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EXPERIMENTAL INVESTIGATION OF CONCRETE FILLED STEEL TUBULAR COLUMNS WITH PARTIALLY SAND REPLACEMENT

A THESIS
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BY

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بسم الله الرحمن الرحيم

﴿خَلَقَ السَّمَاوَاتِ بِغَيْرِ عَمَدٍ تَرَوْنَهَا ۖ وَأَلْقَىٰ فِي الْأَرْضِ رَوَاسِيَ أَن تَمِيدَ بِكُمْ وَبَثَّ فِيهَا مِن كُلِّ دَابَّةٍ ۚ وَأَنزَلْنَا مِنَ السَّمَاءِ مَاءً فَأَنبَتْنَا فِيهَا مِن كُلِّ زَوْجٍ كَرِيمٍ﴾

سورة لقمان الآية ١٠

صدق الله العلي العظيم

Dedication

I dedicate this work to all of my family (parents, sisters and brothers) and friends.

My parents, who did everything possible to this stage of the study, where the journey is long since the primary school to university and did not feel bored or bored in my support.

My sisters and brothers who are my best help in my scientific career

My wife, who has stood with me since the days of our marriage to this moment, where I present this work, is the best support.

My friends who always encouraged me to continue studying.

I dedicate this work to the spirit of **my friend Mustafa Almosoi** who died in August, 2014 and ask God to dwell in paradise.

Certification of the supervisor

I certify that the thesis titled “**EXPERIMENTAL INVESTIGATION OF CONCRETE FILLED STEELTUBULAR COLUMNS WITH PARTIALLY SAND REPLACEMENT**”, which is being submitted by **ATHAR LUAIBI MHAWI,** is prepared under my supervision at the University of Misan/College of Engineering, in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Structures).

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Date: 1 / 9 / 2020

In view of the available recommendations, I forward this thesis for debate by the examining committee.

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Certificate of Examination Committee

We certify that we, the examining committee have read the thesis titled "**EXPERIMENTAL INVESTIGATION OF CONCRETE FILLED STEEL TUBULAR COLUMNS WITH PARTIALLY SAND REPLACEMENT**", and examined the student (**ATHAR LUAIBI MHAWI**) in its content and in what is connected with it and that in our opinion it meets standard of a thesis for the degree of Master of Science in Civil Engineering (Structures).

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ABSTRACT

The Concrete-filled steel Tubular Column (CFST) are used in construction in the mid of 20th century. CFST columns are increasingly used for their many advantages, including high strength, high ductility, and increasing enhancing fire resistance than traditional steel or concrete columns of the same size. The present work is divided into two phases, phase one is the study of the effect of partial substitution of fine aggregates with dune sand, PVC wastes, iron filings, and plastic boxes waste are used as an alternative to the percentage of fine aggregates on mechanical properties of concrete mixture included the compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity, while the second phase is to investigate of the axial load behavior of CFST columns using concrete with partial replacement of fine aggregates with these materials. A composite column specimen is consisted of a steel tube filled with concrete with partial replacement of fine aggregates. The program consists of testing 48 square columns of CFST. The test parameters of CFST specimens included the load capacity, toughness, ductility index, stiffness and strain energy. The test results showed that the materials used as sand replacement improved the mechanical properties of concrete mixtures except PVC sawdust. The increment in mechanical properties compared to control; mix is ranged 4% to 24% for compressive strength, 4% to 41% for splitting tensile, and 0.4% to 13% for flexural strength. The optimum percentages of materials as sand replacement that showed an enhancement in concrete characteristics are 25% dune sand, 2.5% PVC crushed particles, 5% plastic boxes waste, 10% iron fillings. All specimens of CFST stub column showed increase in the load capacity reached to 18% greater than control specimen at replacement ratio of 5% PVC saw dust. For short and long column CFST specimens the replacement ratio of 50% dune sand yielded the higher load capacity namely 8% and 24% greater than control specimens. While the addition of PVC crushed and plastic boxes waste as sand replacement led to reduction load capacity of CFST short

columns specimens by about 5% and 4% at replacement ratio of 5%. The result showed that all specimens of CFST stub column showed lower in the toughness except for iron filing specimens which yielded 9% greater than control specimen at replacement ratio of 5%. For short column CFST specimens the replacement ratio of 5% plastic boxes waste yielded the maximum toughness namely 14% greater than control specimens. For long column CFST specimens the replacement ratio of 10% PVC crushed yielded the maximum toughness namely 82% greater than control specimens. All specimens of CFST stub column exhibit lower strain energy except for iron filing specimen showed 15% greater than control specimen at replacement ratio of 5%. For short column CFST specimens the dosage of 5% plastic boxes waste showed 14% higher strain energy by greater than control specimens. For long column CFST specimens the replacement ratio of 10% PVC crushed revealed the higher strain energy by 82% greater than control specimens.

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Equations

Abbreviations

CFST	Concrete Filled Steel Tube
CHS	concrete-filled circular hollow section
SHS	concrete-filled square
RHS	rectangular hollow section
PVC	Polyvinyl chloride
PVC-S	Polyvinyl chloride sawdust
PVC-C	Polyvinyl chloride crushed
W / C	Water cement ratio
PP	polypropylene
PET	Polyethylene Terephthalate
DI	Ductility index
R	Flexural strength, MPa
T	Splitting tensile strength, MPa
E	Static Modulus of elasticity, MPa
Ec	Static Modulus of elasticity code equation, MPa

Notation

ε	Strain
P	Applied load (N)
b	Width, mm
d	Diameter of the specimens and depth, mm
l	Length, mm
t	Thickness, mm
h	High, mm
f_{cu}	Compressive strength, MPa
f_{st}	Splitting tensile strength, MPa
f_r	Flexural strength, MPa
f'_c	Compressive strength, MPa
N	Load capacity, kN
σ	Stress, MPa

CHAPTER ONE

Introduction

CHAPTER ONE

Introduction

1.1 General

The increase in the use of concrete filled steel tube (CFST) columns in recent years is due to several advantages, including the ability to withstand higher than steel sections alone or employ of reinforced concrete, moreover the utilize of (CFST) in high-rise buildings with high altitudes because the sections of (CFST) are smaller in the volume, smaller in diameter and lighter in the weight comparison to reinforced concrete or steel sections with the same capacity of applied loads [1]. In addition to this the reduction of labor and the disposal of fixed materials such as reinforcing steel and mold materials and all this reduces the time and cost [2]. Furthermore, the advantages characteristics of composite materials to produce a member with strength, enhanced stiffness, and increase load carrying capacity [3]. Solid wastes are materials produced by demolition, debris and human activities such as industrial, electronic, medical and domestic wastes. Sources of solid waste substances divided into residential trash, commercial and institutional. The increase in waste in Iraq is causing many problems, especially since there is no recycling process for these wastes. Some research has been conducted on the use of waste in Iraq and its effect on the use of ordinary concrete or in reinforced concrete only [4]. Therefore, this type of research is carried out on the concrete filled steel tube (CFST) columns.

1.2 Sand Replacement

Sand is one of major component in concrete mixes, fine aggregate occupies proportion range 24-30 % of concrete’s mix. Concrete is a mixture of cement, aggregate and water [5]. Due to the explosive growth of concrete as alternatives materials are necessary. The alternatives are once on cement and again on the aggregates of both types of coarse aggregate and fine aggregate. Sometimes these alternatives are in the form of proportions of the material to be replaced [6]. The substitution of concrete materials is sometimes to compensate for depletion in its primary sources and sometimes to solve an environmental problem or cost save [7]. Examples of materials used as substitutes instead of fine aggregates are: plastic wastes or glass wastes, dune sand and waste lathes. Plastic waste issued as a substitute for fine and coarse aggregates.

1.3 Composite Columns

The main materials of the composite column are concrete and steel, mostly the important properties are strength and stiffness. The action occurs when two different materials are combined very tightly from a structural point of view that can work together as one unit. Because of the combined action, the composite part is harder, stronger than total individuals. However, these structures profits are established in the mid-twentieth century increases in hardness and strength are observed in different types composite structure.

For steel-concrete composite column, steel provides high tensile strength, ductility and construction speed, concrete provides high compression strength, rigidity, and cost savings. Another notable feature associated with the use of composite columns steel tubes act as molds, saving construction costs concrete core. With features of concrete-filled steel tube column, steel frame built after filling concrete without waiting for concrete hardening the advantage is that it can save time and money [8].

The common forms in that period are shown in the Figure (1-1), namely steel-encased concrete column, concrete-filled circular hollow section (CHS), concrete-filled square (SHS), or rectangular hollow section (RHS). The steel-encased column comprises I or H steel cross-section placed within a traditional reinforced concrete or plain concrete. This structure is the earliest type of composite cross-section. Concrete filled steel tubular CFST column, on the other hand, is simply constructed by filling concrete into the hollow section, which is used as a casting mold to the concrete. The steel section is located at the outer perimeter, where it performs most effectively in tension and bending moment. Furthermore, the stiffness of the CFST column is enhanced as the steel section has a greater modulus of elasticity compared with concrete members and a greater moment of inertia owing to the fact that the steel section is situated farthest from the centroid of the cross-section [9].

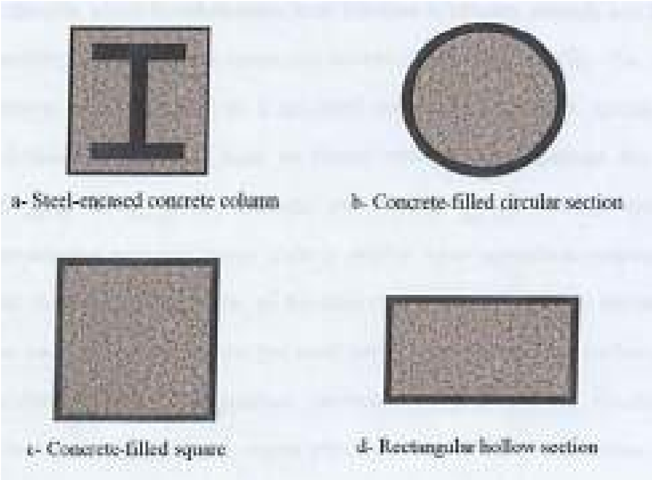


Figure (1- 1) Typical shape cross-section of composite columns

1.4 Statement of The Problem

Sand is strongly influenced on the concrete's freshly mixed and hardened properties, mixture proportion, and economy. Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5mm [5]. Sand use with coarse aggregates to produce a structural concrete and can be also used alone with cement for mortars and plastering works. It is also economical since it is abundant near most construction works. As the demand for fine aggregate is escalating rapidly in construction industry, river sand resources are excessively exploited all over the world. As a result, new sources of sand should be considered, such as dune sand [10].

In many desert regions, there is an abundance of a very fine natural sand known as dune and. In Oman, nearly one quarter of the country is covered with dune sand [6]. Also, China for instance, the dune area accounts for nearly a quarter of the Chinese land area; the abundant dune sand may be used in concrete mixture instead of the river sand. Compared with river sand, dune sand however possesses some critical defects including low fineness modulus (1.44) and poor gradation [10]. In Iraq there are huge areas of dune sand especially in western desert of Iraq. In Misan province there are two regions of dune sand Butera and Buzrgun. Researches indicate an increase in the amount of solid waste in Iraq over time, and this means an increase in its negative impact on health and the environment. Therefore, the use of industrial or consumer waste in concrete mixture is one of the most important factors for recycle of this waste [4].

1.5 Application of (CFST) Column

The use of concrete-filled steel tubular CFST columns for the construction of building structures, bridges and warehouses has become widespread in recent decades. The following some examples of using CFST column in construction fields:

1- The first engineering project adopted CFST is Beijing Metro No.1 as shown in Figure (1-2), because the CFST column size is smaller than the RC column, the available space increases. Good economic effects are obtained. Then all columns of the platform of the second Beijing Metro are adopted CFST column [8].

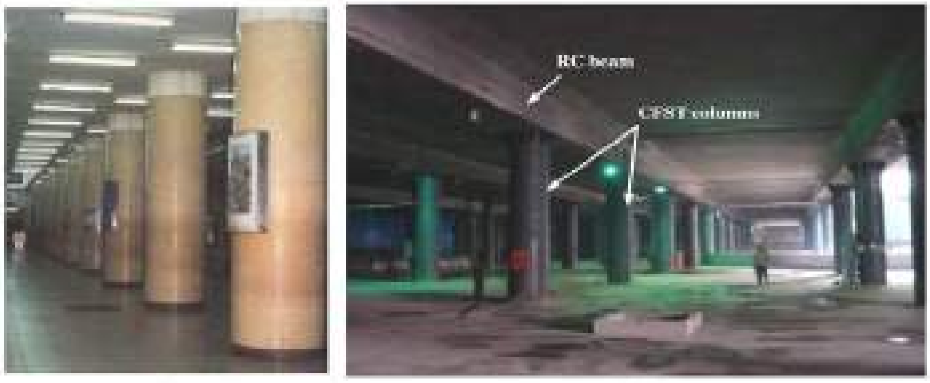


Figure (1- 2) Subway stations (Beijing Metro) using CFST columns

2- The steel tube that use in Benxi steel company (in China) for a power plant as shown in Figure (1-3), is the first industrial building adopted CFST columns in 1972.

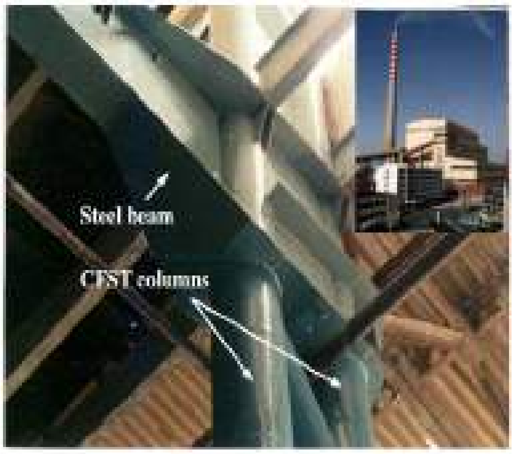


Figure (1- 3) A power plant workshop using CFST columns

3- The application of CFST on high-rise buildings, the highest building in China adopted CFST is Shenzhen SEG Plaza building shown in Figure (1-4) which it is completed in 1999.

Figure (1- 4) SEG Plaza highest building adopted CFST (under construction)

4- Applications of CFST in Bridge Engineering: CFST has a higher compression capacity and ductility ideal for applications arches bridges as shown in Figure (1-5).

Figure (1- 5): First CFST Arch Bridge, China: Wangchang East River Bridge (Span 115 m)

5-The concrete-filled steel tubes can be used in the construction and the upgrade of poles and transmission towers as well. Figures (1-6) and (1-7) are show a long-span transmission tower built in Zhoushan, China [8].

Figure (1- 6) Zhoushan electricity long-span transmission tower

Figure (1- 7) A CFST pole

1.6 Research Aims and Objectives

The present study deals with the use of four types of waste available in Misan province, such as plastic boxes, the waste of the plastic factory (Polyvinyl chloride PVC dust and particles) and Iron filings waste, in addition to dune sand in various percentage in the concrete mix as sand replacement. Furthermore, a comprehensive experimental study focused on the experimental study of CFST columns. The main objectives of the present study are: -

1. Evaluation of the mechanical properties of concrete with sand replacement. The mechanical properties include, compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity.
2. Identify the optimum replacement ratio of waste to be added as partial substitution of sand.
3. The behavior of square steel tubes column infilled with concrete included partially replaced sand is investigated to study the effected of these wastes on the behavior of CFST column.
4. Three heights and sizes of columns that yield three slenderness ratios demonstrated stub, short and long columns. The axial load capacity and failure of columns the main investigated characteristics.

5. Study effect of width of section to thickness of steel tube (D/t) ratio with partially sand replacement by waste materials and dune sand.

1.7 Research Methodology

Steps are taken through a set of sequential steps that represented the following

1. Investigation of existing waste materials that can be used as an alternative to sand, through visiting the collection sites of plastic waste to get plastic boxes, Misan plastic Factory to get PVC wastes, collection of waste resulting from cutting iron.
2. Bringing sand dunes from areas where these dunes are available.
3. Accomplish the experimental works which divided into two phases, the first phase included evaluation of mechanical properties of concrete included dune sand and wastes materials as sand replacement, while the second focused on CFST columns behavior.

1.8 Research Layout

The present thesis includes, five chapters:

Chapter one: This chapter is briefly defining introduction to the problem.

Chapter two: Explored a review of previous studies, it is divided into two categories: the first part is the beginning of using the waste as a fine aggregate. The second part is related to the concrete infilled steel tubular columns.

Chapter three: Presented the experimental program, specifications of materials used and the mixing proportions. Working procedures, specimens' details, methods of preparation and testing are presented.

Chapter four: Inspected and evaluated the results and discussion of the experimental program.

Chapter five: Shows the most important conclusions obtained from experimental work and some recommendations for future work.

CHABTER TWO

CHAPTER TWO

Literature Review

CHAPTER TWO

Literature Review

2.1 Introduction

The available studies in literature that related to the present work are explored in this chapter. The studies are divided into two parts. The first part summaries, the materials that used as partial sand replacement. The second part presented the available studies conducted on CFST with partially replacement of sand in concrete mixture.

2.2 Materials Used as Partially Sand Replacement in (Concrete Mixture)

Concrete is basically a mixture of two components; aggregates and paste [5]. Due to the high demand for concrete and therefore the demand for its components, it is necessary to find alternatives to reduce the consumption of components in the production of concrete. Many researchers used different materials as sand replacement like plastic waste, dune sand, glass wastes, iron filings...etc.

2.2.1 Sand Replacement by Dune Sand

In 2006, Zhang et al. [11] investigated the mechanical properties of concrete made of two types of dune sand as sand replacement with cement/sand ratio (18%,28%,40%,50% and 68%) and effect of dune sand on workability of fresh concrete. The results indicated that the dune sand can be used as a fine aggregate in concrete in general engineering construction, if used with suitable cement/sand ratio, where the workability is extremely poor when the cement/sand ratio is smaller than 50%.

In 2007, Al-Harthy et al. [6] experimentally studied the effect of dune sand on the slump (workability), compressive strength and modulus of elasticity of concrete mixtures with percentage ranged from 10% to 100%. The results showed that when the dune sand content reached a high level (above 50%), workability decreased with increasing dune sand content. In general, compressive strength also decreased with increasing sand dune replacement. However, the maximum strength loss is approximately 25% when the fine aggregate is completely sand replaced by dune sand.

In 2013, Luo et al. [12] presented the study on the properties of concrete made with dune sand from Australian desert with sand/cement ratio from 0.91 to 2.28 and a constant water/cement ratio of 0.5. The results revealed that, at a high level of sand/cement ratio (> 1.41) that very fine particles of dune sand led to reduction in the workability and strength of dune sand concrete.

2.2.2 Sand Replacement by Plastic Wastes

Many types of plastic waste have been reused and invested in construction. Many researchers used plastic waste in different forms and sizes as part in the concrete mixture. There are relatively limited studies on recycled polyvinyl chloride (PVC) in concrete compared to other types of plastic.

In 2014, Kumar et al. [7], used electronic plastic(e-plastic) wastes which consisted of plastic waste from old electronic devices with percentages (10, 20, 30, 40, 50%) as a partial replacement of coarse aggregate in concrete mixtures. The maximum size is 12.5 mm with mixing ratio (1: 2.14: 3.08) and W / C = 0.49. The test is conducted for fresh and hardened concrete at the age of 7 and 28 days. They found that by increasing the proportion of plastic waste used, the compressive strength, splitting tensile strength and flexural strength of the concrete are reduced.

In 2014, Patil et al. [13] used polypropylene (PP) and Polyethylene Terephthalate (PET) as coarse aggregate in the concrete mixture with a percentage of (10, 20, 30, 40, 50) % by volume of aggregate in the mix. The tests are carried out for hardened concrete (compressive and flexural strength) at ages of 7 and 28 days. They observed that the compressive strength decreases as a plastic waste percentage increase. In addition, the flexural strength of the hardened concrete is increased when coarse aggregate is replaced by 10% of polypropylene (PP) and polyethylene terephthalate (PET) at 7 and 28 days.

In 2014, Tapkire et al. [14] utilized polypropylene (PP) and polyethylene Terephthalate (PET) as coarse aggregate replacements with percentage of 10%, 20% and 30% by weight of aggregates with size less than 10 mm, and mixing proportion (1:2.56:3.26) with W/C is 0.5. The tests are carried out for fresh and hardened concrete at the ages of 14 and 28 days. They found that a decreasing in 28-days compressive strength at percentage 10% to 20% and 30% of (PP) as coarse aggregate replacement by 2.5%, 5.2% and 8.1% respectively.

In 2015, Yang et al. [15] used polypropylene (PP) cut into small pieces with lengths from 1.5 mm to 4 mm as sand replacement with percentage of 10%, 15%, 20%, and 30% of sand by volume in the mixture. The tests are carried out for fresh and hardened concrete compressive strength, splitting tensile strength and flexural strength at 7 and 28-days. They observed that the workability increases as a plastic waste percentage increase. In addition, dry density and elastic modulus decrease as a plastic waste percentage increase. The compressive, split tensile, and flexural strength of the hardened concrete are improved against increasing the proportion of the plastic waste used by 15 %.

In 2016, Manjunath et al. [16] used electronic plastic (e-plastic) waste which consisted of plastic waste from old computers, televisions, refrigerators and radiators as a coarse aggregate with maximum size of 20 mm in concrete mixtures with percentage of 10, 20 and 30% and mixing proportion 1.4: 2.4: 0.5 with W / C of 0.5. The tests are conducted on day 7,14 and 28 days of the fresh and hardened concrete.it is observed that the workability, dry density and fresh density are reduced as plastic increase. In addition, the result of 28-days of the compressive, split tensile, and flexural strength of the hardened concrete are reduced by 52.98%, 22.44% and 42.52 respectively at 20% e-plastic as coarse aggregate replacement.

In 2019, Adnan [17] investigated experimentally the effect of polyvinyl chloride (PVC) as sand replacement on mechanical properties of concrete (workability, compressive strength, splitting tensile strength and flexural strength). With four percentages of (PVC) waste are used namely,1.25 %, 2.5 %, 3.75 %, and 5 %. The result showed a reduction in slump by 10%, 25%, 50% and 75% and increase in 28-days compressive strength by 31.7%, 10.7%, 11.1% and 21.81% respectively. In addition, Adnan investigated experimentally the effect of plastic boxes waste as sand replacement on mechanical properties of concrete (workability, compressive strength, splitting tensile strength and flexural strength). Three percentages of plastic boxes waste are used in her study, namely 2.5 %, 5 %, and 10 %. The result showed reduction in slump by 5%, 10%, and 15% respectively and increment in 28-days compressive strength by 2.8% and 30.2% at 2.5%and 5% dosage respectively of plastic boxes waste respectively, while there is a reduction in compressive strength at 10% replacement by 3.03%.

In 2018, Hussein et al. [18] investigated experimentally the effect of adding plastic boxes waste in concrete as replacement of coarse aggregate with maximum size of 20 mm on strength properties of concrete. The concrete mixtures are with percentages of 20%, 40%, 60%, and 80% of plastic boxes wastes as replacement of gravel. The result showed decreasing in 7, 28 and 56-days age compressive strength by 7.37%, 17.68%, 38.6% and 46.65% respectively.

2.2.3 Replacement of Iron Filings

In 2016, Ghannam et al. [19] studied and investigated the strength properties of concrete produced with granite powder and iron powder with percentages of 5%, 10%, 15%, and 20% of the sand by weight for concrete mixtures. that substitution of 10% of sand by weight with granite powder in concrete is the most effective in increasing the compressive and flexural strength compared to other ratios. The test resulted showed that for 10% ratio of granite powder in concrete, the increase in the compressive strength is about 30% compared to normal concrete. Similar results are also observed for the flexure. It is also observed that substitution of up to 20% of sand by weight with iron powder in concrete resulted in an increase in compressive and flexural strength of the concrete.

In 2017, Olutoge et al. [20] studied and investigated the strength properties of concrete produced with iron filings as partial replacement of sand with percentages of 10%, 20% and 30% for concrete mixtures. The results of 28-days test showed that the compressive strength of 10% and 20% replacement with iron filings increased by 3.5% and 13.5% respectively, while a reduction of 8% for 30% replacement ratio. Split tensile strength of 10% and 20% dosage is increased by 12.7% and 1% respectively, while decreased by 1.7% for 30% dosage. flexural strength of concrete increased by 11.1% and 4.8% for 10% and 20% dosage respectively, while decreased by 1.6% for 30% replacement.

In 2018, Tunga et al. [21] attempted to study the effect of adding residues such as waste lathes as replacement to fine aggregates. The fine aggregate is being replaced with lathe waste at various percentages like 2%, 4%, 6% and 8% and characteristics of concrete like compressive strength, split-tensile strength are to be studied. The results showed that the using of lathe waste with percentage of 2% and 4% caused an increase in the compressive strength by 18.8% and 11% respectively and it is found that for 2% replacement there caused 13% of increment in split tensile strength after 7days and 12% after 28days.

2.3 Concrete Filled Steel Tubular (CFST) with Sand Replacement

According to researcher knowledge there is limited studies of CFST with dune sand as replacement of fine aggregate, while there are no any studies (according to researcher knowledge) related to using plastic wastes or iron filings in CFST column as sand replacement.

In 2014, Wang et al. [22] attempted to investigate the behavior of concrete-filled steel tubular (CFST) stub columns and beams using 10% dune sand as sand replacement. The main parameters of stub column specimens are the concrete strength, the steel ratio and cross-sectional type. They used 26 specimens of columns and beams, including 10% dune sand CFST stub columns, 4 stub hollow steel columns, 6 reinforcement concrete stub columns with dune sand and 6 dune sand CFST beams with rectangular cross-section. The result of concrete mixtures with dune sand as sand replacement have low slump and the failure mode of CFST column with dune sand concrete are similar to those of normal CFST columns. The ductility index of CFST stub columns are better than reinforcement concrete columns.

In 2018 Qing-Xin et al. [10] studied the behavior of steel tube filled with concrete contained dune sand. A total of 24 columns specimens are tested, including 20 CFST columns for sand dune and 4 reference columns for hollow reference steel tubes. They studied the effects of thickness, cross section dimensions and concrete infilled on behaviour CFST stub columns. The results of dune sand (CFST) stub column specimens are similar to conventional (CFST) stub columns in ductility and mode of failure, where the outward local buckling occurred in all concrete-filled square specimens. For most of them, the outward local buckling appeared near the mid-height section, with one exception, where the local buckling appeared near the end of the column.

2.4 Summary

A brief presentation of main studies related to the present study are summarized in in Table (2-1). Based on previous review and Table (2-1) the main topics studied by researchers are presented in the following summary:

- From literature, using 50% of dune sand as sand replacement led to hard workability of concrete mixture. There for, in the present study the percentage of dune sand is (10%,25% and 50%) and not exceed 50%
- From literature, using (PVC) sawdust as sand replacement with different percentage. In present study using (PVC) crushed as particles in concrete mixtures.
- From researches, using 30% of iron filing led to decrease in compressive strength. In the present study the percentage of iron filing is (2.5%,5% and 10%).
- There are limited researchers related to dune sand in concrete filled steel tubular (CFST) columns.
- There are no researchers related to use (PVC), plastic boxes waste and iron filings in concrete filled steel tubular (CFST) columns as sand replacement. In present study using these materials as sand replacement in (CFST).

Table (2-1) Summary of Studies

Author	Type of material	Usage and dimension	Percentage of replacements	Remark
Zhang et al. 2006 [11]	Two types of dune sand	Sand replacement	cement/sand ratio (18,28,40,50 and 68)	workability is extremely poor when the cement/sand ratio is smaller than 50%.
Al-Harthy et al. 2007 [6]	dune sand	Sand replacement	from 10% to 100% of sand replacement.	Content above 50%, workability decreased
Luo et al. 2013 [12]	dune sand from Australian desert	Sand replacement	Sand/cement ratio from 0.91to 2.28	At a high level of sand/cement ratio (> 1.41) led to reduction in the workability
Kumar et al. 2014 [7]	e-plastic	coarse aggregate with max. size of 12.5 mm	with percentages (10, 20, 30, 40, 50%) and mixing ratio (1: 2.14: 3.08) and W / C = 0.49	They found that by increasing the proportion of plastic waste used, the compressive strength, splitting tensile strength and flexural strength of the concrete are reduced
Patil et al. 2014 [13]	Poly-propylene (PP) and Poly-ethylene Terephthalate (PET)	coarse aggregate	with a percentage of (10, 20, 30, 40, 50) % by volume of aggregate	flexural strength is increased when coarse aggregate is replaced by 10% of (PP) and (PET)
Tapkire et al. 2014 [14]	Poly-propylene (PP) and Poly-ethylene Terephthalate (PET)	coarse aggregate with size less than 10 mm	With percentage of 10%, 20% and 30% by weight of aggregates and mixing proportion (1:2.56:3.26) with W/C is 0.5	Decreasing in compressive strength at percentage 10% to 20% and 30% of (PP)
Yang et al. 2015 [15]	Poly-propylene (PP)	sand replacement with lengths from 1.5 mm to 4 mm	with percentage of 10%, 15%, 20%, and 30% of sand by volume	the workability increases as a plastic waste percentage increase
Manjunath et al. 2016 [16]	e-plastic waste	as a coarse aggregate with max. size of 20 mm	with percentage of 10, 20 and 30% and mixing proportion 1.4: 2.4: 0.5 with W / C of 0.5	the compressive, split tensile, and flexural strength of the hardened concrete are reduced by 52.98%, 22.44% and 42.52 respectively at 20% e-plastic
Adnan 2019 [17]	polyvinyl chloride (PVC) with max. size of 10 mm	Sand replacement	(PVC) waste is 1.25 %, 2.5 %, 3.75 %, and 5 %.	reduction in slump by 10%, 25%, 50% and 75% and increase in compressive strength by 31.7%, 10.7%, 11.1% and 21.81%.
Adnan 2019 [17]	Plastic boxes waste with max. size 12.7 mm	Sand replacement	percentages of 2.5 %, 5 %, and 10 %.	reduction in slump by 5%, 10%, and 15%. increment in compressive strength by 2.8% and 30.2%
Hussein et al. 2018 [18]	Plastic boxes waste	Coarse aggregate with max. size of 20 mm	percentages of 20%, 40%, 60%, and 80%	decreasing in compressive strength by 7.37%, 17.68%, 38.6% and 46.65% respectively.
Olutoge et al. 2017 [20]	Iron filings	Sand replacement	percentage of 10%, 20% and 30%	Increase in compressive strength 3.5% and 13.5%, while decreased by 1.7% for the 30%
Tunga et al. 2018 [21]	waste lathes	fine aggregates	various percentages like 2%, 4%, 6% and 8%	the using of lathe waste with percentage of 2% and 4% increase in the compressive strength by 18.8% and 11% respectively

CHABTER THREE

CHAPTER THREE

Experimental Work

CHAPTER THREE

Experimental Work

3.1 General

An evaluation of the properties of materials used in the production of the concrete mixture is included in this chapter. The details of the materials used (cement, fine aggregate, coarse aggregate, water mixtures and additives), the physical and chemical properties, and their proportion in each concrete mixture are presented. Also, the materials used as sand replacement, such as dune sand, PVC waste, plastic box waste and iron filings waste are presented.

The test program included testing of 463 samples; 192 cubes for concrete compressive strength, 96 concrete cylinders for splitting tensile strength,16 cylinders to measure the modulus of elasticity, 96 prisms for flexural strength, while the columns specimens tested for axial loadings, included 3 empty tubes ,9 plain concrete columns and 48 concrete filled steel tube (CFST) in different lengths and sizes (stub, short and long).

Tests are carried out in the Laboratories of Civil Engineering Faculty / University of Misan and the laboratory of the Technical Institute of Amara.

3.2 Work Program

The program of work has been carried out in two parts, the first part is related to the partial replacement of the sand by certain waste materials and dune sand, while the second part is related to investigate the behavior of concrete filled steel tube CFST columns concrete mixes with partially replaced sand.

For preparing to the study, firstly, the information is collected on the largely spread waste in Misan province that could be used as sand replacement in concrete, the plastic waste and iron filings resulting from iron cutting machines are selected. Since, natural resources material such as sand dunes is used as sand replacement. These selected materials do not need process. The second part related to CFST column, by using steel tube filled with concrete mix. The dimensions of column height, side length and thickness are restricted by several limitations, mainly the available testing machine (available in Misan province laboratories). The maximum available load capacity of testing machine is 1000 kN and total available height of 550 mm.

3.3 Properties of Concrete Materials

Standard tests are carried out for the materials make up the concrete mixes in the present study. It is included physical and chemical properties of cement and aggregates gradient (sand and gravel).

3.3.1 Cement

The cement is used in concrete mixes is the Portland cement Type (I). The laboratory tests of cement are conducted at the Construction Materials Laboratory of Amara Technical Institute. Measurements based on Specification ASTM C109/C109M-16 [23] and ASTM C150/C150M-17 [24]. Physical and chemical tests are listed in Table (3-1) & (3-2) respectively.

Table (3- 1) Physical Properties of Cement

Physical properties	**Test result**	**ASTM C109/C109M-16** [23]**&C150/C150M-17** [24]
Fineness Using Blain Air Permeability Apparatus (m^2/kg)	384	> 260
Setting time Using Victa's Method Initial setting (min.) Final setting (hrs: min.)	 120 3:45	 ≥45min ≤ 10 hrs.
Compressive strength of mortar (MPa): 3-days 7-days	 20.8 27.4	 ≥ 12 ≥ 19
Soundness Using Autoclave Method	0.22	≤ 0.8

Table (3- 2) Chemical Composition of Cement

Composition name	**Abbreviation**	**by weight%**	**ASTM C150/C150M-17** [24]
Lime	CaO	63.96	-
Silica	SiO2	21.32	-
Alumina	Al2O3	4.58	-
Iron oxide	Fe2O3	3.25	-
Sulfate	SO3	2.48	≤ 2.8%
Magnesia	MgO	2.75	≤ 5%
Loss on Ignition	L.O.I.	3.46	≤ 4%
Lime saturation Factor	L.S.F.	0.97	0.66-1.02
Insoluble residue	I.R.	1.07	≤ 1.5%

3.3.2 Fine Aggregate (Sand)

Natural sand from the Basra region in the south of Iraq is utilized in this study. The grading of sand is presented in Table (3-3) and Figure (3-1), while the physical and chemical properties of the sand based on Iraqi Specification No.45/1984 [25] are presented in Table (3-4).

Table (3- 3) Grading of the Fine aggregate

Sieve Size (mm)	Passing %	Limits of IQ.S % Passing (Zone II)
10	100	100
4.75	96.35	90-100
2.36	86.25	75-100
1.18	68.80	55-90
0.6	46.20	35-59
0.3	23.05	8-30
0.15	3.80	0-10

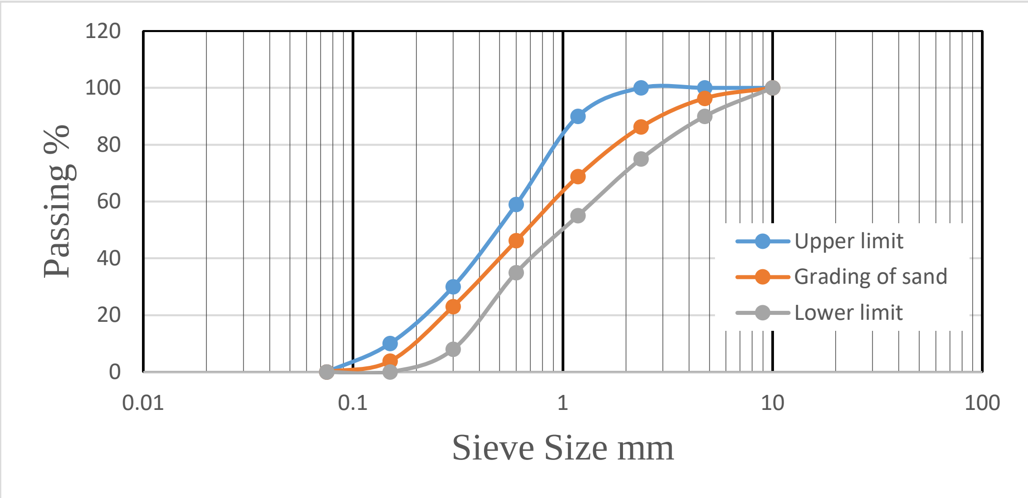


Figure (3- 1) Grading curve of fine aggregate (Sand)

Table (3- 4) Physical and Chemical properties of Fine Aggregate

Physical properties	Test result	Limit of Iraqi Specifications
Specific gravity	2.56	-
Sulphate content (SO3%)	0.29%	0.75% (max)
Absorption%	0.75%	-
Fineness	2.75	-

3.3.3 Coarse Aggregate

The coarse aggregate used in this study is naturally available in Chilat region eastern Amarah. The maximum size of gravel of (10 mm) is used. The properties of the gravel are shown in Table (3-5). The grading of coarse aggregate according to the Iraqi SpecificationNo.45/1984 [25] is shown in Table (3-6).

Table (3- 5) Physical and chemical properties of coarse aggregate

Properties	Test results	Limits of IQ.S No.45/1984
Specific gravity	2.55	-
Absorption %	0.73%	-
Sulphate content	0.045%	≤0.1%

Table (3- 6) Sieve analysis of coarse aggregate

NO.	Sieve size(mm)	Cumulative passing %	Limit of IQ.S No.45/1984%Passing
1	14	100	100
2	10	92.1	85-100
3	5	15.6	0-25
4	2.36	0.7	0-5

3.3.4 Mix Water

Reverse osmosis (R.O.) water is utilized for mixing and curing all the specimens.

3.3.5 Admixture

Super plasticizer modified polycarboxylates based polymer admixture is used in this study. According to specifications ASTM C494-99 types A and G [26], the specifications details of superplasticizer shown in Table (3-7). Two percentages of super plasticizer are used by weight of cement, (0.8) and (0.3) in concrete tests while one percentage of (0.3) in columns specimens. The purpose of using of the plasticizer is to increase the workability of the mixing process.

Table (3- 7) Technical properties of Flocrete PC 260

Chemical Base	Modified polycarboxylates based polymer
Appearance/colors	Light yellow liquid
Freezing point	-7ºC approximately
Specific gravity @25ºC	1.1±0.02
Fire	nonflammable
Air entrainment	Typically, less than 2 % additional air is entrained above control mix at normal dosages
Dosage	0.5 to 3.0 liter per 100 kg of binder
Storage condition/Shelf Life	12 months if stored at temperatures between 2ºCand 50ºC

3.4 Properties of Replacement Materials

3.4.1 Plastic Materials

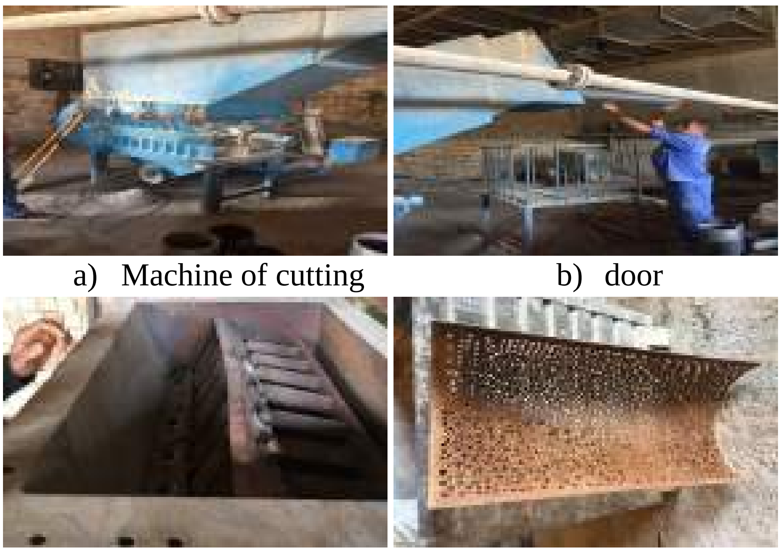
Three types of plastic wastes are used in the present study ,1 Polyvinyl Chloride crushed pipes (PVC-C), 2 Polyvinyl Chloride sawdust (PVC-S), and 3 crushed plastic boxes. In the present study all waste materials are passed through sieve No. 4 with a hole (4.75) mm to achieve maximum size less than 4.75 mm.

3.4.1.1 Polyvinyl Chloride Crushed pipes (PVC-C)

Polyvinyl chloride-crushed pipes (PVC-C) is obtained from Misan Plastic Factory. Since small pieces obtained from the process of cutting the waste parts of pipes. The size of the pieces is shown in Table (3-8) with a maximum size is 4.75 mm. This type of plastic is irregular in shape (non-spherical) the color is gray as shown in Figure (3-2).

Figure (3- 2) Sample of (PVC-C) plastic

The plastic wastes of PVC-C are cutting by a machine manufactured for this purpose as shown in Figure (3-3). It has weight 800kg, dimensions of (150 cm length, 80 cm width, and 220 cm height), and with a capacity up to 30 Hp motor. At the top there is a door opens to insert the pipes to be cut, where contain inside four sharp fans to cut the PVC pipes and the bottom is a filter with dimensions (100 ×60 cm) as shown in Figure (3-3-d).



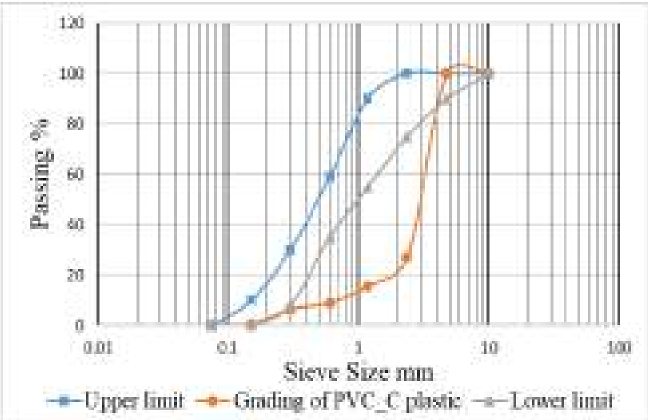
a) Machine of cutting
b) door
c) Sharp fans
d) filter

Figure (3- 3) Special machines to crash plastic pipes

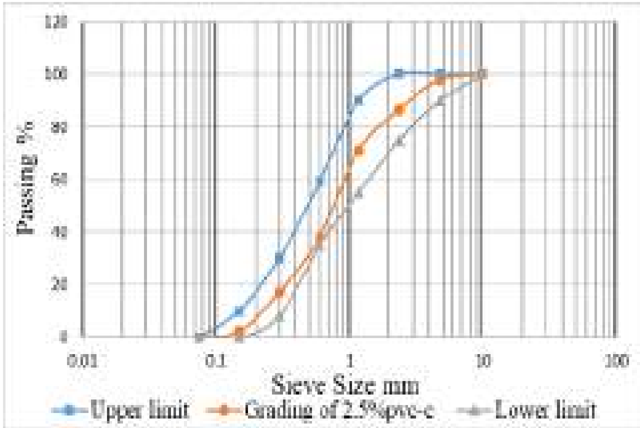
Figure (3-4) shows sieve analysis of different percentage of (PVC-C) waste plastic. The sieve gradient of plastic particles of (PVC-C) alone does not meet the Iraqi specification of all the sieves as shown in Table (3-8) and Figure (3-4-a), but when using this material as a partial replacement of sand (2.5,5 and 10%) it is evident from Figure (3-4-b, c and d) that the gradient of the mixture corresponding to Iraq specifications No. 45/1984 of zone (II) [25].

Table (3- 8) Sieve analysis of (PVC-C) Plastic

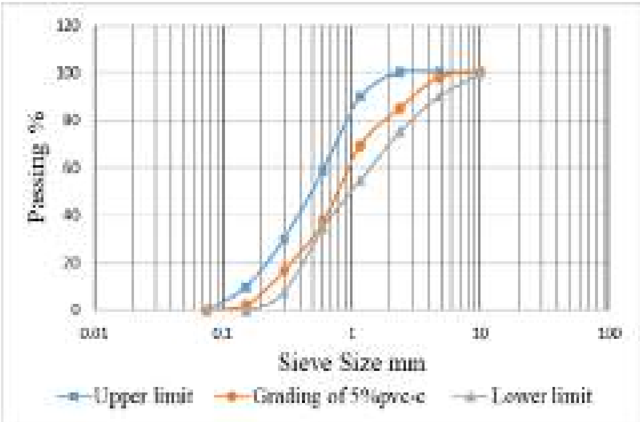
Sieve Size (mm)	Passing %					Limits of IQ.S % Passing (Zone II)
	100% Sand	100% PVC-C	97.5%Sand + 2.5%PVC-C	95%Sand + 5%PVC-C	90%Sand + 10%PVC-C	
10	100	100	100	100	100	100
4.75	96.3	100	97.96	98.03	98.14	90-100
2.36	86.2	27.21	86.43	84.91	81.86	75-100
1.18	68.8	15.62	71.16	69.74	66.89	55-90
0.6	46.2	8.97	38.1	37.34	35.84	35-59
0.3	23.0	6.41	17.25	16.97	16.40	8-30
0.15	3.80	0.54	2.37	2.32	2.23	0-10



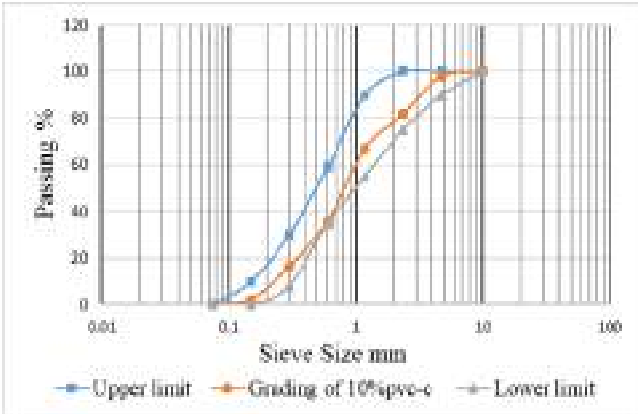
a) Sieve analysis of pvc-c



b) Sieve analysis of (2.5% pvc-c) of sand



c) Sieve analysis of (5% pvc-c) of sand



d) Sieve analysis of (10% pvc-c) of sand

Figure (3- 4) Grading curves of (PVC crushed) plastic as a partially replacement of sand

3.4.1.2 Polyvinyl Chloride sawdust (PVC-S)

The plastic wastes of PVC-sawdust are collected as by product of PVC sawdust pipe cutting in Misan plastic Factory as shown in Figure (3-5). PVC sawdust (PVC-S) is collected from Misan Plastic Factory. They are small dust pieces obtained from the process of producing pipes as by product.

a)Cutter of PVC pipes b)PVC dust waste in Misan plastic Factory

Figure (3- 5) Cutter of plastic pipes and (PVC-dust)

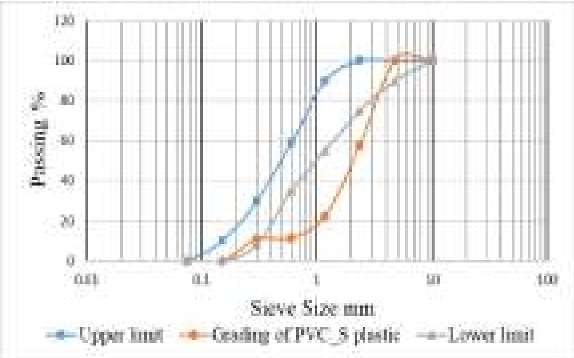
The sieve analysis of this material is shown in Table (3-9) with a maximum size of particles is 4.75 mm. This type of plastic is irregular in shape (non-spherical), or it may be in the form of flat straps with white color as shown in Figure (3-6).

Figure (3- 6) Sample of (PVC-S) plastic

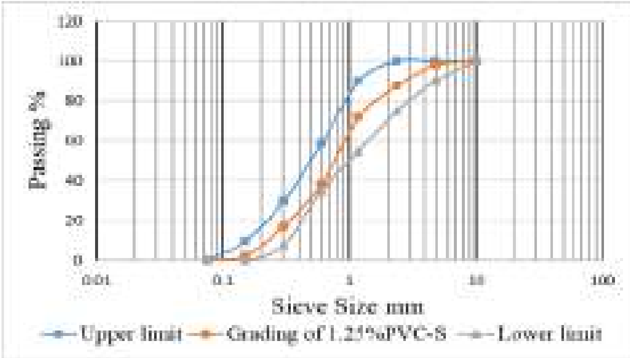
Table (3- 9) Sieve analysis of (PVC-S) Plastic

Sieve Size (mm)	Passing %					Limits of IQ.S % Passing (Zone II)
	100% Sand	100% PVC-S	98.75%Sand + 1.25%PVC-S	97.5%Sand + 2.5%PVC-S	95%Sand + 5%PVC-S	
10	100	100	100	100	100	100
4.75	96.3	100	97.96	97.98	98.03	90-100
2.36	86.2	57.54	87.57	87.19	86.43	75-100
1.18	68.8	22.51	71.96	71.34	70.09	55-90
0.6	46.2	11.37	38.50	38.16	37.47	35-59
0.3	23.0	10.67	17.44	17.35	17.18	8-30
0.15	3.80	0.00	2.39	2.36	2.29	0-10

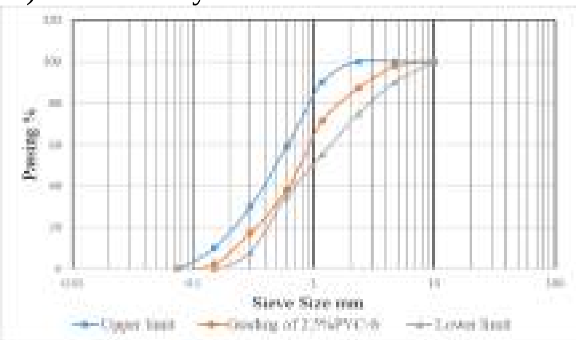
Figure (3-7) showed sieve analysis of different percentage of (PVC-sawdust) waste plastic. The sieve gradient of plastic granules of (PVC-S) alone does not meet the Iraqi specification of all the sieves as shown in Table (3-9) and Figure (3-7-a), but when using this material as a partial replacement of sand (1.25,2.5 and 5%) it is evident from Figure (3-7-b, c and d) that the gradient of the mixture corresponding to Iraq specifications No. 45/1984 of zone (II) [25].



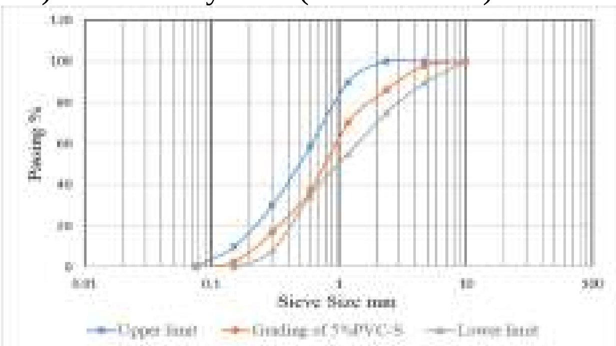
a) Sieve analysis of PVC-S



b) Sieve analysis of (1.25%PVC-S) of sand



c) Sieve analysis of (2.5% PVC-S) of sand



d) Sieve analysis of (5%pvc-s) of sand

Figure (3- 7) Grading curves of (PVC-S) plastic as a partially replacement of sand

3.4.1.3 Box Plastic Waste

The particles of crushed plastic boxes are produced by crushing the plastic boxes from the waste container in Misan province as shown in Figure (3-8). The maximum size of particles is 4.75 mm. This type is very irregular shape and it had many colors (red, green and yellow) as shown in Figure (3-9).

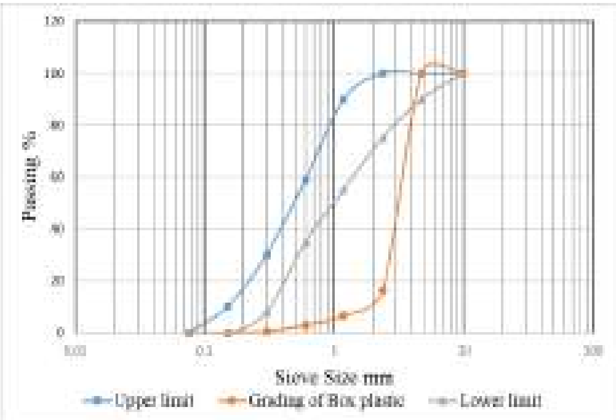
Figure (3- 8) Sample of box crushed plastic

a) Box before crushed

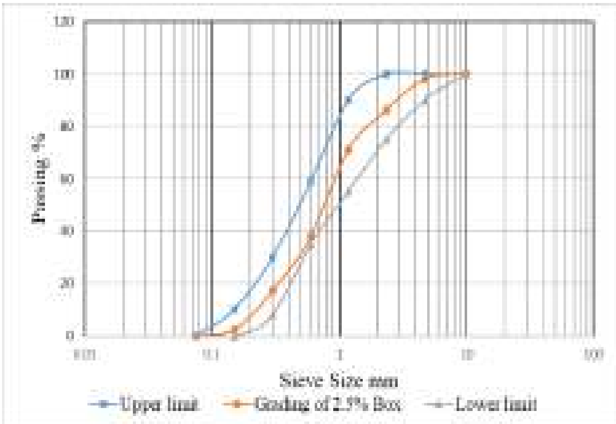
b) Box after crushed

Figure (3- 9) Box plastic before and after crushing

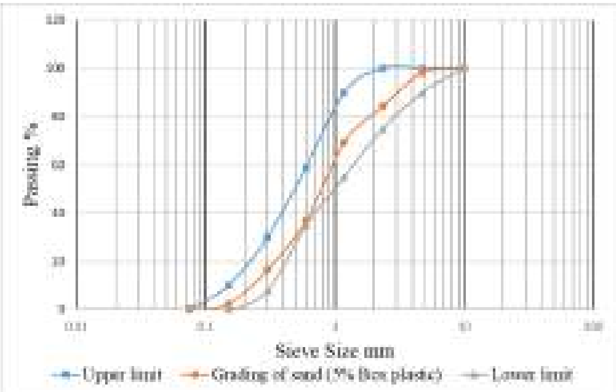
Figure (3-10) shows sieve analysis of different percentage of box plastic waste. the sieve gradient of plastic granules of (box plastic) alone does not meet the Iraqi specification of all the sieves as shown in Table (3-10) and Figure (3-10-a), while using this material as a partial replacement of sand (2.5%, 5% and 10%) it is clear from Figure (3-10-b, c and d) that the gradient of the mixture achieving Iraq specifications No. 45/1984 of zone (II) [25].



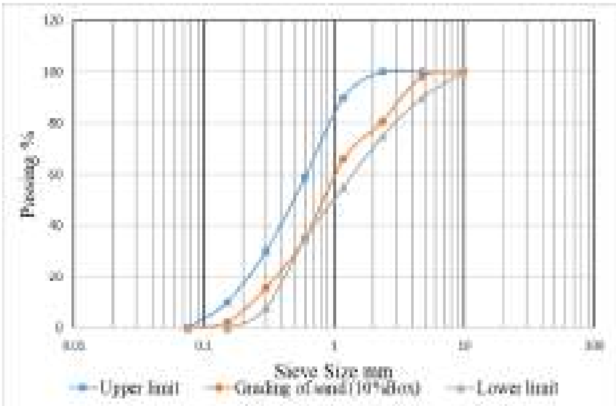
a) Sieve analysis of Box plastic



b) Sieve analysis of (2.5%Box) of sand



c) Sieve analysis of (5% Box) of sand



d) Sieve analysis of (10%Box) of sand

Figure (3- 10) Grading curves of box plastic as a partially replacement of sand

Table (3- 10) Sieve analysis of box plastic

Sieve Size (mm)	Passing %					Limits of IQ.S % Passing (Zone II)
	100% Sand	100% Box	97.5%Sand + 2.5%Box	95%Sand + 5%Box	90%Sand + 10%Box	
10	100	100	100	100	100	100
4.75	96.35	100	97.98	98.03	98.14	90-100
2.36	86.25	16.31	86.16	84.36	80.78	75-100
1.18	68.80	6.50	70.94	69.29	65.98	55-90
0.6	46.20	2.79	37.95	37.04	35.24	35-59
0.3	23.05	0.53	17.10	16.68	15.83	8-30
0.15	3.80	0.00	2.36	2.29	2.17	0-10

The plastic boxes wastes are cutting by a special machine manufactured for this purpose as shown in Figure (3-11). Machine has weight is equal to 600 kg, dimensions of (140 cm Length, 130 cm width, and 220 cm Height), and with a capacity up to 35 Hp motor. At the top there is a door opens to insert the box to be cut, where contain inside three sharp fans to cut the plastic boxes and the bottom is a filter with dimensions (80 ×60 cm) and openings can be changed to the required size through which pieces are extracted from the bottom.

a) Machine of crushed

b) Other side of machine

c) Sharp fans

d) filter

Figure (3- 11) Special machines to crash boxes

3.4.2 Dune Sand

Dune sand is obtained from western region of Misan province Butera desert. As shown in Figure (3-12). The grading of the dune sand is located within zone IV according to the classification of Iraqi Standards No. 45/1984 [25]. The dune sand grading does not meet with Iraq standard. The grading of dune sand used in this study is near the grading of Oman dune sand [6] as shown in Table (3-11).

a) Dune sand in nature

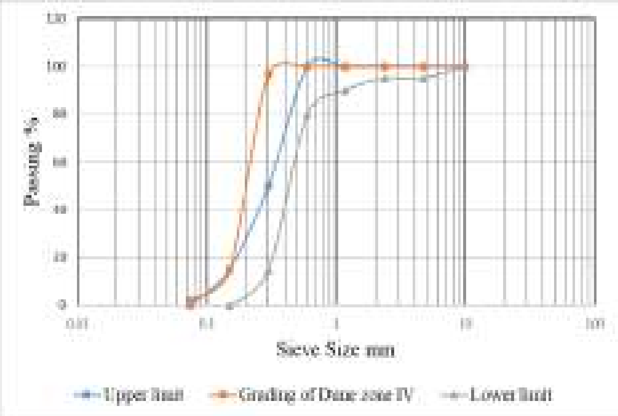
b) Sample of dune sand

Figure (3- 12) Dune sand in nature and sample of dune sand

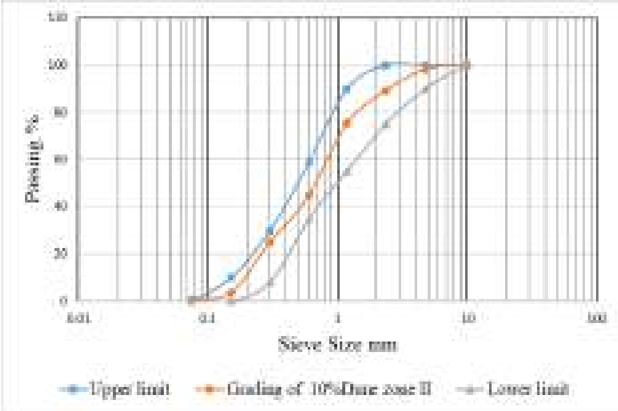
Table (3- 11) Sieve analysis of dune sand

Sieve Size (mm)	Passing %					Oman dune sand	Limits of IQ.S % Passing (Zone II)
	100% Sand	100% Dune	90%Sand + 10% Dune	75%Sand + 25% Dune	50%Sand + 50% Dune		
10	100	100	100	100	100	100	100
4.75	96.35	100	98.14	98.45	98.96	100	90-100
2.36	86.25	100.00	89.15	90.96	93.97	100	75-100
1.18	68.8	99.98	75.33	79.44	86.28	100	55-90
0.6	46.2	99.96	44.92	54.09	69.38	99.96	35-59
0.3	23.05	96.89	24.86	35.87	54.21	39.2	8-30
0.15	3.8	15.00	3.58	5.32	8.23	0.92	0-10

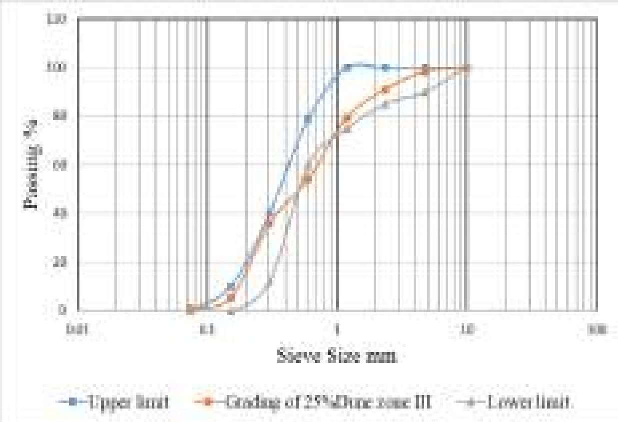
Figure (3-13) presents the sieve analysis of the dune sand with deferent percentage as sand replacement, the results indicate that it meets the limits for the fine aggregates gradations specified in standards at 10% replacement as shown in Figure (3-13-b) and its little deviate at (10%,25%and 50%) as shown in Figure (3-13-a, c and d).



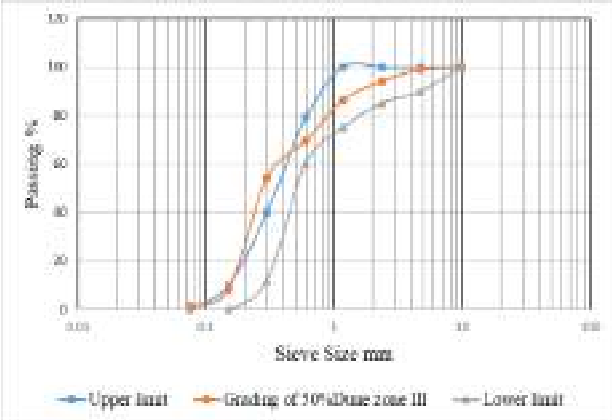
a) Sieve analysis of Dune (zone IV)



b) Sieve analysis of (10%Dune) of sand



c) Sieve analysis of (25% Dune) of sand



d) Sieve analysis of (50%Dune) of sand

Figure (3- 13) Grading curves of dune sand as a partially replacement of sand

3.4.3 Iron Filings

Iron filings are collected from the local workshops in Misan province. Figure (3-14) shows color and shape of iron filings sample. These granules are side product of iron manufacturing as shown in Figure (3-15).

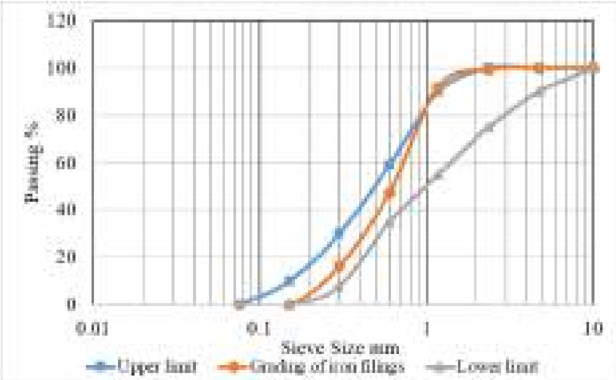
Figure (3- 14) Sample of iron fillings

Figure (3- 15) Iron fillings by product of iron cutter

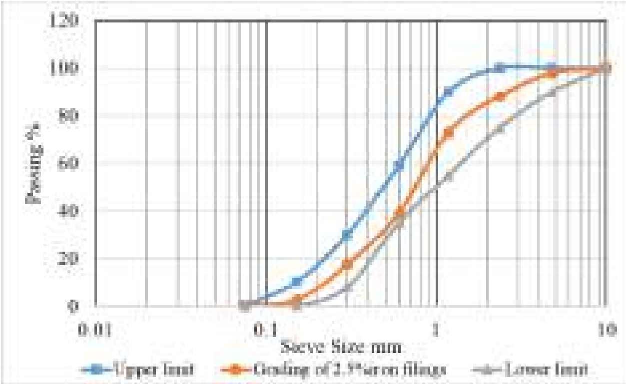
The grading located according to Iraqi Specifications No. 45/1980 Zone II. Iron fillings grading does not meet the Iraqi specification as shown in the Table (3-12) and Figure (3-16).

Table (3- 12) Sieve analysis of Iron sawdust

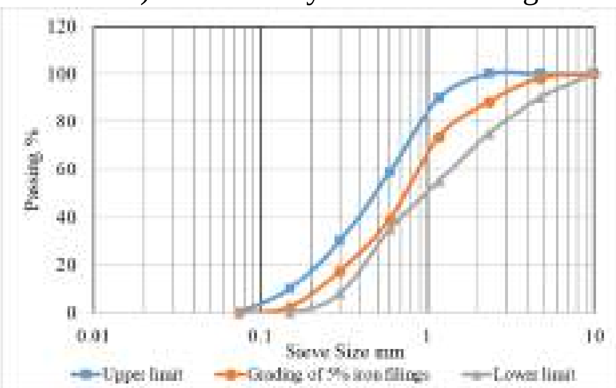
Sieve Size (mm)	Passing %					Limits of IQ.S % Passing (Zone II)
	100% Sand	100% Iron fillings	97.5%Sand + 2.5%Iron	95%Sand + 5%Iron	90%Sand + 10%Iron	
10	100	100	100	100	100	100
4.75	96.35	100	97.98	98.03	98.14	90-100
2.36	86.25	99.28	88.23	88.51	89.08	75-100
1.18	68.8	91.99	73.08	73.56	74.53	55-90
0.6	46.2	47.40	39.01	39.23	39.66	35-59
0.3	23.05	16.30	17.49	17.46	17.40	8-30
0.15	3.8	0.00	2.36	2.29	2.17	0-10



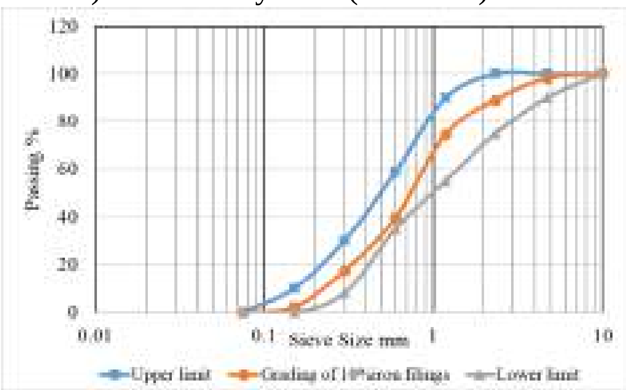
a) Sieve analysis of Iron filling



b) Sieve analysis of (2.5%Iron) of sand



c) Sieve analysis of (5% Iron) of sand



d) Sieve analysis of (10%Iron) of sand

Figure (3- 16) Grading curves of iron filings as a partially replacement of sand

3.5 Reference Concrete Mix

The initial concrete mix proportions are calculated according to ACI Committee 211.1-91 [27] then checked by trial batches. After adding the super plasticizer, the amount of water modified. The optimum admixture dose is obtained by increasing the dosage of the admixture gradually and adjusting the water cement ratio to obtain the same workability by using the slump test. The dosage of the admixture in the product ranged from 0.1% to 0.3%. The first trial mix started with a dosage 0.1% of cement weight, and the dose increased at steps of 0.1% of cement weight at each trial until optimum quantity is obtained which it is 0.3%. by weight of cement at 0.39 water cement ratio. The proportion of reference concrete mix is listed in Table (3-13)

Table (3- 13) Reference Concrete Mix Used

Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	(w/c) %	SP%
495	662	1008	0.39	0.3

3.6 Experimental Program Procedure

The experimental program included many mixtures to study the effect of presence of plastic waste, sand dunes and iron filings on concrete properties. Three different ratios are used for each waste material to study these ratios and thus compare with the reference mix. Since mixtures are used to fill the steel tubes of different sizes to investigate their effect on the behavior of the (CFST) column. Thus, the experimental work is divided into two main Phases.

1) Phase I: focused on the effect of added materials as partially sand replacement on the mechanical properties of concrete. 192 cubes with dimensions of (100×100×100) mm, 96 cylinders with dimensions of (100×200) mm, 96 prisms with dimensions of (100×100×500) mm, and16 cylinders with dimensions of (150×300) are casting for all percentage to calculate compressive, split tensile, flexural strengths, and modulus of elastic respectively.
2) Phase II: focused on the effect of supplementary waste materials as sand replacement on the structural behavior of (CFST) column specimens, 48 (CFST) columns with various mixes and sizes are casted, evaluated and compared with the reference’s columns.

3.7 Concrete Mixes with Sand Replacement

There are five types of mixtures with different materials as sand replacement namely, plastic boxes particles, PVC crushed, PVC sawdust, dune sand and iron filings. Accordingly, this section is divided into five parts, each part focused on one type of that materials, via mixture proportion and percentages that used in the mix.

Super plasticizer is added to all mixes with 0.8% and 0.3% by weight of cement since it is found that alternative materials like plastic and dune sand reduces the workability of the mix. Slump test is accomplished for each batch. The flowchart for different concrete mixtures is shown in Figure (3-17).

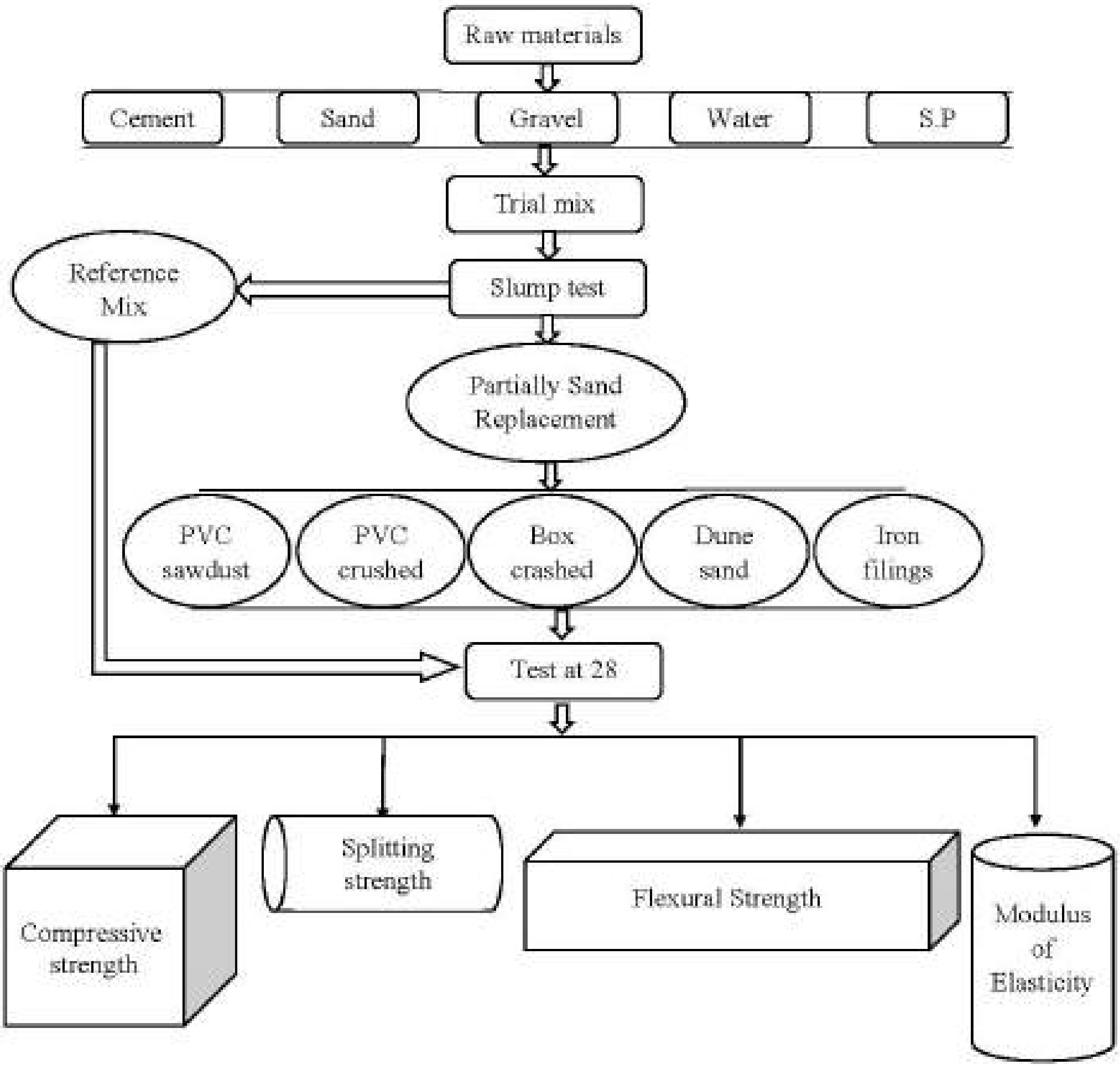


Figure (3- 17) Flowchart for the experimental work for the concrete mixes

3.7.1 Type I: Mixtures with Polyvinylchloride crushed (PVC-C)

Crushed PVC pipes (PVC-C) is obtained from Misan Plastic Factory in the center of the province. PVC-C waste is used immediately after passing the granules from sieve number 4, (4.75 mm), the maximum particle size obtained is 4.75 mm and used in concrete mixture with different proportions of sand replacement by weight. Three percentages of plastic waste are used in this study, they are 2.5%, 5% and 10%.

Table (3- 14) Concrete mixture proportion with PVC-C

Material (kg/m³) \ Replacement ratio	Non	2.5%	5%	10%
Cement	495	495	495	495
Gravel	1008	1008	1008	1008
Sand	662	645.45	628.9	595.8
PVC_C	-	16.55	33.1	66.2
Water	193.05	193.05	193.05	193.05
SP	1.485	1.485	1.485	1.485

3.7.2 Type II: Mixtures with Polyvinyl chloride dust (PVC-S)

PVC sawdust waste (PVC-S) is obtained from Misan Plastic Factory as side production of cutting the plastic pipe as a sawdust. PVC-S waste is used immediately after passing the granules from sieve number 4, (4.75 mm), the maximum particle size obtained is 4.75 mm and used in concrete mixture with different proportions of sand replacement by weight, which is used (w/c = 0.39) and shown in Table (3-15). Three different percentages 1.25%, 2.5%, and 5% of plastic waste are investigated in the study.

Table (3- 15) Concrete mixture proportion with PVC-S

Material (kg/m³) \ Replacement ratio	Non	1.25%	2.5%	5%
Cement	495	495	495	495
Gravel	1008	1008	1008	1008
Sand	662	653.72	645.45	628.9
PVC_S	-	8.275	16.55	33.1
Water	193.05	193.05	193.05	193.05
SP	3.96	3.96	3.96	3.96

3.7.3 Mixtures with Crushed Plastic Boxes

Plastic boxes are collected from waste containers in Misan province and used in the concrete mixture as a sand replacement by weight. Three percentages of plastic box waste are used in the present study, namely 2.5 %, 5 %, and 10 % with constant w/c of 0.39 as shown in Table (3-16). The waste is crushed by machine to get maximum size of 4.75 mm.

Table (3- 16) Concrete mixture proportion with boxes plastic

Material (kg/m^3) \ Replacement ratio	Non	2.5%	5%	10%
Cement	495	495	495	495
Gravel	1008	1008	1008	1008
Sand	662	645.45	628.9	595.8
Box plastic	-	16.55	33.1	66.2
Water	193.05	193.05	193.05	193.05
SP	1.485	1.485	1.485	1.485

3.7.4 Mixtures with Dune Sand

Dunes Sands are brought from the western area of Misan province. The model is collected from different areas of sand dune to obtain a complete sample. The sand dunes are mixed with the concrete mix with three percentages: 10%, 25% and 50% with w/c of 0.39 as shown in Table (3-17).

Table (3- 17) Concrete mixture proportion with Dune sand

Material (kg/m^3) \ Replacement ratio	Non	10 %	25%	50%
Cement	495	495	495	495
Gravel	1008	1008	1008	1008
Sand	662	595.8	496.5	331
Box plastic	-	66.2	165.5	331
Water	193.05	193.05	193.05	193.05
SP	1.485	1.485	1.485	1.485

3.7.5 Mixtures with Iron filings

Iron filings are bringing from the blacksmith workshops in Misan province.it are mixed with concrete as a replacement for sand and three proportions are 2.5%, 5% and10% are used as shown in Table (3-18).

Table (3- 18) Concrete mixture proportion with iron filling

Material (kg/m3) \ Replacement ratio	Non	2.5%	5%	10%
Cement	495	495	495	495
Gravel	1008	1008	1008	1008
Sand	662	645.45	628.9	595.8
Iron filing	-	16.55	33.1	66.2
Water	193.05	193.05	193.05	193.05
SP	1.485	1.485	1.485	1.485

3.8 Mixing and Casting Procedure

The mixture is batching in the structural laboratory of the Faculty of Engineering at the University of Misan according to the following steps:

1- Supply the basic materials of the concrete mixture and place in a suitable area, where the cement should store in a dry place to keep it away from moisture.
2- The coarse aggregates and fine aggregates are washed and spread on a mattress to reach a saturated surface dry condition (SSD).
3- Preparation of materials to be added as an alternative to sand is passed through sieve No. 4.
4- Weigh the dry material that generates the concrete mixture and substances for sand are placed in the mixer, weight of water used in mixing. Then weight of the plasticizer, add the water mixed with the plasticizer to the mixer gradually.
5- Concrete mix are casted in iron formwork; Cleaning molds from any casting residues, the molds are painted with oil coating to prevent adhesion between fresh concrete and mold. After concrete casting, it is compacted using rod according to type of mold. Leaving concrete in mold to 24 hours from casting day, then the molds are removed and samples are placed in a water basin for 7 and 28 days
6- After completing the casting and processing the forms let within water for 7 and 28 days, the samples are extracted and wiped with a piece of cloth for the purpose of cleaning them from the sediments and dirt that are formed as a result of being placed in the water basin and the result of the hydration process as well as cleaned with a cloth rag and then transferred to the concrete laboratory in the Faculty of Engineering.

3.9 Structural Members Column Specimens

Three type of (CFST) columns are used in this study to cover the behavior under different slenderness ratio namely, stub, short and slender columns. All specimens steel tube of square cross section with dimensions are shown in Table (3-19) and Figure (3-18). Stub column with height (300 mm), width of (B =150 mm) and sheet thickness (4 mm), while short column with height (400 mm), width

(B=100 mm) and plate thickness (3 mm) and finally long column with height (550 mm), width (80 mm) and plate thickness (3mm). All these columns are filled with three different proportions of sand replacement concrete.

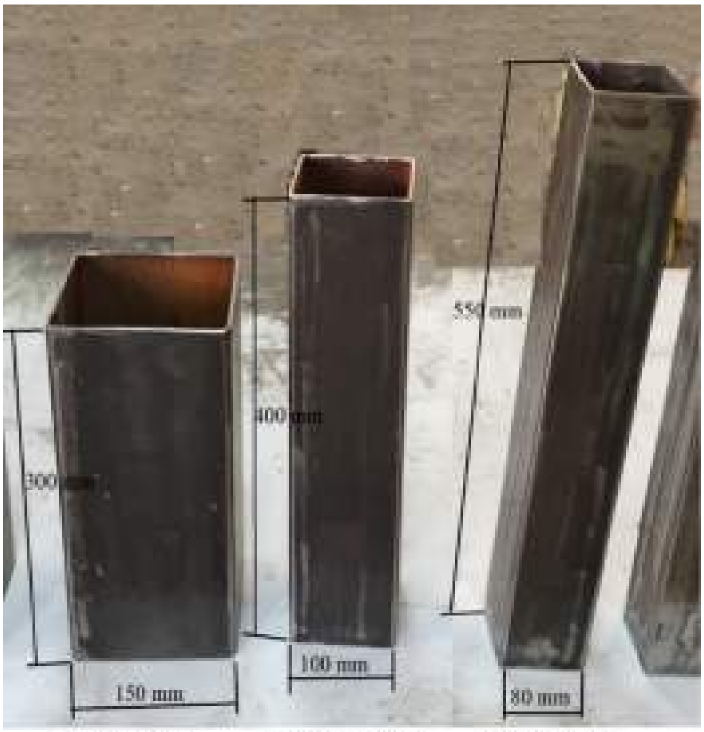
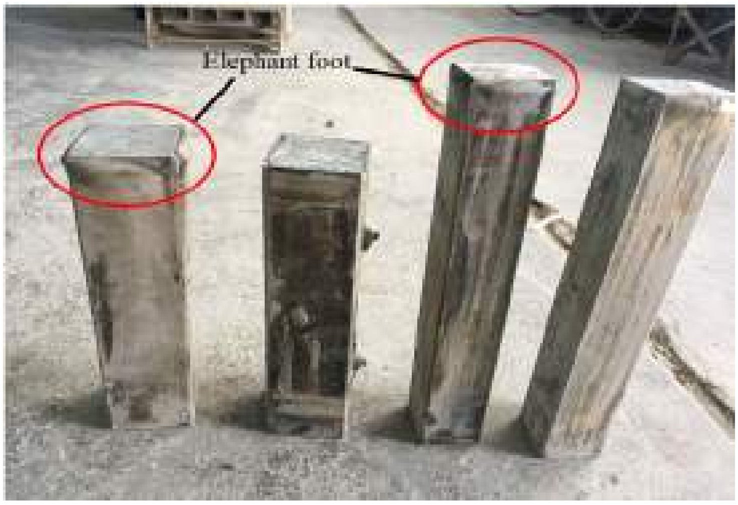


Figure (3- 18) dimensions of column specimens

Table (3- 19) The dimensions of the square specimens.

Type	B (mm)	t (mm)	L (mm)	L/r	L/B	B/t
stub column	150	4	300	-	2	37.50
	150	4	300	-	2	37.50
	150	4	300	-	2	37.50
short column	100	3	400	13.89	-	33.33
	100	3	400	13.89	-	33.33
	100	3	400	13.89	-	33.33
long column	80	3	550	23.87	-	26.67
	80	3	550	23.87	-	26.67
	80	3	550	23.87	-	26.67

During testing the trial specimens of short and slender CFST columns, the problem of “elephant foot failure” is faced at ends of column specimens as shown in Figure (3-19 a). This problem interested several researchers works of steel or composite steel columns [28]. To overcome the problem in the present work, a steel cap consists of a hat with thickness of 8 mm is used as shown in the Figure (3-19 b), hence the cap installed of both ends of column specimens.



a) Elephant foot failure

b) Cap

c) Mid span local failure

Figure (3- 19) Elephant failure problem and use cap

3.10 Testing of Steel

3.10.1 Coupons

The hollow steel tubes used in the present study have three different width (B) of 80, 100 and 150 mm, two different wall thicknesses (t) of 3 and 4 mm and three specimen lengths (L) of 300, 400, 550 mm. The tests samples are cut from 6.0m long square tubes. To obtain yield and ultimate stresses of steel columns a coupons sample are used. The sample preparation of the steel coupon and testing are carried out according to the ASTM A370 [29], where the tubes have been cut, opened and flattened into a steel plate. Then the coupons samples are extracted from this plate in the workshop. Figure (3-20) shows sample of coupon and testing machine.

Figure (3- 20) Coupon test

3.10.2 Empty steel tubes

After cutting the steel square tube column to the desired length, the edges of the specimen are arranged and two removable caps are placed at the bottom and top of the model. The dimensions of specimens are shown in Table (3-19). Figure (3-21) shows preparation hollow section column specimens.

Figure (3- 21) Preparation hollow section column specimens

3.11 Testing of Concrete Samples

3.11.1 Slump Test

Workability is one of the important characteristics of fresh concrete. It is said that the properties of fresh concrete are applicable when they have proper consistency, are treated without separation, are poured without loss of homogeneity and compacted with minimal effort. The slump test is performed for fresh concrete according to ASTM C143/C143M-15a [30]. It is considered as one of the most important method to determine the workability of fresh concrete.

3.11.2 Compressive Strength Test

The British standards BS1881: Part 16:1983 [31] is adopted to examine the compressive strength of concrete using cubic specimens (100×100×100) mm. This test is done by using a compression (ELE) machine with a capacity of (2000 kN) as shown in Fig. (3-22).

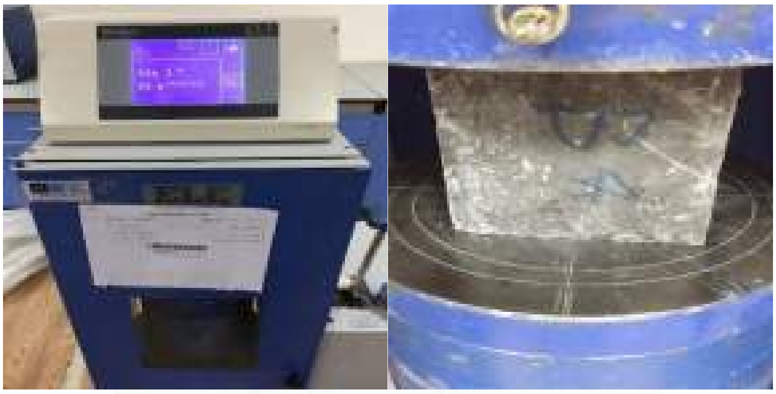


Figure (3- 22) Compressive strength test

3.11.3 Flexural Strength Test

The ASTM-C293-16 [32] is implemented to demonstrate the flexural strength of concrete using prism specimens (100×100×500) mm. This test carried out by using Flexural machine with a capacity of (50 kN) as shown in Figure. (3-23).

In the case of prisms with rectangular cross section the flexural strength (modulus of rupture) is computed by the following formula.

$$R = \frac{3PL}{2bd^2} \quad \text{.......Eq. (3- 1)}$$

Where:

R: modulus of rupture (MPa)

P: the maximum applied load (N)

L: length of span (mm)

b: average of the specimen width (mm)

d: average of specimen depth (mm) [32]

Figure (3- 23) Flexural strength test

3.11.4 Splitting Tensile Strength Test

ASTM C496-11 [33] is used to evaluate the splitting tensile strength of the concrete by applying compression load to the cylinder (100 mm dia. and 200 mm height) in a horizontal pattern as shown in Figure (3-24).

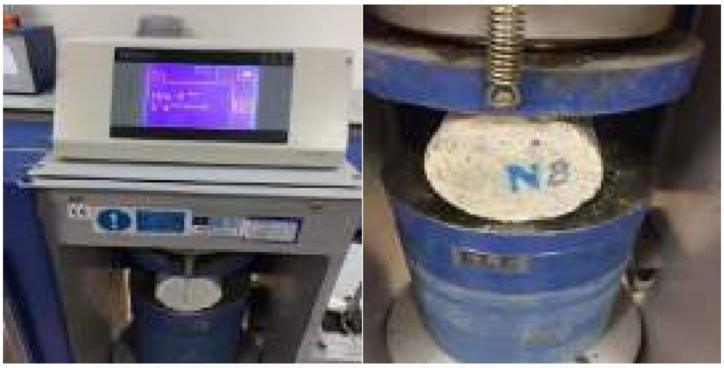


Figure (3- 24) Split tensile strength test

An average of three readings is recorded for each type of mixture. This test is used by the ELE machine with a capacity (2000 kN). Splitting tensile strength is calculated by Equation (3-2).

$$T = \frac{2P}{\pi l d} \quad \text{Eq. (3- 2)}$$

Where:

T= splitting tensile strength

P = applied load (N)

d = diameter of the specimens (mm)

l = specimen length (mm) [33]

3.11.5 Static Modulus of Elasticity

According to ASTM C469-14 [34] the modulus of elasticity is carried out. Cylinders specimens with dimensions 150×300 mm are utilized to determine static modulus. This test is achieved by compression machine capacity of 2000 kN by using the compressometer with gauge length is 150 mm and dial gauge of sensitiveness (0.01mm) as shown in Figure (3-25).

The elastic modulus is calculated from the slope of the straight line drawn from the original up to 0.4 f'c. Thus the modulus of elasticity is obtained according to following formula.

$$E = \frac{S_2 - S_1}{\varepsilon_2 - 0.000050} \quad \text{.......Eq. (3- 3)}$$

where

E = chord modulus of elasticity, MPa [psi],

s_2 = stress corresponding to 40 % of ultimate load,

s_1 = stress corresponding to a longitudinal strain, $\varepsilon_{2,}$ of 50 millionths, MPa[psi]

ε_2= longitudinal strain produced by stress S_2.

Figure (3- 25) Modulus of elasticity Measurement

3.12 Devices and Machines

3.12.1 Strain Gauges

Two types of strain gauges are used for the purpose of measuring the strain of the column models. One for steel surface columns, (CFST) and hollow columns, and the other is used for concrete columns.

a) strain gauge type I

This type of strain gauges has length of 5 mm and used on the outside of steel columns such as (CFST) columns and hollow columns are shown in Figure (3-26). The sizes and details of this type of strain gauges are shown in the Table (3 -20). Two strain gauges are fixed at the middle of the column height, vertical strain gauge, to measure the longitudinal strains and horizontal to measure the hoop strains.

Table (3- 20) Strain gauges type 1 characteristics

Type	Dimensions (mm)				Gauge factor (%)	Gauge resistance (Ω)
	Gauge		Backing			
	length	width	length	width		
QFLAB-5-11	5	2	10	3	2.12±1	120±0.5

Figure (3- 26) Strain gauge type I

b) strain gage type II

This type of strain gauge has length of 10 mm and used on the outside of concrete columns as shown in Figure (3-27). The size of this type is larger than the first type depending on the maximum aggregate size 10 mm, there for 10 mm strain gauge is used as detailed in Table (3-21).

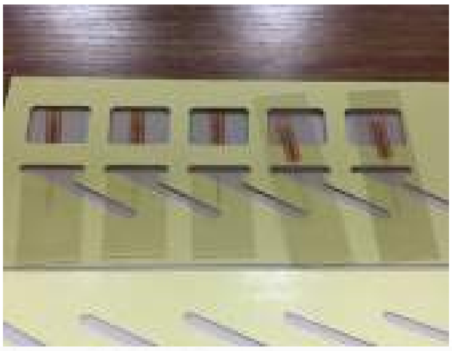


Figure (3- 27) Strain gauge type II

Table (3- 21) Strain gauge type2 details

Type	Dimensions (mm)				Gauge factor	Gauge resistance
	Gauge		Backing			
	length	width	length	width		
PFL-10-11	10	2	17	5	2.12±1	120±0.3

3.12.2 Data Acquisition (Strain Indicator)

Strain indicator Type (Wykeham Farrance) is used in the present study as shown in the Figure (3-28). It Consists of main device, channels' Hub to connect wires, laptop and UBS device to maintain stable voltage.

Figure (3- 28) Data logger

3.12.3 Calibration of strain gauges

To ensure identical results of strain gauges, calibration is done by using an iron plate with dimensions (300×28 ×3) mm and some weights for the purpose of calculating strain as shown in Figure (3-29) [35].

Figure (3- 29) Tool of calibration of strain gauges

$$\varepsilon = \frac{6pl}{Ebd^2} \qquad \text{Eq. (3- 4)}$$

Experimental strain is compared with strain of equation (3-4) [35]. Results of calculating strain and calibration factor is shown in Table (3-22) and Figure (3-30).

Table (3- 22) Calculation of calibration factor

Load gm	Reading	ΔR	Theoretical strain	factor of calibration	Micro strain
0	13940	0	0	-	0
255	14280	340	0.00009	3832824	0.00010
510	14540	600	0.00018	3381903	0.00018
765	14810	870	0.00027	3269173	0.00026
1020	15100	1160	0.00035	3269173	0.00034
1280	15420	1480	0.00045	3323777	0.00044
1780	16000	2060	0.00062	3326805	0.00061
2280	16540	2600	0.00079	3278073	0.00076
				3383104	

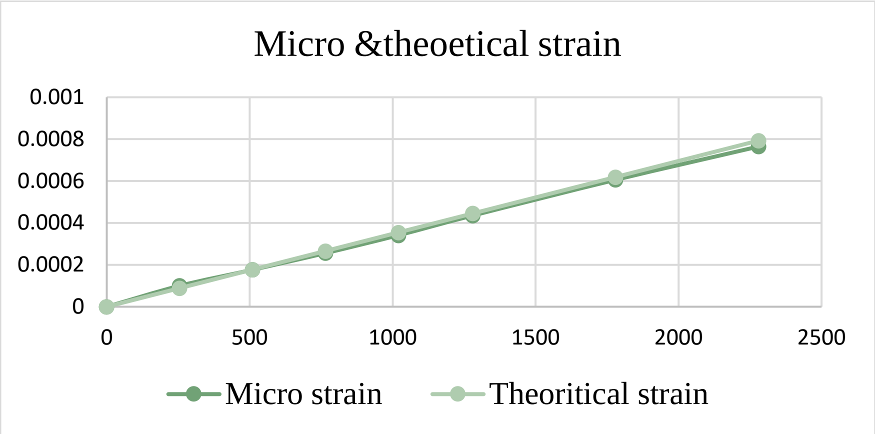


Figure (3- 30) Calibration of strain gauges

3.12.4 Dial Gauges

Three dial gauges of capacity 25 mm and accuracy of 0.001 is used in this work. The magnetic stands are used to the dial gauges in mount the test device, as shown in Figure (3-31).

Figure (3- 31) Dial gauges

3.12.5 Devices of Testing of Column Specimens

The columns are tested to prepared in two machines. There are divided into two groups, the first group is examined in a 100 tons' capacity machine, namely the long and short columns. The second group is stub columns (pedestal columns), which is tested in a 200 tons' capacity machine. Both groups are contained three types of columns are hollow columns, steel tube filled with concrete and concrete column only.

Three universal testing machines are used throughout the testing program. The first one is 200-ton compression testing machine ELE which is used for the testing of the stub (CFST, concrete columns and hollow steel tubes) specimens, second is 100-ton compression testing machine MARUI is used for testing of the short and long (CFST, concrete columns and hollow steel tubes) specimens, and the last one, universal testing machine Liya, is used for the coupon steel tests. All testing machines are shown in Figure (3-32).

a) ELE machine

b) MARUI machine

c) Liya machine

Figure (3- 32) Universal testing machines

3.13 Test Setup & Instrumentation

Two strain gauges are installed on the middle of the column as shown in Figure (3-33). After operating the machine, the upper plate is placed at a height that fits the height of the column, then start lowering the upper plate to touch the surface of the column cap, two dial gauges are installed on columns one at the middle of the column to measure the horizontal displacement and another installed on the column cap to measure the shortening, the preparing and install specimens are shown in Figures (3-33) to (3-36). The load is applied gradually in increments and the observation of the applied loads, displacements and failure mode are marked.

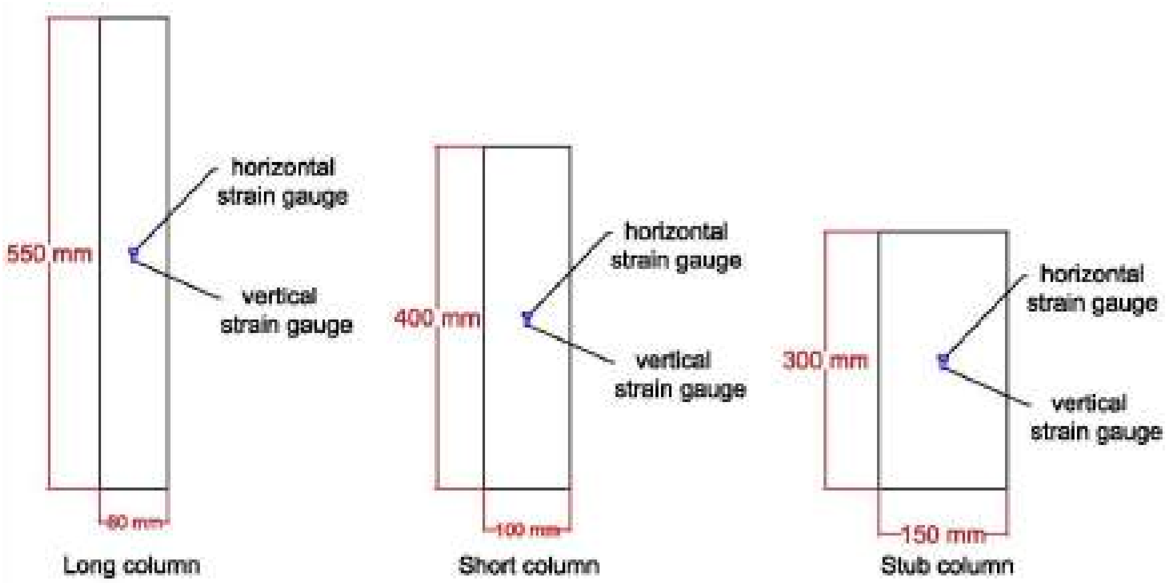


Figure (3- 33) Position of strain gauge on column specimens

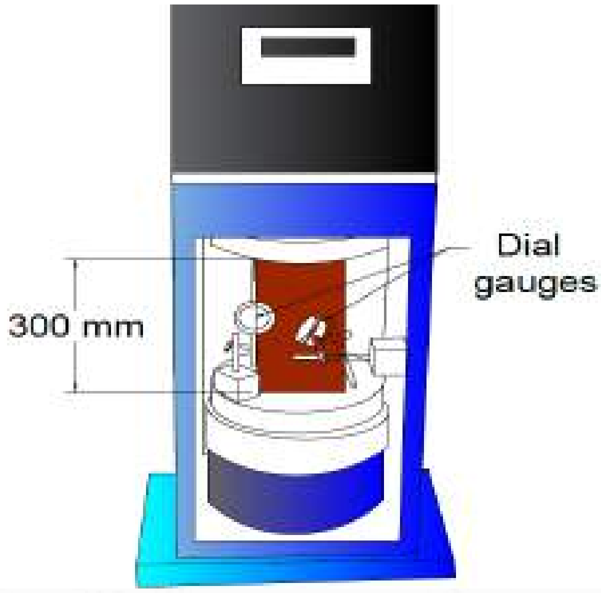


Figure (3- 34) Test arrangement of stub column

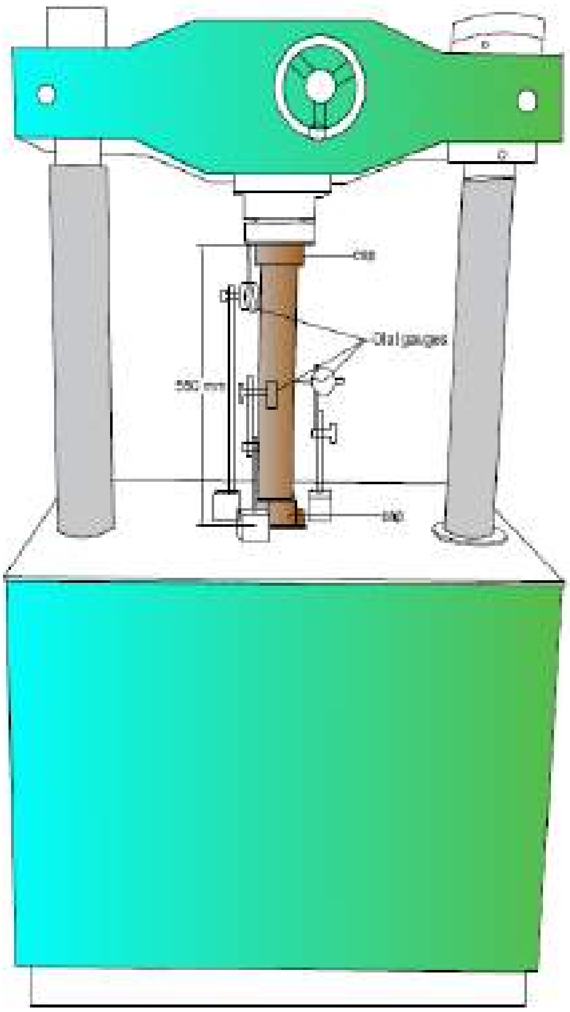


Figure (3- 35) Test arrangement of long column

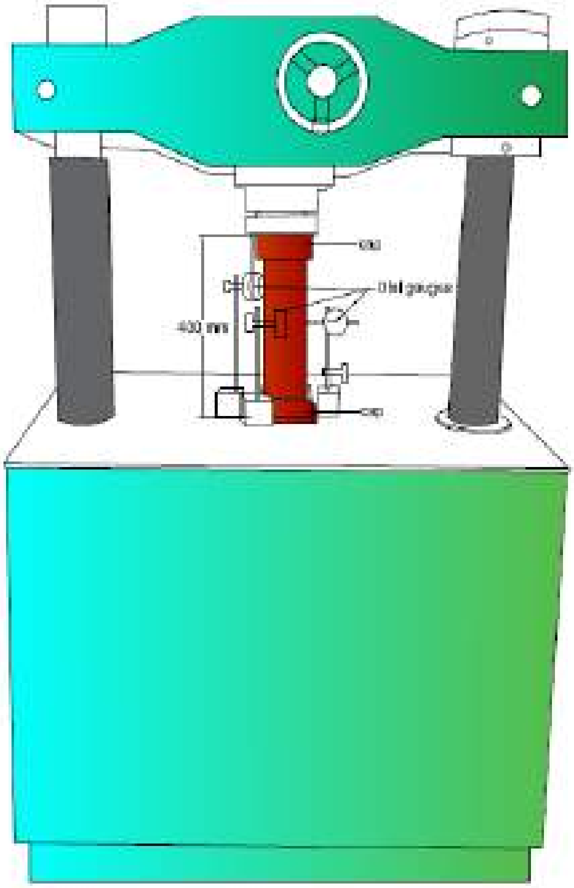


Figure (3- 36) Test arrangement short column

3.14 Concrete Filled Steel Tube Columns

After completing the casting and curing of the specimens with water for 28 days as shown in Figure (3-37), the samples are extracted and cleaned well from the residual and dirt that are formed as a result of being placed in the water basin and the result of the process of hydration. Strain gauges are attached to the steel section at the mid-height of the column to measure axial and hoop strains. The average axial shortening of the stub column is recorded by dial gage which is located on side of the bottom (moving) end-platens of the testing machine. The top of the short and long columns is capped to ensure a smooth and level and to prevent elephant failure in the two ends of column loading surface. Figure (3-38) shows the arrangement for the concrete-filled steel tubular column under an axial load.

a) Casting of (CFST) specimens

b) Curing of (CFST) specimens

c) After 28 days curing

d) Preparation for Test

Figure (3- 37) Casting and curing of (CFST) column specimens

a) Long (CFST) column

b) Short (CFST) column

c) Stub (CFST) column

Figure (3- 38) Install the (CFST) column specimens inside the machine

3.15 Non-Composite Column Specimens

3.15.1 Concrete column specimens

The concrete columns are also in the form of stub, short and long column by three samples of each type and are carried out the same steps of pouring models and removing molds after 24 hours then curing for 28 days in the water basin. The specimens are prospered to facilitate the process of sticking the strain gauge while softening the area of strain gauge installation. The samples are transferred to the concrete laboratory at the Technical Institute of Amara. The specimens are examined by two separate devices where the stub columns are examined in a test machine 2000 kN capacity is either columns with a height of 400 mm and a height of 550 mm are examined with a Machin 100 tons' capacity. the upper plate is placed at a height that fits the height of the column, then start lowering the upper plate to touch the surface of the column but the height between the plates is appropriate. In contact with the upper end of the column The dial gauge is installed and the gauge counter is zero set. The strain gauges' wires are also connected with the Data Logger. The dimensions of specimens are illustrated in Table (3-23). Figure (3-39) shows the arrangement for the concrete column specimens under an axial load.

Figure (3- 39) Install concrete column specimens inside the machine

Table (3- 23) Dimensions of the tested square concrete column specimens

No.	Specimen ID	Width (B) mm	High (h) mm
1	NORL30B15t0-1	150	300
2	NORL40B10t0-1	100	400
3	NORL55B8t0-1	80	550

3.15.2 Hollow steel

The hollow column specimens are classified of stub, short and long column by three samples of each type. The strain on the surface of specimens are measured. The dimensions of specimens are shown in Table (3-24). Figure (3-40) shows the arrangement for the hollow steel tubular column under an axial load.

Figure (3- 40) Arrangement hollow section column specimens

Table (3- 24) Dimensions of hollow square section specimens

No.	Specimen ID	Width (B) mm	Thickness (t) mm	High (h) mm
1	HOLL30B15t4-1	150	4	300
2	HOLL40B10t3-1	100	3	400
3	HOLL55B8t3-1	80	3	550

3.16 Test Variables

A square steel tubes filled by concrete mixtures with partially sand replacement with five materials (PVC wastes, plastic boxes waste, dune sand and iron filings) are tested under axial compressive loading to investigate the effect of these materials on (CFST) columns behavior. In present study the test variables in addition to concrete mixes included the following.

1- Steel tube width to thickness ratio (D/t), where three ratios of 37.5, 33.3 and 26.7 are considered.

2- Slenderness ratios, three slenderness ratios are considered:

   – Kl/r less than 22 to ensure that columns specimens behave as short column, namely column height = 400 mm.

   – Kl/r more than 22 for column not braced against side sway [36] to ensure that column specimens behave as long columns, namely column height =550 mm.

   – Very short column height of two times the column width to ensure that columns specimens behave as stub column, namely column height =300 mm.

The using of these three ranges of column height (stub, short and long) are to cover as possible failure modes of columns namely shear failure, compressive failure, local buckling or global buckling.

The specimens are labelled according to their dimensions and concrete infill according to the code XLBt-z.

Where

X: IRN for iron filings sand replacement.

: DNS for dune sand replacement of sand.

: PVC for PVC crushed sand replacement.

: PVS for PVC sawdust sand replacement.

: BXC for plastic Boxes waste sand replacement.

L: Length or height of columns in cm, either 30,40 or 55 cm.

B: Width of square cross section in mm, j either 80,100 or 150 mm.

t: Wall thickness of steel tube in mm, k either 3 or 4 mm.

z: 0 control mix, 1,2 or 3 represent the dosage number of each material as sand replacement, for example for plastic boxes waste 1,2 and 3 represent 2.5%,5% and 10% replacement ratio respectively. The test variables for all specimens are listed in Table (3-25).

Table (3- 25) Dimensions and properties of (CFST) specimens

No.	Specimen ID	Width (B) mm	Thickness (t) mm	High (h) mm	Sand replacement%	Replacement material
1	CTRL30B15t4-0	150	4	300	0	-
2	CTRL40B10t3-0	100	3	400	0	-
3	CTRL55B8t3-0	80	3	550	0	-
4	DNSL30B15t4-1	150	4	300	10	Dune sand
5	DNSL30B15t4-2	150	4	300	25	Dune sand
6	DNSL30B15t4-3	150	4	300	50	Dune sand
7	DNSL40B10t3-1	100	3	400	10	Dune sand
8	DNSL40B10t3-2	100	3	400	25	Dune sand
9	DNSL40B10t3-3	100	3	400	50	Dune sand
10	DNSL55B8t3-1	80	3	550	10	Dune sand
11	DNSL55B8t3-2	80	3	550	25	Dune sand
12	DNSL55B8t3-3	80	3	550	50	Dune sand
13	PVCL30B15t4-1	150	4	300	2.5	PVC crushed
14	PVCL30B15t4-2	150	4	300	5	PVC crushed
15	PVCL30B15t4-3	150	4	300	10	PVC crushed
16	PVCL40B10t3-1	100	3	400	2.5	PVC crushed
17	PVCL40B10t3-2	100	3	400	5	PVC crushed
18	PVCL40B10t3-3	100	3	400	10	PVC crushed
19	PVCL55B8t3-1	80	3	550	2.5	PVC crushed
20	PVCL55B8t3-2	80	3	550	5	PVC crushed
21	PVCL55B8t3-3	80	3	550	10	PVC crushed
22	PVSL30B15t4-1	150	4	300	1.25	PVC sawdust
23	PVSL30B15t4-2	150	4	300	2.5	PVC sawdust
24	PVSL30B15t4-3	150	4	300	5	PVC sawdust
25	PVSL40B10t3-1	100	3	400	1.25	PVC sawdust
26	PVSL40B10t3-2	100	3	400	2.5	PVC sawdust
27	PVSL40B10t3-3	100	3	400	5	PVC sawdust
28	PVSL55B8t3-1	80	3	550	1.25	PVC sawdust
29	PVSL55B8t3-2	80	3	550	2.5	PVC sawdust
30	PVSL55B8t3-3	80	3	550	5	PVC sawdust
31	IRNL30B15t4-1	150	4	300	2.5	Iron filling
32	IRNL30B15t4-2	150	4	300	5	Iron filling
33	IRNL30B15t4-3	150	4	300	10	Iron filling
34	IRNL40B10t3-1	100	3	400	2.5	Iron filling
35	IRNL40B10t3-2	100	3	400	5	Iron filling
36	IRNL40B10t3-3	100	3	400	10	Iron filling

37	IRNL55B8t3-1	80	3	550	2.5	Iron filling
38	IRNL55B8t3-2	80	3	550	5	Iron filling
39	IRNL55B8t3-3	80	3	550	10	Iron filling
40	BXCL30B15t4-1	150	4	300	2.5	Box crushed
41	BXCL30B15t4-2	150	4	300	5	Box crushed
42	BXCL30B15t4-3	150	4	300	10	Box crushed
43	BXCL40B10t3-1	100	3	400	2.5	Box crushed
44	BXCL40B10t3-2	100	3	400	5	Box crushed
45	BXCL40B10t3-3	100	3	400	10	Box crushed
46	BXCL55B8t3-1	80	3	550	2.5	Box crushed
47	BXCL55B8t3-2	80	3	550	5	Box crushed
48	BXCL55B8t3-3	80	3	550	10	Box crushed

CHAPTER FOUR

Results and Discussions

CHAPTER FOUR

Results and Discussions

4.1 General

Generally, this chapter presents the results of concrete mechanical properties for different materials as sand replacement. In addition, the test results for various types of column specimen is presented, i.e., stub, short and long columns, as well as, plain concrete columns and hollow iron columns, to investigate the behavior of (CFST) columns for different materials partially replaced the sand.

Firstly, this chapter focused on the evaluation the effect of PVC sawdust, PVC crushed waste, dune sand, iron filings and plastic boxes wastes as partially sand replacement on the concrete properties, then the behavior of CFST columns of different concrete mixtures are investigated.

For CFST column investigations the main topics discussed in the present chapter include : theoretical results compared to experimental results of column specimen; the effect of some parameters on the behavior of CFST columns such as the ratio of D / t and L / D .The comparison of the control column specimen with other specimen of sand replacement are accomplished via toughness or energy absorption; ductility index; stiffness; mode of failure; load capacity; maximum deflection and area under stress-strain curve or strain energy.

Results of Concrete Mixtures Tests

The results of concrete mixtures tests illustrated the mechanical properties of concrete with partially replacement of sand using dune sand; PVC crushed; PVC sawdust; iron filings and crushed box plastic, in terms of workability, compression strength, flexural strength and tensile splitting strength.

4.2.1 Fresh Concrete

4.2.1.1 Slump of mixtures

According to BS EN 206: 2013 [37], workability is classified in 5categories of S1, S2, S3, S4 and S5. Slump ranges are:

- S1: 10-40 mm
- S2: 50-90 mm
- S3: 100-150 mm
- S4: 160-210 mm
- S5: $\geq$ 210 mm [37]

The mixtures are prepared for different proportions of sand replacement; slump test is taken immediately after mixing process to ensure that mixes meet workability requirements with (w/c= 0.39). Slump cone test is adopted for each mix that contains different replacement ratio of sand.

The results showed that workability decreased as the percentage of sand replacement increased except for iron filings in which the workability are increased with increasing the percentage of sand replacement with iron filings as shown in Table (4-1) and Figure (4-1). Thus, the iron filings showed uncommon and desired effect on the concrete properties by increasing the concrete workability.

The reduction of workability with increase the percentage of sand replacement with waste materials are agree with conclusions of many researchers. Batayneh et al. [38] showed the slump of concrete mix included 20% ground plastic as sand replacement is reduced by 25%. Figure (4-1) showed that the plastic boxes as sand replacement has negligible effect on concrete workability. Similarly, Crushed PVC waste had considerable effect on concrete workability at high percentage of sand replacement namely larger than 5% slump reduction of 33%, while had negligible effect for percentage less than 5% with reduction of slump is 2%. The decreasing in slump when using PVCC related to shape of plastic which is usually sharp edge and irregular that means increase the surface area of particles.

The two materials that had large effect on concrete workability are iron filings and PVC sawdust waste as shown in Figure (4-1), where PVC sawdust waste sharply reduced the concrete workability by about 44% at low percentage of 1.25%, this due to its relatively small size, shape and texture that absorb the water from the concrete mix.

On the other hand, the iron filings improve the concrete workability by about 22%,50% and 67% as the percentage of sand replacement increased from 2.5%,5% and 10% respectively. This positive effect of iron filings on concrete workability is not rare compared to recycled concrete types.

The increased workability of the concrete mixture when using iron filings instead of sand indicates that it is not absorbed water, in addition to the surface of iron filings granules reduces friction and increases the slip of the granules in the concrete mixture.

Table (4- 1) Results of slump tests with partially sand replacement.

Material type	Replacement percentage (%)	Slump Test (mm)	Workability range	different in Slump (%)
control	-	90	S2	-
Dune sand	10	80	S2	-11
	25	60	S2	-33
	50	25	S1	-72
PVC crushed	2.5	88	S2	-2
	5	80	S2	-11
	10	60	S2	-33
PVC sawdust	1.25	50	S2	-44
	2.5	25	S1	-72
	5	0	S1	-100
Iron Filling	2.5	110	S3	+22
	5	135	S3	+50
	10	150	S3	+67
Box plastic	2.5	85	S2	-6
	5	80	S2	-11
	10	75	S2	-17

(+) increase
(-) decrease

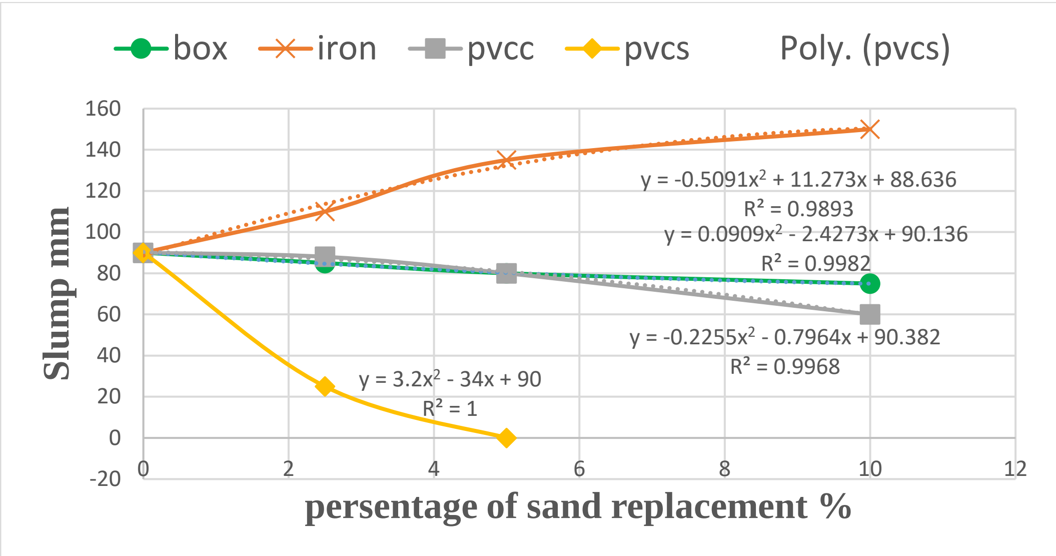


Figure (4- 1) Results of slump tests for replacement materials

The using of dune sand as partially sand replacement more than 10% have negative effect on concrete workability as shown in Figure (4-2), in which at percentage of 50% the workability is very difficult. The reason for the difficulty of workability when using dune sand is due to the increase in the surface area of the dune sand grain fine particles, which requires more water

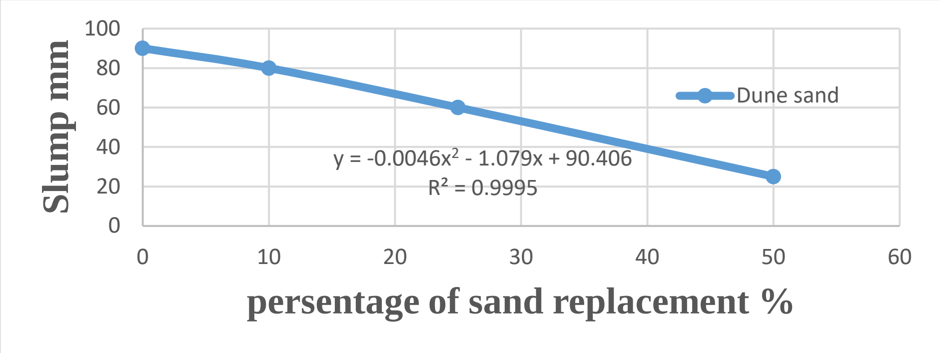


Figure (4- 2) Results of slump tests for dune sand

4.2.2 Hardened Concrete

4.2.2.1 Compressive Strength

The results of compressive strength of cubes 100×100×100 for concrete mixtures with partial replacement of sand are shown in Table (4-2). The sand has been partially replaced by wasted materials and each material has been replaced in several proportions. The results showed the following.

Table (4- 2) Results of compressive strength tests of all replacement materials.

Material type	Replacement percentage (%)	compressive strength f_{cu} (MPa)		different in compressive (%)		7/28 Ratio
		7 days	28 days	7 days	28 days	
control	-	30.13	44.65	0	-	0.67
Dune sand	10	38.17	47.27	+27	+6	0.81
	25	41.87	55.73	+39	+25	0.75
	50	25.15	46.33	-17	+4	0.54
PVC crushed	2.5	38.73	55.80	+29	+25	0.69
	5	35.90	50.10	+19	+12	0.72
	10	32.23	52.43	+7	+17	0.61
PVC sawdust	1.25	46.90	41.53	+56	-7	1.13
	2.5	36.97	44.10	+23	-1	0.84
	5	27.70	35.47	-8	-21	0.78
Iron Filling	2.5	38.93	49.53	+29	+11	0.79
	5	39.03	52.30	+30	+17	0.75
	10	48.83	55.63	+62	+25	0.88
Box plastic	2.5	35.60	44.17	+18	-1	0.81
	5	43.97	52.27	+46	+17	0.84
	10	29.87	33.23	-1	-26	0.90

Dune sand: It is observed from Table (4-2) and Figure (4-3), that all samples which contain dune sand with substitute 10% ,25% and 50 % show an increase in 28-days compressive strength by about 6%,25% and 4% respectively and specimens which contain dune sand with dosages 10% to 25 % show an increase in 7-days compressive strength by about 27% and 39% respectively. However, there is a decrease in compressive strength by about 17% at 7-day test for 50% of dune sand. The mix that contains on 25% of dune sand as sand replacement is the best percentage which gave a compressive strength of 55.73 MPa (25% greater than control mix)

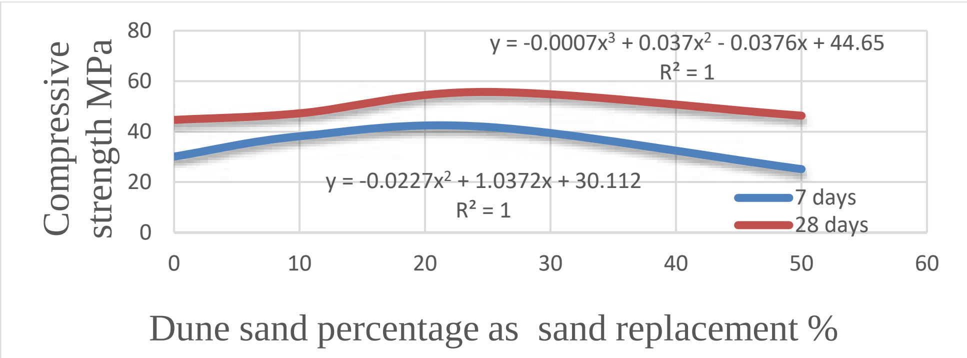


Figure (4- 3) Result of compressive test for dune sand

PVC crushed: Table (4-2) and Figure (4-4) illustrated, that all samples which contain PVC-C particles with dosages 2.5% ,5 % and 10% showed an increase in compressive strength by about 25%,12% and 17% respectively for 28 days and showed increase 29%,19% and 7% for 7days respectively. An Increasing of compressive strength of mix contain PVC crushed related to shape of particle which is usually sharp edge and irregular that means increase the interlock of mix proportions, as well as manufacture of pipes of PVC crushed under high pressure and thus the granules that result from these pipes have good compressive strength.

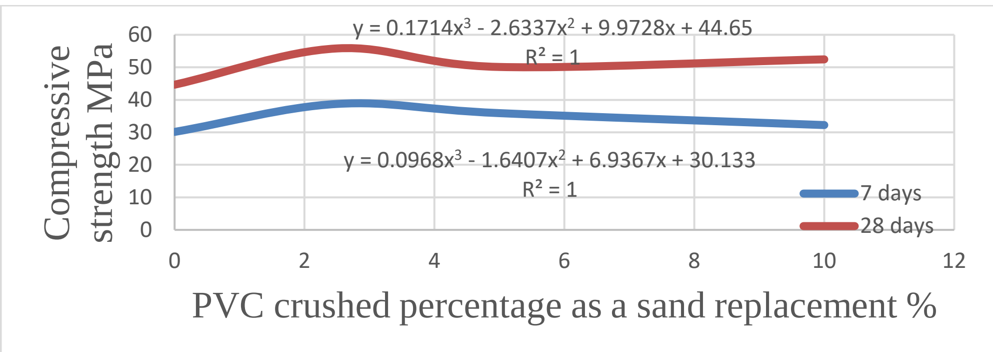


Figure (4- 4) Result of compressive test for (PVCC)

PVC sawdust: From Table (4-2) and Figure (4-5), its clearly that all samples which contain PVC sawdust (PVCS) with dosages ranged from1.25% to 5 % show a decrease in compressive strength by about 7%,1%, and 27% for 28-day test.As a result, the compressive strength decreases with the increase of PVCS content compared to the reference mixture of all mixes for both 7 and 28 days. Except at mix contain 1.25% and 2.5% are good early compressive strength in 7 days' age 46.9 MPa and 36.97 MPa respectively namely larger than control mix by 56% and 23%. Thus the PVC sawdust with dosage of 1.25% presented higher early compressive strength and acceptable 28 days' compressive strength with environmentally benefit by waste recycled

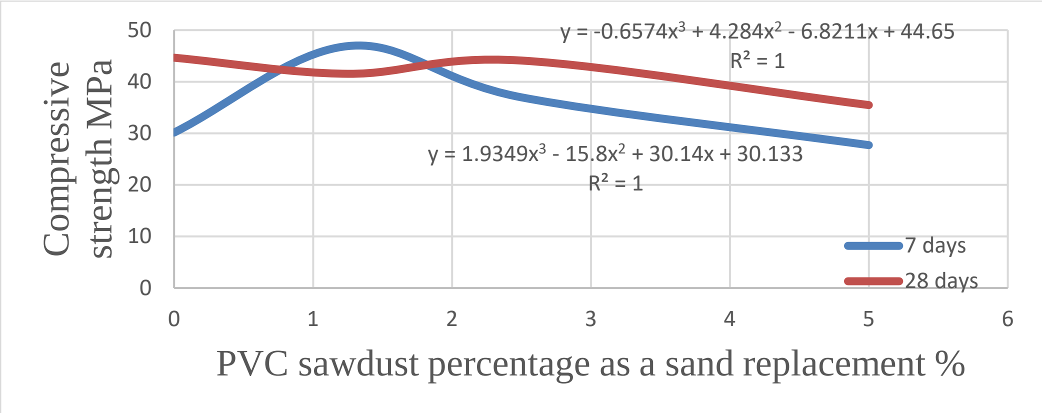


Figure (4- 5) Result of compressive test for (PVCS)

Iron filings: The addition of iron filings to concrete mixtures as substitution of sand showed a remarkable increase in compressive strength as shown in Table (4-2) and Figure (4-6). for 7 and 28-day test.

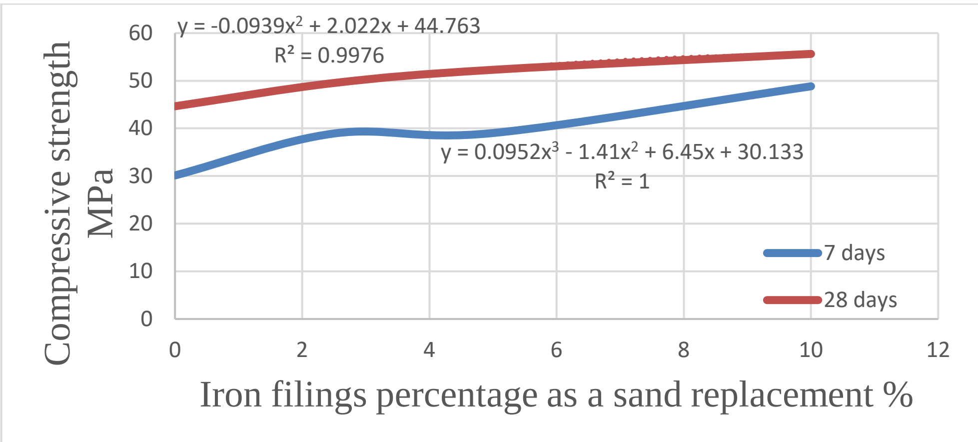


Figure (4- 6) Result of compressive test for iron filings

The compressive strength increased at the percentage of iron filings increased for 2.5% to 10%. The compressive strength in 7 days' age for percentages 2.5%,5% and

10% are 38.93 MPa,39.03MPa and 48.83MPa that means the compressive strength larger than control mix by 29%, 30% and 62% respectively.

Plastic boxes waste: The effect of plastic boxes waste particles on concrete compressive strength is shown in Table (4-2) and Figure (4-7). It is observed that the samples contain box plastic waste particle with ratio of 5% showed an increase in compressive strength in 28 days' age 52.27 MPa namely more than reference mix by about 17%, but dosages 2.5% and 10% of plastic box particles gave less compressive strength than reference by about 1% and 26% respectively. While good early compressive strength is observed in 7 days' age of 35.6 MPa and 43.97 MPa respectively, namely larger than control mix by 18% and 46%. Thus the plastic boxes waste with dosage of 2.5% presented higher early compressive strength and acceptable 28 days' compressive strength with environmentally benefit by waste recycled.

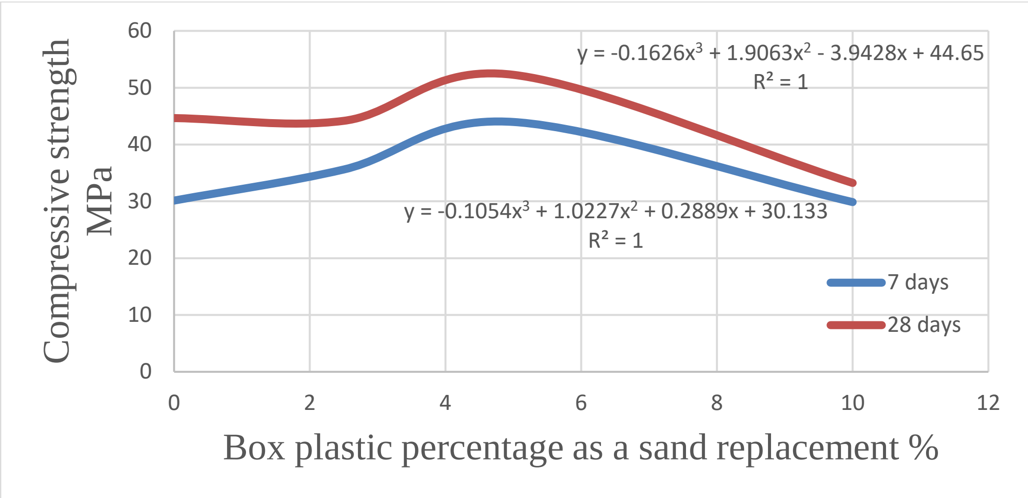


Figure (4- 7) Result of compressive test for Box plastic

4.2.2.2 Failure Modes Compressive Strength

The failure mode of all cubes that contain different types of materials as sand replacement showed that cubes are not crushed suddenly as for reference mix, and after failure, the cubes are not fractured as pieces but kept its shape with surface cracks, this shows the ductility provided by the presence of plastic waste. Figure (4-8) showed the failure mode of cubes with different Percentage of sand replacement. Figure (4-9) showed results of compressive strength at 28 days' age tests of all replacement materials.

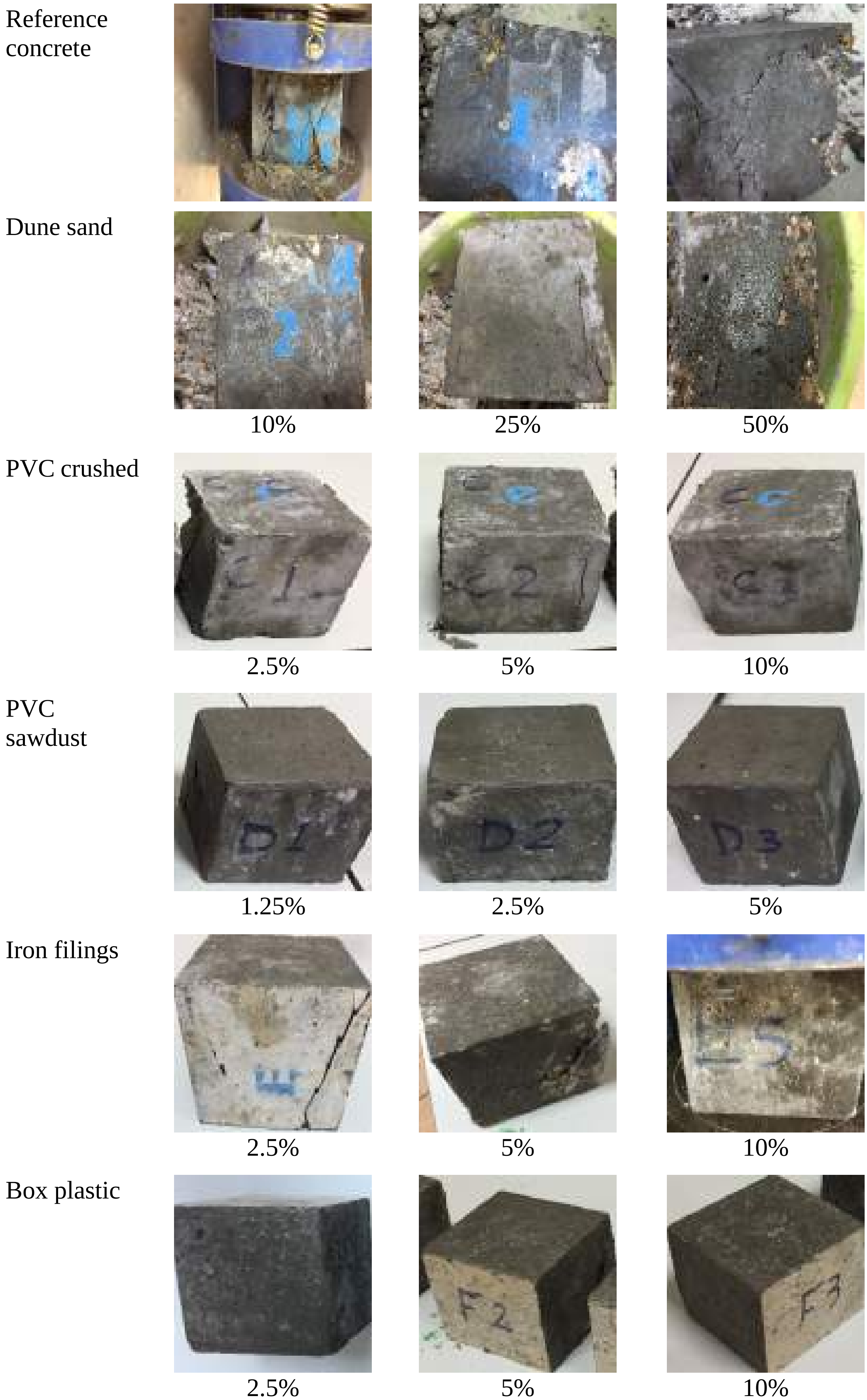


Figure (4- 8) Failure modes of concrete cubes with different Percentage of sand replacement

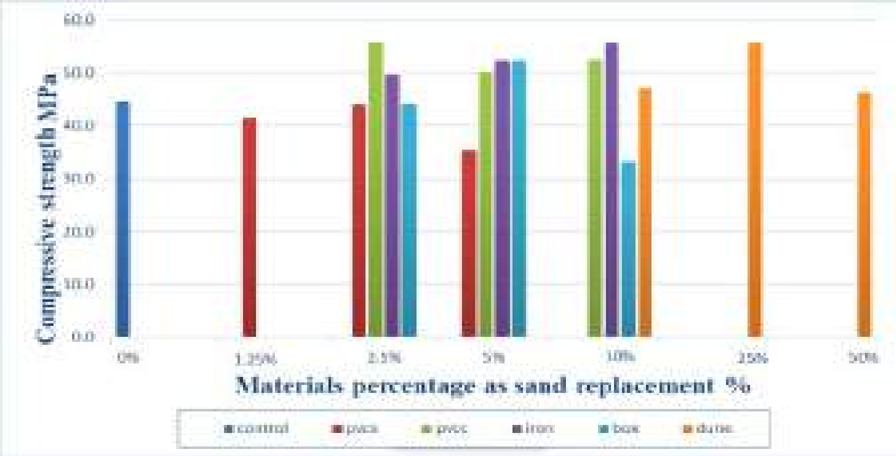


Figure (4- 9) Compressive strength at 28 days age tests of all replacement materials.

4.2.2.3 Splitting Tensile Strength

The results of splitting tensile test showed acceptable values when using alternative materials for sand as evident in Table (4-3), so the decrease is not more than 10% at 2.5% Box plastic as a sand replacement, while the higher increment splitting tensile strength of 22% is recorded for 5% partially replacement by iron filings.

$$f_{st} = 0.56\sqrt{f'c}$$ ....Eq. (4- 1)

The splitting tensile strength is computed according to Equation (3-2) [33] and tensile strength equation of ACI 318-14 Equation (4-2) [39]. The results are shown in Table (4-3), with an average value of 3MPa, as following

Table (4- 3) Results of Splitting tensile strength tests at 28 days age of all replacement.

Material type	**Replacement percentage (%)**	**Experimental Splitting tensile strength T (MPa)**	**change in splitting (%)**	**Splitting tensile strength f_{st} (MPa) ACI - eq (4-2)** [39]	**Experimental / ACI cod Eq ratio T/ f_{st}**
Control	-	2.77	-	3.3	0.83
Dune sand	10	2.90	+5	3.4	0.84
	25	3.00	+8	3.7	0.80
	50	3.30	+19	3.4	0.97
PVC crushed	2.5	2.70	-2	3.7	0.72
	5	3.90	+41	3.5	1.10
	10	2.93	+6	3.6	0.81
PVC sawdust	1.25	2.87	+4	3.2	0.89
	2.5	3.27	+18	3.3	0.98
	5	2.73	-1	3.0	0.92
Iron Filling	2.5	2.63	-5	3.5	0.75
	5	3.37	+22	3.6	0.93
	10	3.07	+11	3.7	0.82
Box plastic	2.5	2.50	-10	3.3	0.75
	5	2.90	+5	3.6	0.80
	10	2.63	-5	2.9	0.91

Dune sand: dune sand showed increasing of splitting tensile strength for all dosages 10%,25%,50% by about 5%,8% and 19% respectively, Figure (4-10) showed increasing of splitting tensile strength with increasing of dune sand as a partially sand replacement and the best increment is at 50% of dune sand of 3.3 MPa.

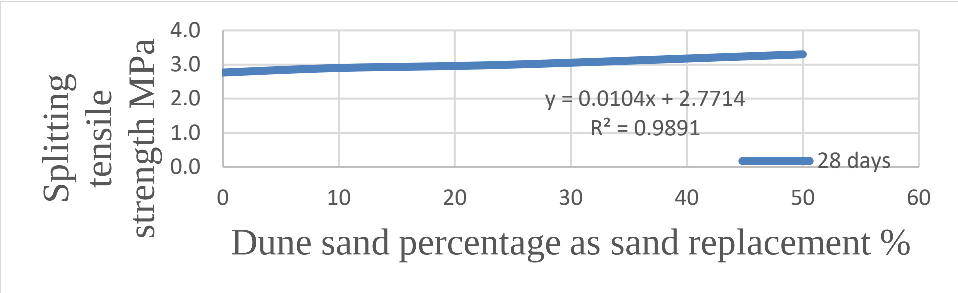


Figure (4- 10) Result of splitting tensile test for dune sand

PVC crushed: It is evident from Table (4-3) and Figure (4-11), that the samples with PVC crushed particles of dosages of 5% and 10 % showed an increase in splitting tensile strength by about 41% and 6% respectively, while the dosage of 2.5% showed a decreasing in splitting tensile strength by 2% compared to control mix. The mix that contains on 5% of PVCC particles as replacement of sand is the optimum percentage which gave a splitting tensile strength of 3.9 MPa.

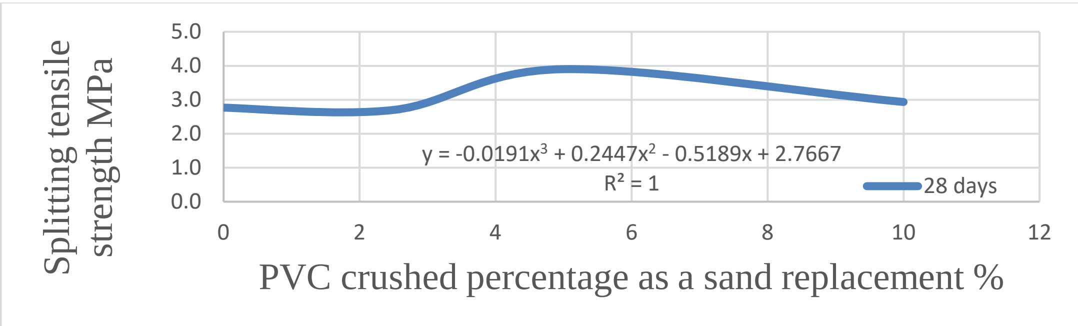


Figure (4- 11) Result of splitting tensile test for PVC crushed

PVC sawdust: From Table (4-3) and Figure (4-12), the samples that contain PVC sawdust with dosages 1.25% and 2.5 % showed an increasing in splitting tensile strength for 28-day test by 4% and 18% respectively.

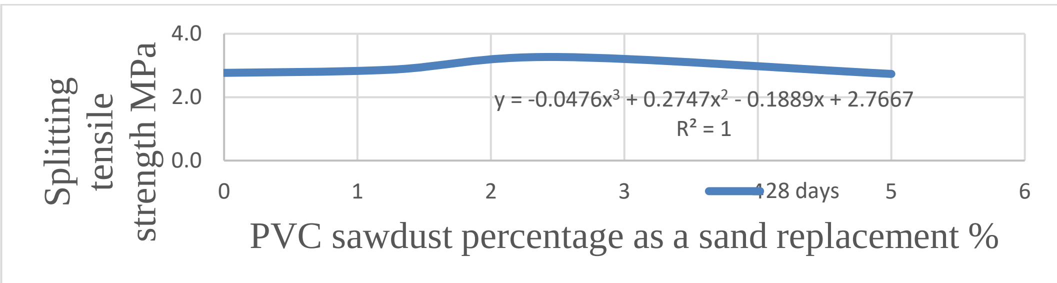


Figure (4- 12) Result of splitting tensile test for PVC sawdust

While the dosage of 5% showed a splitting tensile strength of 2.73 MPa closed to control mix. The mix that contains on 2.5% of PVC sawdust as replacement of sand is the optimum percentage which gave a splitting tensile strength of 3.27MPa.

Iron filings: Using the iron filling as sand replacement showed an increasing in splitting tensile strength at 5% and 10% replacement of iron filings by about 22% and 11% respectively. The replacement of 2.5% showed reduction in splitting tensile strength by 5% compared control mix.

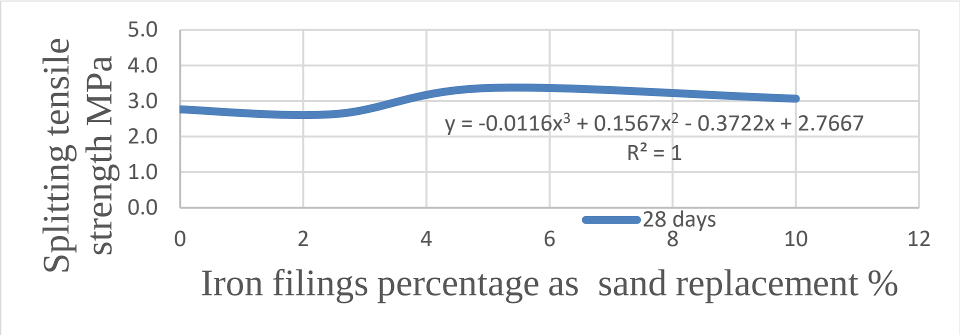


Figure (4- 13) Result of splitting tensile test for iron filings

Plastic boxes waste: The effect of plastic boxes particles on concrete splitting tensile strength is shown in Table (4-3) and Figure (4-14). It is observed that the samples contain box plastic waste particle showed a decrease in splitting tensile strength for replacement 2.5% and 10% by 10% and 5% respectively. The higher splitting tensile strength is obtained at dosage 5% of 2.9 MPa which greater than control mix by 5%.

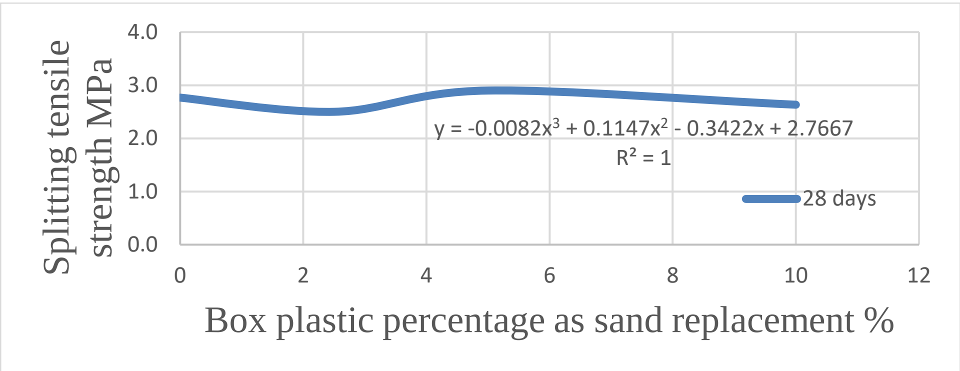


Figure (4- 14) Result of splitting tensile test for plastic box plastic waste.

4.2.2.4 Failure Modes of Splitting Tensile Strength

The concrete cylinder failure mode of the control mixture is suddenly crushed and completely divided into two parts, while there is no complete separation of fracture in the cylindrical samples that contain materials wastes as sand replacement, but there are cracking development and spreading on the sample surface as shown in Figure (4-15).

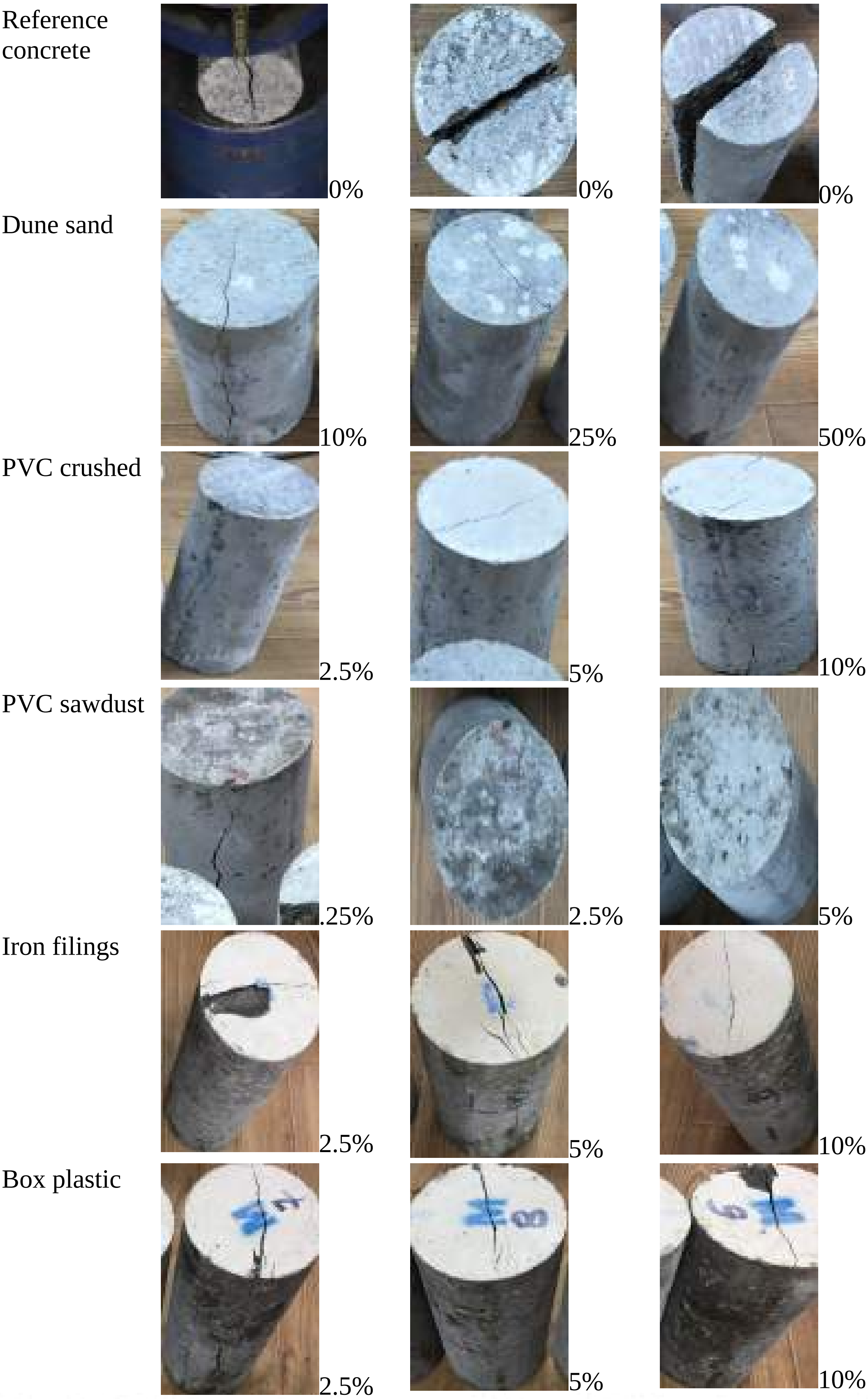


Figure (4- 15) Failure modes of concrete cylinders with different Percentage of sand replacement

However, indicate that ductility provided by materials wastes for concrete? Figure (4-16) showed Splitting tensile strength at 28 days' age tests of all replacement materials.

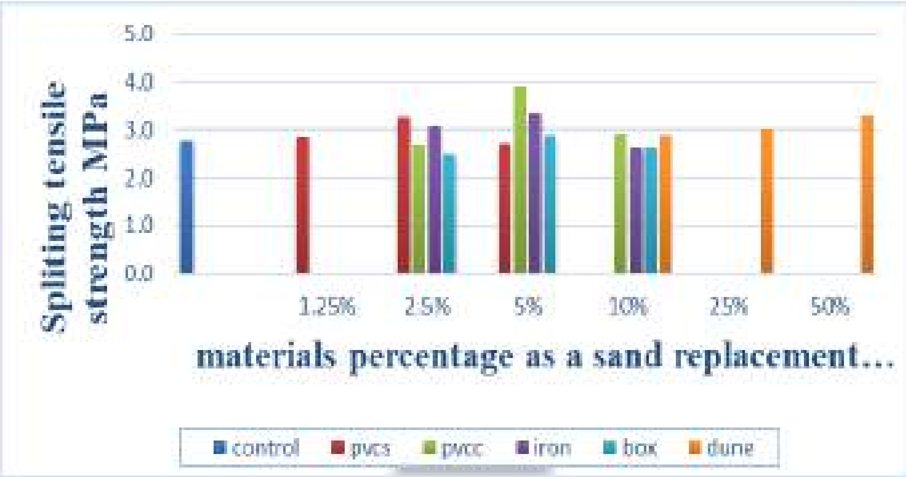


Figure (4- 16) Splitting tensile strength at 28 days age tests of all replacement materials.

4.2.2.5 Flexural Strength

The flexural strength is computed according to Equation (3-1) [32] and flexural strength equation of ACI 318-19 Equation (4-2) [36].

$$f_r = 0.62\sqrt{f'c} \quad \text{.......Eq. (4- 2)}$$

The results of flexural strength concrete mixes with partially replacement of sand are listed in Table (4-4) and Figures (4-17) to (4-21) and discussed below.

Table (4- 4) Results of Flexural strength tests of all replacement materials.

Material type	**Replacement percentage (%)**	**Experimental Flexural strength R (MPa)**	**change in Flexural R (%)**	**Flexural strength f_r (MPa) ACI 318 code- eq (4-4)** [39]	**Experimental / ACI cod Eq ratio R / f_r**
control	-	6.90	0	3.7	1.86
Dune sand	10	7.33	+6	3.8	1.92
	25	7.81	+13	4.1	1.89
	50	7.15	+4	3.8	1.89
PVC crushed	2.5	6.93	+0.4	4.1	1.67
	5	7.75	+12	3.9	1.97
	10	7.27	+5	4.0	1.81
PVC sawdust	1.25	6.76	-2	3.6	1.89
	2.5	6.14	-11	3.7	1.67
	5	5.42	-22	3.3	1.64
Iron Filling	2.5	7.02	+2	3.9	1.80
	5	7.65	+11	4.0	1.91
	10	7.13	+3	4.1	1.72
Box plastic	2.5	6.79	-2	3.7	1.84
	5	7.20	+4	4.0	1.80
	10	3.42	-50	3.2	1.60

Dune sand: It is observed from Table (4-4) and Figure (4-17), that all samples which contain dune sand with dosages 10% ,25% and 50 % showed an increase in 28 days' flexural strength by about 6%,13% and 4% respectively. The mix that contains on 25% of dune sand as sand replacement is the optimum percentage which gave a flexural strength of 7.81MPa.

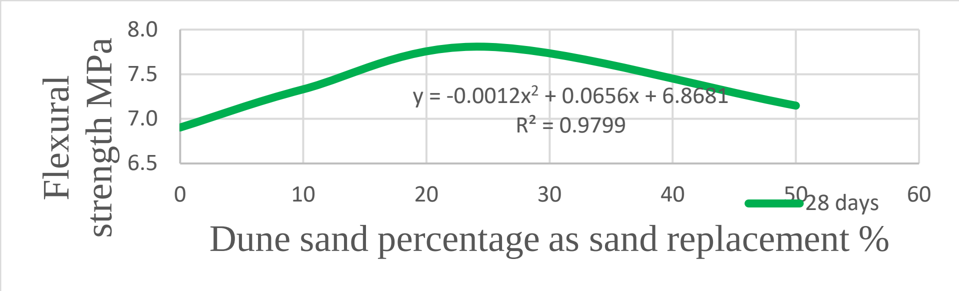


Figure (4- 17) Result of flexural strength test for dune sand

PVC crushed: It is evident from Table (4-4) and Figure (4-18), that the samples with PVCC particles dosages of 5% and 10 % showed an increase in splitting tensile strength by about 12% and 5% respectively. The optimum flexural strength is at 5% of PVCC of 7.75 MPa, while the dosage of 2.5% showed a flexural strength of 6.93 MPa closed to control mix (0.4% more than control mix).

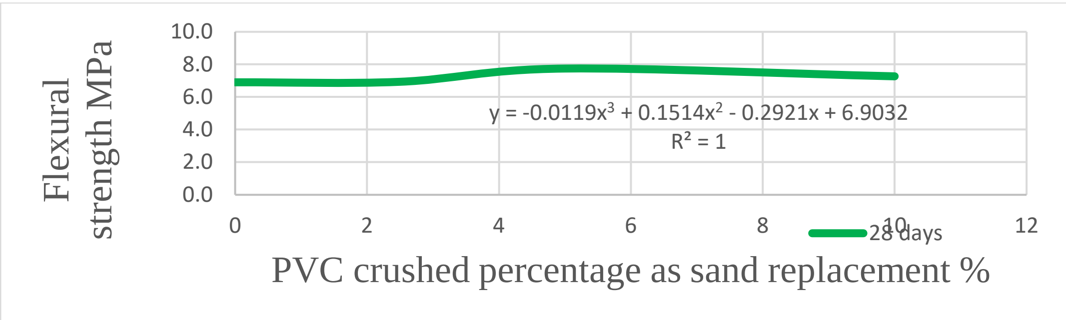


Figure (4- 18) Result of flexural strength test for (PVC crushed)

PVC sawdust: From Table (4-4) and Figure (4-19), it is evident that all samples which contain PVC sawdust (PVCS) with dosages ranged from1.25% to 5 % showed a reduction in 28-days flexural strength by about 2%,11%, and 22% respectively.

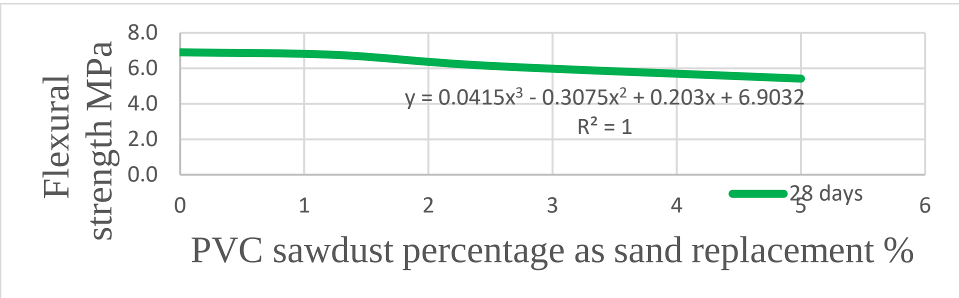


Figure (4- 19) Result of flexural strength test for (PVC sawdust)

Iron filings: The addition of iron filings to concrete mixtures showed a remarkable increase in 28-days flexural strength as shown in Table (4-4) and Figure (4-20). Using an iron filling showed increasing in flexural strength from 2.5% to 10% dosages of iron filings by about 2%,11% and 3% respectively. The dosage of 5% of iron filings gives optimum flexural strength of 7.65MPa.

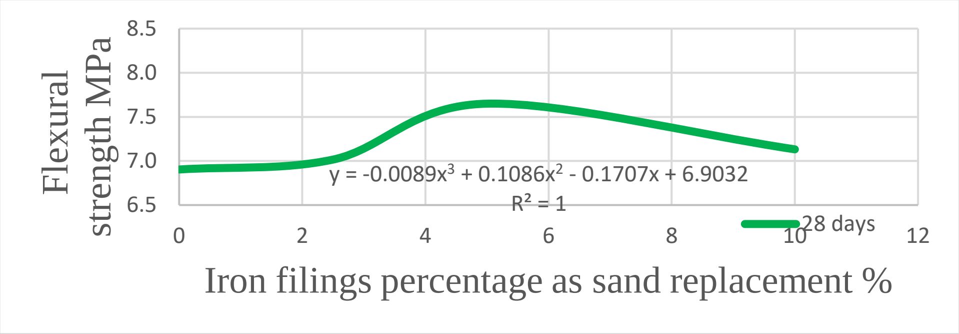


Figure (4- 20) Result of flexural strength test for iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on concrete flexural strength is shown in Table (4-4) and Figure (4-21). It is observed that the samples contain box plastic waste particle with dosage of 5% showed an increase in 28-days flexural strength of 7.2 MPa namely more than reference mix by about 4%, but dosages 2.5% and 10% of plastic box particles gave less flexural strength than reference by about 2% and 26% respectively.

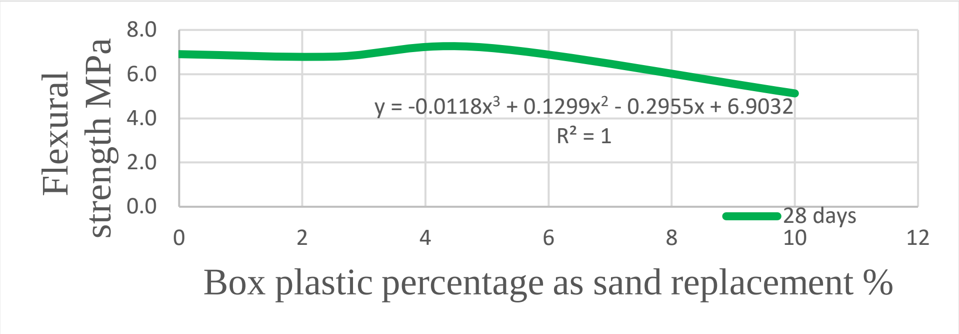


Figure (4- 21) Result of flexural strength test for plastic boxes waste

4.2.2.6 Failure Modes of Flexural Strength

The failure modes of prisms are shown in Figure (4-22), in which for reference samples the flexural failure led to complete fracture of the samples and divided it into two separate pieces. For samples contained PVC sawdust although the samples are failed there is no movement in fracture path and the samples still appear as one unit. This is a very important impact of waste on flexural behavior of member, due to they reduce the development and spreading of cracks. While other samples that contain dune sand, PVC crushed, iron filings and plastic boxes waste divided it into two separate pieces. Figure (4-23) showed flexural strength at 28 days' age tests of all replacement materials.

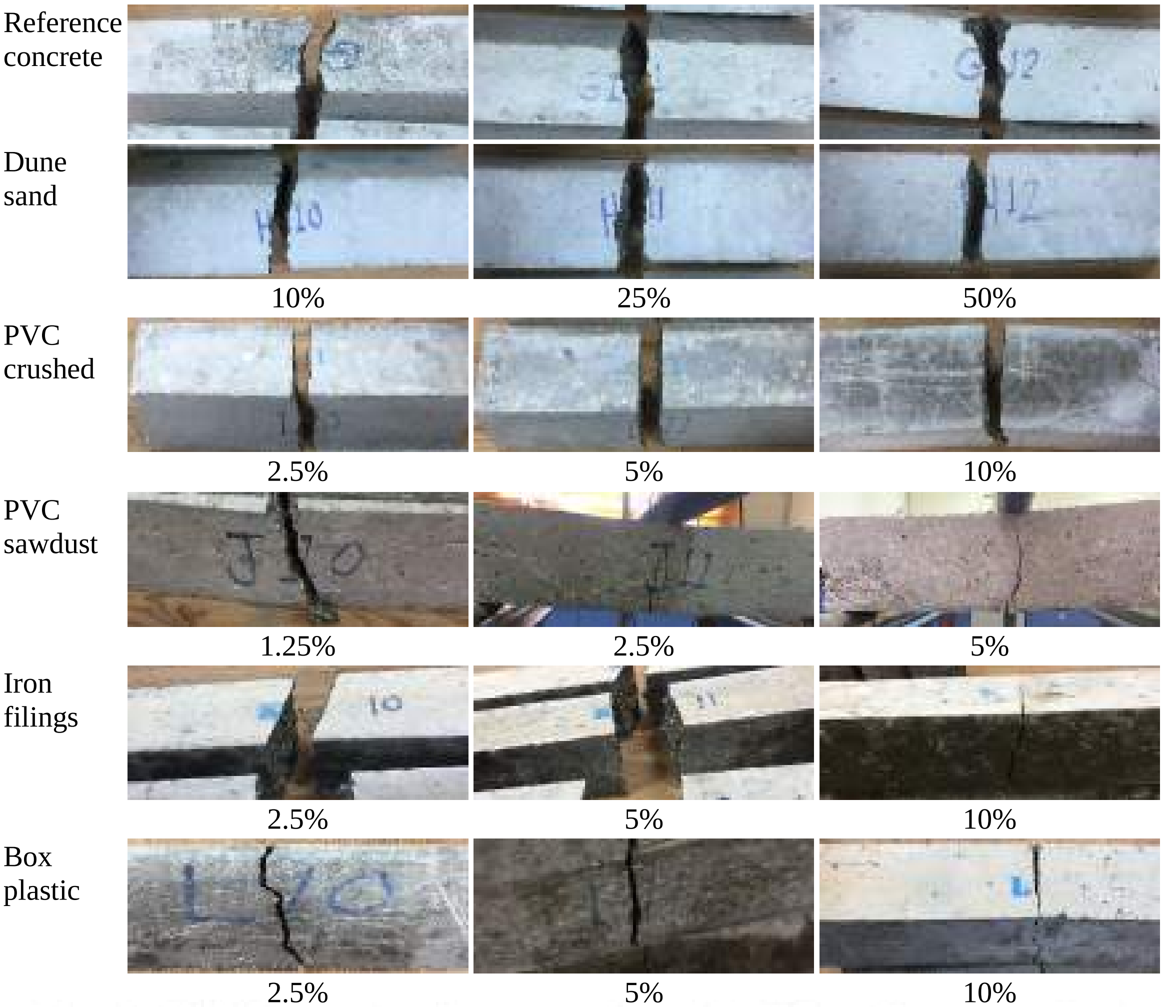


Figure (4- 22) Failure modes of concrete prisms with different Percentage of sand replacement

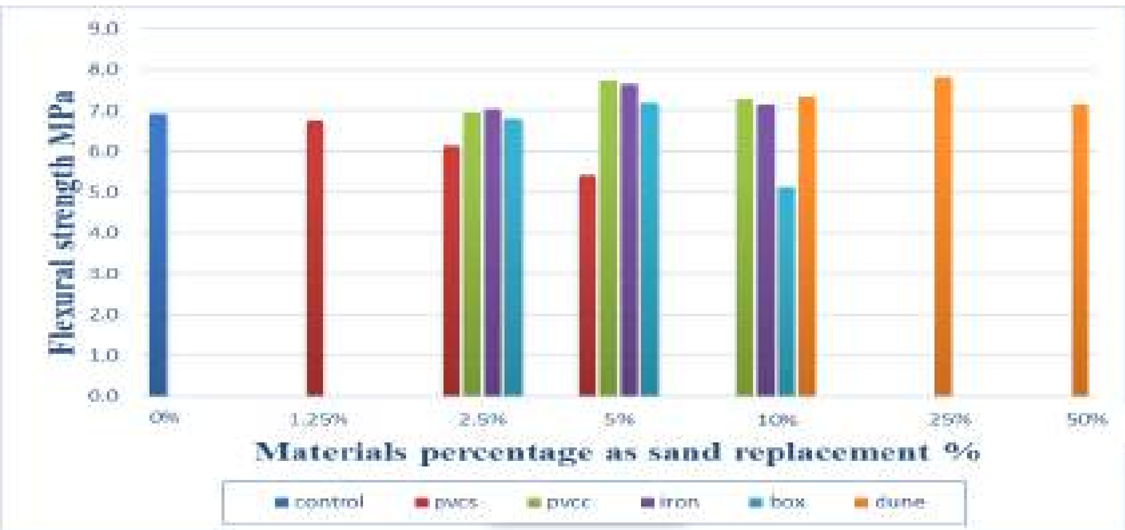


Figure (4- 23) Flexural strength at 28 days age tests of all replacement materials.

4.2.2.7 Static Modulus of Elasticity

The static modulus of elasticity of concrete mixtures with partially sand replacement is carried out according to ASTM C469 [34]. It is calculated by formula (3-3) and ACI 318-19 code equation (4-3) [36].The elastic modulus values for different percentages of materials replaced sand are shown in the Table (4-5) and the stress-strain curves are shown in the Figures (4-24) to (4-28).

$E_c = 4700\sqrt{f'c}$ ....Eq. (4- 3)

Table (4- 5) Modulus of elasticity of concrete mixtures.

Material type	Replacement percentage (%)	Modulus of elasticity E (MPa)	change (%)	E_c (MPa) of ACI eq (4-4) [39]	Experimental / ACI Eq ratio
control	-	27780	0	28940	0.96
Dune sand	10	37025	+33	31365	1.18
	25	22635	-19	26576	0.85
	50	28724	+3	25000	1.15
PVC crushed	2.5	30210	+9	29369	1.03
	5	30866	+11	27042	1.14
	10	26677	-4	25981	1.03
PVC sawdust	1.25	33423	+20	25981	1.29
	2.5	27090	-2	25764	1.05
	5	22132	-20	25819	0.86
Iron Filling	2.5	30441	+10	28505	1.07
	5	33125	+12	29686	1.05
	10	34392	+19	28307	1.17
Box plastic	2.5	27780	+24	30084	1.14
	5	28294	+2	26149	1.08
	10	27042	-3	23901	1.13

Dune sand: It is observed from Table (4-5) and Figure (4-24), that all samples which contain dune sand with dosages 10% and 50 % showed an increase in 28-days modulus of elasticity by about 33% and 3% respectively. While The mix that contains on 25% of dune sand as sand replacement showed decrease in modulus of elasticity by 19%. The mix that contains on 10% of dune sand as sand replacement is the optimum percentage which gave modulus of elasticity of 37025MPa.

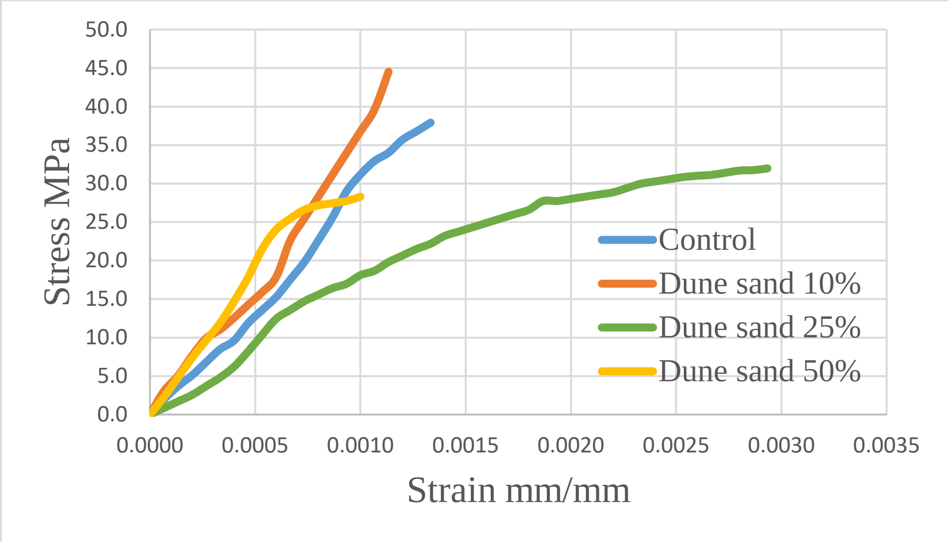


Figure (4- 24) Stress-strain curves of concrete mixtures with dune sand as sand replacement

PVC crushed: It is evident from Table (4-5) and Figure (4-25), that all samples which contain PVC crushed particles with substitution 2.5% and 5 % showed an increase in 28-days modulus of elasticity by about 9% and 11% respectively and showed decrease by 4% for 10% PVC crushed. The mix that contains on 5% of PVC crushed particles as replacement of sand is the best percentage which gave a modulus of elasticity of 30866 MPa.

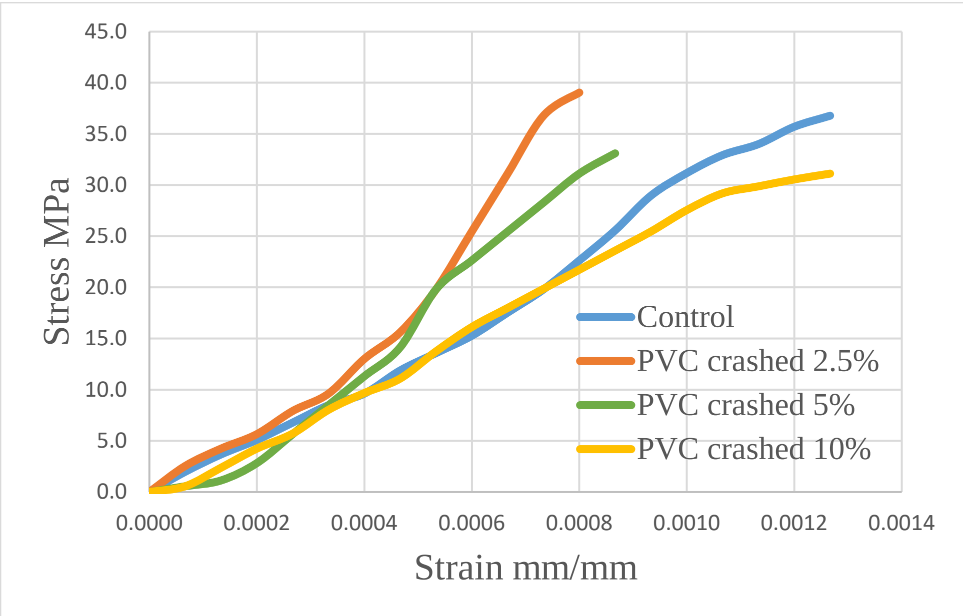


Figure (4- 25) Stress-strain curves of concrete mix with PVC crushed

PVC dust: From Table (4-5) and Figure (4-26), that the samples which contain (PVCS) with ratio 2.5% and 5% show a decrease in 28-days modulus of elasticity strength by about 2% and 20% respectively, while it showed increase in modulus of elasticity of 20% at mix that contains 1.25% of PVCS as replacement of sand and it is continued the optimum percentage which gave a modulus of elasticity 33423 MPa.

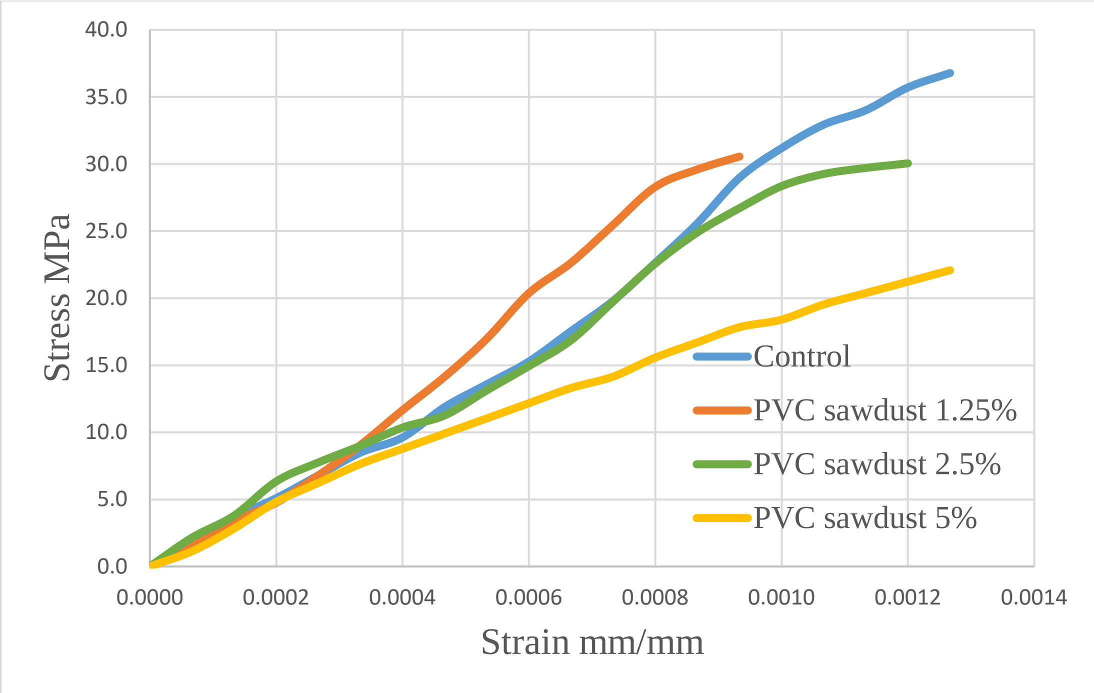


Figure (4- 26) Stress-strain curves of concrete mixtures with PVC sawdust as sand replacement

Iron filings: The addition of iron filings to concrete mixtures as sand replacement showed a remarkable increase in 28-days modulus of elasticity as shown in Table (4-5) and Figure (4-27).

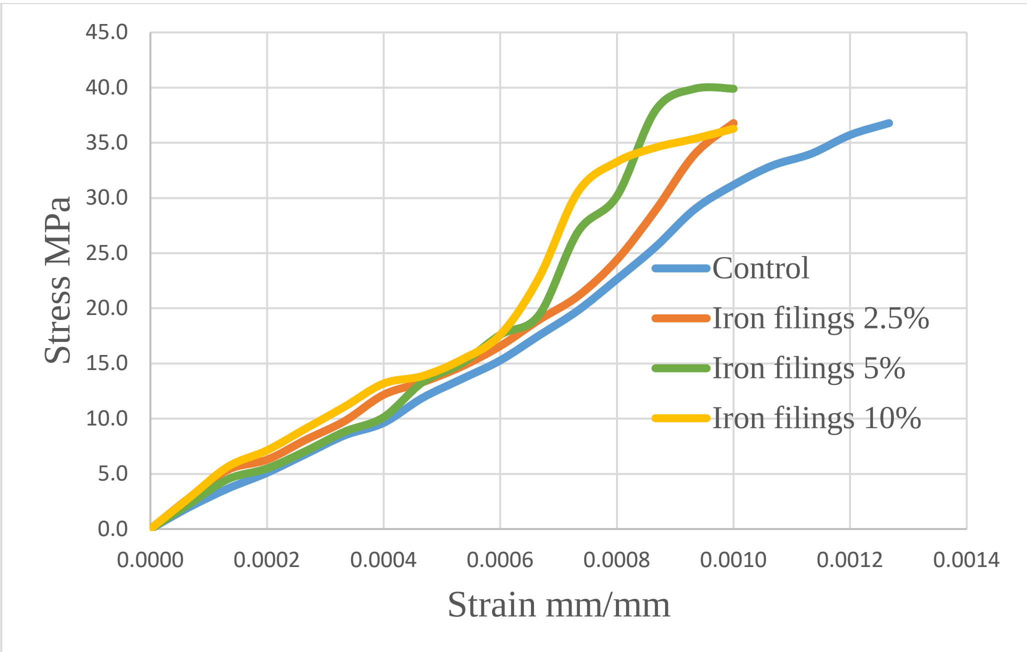


Figure (4- 27) Stress-strain curves of concrete mixtures with iron filings as sand replacement

The modulus of elasticity increased as iron filings increased for 2.5%,5% and 10% which presented 28-days modulus of elasticity of 30441 MPa, 31181 MPa and 33125 MPa respectively, that means the modulus of elasticity of iron filings larger than specimens of control mix by 10%, 12% and 19% respectively.

Plastic boxes waste: The effect of plastic boxes waste particles on concrete modulus of elasticity is illustrated in Table (4-5) and Figure (4-28). It is observed that the samples contain box plastic waste particle with replacement of 2.5% and 5% showed an increase in 28-days modulus of elasticity by about 24% and 2%, but dosage 10% of plastic box particles gave less compressive strength than reference by about 3%.

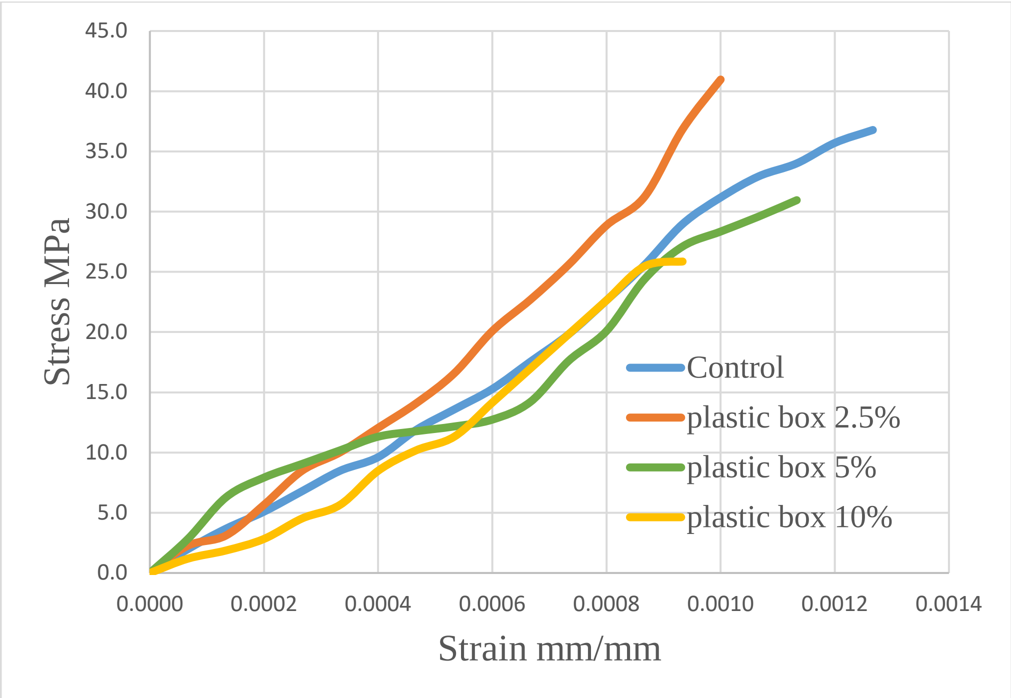


Figure (4- 28) Stress-strain curves of concrete mixtures with plastic boxes waste as sand replacement

4.2.2.8 Mode of Failure of Concrete Cylinders

Similar to cubes failure modes, the concrete cylinder failure mode of the control mixture is crushed, while there is no complete separation in the cylindrical samples that contain materials wastes as sand replacement, but there are cracking development and spreading on the sample surface as shown in Figure. (4-29), which indicate that ductility provided by materials wastes for concrete.

Reference concrete



Dune sand


10%

25%

50%

PVC crushed


2.5%

5%

10%

PVC sawdust


1.25%

2.5%

5%

Iron filings


2.5%

5%

10%

Box plastic


2.5%

5%

10%

Figure (4- 29) Failure mode of cylinders for modulus of elasticity.

4.2.3 Summary of Mechanical Properties

Table (4-6) includes the best percentage of materials added to the concrete as sand replacement that gave optimum value of concrete properties as following:

Dune sand:

The percentage of 25% is yielded the best in compressive strength and flexural strength of 55.73 MPa and 7.81 respectively namely more than control by 25% and 13%.

PVC crushed:

The percentage of 5% yielded the best results for all properties of concrete except compressive strength where 2.5% yielded the best result of 55.8 MPa by 25% more than control. Thus 5% of PVCC yielded Splitting tensile strength of 3.9MPa, flexural strength of 7.75MPa and modulus of elasticity of 30866MPa that mean increased more than concrete mix of 3.9MP,7.75MPa and 30866MPa namely by 41%,12% and 11% respectively.

PVC sawdust:

The percentage of 1.25% yielded the lowest reduction in slump test and flexural strength of 50mmand 6.76 MPa respectively and namely by about 44% and 2% less than control mix, while yielded of 33423 MPa, namely 56% greater than control mix increment. The percentage of 1.25% of sawdust showed reduction in compressive by 7% less than control, while the percentage 2.5% yielded the best compressive strength closed to control mix (1% less than control mix).

Iron filings:

The replacement of 10% yielded the best results for slump test, compressive strength and modulus of elasticity of 150 mm, 55.63MPa and 34392MPa respectively, namely greater than control mix by 67% ,25%and 19%.

Plastic boxes waste:

Concrete prepared with 5% replacement ratio of plastic boxes waste as fine aggregate exhibits a much better compressive strength, splitting tensile strength, flexural strength having values 52.27 MPa,2.90MPa and 7.20MPa respectively, which means 17% ,5% and 4% greater than control mix.

Table (4- 6) Best percentage for the substitution

Material type		Slump Test (mm)	compressive strength f_{cu} (MPa)	Splitting tensile strength T (MPa)	Flexural strength R (MPa)	Modulus of elasticity E (MPa)
control		90	44.65	2.77	6.90	27780
Dune sand	Replacement %	10	25	50	25	10
	Value	80	55.73	3.30	7.81	37025
	Change %	-11	+25	+19	+13	+33
PVC crushed	Replacement %	5	2.5	5	5	5
	Value	80	55.80	3.90	7.75	30866
	Change %	-11	+25	+41	+12	+11
PVC sawdust	Replacement %	1.25	2.5	2.5	1.25	1.25
	Value	50	44.10	3.27	6.76	33423
	Change %	-44	-1	+18	-2	+20
Iron Filling	Replacement %	10	10	5	5	10
	Value	150	55.63	3.37	7.65	34392
	Change %	+67	+25	+22	+11	+19
Box plastic	Replacement %	2.5	5	5	5	2.5
	Value	85	52.27	2.90	7.20	27780
	Change %	-6	+17	+5	+4	+24

4.3 Investigation of Columns Specimens

The columns specimens are divided into three groups depend on their dimensions are (stub, short and long columns). Each group included steel tube columns filled with concrete mixes with partially sand replacement.

4.4 Stub Columns

4.4.1 Axial load Capacity

The axial load capacity of all (CFST) stub columns specimens are shown in Table (4-7). The experimental results are compared with theoretical equation to show the relative increasing due to confinement of concrete by steel tube.

Table (4- 7) Experimental and theoretical axial load capacity for stubs columns.

Material type	Replacement (%)	sample code	$N_{Exp.}$ (kN)	*Change in $N_{Exp.}$ (%)*	$N_{theo.}$ (kN)	N_{Exp} / $N_{theo.}$ ratio
control	-	CTRL30B15t4-0	1220	0	1098	1.11
Dune sand	10	DNSL30B15t4-1	1218	0	1116	1.09
	25	DNSL30B15t4-2	1299	+6	1174	1.11
	50	DNSL30B15t4-3	1300	+7	1110	1.17
PVC crushed	2.5	PVCL30B15t4-1	1299	+6	1175	1.11
	5	PVCL30B15t4-2	1395	+14	1136	1.23
	10	PVCL30B15t4-3	1331	+9	1152	1.16
PVC sawdust	1.25	PVSL30B15t4-1	1269	+4	1077	1.18
	2.5	PVSL30B15t4-2	1180	-3	1094	1.08
	5	PVSL30B15t4-3	1436	+18	1035	1.39
Iron Filling	2.5	IRNL30B15t4-1	1341	+10	1174	1.14
	5	IRNL30B15t4-2	1253	+3	1132	1.11
	10	IRNL30B15t4-3	1328	+9	1151	1.15
Box plastic	2.5	BXCL30B15t4-1	1362	+12	1095	1.24
	5	BXCL30B15t4-2	1301	+7	1151	1.13
	10	BXCL30B15t4-3	1200	-2	1019	1.18

Dune sand: It is observed from Table (4-7) and Figure (4-30), that samples which contain dune sand with dosages 25% and 50 % show an increase in load capacity of 1299 kN and 1300 kN.

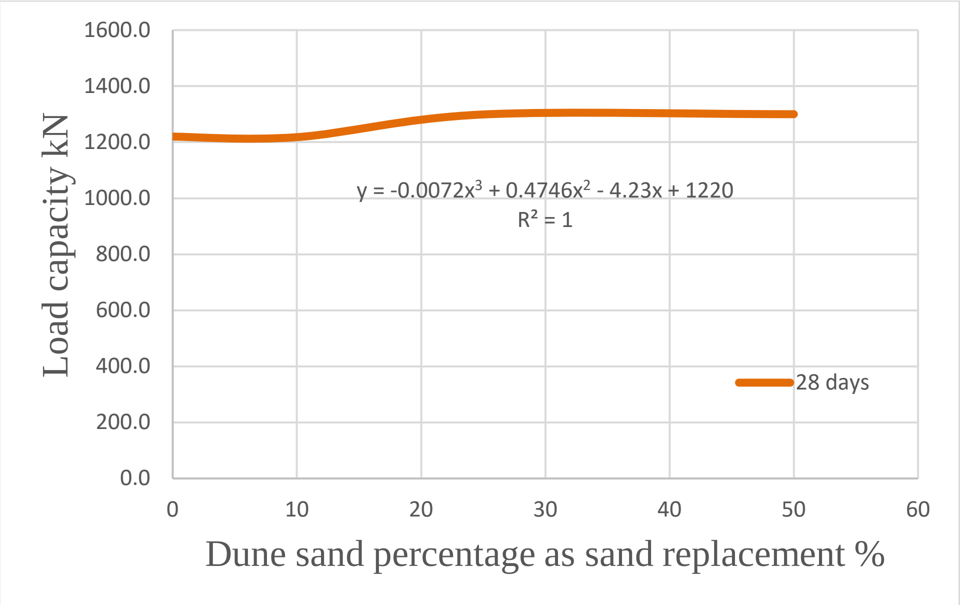


Figure (4- 30) Load capacity of stub column with dune sand

PVC crushed: It is evident from Table (4-7) and Figure (4-31), that all (CFST) samples which contain PVC crushed particles with dosages 2.5% ,5 % and 10% show an increase in load capacity by about 6%, 14% and 9% respectively for 28 days. The mix that contains on 5% of PVCC particles as replacement of sand is the optimum percentage which resulted a load capacity of 1395 kN (14% greater than control specimen).

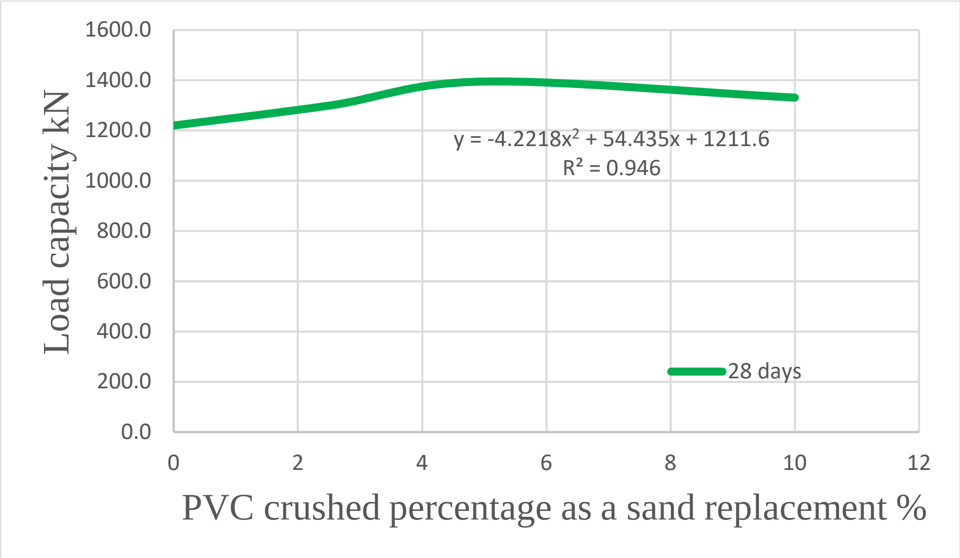


Figure (4- 31) Load capacity of stub column with PVC crushed

PVC sawdust: From Table (4-7) and Figure (4-32), that the (CFST) samples which contain PVC sawdust (PVCS) with dosages 1.25% and 5 % show an increase in load capacity by about 4% and 18% for 28-day test

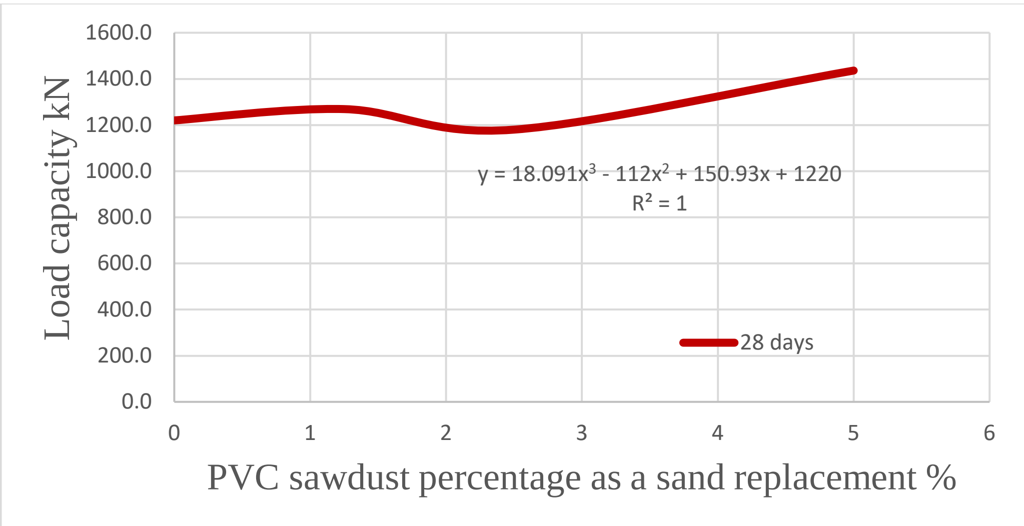


Figure (4- 32) Load capacity of stub column with PVC sawdust

While it shows decrease in dosage 2.5%, by 3%. The mix that contains on 5% of PVC sawdust as replacement of sand is the optimum percentage which revealed a load capacity of 1436 kN namely 18% greater than control specimen.

Iron filings: The addition of iron filings to concrete mixtures as a substituted sand showed an increasing in load capacity of CFST samples for all replacement as shown in Table (4-7) and Figure (4-33) for 28-day test. Using an iron filling as replacement ratio showed increasing in load capacity at 2.5%, 5% and 10% replacement ratio of iron filings by about 10%,3% and 9% respectively, compared control mix. The dosage of 2.5% of iron filings gives optimum load capacity of 1341 kN, namely 10% greater than control specimen.

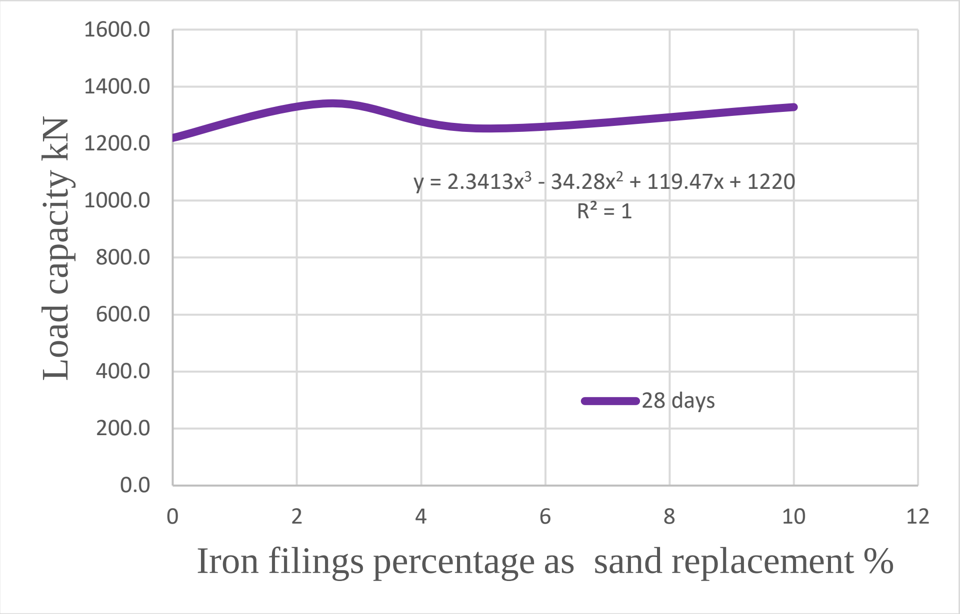


Figure (4- 33) Load capacity of stub column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on load capacity of CFST samples is shown in Table (4-7) and Figure (4-34).

It is indicated that the samples contain plastic boxes waste particle with replacement ratio of 2.5% and5% showed an increase in load capacity in 28 days' age 1362 kN and 1301 kN, namely more than control specimen by about 12% and 7% respectively, but dosages 10% of plastic box particles gave less load capacity than reference by about -2%. The dosage of 2.5% of plastic boxes waste gives optimum load capacity of 1362 kN, so the load capacity increase by 12% greater than control specimen.

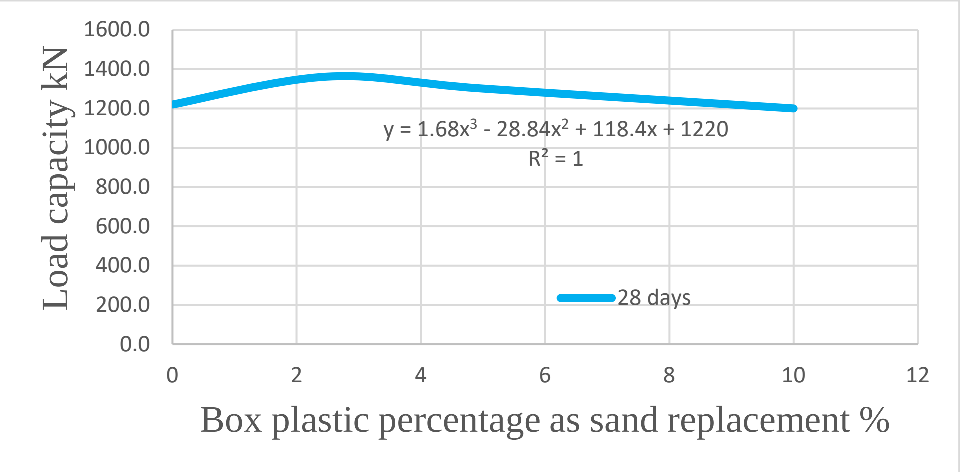


Figure (4- 34) Load capacity of stub column with plastic boxes waste

4.4.2 Theoretical Load Capacity of composite column

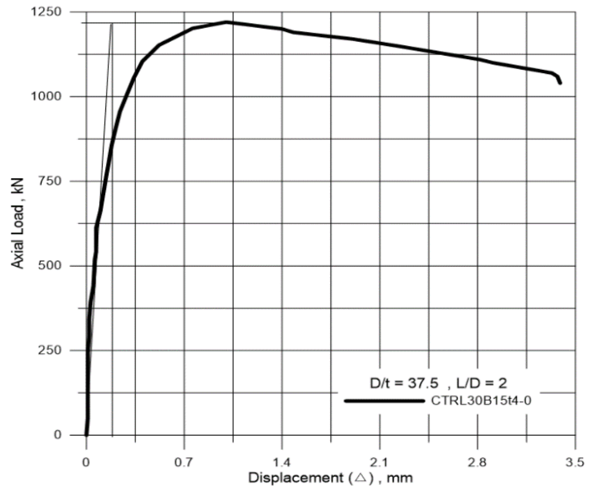
The theoretical load capacity of column is the sum of concrete capacity and steel capacity through the theoretical equation [36] [40].

$$N_{theo} = 0.8 f_c' Ac + f_y As \quad \text{.......Eq. (4- 4)}$$

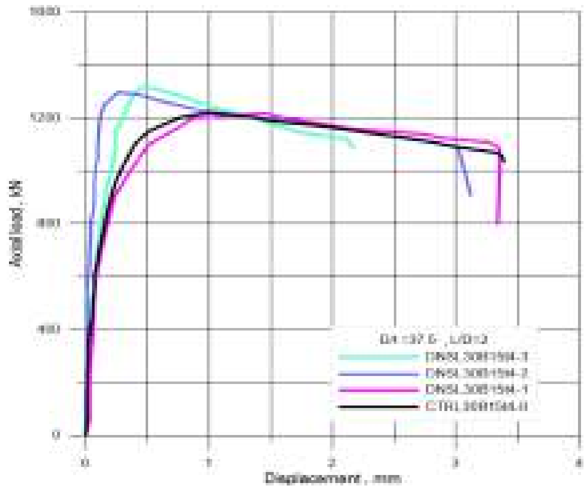
Commonly the experimental capacity of concrete filled steel tube is greater than the theoretical capacity of column because theoretical load capacity ignores the fact that the concrete's compression capacity increases due to confinement [41]. The results of load capacity of stub column specimens are shown in Tables (4-7). The difference ranged from 3% to 19% is evident by comparing the experimental results with theoretical results except for 15% PVC sawdust which reached 33%. Thus this equation yielded acceptable estimation for column loading capacity for control specimen and samples with sand replacement.

4.4.3 Load-Displacement Curve

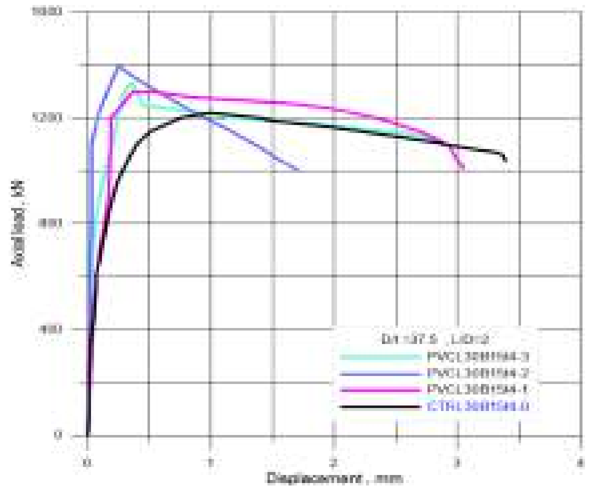
Toughness is the ability of a structure to absorb and dissipate energy. It is calculating from area under load displacement curve (P –Δ) that shown in Figure (4-35). The toughness or ability to absorb energy considered one of the most important characteristics of (CFST) columns. From the displacement load pattern, it is clear that although the stub columns, have a higher load capacity than the long columns, but have less displacement.



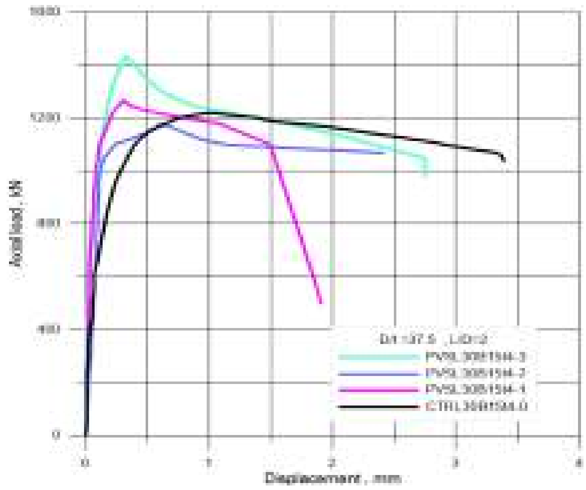
a) Reference specimen



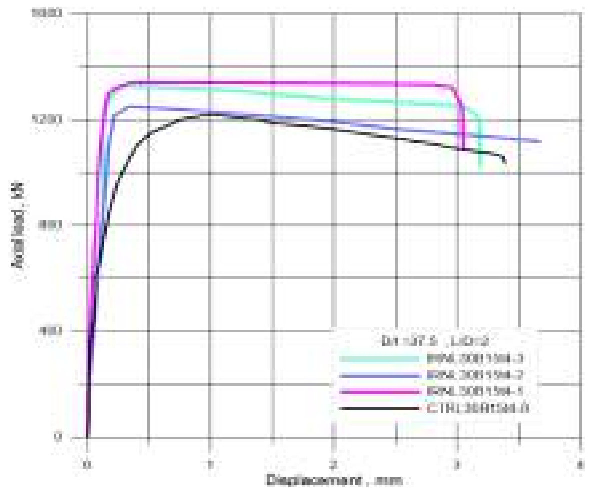
b) Dune sand replacement



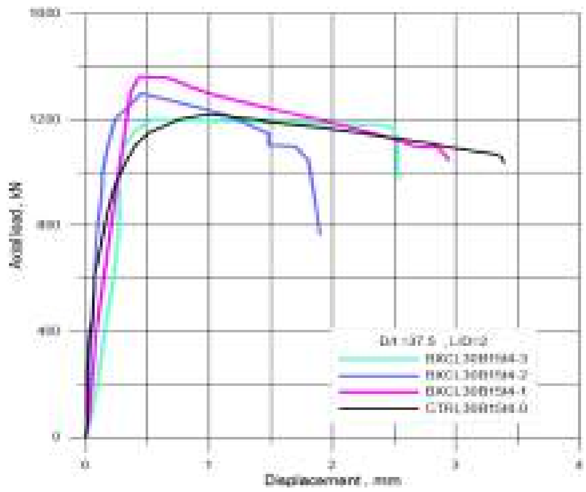
c) PVC crushed replacement



d) PVC sawdust replacement



e) Iron filings replacement



f) Plastic boxes waste replacement

Figure (4- 35) Load displacement curve of (CFST) stub column specimens

Therefore, the best comparison is made by calculating the area under the load displacement curve to determine the energy absorption. Table (4-8) shows the toughness values for each specimen.

Table (4- 8) Toughness of (CFST) with partially sand replacement

Material type	**Replacement percentage (%)**	**sample code**	***Toughness kN.mm***	***Change %***	***Δmax, mm***
control	-	CTRL30B15t4-0	3773	0	3
Dune sand	10	DNSL30B15t4-1	3114	-17	3
	25	DNSL30B15t4-2	3596	-5	3
	50	DNSL30B15t4-3	2522	-33	2
PVC crushed	2.5	PVCL30B15t4-1	3694	-2	3
	5	PVCL30B15t4-2	2176	-42	1
	10	PVCL30B15t4-3	3690	-2	3
PVC sawdust	1.25	PVSL30B15t4-1	2070	-45	2
	2.5	PVSL30B15t4-2	2467	-35	2
	5	PVSL30B15t4-3	3249	-14	1
Iron Filling	2.5	IRNL30B15t4-1	3993	6	3
	5	IRNL30B15t4-2	4117	9	4
	10	IRNL30B15t4-3	4014	6	3
Box plastic	2.5	BXCL30B15t4-1	3340	-11	2
	5	BXCL30B15t4-2	2193	-42	2
	10	BXCL30B15t4-3	2771	-27	3

Dune sand: From the Table (4-8) and Figure (4-36), it is indicated that the increase of dune sand as partially replacement lead to decrease toughness for all percentage of 10%, 25% and 50% by 3114 kN.mm,3596 kN.mm and 2522 kN.mm, namely 17%,5% and 33% respectively, maximum displacement still close to control specimen, namely near 3 mm. Although the 50% of dune sand take optimum value of toughness 3596 kN.mm, but still less than the reference one.

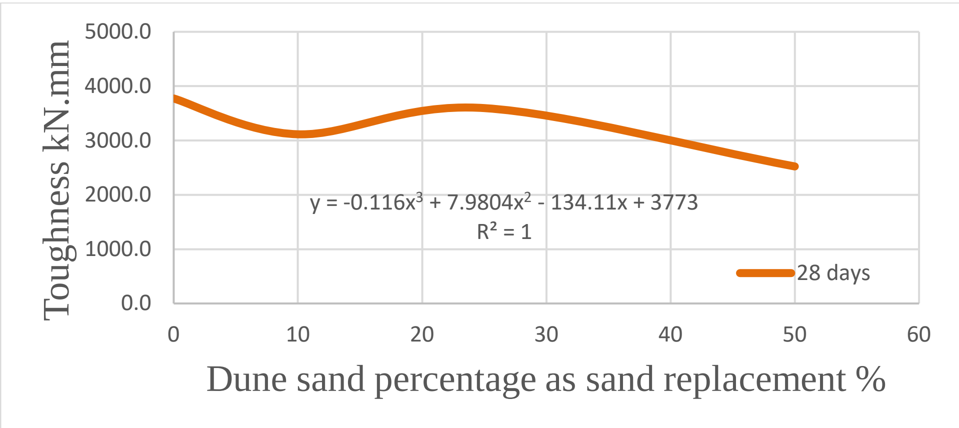


Figure (4- 36) Toughness of stub column with dune sand

PVC crushed: From the Table (4-8) and Figure (4-37), the using PVC crushed as a substitute for sand in (CFST) columns, the value of toughness decreases with all percentages of 2.5%, 5% and 10% by 3694 kN.mm,2176 kN.mm and 3690, means less than control specimen by 2%,42% and 2% respectively although maximum displacement still close to the reference column specimen with 3mm at substitution of 2.5%.

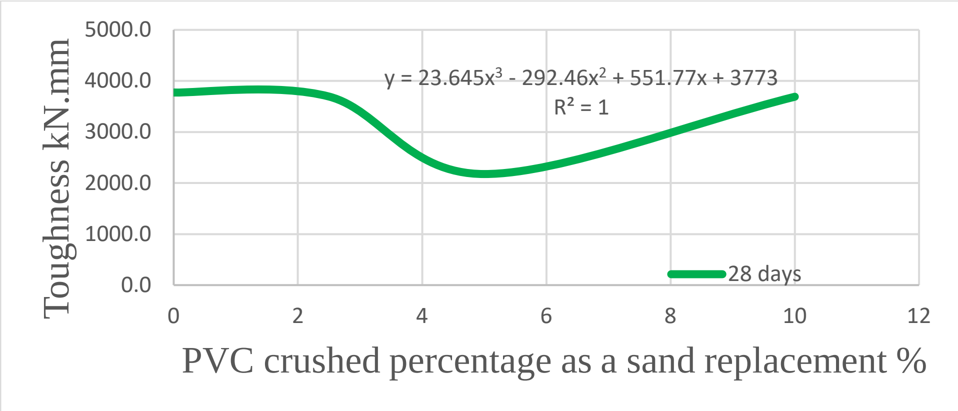


Figure (4- 37) Toughness of stub column with PVC crushed

PVC sawdust: From the Table (4-8) and Figure (4-38), column specimens are containing PVC sawdust show a decrease in toughness for all percentages 1.25%, 2.5% and 5% of 2070 kN.mm,2467 and 3249 kN.mm, namely less than control specimen by 45%, 35% and 14% respectively. However, the increase in the dosage of in the PVC sawdust lead to decrease in maximum displacement is 2 mm.

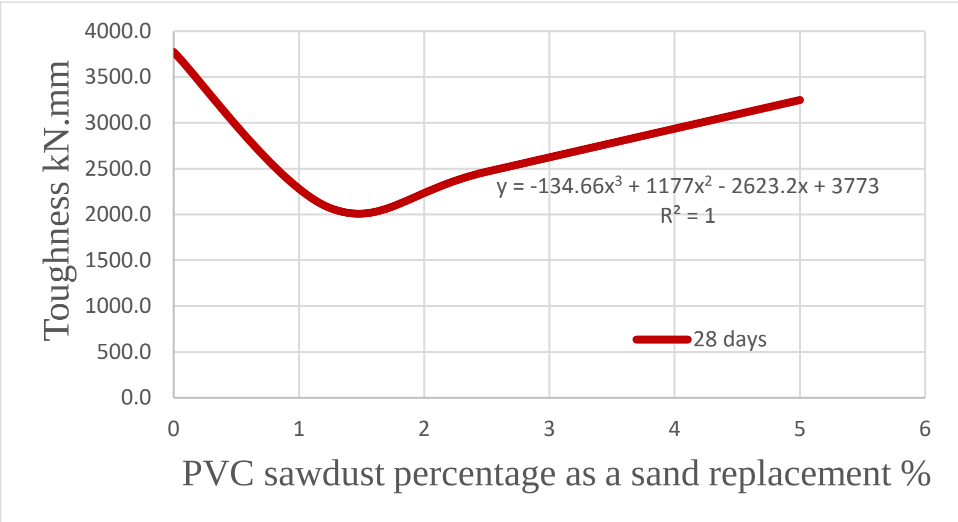


Figure (4- 38) Toughness of stub column with PVC sawdust

Iron filings: From the Table (4-8) and Figure (4-39), the toughness values for iron filings are clearly more than control specimen for all percentages 2.5%, 5% and 10% of 3993,4117 and 4014 kN.mm namely more than control specimen by 6%, 9% and 6% respectively. The dosage of 5% is the optimum percentage of iron filings for the toughness 4117 kN.mm. Thus, the use of iron filings in concrete mix led to increase toughness with increasing of iron filing in the concrete mix. The maximum displacement is more than that of reference column specimen with little increment namely 4mm in 5% of iron filings dosage.

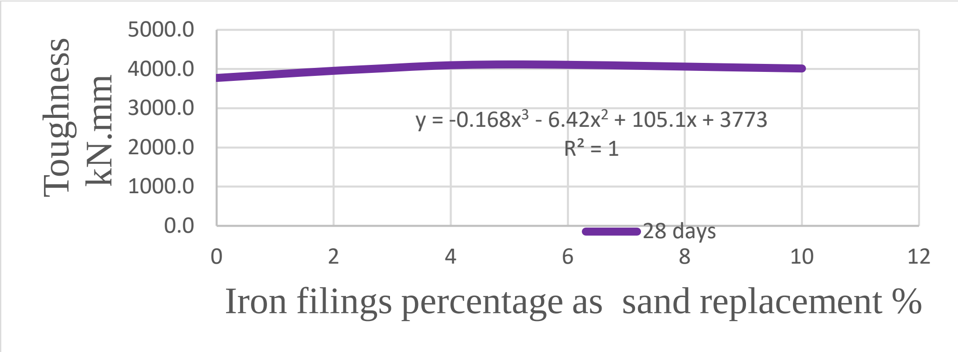


Figure (4- 39) Toughness of stub column with iron filings

Plastic boxes waste: The effect of plastic boxes waste on specimen's toughness is shown in Table (4-8) and Figure (4-40). It is observed that the samples contain box plastic waste particle with dosages 2.5%, 5% and 10% showed a decrease in toughness of 3340kN.mm,2193kN.mm and 2771kN.mm, namely by about 11%,42% and 27% respectively. The best replacement ratio is 2.5% which yield toughness less than control specimen by 11 %.

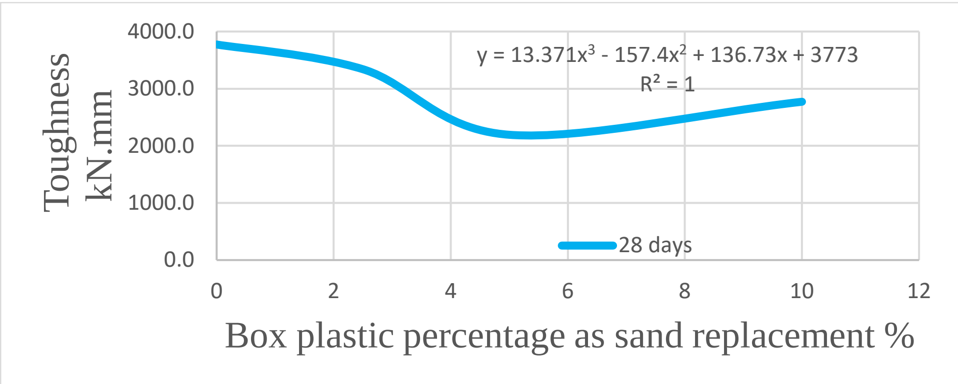


Figure (4- 40) Toughness of stub column with plastic box waste

4.4.4 Ductility Index (DI)

Ductility is an important criterion for column structures. It is defined as the ability of a material or structural member to undergo inelastic deformations with acceptable degrees of stiffness and strength reduction [42].

The ductility can be obtained from the load displacement curve by dividing the displacement ($\Delta_{0.85}$) on the displacement (Δ_u) as shown in Figure (4-41). Thus the ductility is obtained by Equation (4-8), [9].

$$DI = \frac{\Delta_{0.85}}{\Delta_u} \qquad \text{Eq. (4- 5)}$$

Where

$\Delta_{0.85}$ is the displacement at 0.85 of ultimate load after failure.

Δ_u is the displacement at ultimate load

The ductility for all (CFST) column is presented in Table (4-9)

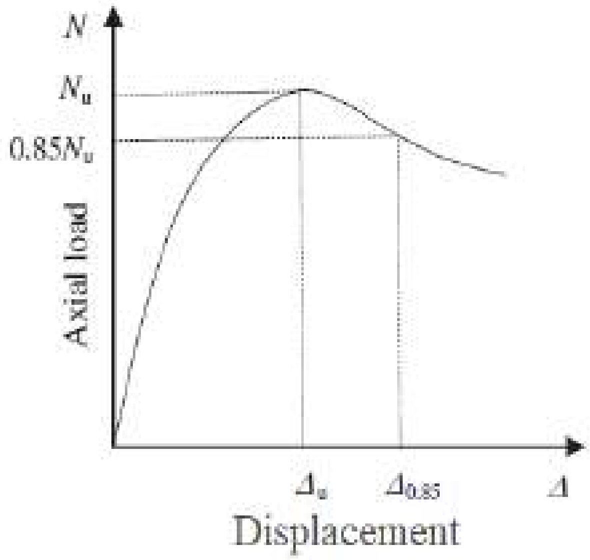


Figure (4- 41) Ultimate and maximum displacement as cited in Ref. [9]

Table (4- 9) Results ductility index of (CFST) stub column specimen.

Material type	Replacement percentage (%)	Specimen	N_{Exp} (kN)	DI	Change %
control	-	CTRL30B15t4-0	1220	3.39	0
Dune sand	10	DNSL30B15t4-1	1218	2.31	-32
	25	DNSL30B15t4-2	1299	10.28	+203
	50	DNSL30B15t4-3	1300	4.43	+31
PVC crushed	2.5	PVCL30B15t4-1	1299	5.37	+59
	5	PVCL30B15t4-2	1395	4.74	+40
	10	PVCL30B15t4-3	1331	7.56	+123
PVC sawdust	1.25	PVSL30B15t4-1	1269	8.59	+153
	2.5	PVSL30B15t4-2	1180	4.79	+41
	5	PVSL30B15t4-3	1436	3.62	+7
Iron Filling	2.5	IRNL30B15t4-1	1341	8.47	+50
	5	IRNL30B15t4-2	1253	10.40	+207
	10	IRNL30B15t4-3	1328	10.50	+210
Box plastic	2.5	BXCL30B15t4-1	1362	5.46	+61
	5	BXCL30B15t4-2	1301	3.80	+12
	10	BXCL30B15t4-3	1200	4.63	+37

Dune sand: It is observed from Table (4-9) and Figure (4-42), that specimens which contain dune sand with replacement ratio 25% and 50 % exhibit an increase in ductility index of 10.28, 4.43, namely by about 203% and 31% greater than control specimen respectively for 28 days. However, specimens which contain dune sand with replacement ratio 10% shows a decrease in ductility index by about 32%. It is indicated that the mix with 25% of dune sand as sand replacement is the optimum percentage which revealed a ductility index of 10.28, namely greater than control specimen by 203%.

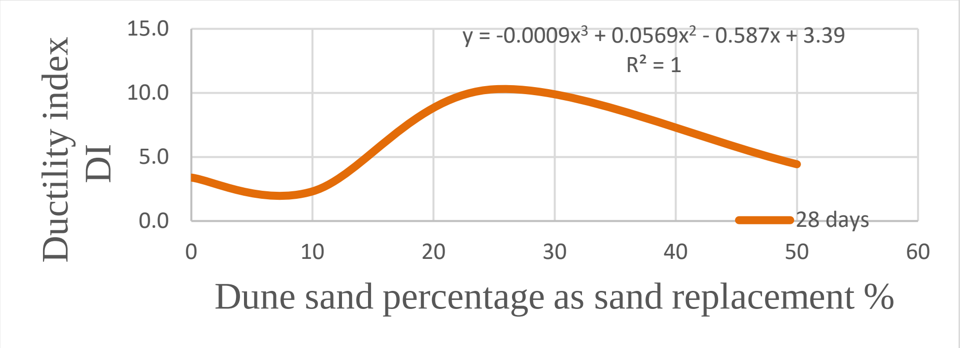


Figure (4- 42) Ductility index of stub column with dune sand

PVC crushed: It is evident from Table (4-9) and Figure (4-43), that all samples which contain PVC crushed particles with dosages 2.5% ,5 % and 10% showed an increase in ductility index of 5.37, 4.74 and 7.56, namely greater than control specimen by 59%, 40% and 123% respectively. The mix that contains on 10% of PVC crushed as sand replacement is the optimum percentage which gave a ductility index of 7.56, namely greater than control specimen by 123%.

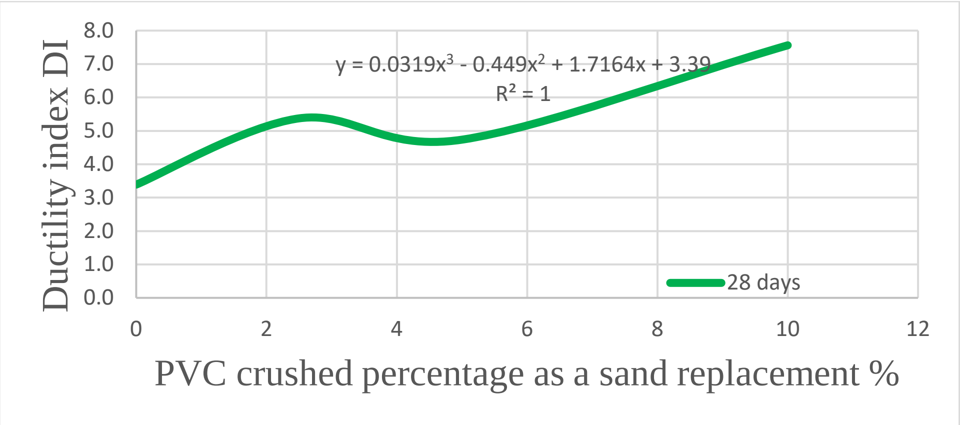


Figure (4- 43) Ductility index of stub column with PVC crushed.

PVC sawdust: Table (4-9) and Figure (4-44), showed that all samples which contain PVC sawdust (PVCS) with dosages 1.25%, 2.5% and 5 % presented an increasing in ductility index of 8.59, 4.79 and 3.62, namely greater than control specimen by 153%,41%, and 7% respectively. Concrete mix prepared with 1.25% of PVC sawdust as sand replacement is the best percentage which gave a ductility index of 8.59, namely greater than control specimen by 153%.

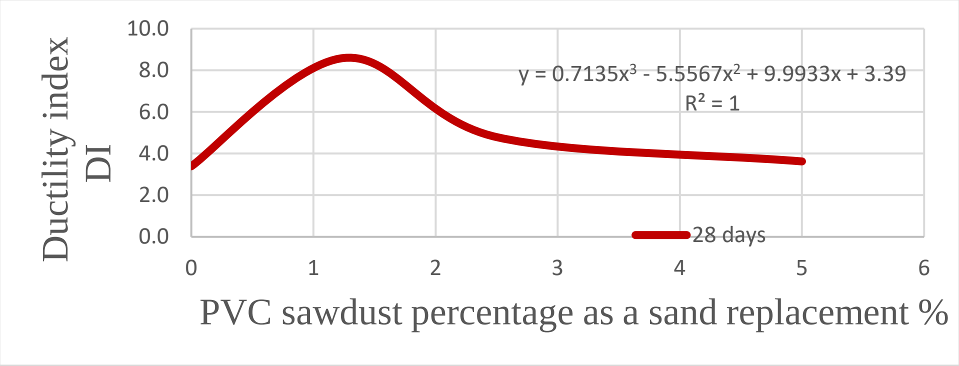


Figure (4- 44) Ductility index of stub column with PVC sawdust .

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed a remarkable increase in ductility index as shown in Table (4-9) and Figure (4-45). proportioned increase in ductility index with an increase for replacement ratio 2.5%, 5% and 10% which presented a ductility index of 8.47,10,40 and 10.50 that means the ductility index of specimens that contained iron filings larger than specimens of control mix by 50%, 207% and 210% respectively. The mix that contains on 10% of iron filings as sand replacement is the optimum percentage which detected a ductility index of 10.50, namely greater than control specimen by 210%.

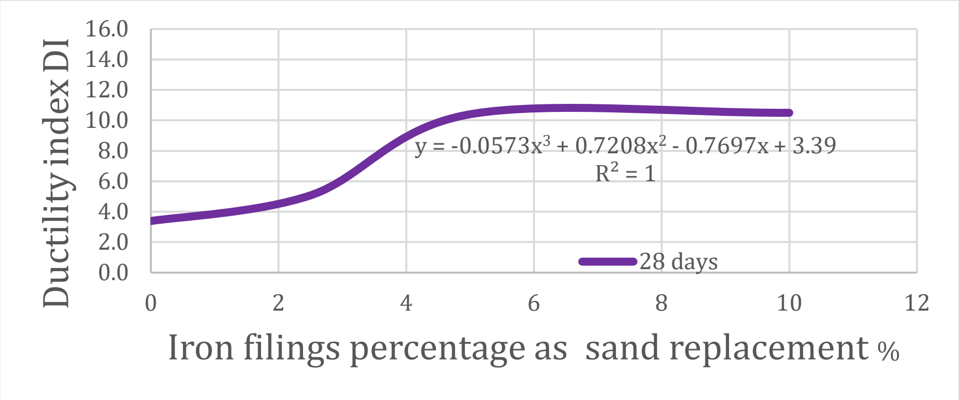


Figure (4- 45) Ductility index of stub column with iron filings

Plastic boxes waste: An increase in plastic boxes waste particles with replacement ratio 2.5%,5% and 10% caused an increase in ductility index by about 61%, 12% and 37% respectively, where ductility index 5.46, 3.80 and 4.63. Moreover, as previously noted, specimens with 2.5% resulting optimum ductility index 5.46. The effect of plastic boxes waste particles on CFST columns ductility index is shown in Table (4-9) and Figure (4-46).

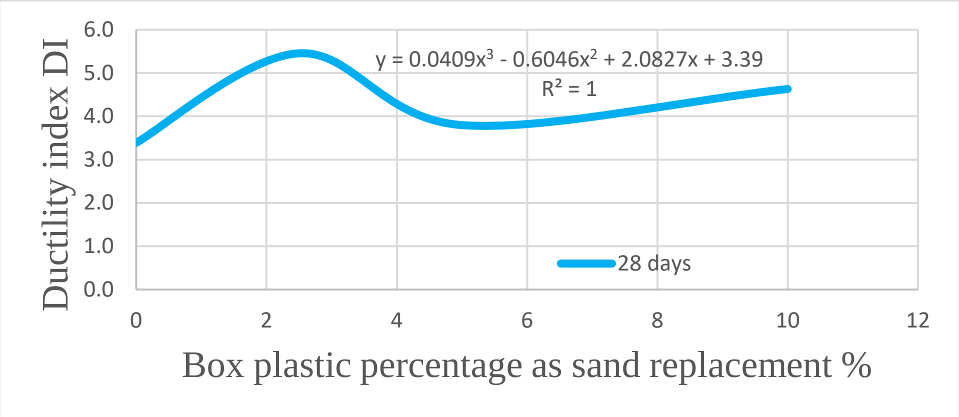


Figure (4- 46) Ductility index of stub column with plastic boxes waste

4.4.5 Stiffness

Stiffness refers to the tangent stiffness for a load displacement curve [43]. The stiffness of the columns increases as the compressive strength of concrete filled it increases. This is because the modulus of elasticity of concrete increases as a compressive strength increase. initial behavior is depended on concrete stiffness. The stiffness values of (CFST) stub column specimens with sand replacement are shown in Table (4-10)

Table (4- 10) Stiffness of (CFST) with partially sand replacement.

Material type	**Replacement percentage (%)**	**Specimen**	***stiffness(k) kN/mm***	***Change %***
control	-	CTRL30B15t4-0	4820	0
Dune sand	10	DNSL30B15t4-1	4556	-5
	25	DNSL30B15t4-2	9000	+87
	50	DNSL30B15t4-3	5586	+16
PVC crushed	2.5	PVCL30B15t4-1	5224	+8
	5	PVCL30B15t4-2	7738	+61
	10	PVCL30B15t4-3	9000	+87
PVC sawdust	1.25	PVSL30B15t4-1	7593	+58
	2.5	PVSL30B15t4-2	8189	+70
	5	PVSL30B15t4-3	9564	+98
Iron Filling	2.5	IRNL30B15t4-1	11198	+132
	5	IRNL30B15t4-2	6753	+40
	10	IRNL30B15t4-3	6240	+29
Box plastic	2.5	BXCL30B15t4-1	3766	-22
	5	BXCL30B15t4-2	7214	+50
	10	BXCL30B15t4-3	2829	-41

Dune sand: It is observed from Table (4-10) and Figure (4-47), that samples which contain dune sand with dosages 25% and 50 % showed an increase in stiffness of 9000kN/mm and 5586kN/mm, namely greater than control specimen by 87% and 16% respectively, while the specimens which contain dune sand with dosages 10% showed a decrease in stiffness by about 5% compared to control specimen. It can be found that the specimen contains 25% of dune sand replacement exhibit much increase in stiffness about 9000kN/mm compared with reference specimen which equal to 4820 kN/mm.

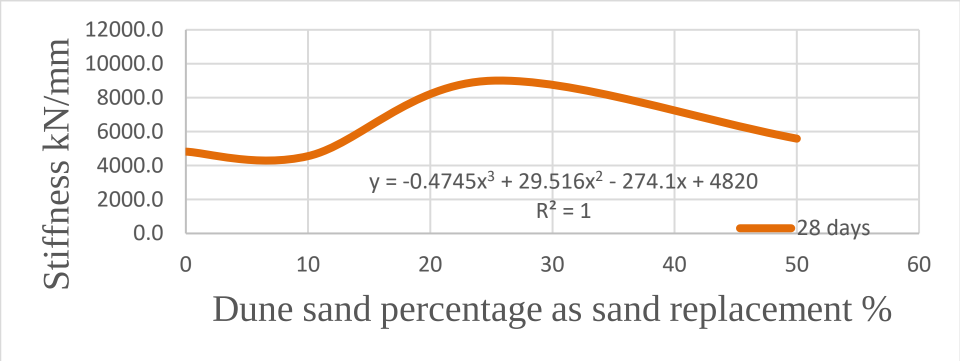


Figure (4- 47) Stiffness of stub (CFST) column with dune sand

PVC crushed: It is evident from Table (4-10) and Figure (4-48), that all samples which contain PVC crushed with dosages 2.5% ,5 % and 10% showed an increase in stiffness of 5224 kN/mm, 7738 kN/mm and 9000 kN/mm, namely greater than control specimen by 8%, 61% and 87% respectively. The mix that contains on 10% of PVC crushed as sand replacement is the optimum percentage which gave a stiffness of 9000 kN/mm, namely greater than control specimen by 87%.

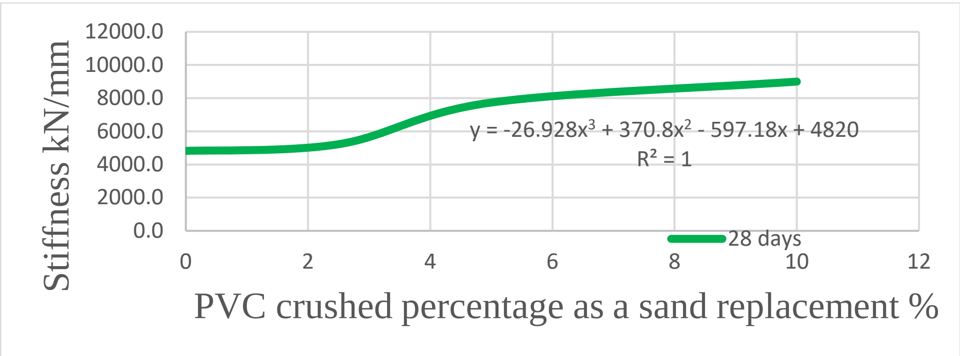


Figure (4- 48) Stiffness of stub (CFST) column with PVC crushed.

PVC sawdust: Table (4-10) and Figure (4-49), showed that all samples which contain PVC sawdust (PVCS) with dosages 1.25%, 2.5% and 5 % presented an increasing in stiffness of 7593 kN/mm, 8189 kN/mm and 9564 kN/mm, namely greater than control specimen by 58%,70%, and 98% respectively. The mix that contains on 5% of PVC sawdust as sand replacement is the optimum percentage which gave a stiffness of 9564 kN/mm, namely greater than control specimen by 98%.

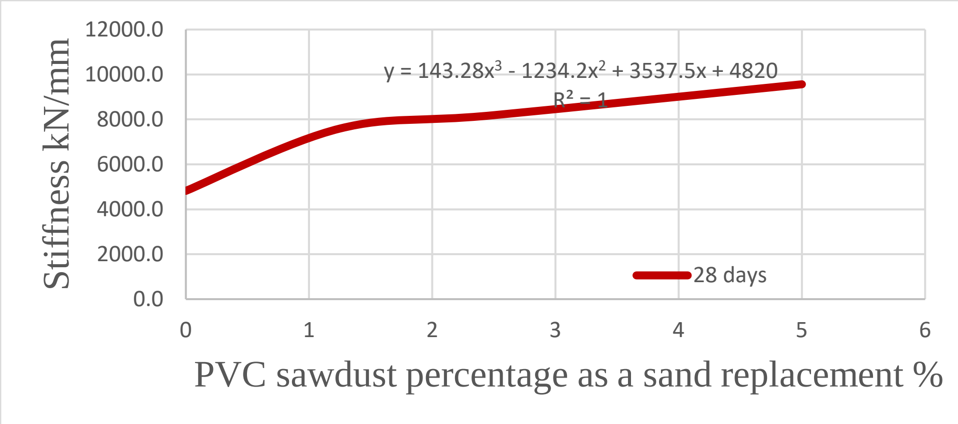


Figure (4- 49) Stiffness of stub (CFST) column with PVC sawdust .

Iron filings: It is evident from Table (4-10) and Figure (4-50), that all samples which contain iron filings with dosages range from 2.5%, 5% and 10 % showed an increase in stiffness of 11198 kN/mm,6753kN/mm and 6240 kN/mm, namely greater than control specimen by 132%, 40% and 29% respectively. The mix that contains on 2.5% of iron filings as sand replacement is the optimum percentage which gave a stiffness of 11198 kN/mm, namely greater than control specimen by 132%.

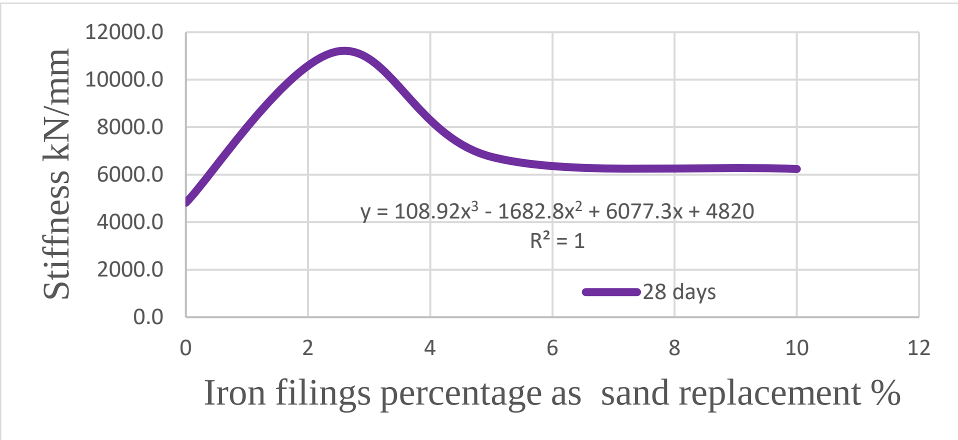


Figure (4- 50) Stiffness of stub (CFST) column with Iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on CFST column stiffness is shown in Table (4-10) and Figure (4-51). It is observed that the samples contain box plastic waste particle with dosage of 2.5% and 10% showed a decrease in stiffness of 3766 kN/mm and 2829 kN/mm, namely 22% and 41% less than reference specimens, but dosages 5% of plastic box particles gave stiffness of 7214 kN/mm namely 50% more than reference specimen.

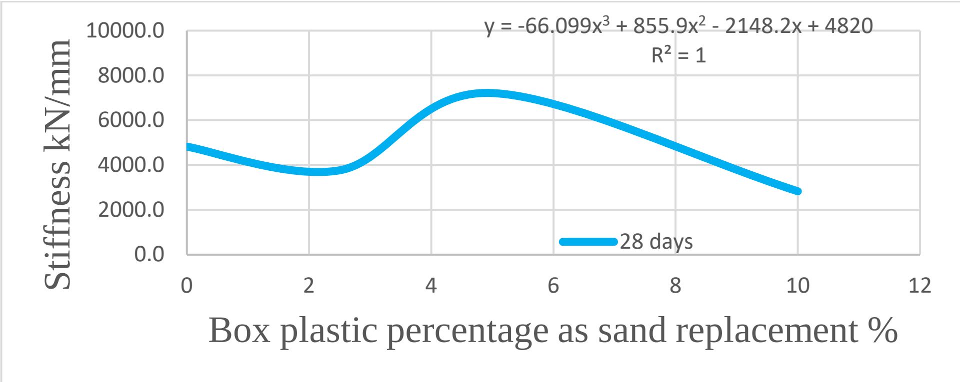


Figure (4- 51) Stiffness of stub (CFST) column with plastic boxes waste

4.4.6 Modes of Failure

One of the important things in columns investigations is the mode of failure, in concrete filled steel tubular (CFST) stub column specimens the mode of failure depends on the properties of the materials that consisted it (in filled concrete and steel tube) and the geometric of the column that lead to failure mechanism. In general, two failure modes are observed for concrete filled steel tube (CFST); local buckling and global buckling. Stub (CFST) column specimen's failure with the first type (local buckling) and it may be sub divided to shear failure and crushed of concrete core.

Figure (4-52) displays the failure modes of the stub (CFST) columns specimens. Outward local buckling is observed for all the tested (CFST) stub column specimens, the local buckling ranges from mid span to the middle of the upper half region. Two mechanisms of local buckling failure of stub columns are observed, the first one is initiated by crushing of concrete core then bulge steel outward in same level as shown in Figure (4-52 a,b,c,d,e,f,h,n,o and p), while the second mechanism is started by shear failure in concrete core then bulge steel outward along inclined shear failure plane of concrete core as shown in Figure (4-52 g,i,j,k,l and m). Table (4-11) showed the mode of failure of (CFST) stub column specimens.

Table (4- 11) The mode of failure of stub (CFST) columns

Material type	Replacement percentage (%)	Specimen	Mode of failure
control	-	CTRL30B15t4-0	concrete crushed
Dune sand	10	DNSL30B15t4-1	concrete crushed
	25	DNSL30B15t4-2	concrete crushed
	50	DNSL30B15t4-3	concrete crushed
PVC crushed	2.5	PVCL30B15t4-1	concrete crushed
	5	PVCL30B15t4-2	concrete crushed
	10	PVCL30B15t4-3	Shear + concrete crushed
PVC sawdust	1.25	PVSL30B15t4-1	concrete crushed
	2.5	PVSL30B15t4-2	Shear + concrete crushed
	5	PVSL30B15t4-3	Shear failure
Iron Filling	2.5	IRNL30B15t4-1	Shear failure
	5	IRNL30B15t4-2	Shear failure
	10	IRNL30B15t4-3	Shear failure
Box plastic	2.5	BXCL30B15t4-1	concrete crushed
	5	BXCL30B15t4-2	concrete crushed
	10	BXCL30B15t4-3	concrete crushed

4.4.7 Stress-Strain Curves

4.4.7.1 Axial strain

The stress-strain curves consist of three zones. The first zone represents the composite action of concrete and steel tube to resist the loading, which continue up to plastic behaviour near yield point. The second zone is the transition region entered in which the tube exerts a lateral pressure on the core to counteract the core's tendency for stiffness degradation. Finally, a third zone is noted in which the tube is fully activated, and the stiffness is generally stabilized around a constant rate. The response in the third region is mainly dependent on the stiffness of the tube. Table (4-12) presented yield and ultimate capacity of stress and strain of (CFST) stub column specimens. The contribution of concrete is important in delaying the occurrence of buckling in steel; therefore, steel does not reach yield. Thus, the effect of sand replacement is evident by increasing the values of yield stress. Where the yield stress of 44 MPa, 45 MPa, 45 Mpa, 44 MPa and 45 MPa at 50% dune sand, 10% PVC crushed, 5% PVC sawdust, 2.5% iron filings and 2.5% plastic boxes waste respectively

Figure (4- 52) Mode of failure of (CFST) stub column specimens

Table (4- 12) Vertical stress strain of (CFST) stub with partially sand replacement

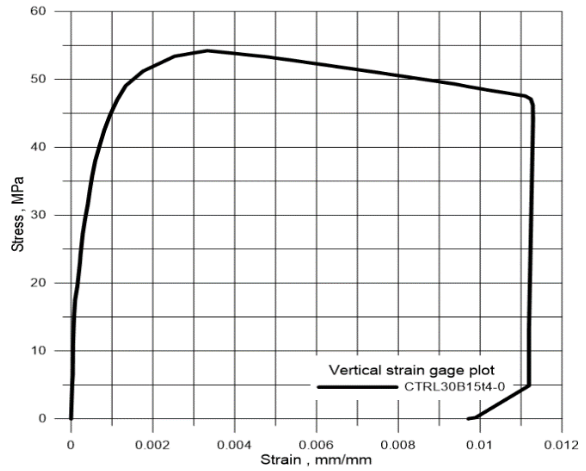
Material type	Replacement percentage (%)	sample code	*Yield zone*		*Ultimate capacity*	
			ε_y	σ_y MPa	ε_u	σ_u MPa
control	-	CTRL30B15t4-0	0.00070	40	0.0033	54
Dune sand	10	DNSL30B15t4-1	0.00078	40	0.0048	54
	25	DNSL30B15t4-2	0.00025	42	0.0015	57
	50	DNSL30B15t4-3	0.00068	44	0.0016	59
PVC crushed	2.5	PVCL30B15t4-1	0.00057	40	0.0018	58
	5	PVCL30B15t4-2	0.00005	44	0.0019	58
	10	PVCL30B15t4-3	0.00005	45	0.0003	59
PVC sawdust	1.25	PVSL30B15t4-1	0.00023	42	0.0006	56
	2.5	PVSL30B15t4-2	0.00002	41	0.0016	52
	5	PVSL30B15t4-3	0.00036	45	0.0011	64
Iron Filling	2.5	IRNL30B15t4-1	0.00031	44	0.0020	60
	5	IRNL30B15t4-2	0.00047	40	0.0026	55
	10	IRNL30B15t4-3	0.00044	44	0.0028	59
Box plastic	2.5	BXCL30B15t4-1	0.00091	45	0.0014	61
	5	BXCL30B15t4-2	0.00049	45	0.0015	58
	10	BXCL30B15t4-3	0.00091	40	0.0018	53

4.4.7.2 Energy

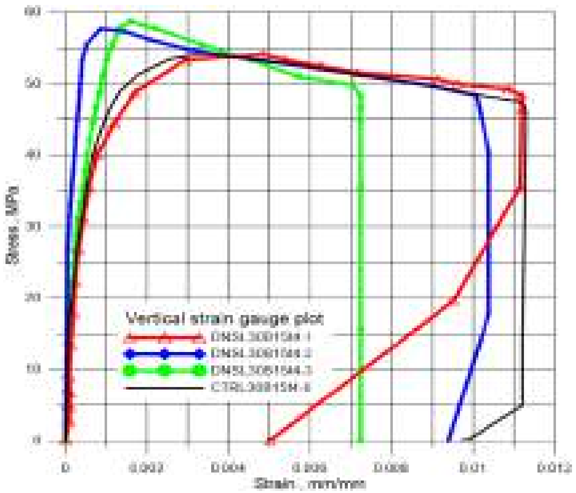
Energy is calculating from area under stress-strain curve. Figure (4-53) shows stress-strain curves of (CFST) stub columns. The curves have been grouped according to type of materials used as sand replacement. Table (4-13) indicated vertical strain energy of (CFST) stub column specimens.

Table (4- 13) Energy of (CFST) vertical with partially sand replacement

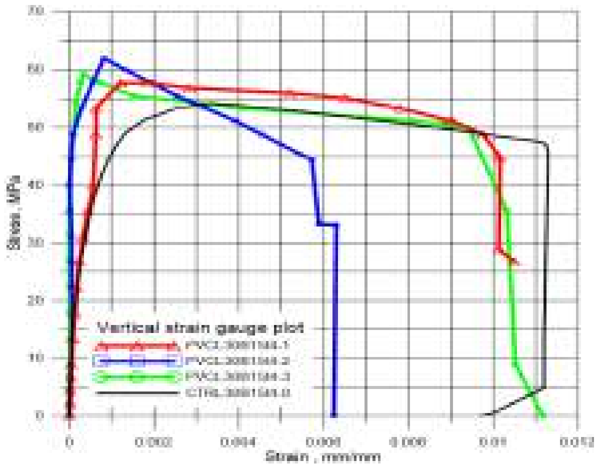
Material type	Replacement percentage	Sample code	Strain energy kpa	Change %
control	-	CTRL30B15t4-0	553	0
Dune sand	10	DNSL30B15t4-1	461	-17
	25	DNSL30B15t4-2	533	-4
	50	DNSL30B15t4-3	374	-32
PVC crushed	2.5	PVCL30B15t4-1	547	-1
	5	PVCL30B15t4-2	322	-42
	10	PVCL30B15t4-3	547	-1
PVC sawdust	1.25	PVSL30B15t4-1	307	-45
	2.5	PVSL30B15t4-2	366	-34
	5	PVSL30B15t4-3	481	-13
Iron Filling	2.5	IRNL30B15t4-1	592	+7
	5	IRNL30B15t4-2	638	+15
	10	IRNL30B15t4-3	595	+8
Box plastic	2.5	BXCL30B15t4-1	495	-11
	5	BXCL30B15t4-2	325	-41
	10	BXCL30B15t4-3	411	-26



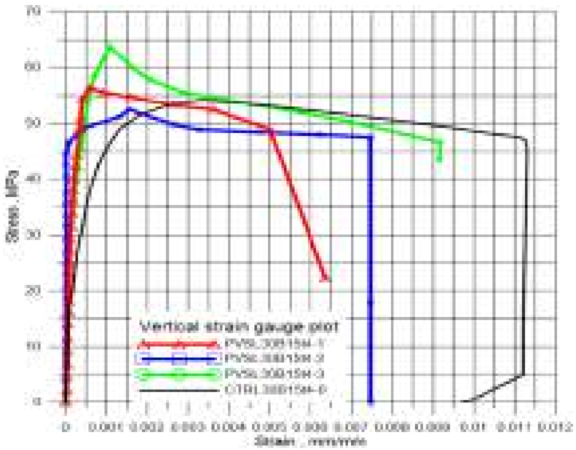
a) Reference specimen



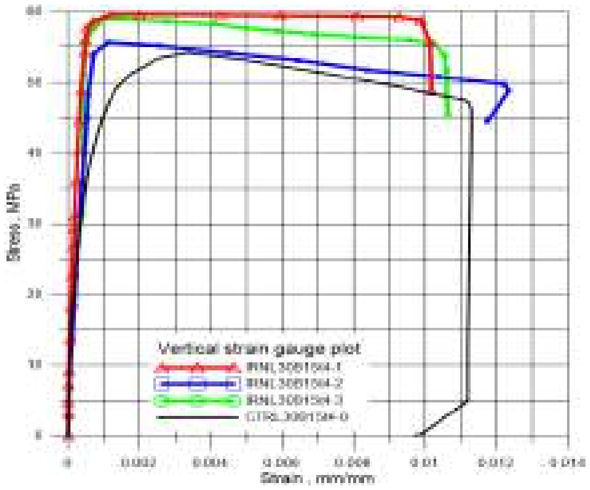
b) Dune sand replacement



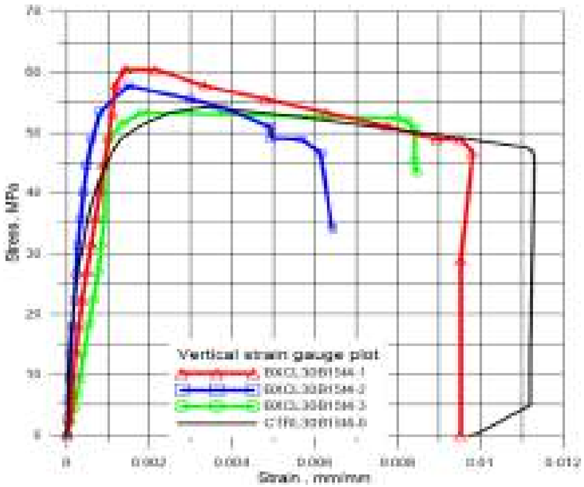
c) PVC crushed replacement



d) PVC sawdust replacement



e) Iron filings replacement



f) Plastic boxes waste replacement

Figure (4- 53) Vertical stress-strain (σ – ε) curves of CFST column specimens

Dune sand: It is observed from Table (4-13) and Figure (4-54), that all samples which contain dune sand with dosages range of 10%, 25% and 50 % showed a decrease in strain energy of 461 kpa, 533 kpa and 374 kpa, that is less than control specimen by 17%, 4% and 32% respectively. The mix that contains on 25% of dune sand as sand replacement is the optimum percentage which indicated a strain energy of 533 kpa. Table (4-12) showed that the optimum yield stress of specimen with 50% dune sand is 44 MPa.

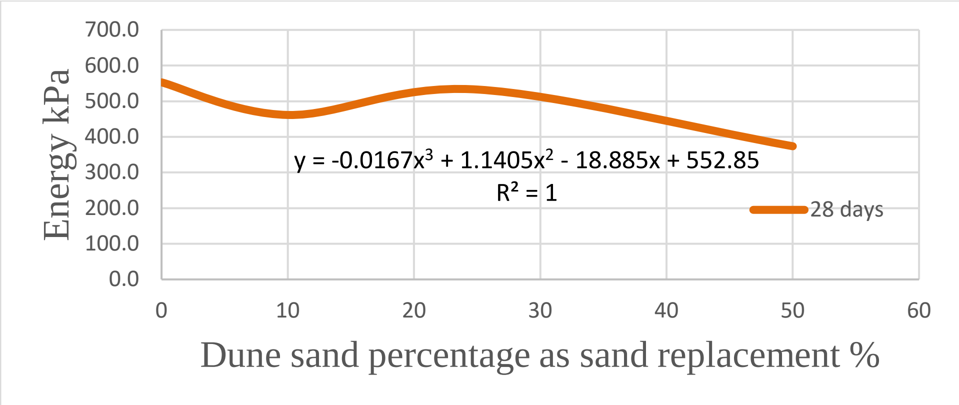


Figure (4- 54) Strain energy of (CFST) stub column with dune sand

PVC crushed: It is evident from Table (4-13) and Figure (4-55), that all samples which contain PVC crushed particles with dosages 2.5% ,5 % and 10% show a decrease in strain energy by about 1%,42% and 1% respectively. The mix that contains on 10% of PVCC particles as replacement of sand is the optimum percentage which gave a strain energy of 547 kPa. Table (4-12) showed that the optimum yield stress of specimen with 10% PVC crushed is 45 MPa.

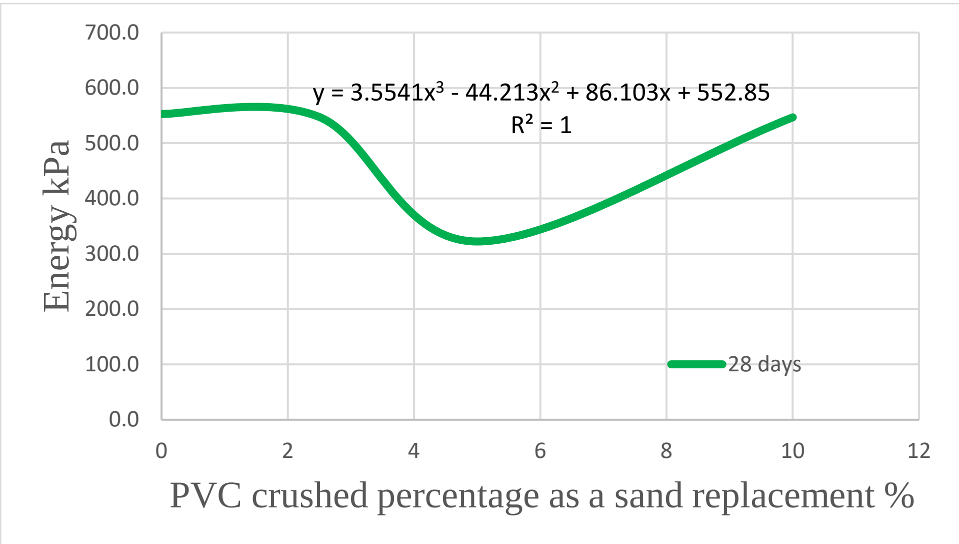


Figure (4- 55) Strain energy of stub column with PVC crushed

PVC sawdust: Table (4-13) and Figure (4-56), showed that all samples which contain PVC sawdust (PVCS) with dosages 1.25%, 2.5% and 5 % showed a decrease in strain energy by about 45%, 34% and 13% compared to control specimen respectively. The mix that contains on 5% of PVC sawdust as sand replacement is the optimum percentage which gave a strain energy of 481 kPa. Table (4-12) showed that the optimum yield stress of specimen with 10% PVC sawdust is 45 MPa.

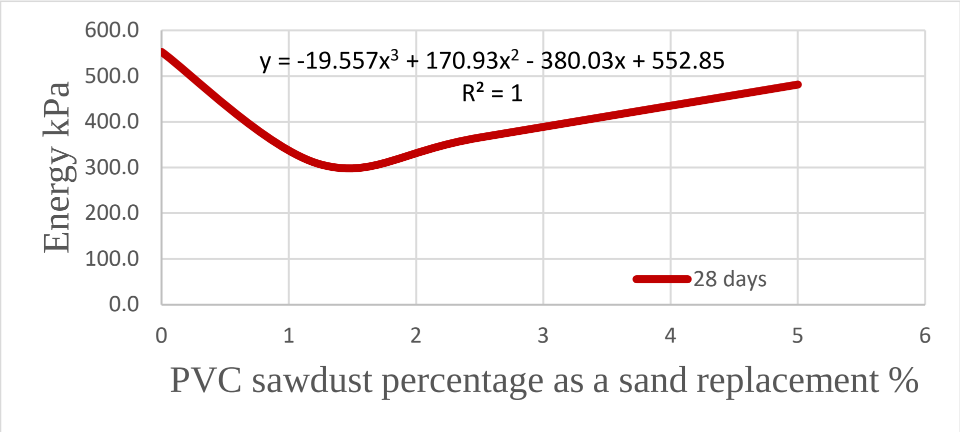


Figure (4- 56) Strain energy of stub column with PVC sawdust

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed an increase in strain energy as shown in Table (4-13) and Figure (4-57). Using an iron filling showed an increasing in strain energy of 592 kPa,638 kPa and 595 kPa at 2.5%, 5% and 10% replacement ratio of iron filings namely greater than control specimen by 7%,15% and 8% respectively. The mix that contains on 2.5% of iron filings as sand replacement is the optimum percentage which gave a strain energy of 638 kPa, namely greater than control specimen by 15%. Table (4-12) showed that the optimum yield stress of specimen with 10% iron filings is 44 MPa.

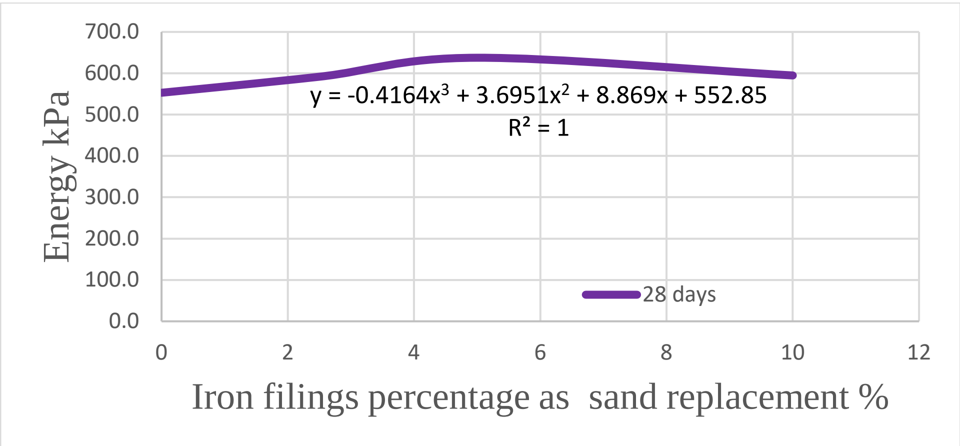


Figure (4- 57) Strain energy of stub column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on strain energy is shown in Table (4-13) and Figure (4-58). It is observed that the samples contain box plastic waste particle with dosage of 2.5%,5% and 10% showed a decrease in strain energy of 495 kPa, 325 kPa and 411 kPa, namely less than reference specimen by about 11%, 41% and 26% respectively. The mix that contains on 2.5% of plastic boxes waste as sand replacement is the optimum percentage which gave a strain energy of 495 kPa. Table (4-12) showed that the optimum yield stress of specimen with 5% plastic boxes waste is 45 MPa.

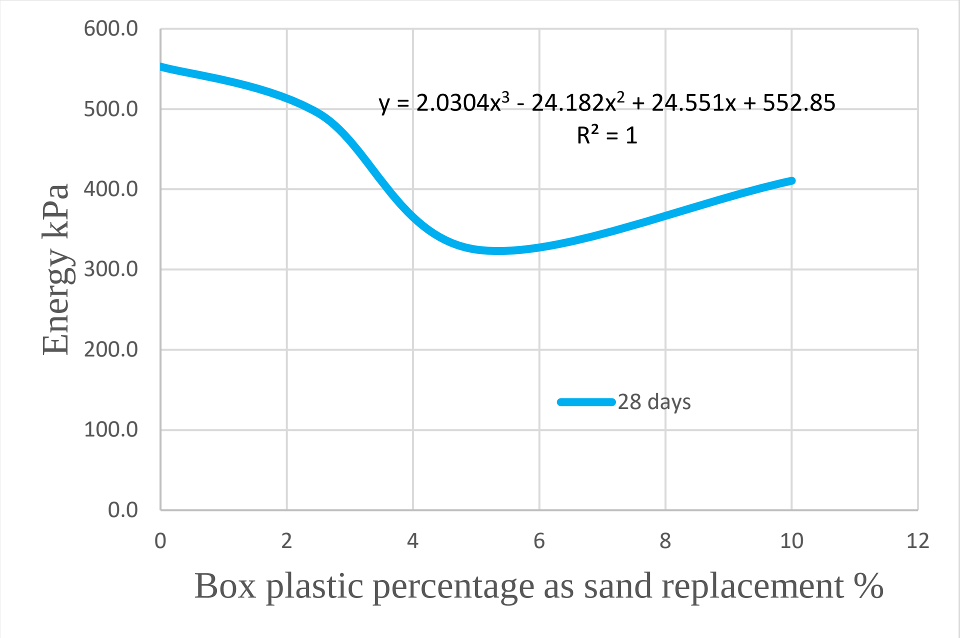
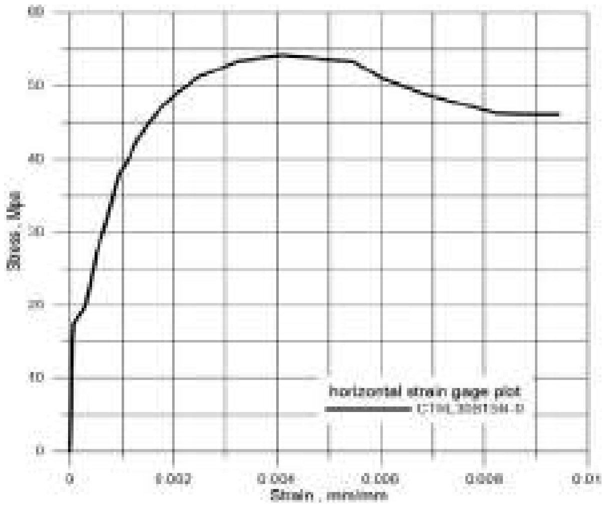


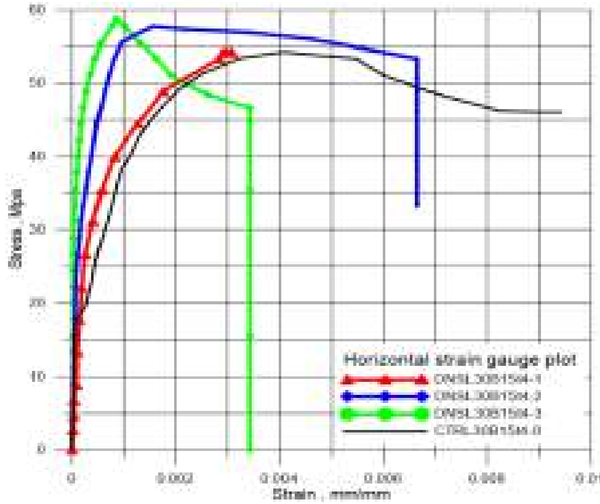
Figure (4- 58) Strain energy of (CFST) stub column with plastic boxes waste

4.4.7.3 Lateral Strain

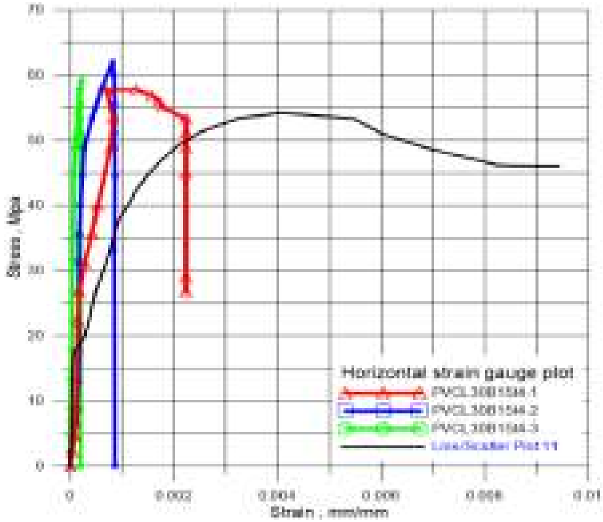
Response in the lateral direction is closer to a straight line than the response in the axial direction as shown in Figure (4-59). This is due to excessive cracking of the concrete core which is no longer a homogeneous material. Therefore, lateral expansion of the specimen is directly dependent on the response of the tube, which is assumed to be linearly-elastic. Although the third region depends entirely on steel tube, the first and second regions is an important value resulting from the effect of concrete and, accordingly, the effect of sand replacement. However, the effect of sand replacement depends on the type of material replacement (dune sand, PVC crushed, PVC sawdust, iron fillings and plastic boxes waste).



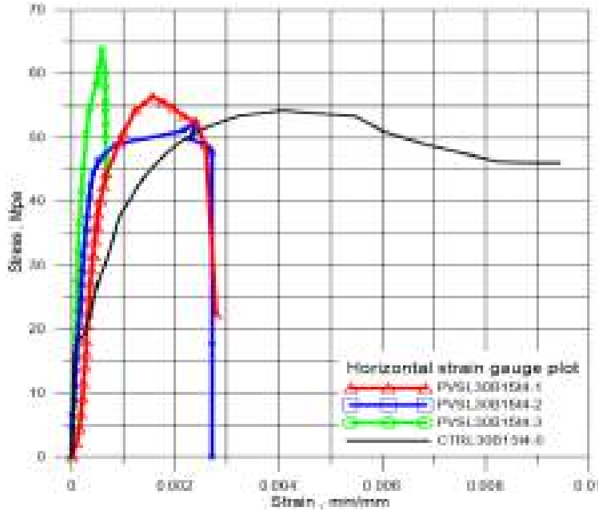
a) Reference specimen



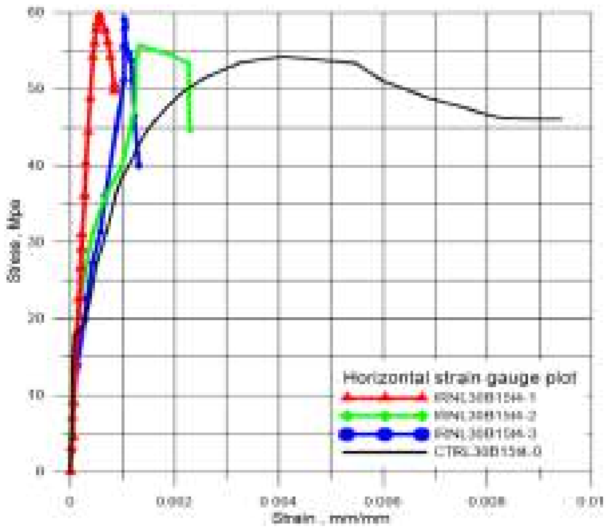
b) Dune sand replacement



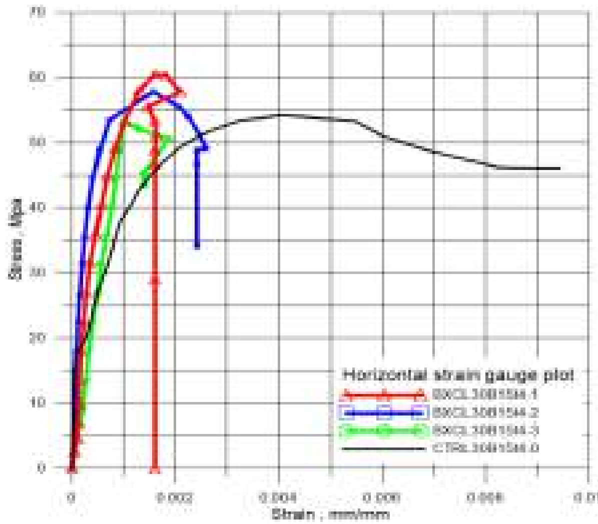
c) PVC crushed replacement



d) PVC sawdust replacement



e) Iron filings replacement



f) Plastic box waste replacement

Figure (4- 59) Horizontal stress-strain (σ – ε) curves of CFST stub column specimens

4.5 Short Columns

4.5.1 Axial Load Capacity

The load capacity of all (CFST) short columns specimens are shown in Table (4-14). The experimental results are compared with theoretical equation to show the relative increasing due to concrete by steel tube.

Table (4- 14) Experimental and theoretical axial load capacity for short columns.

Material type	Replacement percentage (%)	sample code	N_{Exp} (kN)	*Change in* $N_{Exp.}$ *(%)*	$N_{theo.}$ *(kN)*	N_{Exp} / $N_{theo.}$ *ratio*
control	-	CTRL40B10t3-0	807	0	517	1.56
Dune sand	10	DNSL40B10t3-1	779	-3	525	1.48
	25	DNSL40B10t3-2	755	-6	551	1.37
	50	DNSL40B10t3-3	870	+8	522	1.67
PVC crushed	2.5	PVCL40B10t3-1	761	-6	551	1.38
	5	PVCL40B10t3-2	763	-5	533	1.43
	10	PVCL40B10t3-3	708	-12	541	1.31
PVC sawdust	1.25	PVSL40B10t3-1	828	+3	507	1.63
	2.5	PVSL40B10t3-2	759	-6	515	1.47
	5	PVSL40B10t3-3	791	-2	489	1.62
Iron Filling	2.5	IRNL40B10t3-1	853	+6	550	1.55
	5	IRNL40B10t3-2	730	-10	532	1.37
	10	IRNL40B10t3-3	690	-14	540	1.28
Box plastic	2.5	BXCL40B10t3-1	659	-18	515	1.28
	5	BXCL40B10t3-2	771	-4	540	1.43
	10	BXCL40B10t3-3	644	-20	482	1.34

Dune sand: It is observed from Table (4-14) and Figure (4-60), that samples which contain dune sand with replacement of 10 % and 25% show a decrease in load capacity of 759 kN and 755 kN, namely decreasing by about 6% and 3% of 28 days' age. The mix that contains on 50% of dune sand as sand replacement is the optimum percentage which gave a load capacity of 870 kN (8% greater than control specimen)

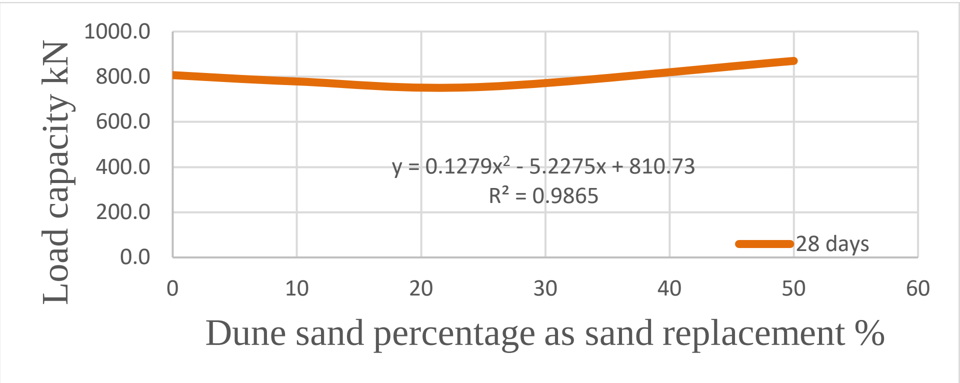


Figure (4- 60) Load capacity of CFST short column with dune sand

PVC crushed: It is evident from Table (4-14) and Figure (4-61), that all (CFST) samples which contain PVC crushed particles with dosages 2.5% ,5 % and 10% show a decrease in load capacity by about 6%, 5% and 12% respectively for 28 days. The mix that contains on 5% of PVCC particles as replacement of sand is the optimum percentage which gave a load capacity of 763 kN.

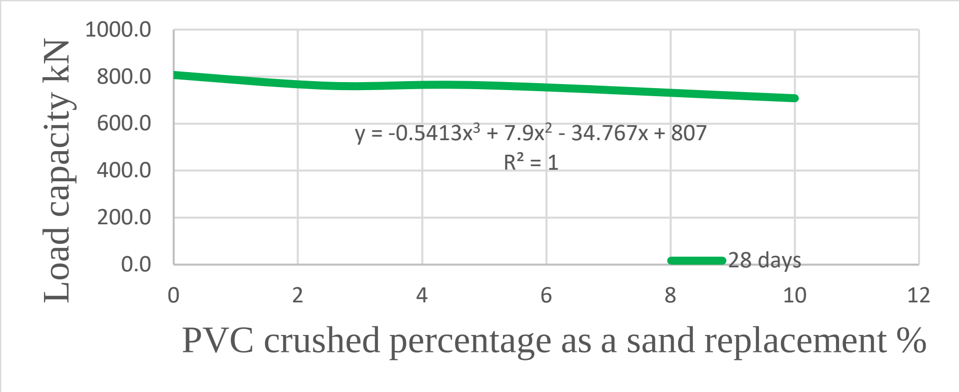


Figure (4- 61) Load capacity of CFST short column with PVC crushed

PVC sawdust: From Table (4-14) and Figure (4-62), that the (CFST) samples which contain PVC sawdust (PVCS) with dosages 2.5% and 5 % show a decrease in load capacity by about 6% and 2% for 28-day test, while it shows an increase in dosage 1.25%, namely by 3%, the mix that contains on 1.25% of PVC sawdust as sand replacement is the optimum percentage which gave a load capacity of 828 kN namely by 3% greater than control specimen.

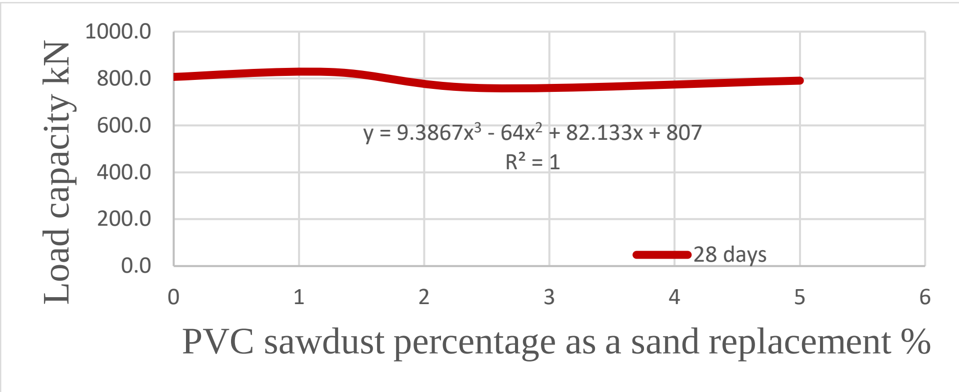


Figure (4- 62) Load capacity of CFST short column with PVC sawdust

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed an increasing in load capacity at 2.5% dosage by about 6% as shown in Table (4-14) and Figure (4-63) for 28-day test. Using an iron filling as replacement showed an increasing in load capacity at 5% and 10% dosages of iron filings by about 10% and 14% respectively, compared control mix. The dosage of 2.5% of iron filings gives optimum load capacity of 853 kN, namely 6% greater than control specimen.

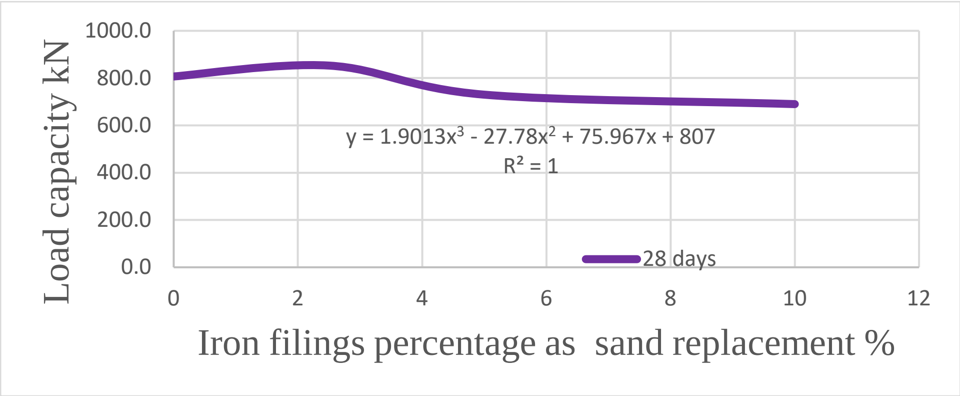


Figure (4- 63) Load capacity of CFST short column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on load capacity of CFST samples is shown in Table (4-14) and Figure (4-64). It is observed that the samples contain plastic boxes waste particle with dosage of 2.5%, 5% and 10% showed a decrease in load capacity in 28 days' age 659 kN ,771 kN and 644 kN, namely less than reference mix by about 18%,4% and 20%, the dosages 5% of plastic box particles gives optimum value of 771 kN.

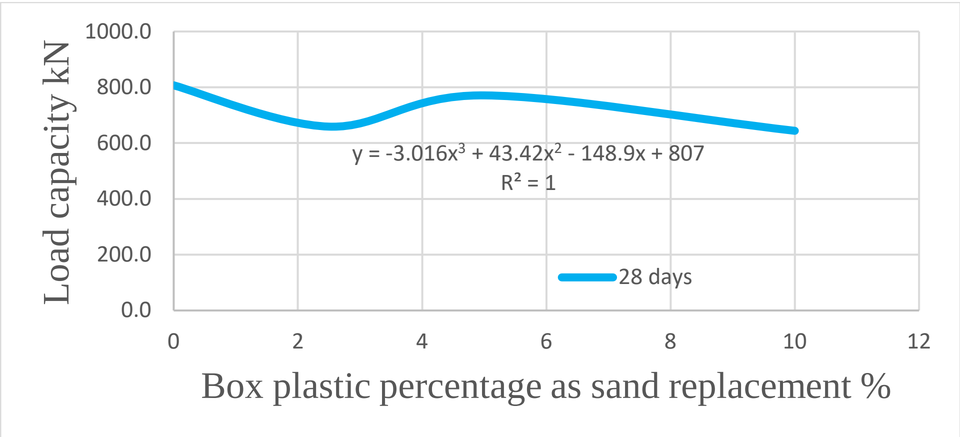


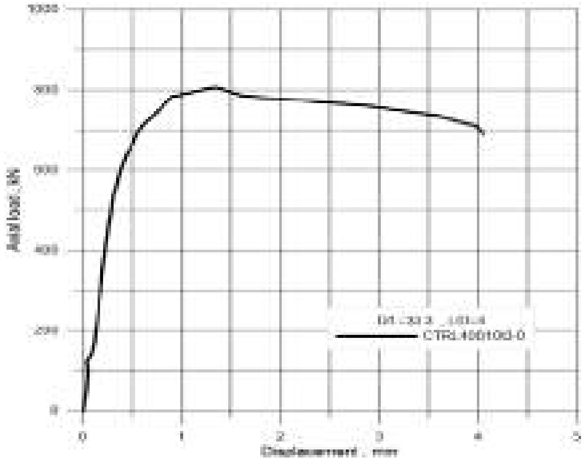
Figure (4- 64) Load capacity of CFST short column with plastic boxes waste

4.5.2 Theoretical Load Capacity of composite column

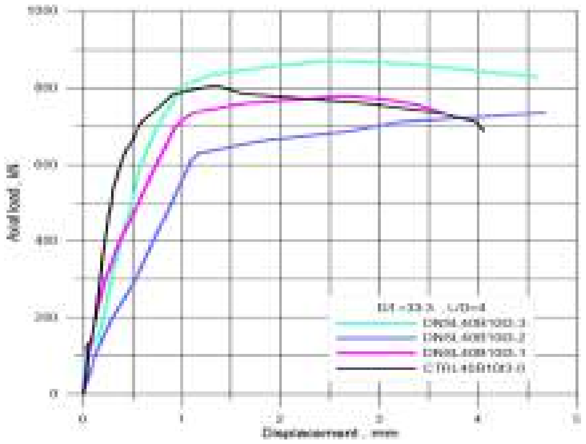
The results of load capacity of short column specimens are shown in Tables (4-14). The difference ranged from 21% to 49% is evident by comparing the experimental results with theoretical results except for 1.25%, 5% PVC sawdust and 50% dune sand which reached 56%, 56% and 59% respectively.

4.5.3 Load-Displacement Curve

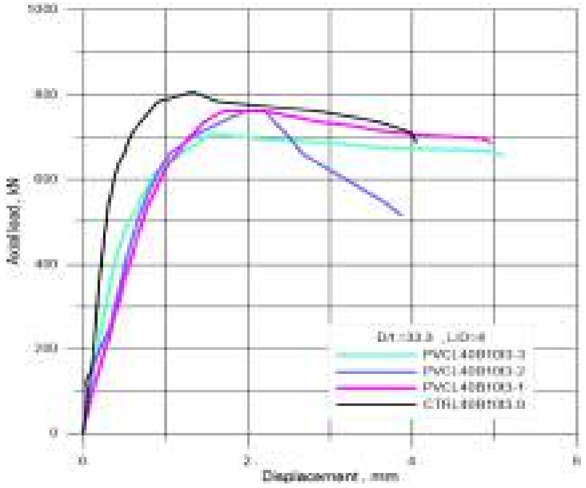
Toughness values for the short column specimens are shown in Table (4-15) and are calculated from the curves in the Figure (4-65), where the area under the curve is calculated for all column specimens.



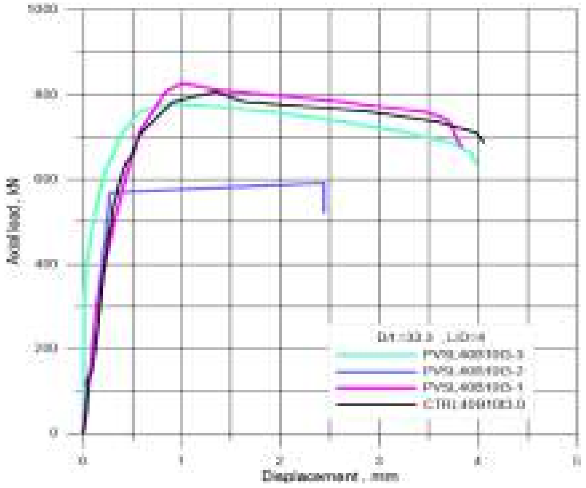
a) Reference specimen



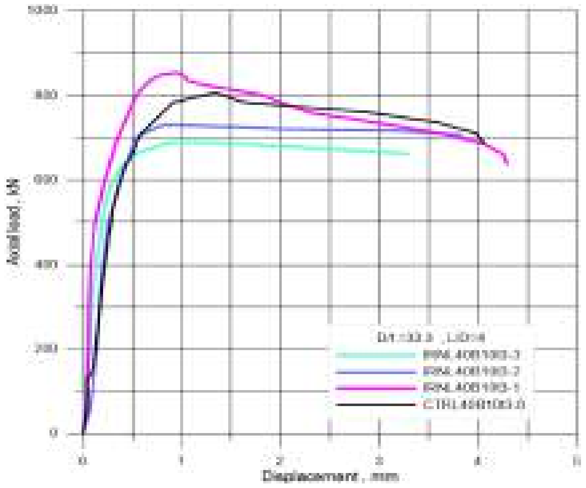
b) Dune sand replacement



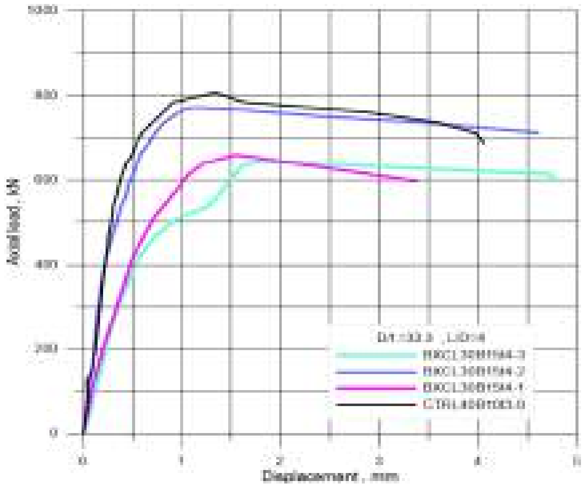
c) PVC crushed replacement



d) PVC sawdust replacement



e) Iron filings replacement



f) Plastic boxes waste replacement

Figure (4- 65) Load displacement curve of (CFST) short column specimens

Table (4- 15) Toughness of (CFST) with partially sand replacement.

Material type	Replacement percentage (%)	Sample code	*Toughness kN.mm*	*Change %*	*Δmax* mm
control	-	CTRL40B10t3-0	2899	0	4
Dune sand	10	DNSL40B10t3-1	2264	-22	3
	25	DNSL40B10t3-2	2632	-9	5
	50	DNSL40B10t3-3	3116	+8	4
PVC crushed	2.5	PVCL40B10t3-1	3204	+11	5
	5	PVCL40B10t3-2	2222	-23	3
	10	PVCL40B10t3-3	3174	+10	5
PVC sawdust	1.25	PVSL40B10t3-1	2904	0	4
	2.5	PVSL40B10t3-2	1335	-54	2
	5	PVSL40B10t3-3	2670	-8	4
Iron Filling	2.5	IRNL40B10t3-1	2990	+3	3
	5	IRNL40B10t3-2	3186	+10	5
	10	IRNL40B10t3-3	3194	+10	5
Box plastic	2.5	BXCL40B10t3-1	1875	-35	3
	5	BXCL40B10t3-2	3294	+14	5
	10	BXCL40B10t3-3	2696	-7	5

Dune sand: From the Table (4-15) and figure (4-66), it is noted that the increase of dune sand as partially replacement lead to decrease toughness in 2.5% and 5% by 2264 kN.mm,2632 kN.mm respectively, by about 22%,9% respectively, while 10% dune sand fulfill increasing by about 8% dune sand to be optimum dosage of 3116 kN.mm. with increasing of maximum displacement of 3mm,5mm and 4mm respectively.

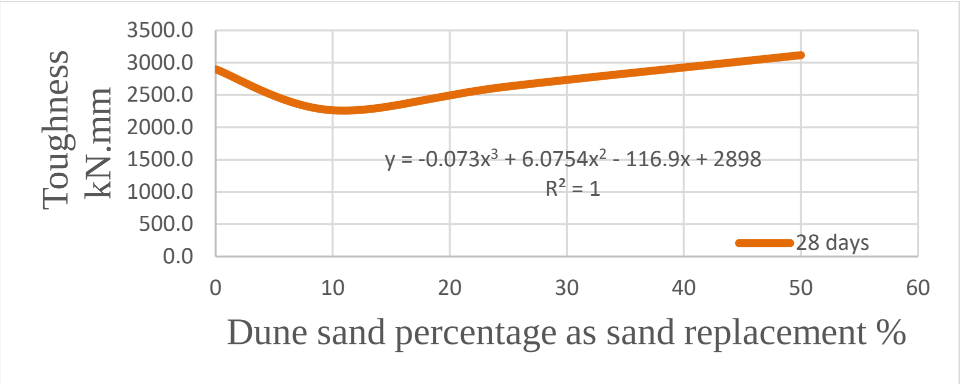


Figure (4- 66) Toughness of short column with dune sand

PVC crushed: From the Table (4-15) and Figure (4-67), the using PVC crushed as a substitute for sand in (CFST) columns, the value of toughness is 3204 kN.mm,3174 kN.mm at 2.5% and 10% ratio, that means it increases about 11% and 10% respectively, while toughness is decreased at 5% PVC crushed with 3174 kN.mm, namely by about 23%. The maximum displacement fulfills increasing at 2.5% and

10% PVC crushed of 5mm, and 5% PVC crushed is closed to reference specimen of 3 mm.

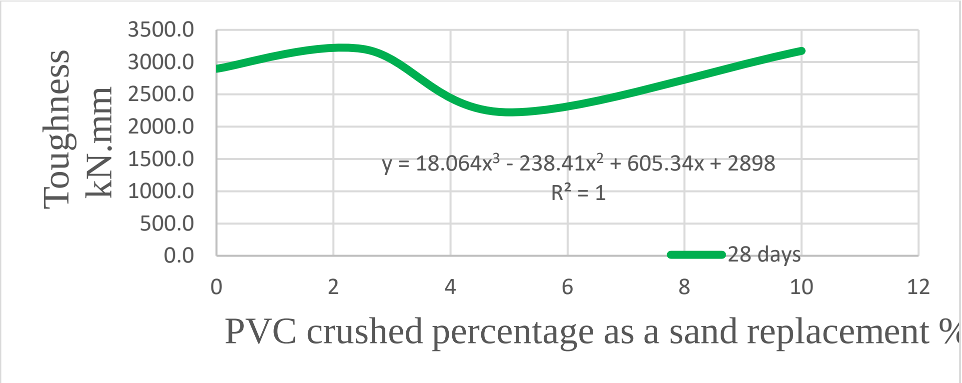


Figure (4- 67) Toughness of short column with PVC crushed

PVC sawdust: From the Table (4-15) and figure (4-68), column specimens are containing PVC sawdust show a noticeable decrease of percentage range from 2.5% to 5% of 1335 kN.mm and 2670 kN.mm, namely by about 54% and 8% however, the increase in the value of in the PVC sawdust ratio lead to increase in maximum displacement namely 4mm in 2.5% and 10% PVC sawdust.

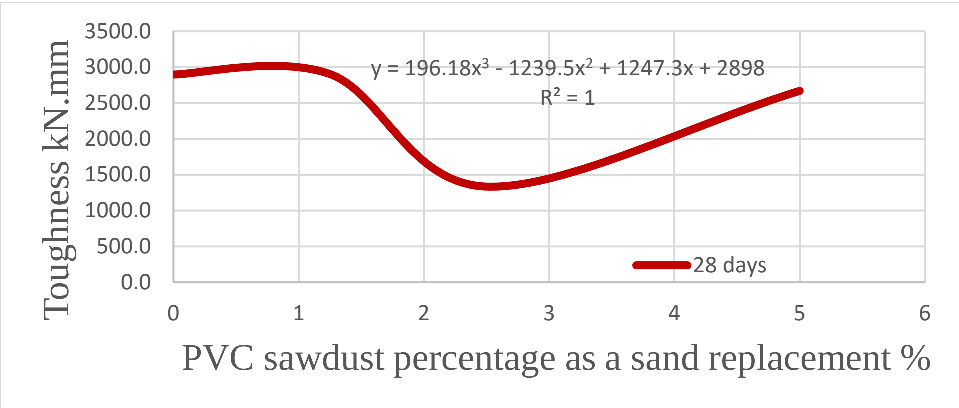


Figure (4- 68) Toughness of short column with PVC sawdust

Iron filings: From the Table (4-15) and figure (4-69), the toughness values are increased for the specimens in which the iron filings are used with increment of percentage of iron filing for all percentage from 2.5% to 10% of 2990 kN.mm ,3186 kN.mm and 3194 kN.mm respectively. The optimum value 3194kN.mm is at 10% iron filings. The maximum displacement still close to reference column specimen in 2.5% iron filing, but little increment namely 5mm in 5% and 10% iron filing dosage respectively.

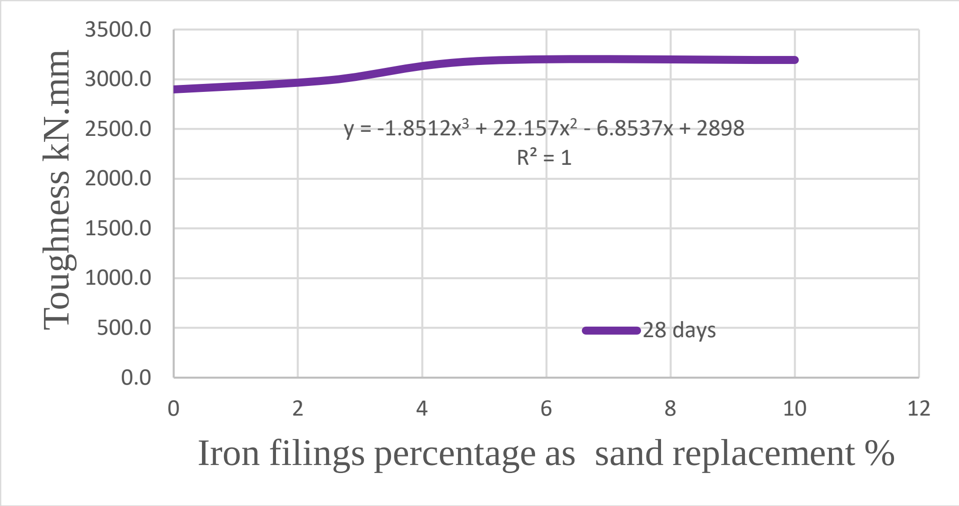


Figure (4- 69) Toughness of short column with iron filings

Plastic boxes waste: The effect of plastic boxes particles on toughness is shown in Table (4-15) and Figure (4-70). It is observed that the samples contain box plastic waste particle with dosage 2.5% and 10% showed a decrease in toughness of 1875 kN.mm and 2696 kN.mm, namely by about 35% and 7% respectively. The optimum is dosages 2.5% of 3294 kN.mm namely 14%. The maximum displacement still close to reference column specimen in 2.5% plastic boxes waste, but increment namely 5mm in 5% and 10% plastic boxes waste replacement respectively.

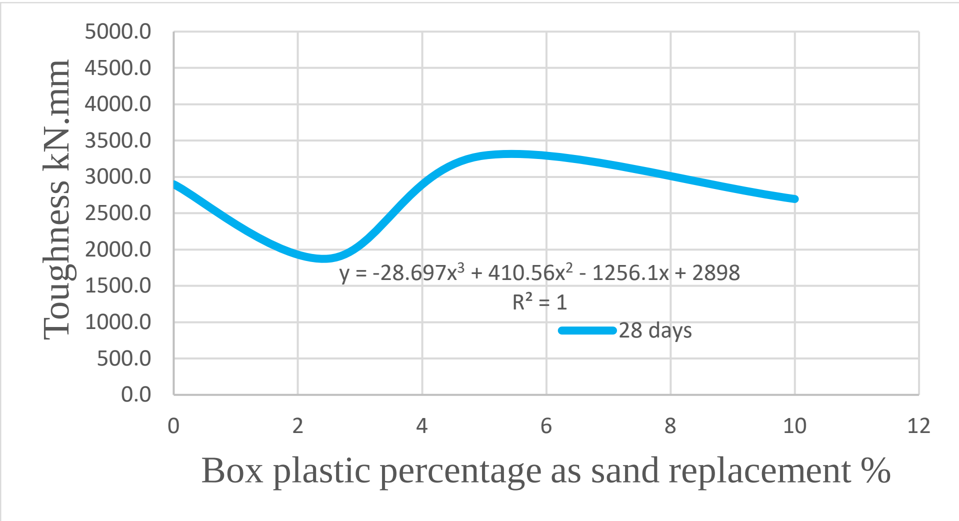


Figure (4- 70) Toughness of short column with plastic box waste

4.5.4 Ductility Index (DI)

Ductility index of short column specimens is shown in Table (4-16). The maximum value of is DI=5.70 at 5% of iron replacement, and the minimum value DI= 0.97 at 25% of dune sand, compared with control specimen of value 3.03

Table (4- 16) Results ductility index of (CFST) short column specimen

Material type	Replacement percentage (%)	Specimen	N_{Exp} (kN)	DI	Change %
control	-	CTRL40B10t3-0	807	3.03	0
Dune sand	10	DNSL40B10t3-1	779	1.34	-56
	25	DNSL40B10t3-2	755	0.97	-68
	50	DNSL40B10t3-3	870	1.85	-39
PVC crushed	2.5	PVCL40B10t3-1	761	2.90	-4
	5	PVCL40B10t3-2	763	1.39	-54
	10	PVCL40B10t3-3	708	3.30	+9
PVC sawdust	1.25	PVSL40B10t3-1	828	3.75	+24
	2.5	PVSL40B10t3-2	759	1.00	-67
	5	PVSL40B10t3-3	791	4.50	+48
Iron Filling	2.5	IRNL40B10t3-1	853	3.11	+3
	5	IRNL40B10t3-2	730	5.70	+88
	10	IRNL40B10t3-3	690	4.57	+51
Box plastic	2.5	BXCL40B10t3-1	659	2.21	-27
	5	BXCL40B10t3-2	771	4.39	+45
	10	BXCL40B10t3-3	644	2.09	-31

Dune sand: It is observed from Table (4-16) and Figure (4-71), that specimens which contain dune sand with all replacement ratio of 10%, 25% and 50 % show a decrease in ductility index of 1.34, 0.97 and 1.85, namely by about 56%, 68% and 39% respectively for 28 days less than reference specimen.

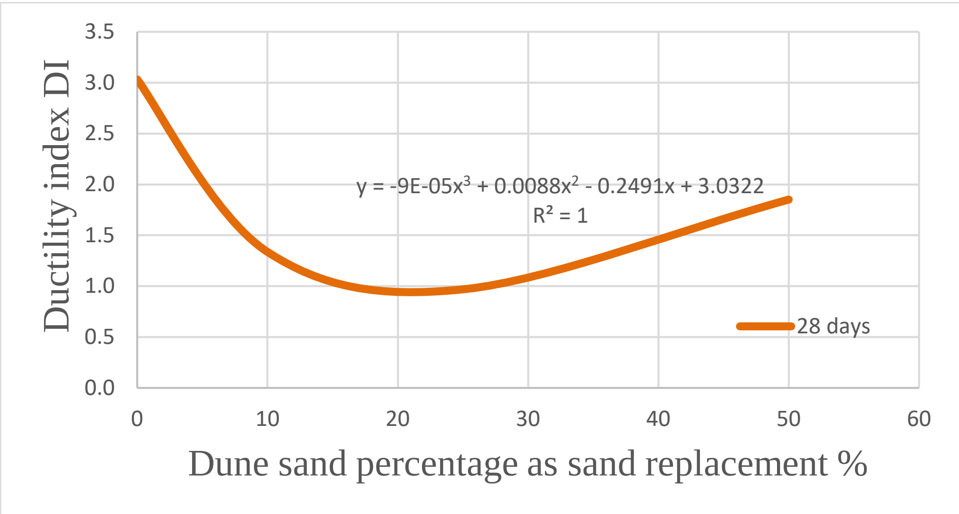


Figure (4- 71) Ductility index of short column with dune sand

PVC crushed: It is evident from Table (4-16) and Figure (4-72), that samples which contain PVC crushed particles with replacement ratio 2.5% to 5 % show a decrease in ductility index of 2.9 and 1.39, that means a decrease by about 4% and 45% respectively for 28 days less than reference specimen, while percentage 10%

of PVC crushed gives 3.30 namely increased 9% more than reference specimen to be optimum value at 10% PVCC.

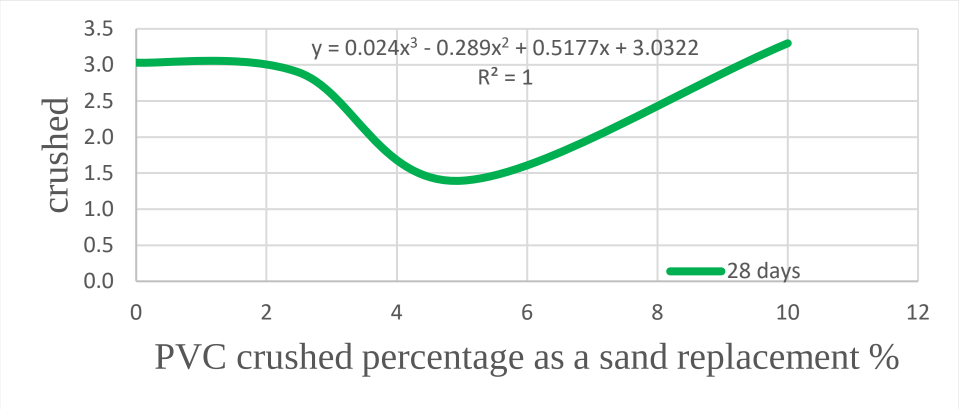


Figure (4- 72) Ductility index of short column with PVC crushed

PVC sawdust: From Table (4-16) and Figure (4-73), that samples which contain PVC sawdust (PVCS) with dosages 1.25% and 5 % show an increased in ductility index of (3.75 and 4.50), by about 24% and 48% for 28-day test more than reference specimen. While 2.5% shows a decrease 1.00% namely 67% less than reference specimen. The mix that contains on 5% of PVC sawdust as sand replacement is the optimum percentage which a ductility index is 4.50, greater than control specimen by 48%.

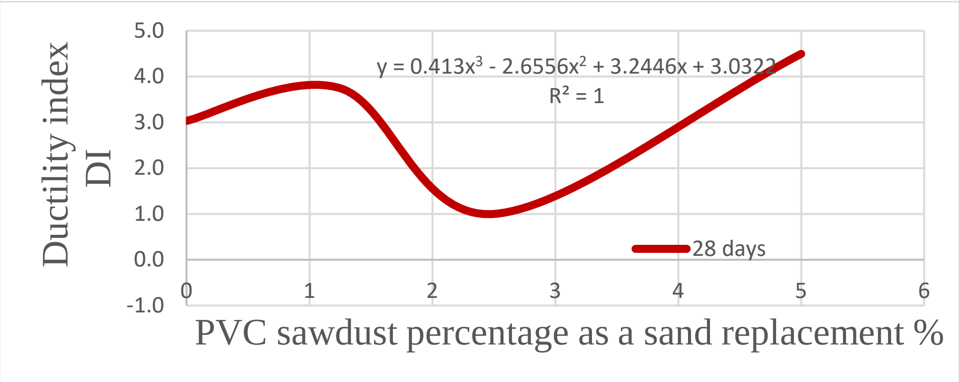


Figure (4- 73) Ductility index of short column with PVC sawdust

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed an increase in ductility index as shown in Table (4-16) and Figure (4-74). The ductility index is increased in the percentage of iron filings from 2.5% to 10% which presented a ductility index in 28 days' age of 3.11,5.70 and 4.57 that means the ductility index of specimens that contained iron filings larger than specimens of control mix by 3%, 88% and 51%. The mix that contains on 5% of iron filings as sand replacement is the optimum percentage which give a ductility index of 5.70% greater than control specimen by 88%.

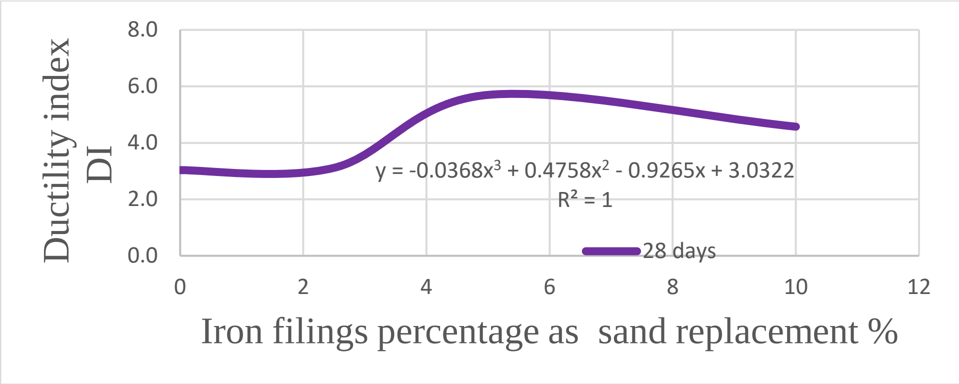


Figure (4- 74) Ductility index of short column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on concrete ductility index is shown in Table (4-16) and Figure (4-75). It is observed that the samples contain box plastic waste particle with dosage of 2.5% and 10% showed a decrease in ductility index in 28 days' age of 2.21 and 2.09, namely less than reference specimen by about 27% and 31% respectively. The mix that contains on 2.5% of plastic boxes waste as sand replacement is the optimum percentage which gave a ductility index of 4.39, greater than control specimen by 45%.

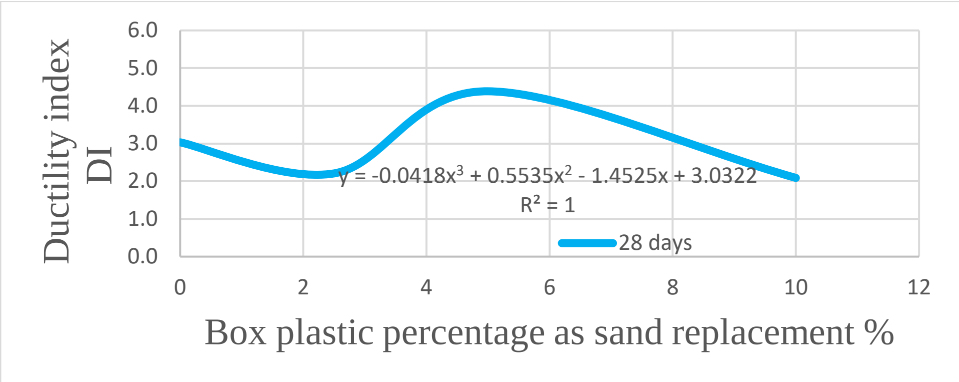


Figure (4- 75) Ductility index of short column with plastic boxes waste

4.5.5 Stiffness

Strength and stiffness are the most important properties in a material. The strength of the material dominates the determination of the collapse load of a structure, whilst its stiffness ensures that the structure does not failure rapidly under the load. Table (4-17) shows stiffness results of (CFST) short column specimens with sand replacement.

Table (4- 17) Stiffness of (CFST) with partially sand replacement.

Material type	Replacement percentage (%)	sample code	stiffness(k) kN/mm	Change %
Control	-	CTRL40B10t3-0	1665	0
Dune sand	10	DNSL40B10t3-1	886	-47
	25	DNSL40B10t3-2	560	-66
	50	DNSL40B10t3-3	1026	-38
PVC crushed	2.5	PVCL40B10t3-1	688	-59
	5	PVCL40B10t3-2	732	-56
	10	PVCL40B10t3-3	927	-44
PVC sawdust	1.25	PVSL40B10t3-1	1552	-7
	2.5	PVSL40B10t3-2	2030	+22
	5	PVSL40B10t3-3	5018	+201
Iron Filling	2.5	IRNL40B10t3-1	2783	+67
	5	IRNL40B10t3-2	1936	+16
	10	IRNL40B10t3-3	2677	+61
Box plastic	2.5	BXCL40B10t3-1	834	-50
	5	BXCL40B10t3-2	1401	-16
	10	BXCL40B10t3-3	639	-62

Dune sand: It is observed from Table (4-17) and Figure (4-76), that all samples which contain dune sand with percentage of 10%, 25% and 50 % showed a decrease in stiffness of 886kN/mm,560kN/mm and 1026kN/mm, by about 47%, 66%and 38% respectively for 28 days and specimens which contain dune sand with dosages 50% showed a decrease in stiffness by about 38%. The best percentage which gave a stiffness of 1026 kN/mm at 50% dosage.

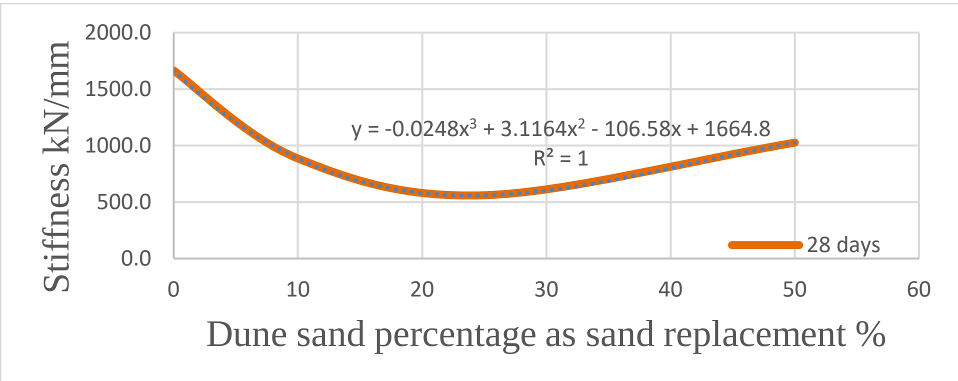


Figure (4- 76) Stiffness of short (CFST) column with dune sand

PVC crushed: From the Table (4-17) and figure (4-77), that all samples which contain PVC crushed with percentage of 2.5%, 5% and 10% showed a decrease in stiffness of 688 kN/mm,732 kN/mm and 927 kN/mm, namely by about 59%, 56%

and 44% respectively less than reference specimen. The optimum percentage 10% gives 927 kN/mm.

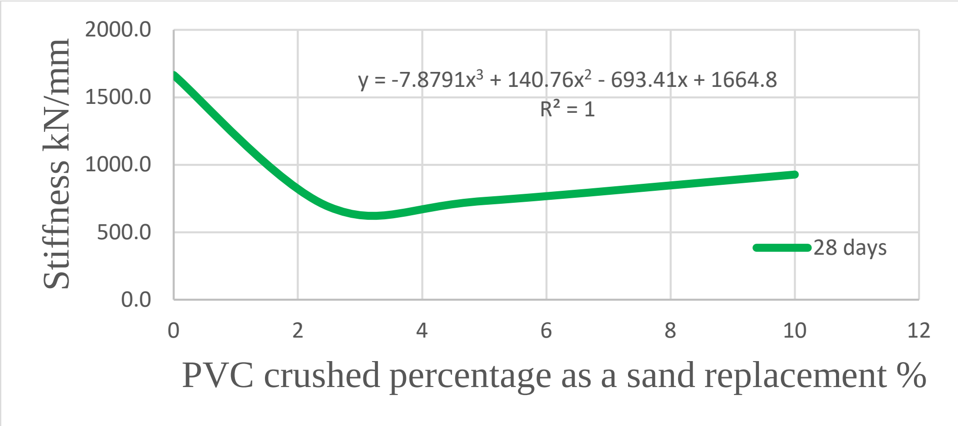


Figure (4- 77) Stiffness of short (CFST) column with PVC crushed

PVC sawdust: From the Table (4-17) and figure (4-78), column specimens are containing PVC sawdust show an unnoticeable decrease of percentage 1.25% by about 7% less than reference specimen, while percentage ranged from 2.5% to 5% showed an increase stiffness of 2030 kN/mm and 5018 kN/mm, namely by about 22% and 201% respectively. The stiffness at 5% dosage gives optimum value of 2030 kN/mm by about 201% more than reference specimen.

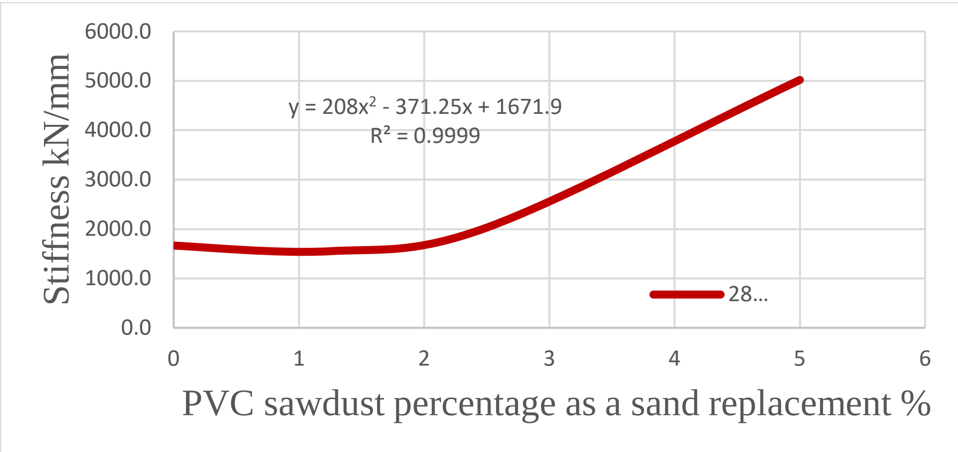


Figure (4- 78) Stiffness of short (CFST) column with PVC sawdust

Iron filings: It is evident from Table (4-17) and Figure (4-79), that all samples which contain iron filings with dosages of 2.5%, 5% and 10 % showed an increase in stiffness of 2783 kN/mm,1936kN/mm and 2677 kN/mm, namely by about 67%, 16% and 61% respectively for 28 days' age. The mix that contains on 2.5% of iron filings as sand replacement is the optimum percentage which gave a stiffness of 2783 kN/mm, namely greater than control specimen by 67%.

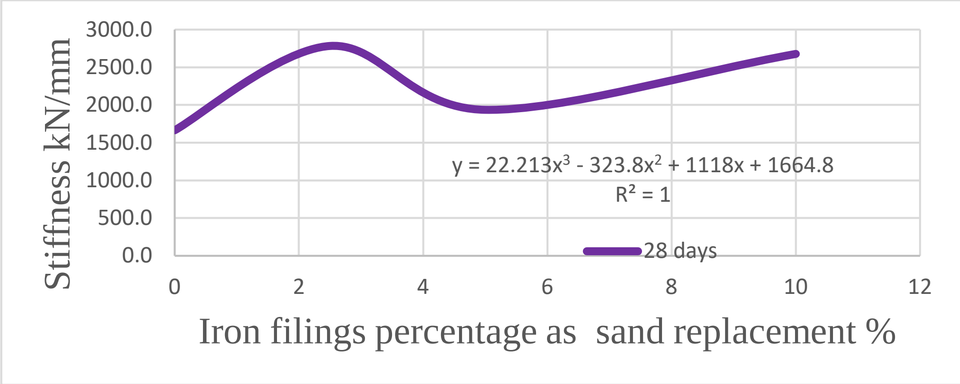


Figure (4- 79) Stiffness of short (CFST) column with Iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on concrete compressive strength is shown in Table (4-17) and Figure (4-80). It is observed that the samples contain box plastic waste particle with percentage ranged from 2.5% to 10% showed a decrease in stiffness in 28 days' age of 834 kN/mm, 1401 kN/mm and 639 kN/mm, by about 50%,16% and 62% respectively less than reference specimens.

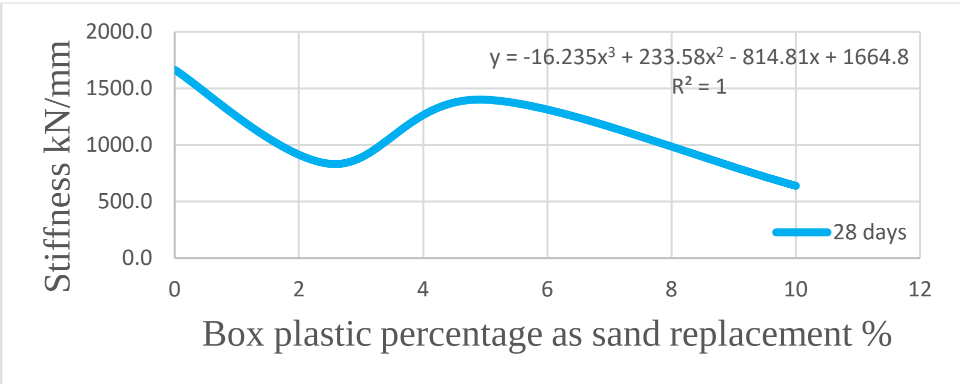


Figure (4- 80) Stiffness of short (CFST) column with plastic boxes waste

4.5.6 Mode of Failure

Figure (4-81) and Table (4-18) display the failure modes of the (CFST) short columns specimens. In general, two failure modes are observed for concrete filled steel tube (CFST); local buckling and global buckling. Most (CFST) short column specimen's failure with the first type (local buckling) and rare of short (CFST) columns failure with global buckling. The local buckling failure of (CFST) short columns specimens it may be sub divided to shear failure and crushed of concrete core. Most short (CFST) column specimen's failure with crushed of concrete core and rare of short (CFST) columns failure with shear failure.

Figure (4- 81) Mode of failure of (CFST) short column specimens

Table (4- 18) The model of failure of short (CFST) columns

Material type	Replacement percentage (%)	Specimen	Mode of failure
Control	-	CTRL40B10t3-0	concrete crushed
Dune sand	10	DNSL40B10t3-1	Global buckling
	25	DNSL40B10t3-2	concrete crushed
	50	DNSL40B10t3-3	Shear failure
PVC crushed	2.5	PVCL40B10t3-1	concrete crushed
	5	PVCL40B10t3-2	concrete crushed
	10	PVCL40B10t3-3	concrete crushed
PVC sawdust	1.25	PVSL40B10t3-1	concrete crushed
	2.5	PVSL40B10t3-2	concrete crushed
	5	PVSL40B10t3-3	concrete crushed
Iron Filling	2.5	IRNL40B10t3-1	concrete crushed
	5	IRNL40B10t3-2	concrete crushed
	10	IRNL40B10t3-3	Shear failure
Box plastic	2.5	BXCL40B10t3-1	concrete crushed
	5	BXCL40B10t3-2	concrete crushed
	10	BXCL40B10t3-3	Global buckling

4.5.7 Stress-Strain Curves

4.5.7.1 Axial strain

Table (4-19) presented yield and ultimate capacity of stress and strain of (CFST) short column specimens.

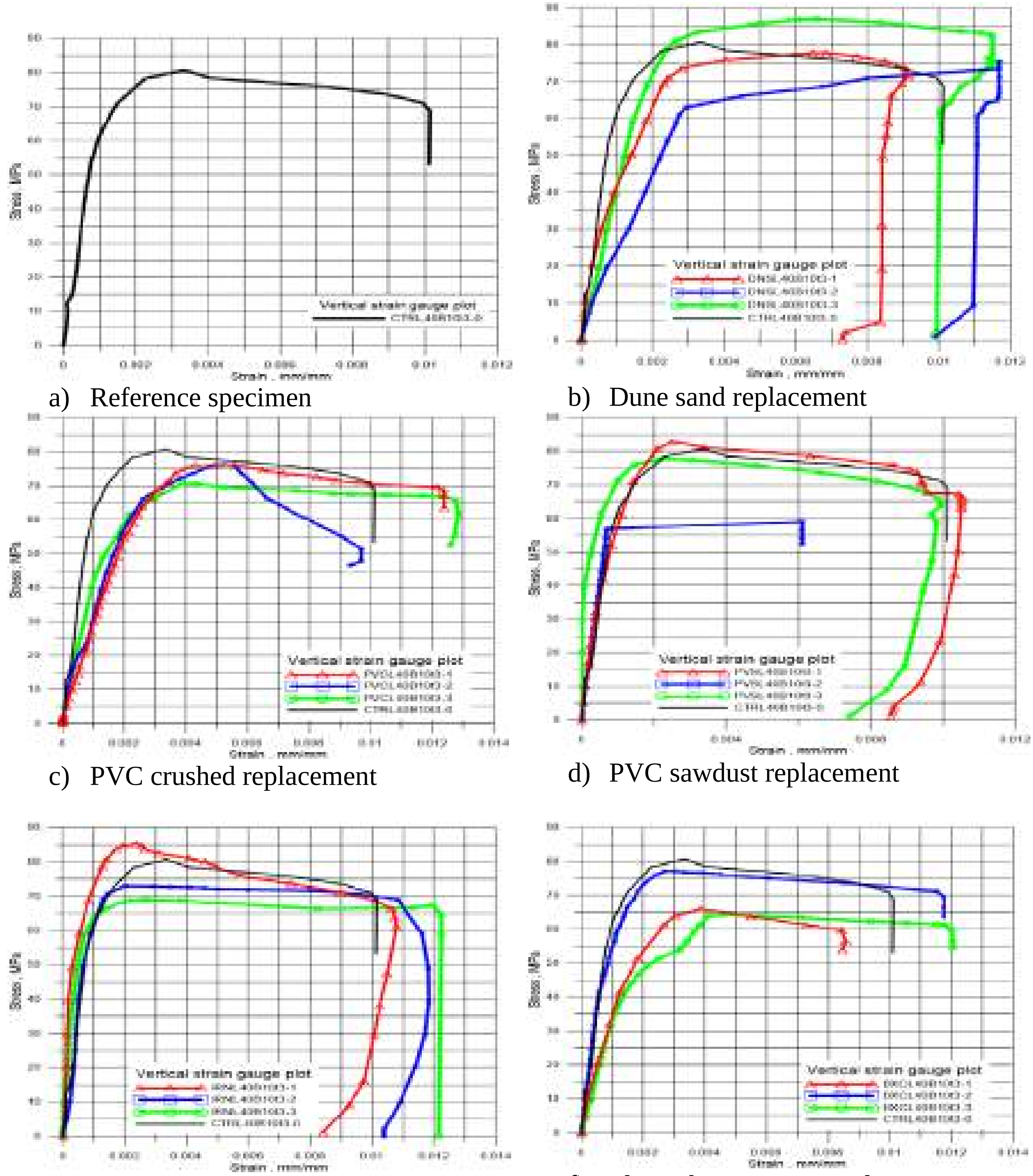
Table (4- 19) Vertical stress strain of (CFST) short with partially sand replacement

Material type	Replacement percentage (%)	sample code	*Yield zone*		*Ultimate capacity*	
			ε_y	σ_y MPa	ε_u	σ_u MPa
Control	-	CTRL40B10t3-0	0.0013	69	0.0033	81
Dune sand	10	DNSL40B10t3-1	0.0023	70	0.0065	78
	25	DNSL40B10t3-2	0.0031	63	0.0117	76
	50	DNSL40B10t3-3	0.0024	79	0.0066	87
PVC crushed	2.5	PVCL40B10t3-1	0.0026	64	0.0050	76
	5	PVCL40B10t3-2	0.0026	66	0.0052	76
	10	PVCL40B10t3-3	0.0022	61	0.0039	71
PVC sawdust	1.25	PVSL40B10t3-1	0.0014	71	0.0025	83
	2.5	PVSL40B10t3-2	0.0007	56	0.0061	59
	5	PVSL40B10t3-3	0.0005	61	0.0022	78
Iron Filling	2.5	IRNL40B10t3-1	0.0010	72	0.0024	85
	5	IRNL40B10t3-2	0.0009	62	0.0020	73
	10	IRNL40B10t3-3	0.0007	59	0.0027	69
Box plastic	2.5	BXCL40B10t3-1	0.0023	56	0.0039	66
	5	BXCL40B10t3-2	0.0015	66	0.0027	77
	10	BXCL40B10t3-3	0.0032	54	0.0046	64

The contribution of concrete is important in delaying the occurrence of buckling in steel, therefore, steel does not reach yield. Thus, the effect of sand replacement is evident by increasing the values of yield stress. Where the yield stress of 79 MPa, 66 MPa, 71 MPa, 72 MPa and 66 MPa at 50% dune sand, 5% PVC crushed, 1.25% PVC sawdust, 2.5% iron filings and 5% plastic boxes waste respectively.

4.5.7.2 Energy

Energy values of (CFST) short column specimens are calculated from the stress strain curves in Figure (4-82). The values of energy are recorded in the Table (4-20).



a) Reference specimen
b) Dune sand replacement
c) PVC crushed replacement
d) PVC sawdust replacement
e) Iron filings replacement
f) Plastic boxes waste replacement

Figure (4- 82) Vertical stress-strain (σ – ε) curves of CFST short column specimens

Table (4- 20) Energy of (CFST) with partially sand replacement.

Material type	Replacement percentage (%)	sample code	Energy kPa	Change %
Control	-	CTRL40B10t3-0	725	0
Dune sand	10	DNSL40B10t3-1	566	-22
	25	DNSL40B10t3-2	658	-9
	50	DNSL40B10t3-3	779	+7
PVC crushed	2.5	PVCL40B10t3-1	801	+10
	5	PVCL40B10t3-2	556	-23
	10	PVCL40B10t3-3	794	+9
PVC sawdust	1.25	PVSL40B10t3-1	392	-46
	2.5	PVSL40B10t3-2	334	-54
	5	PVSL40B10t3-3	667	-8
Iron Filling	2.5	IRNL40B10t3-1	798	+10
	5	IRNL40B10t3-2	797	+10
	10	IRNL40B10t3-3	801	+10
Box plastic	2.5	BXCL40B10t3-1	469	-35
	5	BXCL40B10t3-2	824	+14
	10	BXCL40B10t3-3	674	-7

Dune sand: It is observed from Table (4-20) and Figure (4-83), that all samples which contain dune sand with replacement of 10% and 25% showed a decrease in strain energy of 566 kPa and 658 kPa, less than control specimen by 22%, and 9% respectively. The mix that contains on 50% of dune sand as sand replacement is the optimum percentage which indicated a strain energy of 779 kPa.

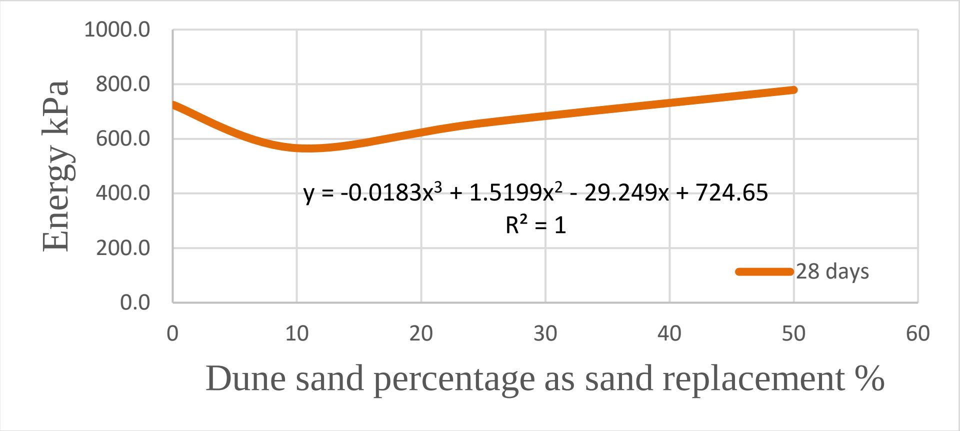


Figure (4- 83) Strain energy of (CFST) short column with dune sand

PVC crushed: It is evident from Table (4-20) and Figure (4-84), that samples which contain PVC crushed particles with dosages 5 % showed a decrease in strain energy by about 23%, while samples with dosages of 2.5% and 10% showed an increase in strain energy of 801 kPa and 794 kPa by 10% and 9% increasing more than control specimen. The mix that contains on 2.5% of PVCC particles as replacement of sand is the optimum percentage which gave a strain energy of 801 kPa.

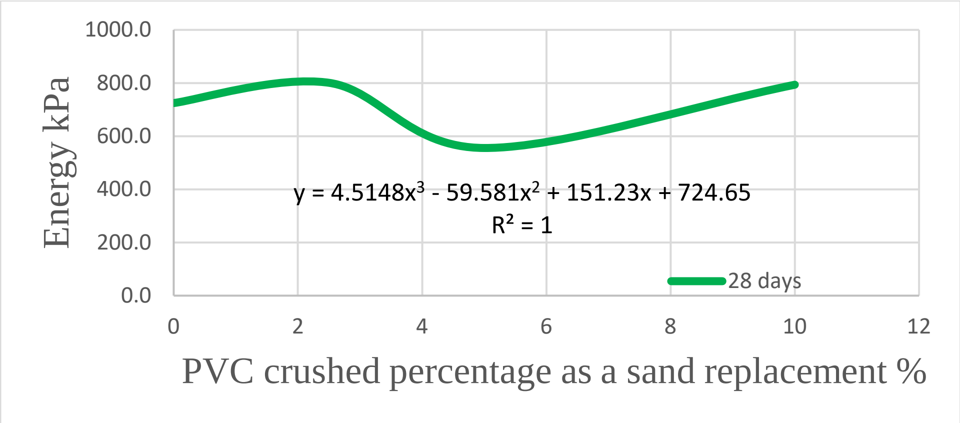


Figure (4- 84) Strain energy of short column with PVC crushed

PVC sawdust: Table (4-20) and Figure (4-85), showed that all samples which contain PVC sawdust (PVCS) with replacement of 1.25%, 2.5% and 5 % showed a decrease in strain energy by about 46%, 54% and 8% compared to control specimen respectively. The mix that contains on 5% of PVC sawdust as sand replacement is the optimum percentage which gave a strain energy of 667 kPa.

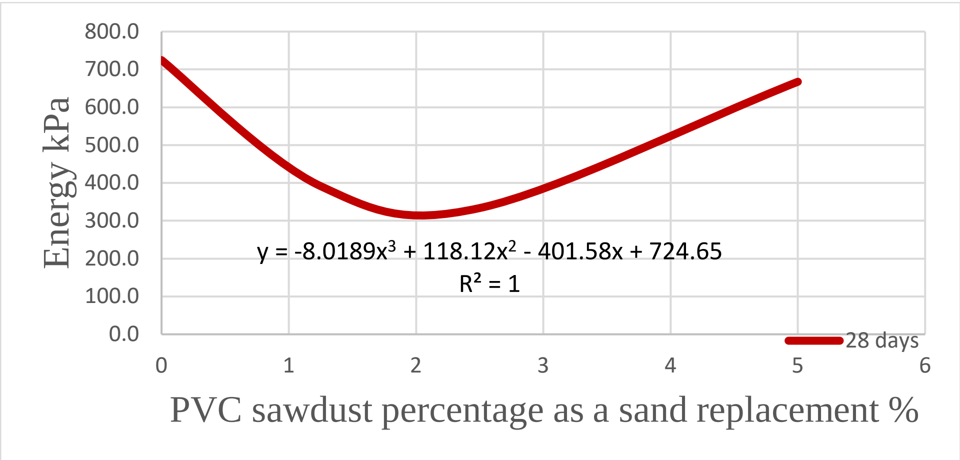


Figure (4- 85) Strain energy of short column with PVC sawdust

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed an increase in strain energy as shown in Table (4-20) and Figure (4-86). Using an iron filling showed an increasing by 10% for all replacement ratio of 2.5%, 5% and 10% iron filings, strain energy of 798 kPa,797 kPa and 801 kPa. The mix that contains on 10% of iron filings as sand replacement is the best ratio which indicated a strain energy of 801 kPa, greater than control specimen by 10%.

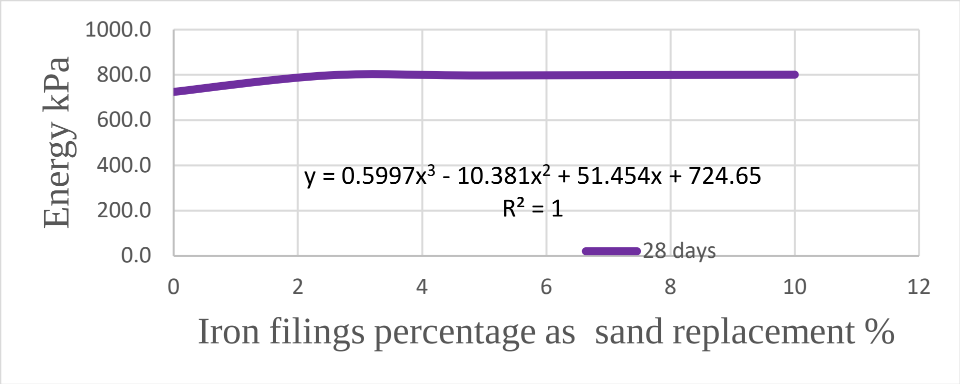


Figure (4- 86) Strain energy of short column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on strain energy is shown in Table (4-20) and Figure (4-87). It is observed that the sample contain plastic boxes waste particle with dosage of 5% showed an increase in strain energy of 824 kPa, by about 14% compared with reference. While the samples contain plastic boxes waste particle with dosages of 2.5% and 10% showed a decrease in strain energy of 469 kPa and 674 kPa respectively, namely less than reference specimen by about 35% and 7%. The mix that contains on 5% of plastic boxes waste as sand replacement is the optimum percentage which gave a strain energy of 824 kPa.

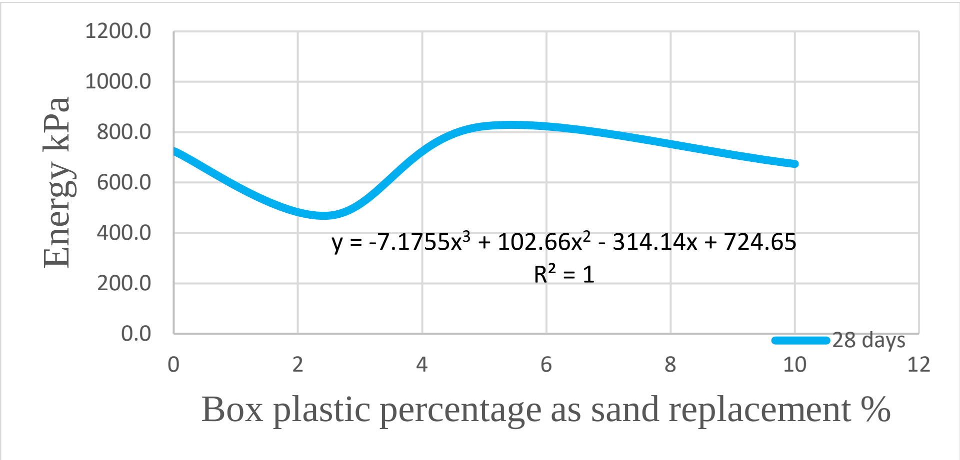


Figure (4- 87) Strain energy of (CFST) short column with plastic boxes waste

4.5.7.3 Lateral strain

Figure (4-88) showed curves response lateral strain of (CFST) short column specimens. The first zone response in the lateral direction approximately linearly behavior is closer to a straight line. The first and second regions is an important value resulting from the effect of concrete and, accordingly, the effect of the materials involved in its production.

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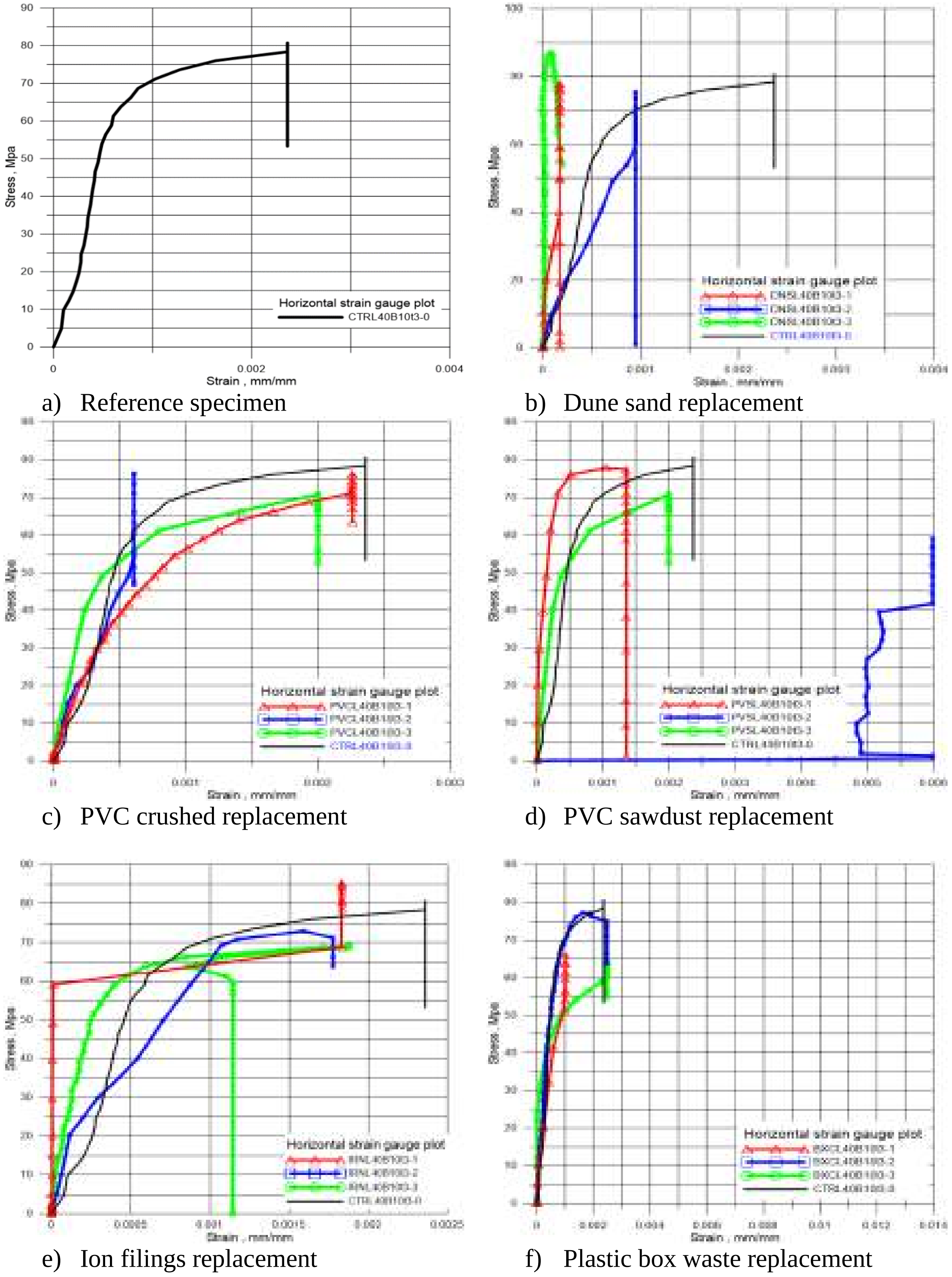


a) Reference specimen
b) Dune sand replacement
c) PVC crushed replacement
d) PVC sawdust replacement
e) Ion filings replacement
f) Plastic box waste replacement

Figure (4- 88) Horizontal stress-strain (σ – ε) curves of CFST short column specimens

4.6 Long Columns

4.6.1 Axial Load Capacity

The load capacity of all (CFST) long columns specimens are shown in Table (4-21). The experimental results are compared with theoretical equation to show the relative increasing as restriction concrete by steel tube.

Table (4- 21) Experimental and theoretical axial load capacity for long columns.

Material type	Replacement percentage (%)	sample code	N_{Exp} (kN)	*Change in* $N_{Exp.}$	$N_{theo.}$ *(kN)*	N_{Exp} / $N_{theo.}$
Control	-	CTRL55B8t3-0	474	0	387	1.23
Dune sand	10	DNSL55B8t3-1	552	+16	392	1.41
	25	DNSL55B8t3-2	549	+16	408	1.34
	50	DNSL55B8t3-3	586	+24	390	1.50
PVC crushed	2.5	PVCL55B8t3-1	549	+16	409	1.34
	5	PVCL55B8t3-2	545	+15	397	1.37
	10	PVCL55B8t3-3	557	+18	402	1.39
PVC sawdust	1.25	PVSL55B8t3-1	471	-1	381	1.24
	2.5	PVSL55B8t3-2	465	-2	386	1.21
	5	PVSL55B8t3-3	480	+1	369	1.30
Iron Filling	2.5	IRNL55B8t3-1	537	+13	408	1.32
	5	IRNL55B8t3-2	559	+18	396	1.41
	10	IRNL55B8t3-3	530	+12	402	1.32
Plastic box	2.5	BXCL55B8t3-1	542	+14	386	1.41
	5	BXCL55B8t3-2	461	-3	402	1.15
	10	BXCL55B8t3-3	525	-11	364	1.44

Dune sand: It is observed from Table (4-21) and Figure (4-89), that all samples which contain dune sand with substitutions ranges 10%, 25% and 50 % show an increase in load capacity by about 16% ,16% and 24% respectively for 28 days, because increasing the compressive strength of concrete filling with sand replacement by dune sand.

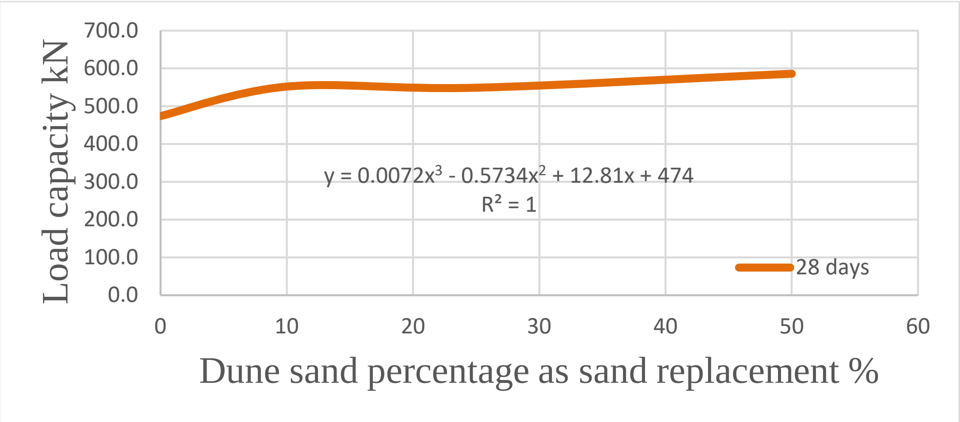


Figure (4- 89) Load capacity of long column with dune sand

PVC crushed: It is evident from Table (4-21) and Figure (4-90), that all samples which contain PVC crushed particles with dosages 2.5% ,5 % and 10% show an increase in load capacity by about 16%,15% and 18% respectively for 28 days. The mix that contains on PVCC particles as replacement of sand causes an increase in load capacity.

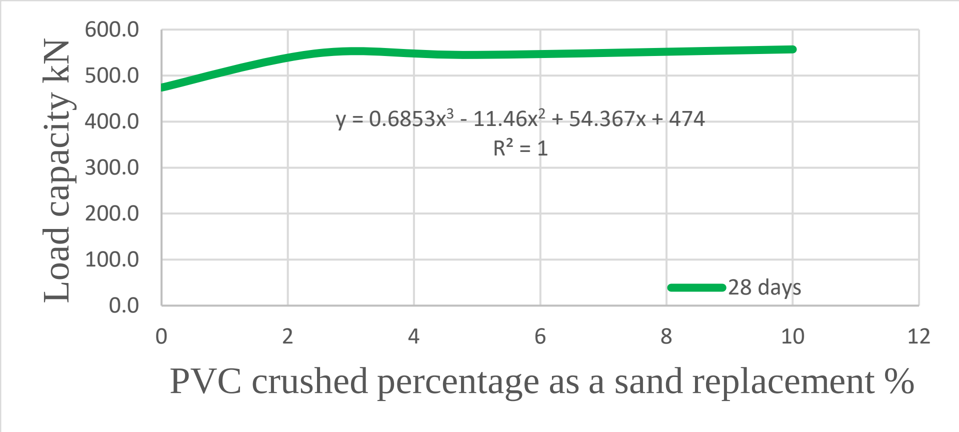


Figure (4- 90) Load capacity of long column with PVC crushed

PVC sawdust: From Table (4-21) and Figure (4-91), that samples which contain PVC sawdust (PVCS) with replacement 1.25% and 2.5% show decrease in load capacity by 1%, 2%. The mix that contains on 5% of PVC sawdust as replacement of sand is the optimum percentage which gave a load capacity of 480 kN with increase by 1% compared with control specimen. This means that for specimens made with PVC sawdust as replacement exhibited approximately the same load capacity compared with reference specimens.

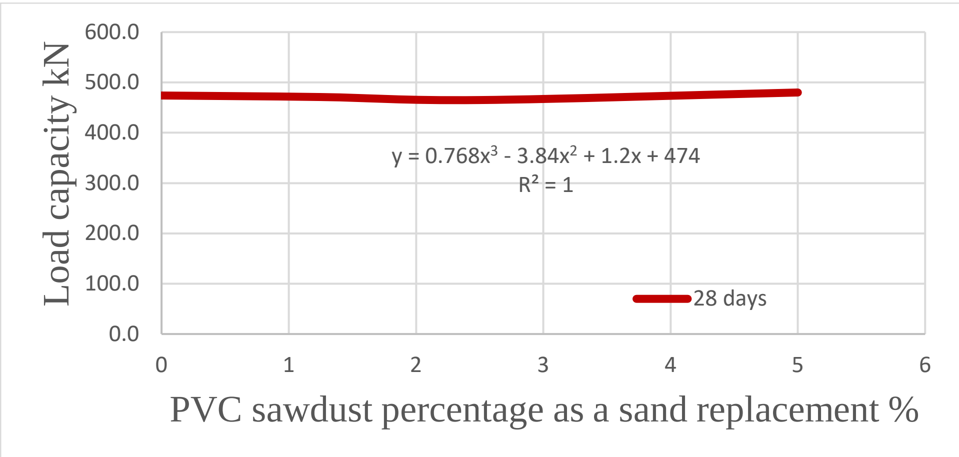


Figure (4- 91) Load capacity of long column with PVC sawdust

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed an increasing in load capacity of CFST samples for all dosage as shown in

Table (4-21) and Figure (4-92) for 28-day test. Using an iron filling as replacement showed increasing in load capacity at 2.5%, % and 10% dosages of iron filings by about 13%,18% and 12% respectively. compared control mix. The dosage of 2.5% of iron filings gives optimum load capacity of 559 kN, namely 18% greater than control specimen.

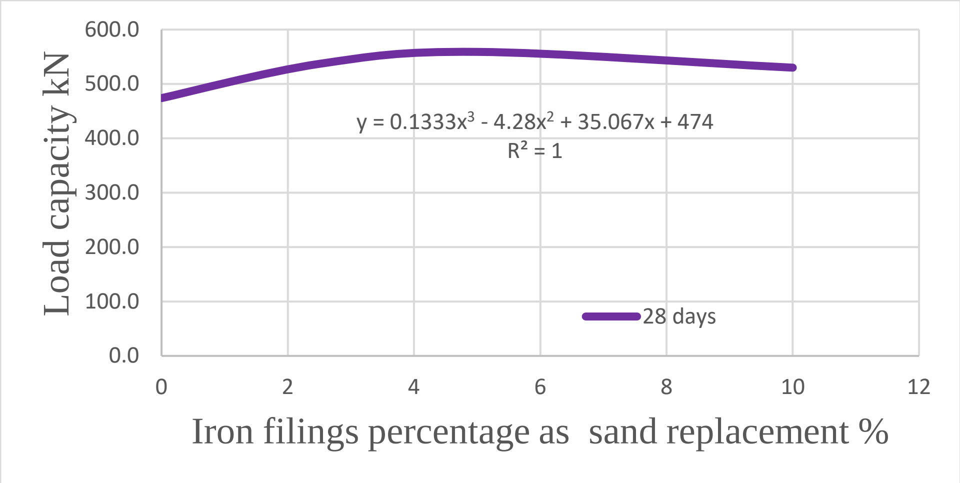


Figure (4- 92) Load capacity of long column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on load capacity of CFST samples is shown in Table (4-21) and Figure (4-93). It is observed that the samples contain box plastic waste particle with dosage of 2.5% and10% showed an increase in load capacity in 28 days' age 542 kN and 525 kN, namely more than control specimen by about 14% and 11% respectively, but dosages 10% of plastic box particles gave less load capacity than reference by about 2%. The dosage of 2.5% of plastic boxes waste gives optimum load capacity of 542 kN, namely 14% greater than control specimen.

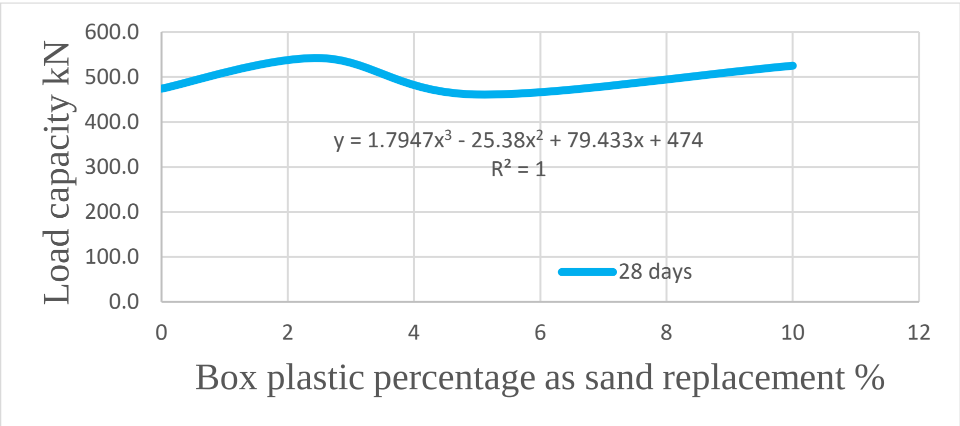


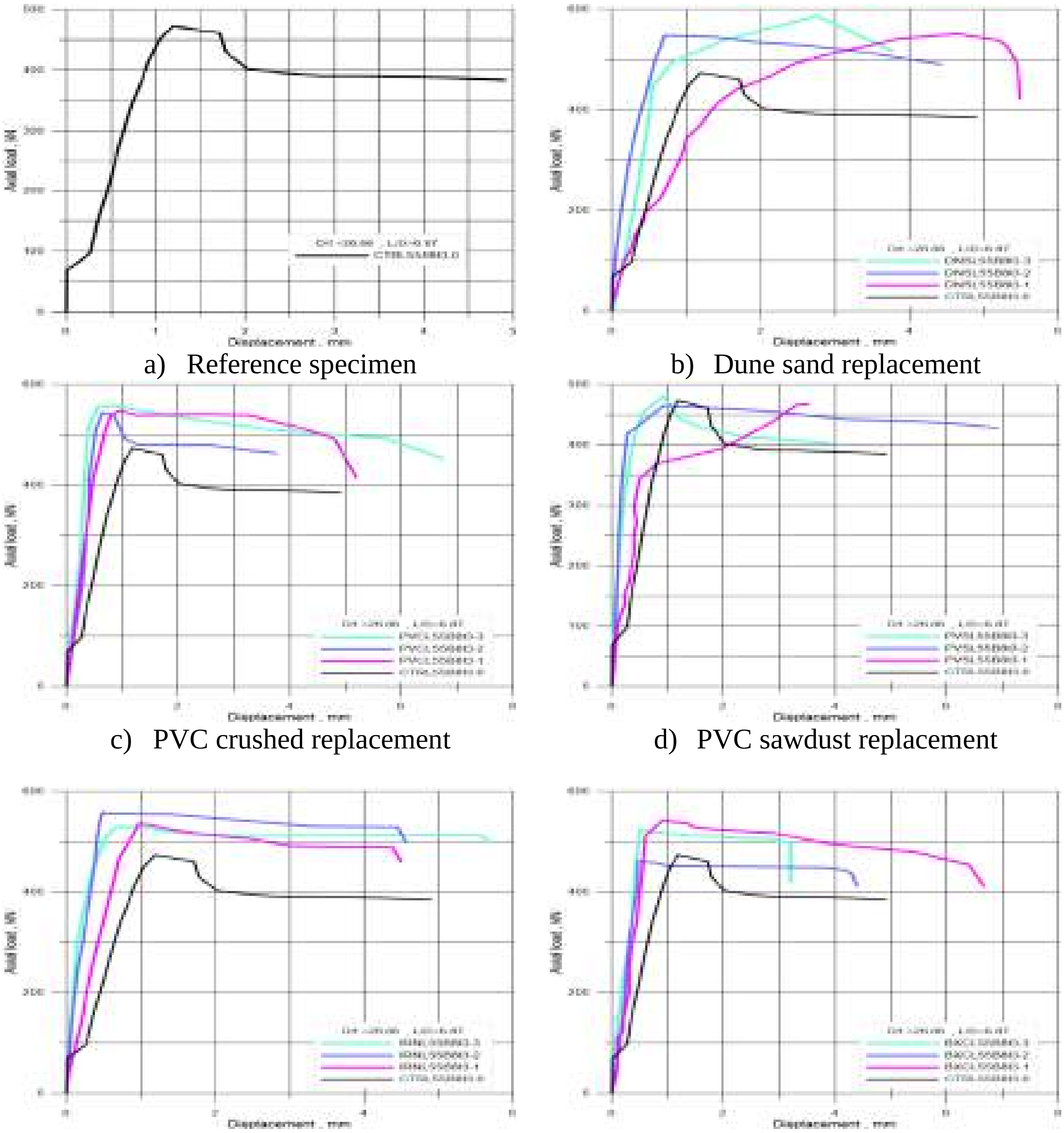
Figure (4- 93) Load capacity of long column with plastic boxes waste

4.6.2 Theoretical Load Capacity of composite column

The results of load capacity of long column are shown in Tables (4-21). The difference ranged from 10% to 40% is evident by comparing the experimental with theoretical results except for 50% replacement of dune sand which reached 44 %.

4.6.3 Load-Displacement Curve

Load displacement of long (CFST) column are shown in Figure (4-94). In general, the results of long column specimens are less than other column (stub and short).



a) Reference specimen

b) Dune sand replacement

c) PVC crushed replacement

d) PVC sawdust replacement

e) Iron filings replacement

f) Plastic boxes waste replacement

Figure (4- 94) Load displacement curve of (CFST) long column specimens

Toughness are shown in Table (4-22). The minimum value of column specimens is (1513 kN.mm) at 10% plastic boxes waste and maximum value is (3317 kN.mm) at 10% of PVC crushed.

Table (4- 22) Toughness of (CFST) with partially sand replacement.

Material type	**Replacement percentage (%)**	**sample code**	***Toughness kN.mm***	***Change %***	***Δmax***
Control	-	CTRL55B8t3-0	1824	0	2
Dune sand	10	DNSL55B8t3-1	2427	+33	5
	25	DNSL55B8t3-2	2208	+21	4
	50	DNSL55B8t3-3	1854	+2	4
PVC crushed	2.5	PVCL55B8t3-1	2566	+41	5
	5	PVCL55B8t3-2	1686	-8	4
	10	PVCL55B8t3-3	3317	+82	7
PVC sawdust	1.25	PVSL55B8t3-1	1311	-28	4
	2.5	PVSL55B8t3-2	3032	+66	7
	5	PVSL55B8t3-3	1593	-13	3
Iron Filling	2.5	IRNL55B8t3-1	1911	+5	4
	5	IRNL55B8t3-2	2115	+16	5
	10	IRNL55B8t3-3	2500	+37	6
Box plastic	2.5	BXCL55B8t3-1	3181	+74	5
	5	BXCL55B8t3-2	1996	+9	4
	10	BXCL55B8t3-3	1513	-17	3

Dune sand: From the Table (4-22) and Figure (4-95), it is noted that the increase of dune sand as partially replacement lead to increase for all percentage of 10%, 25% and 50% by 2427 kN.mm,2208 kN.mm and 1854 kN.mm, namely 33%,21% and 2%. The optimum percentage is 25%dune sand 2427 kN.mm, namely 33% more than reference specimen. The maximum displacement in all percentage from 25% to 50is more than reference of 5mm,4mm and 4mm respectively.

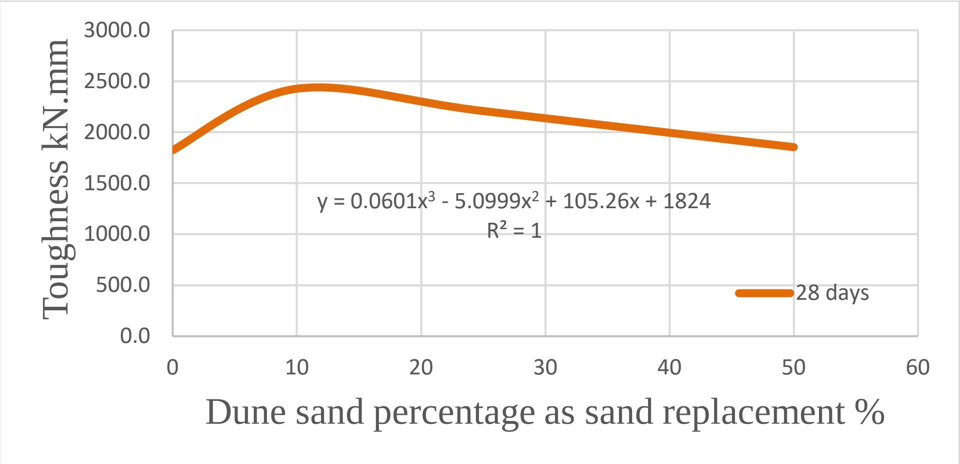


Figure (4- 95) Toughness of long column with dune sand

PVC crushed: From the Table (4-22) and figure (4-96), the using PVC crushed as a substitute for sand in (CFST) columns, the value of toughness increases with percentage 2.5% and 10% of 2566 kN.mm and 3317 kN.mm, namely by about 41% and 82%, while at 5% PVC crushed dosage toughness of 1686 kN.mm, namely with 8% decrease lees than reference specimen. The optimum percentage 10% PVC crushed gives 3317 kN.mm of toughness. The maximum displacement in all percentage from 2.5% to 10% are more than reference of 5mm,4mm and 7mm respectively.

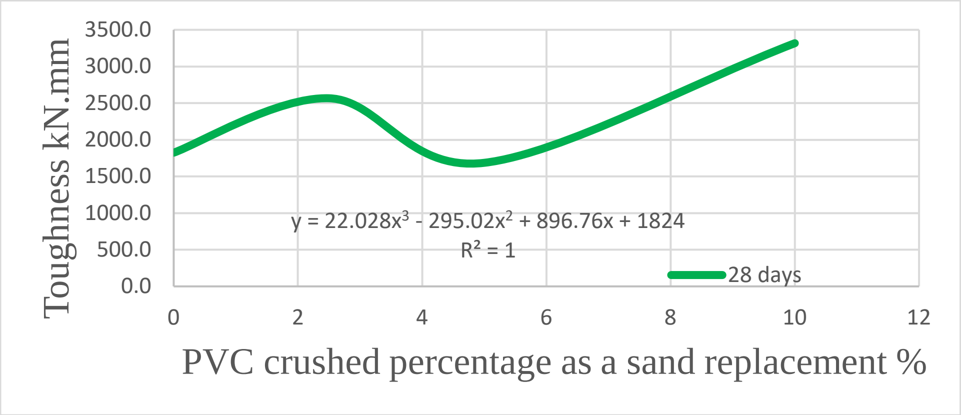


Figure (4- 96) Toughness of long column with PVC crushed

PVC sawdust: From the Table (4-22) and Figure (4-97), column specimens are containing PVC sawdust show a decrease in toughness at percentage 1.25% and 5% of 1311 kN.mm and 1593 kN.mm, namely by about 28% and 13%, while 2.5% PVCS substitution causes increase in toughness of 3032 kN.mm, by 66% more than reference specimen.

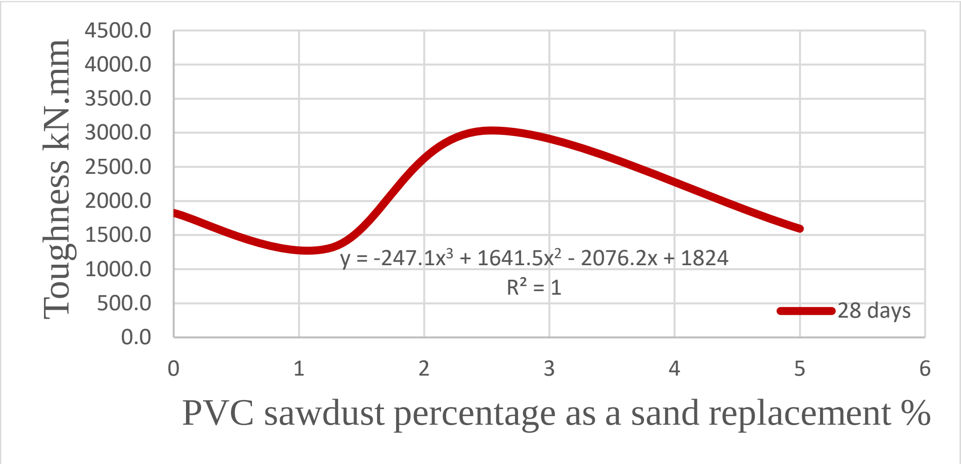


Figure (4- 97) Toughness of long column with PVC sawdust

Iron filings: From the Table (4-22) and figure (4-98), the toughness values for the models in which the iron filings are used are clearly increasing in toughness with increment on percentage of iron filing for all percentage from 2.5% to 10% of 1911kN.mm,2115 kN.mm and 2500 kN.mm respectively. The optimum value 2500 kN.mm is at 10% iron filings. relationship is still achieved in the use of iron filings in terms of increasing toughness with increment of iron filing in the concrete mix. The maximum displacement is increased proportionally with iron filings replacement ratio of 2.5%, 5% and these which equal to 4mm,5mm and 6mm respectively.

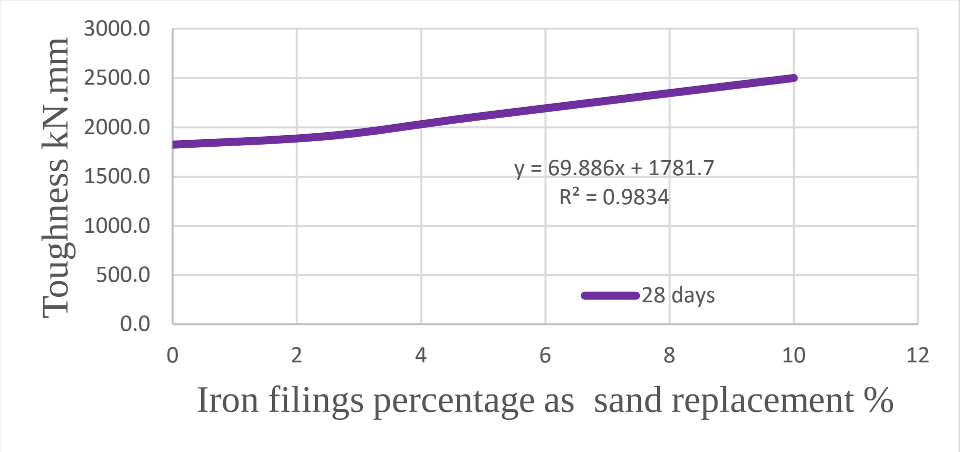


Figure (4- 98) Toughness of long column with iron filings

Plastic boxes waste: The effect of plastic boxes waste on toughness is shown in Table (4-22) and Figure (4-99). It is indicated that the samples contain box plastic waste particle with replacement ratio of 2.5% to 5% exhibited an increase in toughness of 3181 kN.mm and 1996 kN.mm,

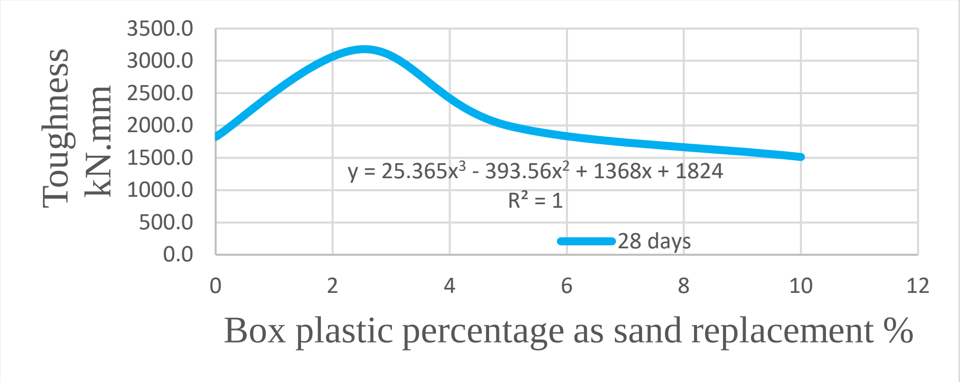


Figure (4- 99) Toughness of long column with plastic boxes waste

That means increases by about 74% and 9% respectively, while 10% plastic boxes waste shows a decrease 17% less than reference specimen, namely 1513 kN.mm.

The optimum is dosages 2.5% of 3181 kN.mm, namely 74% more than reference specimen. The maximum displacement of percentage of 2.5%, 5% and 10% is 5mm,4mm and 3mm respectively.

4.6.4 Ductility Index (DI)

Table (4-23) shows the values of ductility index of long (CFST)column specimens. The result calculated from Equation (4-5).

Table (4- 23) Results ductility index of (CFST) long column specimen.

Material type	Replacement percentage (%)	sample code	N_{Exp} (kN)	DI	Change %
Control	-	CTRL55B8t3-0	474	1.70	0
Dune sand	10	DNSL55B8t3-1	552	1.18	-31
	25	DNSL55B8t3-2	549	6.32	+272
	50	DNSL55B8t3-3	586	1.37	-19
PVC crushed	2.5	PVCL55B8t3-1	549	5.03	+196
	5	PVCL55B8t3-2	545	5.83	+243
	10	PVCL55B8t3-3	557	6.53	+284
PVC sawdust	1.25	PVSL55B8t3-1	471	1.07	-37
	2.5	PVSL55B8t3-2	465	7.46	+339
	5	PVSL55B8t3-3	480	3.51	+106
Iron Filling	2.5	IRNL55B8t3-1	537	4.01	+136
	5	IRNL55B8t3-2	559	9.40	+453
	10	IRNL55B8t3-3	530	8.43	+396
Plastic boxes	2.5	BXCL55B8t3-1	542	4.00	+135
	5	BXCL55B8t3-2	461	9.34	+449
	10	BXCL55B8t3-3	525	6.37	+275

Dune sand: It is observed from Table (4-23) and Figure (4-100), that specimens which contain dune sand with dosages 10% and 50 % show a decrease in ductility index 1.18 and 1.37, by about 31% and 19% respectively for 28 days. The mix that contain on 25% dune sand as sand replacement is the optimum percentage which gives ductility index of 6.32, that means 272% greater than control specimen.

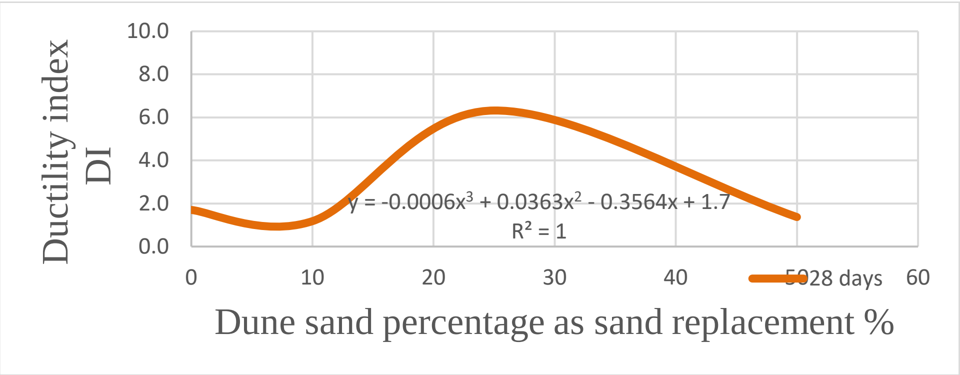


Figure (4- 100) Ductility index of long column with dune sand

PVC crushed: It is evident from Table (4-23) and Figure (4-101), that all specimens which contain PVC crushed particles the ductility index increased of all dosages range from 2.5% to 10% show an increase in ductility index of 5.03, 5.83 and 6.53, that means increase by 196%, 243% and 284% respectively for 28 days more than reference specimen. The mix that contains on 10% of PVC crushed as sand replacement is the optimum percentage which gave a ductility index of 6.53, means greater than control specimen by 284%.

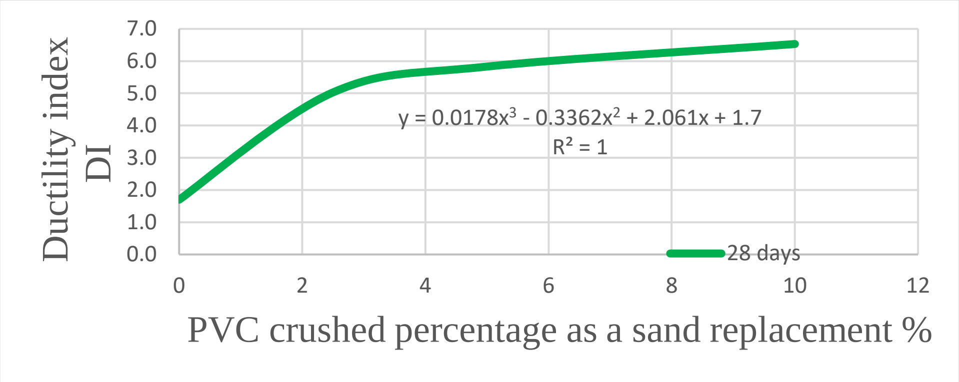


Figure (4- 101) Ductility index of long column with PVC crushed

PVC sawdust: From Table (4-23) and Figure (4-102), that all samples which contain PVC sawdust (PVCS) with replacement ratio of 2.5% and 5 % show an increased in ductility index of (7.46 and 3.51) %, namely by about 339% and 106% for 28-day test more than reference specimen. While percentage of 1.25% PVC sawdust shows a decrease 1.07, by about 37% less than reference specimen. The mix that contains on 1.25% of PVC sawdust as sand replacement is the optimum percentage which gave a ductility index of 7.46, that means greater than control specimen by 339%.

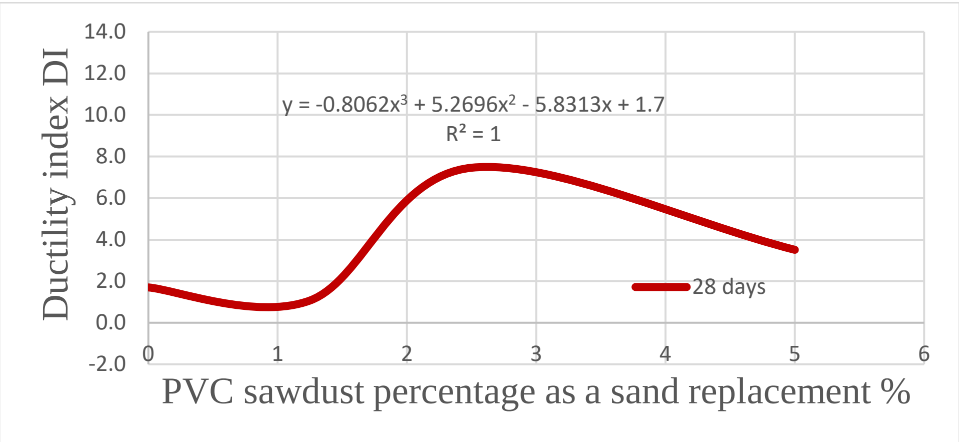


Figure (4- 102) Ductility index of long column with PVC sawdust

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed aa increase in ductility index as shown in Table (4-23) and Figure (4-103). The ductility index is increased of all percentage of iron filings increased for 2.5% to 10% which presented a ductility index in 28 days' age of 9.4,8.43 and 8.88, that means the ductility index of specimens that contained iron filings larger than specimens of control mix by 453%, 396% and 422% respectively. The mix that contains on 2.5% of iron filings as sand replacement is the optimum percentage which gave a ductility index of 9.4%, that means greater than control specimen by 453%.

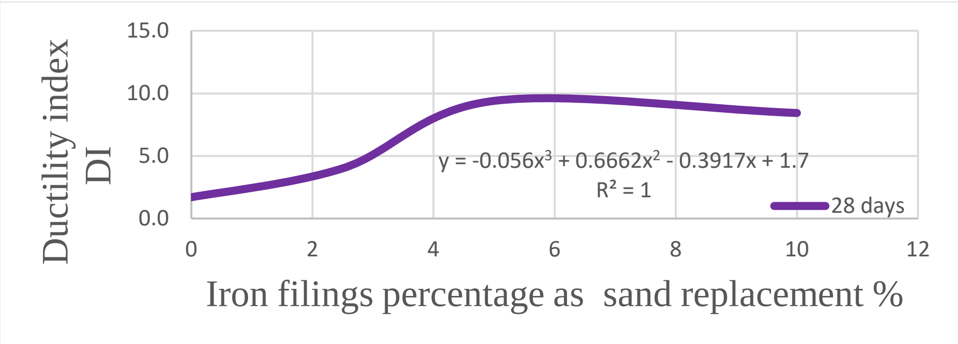


Figure (4- 103) Ductility index of long column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on concrete ductility index is shown in Table (4-23) and Figure (4-104). It is observed that all the samples contain box plastic waste particle with all dosage range from 2.5% to 10% showed an increase in ductility index in 28 days' age of 4.0, 9.34 and 6.37, namely more than reference mix by about 135%, 449% and 275% respectively.

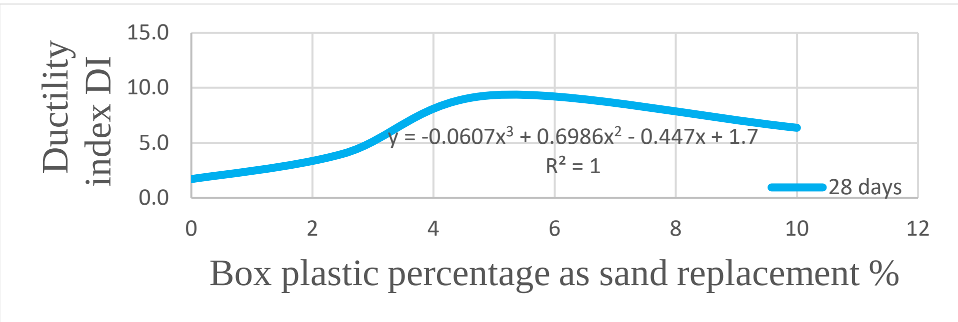


Figure (4- 104) Ductility index of long column with plastic boxes waste

The mix that contains on 5% of plastic boxes waste as sand replacement is the optimum percentage which gave a ductility index of 9.34%, namely greater than control specimen by 449%.

4.6.5 Stiffness

The stiffness value of (CFST) long column specimens are shown in Table (4-24). Due to the fact that stiffness presents the straight line in the load displacement curve, this line depends on the concrete core of the CFST, so the effect of sand replacement with materials has a clear effect on the value of stiffness.

Table (4- 24) Stiffness of (CFST) with partially sand replacement.

Material type	Replacement percentage (%)	sample code	stiffness(k) kN/mm	Change %
Control	-	CTRL55B8t3-0	470	0
Dune sand	10	DNSL55B8t3-1	312	-34
	25	DNSL55B8t3-2	1168	+149
	50	DNSL55B8t3-3	760	+62
PVC crushed	2.5	PVCL55B8t3-1	855	+82
	5	PVCL55B8t3-2	870	+85
	10	PVCL55B8t3-3	1207	+157
PVC sawdust	1.25	PVSL55B8t3-1	688	+46
	2.5	PVSL55B8t3-2	2024	+331
	5	PVSL55B8t3-3	1377	+193
Iron Filling	2.5	IRNL55B8t3-1	690	+47
	5	IRNL55B8t3-2	1238	+163
	10	IRNL55B8t3-3	1685	+258
Box plastic	2.5	BXCL55B8t3-1	757	+61
	5	BXCL55B8t3-2	979	+108
	10	BXCL55B8t3-3	956	+103

Dune sand: It is observed from Table (4-24) and Figure (4-105), that samples which contain dune sand with dosages ranged from 25% to 50 % showed an increase in stiffness of 1168kN/mm and 760kN/mm, by about 149%, and 62% respectively for 28 days and specimens which contain dune sand with dosages 10% showed a decrease in stiffness by about 34%. The optimum percentage which gave a stiffness of 1168 kN/mm at 25% substitution.

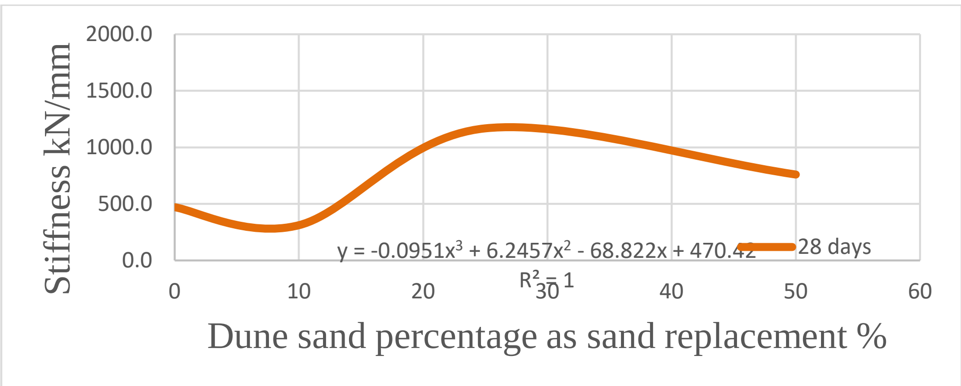


Figure (4- 105) Stiffness of long (CFST) column with dune sand

PVC crushed: From the Table (4-24) and figure (4-106), that all samples which contain PVC crushed as a substitute for sand in (CFST) columns with percentage of 2.5%, 5% and 10% showed the stiffness of 855kN/mm,870 kN/mm and 1207 kN/mm, its means an increase about 82%, 85% and 157% respectively more than reference specimen. The mix that contains on 10% of PVC crushed as sand replacement is the optimum percentage which gave a stiffness of 1207 kN/mm, namely greater than control specimen by 157%.

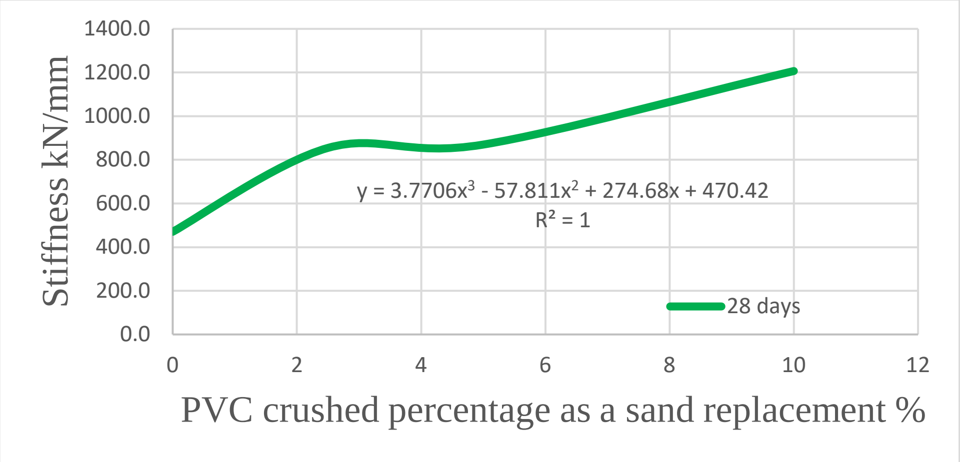


Figure (4- 106) Stiffness of long (CFST) column with PVC crushed

PVC sawdust: From the Table (4-24) and Figure (4-107), that all column specimens which contained PVC sawdust show an increase of percentage ranged from 1.25% to 5% of 688 kN/mm ,2024 kN/mm and 1377 kN/mm by about 46%, 331% and193% respectively more than reference specimen. The mix that contains on 2.5% of PVC sawdust as sand replacement is the optimum percentage which gave a stiffness of 2024 kN/mm, namely greater than control specimen by 331%.

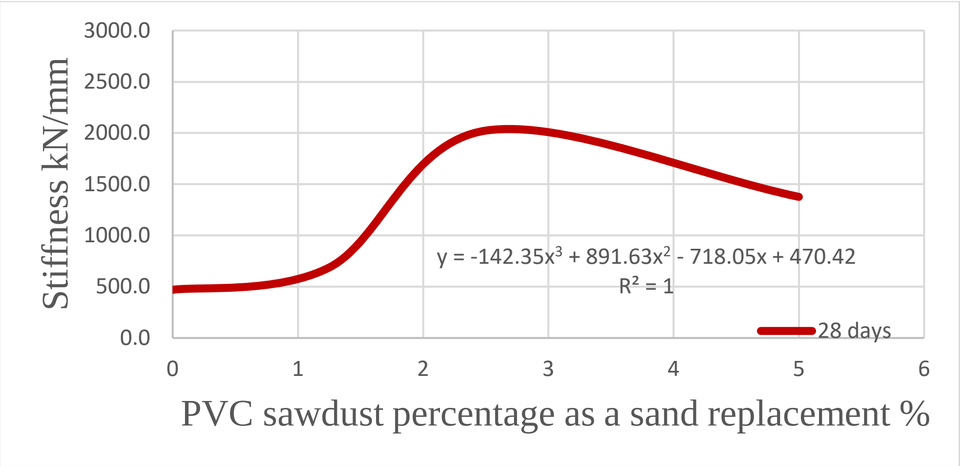


Figure (4- 107) Stiffness of long (CFST) column with PVC sawdust

Iron filings: It is evident from Table (4-24) and Figure (4-108), that all samples which contain iron filings with dosages range from 2.5% to 10 % show an increase in stiffness of 690 kN/mm,1238 kN/mm and 1685 kN/mm, namely by about 47%, 163% and 258% respectively for 28 days' age. The mix that contains on 10% of iron filings as sand replacement is the optimum percentage which gave a stiffness of 1685 kN/mm, namely greater than control specimen by 258%.

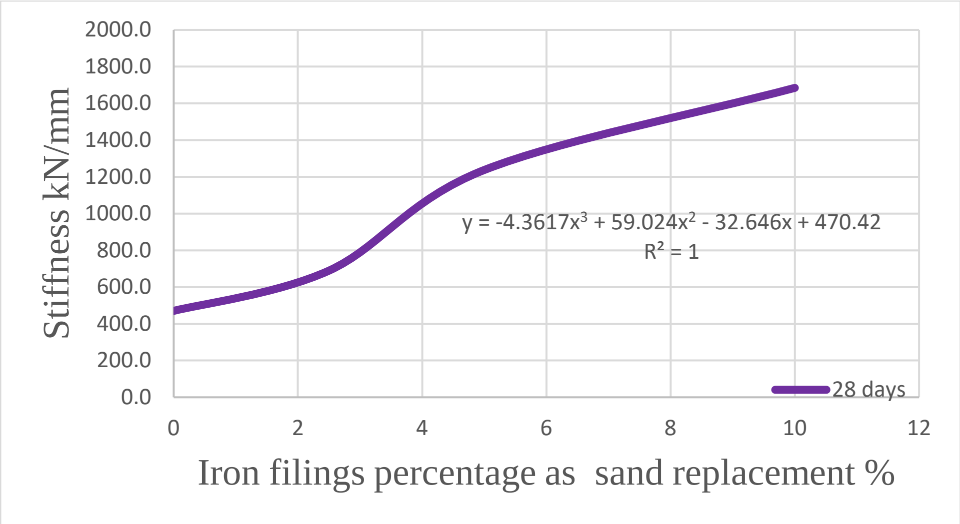


Figure (4- 108) Stiffness of long (CFST) column with Iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on concrete compressive strength is shown in Table (4-24) and Figure (4-109). It is observed that the samples contain box plastic waste particle with percentage of 2.5%, 5% and 10% showed an increase in stiffness in 28 days' age of 757 kN/mm, 979 kN/mm and 956 kN/mm, namely by about 61%,108% and 103% respectively more than reference specimens.

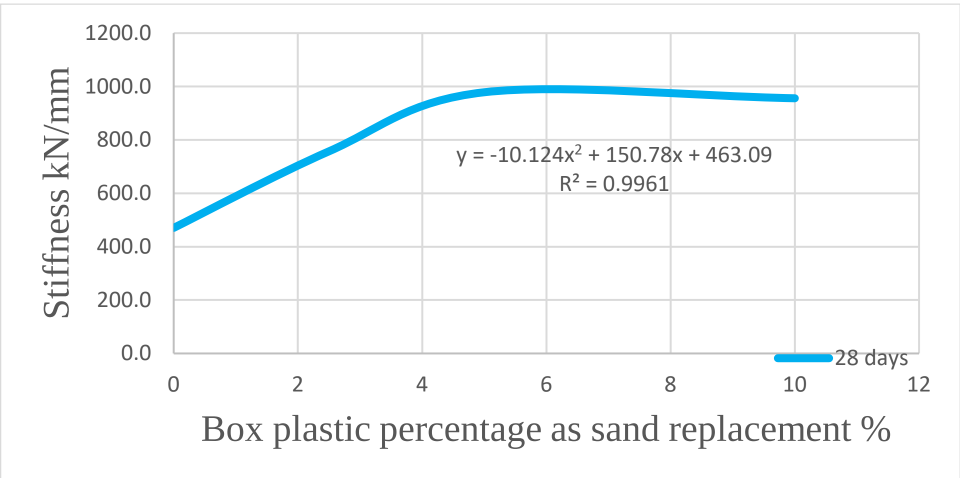


Figure (4- 109) Stiffness of long (CFST) column with plastic boxes waste

4.6.6 Mode of Failure

All test specimens of (CFST) long columns finally are failed due to global buckling, as demonstrated by specimens in Figure (4-110) and Table (4-25). This type of columns has a sufficiently large L/B ratio to cause buckling before any

a b c d

e f g h

Figure (4- 110) Mode of failure of (CFST) long column specimens

significant yielding occurs in the (CFST) long columns. However, from the assessment, all (CFST) long columns in the current study experienced the global buckling occurred and seldom concrete crushing is observed for this type of columns.

Table (4- 25) The model of failure of long (CFST) columns

Material type	Replacement percentage (%)	Specimen	Mode of failure
Control	-	CTRL55B8t3-0	Global buckling with crushed
Dune sand	10	DNSL55B8t3-1	Global buckling
	25	DNSL55B8t3-2	Global buckling
	50	DNSL55B8t3-3	Global buckling
PVC crushed	2.5	PVCL55B8t3-1	Global buckling
	5	PVCL55B8t3-2	Global buckling
	10	PVCL55B8t3-3	Global buckling
PVC sawdust	1.25	PVSL55B8t3-1	Global buckling
	2.5	PVSL55B8t3-2	Global buckling
	5	PVSL55B8t3-3	Global buckling
Iron Filling	2.5	IRNL55B8t3-1	Global buckling
	5	IRNL55B8t3-2	Global buckling
	10	IRNL55B8t3-3	Global buckling
Box plastic	2.5	BXCL55B8t3-1	Global buckling
	5	BXCL55B8t3-2	Global buckling with crushed
	10	BXCL55B8t3-3	Global buckling

4.6.7 Stress Strain Curves

4.6.7.1 Axial strain

The energy values of (CFST) long samples are calculated from the stress strain curves in Figure (4-111). The strain energy values are recorded in Table (4-26).

Table (4- 26) Vertical stress strain capacity of (CFST) long columns with partially sand replacement

Material type	Replacement percentage (%)	sample code	*Yield zone*		*Ultimate capacity*	
			ε_y	σ_y MPa	ε_u	σ_u MPa
Control	-	CTRL55B8t3-0	0.0019	71	0.0022	74
Dune sand	10	DNSL55B8t3-1	0.0039	73	0.0084	86
	25	DNSL55B8t3-2	0.0010	75	0.0013	86
	50	DNSL55B8t3-3	0.0015	77	0.0050	92
PVC crushed	2.5	PVCL55B8t3-1	0.0011	73	0.0017	86
	5	PVCL55B8t3-2	0.0010	80	0.0012	85
	10	PVCL55B8t3-3	0.0007	80	0.0017	87
PVC sawdust	1.25	PVSL55B8t3-1	0.0025	62	0.0082	74
	2.5	PVSL55B8t3-2	0.0005	65	0.0017	73
	5	PVSL55B8t3-3	0.0007	65	0.0017	75
Iron Filling	2.5	IRNL55B8t3-1	0.0013	73	0.0018	84
	5	IRNL55B8t3-2	0.0007	77	0.0009	87
	10	IRNL55B8t3-3	0.0007	71	0.0012	83
Box plastic	2.5	BXCL55B8t3-1	0.0004	69	0.0012	85
	5	BXCL55B8t3-2	0.0008	65	0.0009	72
	10	BXCL55B8t3-3	0.0008	69	0.0009	82

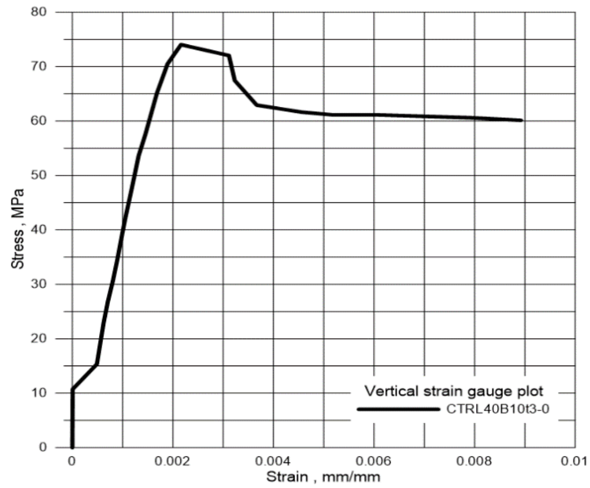
The contribution of concrete is important in delaying the occurrence of buckling in steel, therefore, steel does not reach yield. Thus, the effect of sand replacement is evident by increasing the values of yield stress. Where the yield stress of 77 MPa, 80 MPa, 65 MPa, 73 MPa and 69 MPa at 50% dune sand, 5% PVC crushed, 2.5% PVC sawdust, 2.5% iron filings and 2.5% plastic boxes waste respectively

4.6.7.2 Energy

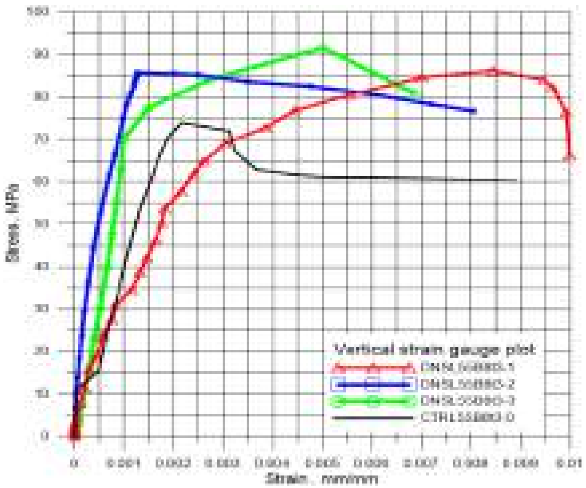
Energy is calculating from area under stress-strain curve. Figure (4-111) show stress-strain curves of (CFST) long columns. The curves have been grouped according to type of materials used as sand replacement. Table (4-27) showed vertical strain energy of (CFST) long columns specimens.

Table (4- 27) Energy of (CFST) long column with partially sand replacement.

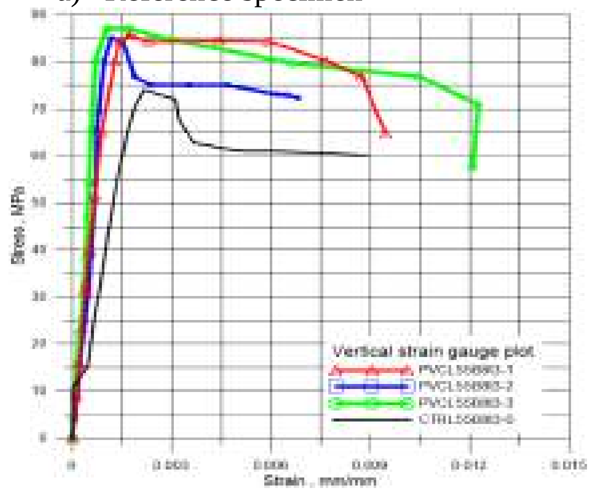
Material type	Replacement percentage (%)	sample code	Energy kPa	Change %
Control	-	CTRL55B8t3-0	518	0
Dune sand	10	DNSL55B8t3-1	689	+33
	25	DNSL55B8t3-2	627	+21
	50	DNSL55B8t3-3	527	+2
PVC crushed	2.5	PVCL55B8t3-1	729	+41
	5	PVCL55B8t3-2	479	-8
	10	PVCL55B8t3-3	942	+82
PVC sawdust	1.25	PVSL55B8t3-1	522	+1
	2.5	PVSL55B8t3-2	861	+66
	5	PVSL55B8t3-3	453	-13
Iron Filling	2.5	IRNL55B8t3-1	592	+14
	5	IRNL55B8t3-2	674	+30
	10	IRNL55B8t3-3	811	+56
Box plastic	2.5	BXCL55B8t3-1	930	+80
	5	BXCL55B8t3-2	567	+9
	10	BXCL55B8t3-3	430	-17



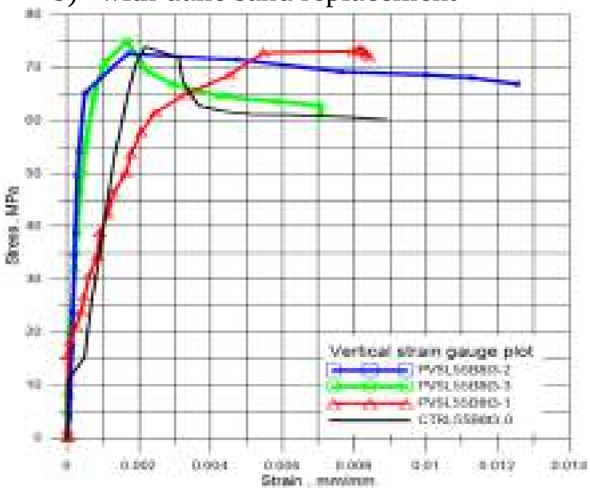
a) Reference specimen



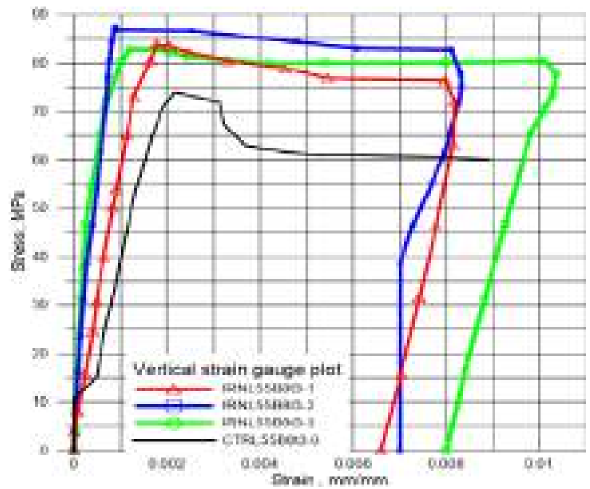
b) with dune sand replacement



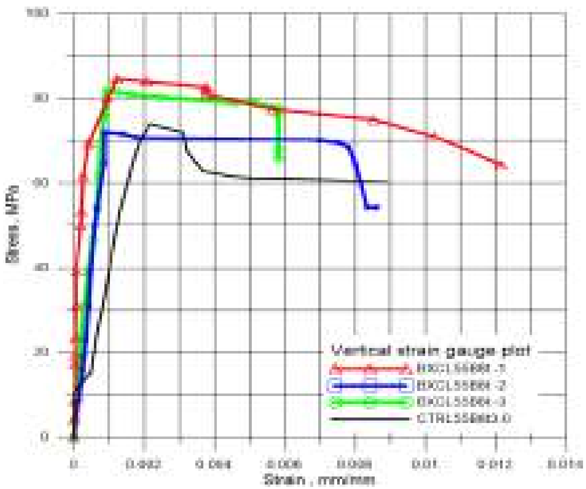
c) with PVC crushed replacement



d) with PVC sawdust replacement



e) with iron filings replacement



f) with plastic boxes waste replacement

Figure (4- 111) Vertical stress-strain (σ – ε) curves of CFST long column specimens

Dune sand: It is observed from Table (4-27) and Figure (4-112), that all samples which contain dune sand with dosages range of 10%, 25% and 50 % showed an increase in strain energy of 689 kPa, 627 kPa and 527 kPa, namely less than control specimen by 23%, 21% and 2% respectively. The mix that contains on 10% of dune sand as sand replacement is the optimum percentage which gave a strain energy of 689 kPa. (33% more than control specimen).

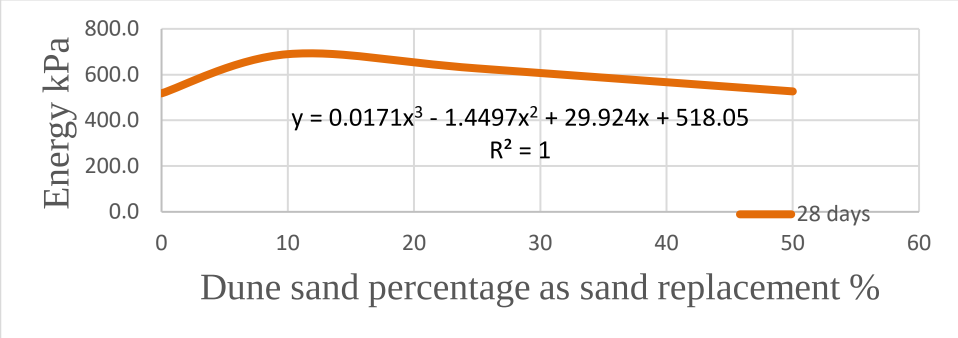


Figure (4- 112) Strain energy of (CFST) long column with dune sand

PVC crushed: It is evident from Table (4-27) and Figure (4-113), that all samples which contain PVC crushed particles with dosages 2.5% and 10% show an increase in strain energy by about 41% and 82% respectively, while sample which contain PVC crushed particles with dosages 5% showed a decrease in strain energy by about 8%. The mix that contains on 10% of PVCC particles as replacement of sand is the optimum percentage which indicated a strain energy value of 942 kPa, 82% greater than control specimen.

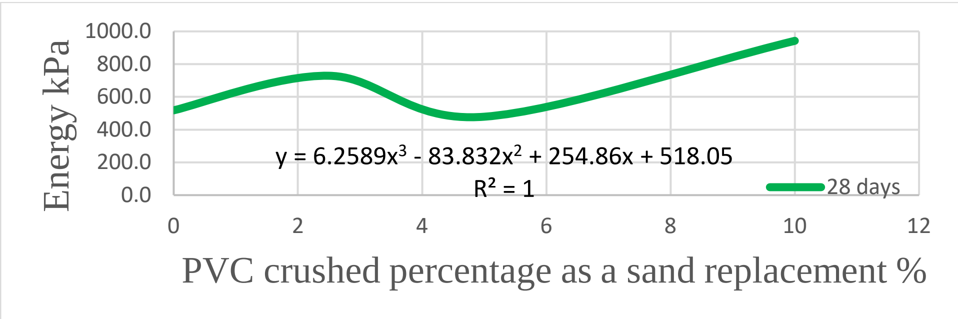


Figure (4- 113) Strain energy of long column with PVC crushed

PVC sawdust: Table (4-27) and Figure (4-114), showed that samples which contain PVC sawdust (PVCS) with dosages 1.25% and 2.5%.

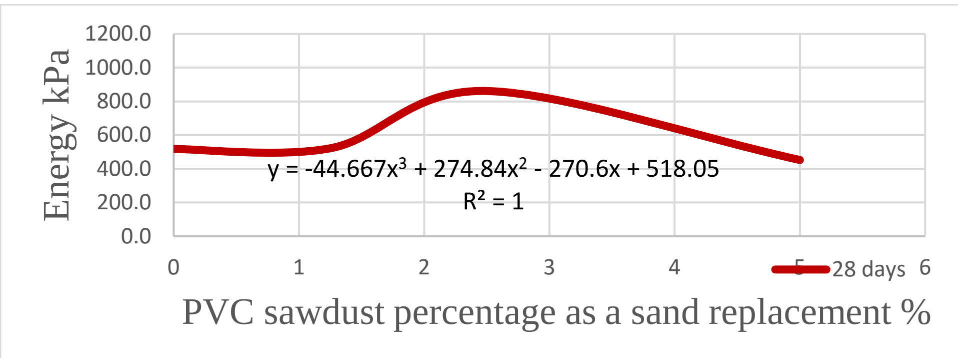


Figure (4- 114) Strain energy of long column with PVC sawdust

showed an increase in strain energy by about 1% and 66% compared to control specimen respectively, while sample which contain PVC sawdust (PVCS) with dosages of 5 % showed a decrease in strain energy by about 13% compared to control specimen

Iron filings: The addition of iron filings to concrete mixtures as substituted sand showed an increase in strain energy as shown in Table (4-27) and Figure (4-115). Using an iron filling showed an increasing in strain energy of 592 kpa,674 kpa and 811 kpa at 2.5%, 5% and 10% dosages of iron filings namely greater than control specimen by 14%,30% and 56% respectively.

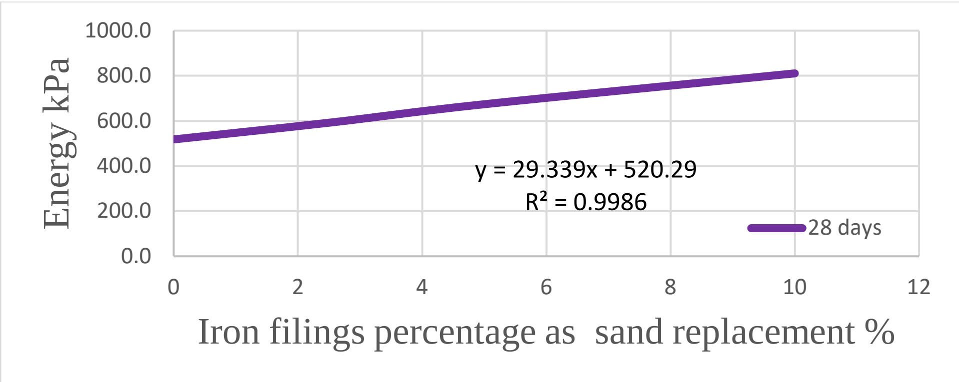


Figure (4- 115) Strain energy of long column with iron filings

Plastic boxes waste: The effect of plastic boxes waste particles on strain energy is shown in Table (4-27) and Figure (4-116). It is observed that the samples contain box plastic waste particle with dosage of 2.5% and 5% showed an increase in strain energy of 930 kPa and 567 kpa, while the sample contain box plastic waste particle with dosage of 10% showed a decrease in strain energy of 430 kPa. The mix that contains on 2.5% of plastic boxes waste as sand replacement is the optimum percentage which gave a strain energy of 930 kPa.

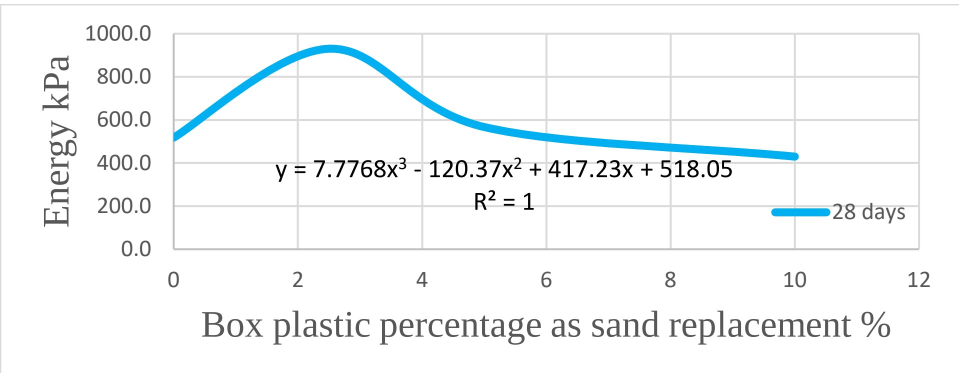
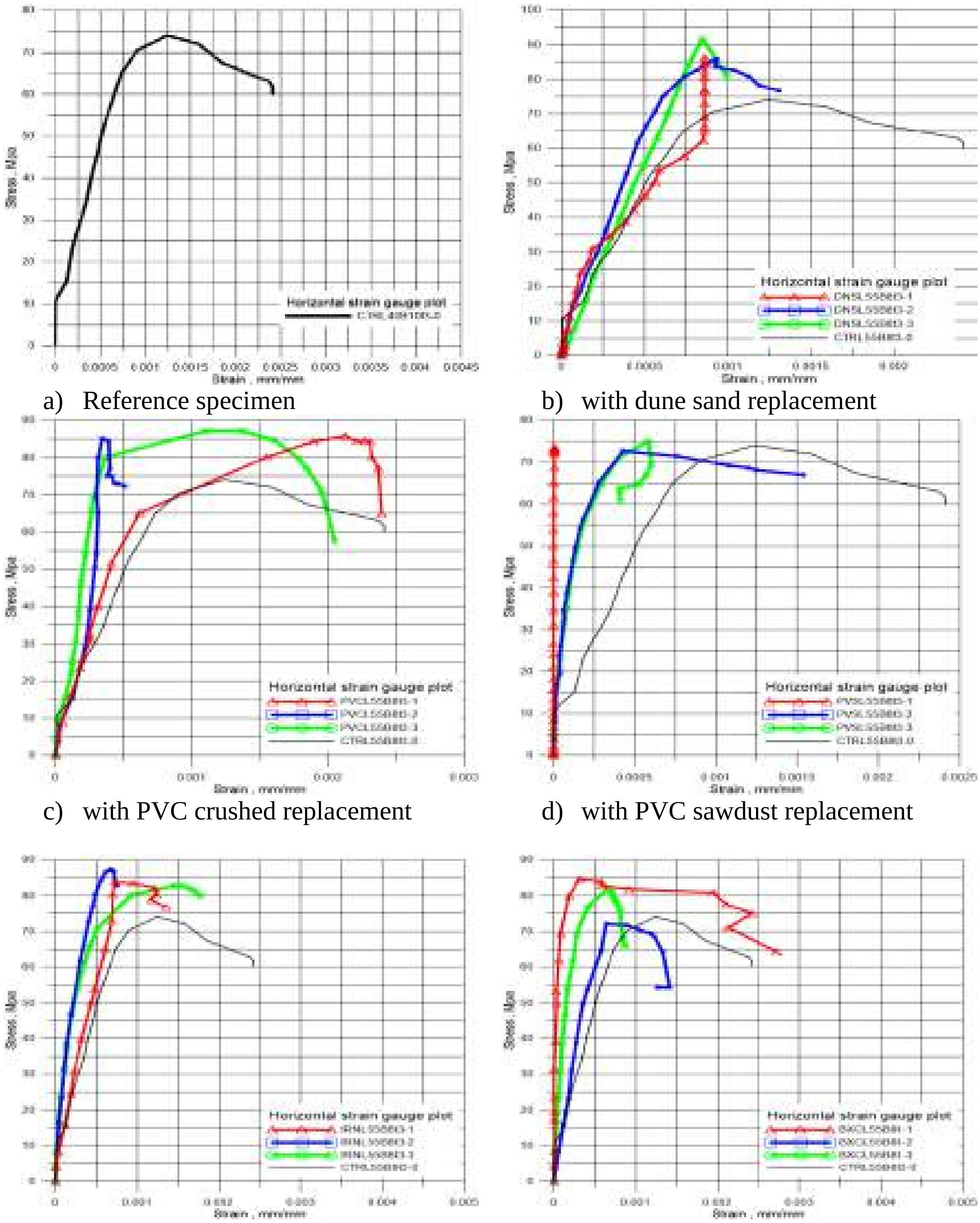


Figure (4- 116) Strain energy of (CFST) long column with plastic boxes waste

4.6.7.3 Lateral strain

Figure (4-117) showed curves response lateral strain of (CFST) long column specimens. The first and second regions is an important value resulting from the effect of concrete and, accordingly, the effect of concrete that infilled steel tubular with sand replacement.



a) Reference specimen
b) with dune sand replacement
c) with PVC crushed replacement
d) with PVC sawdust replacement
e) with iron filings replacement
f) with plastic box waste replacement

Figure (4- 117) Horizontal stress-strain (σ – ε) curves of CFST long column specimens

CHABTER FIVE

CHAPTER FIVE

Conclusion and Recommendations

CHAPTER FIVE

Conclusion and Recommendations

5.1 General

In this chapter, the main conclusions of the present work and the recommendations for future work are summarized as follows.

5.2 Mechanical Properties of Concrete Mixture with Partially Replaced Sand

Based on the results of experimental program focused on concrete mixtures with different percentages of dune sand, PVC waste, iron filings and plastic boxes waste as sand replacement, and also based on the results of testing 48 (CFST) column specimens with different percentages of materials as sand replacement, the following conclusions can be drawn:

1- The slump of concrete mixes is increased by 67% compared to control mix at sand replacements percentages of 10% iron filings. While the addition of dune sand, PVC crushed, PVC sawdust and plastic boxes waste as sand replacement led to reduction slump by about 11%, 2%, 44% and -6% at replacement ratio of 10%, 2.5%, 1.25% and 2.5% respectively as best dosage.

2- The compressive strength of concrete mixes is increased by 25%, 25%, 25% and 17% compared to control mix at sand replacements percentages of 25% dune sand, 2.5% PVC crushed, 10% iron filings and 5% plastic boxes waste respectively. However, the addition of PVC sawdust as sand replacement led to reduction compressive strength by about -1% at dosage of 2.5% as best dosage.

3- The splitting tensile strength of concrete mixes is increased by 19%, 41%, 18%, 22% and 5% compared to control mix at sand replacements percentages of 50% dune sand, 5% PVC crushed, 2.5% PVC sawdust, 5% iron filings and 5% plastic boxes waste respectively.

4- The flexural strength of concrete mixes is increased by 13%, 12%, 11% and 4% with sand replacements ratio of 25% dune sand, 5% PVC crushed, 5% iron filings and 5% plastic boxes waste respectively. While the flexural strength decrease by 2% with sand replacements ratio of 1.25% PVC sawdust.

5- The static modulus of elasticity of concrete mixes is increased by 33%, 11%, 20%, 19% and 24% compared to control mix at sand replacements percentages of 10% dune sand, 5% PVC crushed, 1.25% PVC sawdust, 10% iron filings and 2.55% plastic boxes waste respectively.

5.3 Axial Behavior of CFST Columns Made with Partially Replaced Sand

1- The load capacity of CFST stub columns specimens is increased by 7%, 14%, 18%, 10% and 12% compared to control specimen for sand replacements percentages of 50% dune sand, 5% PVC crushed, 5% PVC sawdust, 2.5% iron filings and 2.5% plastic boxes waste respectively. The load capacity of CFST short columns specimens is increased by 8%, 3% and 6% compared to control specimen for sand replacements percentages of 50% dune sand, 1.25% PVC sawdust and 2.5% iron filings respectively. However, the addition of PVC crushed and plastic boxes waste as sand replacement led to reduction of load capacity of CFST short columns specimens by about 5% and 4% at replacement ratio of 5% and 5% respectively as best substitution. The load capacity of CFST long columns specimens is increased by 24%, 18%, 1%, 18% and 14% compared to control specimen at sand replacements percentages of 50% dune sand, 10% PVC crushed, 5% PVC sawdust, 5% iron filings and 2.5% plastic boxes waste respectively.

2- The ductility index of CFST stub columns specimens is increased by 203%, 123%, 153%, 210% and 61% compared to control specimen at sand replacements percentages of 25% dune sand, 10% PVC crushed, 1.25% PVC sawdust, 10% iron filings and 2.5% plastic boxes waste respectively. The ductility index of CFST short columns specimens is increased by 9%, 48%, 88% and 45%

compared to control specimen at sand replacements percentages of 10% PVC crushed, 5% PVC sawdust 5% iron filings and 5% plastic boxes waste respectively. Nevertheless, the addition of dune sand as sand replacement expressed reduction of ductility index of CFST short columns specimens by about 39% for replacement ratio of 50%. Furthermore, the ductility index of CFST long columns specimens is increased by 272%, 284%, 339%, 453% and 449% compared to control specimen at sand replacements percentages of 25% dune sand, 10% PVC crushed, 2.5% PVC sawdust 5% iron filings and 5% plastic boxes waste respectively.

3- The stiffness of CFST stub columns specimens is increased by 87%, 87%, 98%, 132% and 50% compared to control specimen at sand replacements percentages of 25% dune sand, 10% PVC crushed, 5% PVC sawdust, 2.5% iron filings, and 5% plastic boxes waste respectively. The stiffness of CFST short columns specimens is increased by 201% and 67% compared to control specimen at sand replacements percentages of 5% PVC sawdust and 2.5% iron filings respectively. While the addition of dune sand, PVC crushed and plastic boxes waste as sand replacement led to reduction stiffness of CFST short columns specimens by about 38%, 44% and 16% at replacement of 50%, 10% and 5% respectively as best dosage. The stiffness of CFST long columns specimens is increased by 148%, 157%,331%, 258% and 108% compared to control specimen at sand replacements percentages of 25% dune sand, 10% PVC crushed, 2.5% PVC sawdust, 10% iron filings and 5% plastic boxes waste respectively.

4- The strain energy of CFST stub columns specimens is increased by 15% compared to control specimen at sand replacements percentages of 5% iron filings. While the addition of dune sand, PVC crushed, PVC sawdust and plastic boxes waste as sand replacement led to reduction strain energy of CFST stub columns specimens by about 4%, 1%, 13% and 11% at dosages of 25%, 2.5%, 5% and 2.5% respectively as best dosage. The strain energy of CFST short columns specimens is increased by 7%, 10%, 10% and 14% compared to control specimen at sand replacements percentages of 50% dune sand, 2.5% PVC crushed, 2.5% iron filings and 5% plastic boxes waste respectively. While the addition of PVC sawdust as sand replacement led to reduction strain energy of CFST short columns specimens by about -8% dosage of 5% as best dosage. The strain energy of CFST long columns specimens is increased by 33%, 82%, 66%, 56% and 80% compared to control specimen at sand replacements percentages of 10% dune sand, 10% PVC crushed, 2.5% PVC sawdust, 10% iron filings and 2.5% plastic boxes waste respectively.

5- Two failure modes are observed in concrete filled steel tube (CFST); local buckling and global buckling. In concrete filled steel tubular (CFST) stub column specimens the mode of failure is the first type (local buckling) and it may be sub divided to shear failure and crushed of concrete core. While the modes of failure in (CFST) short columns specimens are by two kind of failure (local buckling and global buckling). Finally, the global buckling is the failure mode of (CFST) long column specimens.
6- It is found that dune sand improves concrete strength characteristics and showed good enhancement in strength, energy absorption and stiffness of CFST column.
7- It seems that PVC crushed, PVC sawdust improves concrete strength characteristics and showed good enhancement in strength, ductility index and stiffness of CFST column.
8- It can be noticed that iron filings improve both fresh and hardened concrete characteristics and also showed good enhancement in strength, energy absorption, ductility index and stiffness of CFST column.
9- Waste plastic boxes improves early concrete strength characteristics and showed good enhancement in strength and stiffness of CFST column.
10- CFST stub and long columns are affected by the properties of the concrete mixture more than CFST short columns.

5.4 Recommendations

The following recommendations are suggested for future studies.

1- Due to good participation of iron filings in improve fresh and hardened concrete characteristics, so it’s strongly recommended to investigate the behavior of other structural members included iron filings as sand replacement with more range of replacement.
2- From environmental and economical points of views and due to local a viability of dune sand and its positive role in improvement concrete strength characteristics so it’s recommended to study the effect of wide range of dune sand substitution as sand replacement on different structural members.
3- Study the effect of five materials as sand replacement on the behavior of slabs, beams under torsion and beams under shear.
4- Study the effect of coarse aggregate size on the mechanical properties of concrete mixtures with partially replaced sand.
5- Study the effect of materials used as sand replacement of concrete filled steel tubes CFST under biaxial bending and uniaxial bending.
6- Study the effect of materials used as sand replacement of concrete filled full scale steel tubes CFST.
7- Study the effect of waste materials used as sand replacement of concrete filled steel tubes CFST under impact, cyclic and dynamic loadings.

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الملخص

تم استخدام الأنبوب الفولاذي المملوء بالخرسانة (CFST) في المنشآت في منتصف القرن العشرين. يتم استخدام أعمدة (CFST) بشكل متزايد لمزاياها العديدة، بما في ذلك القوة العالية، والليونة العالية، ومقاومة الحريق الأعلى من الأعمدة الفولاذية أو الخرسانية التقليدية من نفس الحجم. ينقسم العمل الحالي إلى مرحلتين، المرحلة الأولى هي دراسة تأثير الاستبدال الجزئي للركام الناعم برمل الكثبان الرملية، ومخلفات بولي فينيل كلوريد (PVC)، وبرادة الحديد، ومخلفات الصناديق البلاستيكية التي استخدمت كبديل لنسبة من الركام الناعم على الخصائص الميكانيكية للخلطة الخرسانية كمقاومة الانضغاط وقوة الشد وقوة الانثناء ومعامل المرونة، بينما المرحلة الثانية هي دراسة السلوك المحوري للعمود (CFST) باستخدام الخرسانة مع الاستبدال الجزئي للركام الناعم بتلك المواد. تتكون عينات العمود من أنبوب فولاذي مملوء بالخرسانة مع استبدال جزئي للركام الناعم. تم عمل ستة عشر خلطة خرسانية متضمنة خليط مرجعي وثلاث خلطات من كل مادة بنسب استبدال: الكثبان الرملية (١٠، ٢٥ و٥٠٪)، بولي فينيل كلوريد مكسر(PVC) (٢,٥، ٥ و١٠٪)، نشارة بولي فينيل كلوريد (PVC) (١,٢٥، ٥ و١٠)، برادة الحديد (٢,٥، ٥ و١٠٪) ومخلفات الصناديق البلاستيكية (٢,٥، ٥، و١٠٪). تضمنت عوامل اختبار عينات CFST سعة التحمل الانضغاط المحوري والمتانة ومؤشر الليونة والصلابة وطاقة الإجهاد. أظهرت النتائج أن المواد المستخدمة كبديل للرمل حسنت الخواص الميكانيكية للخلطات الخرسانية باستثناء نشارة البولي فينيل كلوريد (PVC) إن الزيادة في الخواص الميكانيكية مقارنة بالخلطة المرجعية كان لقوة الانضغاط ٤٪ -٢٤٪، قوة الشد ٤٪ -٤١٪ ولقوة الانثناء ٠,٤ ٪ -١٣٪. أما النسب المثلى لاستخدام المواد كبديل للرمل والتي أظهرت تحسنًا في خصائص الخرسانة هي ٢٥٪ رمل الكثبان، ٢,٥٪ حبيبات بولي فينيل كلوريد مكسر، ٥٪ مخلفات صناديق بلاستيكية، ١٠٪ برادة حديد. وقد أظهرت جميع عينات عمود القزم (CFST) زيادة في سعة التحمل تصل إلى ١٨ ٪ أكبر من العينة المرجعية عند نسبة ٥ ٪ من نشارة (PVC). بالنسبة لعينات (CFST) ذات الأعمدة القصيرة والطويلة، أظهرت نسبة ٥٠٪ من الكثبان الرملية عن سعة تحميل أعلى وهي ٨٪ و٢٤٪ أكبر من العينات المرجعية. بينما أدت إضافة مخلفات الصناديق البلاستيكية و (PVC)المكسرة كبديل للرمل إلى تقليل سعة تحمل عينات الأعمدة القصيرة(CFST) بحوالي ٥٪ و٤٪ عند نسب ٥٪. اما الأعمدة (CFST) القصيرة أعطت اعلى متانة عند نسبة استبدال ٥٪ من الصناديق البلاستيكية وكانت ١٤٪ أكبر من العينة المرجعية. الأعمدة(CFST) الطويلة أعطت أقصى متانة وهي ٨٢٪ اعلى من العينات المرجعية عند نسبة استبدال ١٠٪ PVC المكسر. واظهرت الأعمدة(CFST) القزم انخفاضًا في طاقة الإجهاد باستثناء عينات برادة الحديد التي أعطت ١٥ ٪ أكبر من العينة المرجعية بنسبة استبدال ٥ ٪. بالنسبة لعينات(CFST) ذات العمود القصير، أسفرت نسبة استبدال ٥٪ من مخلفات الصناديق البلاستيكية عن طاقة إجهاد أعلى بنسبة ١٤٪ أكبر من العينات المرجعية. بالنسبة لعينات(CFST) ذات العمود الطويل، أعطت نسبة استبدال ١٠٪ (PVC) المكسر طاقة إجهاد أعلى ٨٢٪ من العينات المرجعية.

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ربيع الاول ١٤٤٢ **تشرين الاول ٢٠٢٠**