain the effects of each exposure. Peak load reduction was found to be roughly 0.3-1 percent in HDPE-confined specimens, but 45-50 percent in unconfined specimens. Furthermore, increasing tube thickness by 30% increases fracture energy by up to 50%. Steel fiber addition has a little effect on load capacity (0.3-1%) but increases energy absorption capacity by up to 20%, according to the findings.

2.6 SUMMARY

Based on the little scholarly attention devoted to the emerging domain of composite building, it is evident that there exists an inadequate amount of research pertaining to the use of HDPE pipes inside composite column systems. Despite the fact that all of these academics saw a lot of potential in this new construction material and openly stated it in their findings and recommendations, this is still the case. The new study looked at a number of variables that had previously escaped the attention of other researchers. The study looked at how tube diameters, tube thickness, and stirrup availability affected the composite columns' compressive strength, ductility, stiffness, deformation, stress, and strain characteristics.

CHAPTER 3

3 MATERIAL AND EXPERIMENTAL PROGRAM

3.1 INTRODUCTION

In this chapter, the focus is on the properties of the material, as well as the experimental work that was done on the specimens themselves. The experimental program included a total of sixteen columnar specimens made of reinforced concrete. Half of the specimens were 200 mm in diameter, while the other half were 110 mm in diameter. Their whole length was 1000 mm. The experiment employed four of the samples as controls. Six were placed into HDPE tubes with a diameter of 110 mm, while the other six were poured into 200 mm tubes. After that, specimens were loaded in an axial compression direction and exposed to stress.

3.2 MATERIAL

3.2.1 CEMENT

Table 3.1 Ingredient of OPC 1

Compound	Value (%)
Sio_2	22.0
Al_2O_3	5.50
Fe_2O_3	3.50
Cao	64.25
MgO	2.50
SO_3	2.90
Na_2O	0.20
K_2O	1.00

The reinforced concrete samples in this investigation were made using Type 1 Ordinary Portland Cement. "Fauji" is a prominent brand of ordinary Portland cement (OPC) in Pakistan, and it was utilized in this project. The composition of chemicals of ordinary Portland cement is given forth in Table 3.1.

3.2.2 FINE AGGREGATES

The investigation made use of sand from the Lawrencpur area that was readily accessible and had a fineness modulus (F.M) of 2.212. The sand was used in a state that was wet but dry on the surface, and it was free of any organic pollutants. Experiments carried out in the lab have led to the identification of some of its most fundamental physical features; they are outlined in Table 3.2.

Table 3.2 Sieve analyses

Sieve No.	**Retained Weight**	**Retained %**	**Cumulative Retained %**	**Passing %**	**Passing weight**
4	8.2		0.5	98.5	1491.8
8	16	0.5	1.4	94.9	1475.8
16	58.4	1	5	52.2	1417.4
30	620	3.9	47	30.6	797.4
50	326.3	41.3	69.2	2.8	471.1
100	424.5	21.7	147.1	0.7	46.6
200	34.9	28.3	49.2	0.7	11.7
Pan	11.7	2.3	99.9	0.7	0
Total	1500	0.8	271.2	Fineness modulus	2.71

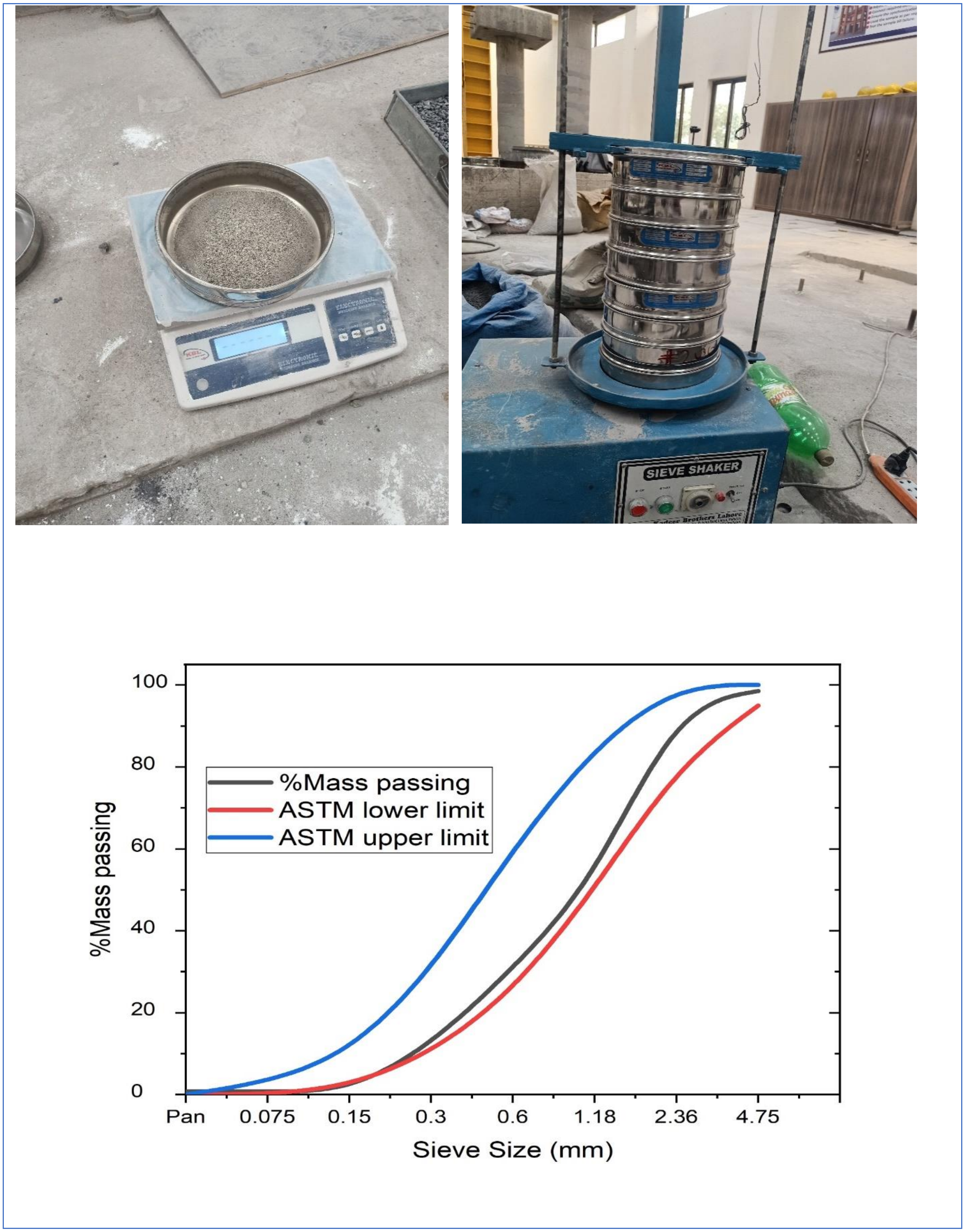


Figure 3.1 sieve analyses

3.2.3 COARSE AGGREGATES

Normal weight aggregates supplied from Khairabad consisting of crushed angular stone were utilised in the current investigation. Coarse aggregates with a maximum size of 12.5mm and a specific gravity of 2.71 were employed in a saturated surface dry (SSD) state according to ASTM C33 (C33 2003). Table 3.3 lists some of its physical properties based on lab testing.

Table 3.3 lists some of its physical properties based on lab testing.

Sr. No	Properties	Results
1	Max Coarse Aggregates Size	12.5mm
2	Fineness Modulus (sand)	2.59
3	Specific Gravity of Fine Aggregates (SSD)	2.57
4	Impact Value of Coarse Aggregates (%)	7.11%
5	Specific Gravity of Coarse Aggregates (SSD)	2.71
6	Crushing Value of Coarse Aggregate (%)	18.92

Figure 3.2 Impact value and crushing value test of Coarse Aggregate

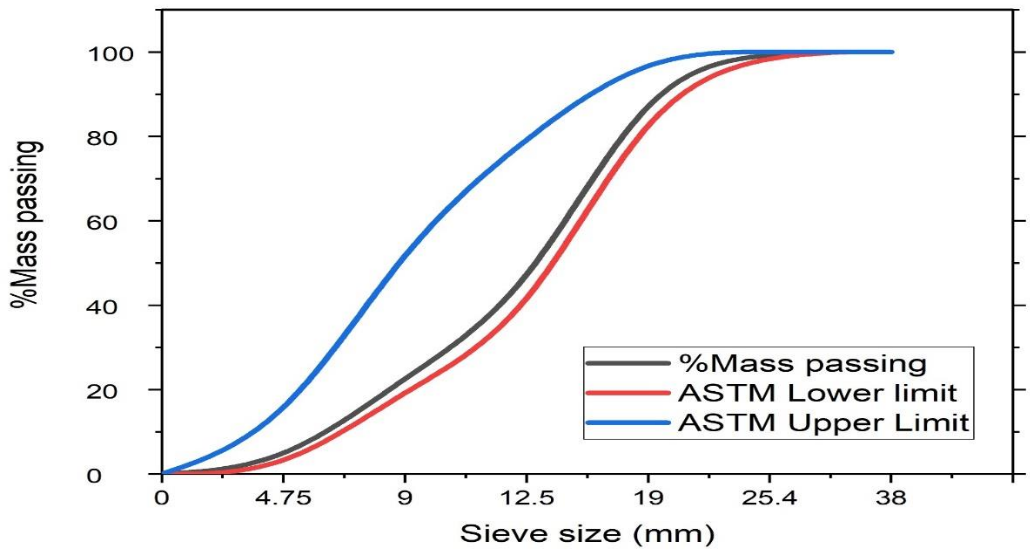


Figure 3.3 Sieve analysis

3.2.4 MINERAL AND CHEMICAL ADMIXTURES

In this experiment, silica fume *Figure 3.4* was used as an admixture. Because silica fumes have a high density and a small average particle size, it improves the microstructure of concrete. The bulk density of the silica fume used was 450 kg/m3. It was acquired by Imporient Chemicals (PVT) LTD, a chemical company that also produces silica fume.

Figure 3.4 silica fume

Superplasticizer was used to make a workable concrete mix with an extremely low water-cement ratio. Chemrite-303 SP is the brand name of the superplasticizer.

3.3 EXPERIMENTAL WORK

3.3.1 MIX PROPORTION

The laboratory-produced concrete for this experiment had a mixed ratio of 1:1.35:2.80 and a water-to-cement ratio of 0.35 (Table 3.4). There were two stages involved in the casting of concrete. In the first phase, the compressive strength of concrete was evaluated using three 150 mm in diameter and 300 mm in height concrete cylinders. This measurement was designed to measure the compressive strength of concrete. In addition, silica fume was used 10 % of cement by weight in the production of HSC as an additive, and superplasticizer chemrite 303 SP was used 1 % of cement as a water reducer agent (high Strength Concrete). Both the aggregate and the sand that was utilised are easily accessible in the surrounding region. The experimental results from the concrete cylinder tests indicate that the material exhibits a strength of 47.51 MPa, as determined by the ASTM C39 standard. Additionally, the axial fracture strain of the material is measured to be 0.0028, while the elastic modulus is determined to be 32.22 GPa. The findings were derived from the results obtained from the experiments.

Table 3.4 Mix proportion of concrete

Cement **(Kg/m^3)**	**Aggregate** **(Kg/m^3)**	**Silica fume** **(Kg/m^3)**	**Sand** **(Kg/m^3)**	**Water** **(Kg/m^3)**	**Superplasticizer** **(Kg/m^3)**
430.6	1340	43	617.3	150.7	4.3

3.3.2 METHODS FOR THE MIXING OF CONCRETE

A horizontal concrete mixer, like the one seen in Figure 3.5, was used to thoroughly mix the constituent parts of the concrete. The various components of the concrete were mixed in accordance with the guidelines outlined in (ASTM C192 / C192M 2016), which were used as a guide (Standard 2016). The procedure for mixing is summed up in the following paragraphs. First, the water for mixing was divided into four equal parts, and then superplasticizer was added to one of the quarters. Coarse aggregates were put into the mixer first, followed by approximately a quarter cup's worth of mixing water. After that, the contents of the mixer were left to combine for about two to three minutes. Second, after the addition of the fine aggregates, the mixture was stirred for an additional two minutes. Subsequently, the binder, consisting of cement and silica fume, was introduced into the mixture and well incorporated, followed by the addition of about two-thirds of the total mixing water. In the end, the remaining superplasticizer was combined with a quarter of the water that had been set aside, and the whole mixture was left to combine until it achieved a consistency that was uniform throughout. After then, the power was off to the machine that mixes concrete, and it was given three to four minutes to cool down. After pausing for a while, the mixing process was resumed, and the total time spent mixing was 2 minutes.

3.3.3 COLUMNAR SPECIMENS

Both High density polyethylene pipelines with diameters of 110 mm and 200 mm were cut to a length of one meter. For the purposes of this investigation, HDPE pipes were used that had nominal pressures of either 16 Bar (pn16), 12.5 Bar (pn12.5), or 10 Bar (pn10) respectively. The pipe thicknesses for the pipe with a diameter of 200 mm were 19.2 mm, 15.5 mm, and 12.55 mm. On the other hand, the pipe thicknesses for the pipe with a diameter of 110 mm were 10.55 mm, 8.6 mm, and 7 mm, respectively. Table 1 contains a listing of the various measurements of both the

Figure 3.5 Concrete Mixer

columns made of high-density polyethylene (HDPE) and reinforced concrete (RC). The columnar specimens were made from a combination of two distinct batches of material. In the initial set of specimens, there were both concrete-filled HDPE tube columns and reinforced concrete (RC) specimens.

Table 3.5 Columnar specimens' specification

Specimens	D mm	E_H GPa	t_f (mm)	f'_{c1} MPa	ϵ_{c1}	f'_{c2} MPa	ϵ_{c2}	f'_{C3} MPa	ϵ_{c3}	E MPa
CONTROL-200	200	_	0	30.76	0.00276	32.27	0.0030	25.8	0.0032	10500
CONTROL-110	110	_	0	28.8	0.00224	29.88	0.0023	23.9	0.0024	12693
16-CHS-200	200	63.28	19.2	46.10	0.00637	57.69	0.0195	46.1	0.0271	10857
12-CHS-200	200	63.28	15.5	40.93	0.00454	46.44	0.0125	37.1	0.0186	11600
10-CHS-200	200	63.28	12.55	34.39	0.0027	39.13	0.0081	31.3	0.0184	15145
16-CHS-110	110	63.28	10.55	46.53	0.00341	51.38	0.0082	41.1	0.0215	15138
12-CHS-110	110	63.28	8.6	38.95	0.00313	45.93	0.0058	36.7	0.0164	15390
10-CHS-110	110	63.28	7	32.6	0.00244	42.13	0.0126	33.7	0.0200	17759
CONTROL-200	200	63.28	19.2	35.43	0.00319	41.28	0.0109	33.0	0.0200	14406
12-CHS-200	200	63.28	15.5	34.15	0.00213	40.72	0.0071	32.5	0.0157	15738
CONTROL-110	200	63.28	12.55	32.11	0.00408	37.90	0.0077	30.3	0.0139	10433
16-CHS-110	110	63.28	10.55	38.11	0.00426	44.35	0.0095	35.4	0.0215	11286
12-CHS-110	110	63.28	8.6	34.15	0.00386	39.36	0.0091	31.4	0.0141	10451
10-CHS-110	110	63.28	7	28.51	0.00282	38.54	0.0084	30.8	0.0177	12918

RC stands for reinforced concrete (CHS restricted with stirrups). The second group of specimens (CH without stirrup confinement) had simply concrete-filled HDPE tube columns. In this study, a total of sixteen specimens were used, with eight specimens having a diameter of 200 mm and the other eight specimens having a diameter of 110 mm. In addition to its function as a control specimen, the reinforced concrete specimen may also have a conduit thickness of 0 mm. The core concrete's cross-sectional area will decrease in direct proportion to the growing thickness of the pipe. Table 1 contains the information that is available for each specimen. The control specimens were taken from the moulds after a time of twenty-four hours, and then they were allowed to cure at a temperature of 23 ± 2 ^{0}C for a total of twenty-eight days.

3.3.4 CAPPING ENDS OF CONCRETE'S CYLINDERS

The typical columnar specimen of concrete has two ends: one smooth end created on the base plate and the other rough end.

Figure 3.6 column capping with Sulphur

Sulphur capping was used to put the non-formed (rough) ends of all specimens planned for compressive testing well within the permitted tolerances of (ASTM C39/C39M 2016) (Concrete and Aggregates 2014) on perpendicularity and planeness. Figure 3.7 depicts the Sulphur capping that was applied to a specimen's end to make it smooth.

3.3.5 INSTRUMENTATIONS AND TEST SET-UP

The experimental investigation was carried out at the Structures lab of the Civil Engineering department at UET Taxila with the help of a compression machine. The experiment was typically set up in the way shown in Figure 3.4, which is illustrated below. The specimens were left to air-dry for some time before testing began. Each specimen was loaded to 80% of its maximum capacity under monotonic loads, and the results were recorded using a data collecting system. To achieve a uniform distribution of stress over the concrete cross section, the specimens experience an axial compressive load that was centrally delivered in a concentric manner. This was accomplished by using a compression testing machine (CTM) equipped with uniform steel end plates and an upper plate that could be adjusted as needed. This was done to obtain the desired result. The weight was distributed evenly throughout the whole of the column. On a compression machine that was hydraulically operated, each column was subjected to axial force at a rate of 0.04 MPa per second. The data from the tests were automatically acquired by a system that collected data. In order to load each specimen uniformly over its full axial section, high-strength Sulphur caping was applied at both the beginning and the end of each specimen. The capacity of the CTM that was utilised was 500 kN. In addition to this, a Linear Variable Displacement Transducer, commonly known as an LVDT, was used on each column in order to measure the axial deformations. The total height deformations of each CHS, CH, and control specimen were measured using a single linear variable displacement transducer (LVDT) (**Error! Reference source not found.**b).

3.4 TEST PROCEDURES

3.4.1 COMPRESSIVE STRENGTH

To evaluate the hardened concrete's ultimate compressive strength, three cylinders were cast with a diameter of 150 mm and a length of 300 mm. Before the cylinders could be tested, they were cured. The method that was used to produce and cure the cylinders was as follows: the inside surfaces of the finished moulds were given a little coating of lubricating oil to prevent concrete from sticking to the mold's walls. This was done in order to ensure that the cylinders would cure properly. After that, concrete was poured into each mold and then agitated with a vibrator to ensure it was spread uniformly. To even out the roughness of the surface that was on top, a trowel was utilised. After that, the cylinders were stopped from moving in any way and left at room temperature for a period of twenty-four hours with no further action taken. After waiting for twenty-four hours, the moulds were broken down and an identifying number and the date that the casting took place were imprinted on the surface of the concrete cylinders. To complete the curing procedure, the cylinders were submerged in water at room temperature until the day of testing. This was performed until the conclusion of the operation. The compressive strength of the material was determined by subjecting the cylinders to a battery of tests after 28 days in an eroid. The ultimate compressive strength of the suggested combination was the focus of the tests conducted on day 28.

3.4.2 STRESS-STRAIN CURVE

The axial strains of each specimen were determined by using the data collected from full-height LVDTs on a data collecting system. On the other hand, the axial stresses of each specimen were determined by utilizing the load that was recorded on a compression testing machine. the loading continued until the load was decreased to 80% of its maximum capacity, at which point it was stopped. Because of this, the HDPE pipes are maintained at a distance of six millimeters below the top and bottom surfaces of the columns. Because HDPE has such a low longitudinal stiffness, the longitudinal stiffness of HDPE tubes is not taken into account in this research because doing so would only provide a marginal change in the comparison between the two materials. In addition, the longitudinal rigidity of HDPE tubes is not taken into consideration since incorporating it would have only a marginal impact on the results of the comparison. The stress-strain curves of the CH specimens exhibit the behaviour of concrete confined just by HDPE, while the stress-strain curves of the CHS specimens demonstrate the response of concrete confined by both HDPE and steel stirrups. Both types of stress-strain curves were generated using the exact same group of CHS and CH specimens as the starting point. Concrete that is solely bound by HDPE may be referred to as "confined concrete" in the stress-strain curves of the CH specimens. These curves show the relationship between stress and strain.

3.4.3 ELASTIC MODULUS

In order to determine the values of the elastic modulus for the RC (control), CH, and CHS specimens, a stress-strain curve was used. The following equation was used to arrive at a

$$E_c = \frac{C_2 - C_1}{\varepsilon_2 - 0.000050}$$

value for the chord modulus that was as close as possible to 200 MPa in accordance with ASTM C469/C469M-14 (2014):

Whereas,

Ec = the modulus of elasticity of the chord.

$C2$ = Stress values corresponding to 0.4 fc'

$C1$ = The magnitude of the stress that corresponds to a strain of 0.000050 along the longitudinal axis

$\varepsilon 2$ = strain along the longitudinal axis caused by C2

3.4.4 STRAIN DUCTILITY

The capacity to undergo further deformation beyond the yield point is referred to as ductility. The ductility of a material may be quantified by evaluating the ratio of the strain at 80% of the maximum stress to the yield strain.

$$\text{Ductility} = \frac{\text{The strain seen at 80\% of the maximum stress level}}{\text{Strain at yield point}}$$

CHAPTER 4

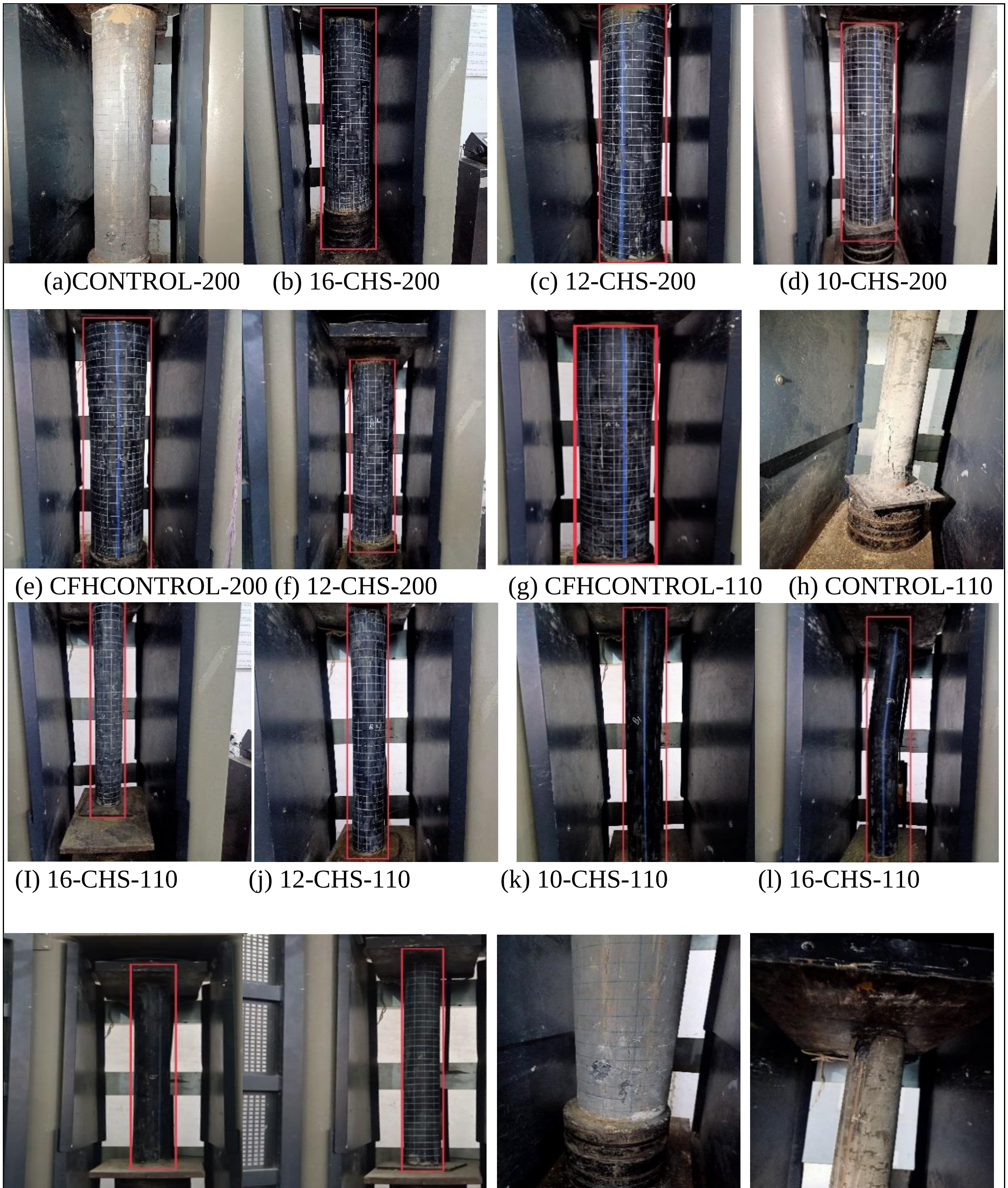
4 RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents a comprehensive description and analysis of the results obtained from tests done on concrete specimens. The tests include a range of parameters, including compressive strength, stress-strain response, failure mechanism, strain value comparison, elastic modulus, and compressive toughness.

4.2 VISUAL ASSESSMENT

The typical failure processes of the specimens are shown in Figure 5. Like the elephant foot buckling failure seen in concrete-filled HDPE tubes, bulges occurred towards the top and bottom ends of the CH (concrete filled HDPE Reinforced concrete) columns (Figure 5 e, f, g, k, l, m). The HDPE pipe did not crack because it had an exceptionally high elongation capacity and could not stretch any farther. The confinement of the CHS, which was made of steel stirrups, failed at the near top and bottom area (Figure 4 b, c, d, I, j, k). As a direct consequence of the high elongation capacity of the HDPE, the HDPE tube began to expand, and as a result, a significant degree of distortion became apparent. As can be seen, the bulging of the column towards the top is greater than the bulging at the lower end (Figure 5). As a consequence of the failure of the CH column with steel stirrups towards the top and bottom ends, the HDPE tubes in these locations were exposed to hoop stresses. As will be seen in the next section, the bulging of HDPE tubes was a time-consuming procedure that resulted in some minor modifications to the axial load-strain behavior (also known as stress-strain behavior).



(a)CONTROL-200 (b) 16-CHS-200 (c) 12-CHS-200 (d) 10-CHS-200

(e) CFHCONTROL-200 (f) 12-CHS-200 (g) CFHCONTROL-110 (h) CONTROL-110

(I) 16-CHS-110 (j) 12-CHS-110 (k) 10-CHS-110 (l) 16-CHS-110

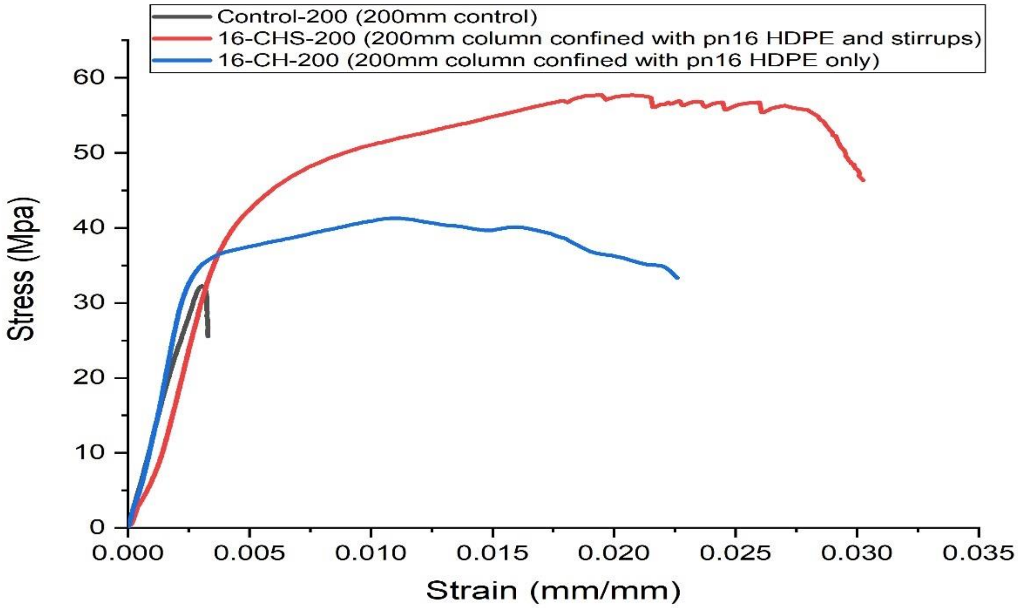
(m) 12-CHS-110 (n) 10-CHS-110 (o) CONTROL-200 (p) CONTROL-110

Figure 4.1 Failure Mode

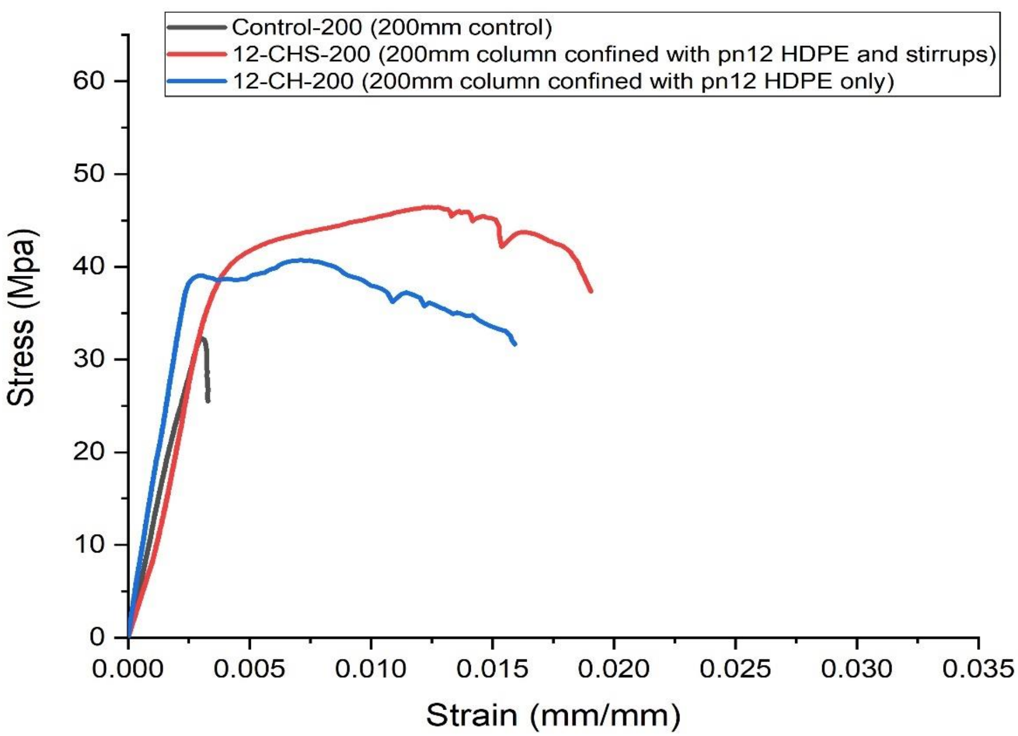
These variations can be seen in the graph. The lateral deformation of a CH column that did not have steel stirrups was greater than that of a CHS column that did have steel stirrups, and the amount of debonding in the end area of a CH column that did not have steel stirrups was greater than that of a CHS column that did have steel stirrups. It was hypothesised that the significant axial motion of the column, which had very little impact on the HDPE tubes' capacity to effectively contain the substance, was the cause of the debonding that occurred at the end region.

4.3 STRESS-STRAIN RESPONSES

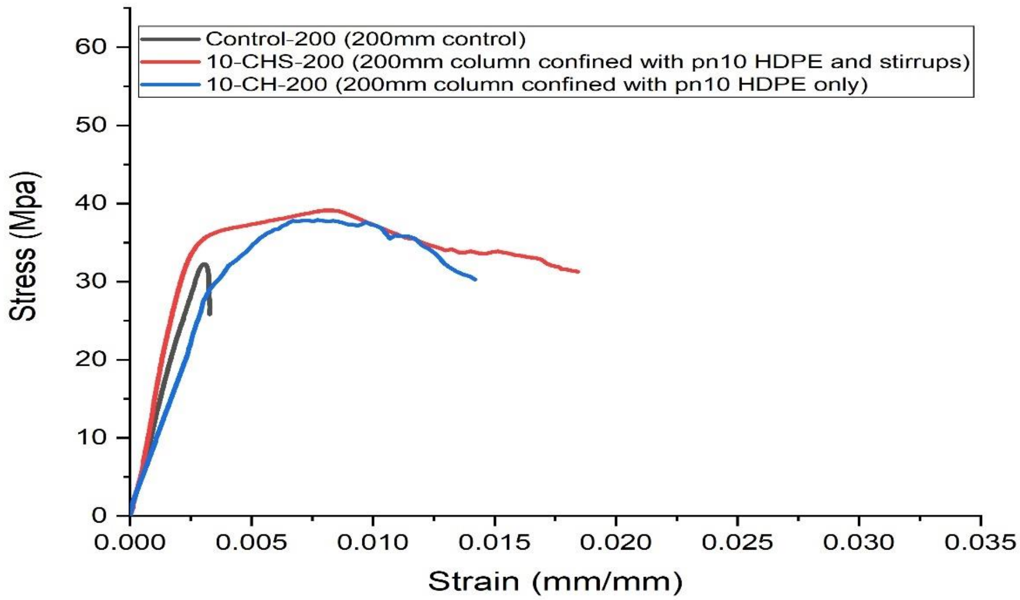
Figure 4.2 shows a graphical representation of the relation between axial stress and axial strain for confined and unconfined concrete (control sample). When calculating the axial strains of each specimen, data from full-height LVDTs were used since they were collected on a data collecting system. The axial stresses were calculated using the load recorded on a compression testing machine. The loading process was continued until the load was brought down to 80% of its maximum capacity. The longitudinal stiffness of HDPE tubes is also not taken into account in this study because including it would not make much of a difference in the comparisons because HDPE has a low longitudinal stiffness. Because of this, the HDPE pipes are kept 6mm below the top and bottom sides. Also, the lengthwise stiffness of HDPE tubes isn't considered because it wouldn't make much of a difference in the comparison. The CHS specimens' stress-strain curves may be referred to as column confined with HDPE and Steel Stirrups, but the CH specimens' stress-strain curves can be referred to as column confined with HDPE only. Both types of stress-strain curves can be found in the CH specimens. In the following section, we will discuss the effects of Steel Stirrups, HDPE thickness, and column diameter on the behaviour of stress and strain.



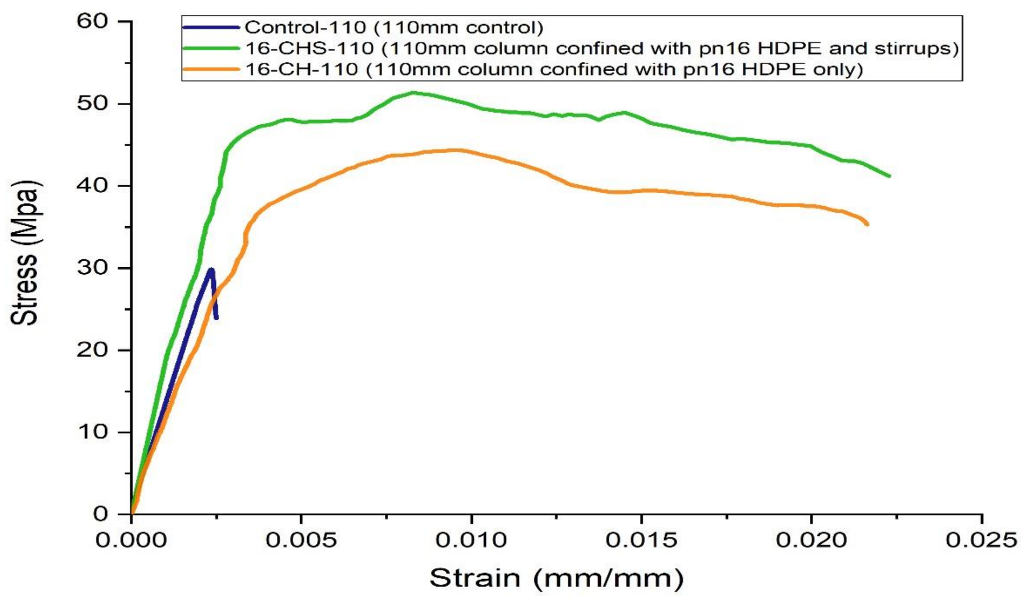
(a)200mm column confined with pn16 HDPE.



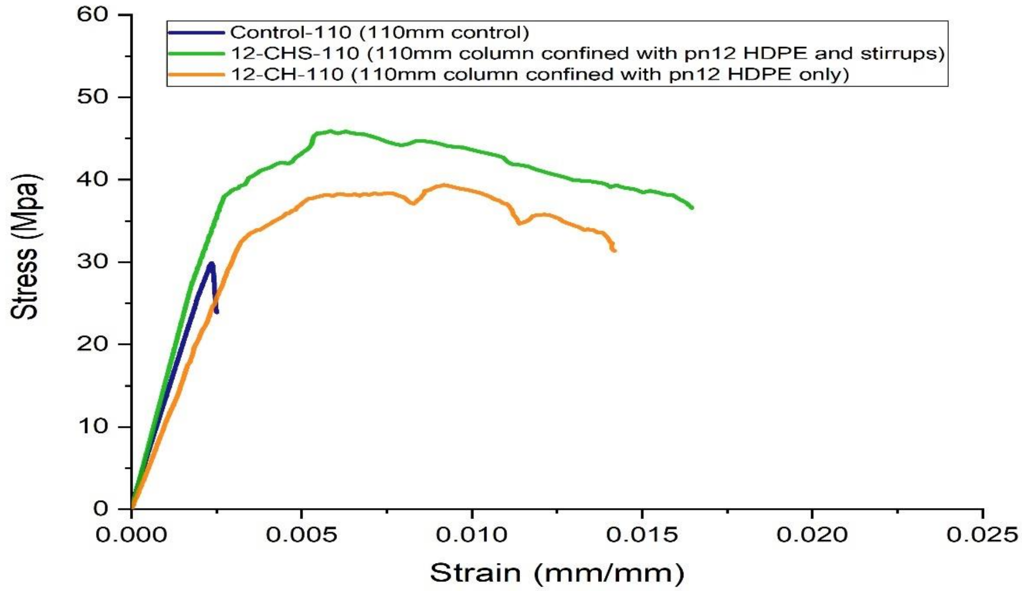
(b) 200mm column confined with pn12 HDPE



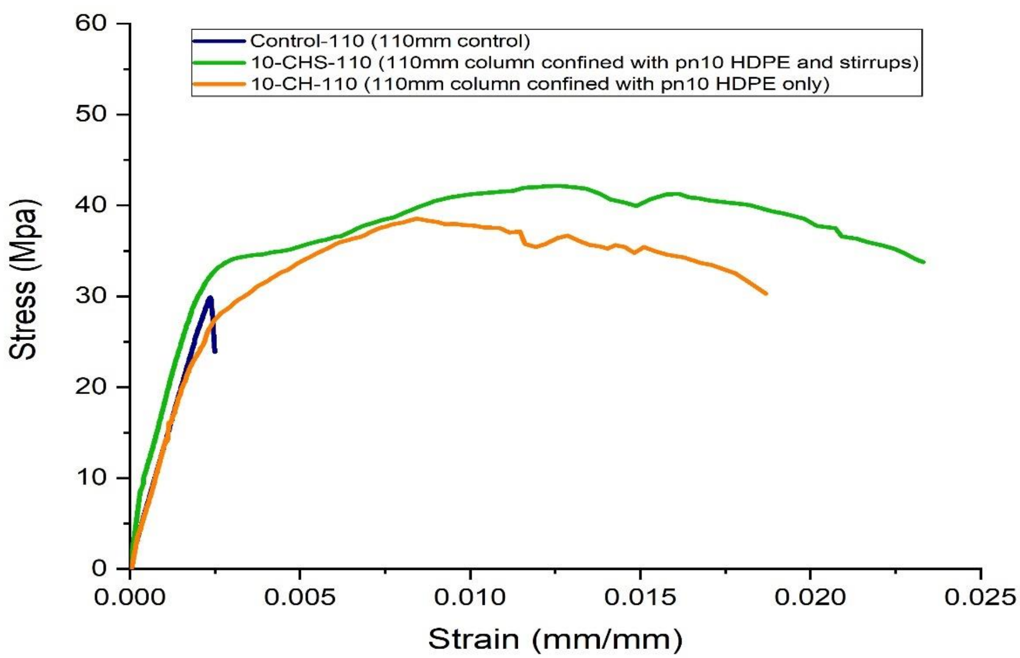
(c)200mm column confined with pn10 HDPE.



(d) 110mm column confined with pn16 HDPE



(e) 110mm column confined with pn12 HDPE



(f) 110mm column confined with pn10 HDPE

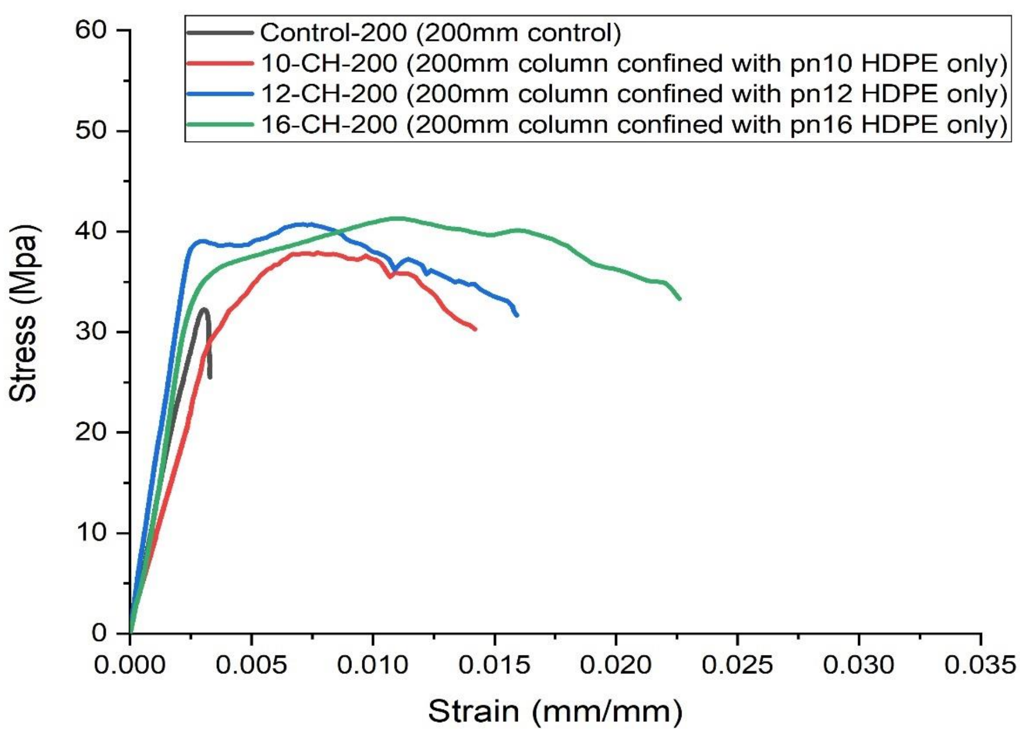
Figure 4.2 Stress-Strain behavior of column with respect to availability of stirrups

4.4 STEEL STIRRUPS

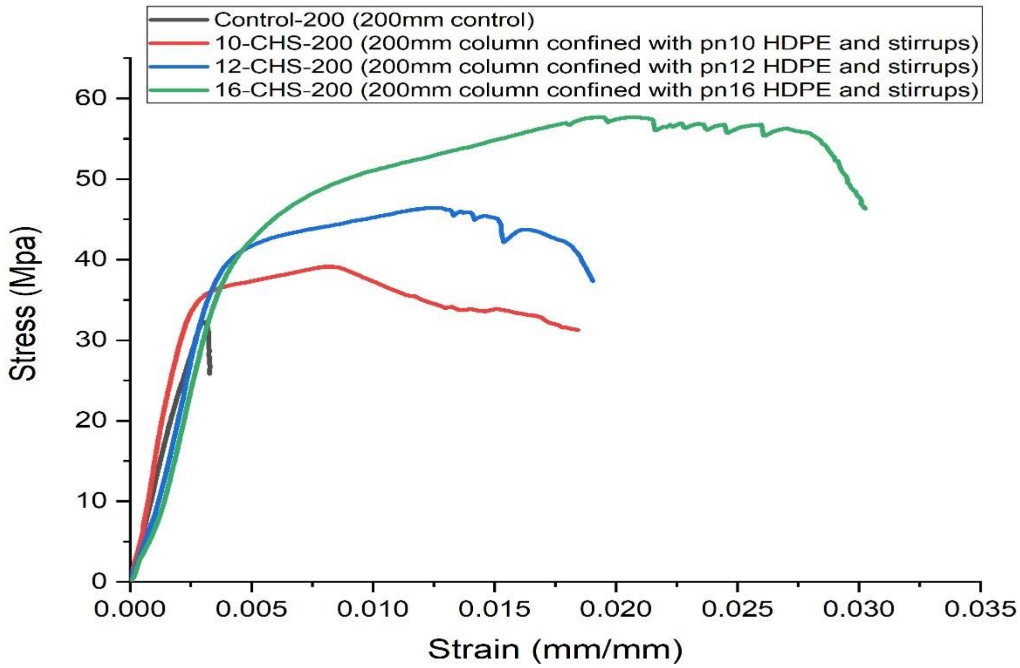
In the stress-strain curves, CH specimens have a lower ultimate value of stress than CHS specimens confined with HDPE tube. This is since the concrete cracked at a modest axial strain (about 0.003), whereas the HDPE tube gave a little more confinement at this strain stage, which caused the concrete to crack. This is because HDPE has a greater tensile stiffness and was found in an elastic condition. Up to the elastic limit, the CH and CHS nearly always exhibit the same behaviour with the control specimens. Nevertheless, during the subsequent loading phase known as the post-peak stage, the stress-strain characteristics of CH and CHS specimens exhibit notable differences compared to RC specimens (as seen in Figure 4.2a, b, c, d, e, f). This is because the HDPE confinement for the CHS and CH comes into action only after the concrete has been severely damaged. Both the CH and CHS columns have a consistent climbing pattern, as follows: The stress-strain behavior of the specimens can be divided into two distinct regions. In the first region, referred to as the linear elastic portion, the specimens exhibit a similar initial slope to unconfined reinforced concrete (RC) specimens. This region is characterized by a yield stress (c1, fc'1). Following the linear elastic portion, the specimens enter a second region known as the post-peak strain hardening portion. In this region, the presence of HDPE confinement contributes to an increase in the ultimate stress of circular hollow sections (CHS) and circular hollows (CH) by more than 70% and 30% respectively, compared to control samples. The linear elastic part up to the yield point was characterised by an initial slope that The HDPE expanded because of the tension, which increased steadily up to the ultimate stress point (ε2, fc'2). The stress-strain curves for CH and CHS exhibit a three-portion behavior of strain hardening-softening-hardening when subjected to HDPE and stirrups confinement. However, when only steel confinement is present, the strain hardening-softening behavior is limited to two portions. This behavior is observed due to the high strength and brittle nature of RC columns. The stress-strain curves of the first kind may be categorized into three unique segments, which are as enumerated below: (1) The first elastic segment extends from the starting point to the first yield stress point (1, f'c1), resembling the behavior seen in the control columns: (2) a strain-hardening (gradually ascending) portion from the yield stress point (1, f'c1) to the ultimate stress point (2, f'c2) due to concrete failure, with the ultimate stress value of CHS for strain hardening increasing as a result. The stress-strain curves for CH and CHS exhibit a three-portion behavior of strain hardening-softening-hardening when subjected to HDPE and stirrups confinement. However, when only steel confinement is present, the strain hardening-softening behavior is limited to two portions. This behavior is observed due to the high strength and brittle nature of RC columns. The stress-strain curves of the first kind may be categorized into three unique segments, which are as enumerated below: (1) The first elastic segment extends from the starting point to the first yield stress point (1, f'c1), resembling the behavior seen in the control columns.

4.5 THICKNESS OF HDPE PIPES

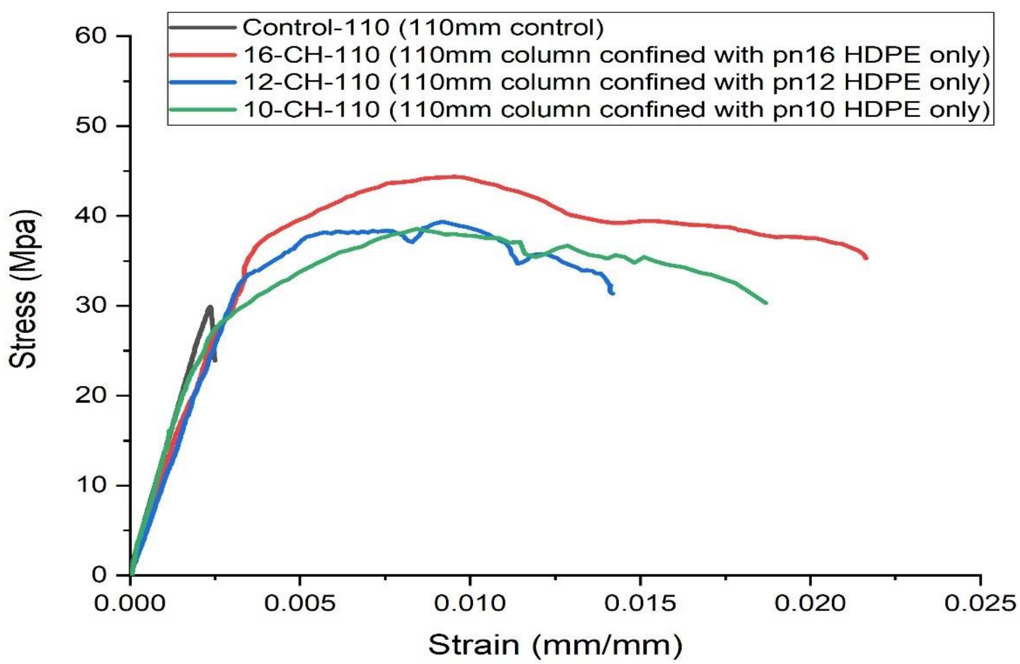
The stress- strain behavior of 200mm diameter concrete- filled HDPE internally confined with stirrup (CHS) tubes is comparable to that of CH tubes (Figure 4.3), although the ultimate stress of CHS was much greater than that of CH. Except for the control specimen, most of the columns exhibit post-peak strain-hardening softening behaviour. This is because the HDPE is activated after the yield point, which causes confinement to cause the material to change its properties. The ultimate stress of the column, in addition to its ductility, increased as a direct result of an increase in the thickness of HDPE tubes (Figure 4.3). The ultimate stress of a column confined with stirrups and HDPE pipe with tube thicknesses of 12.5mm (pn10), 15.5mm (pn12), and 19.2mm (pn16) rose by 21.2%, 44%, and 78%, respectively (Figure 4.3b). The behavior of stress- strain curve for a column with a diameter of 200 mm that was confined with only HDPE tubes of the same dimension as those given above was almost the same, while the corresponding ultimate stress values were lower because stirrups were not available (Figure 4.3a). The stress-strain curve of a 110mm diameter column that was confined with HDPE and stirrups is depicted by the typical curve shown in Figure 4.3d. The ultimate stress values were increased by 40.7%, 53.7%, and 72% for 7mm(pn10), 8.6mm(pn12), and 10.5mm(pn16) thick HDPE pipe respectively. The stress-strain behaviour was the same up to the elastic region for that of column without stirrups. After the first peak, there was an up and down in stress values for that of less thick (7mm and 8.6 mm) HDPE pipe while the 10.5 mm thick pipe almost show same behaviour to that of confined with stirrups (Figure 4.3c, d). On the other hand, the ultimate values were less than those confined with steel stirrups (Figure 4.3c).



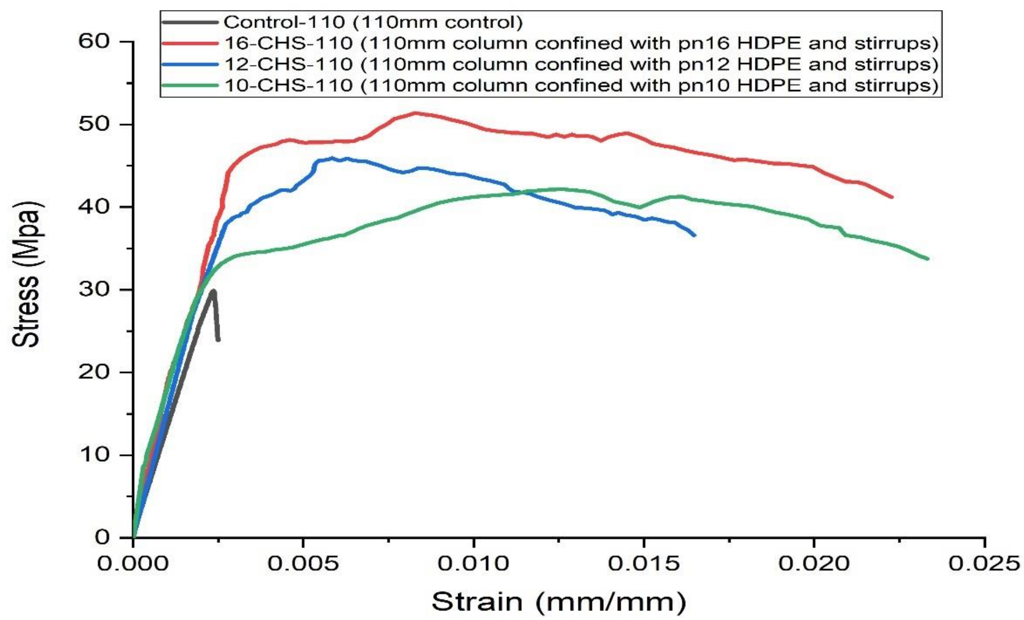
(a) 200mm column confined with different Thickness of HDPE only



(b) 200mm column confined with different Thickness of HDPE and steel stirrups



(c) 110mm column confined with different Thickness of HDPE only

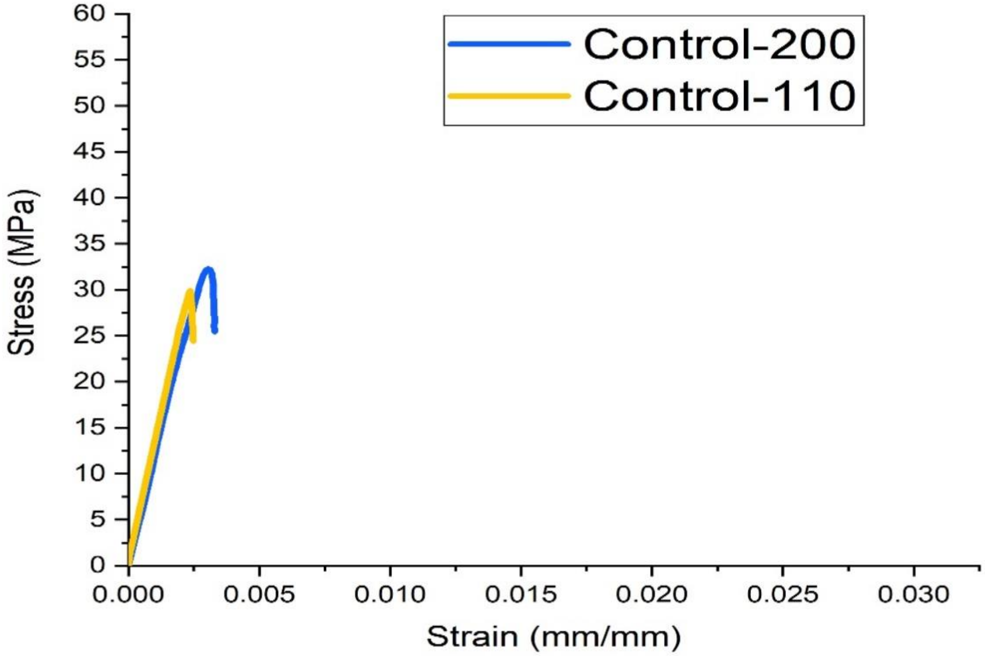


(d) 110mm column confined with different Thickness of HDPE and Steel Stirrups

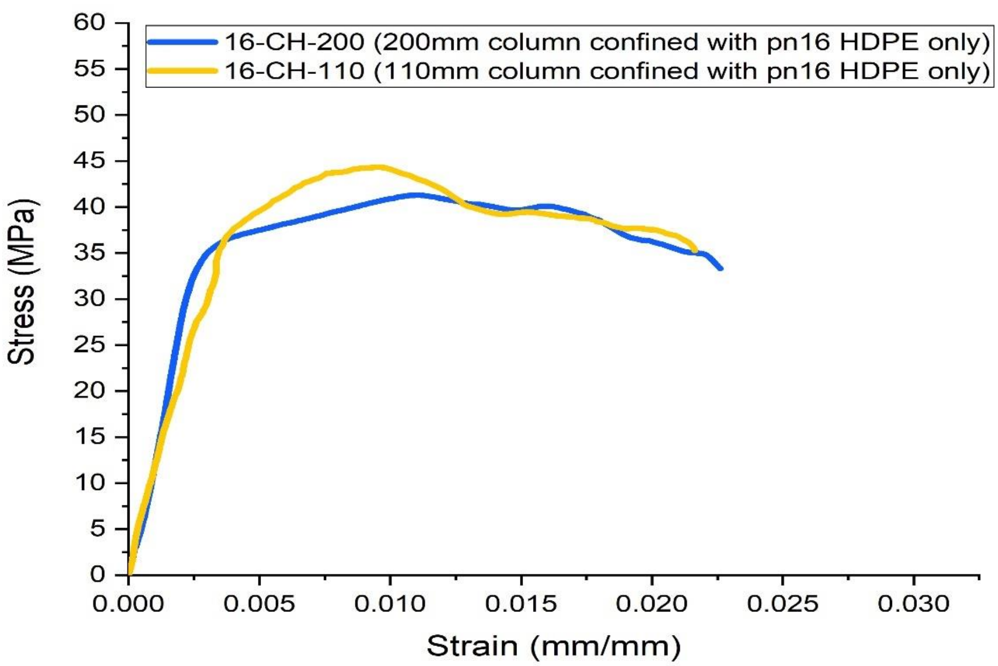
Figure 4.3 Stress-Strain behavior of column with respect to thickness of HDPE

4.6 DIAMETER OF COLUMN

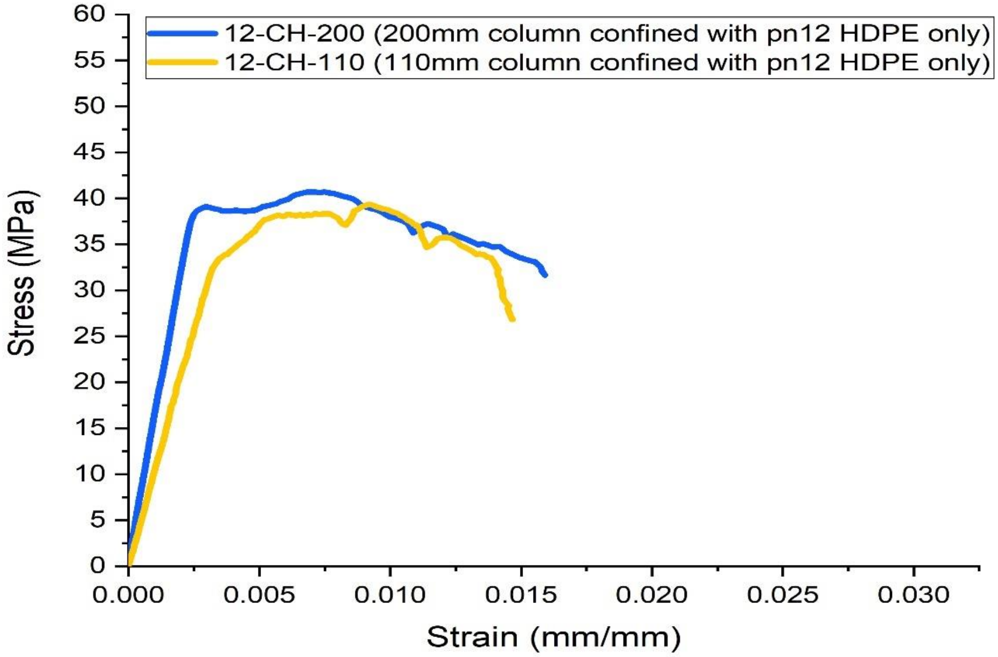
The stress-strain behaviour of columns with diameters of 110mm and 200mm that were contained with HDPE of different thicknesses is shown in Figure 7. Of these columns, half were confined with both steel and HDPE. The ultimate stress was higher for the 200mm specimens than the 110mm specimens, except for the 110mm specimens 10-CHS-110, 16-CHS-110, and 10-CHS-110. These specimens have a higher ultimate stress value than the 200mm specimens 10-CHS-200, CFHCONTROL-200, and CFHCONTROL-110, which indicates that the declination in the ultimate stress as the diameter of the column increases with the use of less thick HDPE tubes (Figure 7 g). In addition, columns with a diameter of 110 mm and no steel stirrups have a higher ultimate stress than columns with a diameter of 200 mm that are restrained only by HDPE tubes (Figure 7b, d). The values of the ultimate stress shown by CHFRC-2 and 12-CHS-110 are almost similar (Figure 7c).



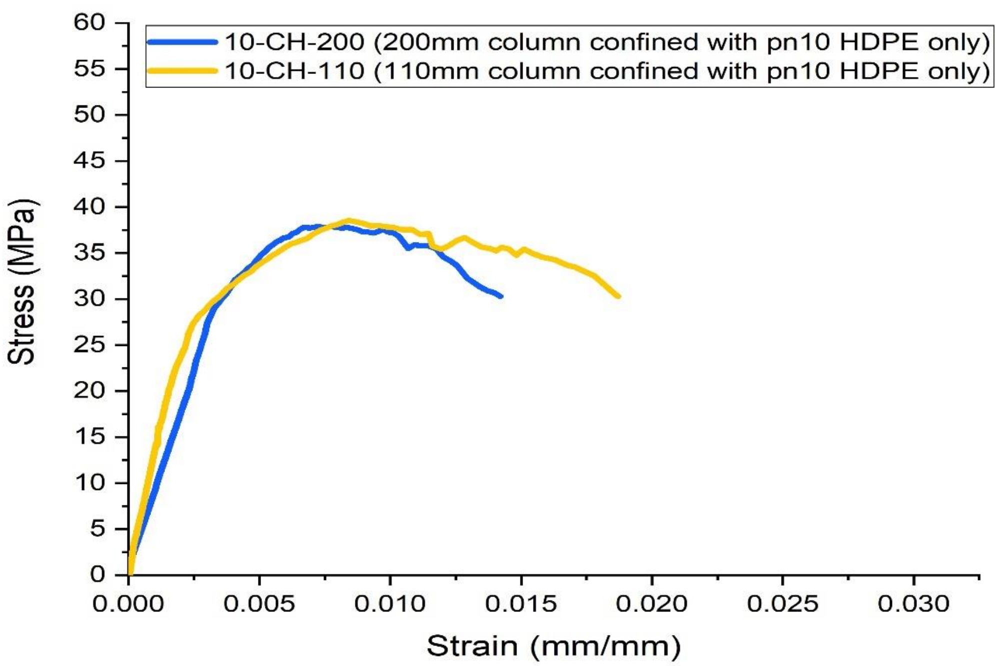
(a) Control columns both 4 and 8 inches



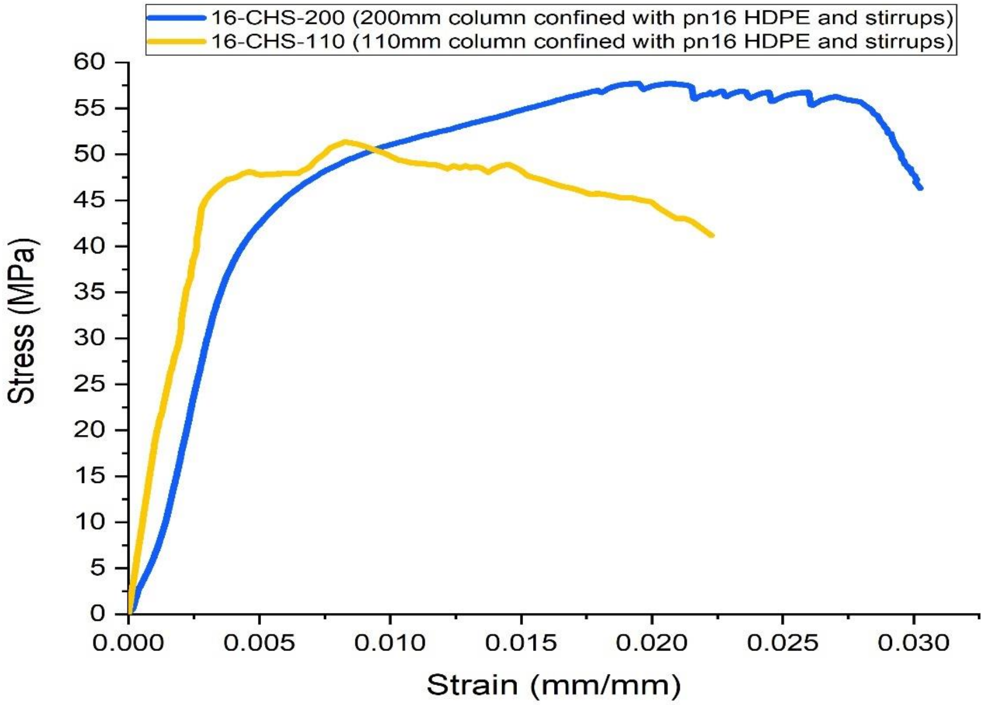
(b) Columns confined with pn16 HDPE only (for both 4 and 8 inch)



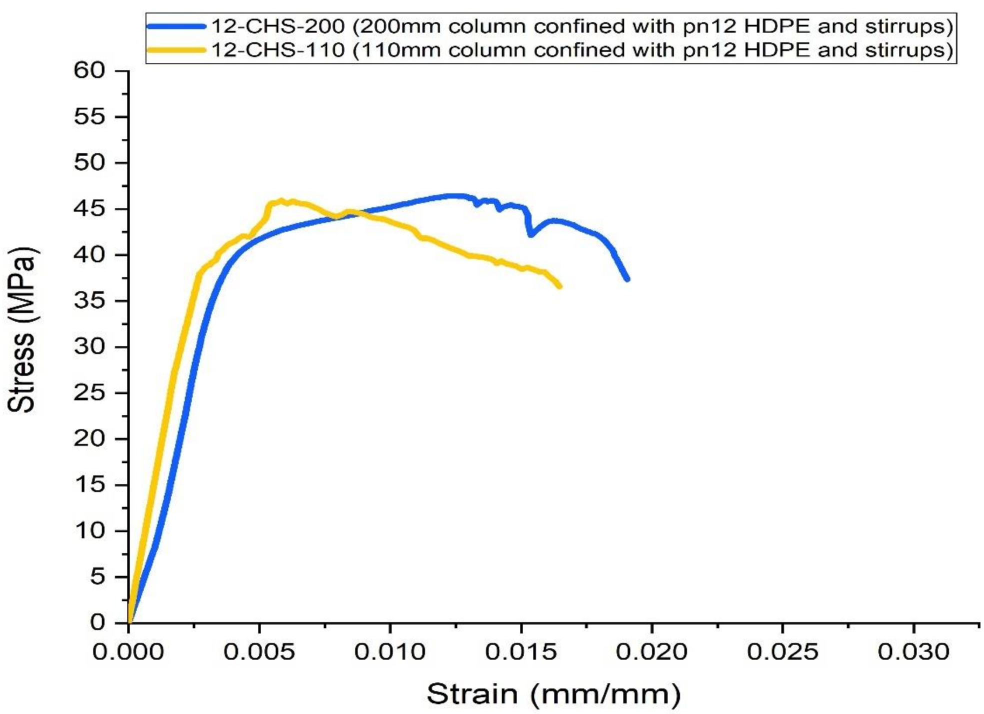
(c) Columns confined with pn12 HDPE only (for both 4 and 8 inch)



(d) Columns confined with pn10 HDPE only (for both 4 and 8 inch)



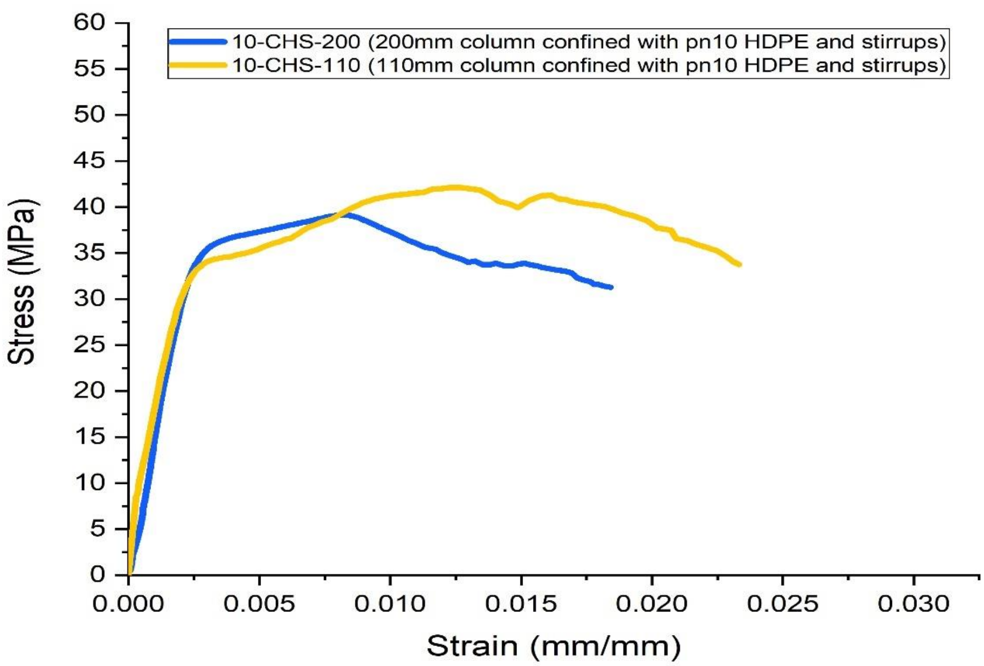
(e) Columns confined with pn16 HDPE and steel stirrups (for both 4 and 8 inch)



(f) Columns confined with pn12 HDPE and steel stirrups (for both 4 and 8 inch)

The peak stress values of CONTROL-200, 16-CHS-200, and 12-CHS-200 were higher by 8%, 12.3%, and 2% than those of CONTROL-110, 16-CHS-110, and 12-CHS-110, respectively. On the other hand, the ultimate stress values of 10-CHS-200, CFHCONTROL-200, and CFHCONTROL-110 were lower by 6.8%, 6.7 percent, and 1.7 percent than those of 10-CHS-110, 16-CHS-110(

Table 1.2).



(g) Columns confined with pn10 HDPE and steel stirrups (for both 4 and 8 inch)

Figure 4.4 Stress-strain behavior of columnar specimens with respect to diameter of column

4.7 ELASTIC MODULUS

Elastic modulus is determined using the stress-strain curve for both control and HDPE constrained specimens. For the RC, CHS, and CH columns, the secant modulus is found by taking the strain equal to 40% of the stress value. Figure 8 depicts the formulations under investigation's absolute elastic moduli in their residual state situations. The results indicate that the HDPE constrained samples maintain a higher elastic modulus when contrasted with the control samples. This was determined by comparing the two sets of samples. The elastic modulus of the column increased, except for 16-CHS-110 and 12-CHS-110, in direct proportion to the decreasing diameter of the column.

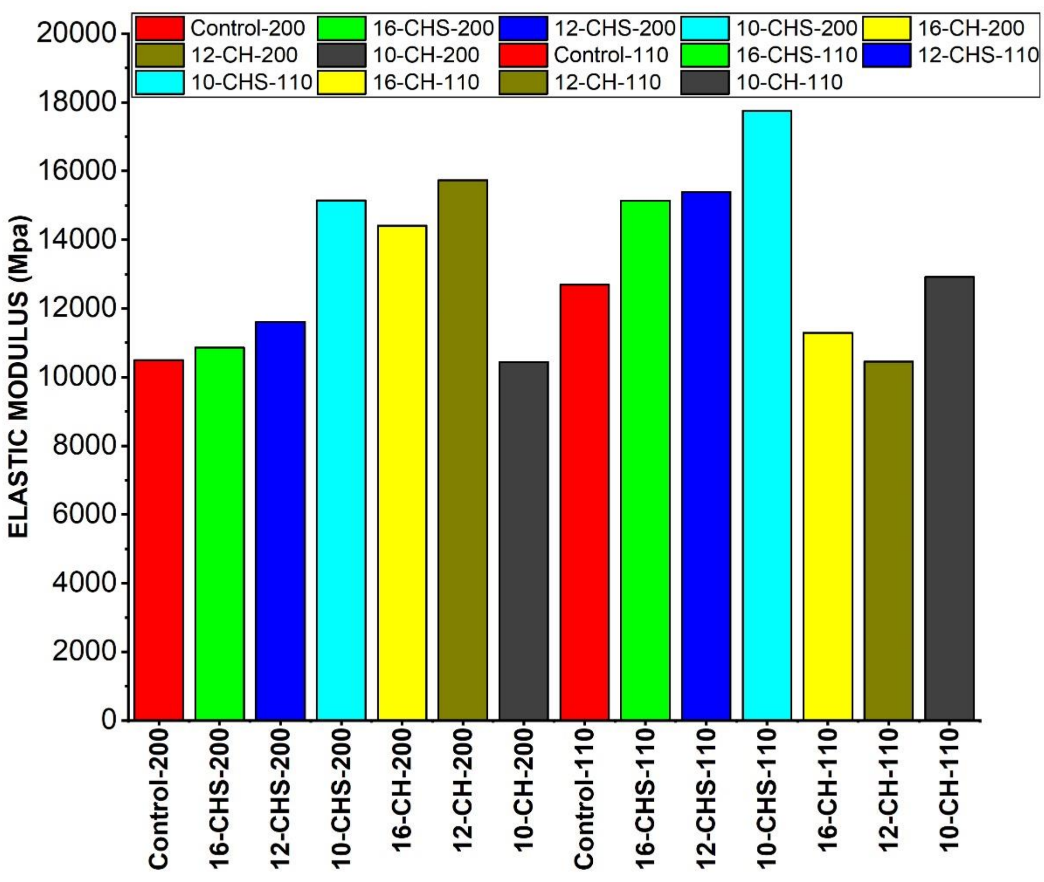


Figure 4.5 Elastic modulus of confined and unconfined columns

When compared to CONTROL-200, 16-CHS-200, 12-CHS-200, 10-CHS-200, and CFHCONTROL-110, Figure 4.5 demonstrates that the elastic modulus of CONTROL-110, 16-CHS-110, 12-CHS-110, 10-CHS-110, and 10-CHS-110 rose by 20.9 percent, 39.4 percent, 32.7 percent, 17.26 percent, and 23.8 percent, respectively. Although the values of 16-CHS-110 and 12-CHS-110 were lower than those of CFHCONTROL-200 and 12-CHS-200 by a respective 21.6 and 33.6 percent, respectively.

4.8 STRAIN DUCTILITY

Determining the specimens' ductility, or their capacity to deform beyond their yield point, is an important characteristic to investigate. Comparing the strain ratio at 80% of peak stress to yield strain measures ductility. Ductility was calculated using HDPE pipe thickness, stirrup availability, and column diameter. The samples that were contained inside HDPE pipes with a thinner wall thickness had the greatest degree of ductility.

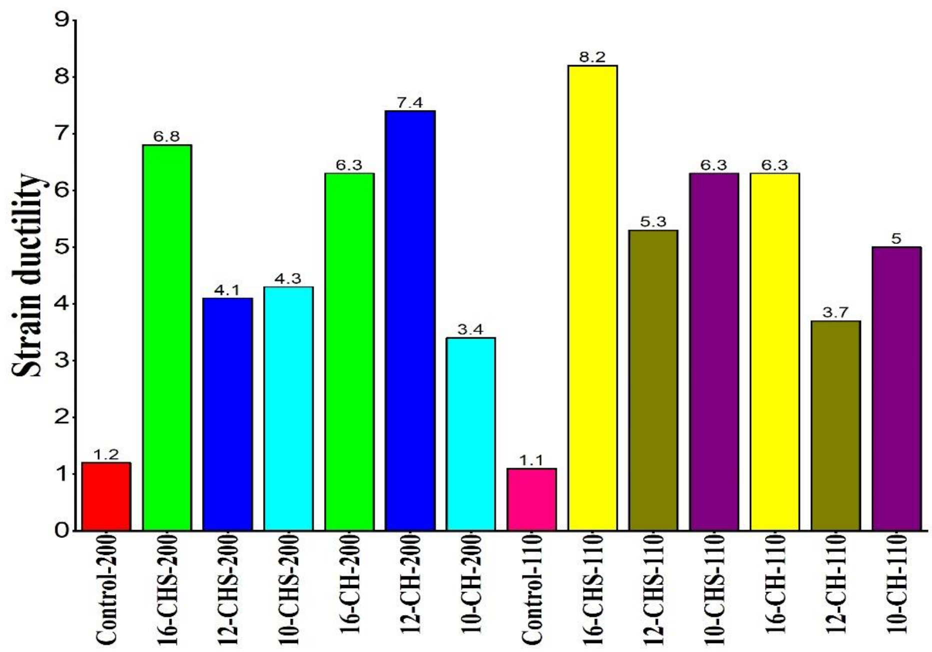


Figure 4.6 Strain Ductility

Figure 4.6 displays the ductility of the control samples in addition to the confined specimens; the ductility of 10-CHS-200 and 10-CHS-110 was 6.8 and 6.3, respectively. The values of strain ductility dropped with an increase in the diameter of the column that was confined with both HDPE and stirrups. On the other hand, the ductility improved in proportion to the increase in the diameter of the column that was made entirely of HDPE. The additional load after the peak was absorbed by HDPE, which demonstrated more ductile behaviour; the improvement in ductility may be ascribed to the HDPE confinement that occurred after the concrete crack.

4.9 COMPRESSIVE TOUGHNESS OR TOTAL CRACK ENERGY ABSORPTION IN COMPRESSION

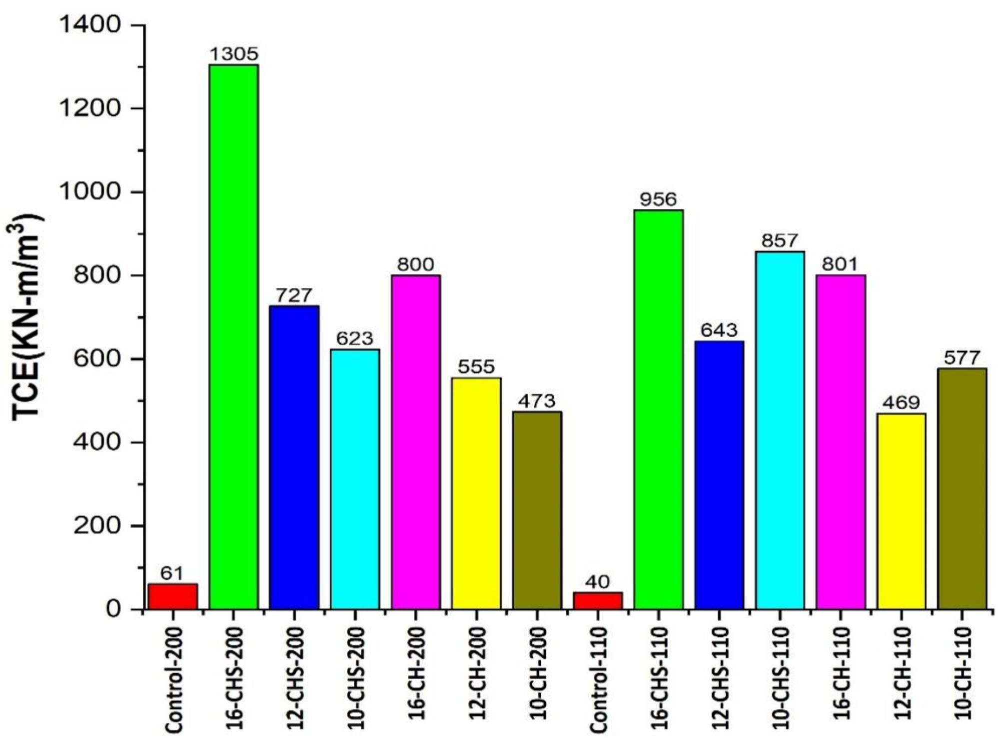


Figure 4.7 Total crack energy

The region that is under the stress- strain curve up until there is a 20% drop in peak stress is what is utilised to calculate compressive toughness. This area is what determines how much energy concrete can absorb before it fails and how well it can resist deformation when it is subjected to compression (TC). To determine the ultimate strain value limit, data from earlier research [55] [56] were used in the calculation. As can be seen in Figure 4.7, the values of energy absorption for every specimen (RC, CHS, and CH) were calculated and exhibited after being analysed. There was a tendency toward increased energy absorption that occurred concurrently with the increase in HDPE tube thickness. The total amount of energy that has been absorbed by CONTROL-200 is 0.06102, which is less than the amounts of 1.30592, 0.95587, 0.80052, and 0.80121 that have been absorbed by 16-CHS-200, 16-CHS-110, and CFHCONTROL-200, respectively. According to the results, there is a correlation between the use of HDPE to enclose the columns and an increase in the quantity of data that is captured.

4.10 PRE-CRACK ENERGY ABSORB IN COMPRESSION (PEC)

The stress-strain curve area from start to yield represents the pre-crack energy. The pre-crack energy of HDPE tubes increased with thickness. As can be shown in Figure 4.8, the pre-crack energy of the HDPE restricted columns was much greater than that of the control sample. Greater pre-crack energy may be seen in the 16-CHS-200, which registers 0.1736. Both HDPE-confined columns and HDPE-confined columns with stirrups exhibited a pattern that was very similar to one another. In a similar vein, the pre-crack energy of CFHCONTROL-200 was measured at 0.0638, while the control sample had a value of 0.04435. A rise in yield point value and an increase in ductility are responsible for the increase in pre-crack energy shown in the restricted sample. For comparison, the pre-crack energy of 16-CHS-110 is 0.09188, whereas that of 16-CHS-200 is 0.1736. As the diameter of the column grew, so did the value of the pre-crack energy.

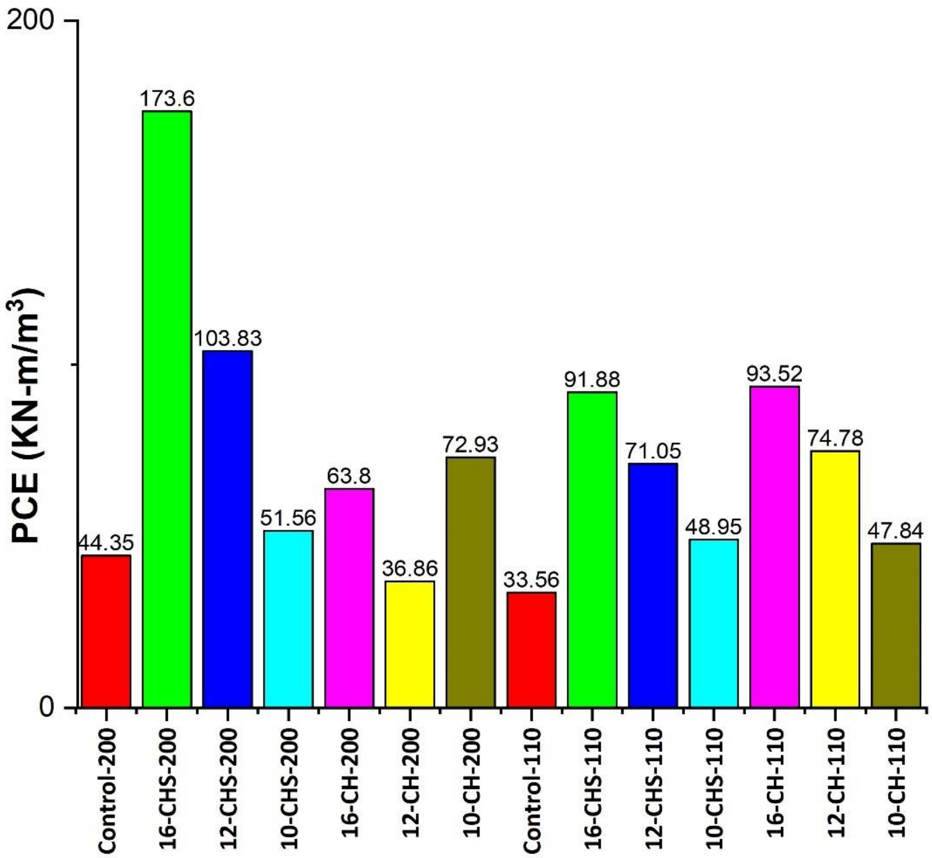


Figure 4.8 Pre crack Energy

4.11 TOUGHNESS INDEX (TI)

The toughness index is determined by comparing the total cracking energy of a confined column to the total crack energy of a control column and calculating the ratio. (TC of confined specimens) / (TC of control specimens) = TI. There is a wide range of thicknesses and configurations available for HDPE tubes, including with and without stirrups. Figure 4.9 presents the hardness indices for each of the various formulations. The control specimen is represented by the red columns, and its hardness may be used to estimate the degree to which the other samples' toughness has increased or decreased. The toughness index values of all the confined specimens exhibit significantly greater values compared to the control sample. The TI rose as the thickness of the HDPE grew; the TI was 21.1 for 16-CHS-200, 23.6 for 16-CHS-110, 13.1 for CFHCONTROL-200, and 19.8 for 16-CHS-110, respectively. The trend was the same for both 110mm and 200mm columns; the TI rose with increasing diameter and increasing thickness of HDPE confinement. This was the case for both sizes of columns. Figure 12 demonstrates that the TI of the confined specimens 16-CHS-200, 16-CHS-110, CFHCONTROL-200, and 16-CHS-110 grew by 2040%, 2265%, 1211%, and 1882 percent, respectively, above their initial values. The greater the rise in TI values, the more the ductility of the restricted columns contributes to the increase.

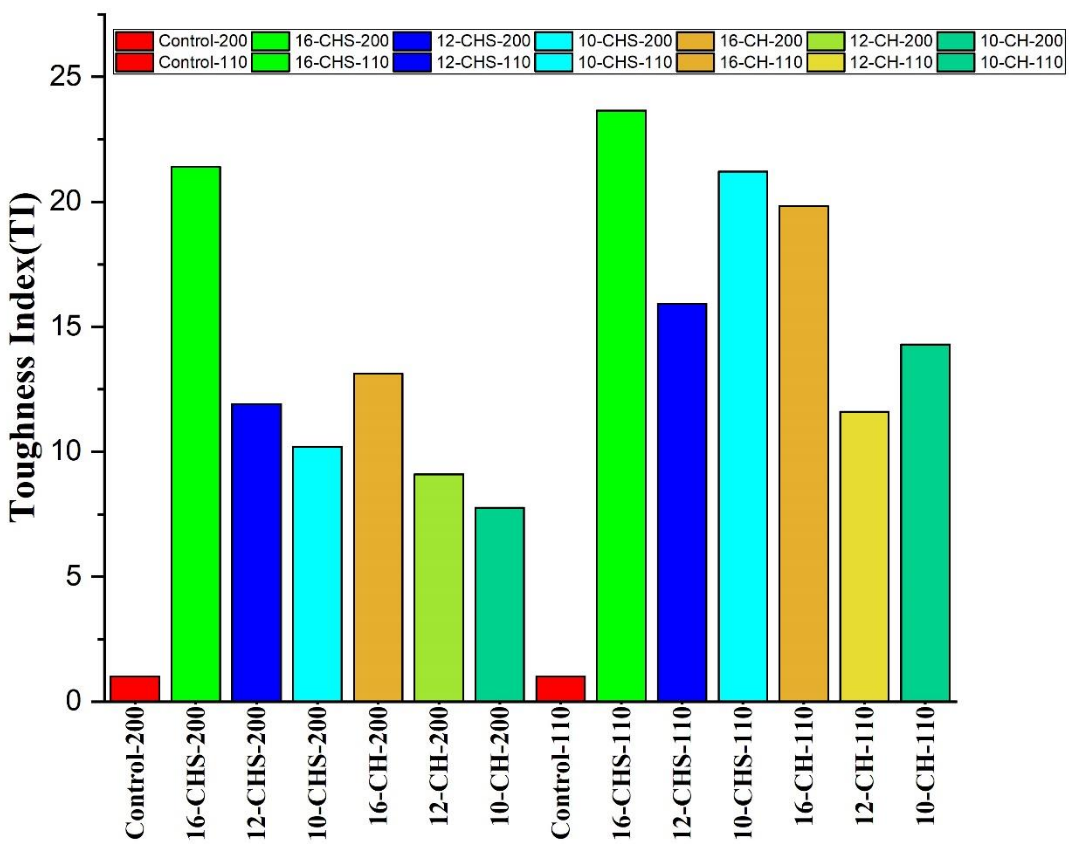


Figure 4.9 Toughness index of confined and unconfined specimens

5 CONCLUSIONS

As part of this study's examination, an investigation was carried out to assess the axial compressive behavior of CHS, CH, and control column specimens. The results of this investigation are shown below. The stress-strain curves, elastic modulus, strain ductility, total crack energy, pre crack energy, and toughness index were all topics that were covered. Additionally, the impact of parameters such as HDPE thickness, column diameter, and stirrup availability on the axial compressive behavior of CHS was also investigated. Based on the findings of the conducted experiments, the made comparisons, and the observations presented in this article, it is possible to draw the following conclusions:

1. The ultimate stress of a 200mm column confined with steel as well as HDPE pipe with thicknesses of 12.5 mm(pn10), 15.5 mm(pn12), and 19.2 mm(pn16) increase by 21.2%, 44%, and 78%, respectively.
2. The ultimate stress values for 110mm column were increased by 40.7%, 53.7%, and 72% for 7mm(pn10), 8.6mm(pn12), and 10.5mm(pn16) thick HDPE pipe respectively.
3. The use of HDPE material significantly enhances the strength of the concrete core and introduces improvements in its deformation capacity.
4. The ultimate strength of the column, as well as its ductility, energy absorption capacity, and toughness index, all enhanced when the thickness of the HDPE tubes were increased.
5. The use of steel stirrups when combined with HDPE confinement leads to an increase in the maximum stress, strain ductility, and overall fracture energy of columnar specimens.
6. The diameter of the column also has an influence on the properties of the column specimens; increasing the diameter of the column enhanced ultimate strength and energy absorption while decreasing strain ductility.

7. The behavior of confined concrete in CHS can be described as exhibiting a combination of strain softening and hardening after reaching the peak strain for specimens with HDPE and stirrups confinement. However, for specimens with only HDPE confinement, the behavior is characterized by strain softening after reaching the peak strain.
8. The ultimate axial strain in HDPE rises as the thickness of the material grows, whereas an increase in confinement stiffness leads to an increase in the material's ability to undergo axial deformation.
9. If we assume that all of the other parameters of the column are the same, then we can say that the axial deformation capacity of the CHS confined with an HDPE tube is noticeably superior than that of the specimen confined with steel stirrups. This is because HDPE tubes can be significantly stretched longer than steel stirrups.

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