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EVALUATION OF ADDING WASTE PLASTIC FIBERS ON SOME PROPERTIES OF MODIFIED FOAMED CONCRETE

A Thesis Submitted To
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سيدنا محمد صل الله عليه وسلم

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والدي العزيز

إلى من كان دعائها سر نجاحي وحنانها بلسم جراحي

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ABSTRACT

Lightweight concrete has superior characteristics, especially in terms of thermal insulation and unit weight, in comparison with normal concrete.The reuse of plastic waste is very important for a sustainable management of solid wastes.This study was undertaken to find ways to enhance some of the properties of foamed concrete through the addition of waste plastic fibers (WPF).The fresh and hardened properties of 1500 kg/m^3 foamed concrete mix was tested to determine the optimum mix for constant water-to-binder ratio of 0.35 and cement content of 350 kg/m^3. 10%, 20% and 2% of cement replacement with silica fume and Class F fly ash and superplasticizer were made to enhance the strength of conventional foamed concrete. WPF in volume fractions (v_f) of 0.25%, 0.5%, 0.75%, 1%, 1.25%, 1.5% and 1.75% respectively and aspect ratios, L/D, of 40, 60, 80 were added. The results of fibers distribution as well as compressive strength and splitting tensile strength for the 1500 kg/m^3 mixes show that the best mix has an aspect ratio (L/D=60) and volume fraction (v_f =1%). Hence, these ratios were used to fabricate mixes with varying densities of 1300, 1500, and 1700 kg/m^3. Consistency test was carried out on all mixes under investigation with nominal densities of 1300, 1500 and 1700 kg/m^3 to determine their spread diameter. The porosity, absorption, compressive strength, splitting tensile strength, flexural strength, modulus of elasticity and toughness of the mixes were measured at age of 7, 14 and 28 days. In term of all selected densities (1300, 1500 and 1700 kg/m^3). The reduction of total porosity for modified mixes were (5.2, 3.7) %, (4.5, 5.2) %, (8.1, 5) % for mixes (Fc3a, Fc3aw), (Fc5a,Fc5aw), (Fc7a, Fc7aw) respectively comparing with conventional mixes Fc3, Fc5 and fc7. The increment of compressive strength for modified were (108, 81) %, (99, 81) %, (64.6, 50) % for mixes (Fc3a, Fc3aw),

(Fc5a, Fc5aw), (Fc7a, Fc7aw) respectively comparing with conventional mixes Fc3, Fc5 and Fc7. The increment of splitting tensil strength for modified mixes were (55.1, 132.8) %, (74, 99.8) %, (85.8, 125.8) % mixes (Fc3a, Fc3aw), (Fc5a, Fc5aw), (Fc7a, Fc7aw) respectively comparing with conventional mixes fc3, fc5 and fc7. The increment of flexural strength for modified were (88.2, 119) %, (60.8, 88.4) %, (59.3, 125) % for mixes (Fc3a, Fc3aw), (Fc5a, Fc5aw), (Fc7a, Fc7aw) respectively comparing conventional mixes Fc3, Fc5 and Fc7. The increment of modulus of elastisity for modified mixes were (410, 56) %, (334, 230) %, (160, 120) % for mixes (Fc3a, Fc3aw), (Fc5a, Fc5aw), (Fc7a, Fc7aw) respectively comparing conventional Mixes Fc3, Fc5 and Fc7. It if found that Fc7aw has the maximum toughness (14.34) Joule followed by Fc5aw(8.24) Joule and Fc3aw(7.8) Joule has the minimum. Test results showed that the addition of WPF with additives has an advantage effect on the hardened properties of foamed concrete. Significant improvements were observed in the compressive strength, splitting tensile strength, flexural strength, and toughness of the modified mixes.

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LIST OF ABBREVIATION AND NOTATIONS

ACI	American concrete institude
ASTM	American Standards test materials
AAC	Autoclaved aerated concrete
A_{bw}	Water absorption%
BCA	British cement assocition
BSE	Backscatter electrone
CTU	Concrete technology unit
1D, 2D,3D	One dimention,two dimention,three dimention
E	Static modulus of elasticity
FC	Foamed concrete
F′c	Compressive strength at 28 day
FA	Fly ash
Fc_3	Conventional foamed concrete of 1300 kg/m^3
Fc3a	foamed concrete of 1300 kg/m^3 with fly ash and silica fume
Fc3aw	foamed concrete of 1300 kg/m^3 with fly ash and silica fume and WPF
Fc5	Conventional foamed concrete of 1500 kg/m^3
Fc5a	foamed concrete of 1500 kg/m^3 with fly ash and silica fume
Fc5aw	foamed concrete of 1500 kg/m^3 with fly ash and silica fume and WPF
Fc7	Conventional foamed concrete of 1700 kg/m^3

Fc7a	foamed concrete of 1700 kg/m^3 with fly ash and silica fume
HAUC	Highway agency unity Company Limited
ITZ	Interfacial transition zone
IUPAC	International union of pure and apllied chemistry
LC	Light concrete
LWFC	Light weight foamed concrete
LWC	Light weight concrete
LAC	Light aggregate concrete
L/D	Aspect ratio
L/M	Ratio of (length of Specimen / M) Where L=300 mm, M=(600 or 150)
LWCs	Light weight foamed concrete fine sand
Plf	Pulverized Ful Ash
PET	Polyethylene Terephthalate
pH	Hydrogen number
SCC	Self compact concrete
SF	Silica fume
SP	superplasticizer
SD	Spread diameter
SSP	Solid state polymerzation
C S H	Calsume silicate hydrate
S EM	Scanning electrone microscope
SE	Secondry electrone
C S H	Calsume silicate hydrate

S EM	Scanning electrone microscope
TRL	Technology readiness level
UPV	Ultra pulse velosity
W_{sat}	Weight of a saturated sample in air
W_{wat}	Weight of a saturated sample in water
W_{dry}	Weight of the oven dry- sample
W_{sat}	Weight of a saturated sample in air
W_{wat}	Weight of a saturated sample in water
WPFRC	Waste plastic fiber reinforce concrete
WPFS	Waste plastic fibers solid
WPF	Waste plastic fiber
WPS	Waste plastic solid
W/C	Water cement ratio
V_w	Volume of water absorption
V_C	Specimen volume
ϕ	Porosity%
ϕ_{vac}	Total porosity%
ϕ_{app}	Apparent porosity%

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Concrete has been used and utilized more commonly as a construction material all over the world for over a century. Concrete industry is being developed day by day since the Portland cement has been invented. Besides, different performances are expected from concrete according to utilization field and structure. These expectations, however, can be met with special concretes such as (Light Weight Concrete, Self Compacting Concrete, and Fiber-Reinforced Concrete, etc.). These special concretes are produced by different methods due to different needs. However light and heavy weight concretes are produced by changing type, quantity and kind of aggregate [1].

Since the 1990s, lightweight concrete, which has a quite superior performance especially in terms of thermal insulation and unit weight compared to normal concrete, has begun to find area of demand with a rising trend [2]. In construction industry, versatile utilization of lightweight concrete produced mostly by a variety of natural or artificial lightweight aggregate is becoming increasingly important. When compared with normal concrete, coarse aggregate is replaced with foam in producing foamed concrete. This helps to establish foamed concrete as an accepted building material.

1.2 Lightweight Concrete

The use of light weight concrete (LWC) as a construction material has significantly increased in the recent years light concrete (LC). LC is characterized by advanced physical characteristics like low cement content, low aggregate content, excellent thermal insulation, and good insulation sound [3,4]. Consequently, LWC is commonly used in several construction sectors, such as thermal components, sound insulation components, infill material for lightweight composite panels, and lightweight blocks [5–7]. The in-place density or unit weight of structural LC is in range of 1440–1840 kg/m^3 compared to that of 2240–2400 kg/m^3 for normal weight concrete. According to ACI 213RT[8], the strength of LC for structural applications must be more than 17 MPa [8].

1.2.1 Foamed Concrete

These are generally regarded as LC that consists of cementations binders with a high void space ratio; they are produced with or without the introduction of fine aggregates. Their mechanical properties are affected significantly by several factors such as the type of filler, ratio of w/c, curing method, as well as its microstructure which includes size and distribution of the air-voids, and total fraction of porosity [9,10]. The foaming method has been proven to have a direct influence on the pore shape, pore size distribution, and total volume ratio of air-voids [10, 13]. Zhang et al. [14] provided a comprehensive review of foaming methods and their influence on mechanical features of concrete material. Additionally, Karthikeyan et al. [15] highlighted the influence of the mixture time ratio in FC on the void connectivity. As the density of a mixture attains a certain level where air bubbles can separate from each other, there is a closure of the void forms;

otherwise, there will be open cell structures in the foamed concrete. Foamed concretes have been stated to have a dry density in range of 400–1600 kg/m^3 and a compressive strength in range of 1–25 MPa [16]. Fomed concretes produced with fly ash, micro silica, and SiO_2 powder have a compressive strength in range of 20–25 MPa and are suitable for structural applications and other load-bearing purposes. The cement replacement percentage replaced with fly ash has a little influence on the strength of FC. Even when a higher percentage of cement proportion is replaced with fly ash, its influence on the compressive strength of the FC is insignificant [17]. The ideal content of pulverized fly ash in FC for achieving the maximum compressive strength is in the region of 20 to 30% [18].

1.3 Waste Plastic

Before now, WPs are dumped into landfill-schemes, but this strategy is not enough to contain the explosive increase in the volume of generated WPs. It became evident that there is a need for another management strategy for WPs. A reasonable percentage of the generated WPs usually end up in the environment [19], and such environmental wastes have posed serious management challenges in recent times. A huge amount of non-biodegradable solid wastes is produced by various industrial activities. Globally, mineral water is usually served in polyethylene terephthalate (PET) bottles, often referred to as plastic bottles. These PET bottles are non-biodegradable but can be recycled for different purposes. Modern plastics are one of the revolutionary developments of the 20^{th} century. They have found an application in several industries, such as construction, automotive, packaging, building electrical and electronics. Since the introduction of PET bottles in the 1930s, their usage has consistently increased. The annual global of PET bottles production between 1950 and 2017 has increased from 1.7 million tons to 335 million tons [20]. Despite the varieties of plastics produced, PET is the most relevant as it currently accounts for about 7% of the total plastic waste [21]. The use of PET plastics in the packaging and presentation of several goods has contributed to its huge generation as most of the PET plastics are discarded into the environment soon after being produced. For instance, PET water and soda containers are discarded after consuming their content, thereby, generating a huge volume of plastic post-consumer waste. There will be a continuous increase in the production of PET wastes in the future; in fact, the estimated annual production of PET waste has been predicted to be doubles each decade [22]. The current management of PET waste is still not sustainable as reported by the study conducted by Themelis et al. at the Columbia University [23][24].

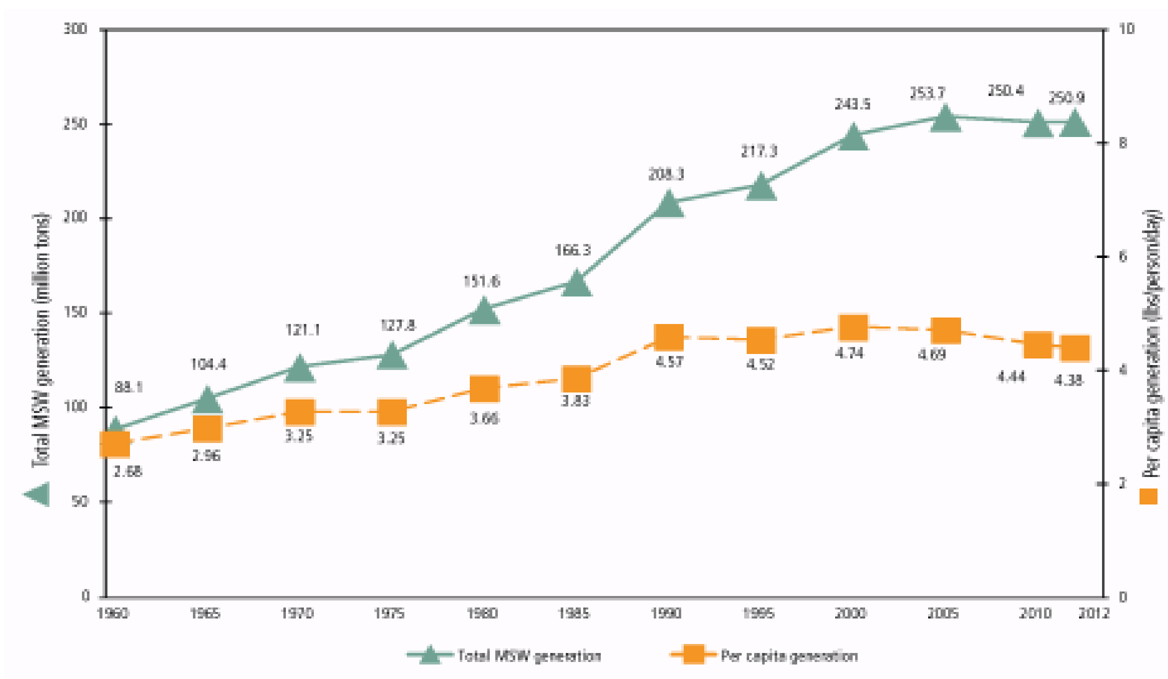


Figure 1.1: Plastic generation and recovery in united state (1960-2012) [24].

This is a chemical compound which belongs to the polymer category. It is characteristically suitable for food packaging but also has several industrial applications. It comes in various shapes such as 1D fibers, 2D plates, or 3D beverage containers. It has a good stability in regular conditions; it is also light and transparent and can be easily colored. PET is non-toxic [25] and always presents the same chemical form of fibers, film, liquid or solid. It has a melting point of 265°C (538 K) irrespective of storage condition. The tensile strength of PET is (86-105) MPa. The PET bottle is mainly advantageous as a relatively small volume of material which can give a container of maximum volume. PET took over from glass in the US market after only two years of its introduction. Initially, it was produced from petrochemicals, in contrast to other plastics that are mainly sourced from coal [25,26].

The last decade witnessed an increase in the use of fiber reinforced concretes. PET is a thermoplastic polymer resin which is commonly used in synthetic fibers [27]. The mechanical properties of concretes can be enhanced by use of waste plastic bottles in fiber form. This incorporation of waste plastic fibers into concretes is a new strategy in the construction sector [28].The incorporation of fibers into concretes has been practiced over a century ago. The early 1900s witnessed the use of asbestos fibers as a concrete additive, while composite materials came into being in the 1950s. This innovation increased the interest in fiber reinforced concretes [27].

Kandasamy and Murugesan [29] investigated the addition of 0.5% by volume of polythene fiber to concrete. This addition resulted in an increase in the cube compressive strength of the produced concretes. An attempt on the development of some self-compacted concrete (SCC) properties through the incorporation of WPF has been reported [30]. Some of the investigations performed on the workability properties of the SCC mixtures were the slump flow diameter, V-funnel flow at the same time, simultaneous T50 slump flow, and L-box height ratio. Similarly, the compressive and flexural strengths of the SCC were also determined in the 7th, 14th, and 28th day. From the results, the plastic fibers were shown to have a significant effect on the properties of the fresh and hardened SCC. The current study investigated the effects of the addition of WPF on the properties of foamed concrete.

1.4 Foamed Concrete with WPF$_s$

The utilization of FC (foamed concrete) as a construction material helps to minimize the self-weight of a structure, and also provides a better fire protection and thermal insulation compared to the normal concrete. The conventional FC is typically fabricated to achieve a low compressive strength, making it suitable for trench reinstatement and void fill, thus, not ideal for structural application. Various studies have reported the addition of fibers in normal concrete for tensile strength enhancement [31]. Banthia and Sheng [32] stated that the brittle properties of concrete can be overcome by the addition of carbon fibers, steel, and polypropylene. The addition of polyolefin fiber can only slightly improve the compressive strength of FC [29]. The slight improvement in compressive strength does not generally affect the applications of fiber reinforced FC. This is because polyolefin fibers are not introduced into FC to improve their compressive strength but to delay the propagation of cracks [33].

1.5 Problems Statement

Nowdays, a need for light weight construction materials suitable for semi-structural and structural applications has mixed. However, to improve light weight concrete proprties , toughness must be considered. Therfore, adding fibers to this modified light weight concrete may be good solution to enhence its mechanical proprties and increas toughness ability . Using of waste plastic fibers (WPF) not only improved the proprties of concrete but also achieved environmental benefit.

In this regard, the idea of this study has become to produce modified light weight construction material (foamed concrete reinforced by WPF) and to investigate its proprties.

1.6 Aim and Objectives

The aim of this study is to examine the potential of using waste plastic fibers in producing foamed concretes, and to evaluate the effect of adding waste plastic fibers on the properties of foamed concrete. The main objectives of this study are:

- To produce modified foamed concrete by using additives(fly ash and silica fume), superplasizer and waste plastic fibers (WPF).
- To determine the optimum content of WPF based on their distribution and mechanical proprties
- To evaluate the effect of WPF, additives and volume fractions and aspect ratio on the proprties of modified foamed concrete.

1.7 Methodology

To achieve the objectives of this syudy the follwing steps will be done:

- Design foamed concrete mixes with densities (1300, 1500, 1700)kg/m^3 by absolute volume method .
- Producing conventional foamed concrete mixes by pre-formed foam method.
- Producing modified foamed concrete mixes (with good strength) by adding additives such as (silica fume and fly ash) and superplasizer.
- Adding waste plastic fibers (WPF) to the modified foamed concrete mixes with different aspect ratios (L/D= 40, 60 ,80) and different volume fractions (v_f%) (0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75%).
- Find. the best aspect ratio from the distribution of WPF and compressive strength of produced mixer .
- Examine best volume fraction(v_f%) from the tensile strength of produced mixes.
- Adoptig the aspect ratio (L/D) and volme fraction (v_f%) for the chosen densities .
- Investigation the effect of WPF on the proprties of modified foamed concrete .

1.8 Layout of the Thesis

The work is presented in five chapters; The second chapter covered a review of the existing literature on lightweight concrete, LW foamed concretes, as well as the types and mechanism of waste plastic fibers. The third chapter presented the materials used in this study, the tools, equipment, all the specifications and the process of required tests in this study. The fourth represented the practical experiments of required properties of modified famed concrete, and its results and discussions. The five chapter presented the conclusions and recommendations.

CHAPTER TWO
LITERATURE REVIEW

2.1 General

There are several sections in this chapter. The first section presents the general background for FC production, while the second section presents the important properties of FC, covering its fresh and hardened proprties , In the third section, WPF such PET content were discussed.

2.2 Lightweight Concrete

The high self-weight of the conventional concretes is one of their major disadvantages; they have a density range of 2200 to 2600 kg/m^3.This huge self-weight makes the conventional concrete unsuitable for structural application. Much effort has previously been dedicated to the reduction of the self-weight of conventional concretes to improve their suitability for structural applications. The LWCs are concreted with a density of about 1850 kg/m^3 [34]. Contrarily, heavyweight concretes (density of more than 3200 kg/m^3) are normally used for radiation shielding.There is basically one way of producing LWC, i.e., through the incorporation of air in the concrete through any of the following ways:A replacement of the usual mineral aggregate with a given portion of light-weight or cellular porous aggregates.The introduction of air bubbles in the mortar in a process called aerated concreting. The exclusion of sand from the normal aggregate. This is referred to as ‘no-fines’ concrete.

The interest in LWC has grown over the years owing to their greater advantages compared to the conventional concretes .The interest in the use of LWC has been heavily promoted by the advances in modern technology and the improved understanding of their benefits. Structural light-weight concretes, a particular type of LWC, is relatively light compared to the conventional concretes but strong enough for structural applications, see table 2.1 [51].

2.2.1 Lightweight Aggregate Concrete

The LACs are often made by using lightweight aggregates. Evidently, different light-weight aggregates differ in their densities. When lightweight aggregates with different densities are used, the density of the resulting concretes also varies. The use of either vermiculite or expanded perlite can result in concretes of low density (around 300 kg/m^3), while concretes of about 1900 kg/m^3 can be produced using expanded slag, bloated clay, sintered fly ash, etc. The strength of LAC can also vary from approximately 0.3- 40 N/mm^2 when using a cement proportion of about 200 to 500 kg/m^3[8]. Majority of the LAC aggregates, except sintered fly ash and bloated clay are rough in texture and angular in shape. When used, they usually produce a harsh mix. The addition of excess amounts of fine materials, pozzolanic materials or other plasticizing admixtures has to be done with caution to improve their workability. The type of fine aggregates used also has an influence on the strength of the resulting mix. Sometimes, natural sand is used instead of crushed light-weight aggregates to improve the strength and workability of concretes. The workability of LWC can be improved through the use of air-entrainment; it will also improve their bleeding tendency. The strength of the LW concretes can also be further reduced by using of air-entrainment [35].

2.2.2 Non-fines Concrete

Another way of light concrete production is to exclude fine conventional concrete aggregates. As the name suggests, non-fines concrete is a type of concretes produced by omitting the fine aggregate fraction of the conventional concretes aggregates. It is made from only coarse aggregate, water, and cement. Most often they are produced with single-sized coarse aggregates of 10 to 20 mm. The use of non-fines concrete is increasing in popularity as it offers some advantages over the normal concrete. The use of single-sized aggregates in no-fines concretes results in concretes with large voids and lightweight [36]. Such concrete has a wide range of application, such as in load-bearing cast, in-situ external walls for multistoried and single storied buildings. They are also used for temporary structures as they have a low initial cost. They can be broken easily and reused as aggregates. They are attractive to architects as construction materials because they can be used as external wall heat insulators due to their higher thermal insulating property. Their rough texture makes them an ideal base for plastering. When subjected to rain exposure, they outer surface of no-fines concrete can be wet but the inner surface will be damp free due to the low capillary action occasioned by the large voids. They are a perfect alternative construction material when sand supply is limited [37].

2.2.3 Aerated Concrete

This type of concrete is made by the introduction of air into the mixture this Portland cement and pulverized siliceous filler such that upon hardening, a uniform cellular structure will be formed. Although it is referred to as aerated concrete, it is not a concrete in the actual sense as it is a mixture of cement, water, and pulverized sand. Aerated concrete is also called gas concrete, cellular concrete, or foam concrete. They can be produced in a variety of ways, such as [38].

a. Through gas formation by a chemical process when the mixture is still in the liquid or plastic state.
b. By introducing preformed stable foam into the slurry.

By introducing pulverized metal such as aluminum powder into the slurry to facilitate a reaction with the liberated calcium hydroxide from limestone during the hydration process and liberate hydrogen gas. The liberated hydrogen gas which is entrapped in the mixture, confers a cellular structure to the concrete when hardened [39].

2.3 Foamed Concrete

This is one kinds of aerated concrete, it a mixture of cement and fine sand with several uniformly distributed small isolated air cells of about see Table 2.2 which presented types concrete containing air [40], throughout the mixture to produce LWCs with difference pore size Table 2.3 presents diameter of poores of differen studies, [41], The Romans were the first to observe that the addition of a small portion of animal blood into a mixture of coarse sand and small gravel with water and hot lime resulted in the formation of small air bubbles after shaking, making the mixture more durable and workable. Significant improvements have been made over the last two decades in the production of better superplasticizers. The availability of foam agents has facilitated the large-scale use of FC and more efforts have been made to study the behavior and properties of FC to simplify their usage for structural purposes [42]. Based on the production method, FC can be grouped into physically lightweight FC which is produced by using foaming agents, and the chemically aerated concrete which is produced by the addition of powdered metals, calcium carbide, and hydrogen peroxide [43]. The lightweight FC produced by the use of foaming agent can either be dry or wet; the wet form is produced by spraying the foaming agent solution over a fine mesh; they are relatively stable and have about 2-5 mm bubbles in size. The dry form is produced by forcing the solution of a foaming agent through several high-density barriers and simultaneously forcing compressed air into the mixing chamber. They are extremely stable with a size of less than 1 mm [44]. In this study ,the dry method was used.

Foamed concretes are widely used in several civil and structural engineering applications due to their low cost, good properties such as light weight, ease of production and placement. The use of FC for low-density applications include cavity filling and insulation, while their higher density usage is in structural applications. Other applications of LW foamed concrete include lightweight blocks and pre-cast panel production, under bituminous finishes during roofing, road sub-base see Table 2.1 , trench reinstatement, fire insulation, shock absorbing barriers especially in airports, thermal insulation, and soil stabilization [45].

Foamed concretes are also categorized into cellular or lightweight concretes. Foamed concretes are produced through either pre-foaming or mixed foaming methods. During the pre-foaming production method, the base mixture and preformed foam solution are separately produced before being mixed together. While mixing the foam, both the base mix ingredients and the surface-active agents are mixed together. Foam is produced during the mixing, giving rise to the cellular structure observed in hardened concrete. The foam, in both approaches, must be relatively stable during the whole process

[46].Furthermore, foamed concretes can be defined as “hyperaerated mortars of mechanically entrained foam in the plastic mortar with more than 20% of air content by volume” [47]. This definition was provided by the Concrete Society in 2009 [48] to differentiate FC from air-entrained concretes with much lower entrained air volume [49]. Foamed concrete was also defined by Dhir et al. [50] as “a cementations material in which air is entrained through the mechanical introduction of a preformed admixture or foam into a mortar”. For clarity sake, the term ‘foamed concrete’ is used rather than foam concrete though they refer to the material.

Table 2-1: Applications of foam concrete [51]

applications	Density (kg/m^3)	Volume (m^3)	advantages	images
Bridge Abutment Backfill (1997)	480-640	6117	-Less overburden on the structure and underlying soils -no lateral pressure on the structure	
Load reduction fill/void fill	430-480	22937	-Greatly reduced loading on the basement floor and roof column piers -no need for additional pilling in the basement	
Oil plat form (1992)	800	2294	-used as impact layer due to its energy absorbing properties	

Continued table (2-1): Applications of foam concrete [51]

Cycle path (1997)	640	917	-minimize deflection of an asphalt cycle path due to soft compressible soils	
Running truck	640-913	2905	-minimize settlement of an asphalt bike due to soft compressible soils	
Road subbase (1998)	480-640	9557	-reduce loads on very poor underlying soils	

Continued table (2-1) Applications of foam concrete [51]				
Tunnel and underground construction (1998-1999)	640	10245	-backfilling due to its excellent fluidity	
Retaining wall back fill (1998-1997)	500	50000	-no compaction and not too much added weight-high performance void-filling -allowed for minimal use of skin friction piles -reduce foundation costs	
Foam concrete being poured	350-1600	-	-Imposes a little vertical stress on substructure -reduce loading on burden soil	

Table 2-2: Total air in concrete [40]

	Density kg/m^3	Typical compressive strength	Base materials	additions	Curing	Typical air content%	Air inclusion	Typical uses
Structural air Entrained Concrete	to 2200 2300	30 to 40MPa	Cement ,sand, coarse, aggregate	Air entrained admixtures	Normal water curing	5.5	Direct addition of air entrained to mixture	Freeze thaw resistance, reduced bleeding
Highly Air Entrained Concrete/Mortar (controlled low strength material)	1850 to 2000	3 to 8 MPa	Cement ,sand, coarse, aggregate Fly ash, limestone	Air entrained admixtures	Normal water curing	20 - 25	Direct addition of air entrained to mixture	Trench and void fill
Autoclaved Aerated Concrete	400 to 700	2.5 to 8 MPa	Cement ,sand	Aluminum powder	Autoclaved at high temperature	70-85	Addition of aluminum powder	Light weight Precast element Inclusion thermal insulation blocks
Foamed Concrete	800 to 1600	<1 to 8 MPa	Cement ,sand	Foam from surfactant	Sealed curing	35-65	i. Preformed foam ii. Mix foaming	Trench and void fill

Table 2-3: Pore size according IUPAC and [41]

name	diametere	Pore type	Size range	name			diameter	Role of water	Paste proprties
micropores	Up to 2nm	Interpartical space between (C S H) sheet	(1-3) nm	Micropores (inter layer)	Gel pores		Up too.5 nm	Water structture involved in bonding	Shrinkage ,creep,at all PH
				micropores			(0.5-2.5)nm	Strongly adsorbed	Shrinkage ,creep,at all PH
Mesopores	2nm to50 nm			Small(gell) capillaries		Capillary pores	(2.5-10)nm	Strong surface tention	Shrinkage (50-80)% RH
		Capillary pores(low w/c)	(10-50)nm	Medium capillaries	Hollow-shell pores		(10-50)nm	Modarate surface	Strength,permebility, shrinkage, ,at high pH>80%
macropores	>50 nm	Capillary pores(high w/c)	(3-5)µm	Large capillaries			50nm-10 µm	Behaves as bulk water	Strength,permebility
		Intrained voids	50 µm-1mm	Entrained air			0.1-1mm		strength

2.4 Specifications of foamed concrete.

The British Cement Association (BCA) initiated the first specification that includes foamed concrete [52]. Between 1991 and 1994, the BCA published the properties, advantages, and recommendations for the application of FC, as well as the guidelines of their strength and minimum thickness through other publications. Being that foamed concretes were earlier used for underground works and void fillings; these BCA publications were targeted at specifying their usage for trench restoration. Nevertheless, a milestone was achieved by the Horne Report which resulted in the passage of a new parliamentary Act that required reinstatement to a given standard by all utilities making openings in highways depending on the reinstatement and excavation method. Following this directive, a new specification was drawn by the Highway agency unity Company Limited (HAUC) for reinstating openings in highways in 1992. This specification later got approval as a Code of Practice with an Appendix section captioned '*Foamed Concrete for Reinstatement'*, taking effect from the 1st of January 1993 [53]. Cellular concretes are LW product made up of Portland cement, and other components such as cement-silica, lime-pozzolan, cement-pozzolan, lime-silica pastes, or pastes made from a mixture of these materials. They have a homogeneous cell structure or void which are produced with either foaming agents or gas-forming chemicals. Cellular concretes that contains other binding agents except Portland cement are usually autoclaved during the curing process. The density of cellular concretes can be controlled by using fine aggregates to replace part or all of the macroscopic air cells. Typically, both fine and coarse LW aggregates are normally used in cellular concretes. The ASTM C796 [54] test guideline provided a way of measuring the performance of foaming chemicals in the laboratory before using them to produce air cells for cellular concretes production. With the help of the Concrete Technology Unit (CTU) of the University of Dundee, the HATRL, in 2001, drafted an application guideline AG39 tagged '***Specification for Foamed Concretes'***. This guideline covered the properties, acceptance criteria, and quality control measures for foamed concretes [49]. Furthermore, the CTU and their industrial partners studied foamed concretes and provided their fundamental understanding [55]. In the UK, the other specifications include specifications on the use of foamed concretes for insulating building foundations, and as a replacement material for the UK Water Industry in 1995 [56,57]. Other parts of the world have followed these developments as well; for instance, in Japan, an industry standard has been identified. Despite being mentioned in the literature, the actual standard is not yet available to date [58].

2.5 Cement and Supplementery Cementation Materials

Foamed concretes are consisted of foamed mortar made from water and cement with or without the addition of sand (fillers) and supplementery cementation materials such fly ash and silica fume. The fomed concrete does not contain any coarse aggregates since it is produced by preformed foam to the concrete's morter. The density of the cast concr ete is controlled by the volume of the preformed foam [59].

a) Portland Cement (PC) as defined in BS EN 197: Part 1: 2000 is the major cement binding agent in FC [60]. The total cement content of FC is usually within 300 and 400 kg/m^3. Higher strength concretes are produced with total cement contents of more than 500 kg/m^3. Above this range, there is no proportional increase in strength even with increased cement content

[61]. However, other researchers have used other types of cement such Portland Pozzolana Cement, Sulfate Resisting Cement, Low Heat Cement, White Cement, Hydrophobic Cement, Water proof Portland Cement, and Colored Cement [27,38,49,50]. For instance, quick hardening PC as defined in BS 915:1983 has been utilized for improving the rate of strength and ultimate strength values in foamed concrete at the early hydration stages [60].

b) Fly ash (FA) is a common alternative component which can be used in FC and can be incorporated into FC mixtures as partial cement replacement (fine FA) or fine aggregates (coarse FA) [64]. Fine FA has been reported to reduce cost and enhance the stability and consistency of mixtures when added to up to 80% cement content [61]. Heat of hydration are reduced when Fine FA is added to the concrete, this is particularly important for FC to enhance their high thermal insulation properties [55]. Furthermore, Jones and Macarthy [3] noted that fine FA addition causes to change the behavior of FC to follow that of normal concrete and also caused peak temperature reduction. Therefore, an early reduction in strength with slower reacting materials should be considered when oncretes are made at low temperatures [53]. This is attributed to the dilution effect of fine FA on the PC which resulted in slower interactions and extended the idle period.

AL-Jumaily et al. [65] stated that the cement industry has over time used several pozzolanic materials which can improve cement properties. A combination of Class C FA (CaO more than 20%) and Portland cement can serve as a cement replacement to the range of 20-35% cement mass. The effects of alkali-silica reactions can be mitigated by replacing Portland cement with Class C FA by at least 25% cement mass. When Portland cement is used with Class F (CaO less 10%) FA can replace up to 20-30% cement mass.

C) Silica fume has been noted to have a small effect on the shrinkage of FC [6]. The replacement of up to 10% cement mass with SF can significantly increase the strength of FC at a foam content of less than 30% [55,60] However, a minimal improvement in the strength of FC can be observed when the foam contents are a bit higher. The hydration heat liberated by SF is not favorable to FC as it can significantly raise the core temperature result in serious effects [3,62]. The addition of SF at a given bottom ash content and age has been stated to increase the compressive strength and heat conductivity of bottom ash LW concrete which was cured in air and autoclaved for 6 h [67,68]. Additionally, an increase in the air curing time was reported to increase the unit weight, heat conductivity, and compressive strength of the bottom ash LW concrete. Thus, the observed increase in the unit weight, heat conductivity, and compressive strength was due to the reduction in the permeable voids volume. A 20% bottom ash replacement and 5% SF resulted in the highest compressive strength of 18.8 MPa after curing in the air and autoclaved for 6 h.

2.6 Fine Sand of foamed concrete.

The compressive strength of FC is much affected by fine sand in comparison to coarse sand aggregate. At any density, mixtures with fine sand usually have higher compressive strength compared to those prepared with coarse sand. Similarly, the variation of fine sand mixtures is higher at a higher density compared to those of coarse sand mixtures (ASTM C128-15) [69]. Similar findings have also been documented in the literature [56,57]. With the exception of the Pozzolana of FA, the use of lower foam volume for any FC density will enhance the strength of the mixture by reducing the volume of the pores and facilitating a uniform pore distribution.A similar enhancement in the compressive strength due to FA introduction was observed by Durack and Weiqing [72], this enhancement was attributed to a strong interparticle bond enhancement between the FA particles and the gel matrix, see Table 2-4 .

Table 2-4:Comparison of strength to density ratio(in MPa per kg/m^3 *1000) [10]

Design density kg/m^3	Strength to density ratio for foam concrete mixes with			
	Coarse sand	Fine sand	Fine sand-fly ash	Fly ash
1000	0.77	1.73	1.68	2.79
1250	3.87	3.63	5.32	7.11
1500	5.04	6.94	8.64	12.66

Kearsley and Visagie [73] observed a similar scenario when investigating effect of pore size on the strength of FC. The effect of sand replacement with FA has been reported [10]. Figure 2.1 presents the relationship between the compressive strength and dry density of FC produced with fine sand and FA, as well as those produces by using a mixture of fine sand and FA as filler. An increase in the FA content at any density results in an increase in the compressive strength. Nambiar and Ramamurthy [10] examined a section of specimens under 20x magnification of value and observed a comparatively uniform pore distribution in FC produced with fine sand, while FC mixtures produced with coarse sand aggregates showed larger and irregular pores. This study shows that the use of coarse sand results in the formation of irregular large pores by causing bubble clustering .

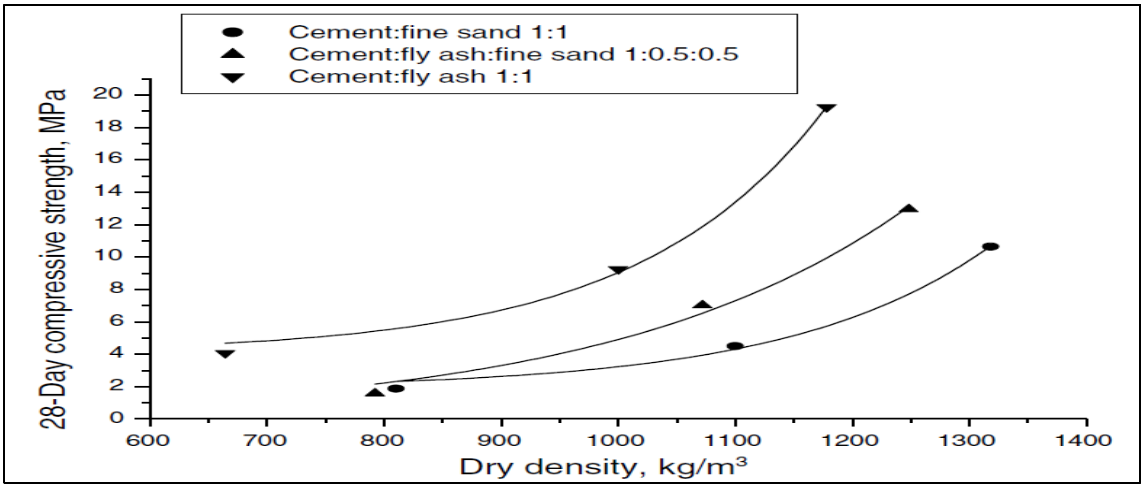


Figure 2.1: Strength density variation for mixes with different filler type [10]

2.7 Water

Water plays a significant role in concretes. The importance of water in FC can be better understood by reviewing the role of water in concretes. During concretes production, water mediates the precipitation of the chemical reaction with cement; it also facilitates workability of the mixture through wetting the aggregate and lubricating the mixture [74,75]. The addition of water to cement to produce concrete has to follow the regulation of the BS EN 1008 standard [76]. This regulation covers drinkable water, as well as recycled water from the concrete processing industries, and non-mains sources water like boreholes. To avoid organic contamination effects on the quality of foam, the Highways Agency and TRL [49] suggested that potable water should be used when working with protein-based foaming agents. Several studies have reported different effects of water on the properties of FC and normal concretes. Dransfield [77] found an increase in the compressive strength and workability when the w/c ratio increased. The study suggested that the w/c has a little effect on the strength of FC.In this study showes that the decreas of w/c incease compressive strength .

2.7.1 Superplasticizer addition

SP are an improved version of the common plasticizers. The SP more developed in Japan in 1960 and in Germany in 1970. The chemical properties of the SP vary from those of normal plasticizers. With the SP, water content can be reduced to about 30% without any significant reduction in the workability of the mix [70]. For the normal plasticizers, water content can only be reduced to about 15% [78]. The SP is used to produce self-leveling, flowing, self-compacting concretes with high strength and performance. The only difference is that SPs are more potent as dispersing and water reducing agents. In the American context, they are referred to as High Range Water Reducers. The use of SPs made it possible to use w/c ratios as low as 0.25 to make flowing concretes of more than 120 MPa compressive strength. SPs have made it possible to use FA, slag and silica fume in the production of concretes with high performance [79]. Plasticizers or superplasticizers can only fluidize mixtures of about 2 to 3 cm initial slump at nominal dosages; no slump concretes require higher dosages of plasticizers or superplasticizers to be fluidized. Significant slump value of improvement can only be observed to the extent of 25 cm or more based on the initial slump value of the concrete, the cement content, and the dosage. Slump values are noted to increase with increase dosages, but beyond a certain dosage limit, there will be no significant increase in the slump value. Sometimes, overdosage can cause a significant harm to the concrete [79]. Figure 2.2 depicts a typical slump-dosage curve

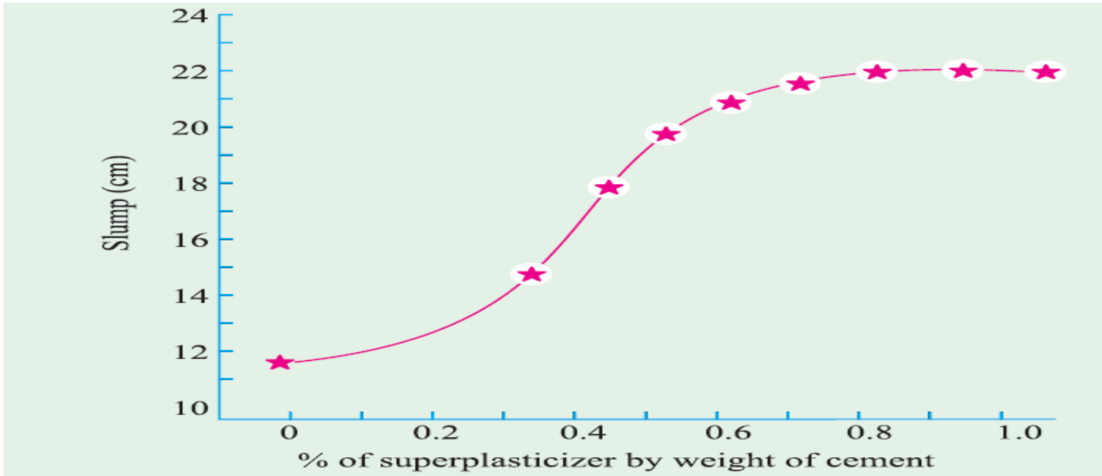


Figure 2.2: Slump variation to the percentage of super plasticizer content [70].

2.7.2 Foam agent

There are two categories of preformed foam; wet and dry foams. The wet foam is mainly produced by spraying water and foaming agent mixture over a fine lattice, while in the case of dry foam, a similar solution is forced through several high-density barriers before forcing compressed air into the mixing container. The size of the wet foam is slightly more than that of dry foam; they are loose and about 2-5 mm in diameter. In terms of stability, the dry foam is relatively more stable and about 1mm in diameter. They are thick and looks like shaving foam. Foams are selected based on the intended FC application [81]. During the production of FC, the properties and quality of a used foam is critical, especially when using more than 50% foam-base material mixture at a density of about 1100 kg/m3 [81]. Foam quality is affected by its density, as well as the foam-making process, the dilution factor of the agent, and the blending process. The foam must remain stable and intact during the pumping, placement, and curing processes [47].

Foam is produced as stable bubbles when foaming agents are mixed with water in a foam generator. Dry preformed stable foams are introduced into fresh LW foamed concretes to control their density. In this study, a foaming agent-water ratio of 1:40 by volume was used to produce LWC foamed concretes in accordance with the ASTM C796 [54]. One of the most significant properties of FC is its density which can be controlled over a wide range by adding a predetermined amount of foam to its mixture [80]. Foams can be introduced into FC mixture either in a preformed state or by introducing foaming agents such as detergents into the mixture. Preformed foams are commonly used foams as they have been reported to be economical, requires no chemical involvement, and guarantees a controllable pore-forming process [5,64]. Preformed foams are made up of air and an aqueous foaming agent. Foaming agents are responsible for the final properties of FC. A failure of the foaming agent can result in the collapse of the mixture, leaving a very dense base mix.

2.8 Foamed Concrete Mixing Process

Foamed concretes are significantly affected by their mixing process as one or more mixing process can have a great effect on the FC quality. Such processes include the type of mixer, the rotation speed of the mixer, as well as the mixing duration. The type of mixer will determine the distribution of the preformed foam [55]. The commonest type of mixer which has been proven a success is those with folding action. These mixers have paddles rotating on a horizontal shaft or a screw action [63]. Contrarily, the use of pan mixers could cause the settlement of the preformed foam on the surface of the mortar instead of folding them in. There is no folding action in the rotating mixers as they rely on free-falling action [76]. Furthermore, rotating mixers cannot produce sufficient base-mix workability as they do not provide enough shear [60]. The required dosage of foam can be affected by rotation speed of ready-mixed trucks [49]. A shortened mixing duration has been reported to result in non-homogeneous FC, while a prolonged mixing duration at high speeds results in foam disintegration [17].

However, it has been stated that no evidence exists to prove the production of excessive air or air loss during a prolonged mixing duration [42]. Foam can be blended with the base mix either on-site or in the plant in ready-mixed trucks [81,83]. For the other system of FC production, it can be executed in two ways, which are the wet and dry in-line system. For the wet method, the foam and the dry base materials are mixed through several static mixers where they are homogenized. As demonstrated in Figure 2.3, the foam can either be injected into the mixer, through a flexible hose, or through a specialized blender [47].

These mixers can blend the base materials and the foam into a homogenized mixture through a perfectly repeatable process. To control the system, the density of the mixture is continuously monitored through an on-board density monitor. The size of the truck does not determine the volume of the output, and this makes it an effective on-site working process [81].

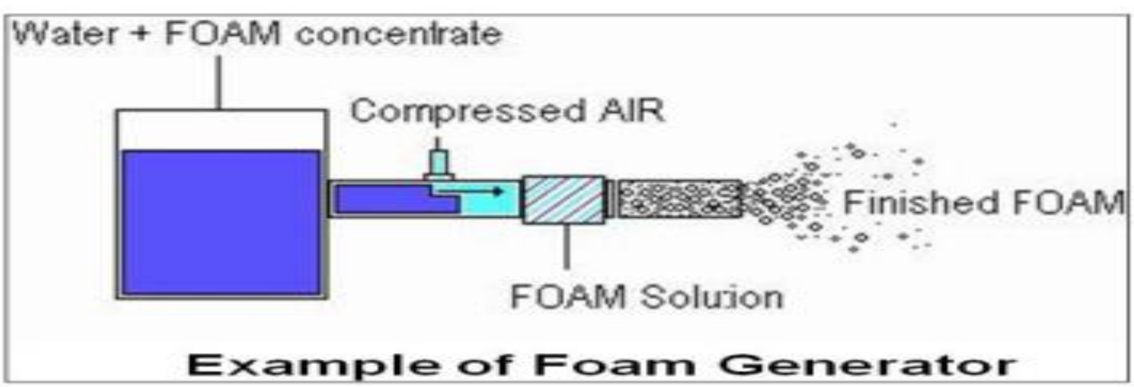


Figure 2.3: Schematic diagram of the production of foam for foamed concrete mixes [82]

For the dry method inline system, the mode of operation is similar to that of the wet inline system, only in the dry method inline system, the dry materials are loaded in silos which can be batched or weighed on-site [65,66]. Upon mixing, the base mix is transferred to the mixing chamber before adding the foam. This is an ideal system in locations where there is a difficulty in obtaining the base materials. Meanwhile, the disadvantage of this method is the need for a large volume of water for making the mixtures on-site, and this is not desirable for work in sites with limited water supply [83]. A foam mixture is prepared by admixing air, water, foaming agent and accelerator under pressure in the foam generator. This foam is charged into the hydrated cement admixture. The substantially homogeneous foam-containing cement slurry is introduced into the mold, and it is thereafter cured at an appropriate station to produce the desired cellular concrete product [85].

Falliano et al. [85] prepared a set of specimens with variant foamed concrete using a protein-based foaming agent. These specimens were in different curing conditions, namely in the air at environmental temperature, in cellophane at an environmental temperature and in water at a controlled temperature of 30°C. Based on the broad cite campaign carried out by the researchers, the strength values were found to depend upon several factors, mainly the water content (in terms of the w/c ratio) and the curing conditions.

According to Hilal [86], the foaming agents must have a chemical composition capable of producing stable air cells in the concrete which resist the physical and chemical forces imposed during mixing, placing and setting of the concrete. An example of a non-ionic foaming agent is illustrated in the formula below.

$$
\begin{array}{ccccccccccccccc}
 & & H & & H & & H & & H & & H & & H & & H & & H & & H & & H & & H & & & \\
H & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & C & - & (OCH_2CH_2) - OH \\
 & & H & & H & & H & & H & & H & & H & & H & & H & & H & & H & & H & & &
\end{array}
$$

2.9 Curing of Foamed Concrete

Since the incetion of concretes, the need for concrete curing has been recognized. Although there are many established methods of conventional curing of concrete, efforts are still ongoing on the curing regimes for FC [87]. Kearsley et al. [62,73,88,89,106,108,116] examined the conventional sealed, water, and air curing methods at different temperatures, the studies of curing also investigated moist and steam curing at both high-pressure steam and atmospheric pressures; a process called autoclaving. From the results of the study, Kearsley concluded the FC which are water-cured showed lower apparent strengths, while those cured at 50°C showed the highest strengths. Similarly, specimens that were sealed in plastic bags and maintained at 22°C also showed good strengths. Curing at increased temperatures usually results concretes with higher compressive strengths but the disadvantage is that such methods are costly [62].

Having studied these curing methods, it was concluded to use sealed in previousely study. In this study, the sample is first wrapped in a cling film and preserved in plastic bags at 22°C ,this method is called sealed curing method,. This is the commonest curing method used by several researchers [15,16,44,65,67-69].

2.10 Properties of Foamed Concrete

As stated in the ASTM C796 [54], there are several characteristics of FC, ranging from their fresh state and early age characteristics to their hardened state characteristics. For this review, emphasis will be placed on the three significant properties of FC, which are their workability in the fresh state, their instability, and their hardening rate at the early age stage. Regarding the hardened state properties of FC, the focus will be on their porosity, water absorption, and density. Furthermore, there will be discussions on the influence of their mechanical properties, in addition to other related properties.In this study,the fresh and hardened proprties were investigated as show :

2.10.1 Fresh Properties of foamed concrete.

All cement-based materials have a transient fresh state, but this transient state plays a significant role in the ultimate performance of the hardened material [72,73]. However, most studies have reported only the characteristics of cement-based materials in their fresh state.Foamed concretes are generally characterized by their free-flowing, self-compacting, and self-leveling properties [51,63,72]. Basically, FC with relatively large amounts of air pores has an excellent workability. They are also pourable, have near-fluid consistency, homogeneous, and low chances of segregation and bleeding. Furthermore, they are easily placed without the need for further consolidation [51]. In normal concretes, the term ‘workability’ is restricted to definitions and measurement methods; however, rheological principles are mainly for the description of fresh concretes’ behaviors [90-93,94]. Hence, the terms of workability and rheology are used to clarify the fresh state of FC (as in all cement–based materials), as earlier described by several researchers [38,52,74]. While the rheological properties of cement-based materials have been well documented [62,73,75-78]. In this study, the spread diameter was mesuerd for all investigation mixes ,it shows the consistency and plastic density of mixes .

2.10.1.1 Stability of foamed concrete.

For a better understanding of the need for stability with respect to the other characteristics of FC, there is a need to explain the term stability. As a determinant of the workability of normal concretes, stability refers to the ability of a concrete material to resist segregation. It is rarely used as a quantified and descriptire property of concrete mixtures[95, 96]. It is necessary to ensure there is an adequate air void system [97, 98] which must be stable during the concreting process.The stability of fresh preformed foam and FC has been described previousely [11,42,50,53,66,74, 81].

With the incorporation of foam FC, it is highly expected that the foam stability will have a significant influence on the fomed concrete, especially when the foam/base mix ratio is above 50% [82]. The stability of foams with larger bubbles and more open cells (as encountered in foams produced by synthetic surfactants) is lower compared to foams produced with protein-based surfactants [55]. Furthermore, foam stability is affected by several factors, including the surface charges, fly ash content, ‘free’ water content, and chemical admixtures [3]. From the study conducted by Jones and McCarthy [3], the stability of FC can be determined by comparing the actual and calculated quantities of foam required to achieve visible plastic density. The stability of FC mixtures has been previously defined by Nambiar and Ramamurthy [13] as a condition at which measured density and design density are equal or nearly equal. In another report, Nambiar and

Ramamurthy [99] defined FC stability as ‘the condition at which the density ratio of a mixture is near unity’. They concluded that the stability of FC largely depends on the foam volume, the base mix consistency, as well as the type of filler.Irrespective of the several definitions of FC stability, the earlier definitions focused on the description of the properties of fresh foamed and preformed FC[100],

According to Neville and Brook [101], stability in normal concrete may be attributed to the cohesion of the mixture; that is, its ability to resist segregation, which is only meaningful under certain conditions. An ideal fluid concrete mixture is a mixture designed to be workable enough, as well as having an acceptable level of stability and resistance against deformations and segregation.

A major advantage of using FC is that they do not collapse after placement [54]. Howeverr, and little effort has been devoted to exploring the validity of stability assumptions.Preliminary studies have focused on instability of FC.

Jones and McCarthy. [55] reported foam collapse during concrete mixing and prosess but suggested that the degree of collapse cannot be predicted as it varies with the constituents of the mixture. Segregation is often a way of checking for the instability of mixtures [53,65]. The lack of literature evidence in this field justified the little interest dedicated to the stability of FC in the previous studies.

Nambiar and et al [99] noted that the stability of FC is mainly affected by the proportion of water in the base mixture, the volume of foam, and the proportion of other solid materials in the mixture. Being that only this study has reported the effect of the constituent materials on the stability of FC, there is a need to investigate other factors which can influence the stability of foamed concretes.

2.10.1.2 Consistency of foamed concrete.

Consistency is a common term used in expressing the degree of mobility or fluidity. However, a concrete that possesses numerous consistency and mobility does not necessarily require appropriate workability for a certain task [102]. Each task needs a certain workability. In addition, a concrete that is appropriate in casting multiple concrete foundations may not be adequate for concrete used in constructing the roof. In the construction of roofing, workable concrete when a vibrator is using cannot be utilized if the concrete is being close-packed with hands. Likewise, the usable concrete in the broad compartment is not adequate for the range section. Thus, workability fully depends on the kind of compaction, nature of the work, size of reinforcement, and section thickness [70,103]

Stability and consistency of freshly mixed fizzed concrete are required to stop the detachment of cement mortar, artificial air bubbles and bubble breakages which can influence its hardened characteristics. The flow cone spread test is employed in the assessment of fresh foamed concrete consistency. In addition, this is well correlated to the fresh mix rheological characteristic [104,105]. Slump test is the main technique employed in the measurement of concrete consistency that can be used either in site or laboratory. This technique is not useful for immensely dry or wet concrete. Moreover, all the parameters of workability and placability of the concrete are not measured using this technique Nevertheless, it is easily utilized as a standard and shows a consistant concrete from one batch to another [106].

2.10.2 Hardened Properties of foamed concrete.

The determination of final and initial set time for foamed concrete has no specific standard technique yet, however, the technique provided in BS 5075:1978 [49] for cement gave the fundamental of appropriate techniques in the foamed concrete preparation.In a previous study [51], strengthening of every stirs did not materialize until 5 h preceding the casting at 20 °C. Figure 2.4 illustrates every foamed concrete blends attained the set limits provided in BS 5075-1:1982 [107] until 9-10 h. Usually, it takes between 12 to 24 h before foamed concrete can be set. The quantities of foam in the mixture have an influence on the strengthening time of the foamed concrete because foaming agents possess retarding admixtures to chemical parallelism. Therefore, the time of stiffening is opposite to the density of foamed concrete [3]. Averagely, it can take about a day strength of 1.0 N/mm^2 for foamed concrete, however, this can be enhanced with using accelerators, rapid hardening cement, increasing the ambient temperature, and insulating formwork [47]. Accelerators are utilized to improve the strength development and reduced strengthening rate of foamed concrete. The mechanism for increasing curing can be utilized on empirical support. Furthermore, Calcium chloride has been categorized as the main efficient accelerator and is usable in most situations of foamed concrete due to carbon steel strengthen that is hardly employed in foamed concrete, contrary to typical strengthened concrete [77].

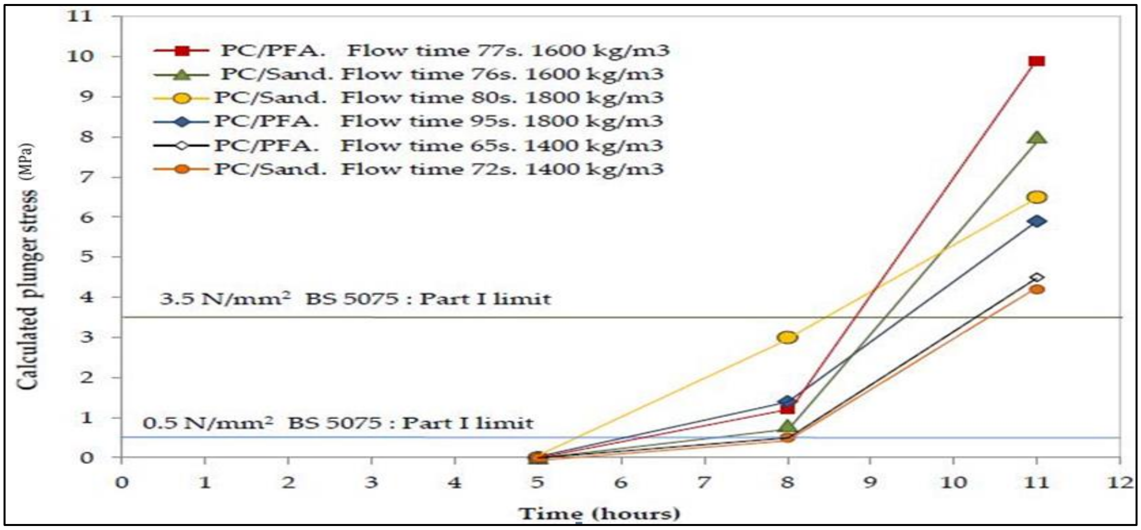


Figure 2.4: . Comparison of stiffening times of various foamed. concrete mixes [52]

2.10.2.1 Density of foamed concrete

The reinforce of light-weight concrete relies on the concrete density. The usage of foam concrete has increased due to its low density and other characteristics mostly thermal insulation feature. The density of aerated concrete ranged between 300 to 800 kg/m^3. For insulation basis, lower density grades are utilized, whereas, in the manufacturing of load-bearing walls or building blocks, medium density grades are employed. In the manufacturing of steel reinforcement and prefabricated structural members, higher density grades are utilized. Table 2.5 represents the density grades of light-weight concretes.There are three types of densities for foamed concrete: designed, measured or cast and oven dry.

Design density is based on which quantities of mix constituents are theoretically obtained. Measured or cast density obtained after casting the mix in the laboratory and oven dry density obtained after oven drying the concrete to a constant mass. It is always difficult to obtain theoretical design density, as the foam expands continuously after its production and foam bubbles restructure when the foam is added to a base mix and during mixing [4].

Table 2-5: Comparison between foamd concrete, and other concrete types [4].

Type of concrete	Foamed concrete	Conventional concrete
Production and setup procedures	Pre-cast,in situ, concrete mixures with foam generatore	Pre-cast,in situ
Compressive strength(MPa)	Up to 58	30-150
Dry density(kg/m^3)	-Grouting,thermal insulation, 400 -non-structural,600- structural1200-1950	Structural 2400
Vibration process	None	needed
Strength development	With age	With age
Thermal insulation (w/mk)	Up to 0.66	Up to 2.1
Sound apsorption	Advance	good

Kearsley and Mostert [108] highlighted a relationship between dry density (ρd) and required casting density (ρm) for concrete densities ranging between 600kg/m^3 and 1200kg/m^3 (Eq. 1) [109]:

$$pm = 1.03pd + 101.96 \qquad (1)$$

Amount of sand usage for manufacturing foamed concrete relies on concrete density. In lower-density foamed concrete, the quantity of sand is little to invalidate the disintegration and segregation of the mix [4]. The importance of foamed concrete density is well documented [9,50]. The capability to manage its density is an important merit of foamed concrete. The characteristics of foamed concrete are strongly affected by designed densities ranging from 300 to 1600 kg/m^3. Besides, no control technique has existed segmenting foamed concrete, the common principles of w/c ratio, maintaining a unit volume and free water content which are used for certain plastic density that suits a prime design criterion [3].

Designing a certain dry density is hard because foamed concrete will remove from the surface between the densities of 50 to 200 kg/m^3 of total mix. The tolerance of plastic density is mostly at ± 50 kg/m^3 of the targeted data, which is mainly for industrial practices in the production of formed concrete [3].The imbalance foamed concrete is responsible for the variation in the densities which may result in unfitness, segregation, collapse, and unpredictability.

The density may increase density preceding solidification if the formed bubbles are collapsed. Moreover, manufactured foamed concrete using protein surfactants may possess similar densities both after 24 h and freshly mixed [110].The changes in design density ratio (estimate fresh against design density) and water-solids ratio utilizing various kinds of filler type for 1000 kg/m^3 presents in Figure 2.5 [10]. At minimum consistency, the density ratio is more than one.

A study conducted by Nambiar and Ramamurthy [10] showed that concrete was too hard to produce adequately which resulted in bubble breakage during the mixing process, this led to higher measured density. In contrast, with increasing water-solids ratio, the increased water content resulted in a watery slurry for detaining bubbles. This resulted in the separation of foam from the concrete, thus causing separation of the mixture that led to higher measured density [10].

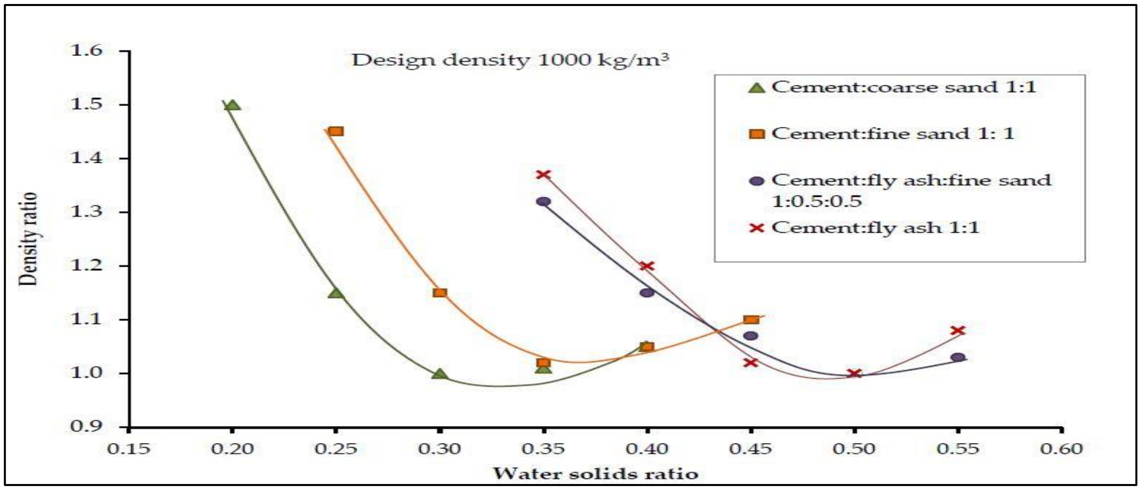


Figure 2.5: Variation of density ratio with water–solids ratio for different filler [10].

2.10.2.2 Porosity of foamed concrete.

The permeability and porosity of concrete are majorly influenced by moisture content: The difference between oven-dried and saturation occurrence has been suggested to improve the permeability with close to two levels of magnitude [96]. However, the foamed concrete porosity represents the addition of voids within paste and entrained air voids. Vacuum Saturation Apparatus is being used to evaluate the porosity of foamed concrete as illustrated by Cabrera and Lynsdale [111]. They measured the porosity of 68-mm diameter slices obtained from 100-mm cube center. Then, the slices were oven-dried at 100 ± 5°C until a stable weight was achieved, then the slices were put inside a desiccator for 3 h. Thereafter, the porosity was determined based on Equation (2).

$$p = \frac{(W_{sat} - W_{dry})}{(W_{sat} - W_{wat})} \times 100\% \qquad (2)$$

where p denotes the vacuum saturation porosity (%), W_{sat} represents saturated sample weight in the air; W_{wat} represents saturated sample weight in water, and W_{dry} denotes the weight of the oven-dried sample.

Kearsley and Wainwright [89] found that a significant relationship exists between porosity and dry density that is majorly not dependent on ash content, ash type, or introduction of the foam. The porosities between within 67% (foamed concrete that has pfa/cement ratio equals to 3 and casting density equivalent to 1000 kg/m^3) to 29% (cement paste that has water/cement ratio equals to 0.3). The paste of cement that has water/cement ratio equivalent to 0.3 without ash had the lowest porosity of 29%. The porosity reduced as the ash content increases based on past studies [17,91-92,112-114] .

2.10.2.3 Water absorption of foamed concrete

Water is an important raw material for mixing concrete. It gives an important role in cement hydration process which helps the production of (C S H) gel. Water is the most abundant fluid in nature which exists in various states. Regardless of its significant role, the water is an agent of deterioration which permeates concrete [115]. Water absorption of foam concrete reduced with a reduced density, this is due to reduced paste volume and hence decline the capillary pore volume. Paste phase is the major factors that affect the water absorption of foam concrete, however, not all artificial pores can take part in water absorption because there is no relationship between them [9, 80]. Using percentage by mass to express water absorption can result in an incorrect result due to numerous variations in density. The permeability of water and oxygen vapor of foam concrete were reported to improve with increasing fly ash content and porosity [116]. Unit weight is directly proportional to the permeability coefficient of lightweight foamed and opposite to pore ratio [117].

Furthermore, it also observed that the water absorption increases with increasing porosity as shown in Figure 2.6 [118-120]. In another view, researchers [89,90,110] have shown that the result from water absorption test gives an estimation of the total pore volume of the concrete, but the concrete permeability cannot be indicated, the water absorption of foamed concrete is mostly affected through the paste phase but not entrained pores which are not interconnected.

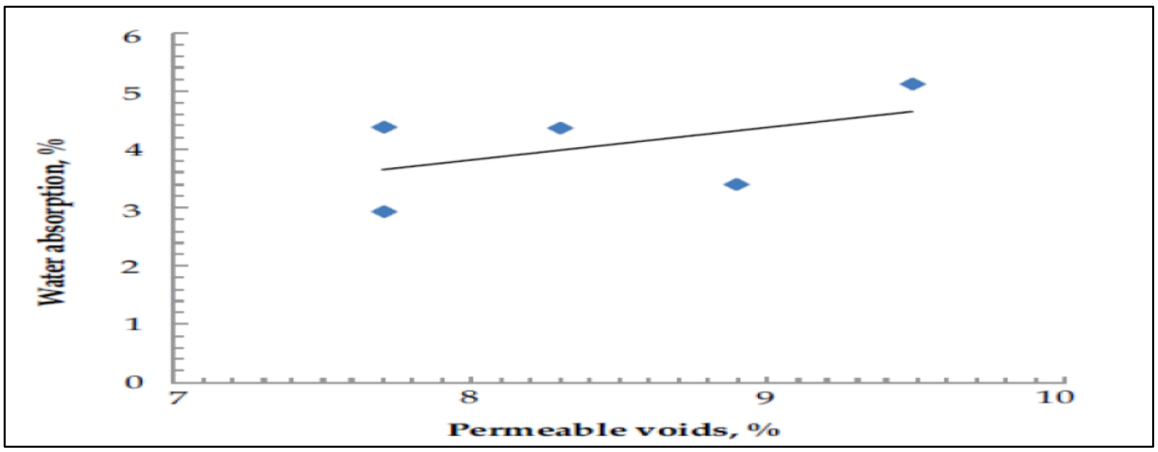


Figure 2.6: Relationship between water absorption and porosity.[102]

2.10.3 Mechanical Properties of foamed concrete.

As the porosity increases, the mechanical characteristics of foamed concrete tends to decline. There may be variation in foamed concrete density for similar water-cement ratio from the homogenization of several quantities of foam that may lead to different void sizes and porosity.

Due to this, any deviation in the foamed concrete microstructure because of the void system might significantly affect the mechanical characteristics in terms of density [120]. The mechanical properties of foamed concrete which affect the relationship between stress and strain are the strength of foamed concrete, strain at optimum stress and initial modulus of elasticity. They encounter noticeable deviations at higher elevated temperatures. In addition, the initial modulus of elasticity and strength of foamed concrete strength decline, whereas the independent data for strain at the optimum stress appreciates [121].

2.10.3.1 Compressive Strength

Previously, strength was not the major problem if foamed concrete is used because it was mainly utilized in highway reinforcement, void filling and some other underground constructions [36,69]. For the foamed concrete densities ranging from 800-1000 kg/m^3, the value of strength ranged from 1-8 N/mm^2 which is abundant for underground constructions [76]. The formed concentrate can be employed as structural substances even with a reduced strength of 25 N/mm^2 [54]. Due to this, a lot of studies have been carried out to evaluate the tendency of improving compressive strengths [12,17,80]. Table 2.6 presents comprehensive characteristics of foamed concrete reflecting the main compressive strength as explained by BCA (1994).

Table 2-6. Summary of properties of hardened foamed concrete [48].

Dry density (kg/m^3)	7-day compressive strength (N/mm^2)	Thermal conductivity (W/mK)	Modulus of Elasticity (kN/mm^2)	Drying Shrinkage (%)
400	0.5 – 1.0	0.1	0.8 – 1.0	0.30 – 0.35
600	1.0 – 1.5	0.11	1.0 – 1.5	0.22 – 0.25
800	1.5 – 2.0	0.17 – 0.23	2.0 – 2.5	0.20 – 0.22
1000	2.5 – 3.0	0.23 – 0.30	2.5 – 3.0	0.18 -0.15
1200	4.5 – 5.5	0.38 – 0.42	3.5 – 4.0	0.11 – 0.19
1400	6.0 – 8.0	0.50 – 0.55	5.0 – 6.0	0.09 – 0.07
1600	7.5 – 10.0	10.0 – 12.0	10.0 – 12.0	0.07 – 0.06

The compressive strength of foamed concrete is influenced the curing regime, density, water/cement ratio, surfactant type, cement content and type [55]. Compressive strength and density are directly proportional whereby as the compressive strength increases, the density also increases [45,80,89]. Figure 2.7 presents this phenomenon, the higher air content in reduced density will cause the foamed concrete to weaken [50]. Nevertheless, density is not completely effective for indicating the quality or strength if the foamed concrete constituents differ [48]. De Rose and Morris [66] observed that as the water/cement ratio increased to 0.45, the strength declined. Beyond 0.45

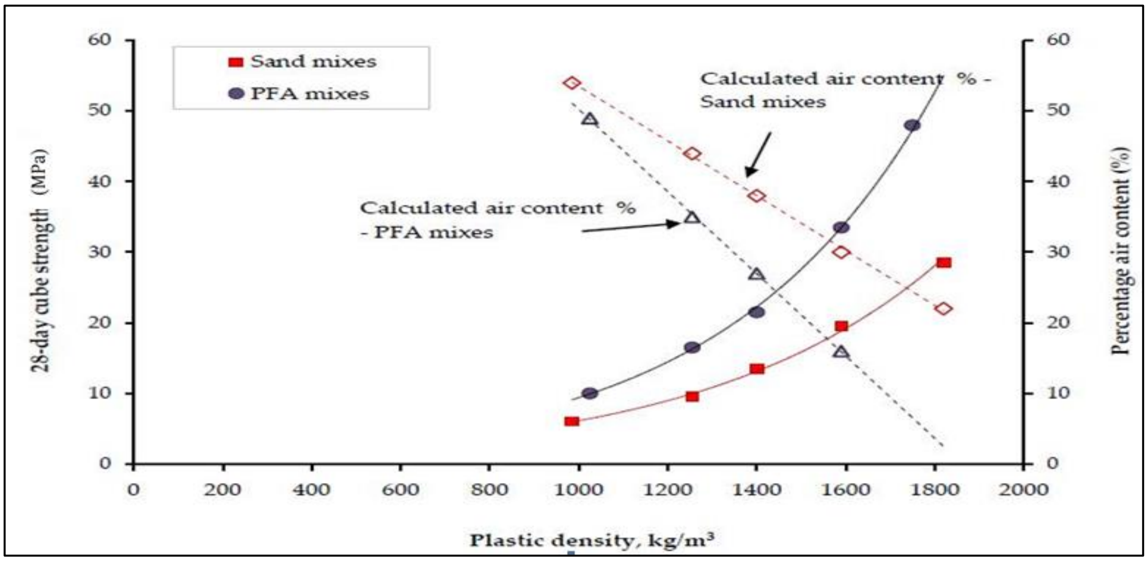


Figure 2.7: Effect of air content on compressive strength [49]

of water/cement ratio, the strength improved with increasing water/cement ratio. In another study, Dransfield [77] reported that the strength improves as the water/cement ratio increases. Moreover, the type of surfactant utilized is essential because it determines the final properties of foamed concrete [63]. Protein-based surfactants resulted in smaller, stronger bubble and more stable structure, thus, more strength foamed concrete can generates bigger bubbles as compared to synthetic surfactants [46,55].

This might be due to the capability of protein surfactants to absorb and retain water in the protein structure, which causes to be absorbent [53].The strength of foamed concrete can significantly be affected by the curing regime. Kearsley and wainwight [17] has observed that optimal strengths were attained from samples preserved at 50°C but it cost, kept in a polyethylene bag, and stored at 22°C. Contrarily, the investigator revealed that samples of water-cured resulted in lower strengths which might be due to the accumulation of pore water pressure within the microstructure of foamed concrete socked. Due to a curing regime needs to be constructed in order to sustain the quality control. Using similar way, strength of foamed concrete and autoclave aerated concrete cannot be equalized. Nevertheless, the hindmost results are managed through factory autoclaving requirements [55].

Harith [16] studied the prospective manufacture of foamed concrete as an allowable structural substance through the variation of the curing techniques. In this contest, sample prisms, cylinder, and cubes were produced to determine the drying shrinkage, modulus of elasticity and comprehensive strength at different ages. The foamed concrete polyurethane samples cured less than four kinds of curing patterns (air curing, water, sealing through membrane-forming curing compound, and moisture).

At the end, polyurethane foamed concrete employed showed the possibility of being used in structural applications. In addition, the obtained results reflected that samples cured through moisture possessed an elevated compressive strength in every age. From Figure 2.8, it was observed that the outcomes of mixing without fly ash resulted in reduced outcomes of compressive strength as compared to that with fly ash under various curing processes for every age with percent as follows: moisture curing (22.6, 20.6

and 11.6), water curing (40.4, 29.1 and 9.2), air curing (9.4, 8.7 and 3.4,) and membrane-forming curing compound (32.2, 23.7 and 8.7) at 56, 28 and 7 days, respectively.

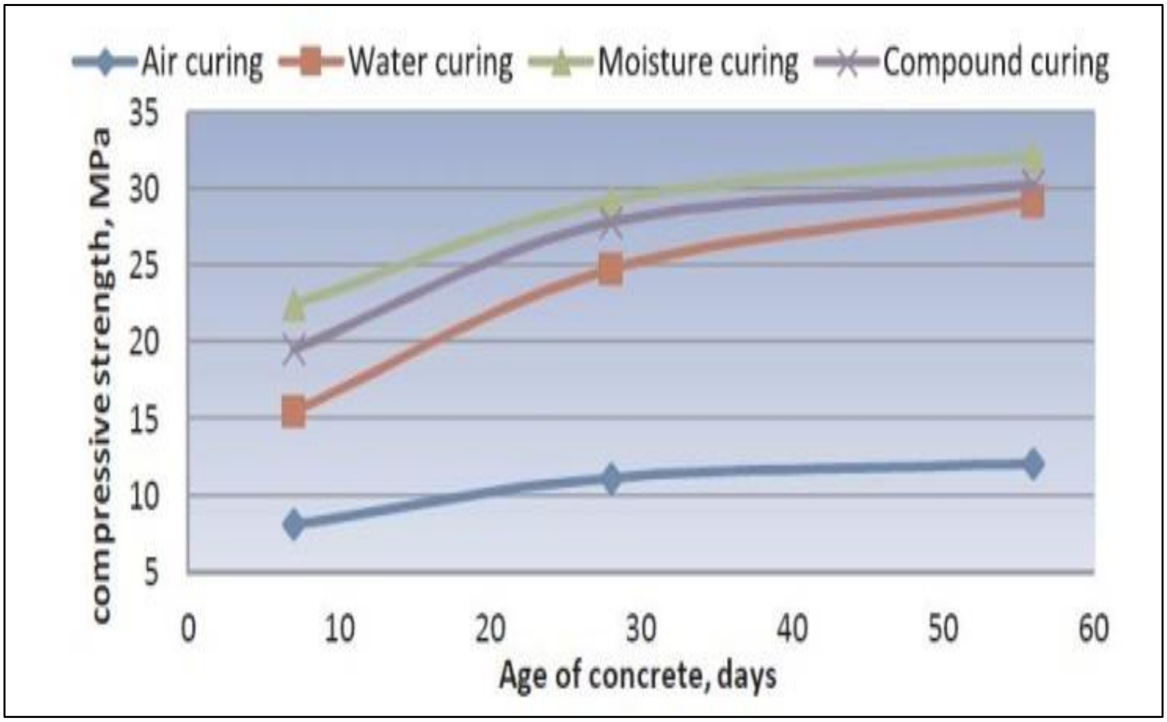


Figure 2.8. Effect of curing on compressive strength [16].

This behavior defines through the influence of fly ash that had a declined porosity at early levels, and occurrence of pozzolanic reaction and emission of calcium hydroxide from hydration of cement reaction with fly ash at later ages. This led to the filling occurrence in the voids among other powder substances and cement. Moreover, steam curing is utilized to produce optimum strength at significantly reduced density within the shortest time in the precast industry [71]. Figure 2.9 summaries the influences of different curing regimes such as water dry curing, water wet curing, 2 days, 7 days, open and moisture curing on compressive strength. The figure illustrated that the lowest compressive strength can be recording when use water dry curing or water wet curing, while hightest compressive strength can be happening when use moisture curing at 22 ºC or steam at 55 ºC. Despite the fact that strength is not a problem of foamed concrete applications [36,69,70], it is a major property that corresponds with others, thus, this shows the aim of investigating compressive strength of foamed concrete in most studies.

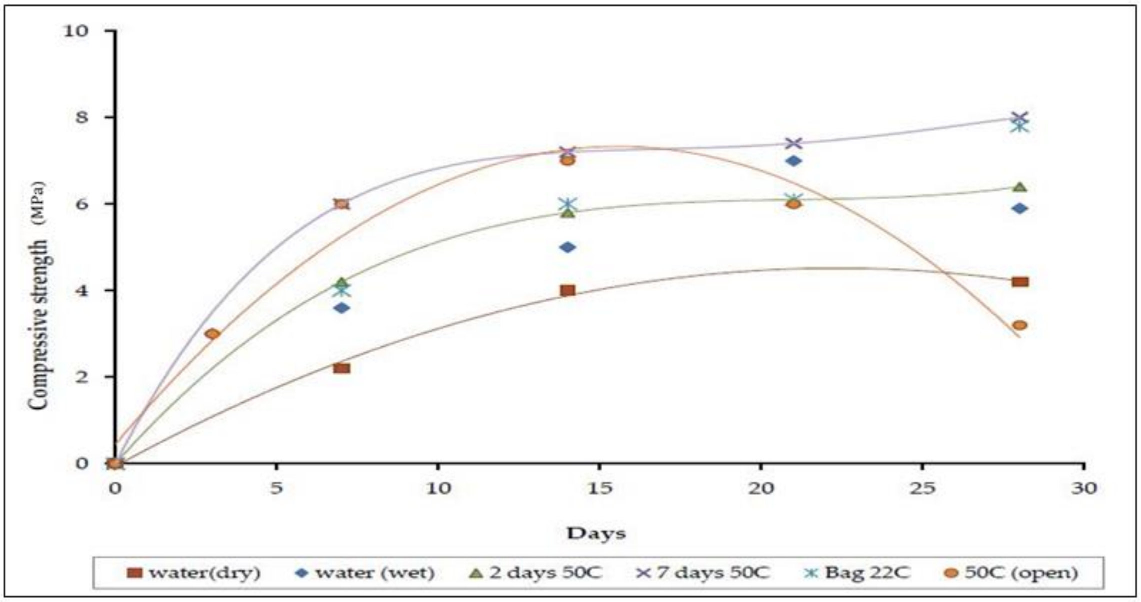


Figure 2.9. Compressive strength foamed concrete mixes with fly ash under different curing regime [72]

2.10.3.2 Tensile Strength

An increase in mix density causes the increase in the tensile strength of foamed concrete (subject to bending). A study conducted by Van Dijk [47] showed (56-day) tensile strengths of 0.51 MPa, 0.32 MPa, 0.17 MPa, and 0.06 MPa, for the mixes that possessed plastic densities of 1500, 1200, 900, and 600 kg/m^3, respectively. In addition, sand/PC mix possessed as optimal splitting tensile strength as compared to FA/PC mix. Figure 2.10 illustrates that there is a noticeable difference between the between cylinder splitting strength and 28 day cube compressive strength. Thus, this variation might be due to the strength acquired through interlocking collections. ASTM

C496M–17 [186] stated that the splitting tensile strength is commonly higher than direct tensile strength, lesser as compared to flexural strength (rupture modulus). ASTM C496M–17 is utilized for designing structural concrete, that has lighter weight to evaluate the shear resistance generated through concrete, and evaluate the expansion length of reinforcement. See Table 2-7 Splitting tensile strength of sand and FA foamed concrete in compared with normal weight and lightweight aggregate concrete [49].

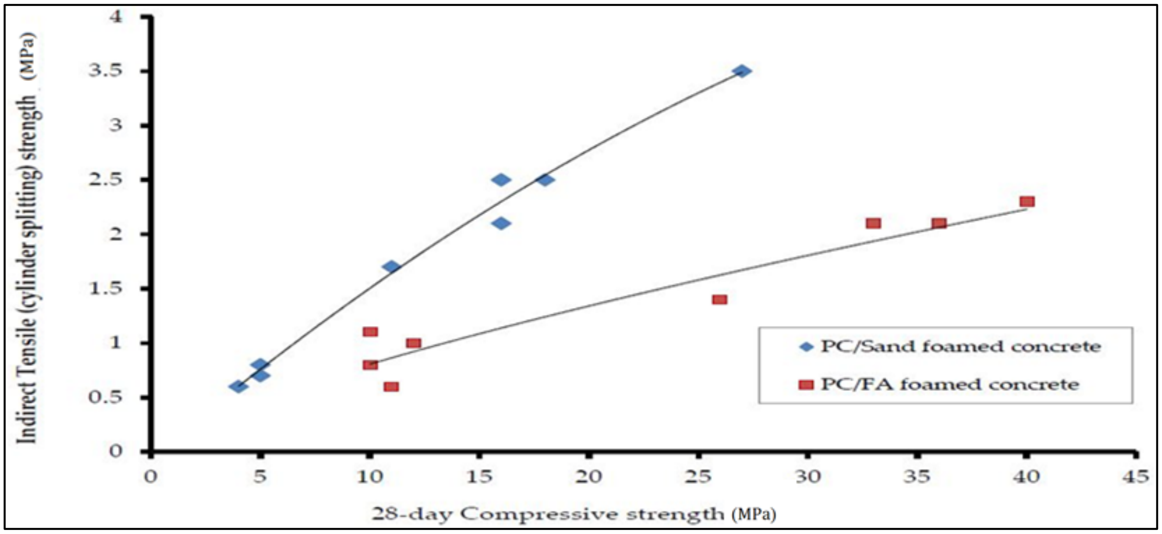


Figure 2.10. Relationship between cylinder splitting strength and 28 day cube [49].

Table 2-7. Splitting tensile strength of sand and FA foamed concrete [49]

Fine aggregate Type	Plastic density kg/m^3	28-day compressive strength N/mm^2	Splitting Tensile Strength (MPa)		
			Foamed concrete	Normal weight	Lightweight aggregate
Sand	1400	13.5	0.8	1.2	1.3
	1600	19.5	1.8	1.6	1.7
	1800	28.5	2.1	2.1	2.2
PFA	1400	21.5	1.5	1.7	1.8
	1600	33.5	2.0	2.3	2.4
	1800	48.0	2.5	3.0	3.1

2.10.3.3 Flexural Strength of foamed concrete.

The flexural strength of foamed concrete with lower density is minimized with an improved water/cement ratio [66]. Adding a 12 mm polypropylene fibers was observed to enhance the foamed concrete tensile strength [62]. Likewise, adding a lower portion of 19mm polypropylene fibers showed a significant improvement in flexural strengths [50]. Nevertheless, the addition of fibers resulted in workability loss of foamed concrete [55] and an increase the cost [49].

ASTM C78-18 [122] describes the method to evaluate the flexural strength of samples cured and processed using Test Methods C192M, practices C31M or C 42M. The results were determined and outlined as rupture modulus. In a similar specimen size, the evaluated strength there are varies variations , moisture conditions at the time of analysis, curing processes and beam was sawed or molded to sizes. However, cracking severally affects the flexural strength as compared to compressive strength [106,112] because flexural strength is highly prone to cracks resulted from the elevated temperatures of concrete , There have been few reported investigations on the flexural behavior of light-weight foamed concrete at high temperature [6,34,57,113,123-125].

2.10.3.4 Static Modulus of elasticity of foamed concrete.

In any structural design, the relationship between stress and strain is important in order to evaluate the elastic limit, behavior, elasticity (optimum allowable stress preceding the permanent deformity of the material), and deformation types. Modulus of elasticity denotes stress divided by strain. In concrete, it relies on constituent stiffness and its relative portion to the mix. Concrete's modulus of elasticity changes from 14 to 40 kN/mm^2 [92,111,112]. ASTM C469-14 [186] describe the analysis technique that covers the evaluation of (1) chord modulus of elasticity (Young's) and (2) Poisson's ratio of diamond-drilled concrete cores and molded concrete cylinders under longitudinal compressive stress.The modulus of elasticity is noticeably reduced in foamed concrete as compared to normal concrete. As illustrated in Table 2.6, the densities within 400 to 1600 kg/m^3 were observed to be between 0.8 to 12 kN/mm^2. The same E-values were observed within 1.0 to 8.0 kN/mm^2 in foamed concrete with dry densities ranged from 500 and 1500 kg/m^3 [76]. For the same strength, the sand mix reflected numerous values as compared to fly ash for similar strength, this has been illustrated in Figure 2.11 [55].

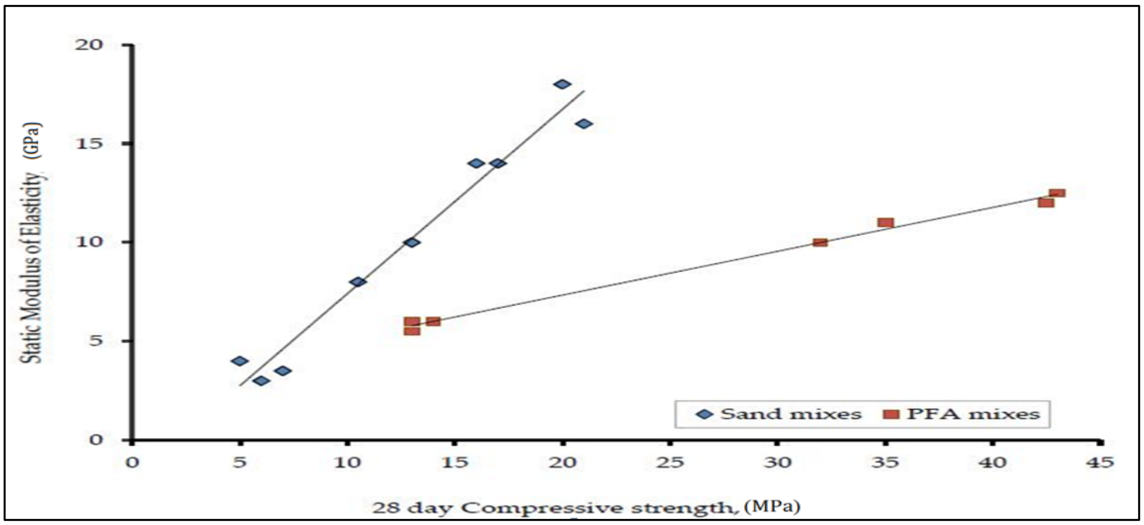


Figure 2.11: Comparison of the relationship modulus of elastisity value define and 28-day cube strength of mixes [49].

This confirms the fact that the modulus of fly ash is lesser compared to sand, hence, sand mix foamed concrete has higher E-values. Adding 0.50% polypropylene fibers reflected noticeable improvements in the modulus of elasticity as illustrated in Table 2.6 [60]. The values obtained remains minimal as compared to that of normal concrete, this expatiates the brittle failure and high deflection seen when studying full-scale foamed concrete beam [55].

2.10.3.5 Toughness of foamed concrete.

Toughness is generally recognized as the most property enhanced by the addition of fiber reinforcement to concrete. Historically, prior to the use of fibers to reinforce concrete, there was no requirement for any standard concrete tests to assess toughness or its associated properties of post-cracking strength and ductility, and it has therefore taken time to develop acceptable methods for testing these new properties.

Toughness index methods have evolved as the most popular practical technique for quantitative measurement of toughness [125-127]. A number of toughness index definitions have been proposed, all defined as ratios of portions of the area under load-deflection graphs produced when testing fiber reinforced concrete specimens. ASTM C1018-97 [128] procedure. Originally proposed by Johnston [129] has emerged as the most widely applicable and reproducible test method.

Arisoy and Wu [130,131] utilized polyvinyl alcohol fibers as support in the aerated concrete that has a density of 800-1600 kg/m^3. Arisoy and Wu observed that the fiber-reinforced aerated concrete reflected improvement in toughness as compared to plain aerated concrete.An alternative toughness definition has been proposed by the Japanese Concrete Institute [132]. In their test method, beams are tested under third-point loading while flexural toughness is taken simply to be the total portion under the load-deflection curve up to a deflection of 1/150th of the span, expressed in absolute units of energy.

Lim et al. [133] investigated the effect of palm oil fuel ash on toughness and of foamed concrete prepared with respective optimal w/c ratio. The first-peak strength characterizes the flexural behavior of the fiber-reinforced concrete up to the onset of cracking, while residual strengths at specified deflections characterize the residual capacity after cracking. Specimen toughness is a measure of the energy absorption capacity of the test specimen. The appropriateness of each parameter depends on the nature of the proposed application and the level of acceptable cracking and deflection serviceability.

Fiber-reinforced concrete is influenced in different ways by the amount and type of fibers in the concrete. In some cases, fibers may increase theresidual load and toughness capacity at specified deflections while producing a first-peak strength equal to or only slightly greater than the flexural strength of the concrete without fibers. In other cases, fibers may significantly increase the first-peak and peak strengths while affecting a relatively small increase residual load capacity and specimen toughness at specified deflection .The first-peak strength, peak strength, and residua strengths determined by this test method reflect the behavior of fiber-reinforced concrete under static flexural loading.

The absolute values of energy absorption obtained in this test are of little direct relevance to the performance of fiber-reinforced concrete structures since they depend directly on the size and shape of the specimen and the loading arrangement.

The results of this test method may be used for comparing the performance of various fiber-reinforced concrete mixtures or in research and development work. They may alsobe used to monitor concrete quality, to verify compliance with construction specifications, obtain flexural strength data on fiber-reinforced concrete members subject to pure bending, Thi study was carried out by Astm 1609 [188].

2.11 Waste Plastic

A reuse of waste plastic is an essential role for sustainable solid waste management. Based on the previous reports, it assists in the recycle and energy-saving production, declining environmental pollution and assist in saving natural resources which cannot be restored. Industrial by-products and wastes can be categorized as the potential of being treated and applied.

wastes Plastic are waste that poses a dangerous effect on the ecosystem because of their long period of degradation. Thus, part of the techniques for reducing their side influences is by applying them in other industries.A lot of efforts have been focused on considering the reuse of plastic waste substances in concrete. This is a new area of investigation by incorporating environmental and concrete technologies together [24,139–142]. A lot of investigations have been carried out on fiber reinforced concrete. The outcomes obtained indicated that concrete reinforced that possessed short plastic fibers gradually increased the outcome of concrete and removes its inadequacies, which include reduced energy absorption capacity, low ductility and low tensile strength [29,128–134]. Polyesters, polypropylene, nylon, and polyethylene are generally utilized in concrete members [135–137]. Amidst these plastic substances, polypropylene fibers are mostly utilized for construction such as pavements and blast resistant concretes [138,139,140].

2.11.1 Poly-ethylene Terephthalate (PET)

With lower cost, good mechanical, thermal, and physical characteristics, PET is part of the generally used polymer substances. The statistic has shown that PET covers over 90% of plastic bottles, PET which has taken 8% share of the world market [151-152]. PET is majorly applied as blow molded bottles, injection molded parts and WPF. PET is produced from ethylene glycol and terephthalic acid by monomers poly-condensation reaction. Production of PET production relies on the chemical reaction of monomers generated through the esterification reactions [153,154]. The monomer of PET comprises two ester groups, one terephthalate and one ethylene group as presented in Figure 2.12. It is a linear thermoplastic which

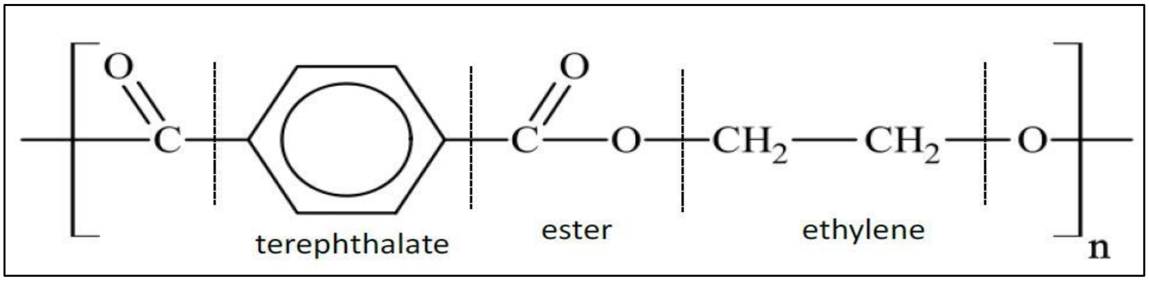


Figure 2.12. Poly (ethylene Terephthalate) molecular structure [155].

can dissolve and mold through heating that makes PET to be reused. However, thermoset plastics do not alleviate but disintegrated at elevated temperature. Thermosets possess strong crosslinking within its bonds while thermoplastics possess intermolecular forces that are weak. The latter are mainly more brittle and harder. PET production entails the trans-esterification or esterification stage whereby the ethylene glycol, dimethyl terephthalate, and terephthalic acid are mixed in the pre-polymerization reaction. Thereafter, the melted mixture was condensed, this gives a reduced molecular weight resin and I.V. Followed by Solid State Polymerization (SSP), an essential method of enhancing the intrinsic viscosity and molecular weight of the PET pellets prior to the usage in the injection molding [142,143]. It should be noted that the processing states of polymers have macroscopic mechanical characteristics and strongly prone to molecular structure [155-156].

2.11.2 Properties of PET

The molecular structure and chemical composition are important in evaluating the characteristics of PET and its copolymers. In general, PET has categorized as a flexible thermoplastic, tough and strong that can be oriented and crystallized in several molecular orderings. General characteristics of using PET are in lightweight, strength, transparency, temperature tolerance, toughness, low water absorbance, wear resistance, design flexibility, corrosion resistance, long shelf life, recyclability, and chemical resistance [158]. After stretching, PET still retains the characteristics of high stiffness, proper orientation, creep resistance, impact resistance, clarity, chemical resistance, and water vapor. To increase the properties, different additives are added to the PET before the manufacturing. To minimize the total cost, modifier and fillers are used as additives to increase the polymer mechanical characteristics [159].

2.12 Waste Plastic Fiber Reinforced Concrete

Several studies have investigated the influence of recycling PET on the concrete properties [147,148–152,162-164]. The recycled fibers of comfortably blend in concrete, allowing new characteristics of the materials [163]. Other study reported that adding tire rubber substances resulted in the concrete of elevated ductility in compressive strength analysis as compared to the one with no tire rubber substances [164].

Soroushian et al. [165] reported that the usage of polypropylene as synthetic fibers can improve the concrete toughness. In another study carried out by Kou et al. [166], the report showed that tensile splitting strength, compressive strength, and workability of lightweight aggregate concrete processed using plastic recycle wastes were minimized. Foti [167] investigated using waste fibers from PET bottles for reinforced concrete, it was observed that the addition of a minute quantity of PET bottles can pose a greater effect on the post-cracking outcome of simple concrete elements. In addition, these fibers increase the plasticity and toughness of the concretes.

Meddah and Bencheikh [168] investigated the effect of length and volume of polypropylene and metallic waste fibers on the toughness, flexural, and compressive strengths of fibers reinforced concretes. The outcomes of the study revealed that polypropylene fibers declined the compressive strength mostly when utilizing lengthy fibers that had elevated volume fraction. A gradual decline in the compressive strength was seen in the composites comprising over 2% metallic waste fibers. Nevertheless, the hybrid and polypropylene fibers improve the flexural strength of reinforced concretes.

Kim et al. [169] studied the fundamental properties of materials and shrinkage drying resistance of concrete reinforced using reprocessed PET fibers. The results involving the comparisons with samples comprising of polypropylene fibers reinforcement showed that concrete reinforced using PET fiber reflected a gradual decline in elastic modulus and compressive strength with increasing the fiber volume fraction. In addition, the recycled polypropylene and PET fiber-reinforced samples reflected a declined in compressive strength of approximately 1–10% and 1–9%, respectively in relation to samples that do not have fiber reinforcement.

Pereira de Oliveira and Casrto-Gomes [170] utilized fibers generated from recycled PET bottles to produce reinforced mortar. They observed that there was a significant increment in the toughness, compressive and flexural strength of mortars using PET fibers. A study conducted by Foti investigated the prospect of reprocessing PET fibers procured from waste bottles of varied shapes. The results reflected that the presence of PET fibers in concrete can improve its ductility [171].Mazaheripour et al. [172] studyed the influence of introducing polypropylene fibers in hardened and fresh characteristics of lightweight self-compacting concrete (density between 1700–2000 kg/m^3). The obtained results indicated that polypropylene fibers do not affect the elastic modulus and compressive strength, nevertheless, using a higher portion of volume improved the flexural strength by 10.7% and tensile strength by 14.4% through splitting tensile strength analysis.

Al-Hadithi [173] studied the influence of joining the chips obtained from cutting beverage plastic bottles using hands (mostly utilize in Iraqi markets) as compact fibers mixed with the gap-graded concrete. Then, the fibers were mixed at varying proportions (1.5, 1 and 0.5%) of concrete volumes. A control concrete mix was provided for comparison purposes. The outcomes showed that the addition of plastic waste fibers in these proportions resulted in enhancement of splitting tensile and compressive strength of concretes. However, there was more enhancement in the splitting tensile strength. Low-velocity impact resistance showed a noticeable increment in every waste plastic fibers reinforced concrete (WPFRC) mixes as compared to that of control. The outcomes reflected that WPFRC of 1.5% showed the optimum impact resistance as compared to others which were 328.6%. In the cases of 1 and 0.5%, the results were 128.6 and 200%, respectively [173]. Cracks in concrete were prevented by Synthetic-fiber reinforcement, synthetic fibers of small diameter (nylon, glass, steel or polypropylene) reducing shrinkage cracking by more than 80% according to independent lab tests.

2.13 Summary

In this section, the prospect of foamed concrete has been outlined as construction substance that has extensive benefits despite its constraints. Despite the reduced number of specifications and analyses that are in existence for foamed concrete, its usage yearly is numerous.The literature has clearly clarified that mix proportion and constituent substances influence the behavior and characteristics of foamed concrete. The prospective influence of variations in constituent substances on the characteristics have been outlined. Previous studies included the use of recycled waste plastic (PET) for substantiality. Past studies have reported various details on characteristics of foamed concrete. Nevertheless, rheology is part of essential properties which is yet to be examined for foamed concrete. In addition, the significance of rheological characteristics in every cement substances has been discussed posing a direct effect on the behavior. However, more studies need to be carried out to examine the influence of mix proportion and constituent substances on the rheological characteristics of waste plastic fibers (PET) and foamed concrete. This can be utilized for predicting the total behavior and the practical usages. More so, the understanding of PET mechanical properties in the mix is an essential area .

This sudy is recognized as first once ,using foam concrete with waste plastic fibers, all the results will be data base for future studies. While theprevious studies were carried out by using ligiht aggregate, miniral admixture and foam concrete with plastic fibers as mentioned in literature review.

CHAPTER THREE

EXPERIMENTAL WORK

3.1 Introduction

The present research is divided into three main experimental stages. The first stage is roduction of foamed concrete, which was then divided into two parts. In the second stage, first half of the concrete was designed according to the required density and the proportion of each raw material was determined. The second half of the mix was fabricated using the mixing procedure. In the third stage, several tests were conducted to investigate the properties of the final product and the factors influencing them. The properties tested are density, porosity, and water absorption, as well as mechanical properties such as compressive strength, splitting tensile strength, flextural strength, modulus of elasticity, toughness, and ultrasonic pulse velocity. Plates (3.1) and (3.2) show the materials, equipment and molds used in this research. Figure (3.1) illustrated the flow chart of the experimental program of this study.

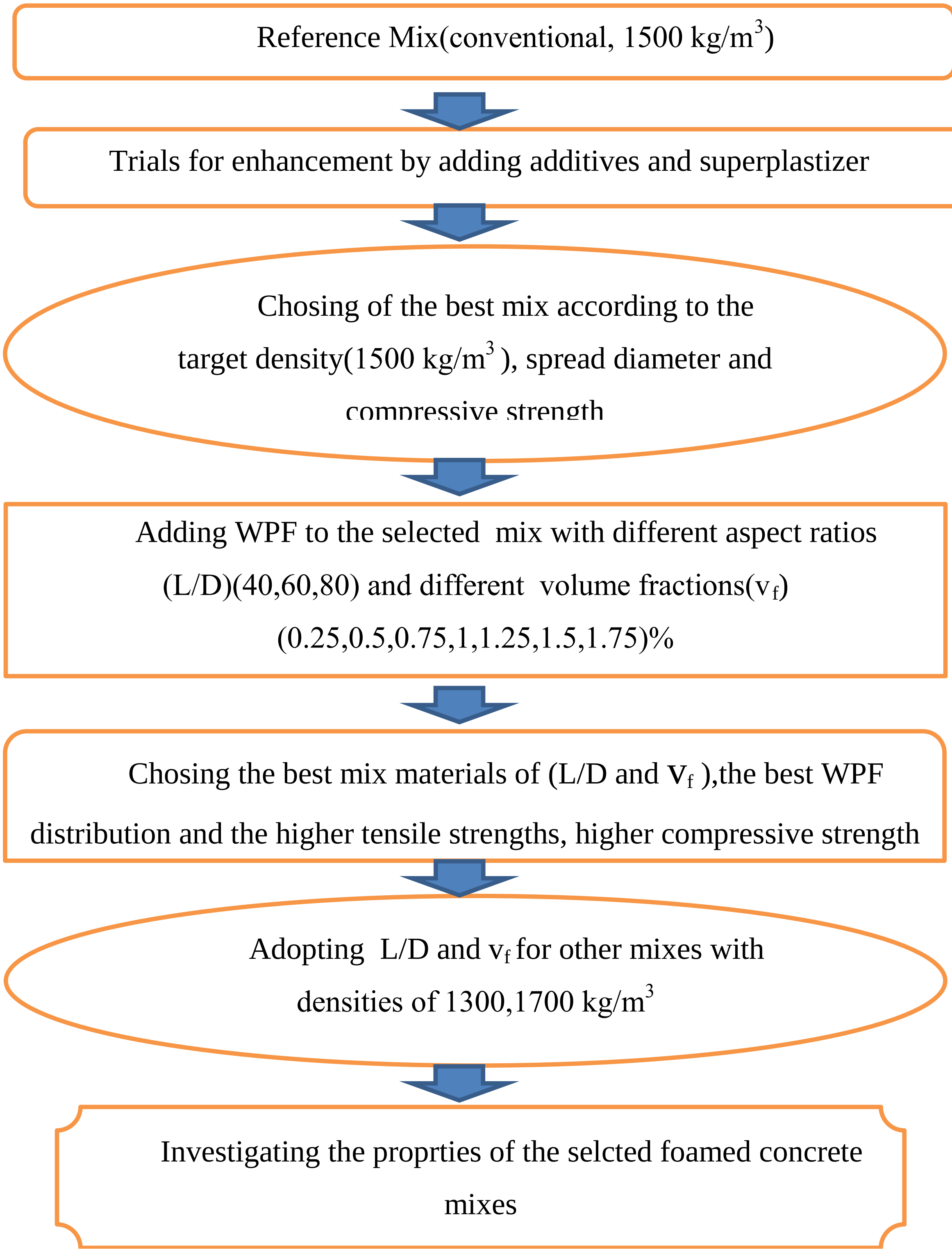


Figure3.1: Flow chart of research

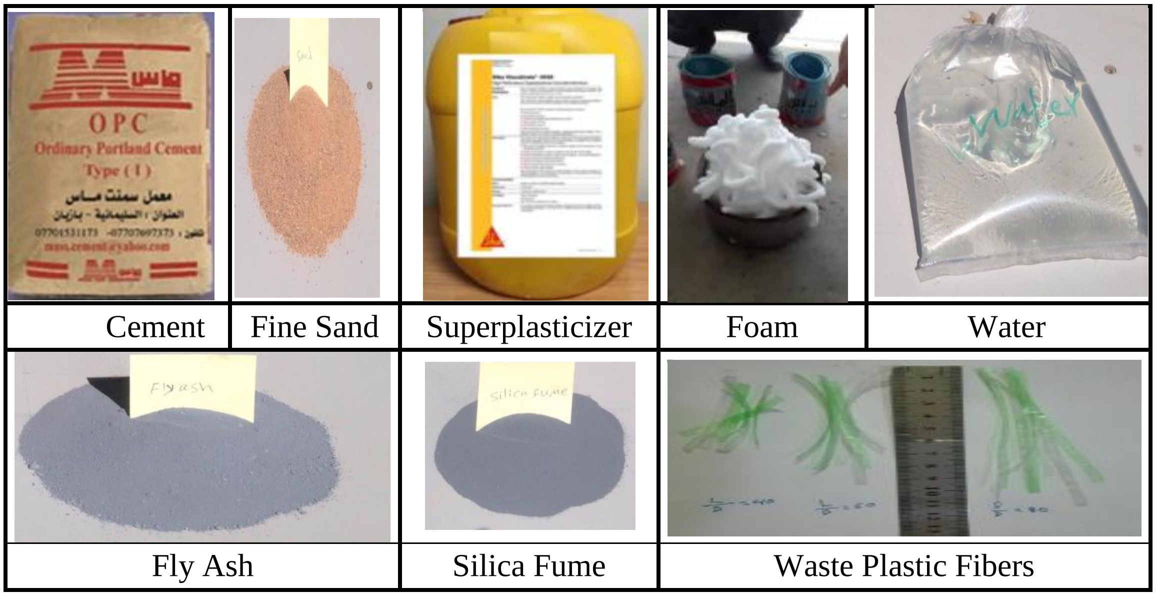


plate 3-1:Materials used of experimental test

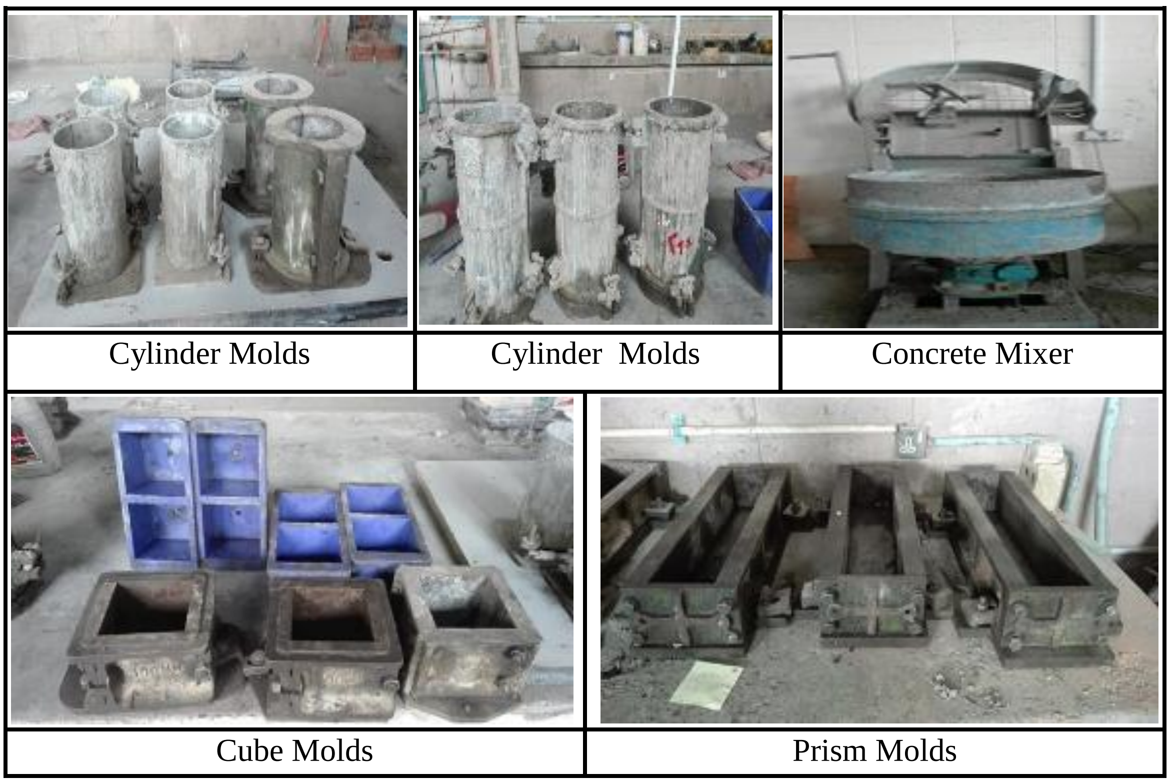


Plate 3-2: Moulds and mixer used for experimental tests

3.2 Materials

3.2.1 Cement

MASS Ordinary Portland Cement type CEM I 42.5R was used throughout the project, see table 3.1. XRD test showen in appendix A .

Table 3-1:Physical proprties for the cement.

Test Type	Specification (the Iraqi standard no.5/1984)	Cement used
Fineness by Blaine air permeability apparatus (cm^2/gr))	>2300	2500
Initial Setting (min)	≥45	120
Final Setting (min)	≤600	240
Soundness by Autoclave method	≤0.8	0.8
Compressive Strength for cement mortar cube (70.7 mm) at,		
(1) Days (MPa)	-	-
(3) Days (MPa)	≥15	27.5
(7) Days (MPa)	≥23	32.9
(28) Days (MPa)	-	-

3.2.2 Fly Ash

Class F fly ash with a specific gravity of 2.09 g/cm^3 and Blaine fineness of 379 m^2/kg used in the present study which was derived from bituminous and anthracite coals and consist primarily of alumino-silicate glass with quarts, mullite and magnetite, Class F , or low calcium fly ash, and contain less than 10% CaO, or from XRF test, ((21.63+1.4+0.02)\26.59))=86% which is according to the requirements of ASTM C618-19 ((Sio_2+Fe_2o+Al_2o)> 70%) [174,175] ,The physical properties and chemical compositions of the fly ash were analyzed at the Ministry of Science and Technology. The results of the analysis are given in Appendix A.

3.2.3 Silica Fume

The present study used silica fume with a specific gravity of 2.2. Analysis of the silica fume was done at the Ministry of Science and Technology, and some of its properties are given in Table (3-2). The XRD test of the silica fume is given in Appendix (A).

Table 3-2: Properties of silica fume [176,177]

	Limit-ASTM-C1240	Silica used	constituent	Content (%) (X R D)
Surface area	≥15m^2/g	27.3m^2/g	SiO_2	91
Moistu re content	Max 3%	0.6%	Fe_2O_3	0.5
Loss of ignition	0.6 %	Max 6%	Al_2O_3	0.2
Total silica	Min 85%	-	CaO	0.2
		94	MgO	0.5
		-	K_2O	0.5
		0.005	N_2O	0.2
			SO_3	0.15
			C1	0.01
			H_2O	0.5

3.2.4 Fine Aggregate

Natural sand from a local region in the Anbar governorate was used to produce the foamed concrete specimen employed in this study. The result of sieve analysis of the sand is shown in Table (3-3). The fine aggregate used in this work is less than 2.36 mm, as specified by [51]. The specific gravity and absorption of the fine sand were calculated according to ASTM-Designation C 128-88, and was found to be 2.665 and 3%, respectively [69].

Table 3-3: Sand Gradient, [101]

Sieve Size (mm)	Percentage				Sand used
	Total limits	Limits of gradient zones			
		Coarse	Moderate	Fine	
10	100	-	-	-	100
5	89-100	-	-	-	97
2.36	60-100	60-100	65-100	80-100	82
1.18	30-100	30-90	54-100	70-10	67
0.6	15-100	15-54	25-80	55-100	51
0.3	5-70	5-40	5-48	5-70	22
0.15	0-15	-	-	-	2.5

3.2.5 Water

Tap water was used to fabricate and cure the specimens in the present study**.**

3.2.6 Superplasticizer

Superplasticizer with the trade name Sika ViscoCrete 5930, which is the third generation superplasticizer for concrete and mortar, was used to modify the mixes in the present study. It meets the requirements for superplasticizer specified by ASTM-C-494 type F [178]. The properties of the superplasticizer are given in Table (3-4).

Table 3-4: Properties of superplasticizer (provided by manufacturer) [179]**.**

Density	1.08 kg/liter
pH	8.0 ±1.0
Chloride content	NIL (EN934-2)

3.2.7 Foam

Foam with a density of 30 kg/m^3 was produced by blending foaming agent with water (1 gr: 40 gr) which was then air-compressed using a foam generator, as shown in Plate (3.3a). Foaming agent in amount of 200 grams was mixed with 8000 grams of water in a closed pan. The compressor was then operated at a pressure of 110 psi to produce foam bubbles, as shown in plate (3-3). The properties of the foam are presented in Table (3-5).

Table 3-5: Properties of foaming agent (provided by the manufacturerand[86])

Appearance	Liquid
Color	Transparent
Specific Gravity	1.01
Chloride Content	Nil
Compatibility with Cement	All Type of Portland Cement
Shelf Live	Up To 2 Years
Surface Tension	41.9 N/cm^2

(a) Foam generator | (b) Process of foam production | (c) Produced foam

Plate 3-3: Production of foam.

3.2.8 Waste Plastic Fiber

A 4 mm x 0.29 mm rectangular waste plastic fiber (WPF) was produced from polyethylene terephthalate (PET). The specific gravity of the WPF is 1.375. Plate (3-4) shows cutting machine and the WPF used in this study. Table (3.6) shows some of the properties of the WPF.

Table 3-6: Physical properties of waste plastic fiber

Dimensions (mm)	Aspect ratio	Density (kg/m^3)	color
48.5*4*0.29	40	1375	Crystalline Green
73.5*4*0.29	60	1375	
97.5*4*0.29	80	1375	

(a) Cutter machine	(b) WPF produced	(c) Length of WPF

Plate 3-4: Plastic cutting machine.

3.3 Tensile Strength of WPF

This test was carried out in accordance with (ASTM- A D 1708-02). The samples were cut into special shapes and tested using a special precise device (max 5 kN load) which is used to determine the tensile, compressive and flexural strengths of different materials, such as ceramic, polymer, rubber and composite materials, as shown in Plate (3.5) [180]. The results of tensile stress for the WPF is shown in Table 3.7. The present study used two type of coloured plastic: crystal plastic which has a high tensile stress of (105 MPa) and green plastic which has a smaller tensile stress (96 MPa) compared to the previous.

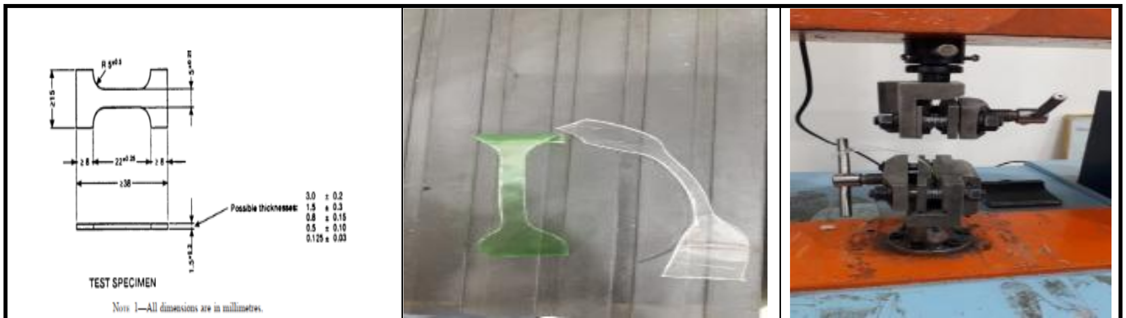
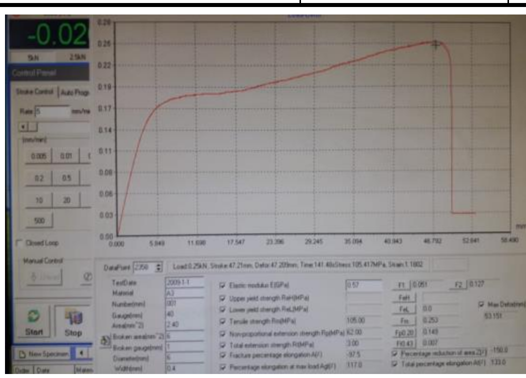
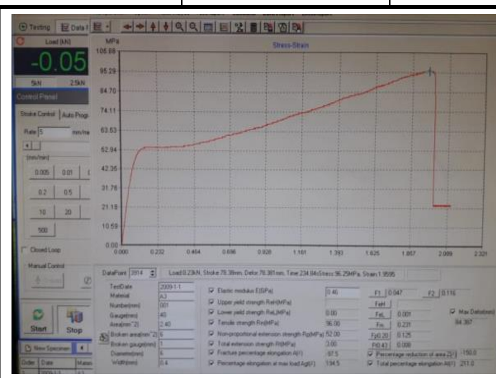


Plate 3-5: Tension test of WPF [180].

Table 3-7: Results of tensile stress of WPF

Type of color of plastic	Max Tensile Stress (MPa)	Max Deflection (mm)	Total percent Elongation%	E (GPa)
Crystal plastic	105	5.3151	133	0.57
Green plastic		8.43	210	0.46





3.3.1 Mix Design

Example for a (1500) kg/m^3 mix.

Absolute volume was used to determine the quantity of each component by using the following equations, where SG represent the specific gravity of each material (see Table 3.8).

AbsoluteVolume **(l/m^3) =** $\frac{C}{3150}+\frac{S}{2650}+\frac{FA}{2090}+\frac{SF}{2200}+\frac{SP}{1100}+\frac{W}{1000}$ + **V_f of WPF………………… (a)**

Foam volume **(l/m^3) = (1-** Absolute Volume**) (l/m^3) ………………… (b)**

The mix design was determined as follows:

Assume that the target density is 1500 kg/m^3.

1- Use 500 kg/m^{3}cement..
2- Use 20% fly ash by weight of cement .
3- Use 10% silica foam by weight of cement.
4- Use 2% viscoCrete5930 superplasticizer by weight of cement .
5- The water-cement ratio (w/b) is 35%.
6- Calculate the total weight of the binder paste materials for steps 1-5 per one cubic meter .
7- The weight of sand is obtained as follows:1500 – (sum of weights of the binder paste materials).
8- Use equation (a) to determine the absolute volume of the materials required percent cubic meter.
9- Use equation (b) to find the volume required for one cubic meter of foam.
10- The final compositions of materials for a 1500 kg/m^3 mix was calculated.

Table 3-8: Specific gravity of all materials

Materials	Specific gravity	Notes
Cement (C)	3.15	Manufactures
Sand (S)	2.665	Calculated
Fly Ash (FA)	2.09	Manufactures
Silica Fume (SF)	2.2	Manufactures
Super Plasticizer (SP)	1.1	Manufactures
Water (w)	1	Manufactures
Waste Plastic Fiber (WPF)	1.375	Calculated

3.4 Mixing, Casting and Curing

Specimens were prepared in accordance with ASTM-Designation C 192-88 [181]. Mixing was done as follows: half of the amount of sand was put in the pan of a mixer, followed by cement (along with silica foam and fly ash, if any). The remaining sand was added, and all components were thoroughly mixed in the pan mixer. Two thirds of the amount of mixing water was added and the mixture was again blended thoroughly. After two minutes, the last one-third of the water and the superplasticizer and WPF were added to the mix. Finally, the foam was added to the wet slurry. All specimens were casted to the molds by two layers method, then a rubber-headed hammer was used to tap the side of the molds in order to decrease the air voids, finally, all the molds have been covered by nylon sheets. All specimens were removed from molds after 24 hours and wrapped with cling film until day of testing. Plate (3-6) show mixing, casting and curing stages. It should be noted that the mixing must not be done excessively to avoid the possibility of altering the unit weight and consistency [103].

d- Casting process	e- Curing process (prism)	f-Curing process (cube)

Plate 3-6: Casting and curing of samples.

3.5 Fresh Properties

3.5.1 Consistency

The consistency of the foamed concrete was measured using the method recommended by Brewer [52]. For freshly mixed low-strength materials by measuring the spread diameter of the fresh foamed concrete mixes. A 75 mm diameter and 150 mm long open-ended cylinder was filled with the mixture and the cylinder was then raised vertically to let the fresh foamed concrete flow downwards. The spread diameter was then measured in two directions. The average of the two measured diameters was calculated and recorded to the nearest 5 mm.

3.6 Hardened Properties

3.6.1 Dry Density

The hardness of a concrete is deterimined based on the measurements of two phases, i.e. the fresh and hardened phases. The difference in values of fresh and hardened densities is measured by dividing the weight by the volume of a specimen. A difference of 100-120 kg/m^3 the fresh and the hardened densities is recommended [182].

3.6.2 Porosity

The porosity test, ***ϕ***, was carried out on (100 mm) cubes, according to ASTM C-642-13[183]. The porosity of the mix was the average of three cubes by using Eq (3-1).

$$\phi = \frac{(W_{sat} - W_{dry})}{(W_{sat} - W_{wat})} \times 100\% \quad \text{...} \quad (3\text{-}1)$$

Where:

W_{sat} is weight of saturated specimens in air after vacuum (gr).

W_{wat} is weight of saturated specimens in water(gr).

W_{dry} is weight of oven-dried specimens(gr).

There are two kinds of porosity: total porosity and apparent porosity.

I-**Total Porosity (*ϕvac*)**

An average of three specimens was used to determine the total porosity of foamed concrete mixes by using the vacuum saturation approach. The test was carried out on 28-day old specimens with a dimension of 100×100×100 mm that have been dried at 100±5˚C until a constant weight was achieved. The specimens were then placed in a desiccator under vacuum for at least three hours. The desiccator was subsequently filled with deionized water to 30mm above the specimens and was left under vacuum for another three hours. The samples were then left under water overnight [61]. Finally, the samples were weighed in air and water to calculate the total (vacuum determined) porosity (ϕvac) by using Eq. (3.1) with the assumption that the specimens are now finally saturated.

II- **Apparent Porosity**

An average of three specimens was used to determinet the apparent porosity, ϕapp, for foamed concrete mixes with a dimension of 100×100×100 mm. The 28-day old specimens were dried at a temperature of 100±5˚C for 2 days until a permenent mass was reached, 7 days was the time where the specimens were submerged in the water in order to reach the permenent weight. The weight of the specimens were measured in air and water. The following equation (3.2) was used to determine the appernet porosity of the specimens:

$$\phi_{app} = \frac{(W_{sat} - W_{dry})}{(W_{sat} - W_{wat})} \times 100\% \quad \text{.......................... ....(3.2)}$$

Where:

ϕ_{app} is apparent porosity (%),

W_{sat} is weight of saturated specimens in air, without vacuum(gr).

W_{wat} is weight of saturated specimens in water (gr).

W_{dry} is weight of oven-dried specimens. (gr).

3.6.3 Water Absorption

Water absorption was calculated using equation (3-3):

$$Abw = \frac{(W_{sat} - W_{dry})}{(Wdry)} \times 100\% \quad \text{......................................(3-3)}$$

Where:

Abw is percentage of absorption in volume

$Wsat$ is saturated weight in air (gr).

W_{dry} is dry weight(gr).

Absorption is usually measured based on mass increase (as a percentage of dry mass) after immersing a specimen that has been dried until a constant mass is reached in water , it was reported [98] that the values of absorption can be measured using different methods and varying immersion periods and/or drying temperature. For instance, 7 days was the time where the specimens were submerged in the water in order to reach the permenent weight [90]; or immersed for 24 hours (ASTM C642-13) [183] or by using the vacuum saturation method.

As pointed out by Nambiar and Ramamurthy [99], the reason for the different absorption method is that water is not efficiently removed when the specimen is dried at a regular temperature. A certain amount of chemically combined water could be removed when specimen is dried at high temperature. In this research, the water absorption of specimens (as an average of three samples for each mix) with a dimension of 100 mm diameter × 25 mm height and have been cured for 28 days under closed conditions, was measured to determine the ease of which water flow through the foamed concrete. An oven was used at 105 ºC to dry the specimens to reach a constant mass. 7 days was the time where the specimens were submerged in the water in order to reach the constant weight.

The absorption of ordinary concrete is defined as the percentage of mass increasing due to drying by oven. The absorption of foamed concrete is defined as a percentage of volume rather than dry mass to avoid the decieving results that are caused by the wide variations in density between mixes [10 89, 98]. Mixes without foam usually show smaller difference in density. The definition of water absorption has no effect on the results of absorption. Therefore, ASTM C796, 1997 was the guide to express the water absoprtion in total volume percentage of specimen [54].

3.7 Mechanical Properties

3.7.1 Compressive Strength

This test was conducted on 100 mm cubes using a digital compression testing machine with a 2000 kN capacity in accordance with ASTM-Designation: C495/C495M-12. The test was conducted at ages of 7, 14 and 28 days, and the average strength of four specimens was adopted for each age. Plate (3-7) shows the device used to measure compressive strength [184].

Plate 3-7: Device of measuring compressive strength.

3.7.2 Splitting Tensile Strength

The splitting tensile strength of 100 diameter ×200 mm cylindrical concrete specimens were measured according to ASTM-Designation: C496-86 [185]. The average tensile strngth of two specimens was obtained at ages of 7, 14, 28 days and was calculated using equation (3-5). Plate (3-8) shows the device used to carry out this test.

$$f_t = 2P/\pi dL \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3\text{-}5)$$

Where:

ft is splitting tensile strength (MPa).
P is maximum applied load (N).
d is diameter of cylinder (mm).
L is length of cylinder (mm).

Plate 3-8: Device for measuring splitting tensile strength.

3.7.3 Flexural Strength

Flexural test was conducted on prisms as required by ASTM-designation: C78-84 [122] to determine the modulus of rupture of all investigated mixes. All specimens(400*100*100)mm were aged for 28 days and were tested under four-point load (with a span length of 300mm) using a flexural machine at the concrete laboratory of the Department of Civil Engineering, University of Anbar, as shown in plates (3.9). The method of calculating the modulus of rupture of all prisms is dependent upon the location of the fracture line. Equation (3-6) was used to calculate modulus of rupture if the location of fracture line is in the middle third of the span length.

Plate 3-9: Device for measuring flexural strength.

$$f_r = PL/bd^2 \quad (3\text{-}6)$$

Where:

fr is modulus of rupture (MPa).

p is ultimate applied load (N).

d is average depth of prism (mm).

b is average width of prism (mm)

L is span length between supports (mm).

Equation (3-7) is used when fracture appears in the middle third of the span length (not exceeding 5% of the span length).

$$f_r = 3\,Pa / bd^2 \quad (3\text{-}7)$$

Where:

a is the average distance measured on the surface tension of the prism between the line of fracture and the nearest support (mm).

3.7.4 Static Modulus of Elasticity

Static modulus of elasticity measurement was done according to ASTM-Designation:C469-02 [186] at 40% of the ultimate load. Concrete cylinders of 150×300 mm were tested under a constant rate of 0.05 mm/min compression. The same testing machine was used to determine the compressive strength of the concrete. The value of static modulus of elasticity was calculated as the average of two cylinders. Figure (3.2) illustrates the general stress-strain behaviour of concrete. This test was carried out at the concrete laboratory, University of Anbar.

$$E=(S_2-S_1)/(\varepsilon_2-\varepsilon_1) \quad (3.8)$$

Where

S_2 is stress corresponding to 40% of ultimate load .

S_1 is stress corresponding to longitudinal strain, ε of 50 millionth.

ε_2 is longitudinal strain produced by stress S_2.

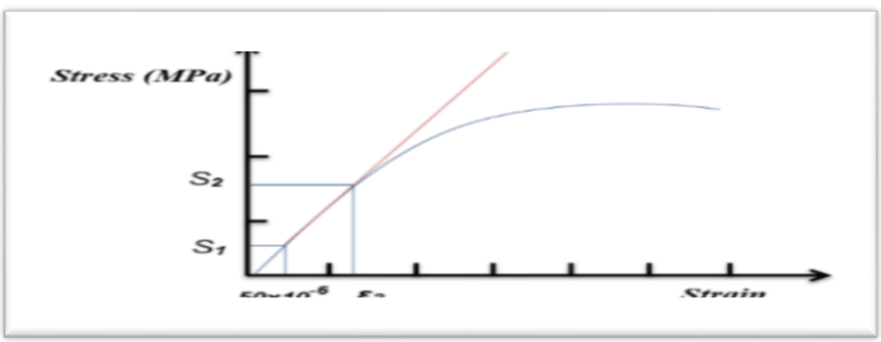


Figure 3-2: General stress-strain behavior for concrete [186].

3.7.5 Toughness

many 100x100x400 mm concrete prisms were cast according to ASTM C1609 [187]. The rate of loading was imposed at (0.075 mm/min) in order to get an accurate relationship between the load and the deflection and to measure the amount of absorbed energy at certain deflection values (especially post-cracking energy). Plate (3-10) shows some of the information regarding the test.

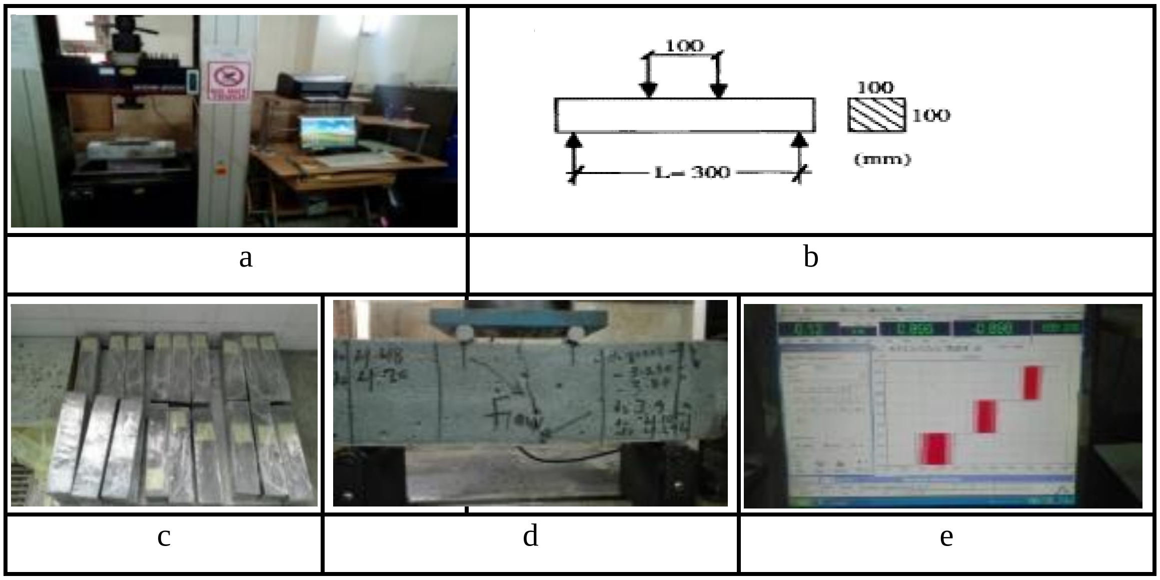


Plate 3-10: Procedure for testing the toughness of mixes.

3.7.6 Ultrasonic Pulse Velocity (UPV)

Utrasonic techniques have been used for the past several years in the geotechnical field and mining science. The dynamic characteristics of prisms are determined in the laboratory and geophysical investigations are carried out in the field by utilizing ultrasonic techniques. This test was conducted according to ASTM C 597-09 [188] using the Portable Ultrasonic Non–destructive Digital Indicating Tester (pundit). A 54 khz transducer was set to allow direct transmission and the transit time was recorded in microseconds. The advantages of using ultrasonic techniques include the ability to assess the quality of concrete without affecting the internal structure of the sample at a relatively low operational cost, and the test is faster, simpler and cheaper than static testing. The quality of concrete is classified by ultrasonic digital tests based on longitudinal pulse velocity, as shown in Table (3.9). The surface of the samples was cleaned using polishing paper and oiled with grease in order to transmit the pulse produced by the transducer to the concrete. Ultrasonic velocity is used to (i) determine the dynamic poisons ratio and modulus of elasticity of concrete, (ii) evaluate the uniformity of concrete in or between members, (iii) assess the quality of concrete, and (iv) identify the alterations in properties of the hardened concrete with time. Plate (3.11) shows a schematic diagram of the ultrasonic device, and several images of the testing. Equation (3-9) was used to determine the ultrasonic pulse velocity in this test.

$$V=L/T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3\text{-}9)$$

Where:

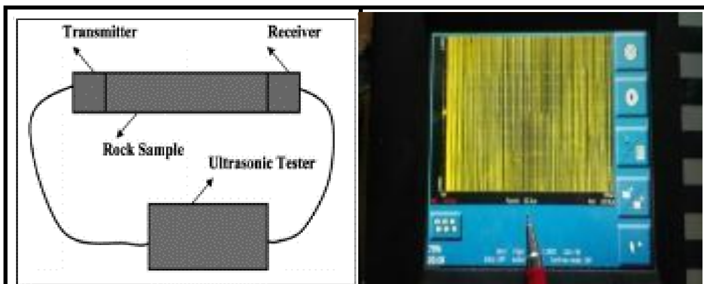
V is ultra sonic pulse velocity, (km/sec).

L is path length (mm).

T is transmit time,(μ sec).

Table 3-9: Quality of concrete as revealed by ultrasonic velocity [87].

Velocity (km/sec)	Quality of concrete
≥4.5	Excellent
3.5-4.5	good
2-3	poor
≤2.4	Very poor



a	b

Plate 3-11: Process in the UPV test**.**

3.8 Scanning Electron Microscopy (SEM)

SEM technique was used to capture the microstructure images of the investigated mixes in order to use them as evidence or justification in the discussion of the results of the study. Generally, the main components of SEM are electron source (gun), magnetic lens system (condenser lens to focus the electron beam as it moves from the source down the column and objective lens to focus the electrons on the surface of the sample), beam movement controller, sample stage, signal detector and amplifier, and a display/data output unit. Plate (3-11) illustrates the principle of SEM.

The SEM works as follows. The direction of the electron beam (primary electron) can be elastically altered without losing energy (elastic scattering process). Otherwise, a significant amount of the energy of the primary electron will be absorbed by the primary electrons and a small amount of the energy will be backscattered due to inelastic scattering process. Overall, these processes can be used to produce other types of elastic scattering process (illustrated in plate (3-12)) [51]. The depth and shape of the interaction volume is influenced by two factors: a) average atomic number of the sample and b) accelerating voltage. Secondary electrons have low energy, typically 50 eV (Electron volts) or less. Since the energy originates near the surface, they are very useful for inspecting the topography of sample surface. Therefore, the microstructure of the foamed concrete mixes was qualified, analyzed, and studied using secondary electron mode (SE). Backscattered electrons (BSE), on the other hand, have very high energy (greater than 50 EV) in comparison to secondary electrons.

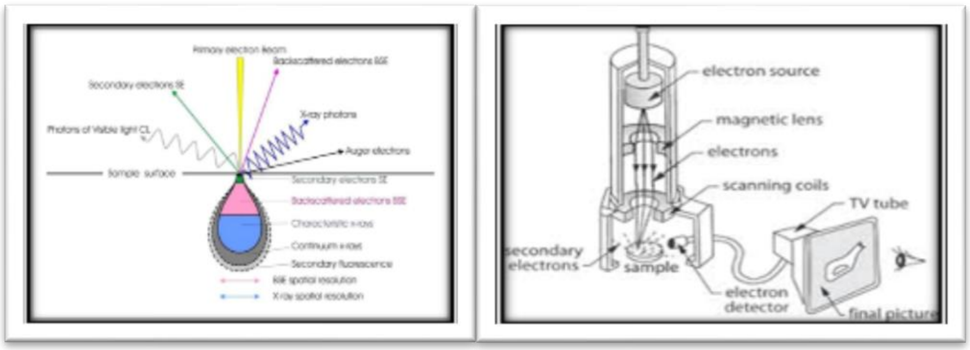


Plate 3.12 : The principle of scanning electron microscopy based on work of electrons and is suitable for materials analysis.

3.9 Length of WPF

After choosing a suitable mix, the aspect ratio $\left(\frac{l}{D}\right)$ of WPF was chosen to be an increment of (20), i.e (40-60-80). WPF length was selected based on aspect ratio, which is 4 mm wide and 0.29 mm thick (measured using an electronic Vernier). The WPF length for each aspect ratio was calculated using the equivalent diameter method and, as shown in the Figure 3.3 and following example, the aspect ratio is (40).

For aspect ratio = 40

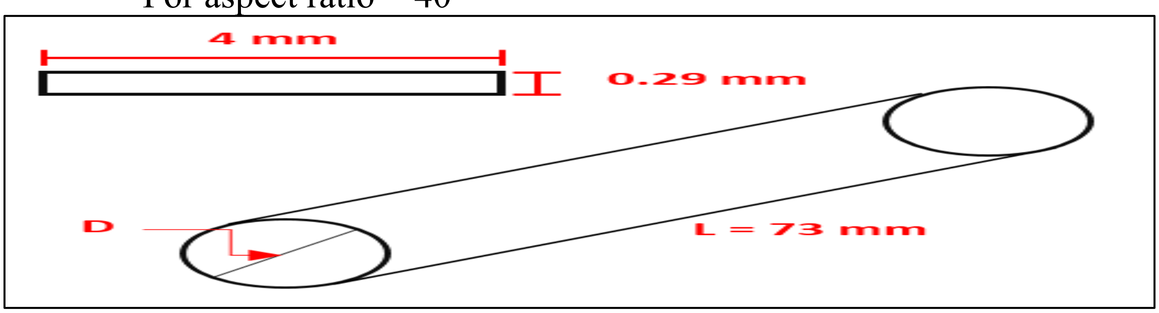


Figure 3.3: Calculation of aspect ratio.

$\boldsymbol{\frac{l}{D} = 40}$ **:**

Calculate the equivalent diameter (D) by area equality:

$$\frac{\pi D^2}{4} = 4 \times 0.29 \rightarrow D = \sqrt{\frac{4 \times 4 \times 0.29}{\pi}}$$

$$D = \sqrt{1.477} \rightarrow D = 1.215\ mm$$

$$\frac{l}{D} = 40 \rightarrow l = D \times 40 = 48.62\ mm \approx 48.5\ mm$$

The same calculations were used for other aspect ratios and the results were tabulated. Table (3.10) shows the details of the three aspect ratios of WPF and the corresponding lengths.

Table 3.10: WPF used in all investigated mixes.

l/D ($\frac{mm}{mm}$)	40	60	80
length of WPF (mm)	48.5	73.5	97.5
Dimensions of section of WPF (mm*mm)	(0.29*4) mm	(0.29*4) mm	(0.29*4) mm

3.10 Preliminary Work

The aim of this study is to produce a modified foamed concrete with sufficient structural strength and semi-structural application. It also seeks to investigate the effect of waste plastic fibers (WPF) on the properties of the modified concrete. Hence a strong mix with a density of 1500 kg/m^3 was fabricated, followed by mixes with densities of 1300 and 1700 kg/m^3. A previous study [51] has shown that modification of conventional foamed concrete mix with varying densities that is sufficient for structural purpose (1300-1900 kg/m^3) requires the addition of additives (fly ash and silica fume) and superplasticizer. A previous study [51] added 20% of fly ash by weight of cement and 10% of silica fume by weight of cement. The dosage of superplasticizer and mixing water were determined by trial and error (see Table (3.11)).

Table 3-11: Trials mixing

Quantities kg/m^3											
Mixes		C*	S*	Fa*	SF*	Foam l/m^3	SP*	w/b	γ*	f′c*	S.D* (cm)
1	Fc5	500	815	0	0	310	0	0.45	1632	2.65	26
2	Fc5a	350	815	100	50	330	7.5	0.35	1337	6.7	24
3	Fc5a	350	815	100	50	280	7.5	0.45	1640	14	20
4	Fc5a	350	815	100	50	330	10	0.37	1681	20.1	19
5	Fc5a	350	815	100	50	330	10	0.35	1513	24	23

*C: cement, S: sand, Fa: fly ash, SF: Silica fume, SD: spread diameter, SP: Superplascizer, γ: dry density, f′c: compressive strength.

Table 3-11 clearly shows that the best mix is (5-Fc5a) due to its low fresh density of (1513 kg/m^3), which is close to the target density of (1500 kg/m^3), with high compresive strength of (24 MPa). Three additional mixes were also fabricated which contain waste plastic fibers (WPF). These mixes were fabricated after determining the optimum aspect ratio and volume fraction of mixes with a density of 1500 kg/m^3 (see Table (3.12)). Table (3.13) shows the properties of the conventional mix (Fc) and the mix modified with additives (Fca) for all densities.

Table 3.12: Mixes with a density of 1500 (kg/m^3) fabricated with all aspect ratios

		Materials (kg/m^3)							
	Mixes	Cement	Sand	Water	Fly ash	Silica fume	SP	Foam l/m^3	WPF%
1500 kg/m^3	Fc5	500	815	200	0	0	0	330	0
	Fc5a	350	815	175	100	50	10	330	0
L/D=40	Fc5aw	350	815	175	100	50	10	330	(0.25, 0.5, 0.75,1, 1.25,1.5, 1.75) %
L/D=60	Fc5aw	350	815	175	100	50	10	330	(0.25, 0.5, 0.75,1, 1.25,1.5, 1.75) %
L/D=80	Fc5aw	350	815	175	100	50	10	330	(0.25, 0.5, 0.75,1, 1.25,1.5, 1.75) %

Table 3-13: Conventional and modified mixes

Materials (kg/m^3)									
Density kg/m^3	Mixes	Cement	Sand	Water	Fly ash	Silica fume	SP	Foam l/m^3	WPF%
1300	Fc3	500	614	200	0	0	0	400	0
	Fc3a	350	614	175	100	50	10	400	0
1500	Fc5	500	815	200	0	0	0	330	0
	Fc5a	350	815	175	100	50	10	330	0
1700	Fc7	500	1015	200	0	0	0	250	0
	Fc7a	350	1015	175	100	50	10	250	0

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

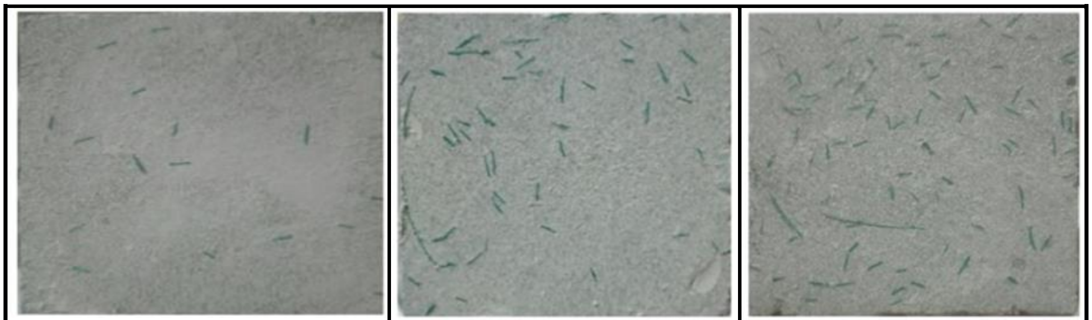
The aim of this reseach is to investigate the effect of adding WPF on the fresh (consistency and wet density) and hardened properties (dry density, porosity, absorption, compressive strength, splitting tensile strength, flexural strength, static modules of elasticity, toughness) of foamed concrete mixes. This chapter presents and discusses the results of all experiments, as well as the effect of incorporating additives and WPF on the properties of foamed concrete.

4.2 WPF Distribution

The distribution of WPF in the foamed concrete were determined by capturing and analysing images of the mixes. This was done by cutting the specimen into10*10*10 cm cubes, which were then cut into seven slices, as shown in Plate (4.1). A very fine white powder was applied to the surface of each slice to identify the WPF. The image of each slice was captured and analyzed using the *Image J* software in

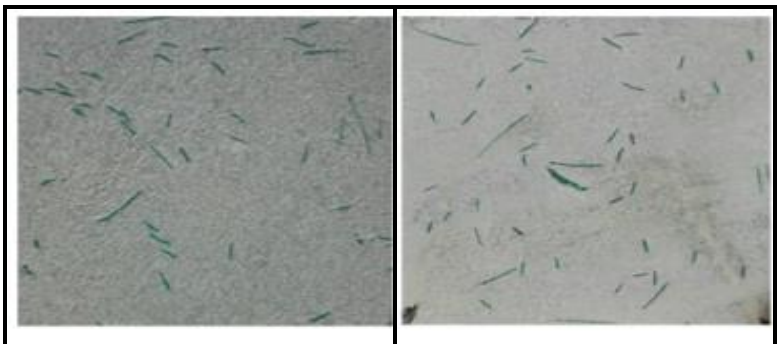
Plate 4-1: Cutting of Waste Plastic Fibers (WPF)

order to calculate the percentage of WPF in each slice. Plates (4.2) and (4.3) show examples of those images. Seven foamed concrete cubes for each aspect ratio ($\frac{l}{D} = 40,\ 60$ and 80) and WPF fraction (0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75%) were casted and cut with a diamond cutter after 28 day of aging. Each slice is about 1 cm thick, while the remaining 2 cm were shaved by the electric cutter.



Fc5aw V_f (0.5%)	Fc5aw V_f (1%)	Fc5aw V_f (1.5%)

Plate 4-2: Slices of cubes of a mix with a density of 1500 kg/m^3 and L/D=60



Fc3aw V_f (1%)	Fc7aw V_f (1%)

Plate 4-3: Slices of cubes of mixes with densities of 1300 and 1700) kg/m^3 and L/D=60.

The surface of each slices was polished and covered with white gypsum powder and cleaned again with a soft cloth, as shown in Plates (4.2) and (4.3). The images of the prepared slices were captured using a Sony 18.2 mica pixel digital camera and were named based on the percentage of WPF and aspect ratio. These images were processed using the *Image J* software to determine the percentage of WPF in each slice (Figure (4.1)).

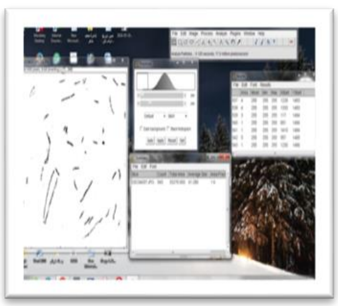
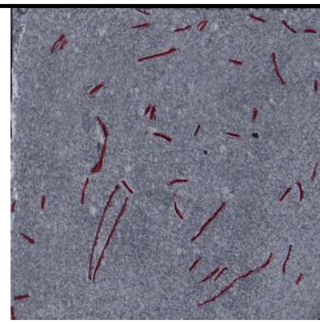
	

Image j software	Orginal image	Binary image

Figure 4.1: Calculation of area of 1500 kg/m^3 mixes with (v_f=1.75%, L/D=60).

Figures (4.2), (4.3) and (4.4) show the curves of the WPF distribution in the foamed concrete for the Fc5aw mix. Figure (4.2) shows the mix with 0.25% WPF and aspect ratios of ($\frac{l}{D} = 40, 60, 80$). The figure shows the WPF is non-uniformly distributed for the three investigated aspect ratios of $\frac{l}{D} = 40, 60, 80$. The distribution WPF is concentrated at the top and bottom of the foamed concrete specimens. Figure (4.3) shows the mixes modified with 1% WPF and with an aspect ratios of ($\frac{l}{D} = 40, 60, 80$), where the area along the height of the cube has a better distribution of WPF than the mix modified with 0.25% WPF. The mix modified with 1% WPF and an aspect ratio of ($\frac{l}{D} = 60$) has the best distribution of WPF. Figure (4.4), the distribution of WPF in the mix containing 1.75% WPF of aspect ratios ($\frac{l}{D} = 40, 60, 80$), is non-uniform distributed at the top and bottom for the three investigated,it is concentrated of the foamed concrete specimens On the contrary, the mix with an aspect ratio of ($\frac{l}{D} = 60$) shows a high concentration of WPF at the top of the cube. Figure (4.1) shows an example of the calculation process. The results of these calculations were used to determine and define the distrbution of WPF in the invistigated foamed concrete mixes, and they clearly show that the mix with a volume fraction of 1% (v_f=1%) and L/D=60 has the best WPF distribution. Therefore, these aspect ratios and fiber volume fraction were chosen for further investigation at varying densities.

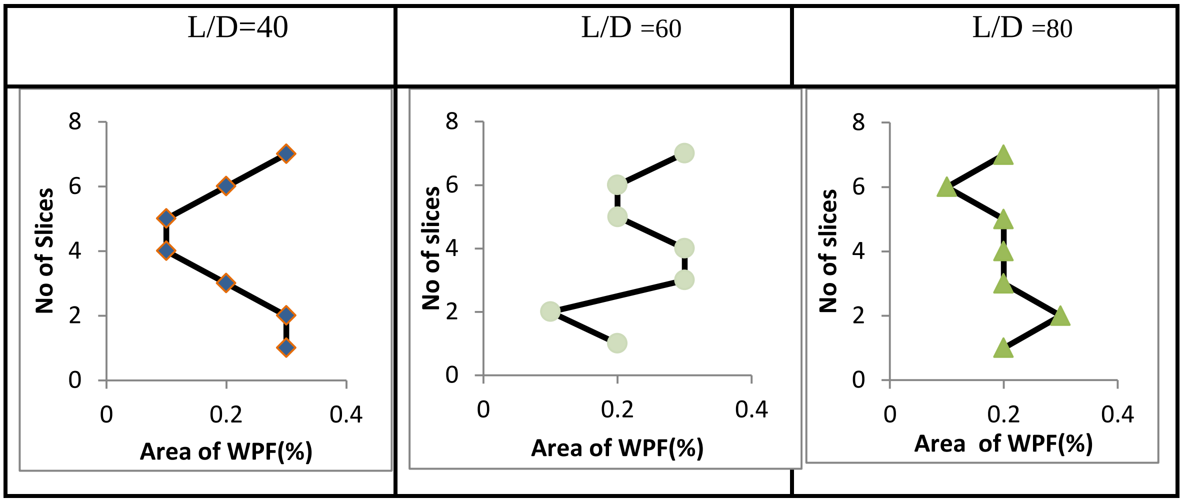


Figure 4.2: WPF distribution in the Fc5aw mix   (v_f-0.25)

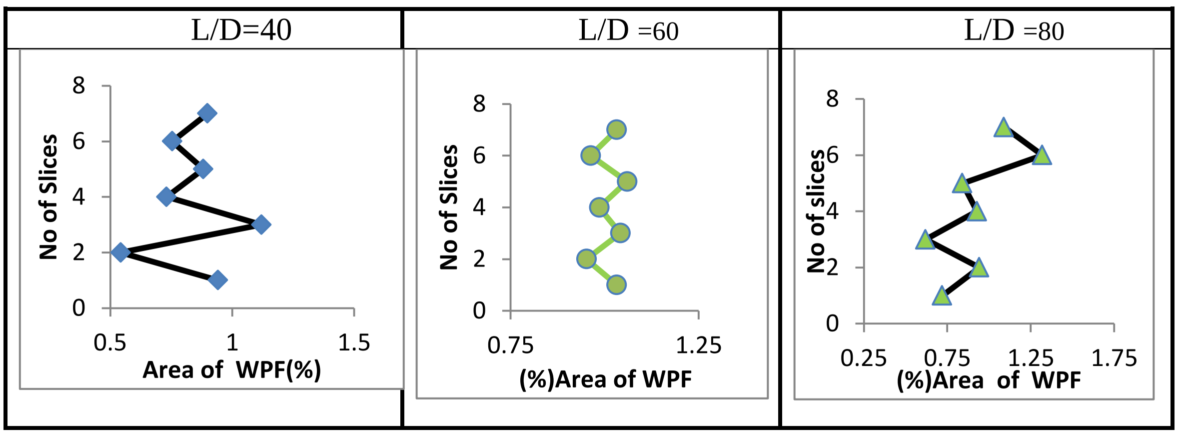


Figure 4.3: WPF distribution in the Fc5aw mix (V_f- 1%)

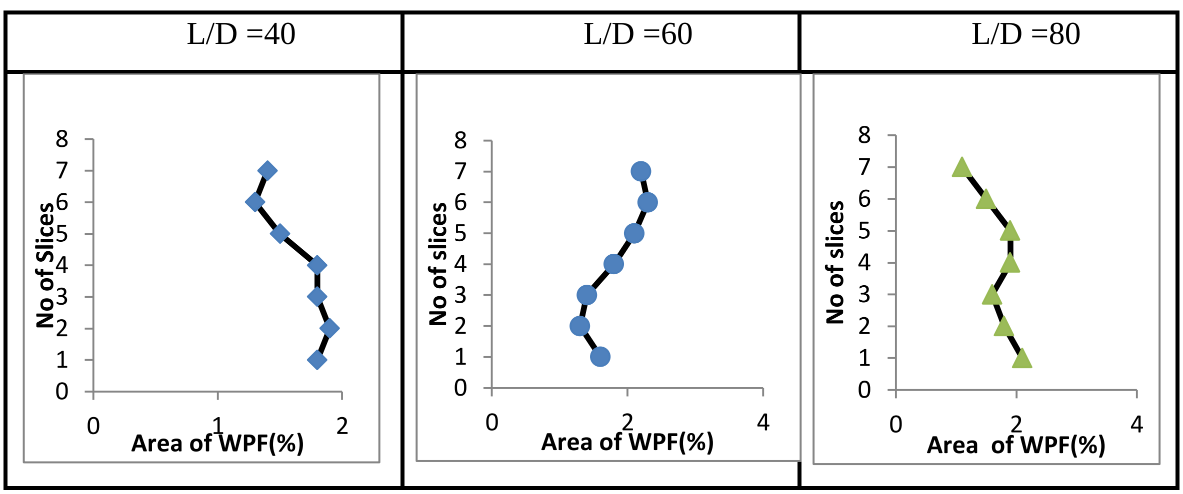


Figure 4.4: WPF distribution in the Fc5aw mix (v_f=1.75%)

4.3 Fresh Properties of foamed concrete

4.3.1 Consistency

Mixes with a density of 1500kg/m^3 were modified with varying percentages of WPF. Figure (4.5) shows that the higher the WPF content the lower the workability of the mixes. For example, the SD was about 23 cm at small fiber fraction of (0.25%) and this value decreased gradually to 12 cm when higher percentages of up to 1.75% fiber fraction had been added to the mix. This finding is consistent [189].

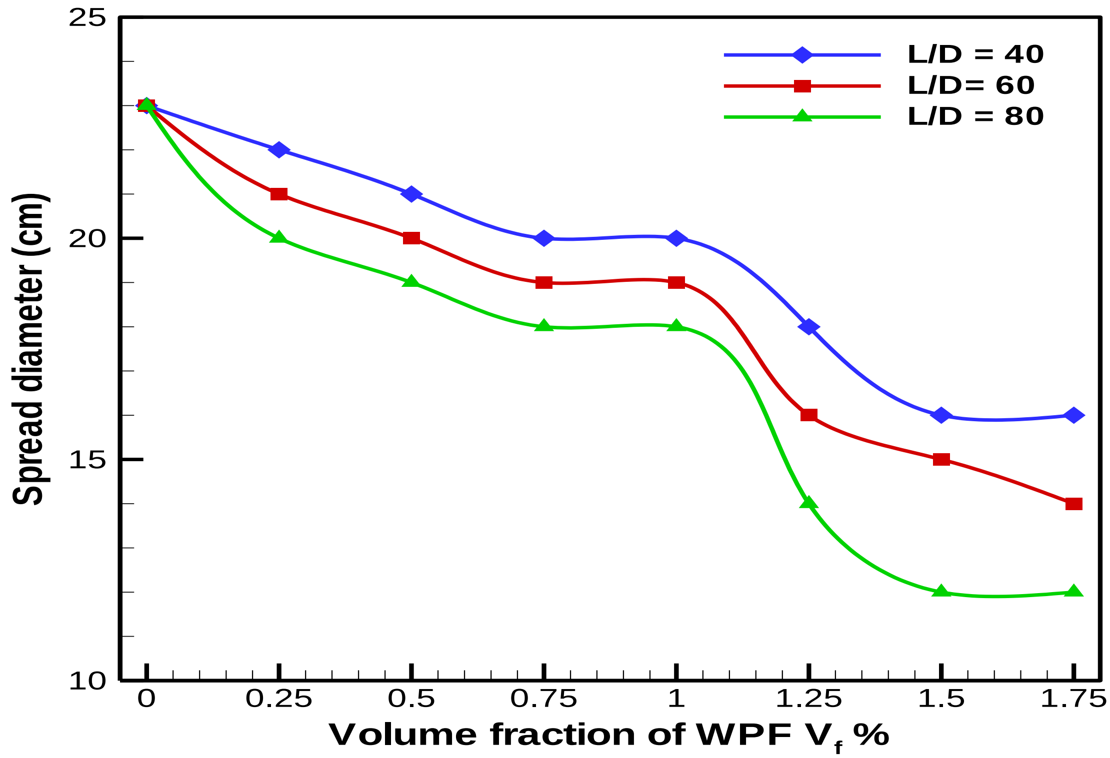


Figure 4.5: Consistency of 1500 kg/m^3 mixes with varying volume fraction of WPF.

For a given volume fraction of WPF (v_f%), SD decreased with higher aspect ratio. This means that the longer the WPF length causes higher the adhesion between components can be (see Figure 4.5). Table (4.1) shows that, for the same L/D, the SD decreased with increasing v_f(%), while for the same v_f (%) the reduction in SD is greater with higher L/D.

Table 4-1: Spread diameter for the 1500 kg/m^3 mixes.

Volume fraction (V_f%)	Spread diameter ,SD (cm)					
	L/D=40		L/D=60		L/D=80	
0	23	Reduction%	23	Reduction%	23	Reduction%
0.25	22	4.3	21	8.6	20	13
0.5	21	8.6	20	13	19	17.3
0.75	20	13	19	17.3	18	21.7
1	20	13	19	17.3	18	21.7
1.25	18	21.7	16	30.4	14	39.1
1.5	16	30.4	15	34.7	12	47
1.75	16	30.4	14	39.1	12	47.8

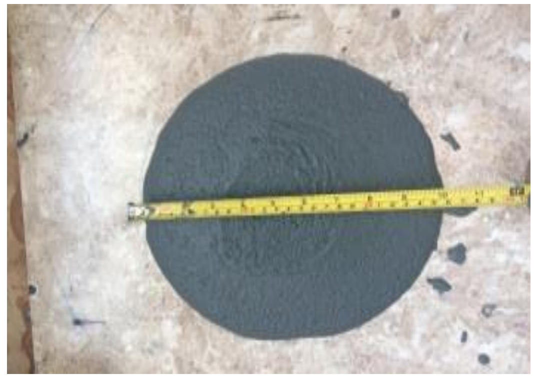
Figure (4.3) shows the image of the best WPF distribution while Figure (4.22) shows the best L/D = 60. The 1300, 1500, 1700 kg/m^3 mixes modified with v_f (1%) and L/D (60) was chosen for the investigation. These mixes were fabricated and all the properties of foamed concrete discussed in section (3.2.9) were determined while the results are shown in Table (4.2).

Table 4-2: Mixes with L/D=60, V_f (1%)

Materials (kg/m^3)									
Density kg/m^3	Mixes	Cement	Sand	Water	Fly ash	Silica fume	SP	Foam l/m^3	WPF %
1300	Fc3	500	614	200	0	0	0	400	0
	Fc3a	350	614	175	100	50	10	400	0
	Fc3aw	350	614	175	100	50	10	400	1
1500	Fc5	500	815	200	0	0	0	330	0
	Fc5a	350	815	175	100	50	0	330	0
	Fc5aw	350	815	175	100	50	10	330	1
1700	Fc7	500	1015	200	0	0	0	250	0
	Fc7a	350	1015	175	100	50	10	250	0
	Fc7aw	350	1015	175	100	50	10	250	1

The consistency and SD for all mixes with three nominal densities of 1300, 1500 and 1700kg/m^3 were measured before and after the addition of WPF. Figure (4.6a) shows that the addition of additives increased the spread diameter. Figure (4.6b) shows that the spread diameter decreased when WPF was added to the foam. This is due to the reduced sliding between the components of the mix. A comparison was made between mixes of the same density which were incorporated with additives (Fc). The addition of WPF to the mix containing additives (Fcaw) resulted in a significant reduction of the SD as for V_f 1.75% as shown in Figure(4.6b) the spread diameter have been clearly reduced due to the excessive amount of WPF to the mix, the v_f 1.75% presents separation of components of mix. The Fc3, Fc5, and Fc7 mixes with higher density have smaller SD. This could be due to the higher amount of sand which caused greater friction action (see Figure (4.7)).

All mixes with the same density that have been modified with additives and with (1%) WPF has a reduced the spread diameter (see Figure 4.8). For the same density mixes, the addition of foam to conventional mixes resulted in smaller spread diameter since the foam reduced the density of mixes (see Figure 4.9) Table (4.4) presents a summary of values of the spread diameter for all mixes.

	
Fc5 SD=15 cm	Fc5a SD= 23cm
a) Effect of additives on spread diameter	

		
V_f 0.25% SD=20 cm	V_f 1% SD=19 cm	V_f 1.75% SD=15 cm
b) Effect of WPF content on spread diameter.		

Figure 4.6: Effects of Additives and WPF on spread diameter.

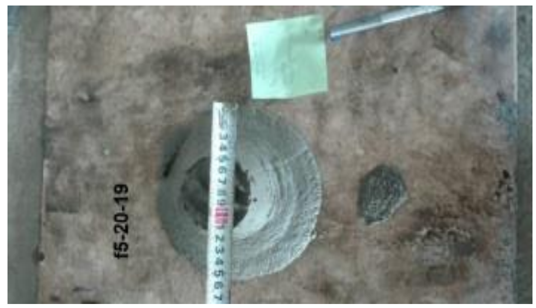
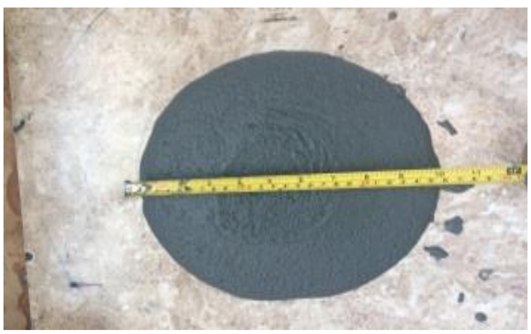
	
Fc3: Unfomed: SD=21 cm	Fc3: Foamed: SD=19 cm
	
Fc5: Unfomed: SD=19 cm	Fc5: Foamed: SD=15 cm
	
Fc7: Unfomed: SD=12 cm	Fc7: Foamed: SD=10 cm

Figure 4.7: Unmodified and modified mixes with foam at densities of 1300, 1500, 1700 kg/m^3

Fc3a: Foamed: SD=27 cm

Fc3aw: Foamed with WPF: SD=21 cm



Fc5a: Foamed: SD= 23 cm

Fc5aw: Foamed with WPF: SD= 19 cm

Fc7a: Foamed: SD=19 cm

Fc7aw: Foamed with WPF: SD=11 cm

Figure 4.8: Effect of WPF on the SD of mixes incorporated with additives

Table 4-3: Effect of incorporating foam on the consistency of investigated mixes.

Mixes	Un-foamed concrete	Foamed concrete	Decreasing%
Fc3	21	19	10
Fc3a	27	23	14.8
Fc3aw	25	21	8.7
Fc5	19	15	21
Fc5a	23	21	8.6
Fc5aw	20	19	5
Fc7	12	10	16.6
Fc7a	19	14	26.3
Fc7aw	13	11	8.3

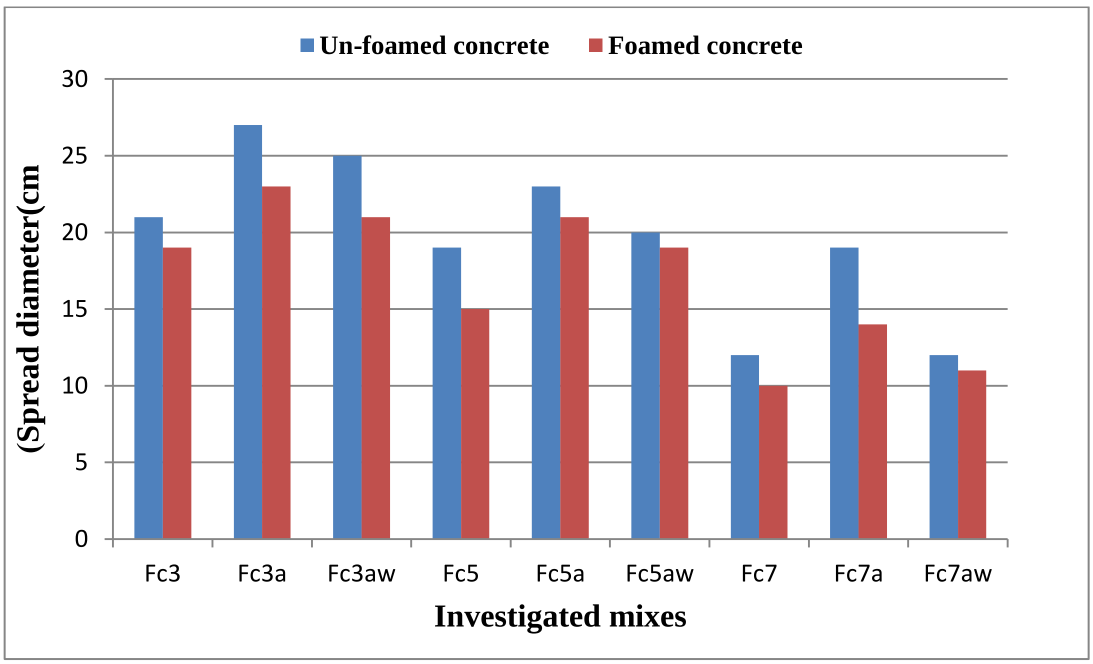


Figure 4.9: Effect of incorporing foam on the consistency of investigation mixes.

Table 4-4: Effect of adding additives and WPF on consistency of investigated mixes.

mixes	Effect of additives with WPF after adding foam	
		Increment%
Fc3	19	-
Fc3a	23	20
Fc3aw	21	10
Fc5	15	-
Fc5a	21	40
Fc5aw	19	20
Fc7	10	-
Fc7a	14	40
Fc7aw	11	10

Figure (4.10) shows that mixes with higher density have smaller SD. It also shows that the addition of fly ash, silica fume, and superplasticizer to the mix resulted in greater spread diameter. Furthermore, the addition of WPF to the mixes which have been incorporated with additives resulted in significantly reduced SD for all densities relative to specimen not containing additivesand WPF.

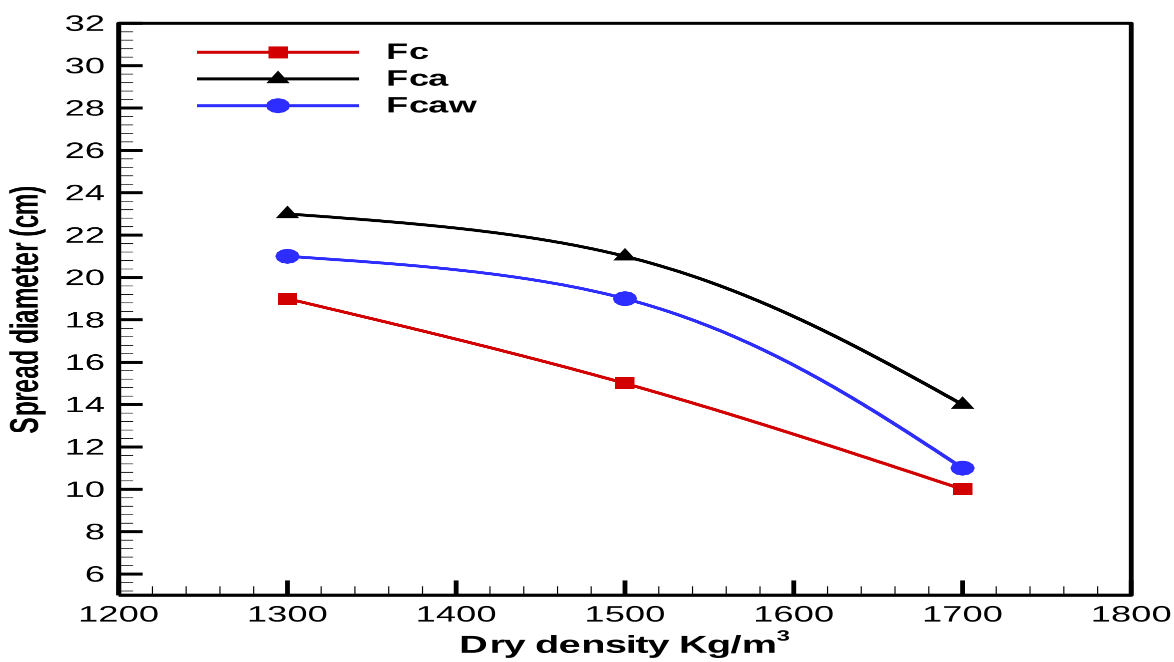


Figure 4.10: Consistency of foamed concrete mixes at densities of 1300, 1500 ,1700 kg/m^3.

4.4 Hardened properties of foamed concrete

4.4.1 Density

Concrete density was measured in two phases, fresh and hardened. The density was determined by weighing the specimens and dividing the weight by the measured volume of the specimen. Dry density was measured at age of 28 days**.** The dry density was observed to decrease with increasing V_f (volume fraction), as shown in Tables (4.5), (4.6) and Figures (4.11), the decreasing of dry density because the WPF formed more additional voids during mixing and the WPF itself is alitle density comparing with foamed concrete. Figure 4.12 illustreates the process of determining the fresh density of the mixes after mixing process.

Table 4-5: Fresh and dry densitiy of 1500 kg/m^3 mixes with different L/D and volume fractions.

Aspect ratio / V_f %	L\D = 40		L/D = 60		L\D = 80	
	Fresh density kg/m^3	Dry density kg/m^3	Fresh density kg/m^3	Dry density kg/m^3	Fresh density kg/m^3	Dry density kg/m^3
0	1576	1553	1576	1553	1576	1553
0.25	1570	1552	1556	1546	1567	1543
0.5	1567	1544.2	1549	1538.6	1552	1531
0.75	1550	1539	1547	1522.5	1542	1510
1	1548	1523	1523	1505	1532	1498
1.25	1539	1509.9	1518	1498.7	1519	1495
1.5	1526	1505.4	1543	1494.7	1542	1489
1.75	1520	1500.9	1567	1488.8	1533	1483

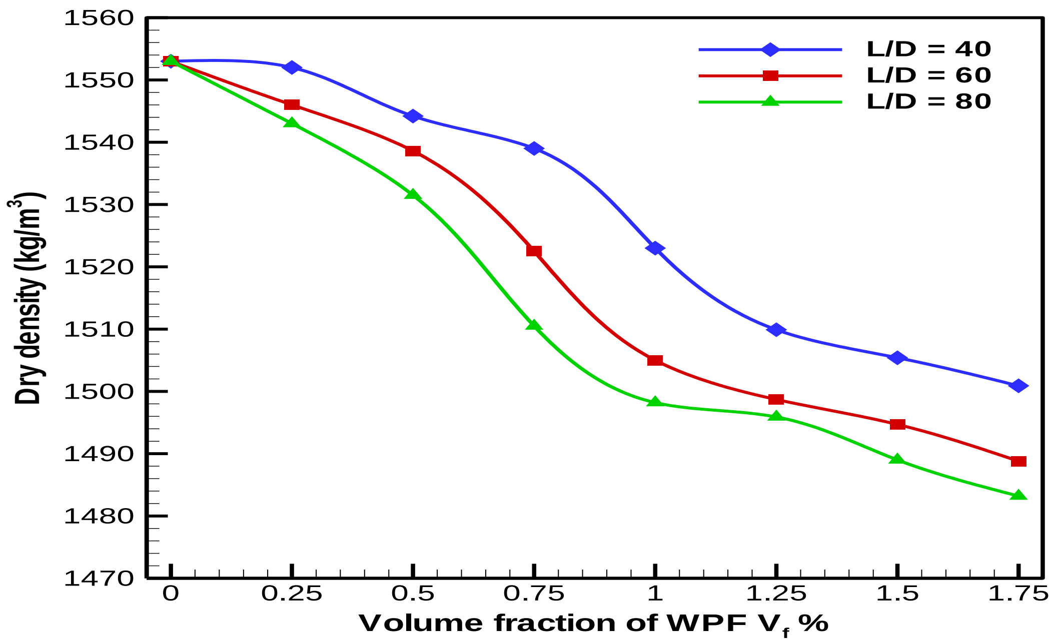


Figure 4.11: Dry density of 1500 kg/m^3 mixes with different L/D values of 40,60,80.

Table 4-6: Fresh and dry density values for all investigated mixes modified with v_f1% and L/D=60

Nominal density (kg/m^3)	Fc mix (kg/m^3)		Fca mix (kg/m^3)		Fcaw mix (kg/m^3)	
	Fresh density	Dry density	Fresh density	Dry density	Fresh density	Dry density
1300	1350	1341	1320	1263	1285	1258
1500	1548	1523	1532	1490	1525	1505
1700	1748	1721	1727	1692	1686	1662

Mix 1300 kg/m^3

Mix 1500 kg/m^3

Mix 1700 kg/m^3

Figure 4.12: Fresh density of 1300,1500 and 1700 kg/m^3 mixes.

4.4.2 Porosity of foamed concrete

4.4.2.1 Total porosity

Equation (3.1) was used to determine the porosity of foamed concrete ,porosity is a measure of entrained air voids volume and the volume of the voids within a paste, gel and capillary pore [13]. Table (4.7) summarises the total porosity of the 1500 kg/m^3 mixes with L/D=60 (Fc5aw). The table shows that the addition of varying volume fractions of WPF (0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75) caused a some change in the porosity of the mixes. This means that there was small formation of new voids when WPF was added, and Figure 4.13. Table (4.7) and Figure (4.13) represents the total porosity values for the mixture 1500 Kg/m^3 and the WPF ratio from (0.25-1.75) %. It is observed from the above Table and Figure that the difference in total porosity is due to the difference in the movement of WPF inside the specimen, and this movement to produce additional voids may be few. From the distribution of WPF (4.2,4.3,4.4), it is noted that the distribution of WPF with high ratios is located at the top of the specimen and the distribution of WPF with low ratios is below the specimen. Because of the presence and absence of WPF inside the specimen leads to presence or absence of addition voids. As for the percentage of WPF (1%), it appears that the highest total porosity , WPF distribution shows that the distribution of the WPF ratio is 1% on each height of specimen, that leads to produce addition voids on each height of specimen compared with the rest of the ratios that are less or greater than 1%. This can be proven by scrutinizing SEM images of mixes modified with different volume fractions of WPF as shown in Figure (4.14).

Table 4-7: Total porosity of 1500 kg/m^3 mix with L/D=60 (fc5aw).

V_f %	0.25	0.5	0.75	1	1.25	1.5	1.75
Total porosity	43.03	43.17	42.72	43.96	42.57	43.15	43.30

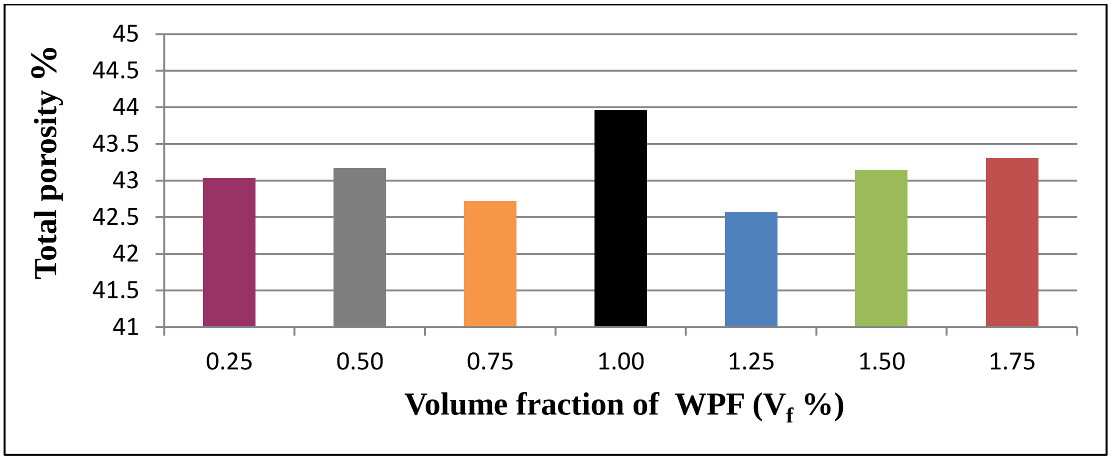
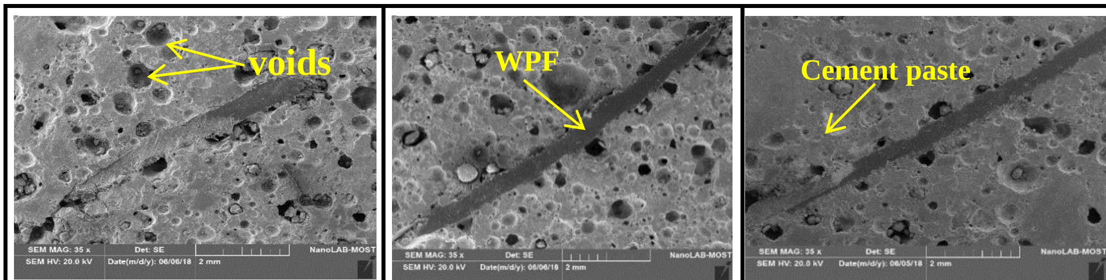


Figure 4.13: Total porosity of mix 1500 kg/m^3 with L/D=60.



L/D=60,V_f=0.25%	L/D=60,V_f=1%	L/D=60,V_f=1.75%

Figure 4.14: SEM image of F5aw mix.

Even though there is justification which have shown that the addition of rigid fibers resulted in the formation of additional voids around WPF, this is not the case in the present study due to the flexibility of the WPF. Table (4.8) and figure 4.15 show the values of total porosity for all investigated mixes. The addition of Fca to mixes with the same density resulted in reduced total porosity when compared with the corresponding conventional mixes (Fc). The addition of combined additives prevented connecting of voids, thus resulting in higher numberjustificate of spread small voids, which in consequence caused a reduction in the measured total porosity. The measured densities of both the Fc and Fca mixes are almost the same. Adding both the additives and the superplasticizer resulted an improvement in the microsrtucture of the cement paste, thus making it less porous [51]. The mix modified with WPF (Fcaw) did not show any change in total porosity when compared to mixes containing additives (Fca), although its porosity remains smaller than that of the conventional mixes (Fc). This indicates that small additional voids were formed with the addition of WPF, as can be seen in Figure (4.16).

Table 4-8: Total porosity values of all investigated mixes

mix	Fc3	Fc3a	Fc3aw	Fc5	Fc5a	Fc5aw	Fc7	Fc7a	Fc7aw
Total Porosity %	56.6	53.6	54.5	44.9	42.9	43.9	38.8	35.7	36.79
Reduction%	-	5.2	3.7	-	4.5	2	-	8.1	5

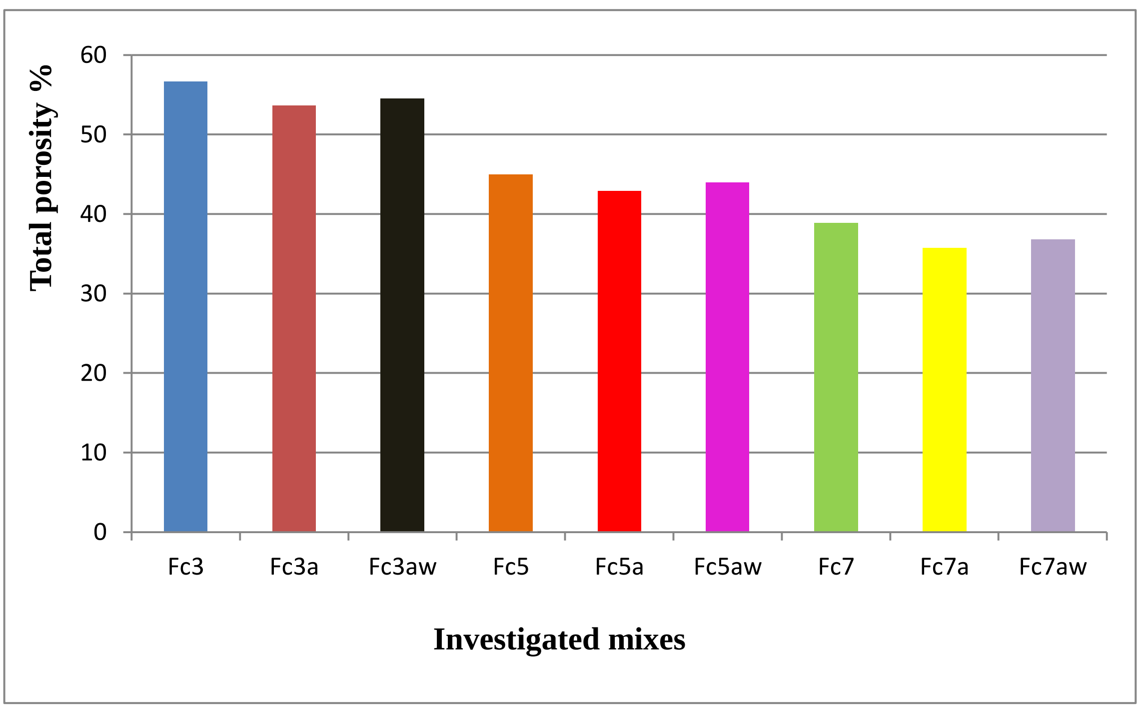


Figure 4.15: Total porosity values of all investigation mixes.

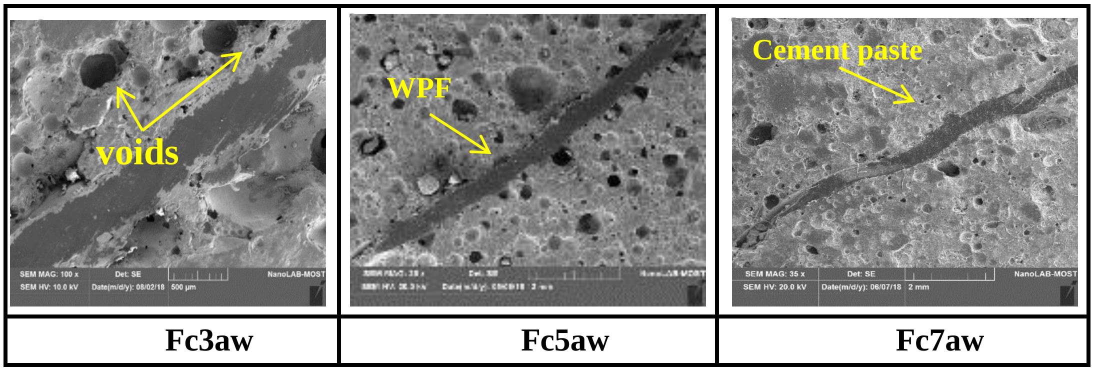


Figure 4.16: SEM images of some of investigated mixes

A lower measured total porosity in mixes modified with additive and WPF (Fcaw) was observed in comparison to that of conventional mix (Fc), as can be seen in Table (4.8).

4.4.2.2 Apparent porosity of foamed concrete

Table (4.9) gives appaerent porosity values of mix fc5aw, Figure 4.17, Table (4.10) gives the apparent porosity values of all investigated mixes (Fc, Fca, and Fcaw); it shows that the measured apparent porosity values by imerssion in water is approximately the same as under normal condition, since water enter the specimens through the connected voids only and not all voids were filled with water. This result shows that the values of apperent porosity decreased with higher density, i.e. when smaller volume fraction of foam was added see Figure 4.18.

Table 4-9: Apparent porosity of 1500 kg/m^3 mix with L/D=60 (fc5aw).

V_f %	0.25	0.5	0.75	1	1.25	1.5	1.75
Apparent porosity%	18.80	15.78	18.7	22	18.4	18.4	20.9

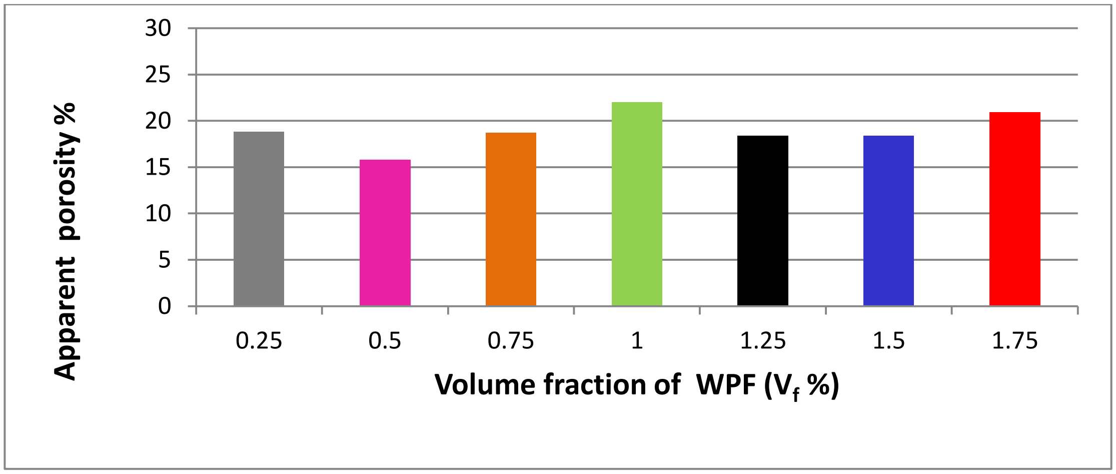


Figure 4.17: Apparent porosity of mix 1500 kg/m^3.

Table 4-10: Apparent porosity of all investigated mixes

mixes	Fc3	Fc3a	Fc3aw	Fc5	Fc5a	Fc5aw	Fc7	Fc7a	Fc7aw
Apparent Porosity%	28.2	26.2	27.06	25.7	21	22	20.1	17.9	18.5
Reduction %	-	7	4.1	-	18.2	14.3	-	11.2	8.3

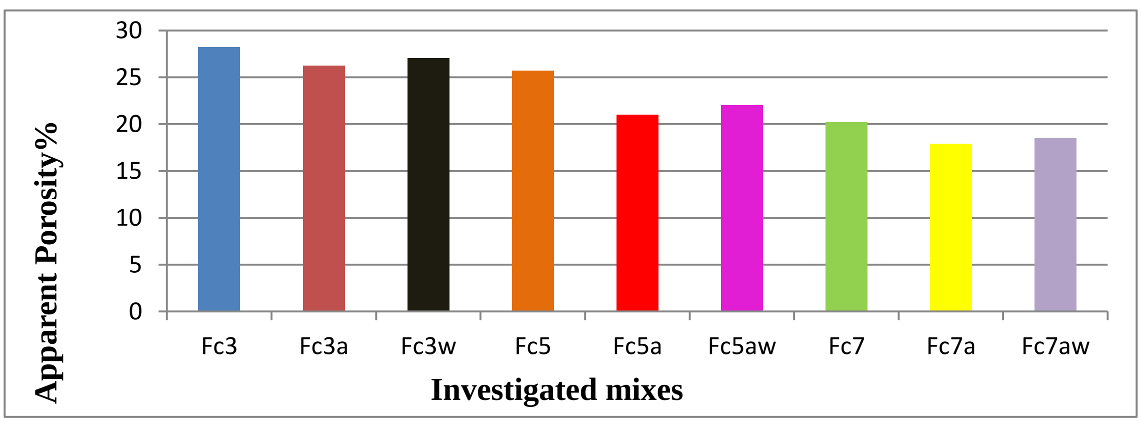


Figure 4.18: Apparent porosity of all investigation mixes.

A comparison of the apparent and total porosities of all investigated mixes show that the apparent porosity measured under normal condition is lower than the total porosity which is determined using the vacuum saturation approach.

4.4.3 Absorption of foamd concrete

Table (4.11) shows the absorption for the 1500 kg/m^3 mix with L/D=60 (Fc5aw). It shows that adding varying volume fractions of WPF, i.e. 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, resulted in a small change in the absorption values. This indicates that small additional void was formed with the incorporation of WPF, see Figure 4.19. Table (4.11) and Figure (4.19) represents the absorption values for the mixture 1500 Kg/m^3 and the WPF ratio from (0.25-1.75) %. It is observed from the above Table and Figure that the difference in absorption is due to the difference in the movement of WPF inside the specimen, and this movement to produce additional voids may be few. From the distribution of WPF (4.2,4.3,4.4), it is noted that the distribution of WPF with high ratios is located at the top of the specimen and the distribution of WPF with low ratios is below the specimen. Because of the presence and absence of WPF inside the specimen leads to presence or absence of addition voids. As for the percentage of WPF (1%), it appears that the highest absorption, WPF distribution shows that the distribution of the WPF ratio is 1% on each height of specimen, that leads to produce addition voids on each height of specimen compared with the rest of the ratios that are less or greater than 1%.

Table 4-11: Absorption of Fc5aw with L/D=60.

V_f %	0.25	0.5	0.75	1	1.25	1.5	1.75
Total absorption%	31.00	31.84	30.91	32.60	30.95	31.72	31.99
Apparent absorption%	13.93	14.53	13.61	16.26	13.40	13.60	15.90

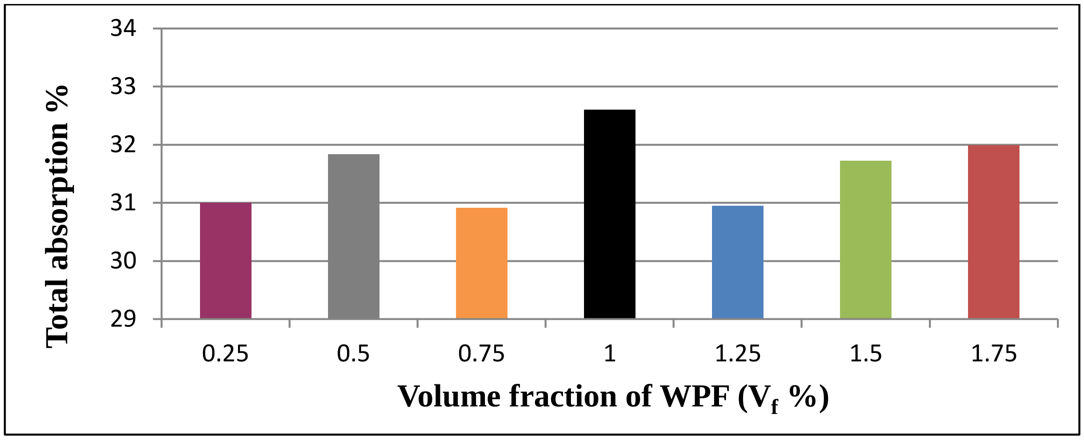


Figure 4.19: Total absorption of 1500 kg/m^3.

Tables (4.12) and (4.13) show the total absorption and apparent absorption values of investigated mixes. The total absorption of the conventional foamed concrete mixes (Fc3, Fc5, Fc7) decreased at higher density due to smaller volume fraction of the added foam. See Figures 4.20, 4.21.

Table 4-12: Total absorption of all investigated mixes

mixes	Fc3	Fc3a	Fc3aw	Fc5	Fc5a	Fc5aw	Fc7	Fc7a	Fc7aw
Total absorption	56.4	50.1	52.7	33.9	31.3	32.6	26.4	21.25	22.18
Reduction %	-	11.1	9.3	-	7.6	3.83	-	8	15.9

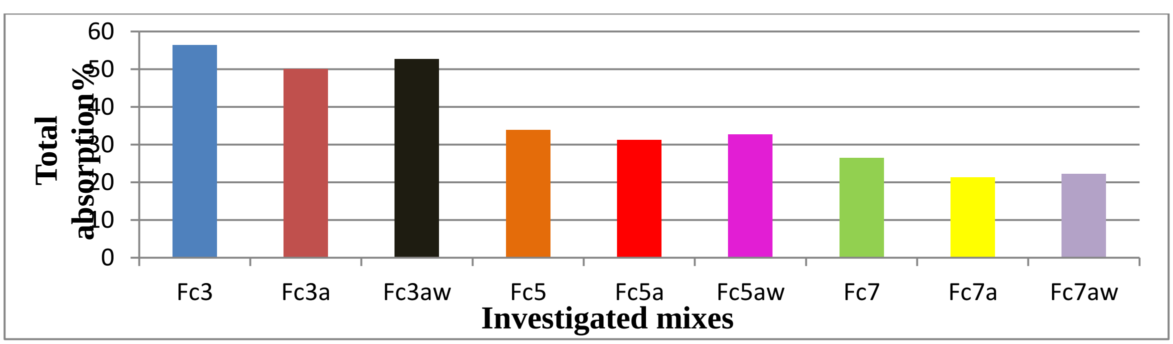


Figure 4.20: Total absorption of all ivestigation mixes.

Table 4-13: Apparent absorption of all investigated mixes

mixes	Fc3	Fc3a	Fc3aw	Fc5	Fc5a	Fc5aw	Fc7	Fc7a	Fc7aw
Apparent Absorption	23.8	21.5	22.23	20.5	17.8	19.26	13	8.15	9.05
Reduction%	-	9.6	6.5	-	13.17	6	-	37.3	30.3

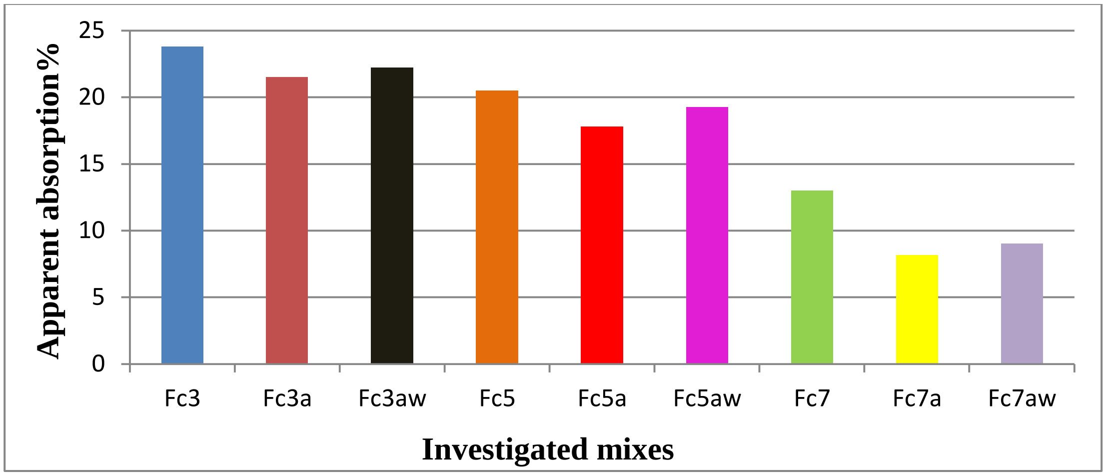


Figure 4.21: Apparent obsorption of all investigation mixes.

The addition of additives to mixes that have same densities resulted in reduced total and apparent absorption in comparison to those of the corresponding unmodified mixes (Fc). The addition of both additives and superplasticizer reduced the absorption of the mixes, thus improving the microstructure of the cement paste [51]. The addition of WPF has no effect on the total and apparent absorptions of the Fcaw mix in comparison to mixes modified with additives (Fca) although this value still smaller than that of the conventional mix (Fc). Furthermore the addition of the combined additives prevents the merging of voids, thus resulting in the presence of additional voids; this in consequence reduced the measured total absorption, as can be seen in Figure (4.14).

4.5 Mechanical Properties of foamd concrete

4.5.1 Compressive Strength

The effect of volume fraction of WPF on the compressive strength of the 1500 kg/m^3 mixes with different aspect ratios (L/D) is shown in Figure (4.22) and Table (4.14). The values of compressive strength at in the range from 11.25 to 23.24 MPa. The highest compressive strength value was observed for the mix with L/D= 60 and (v_f=0.25%). The reduction in compressive strength was observed for all investigated mixes when the amount of WPF was increased. The reduction of compressive strength is probably due to low compresion of WPF. This finding is consistent with those made in previous studies [189]. In addition, the mixes with L/D = 60 for all volume fractions of WPF have in the highest compressive strength [190].

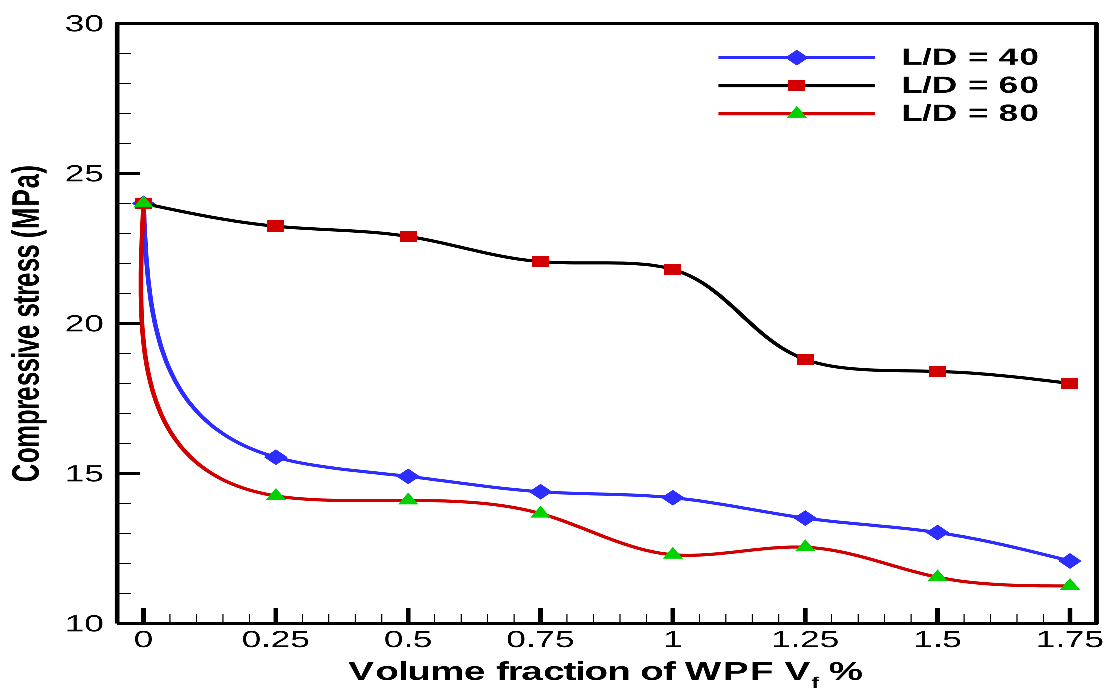


Figure 4.22: Results of compressive strength results of Fc5aw at age of 28 days (V_f (0-1.75), L/D of 40,60 and 80.

Table 4-14: Results of compressive strength of Fc5aw mixes at 28 days

V_f %	L/D =40		L/D =60		L/D =80	
	MPa	Reduction%	MPa	Reduction%	MPa	Reduction %
0	24	0	24	0	24	0
0.25	15.54	35.25	23.24	3	14.25	40.7
0.5	14.9	38	22.9	4.5	14.1	41.3
0.75	14.39	40.1	22.06	8	13.66	43.1
1	14.19	40.1	21.8	10	12.89	46.3
1.25	13.51	43.71	18.8	21.6	12.54	47.7
1.5	13.03	45.71	18.4	23.3	11.54	52
1.75	12.08	49.7	18	25	11.25	53.2

The reduction in compressive strength of mix with an aspect ratio of ($\frac{l}{D} = 40$) is more than mixes with an aspect ratio ($\frac{l}{D} = 60$) due to the non-uniform distribution of WPF, as shown in Figuure (4.3). A similar behavior was observed for mixes with an aspect ratio of ($\frac{l}{D} = 80$), whereas the mixes with an aspect ratio of ($\frac{l}{D} = 60$) show a uniform distribution of WPF, as can be seen in Figure (4.3). WPF caused a reduction in compressive strength due to the weak ITZ between the surface of WPF and the foamed concrete. Table (4.15) shows that the conventional mixes (Fc) with higher densities have higher compressive strength. For a given density, the mixes modified with additives have higher compressive strength in comparison to the conventional (Fc) mix. Those mixes modified with WPF (Fcaw) have lower compressive strength in comparison to any mix modified with additives (Fca) [189] and [191].

Table 4-15: Compressive strength of all investigated mixes at 28 days

mix	7-day(MPa)	14-day(MPa)	28-day(MPa)	Increment %
Fc3	4.77	5.2	5.70	-
Fc3a	9.58	10.83	11.89	108
Fc3aw	8.41	8.86	10.34	81
Fc5	6.95	8.25	12.04	-
Fc5a	12.63	18.39	24	99
Fc5aw	11.54	15.66	21.8	81
Fc7	14.79	16.46	17.19	-
Fc7a	22.7	25.40	28.31	64.6
Fc7aw	20.14	23.22	25.89	50

The 1700 kg/m^3 mix has the highest compressive strength, followed by the 1500 kg/m^3 and 1300 kg/m^3 mixes. This is due to the different volumes of foam added to the mixes i.e more foam means more voids , as shows in Table (4.15). For same density mixes, highest compressive strength in contrast to the conventional mix (Fc) has been produced when these mixes modified with the additive (Fca). The physical and chemical reactions of the fly ash and silica fume resulted in improved cement pastes because of better interlocking between some of the particles. Superplasticizer was added to reduce the amount mixing water, and this resulted in a less porous cement paste [51]. For same density mixes, the highest strength due to adding additives creating a new C S H which this resulted in a less porous cement paste which in consequence improved the compressive strength of the mix. However, the addition of WPF resulted in creation of a weak ITZ, which in turn reduced the strength in contrast to the corresponding mix, as can be seen in Figure (4.23) [189-190,192].

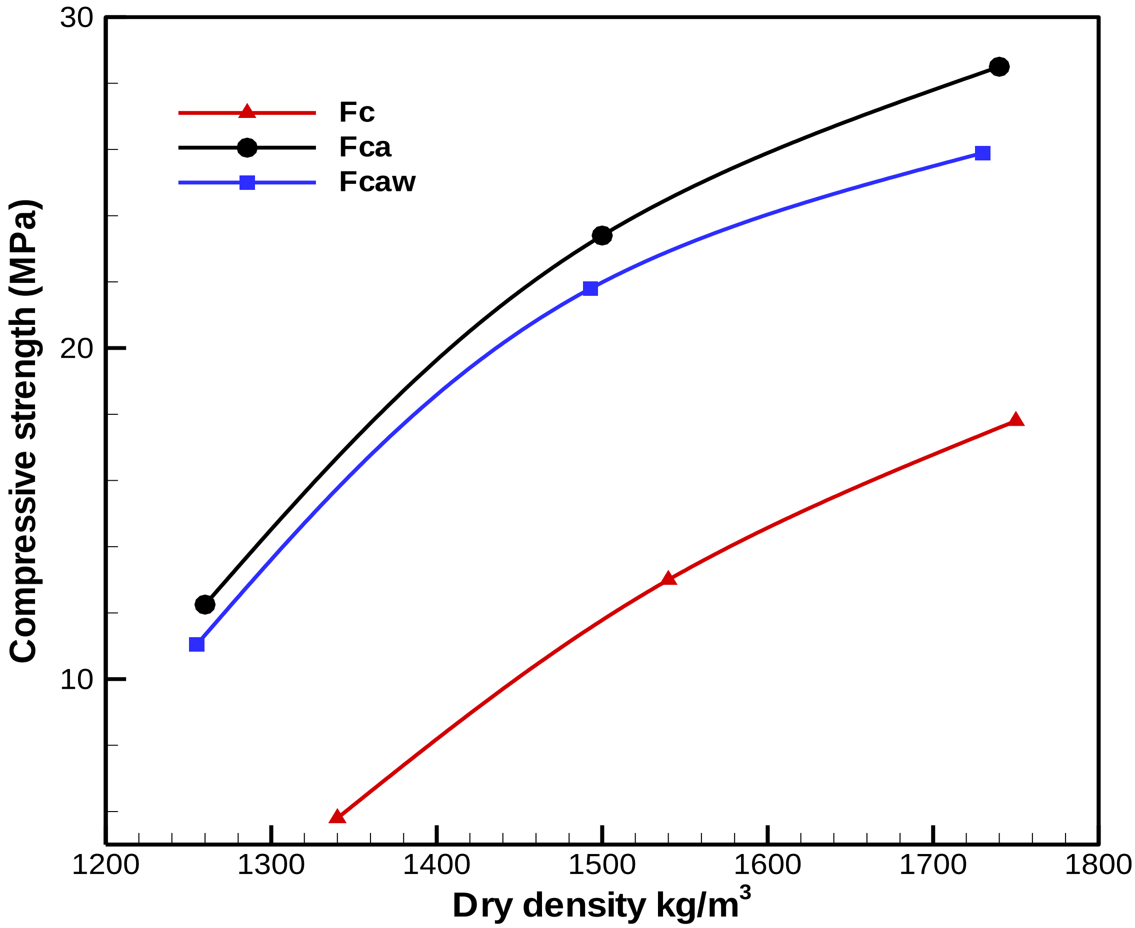


Figure 4.23: Compressive strength of all investigated mixes at age 28 days.

4.5.2 Splitting Tensile Strength of foamed concrete

The splitting tensile strengths of the mixes modified with varying volume fractions of WPF are shown in Figure (4.24). In general, the incorporation of WPF improved the splitting tensile strength of the mixes. The addition of (0.25, 0.5, 0.75, 1.0, 1.25, 1.5, and 1.75) % WPF to the 28-day mixes with an L/D = 60 resulted in a 40.5, 46.9, 52.2, 69.8, 52.9, 27.2 and 20% increase in splitting tensil strength, respectively. The splitting tensile strength for mixes with an aspect ratio of (L/D=60) are higher than those for the mixes with L\D=40 and L/D=80 (see Table (4.16)). This increase in tensile strength is subsequent to the addition of WPF which can be attributed to the strong bond between the WPF and the matrix. specimens that were not modified with WPF failed suddenly once the concrete cracked, while those reinforced with WPF remained intact after failure.

The addition of WPF increased the tensile strength of investigated mixes by reducing non-load cracking (micro cracks) at an early age [189]. Figure (4.24) gives the values of the tensile strength for the Fc5aw mixes with an aspect ratio of L/D = 60 at age of 7 and 28 days. Its clear shows that WPF at a volume fraction of v_f=1% produced the highest tensile strength, which is similar to the findings made by Ahmed and Ali [26].

Figure (4.25) shows splitting tensile strength of three investigated mixes with aspect ratio of L/D = 40, 60 and 80 and a volume fraction of v_f=1%, it can be observed that the mix with an L/D = 60 has the highest tensile strength.

Table 4-16: Tensile strength of the F5aw mixes with L/D=40,60,80 at 28 days

	7-days(MPa)			28- days(MPa)			
V_f (%)	L/D =40	L/D =60	L/D =80	L/D =40	L/D =60	L/D=80	Increment% of L/D=60
0	0.904	0.904	0.904	1.36	1.36	1.36	-
0.25	1.31	1.35	1.22	1.82	1.91	1.74	40.5
0.5	-	1.45	-	-	1.999	-	46.9
0.75	-	1.57	-	-	2.07	-	52.2
1	1.63	1.73	1.52	2.27	2.31	2.06	69.8
1.25	-	1.59	-	-	2.08	-	52.9
1.5	-	1.59	-	-	1.73	-	27.2
1.75	1.48	1.57	1.32	1.43	1.625	1.23	20

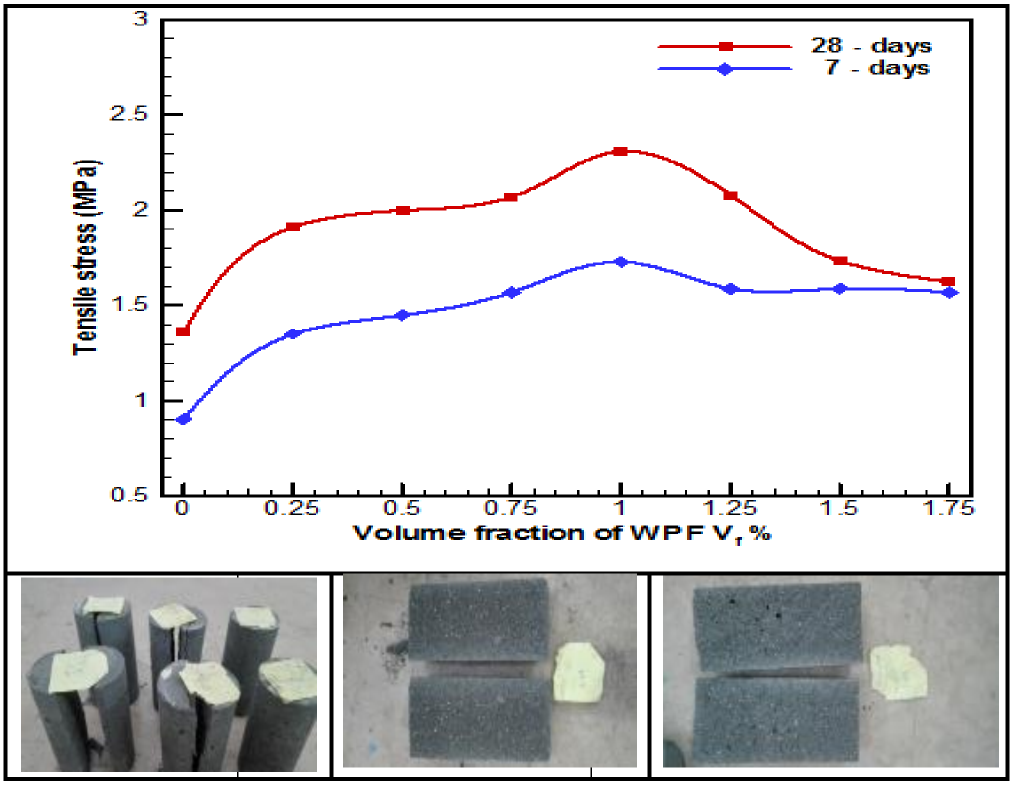


Figure 4.24: Tensile strength Fc5aw of a mix for 28 days and types of failure of mix with L/D=60.

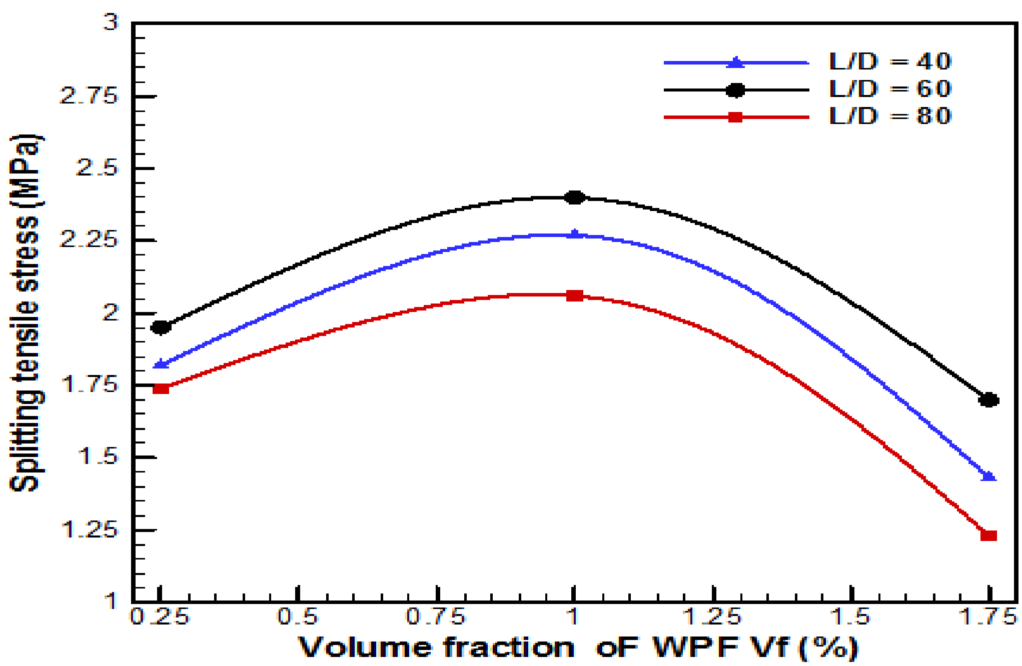
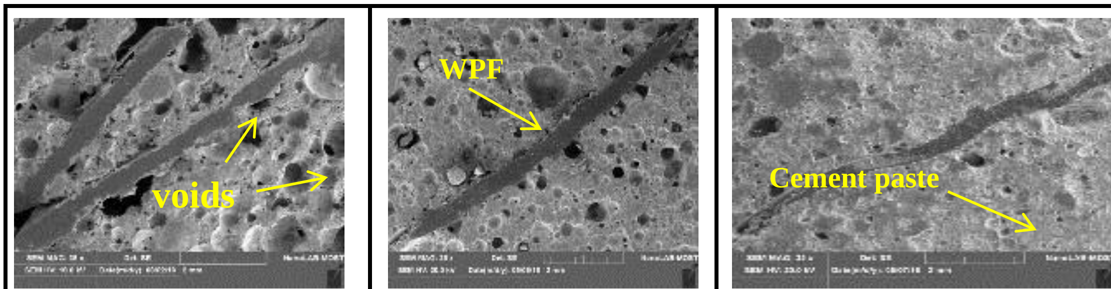


Figure 4.25: Splitting tensile of 1500 kg/m^3 mixes with different aspect ratio and additives at age of 28 days

Figure (4.26) presents the SEM images for the WPF modified mixes with densities of 1300, 1500 and 1700 kg/m^3. The images show that no additional void was formed around the WPF and that the volume of voids decreased with higher density.



Fc3aw	Fc5aw	Fc7aw

Figure 4.26: SEM images for mixes modified with WPF

Based on the WPF distribution in Figure 4.3 , compressive strength, and splitting tensile strength, the mix with L/D = 60 and v_f = 1% produced a normal distribution of WPF and the highest strength. Hence these parameter were chosen for the fabrication of mixes with densities of 1300 and 1700 kg/m^3. The tensile strengths of Fc3, Fc3a, Fc3aw, Fc5, Fc5a, Fc5aw, Fc7, Fc7a, and Fc7aw cylindrical samples were determined after 7 and 28 days of aging, and the results are given in Table (4.17). The results of the mixes modified with WPF are shown in Figure (4.27).

It can be seen from both the table and the figure that the 1700 kg/m^3 mix has the highest tensile strength, followed by the 1500 kg/m^3 and the 1300 kg/m^3 mixes. The tensile strengths of the mixes modified with WPF are higher than those modified with additives, while the latter has a higher tensile strength than the conventional mixes. Splitting strength improved significantly with increasing curing age of the mixes; this is because a less porous of ITZ can be attributed to lower amount of water and a better interlocking at the interface between the sand and the cement paste which was improved by the addition of additives [51].

Table 4-17: Tensile strength of all investigated mixes with (L/D =60) andv_f(1%)

mix	7-day	14-day	28-day	
	MPa	MPa	MPa	Increment%
Fc3	0.42	0.48	0.749	-
Fc3a	0.485	1.173	1.162	55.1
Fc3aw	0.822	1.2775	1.744	132.8
Fc5	0.73	0.86	1.179	-
Fc5a	1.11	1.58	2.062	74.8
Fc5aw	1.2875	1.815	2.356	99.8
Fc7	0.83	0.93	1.344	-
Fc7a	2.235	2.42	2.495	85.6
Fc7aw	2.525	2.875	3.035	125.8

Figure (4.27) shows that the Fc7aw mix has the highest splitting strength, followed by Fc5aw and Fc3aw. Mixes with higher density show a stronger adhesion between the WPF and the cement paste [189].

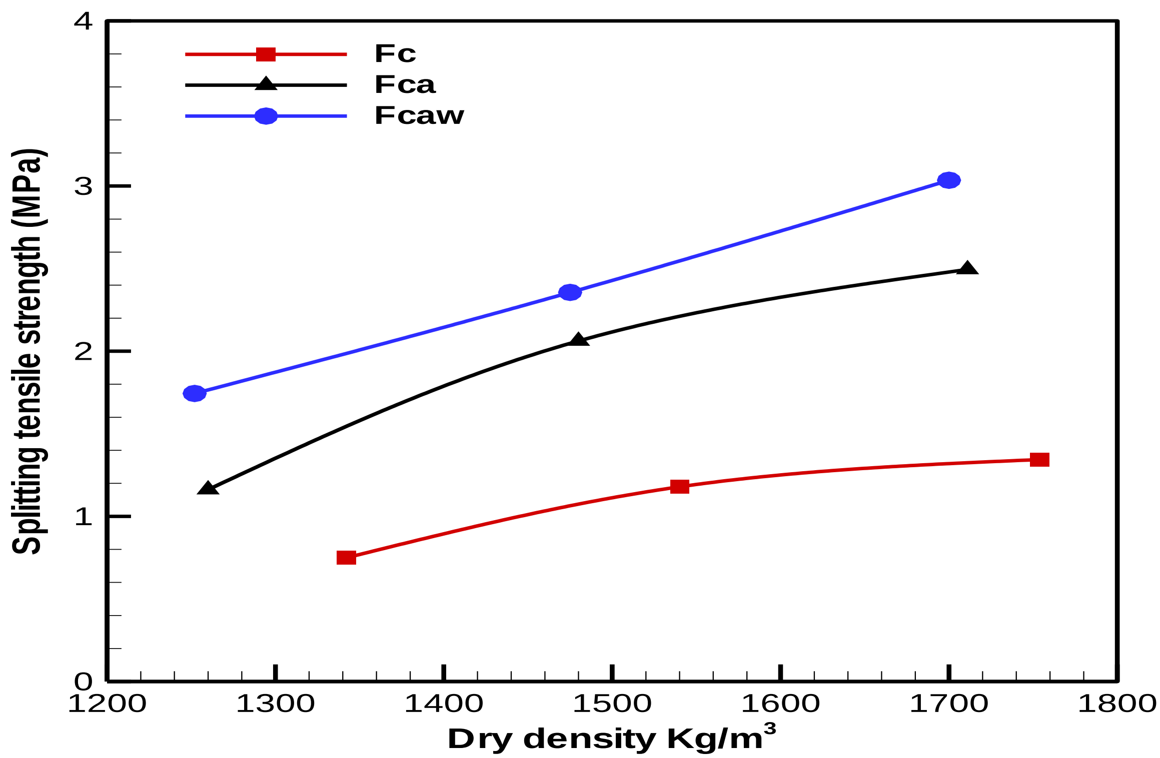


Figure 4.27: Splitting tensile strength of all mixes modified with WPF (v_f=1%) and L/D=60 at age of 28 days.

4.5.3 Flexural Strength

Since the fracture line appeared in the middle third of the span length (see Plate (4.4)), equation (3.6) was used to find the flexural strength for all conventional (Fc) mixes as well as those modified with additives (Fca) and those modified with both additives and WPF (Fcaw). Table (4.18) shows the flextural strength of all mixes. It shows that the Fc7aw mix has the highest flexural strength of 4.107 MPa, followed by Fc7a (2.9 MPa), Fc5aw (2.6 MPa), and Fc5a (2.22 MPa). The Fc3, Fc5 and Fc7 mixes have the lowest strength of 0.972, 1.38, and 1.82 MPa, respectively. The adhesion between WPF and the cement paste in the foam concrete mixes developed a high flexural strength, where higher density indicates a stronger adhesion. The flexural strength of mixes without WPF is lower than those modified with WPF due to the absence of the adhesion resulted from the addition of WPF. In other words, foam concretes have higher ductily when modified with WPF. This behavior is generally expected in presense of WPF due to the increased interdependence of cement paste that results in reduced internal stress, thereby increasing the ultimate applied load [26].

The flexural strength in these mixes is due to the presence of the additives, which distribute the voids in the foamed concrete normally throughout the concrete section.

The voids were uniformly distributed and the additives filled some of the small voids in the foamed concrete by creating a new C S H [190]. The flexural strength of the unmodified mixes (Fc) are low due to the absence of adhesion brought by WPF and the absence of additives. Conventional mixes (Fc) were observed to have very large voids which reduced the flexural strength of the mixes. Table (4.18) shows that the flexural strength of the Fc3, Fc5 and Fc7 and conventional mixes are 0.972, 1.38 and 1.82 MPa, respectively. However, the flexural strength of the mixes modified with additives.

The mixes Fc3a, Fc5a, and Fc7a, increased by 88.2%, 60.8%, and 59.3%, respectively, in comparison to the conventional mixes. Flexural strength improved significantly in all ages due to the same reasons stated for the splitting tensile behavior. The flexural strength of the mixes modified with WPF and additives, namely Fc3aw, Fc5aw, and Fc7aw, increased by 119%, 88.4%, and 125%, respectively, in comparison to the corresponding conventional mixes. It should be noticed that the the Fc7aw mix has the highest flexural strength of 4.103 MPa. Figure 4.28 presented flexural strength of all investigation mixes.

Table 4-18: Flexural strength of all investigated mixes

Mixes	Flexural strength (MPa)	Increment%
Fc3	0.972	-
Fc3a	1.83	88.2
Fc3aw	2.13	119
Fc5	1.38	-
Fc5a	2.22	60.8
Fc5aw	2.6	88.4
Fc7	1.82	-
Fc7a	2.9	59.3
Fc7aw	4.107	125

Fc7	Fc7a	Fc7aw
High length of crack	Medium length of crack	Small length of crack

Plate 4-4: Test of flexural strength of the 1700 kg/m^3 mix

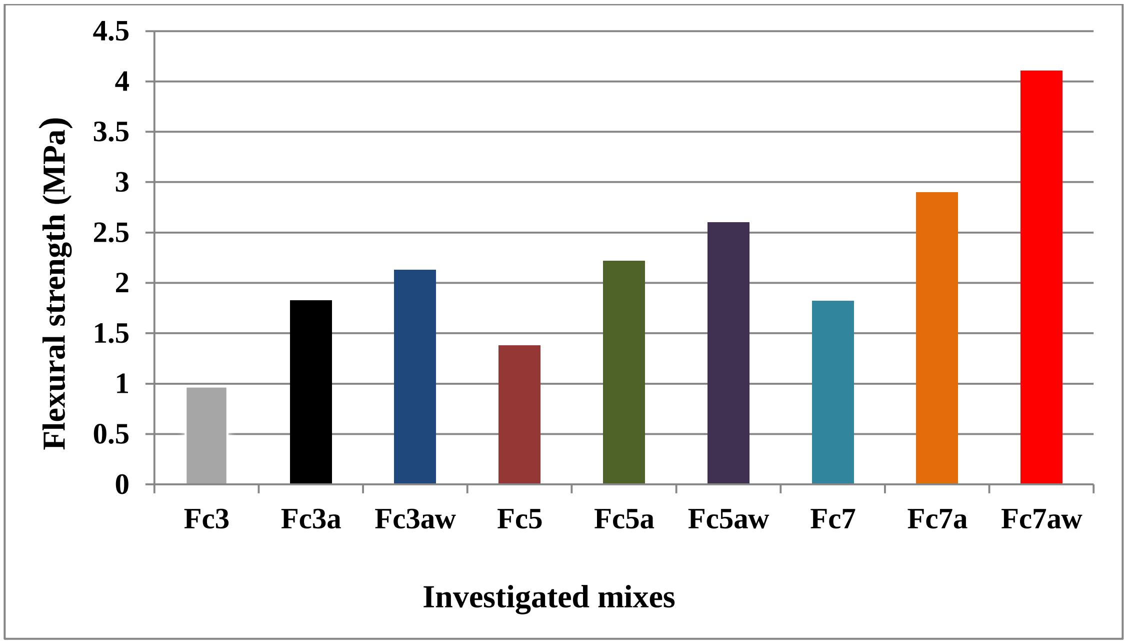


Figure 4.28: Flexural strength of investigation mixes

4.5.4 Static Modulus of Elasticity

The results are presented in Figures (4.29), (4.30) and (4.31) and Table (4.19). Plate (4.5) explains the failure of the specimens. The difference in values of measured modulus of elasticity is due to the difference in the densities (1300 kg/m^3, 1500 kg/m^3, and 1700 kg/m^3), where the mixes with higher density have higher modulus of elasticity.

The amount of sand in the mixes influence the density of the foamed concrete; in the present study the 1700 kg/m^3 mix contains higher amount of sand than the 1500 kg/m^3 mix, and have higher sand content than the 1300 kg/m^3 mix. The amount of foam added also influence the value of static modulus of elasticity. The additives have a strong influence on the mixes with the same density through the formation of new C S H which filled the gel pores of the mix.

The Fc7a specimen has the highest modulus of elasticity of 13.53 Gpa, while the Fc3 specimen has the lowest modulus of elasticity, as can be seen in Table (4.19). The mixes that were not modified with WPF, i.e.

Fc3a, Fc5a, and Fc7a, have the highest modulus of elasticity. For the same density mixes, modified mixes with additives (Fca) have the highest modulus of elasticity in comparison to the conventional mix. WPF have the opposite effect on modulus of elasticity due to the lower modulus of elasticity of the PET and the formation of a new ITZ between the surfaces of the WPF and the cement paste. In addition, the ITZ contains additional small voids which makes it a weak area in the cement paste.

Mixes with higher density have higher modulus of elasticity. For the same density, however, modification of the mixes with additives resulted in higher modulus of elasticity. Finally, for a given mix, a high modulus of elasticity was achieved for the mix with an aspect ratio of L/D=60 in comparison to the mixes with L/D=40 and L/D=80. Figure 4.32 presented all modulus of elastisty of investigation mixes .

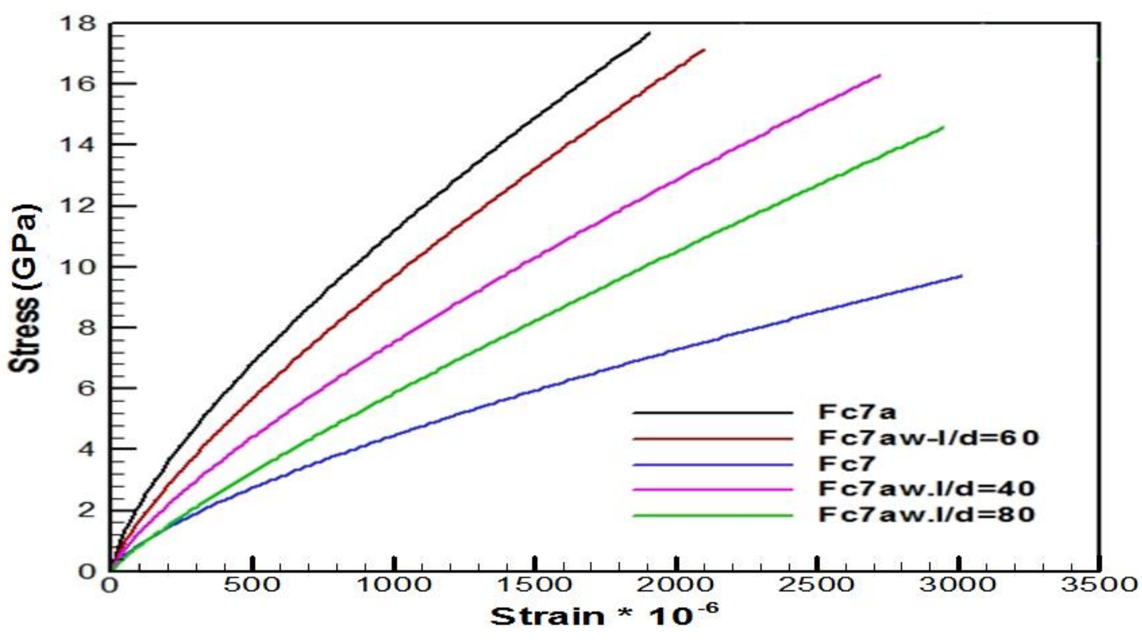


Figure 4.29: Static modulus of elasticity of the 1700 kg/m^3 mix

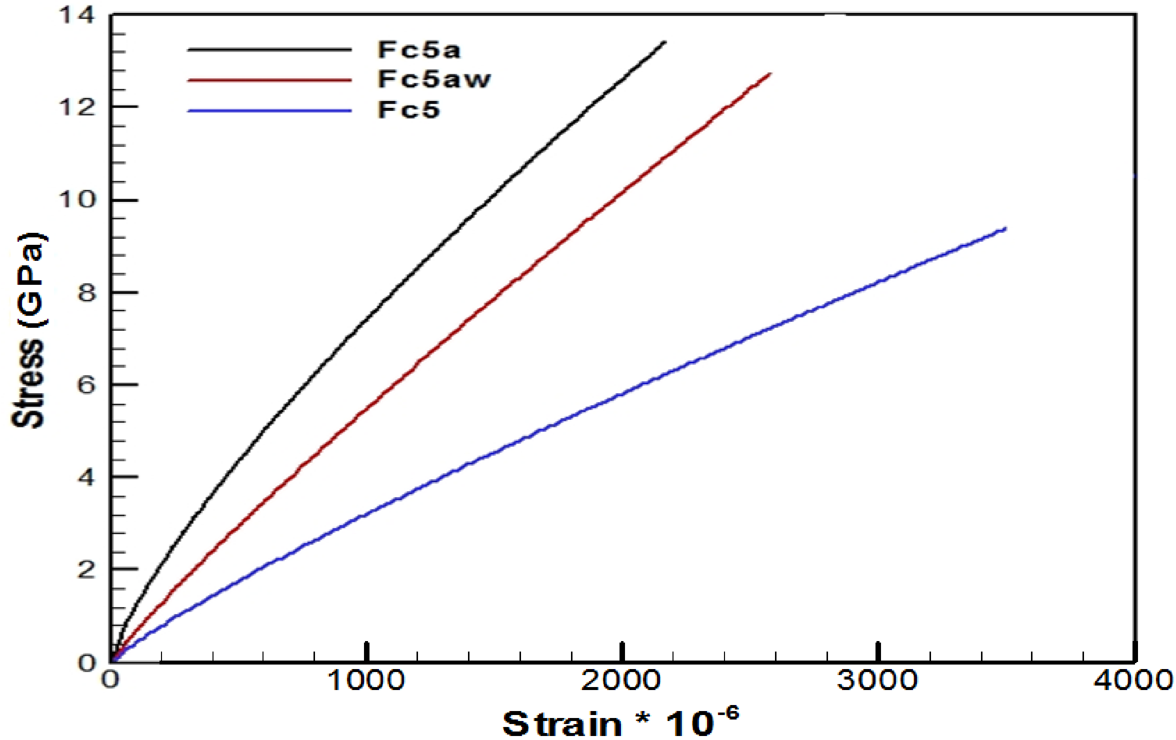


Figure 4.30: Static modulus of elasticity of the 1500 kg/m^3 mix.

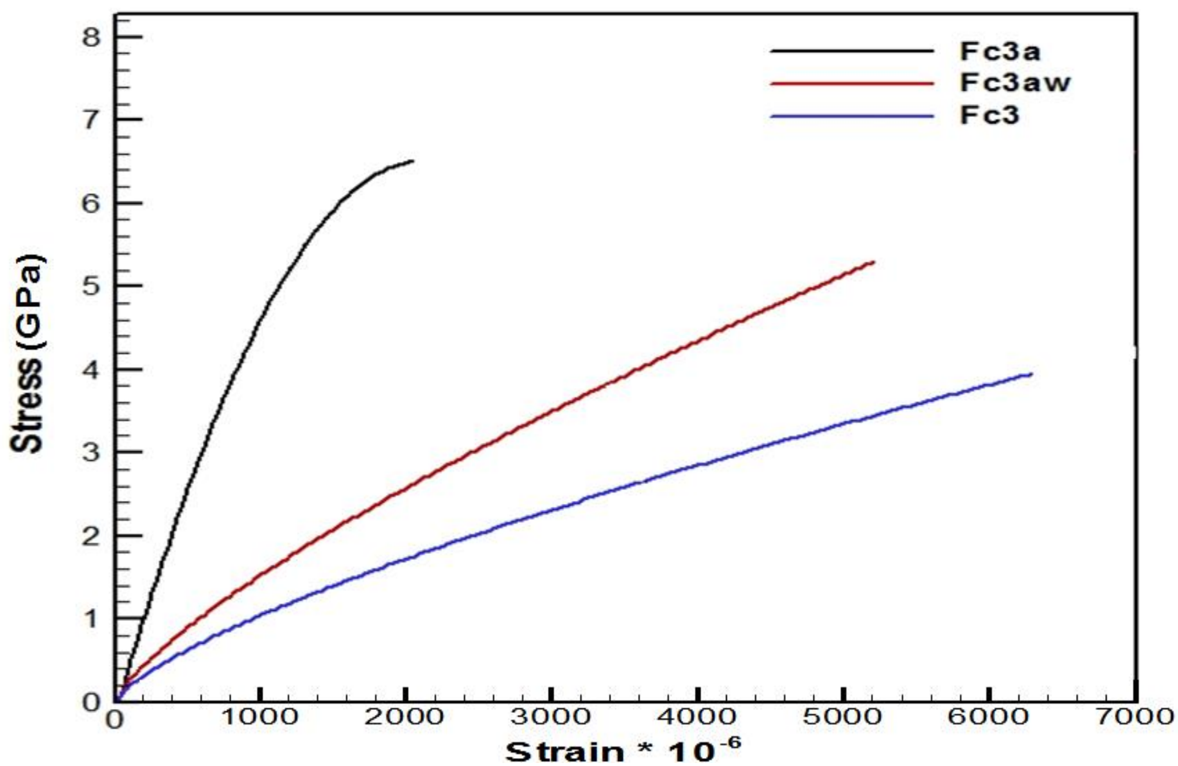


Figure 4.31: Static modulus of elasticity of the 1300 kg/m^3 mix.

Plate 4-5: Shape of failure of all investigated mixes.

Table 4-19: Modulus of elasticity of mixes with L/D=60 and v_f=1%

	N/mm^2	N/mm^2	mm/mm	GPa	Increment%
Mix	s_2	s_1	ε_2	E	
Fc3	1.58	0.05	0.0017	0.927	-
Fc3a	2.612	0.225	0.00054	4.8	410
Fc3aw	2.04	0.075	0.0014	1.45	56
Fc5	2.6	0.125	0.001	2.6	-
Fc5a	5.08	0.3375	0.00047	11.29	334
Fc5aw	4.07	0.29	0.00068	6	230
Fc7	3.16	0.258	0.00062	5.09	-
Fc7a	6.68	0.59	0.0005	13.53	160
Fc7aw(L/D=60)	4.86	0.625	0.0004	12	126
Fc7aw(L/D=40)	4.64	0.575	0.00042	11.32	120
Fc7aw(L/D=80)	4.3	0.323	0.00072	5.85	14

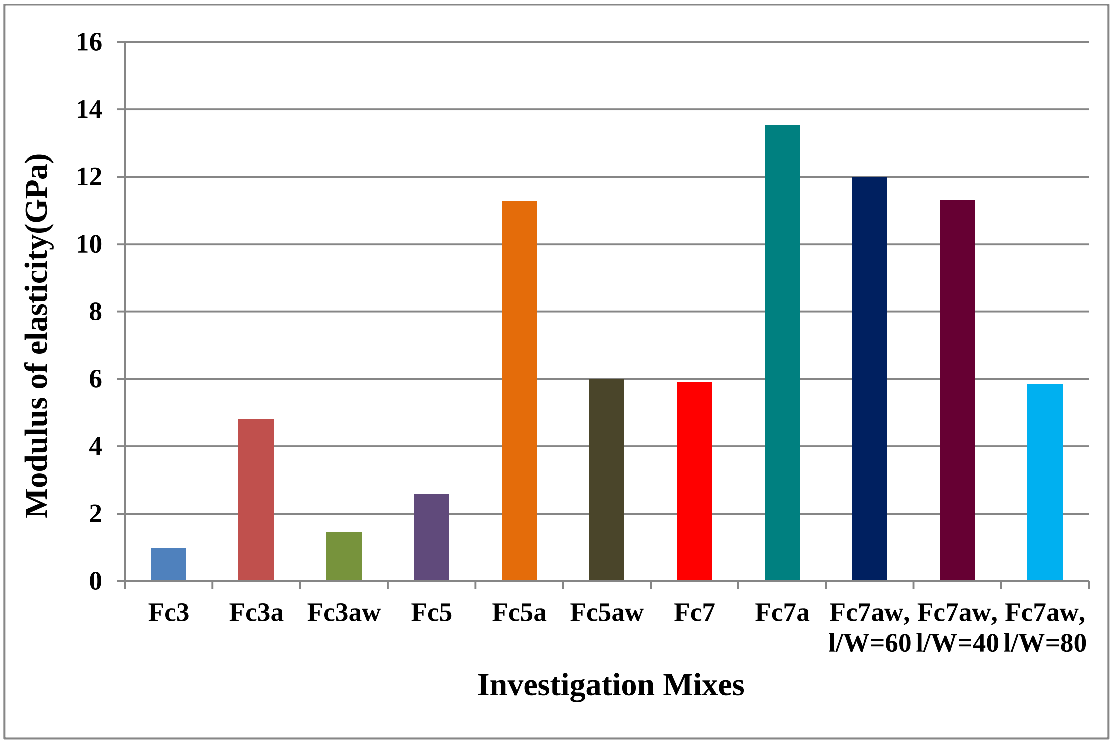


Figure 4.32: Modulus of elasticity of investigation mixes

4.6 Toughness

Toughness is an important characteristic of fiber reinforced concrete (FRC). The load carrying capacity of concrete prior to the cracking stage can be determined based on value of toughness [26]. The requirements of ASTM 1609m-12 [187] for calculating peak load, first-peak and stiffness to final toughness are shown in Table (4.20). The area under the load-deflection curve up to a prescribed deflection represents the toughness of a specimen (see Figures 4.33 and 4.34) [187].

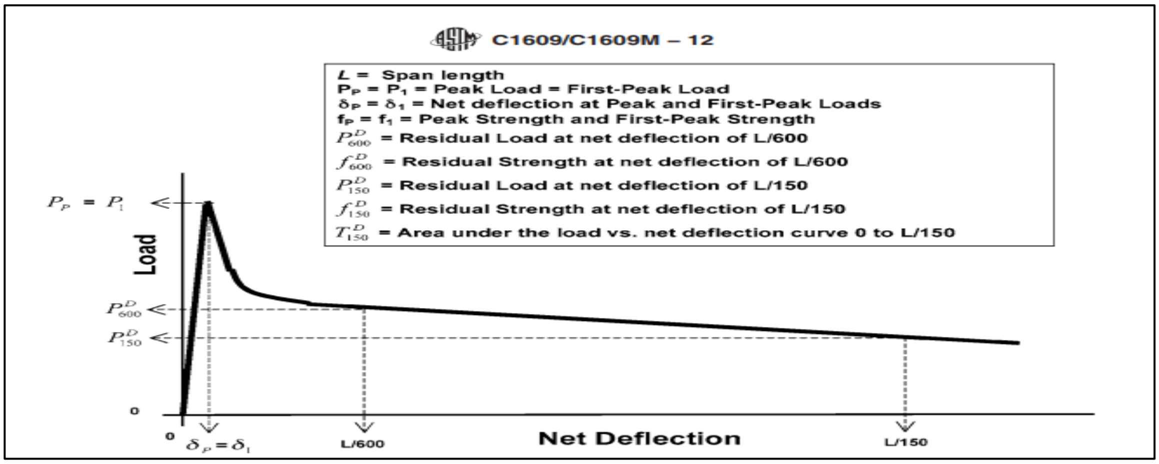


Figure 4.33: General diagram of toughness behaviour in concrete [187]

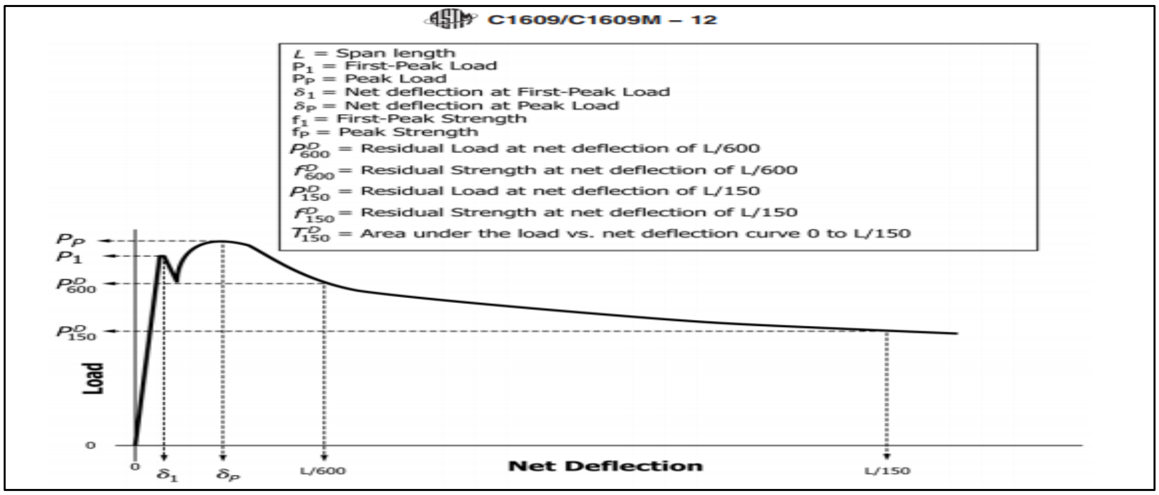


Figure 4.34: General diagram of toughness behavior in concrete [187].

Table (4.20) gives the values of toughness of all investigated mixes. All flexural toughness tests were conducted at a laboratory at the University of Technology-Baghdad. Based on the results of the toughness tests, it can be concluded that the effect of incorporating WPF on the absorbed energy of the post-crack was clear for all prisms when comparing the prisms fabricated from foamed concrete modified with additives with the unmodified prism. The latter failed rapidly when the values of load is equal to peak value. The area under the curve, which represents sample resistance to external loads, was calculated by using Microsoft Excel program (the summation of areas)

Area under curve=$\Sigma((L_1+L_2))*(D_2-D_1)$ (Joule)

Where L_1,L_2: load (kN)

D_1,D_2 : deflection (mm)

Table 4-20: Toughness of all investigated mixes.

mix	Pp(kN)	Fp(MPa)	$P\frac{D}{600}$(kN)	$f\frac{d}{600}$(MPa)	$P\frac{D}{150}$ (KN)	$f\frac{D}{150}$ (MPa)	$T\frac{D}{150}$(joule)
Fc3	4.52	1.35	0	0	0	0	-
Fc3a	5.52	1.65	0	0	0	0	-
Fc3aw	7.68	2.3	3.75	1.125	4.36	1.308	7.8
Fc5	5.28	1.58	0	0	0	0	-
Fc5a	8.04	2.41	0	0	0	0	
Fc5aw	7.84	2.35	4.05	1.216	4.56	1.36	8.24
Fc7	8.24	2.47	0	0	0	0	-
Fc7a	10.08	3.024	0	0	0	0	-
Fc7aw	13.16	4.08	6.84	2.052	8.76	2.62	14.34

Table (4.20) shows that higher values of post crack strength were recorded for the mixes reinforced with WPF, i.e. Fc7aw, Fc5aw and Fc3aw, which have values of 14.34, 8.24 and 7.8 Joule, respectively. It should be noted that this value increases in absorbed energy with greater ratio of length of specimen divided by 600 or 150, L/M for the mixes modified with WPF. This indicates the effect of adding WPF on increasing applied load after cracking [26]. Figures (4.35), (4.36) and (4.37) show that the bearing capacity values of the foamed concrete mixes which were not modified with WPF are lower than those of the WPF reinforced concrete. Based on Table (4.20), it can be concluded that the prisms of higher density have higher peak loads while the prisms fabricated with low foamed concrete densities have the lowest peak load values. The addition of silica fume and fly ash resulted in the formation of a new C S H, which filled a portion of the small voids in the cement paste, while the WPF enhanced the toughness of the mixes.

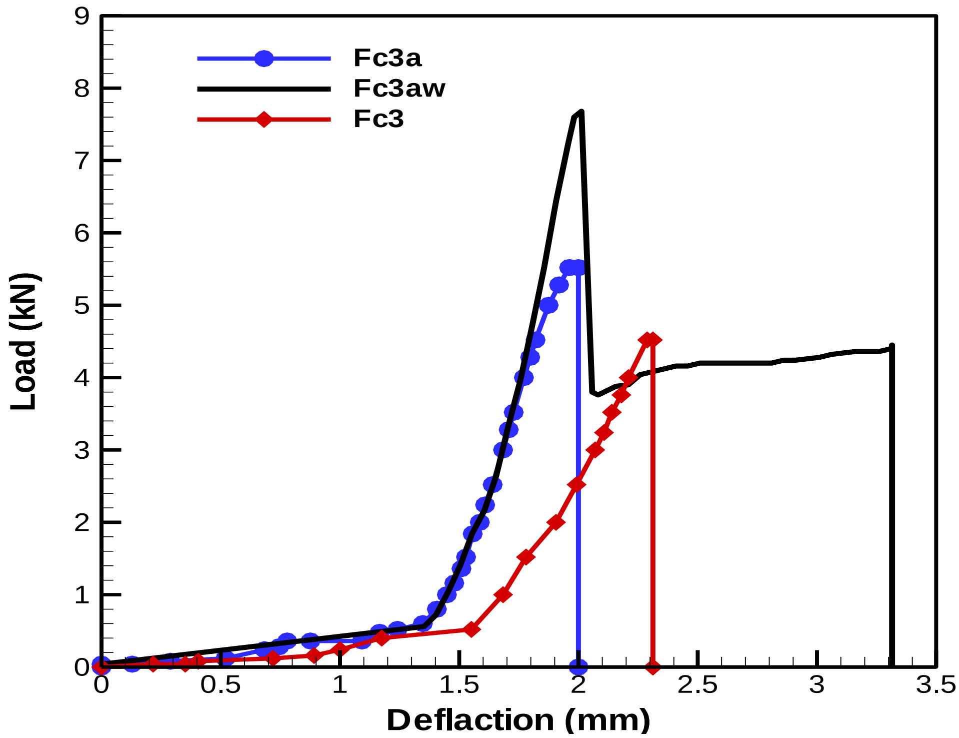


Figure 4.35: Toughness of 1300 kg/m^3 mix

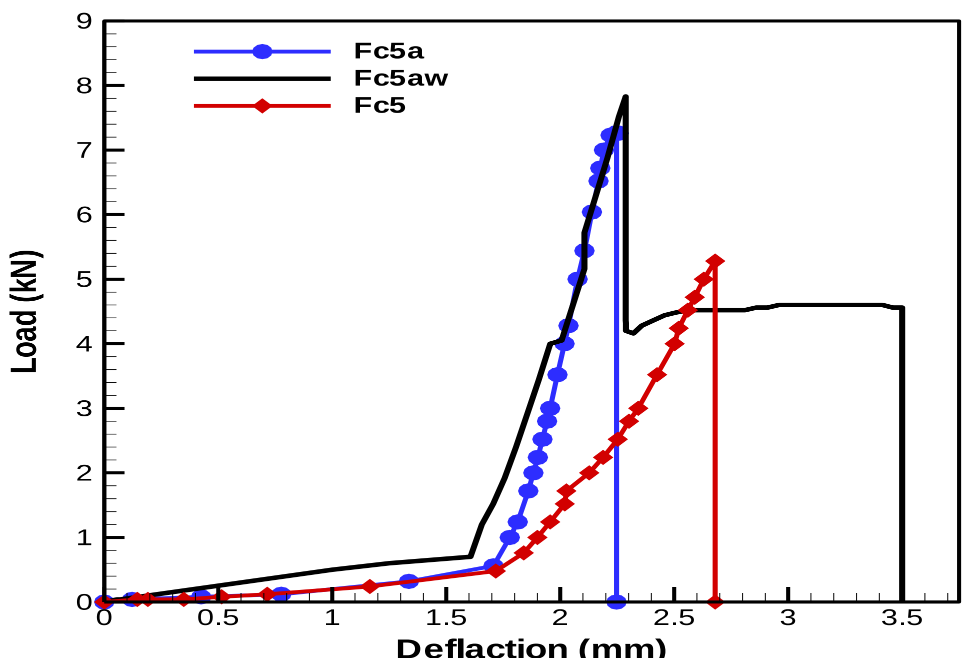


Figure 4.36 Toughness of 1500 kg/m^3 mix.

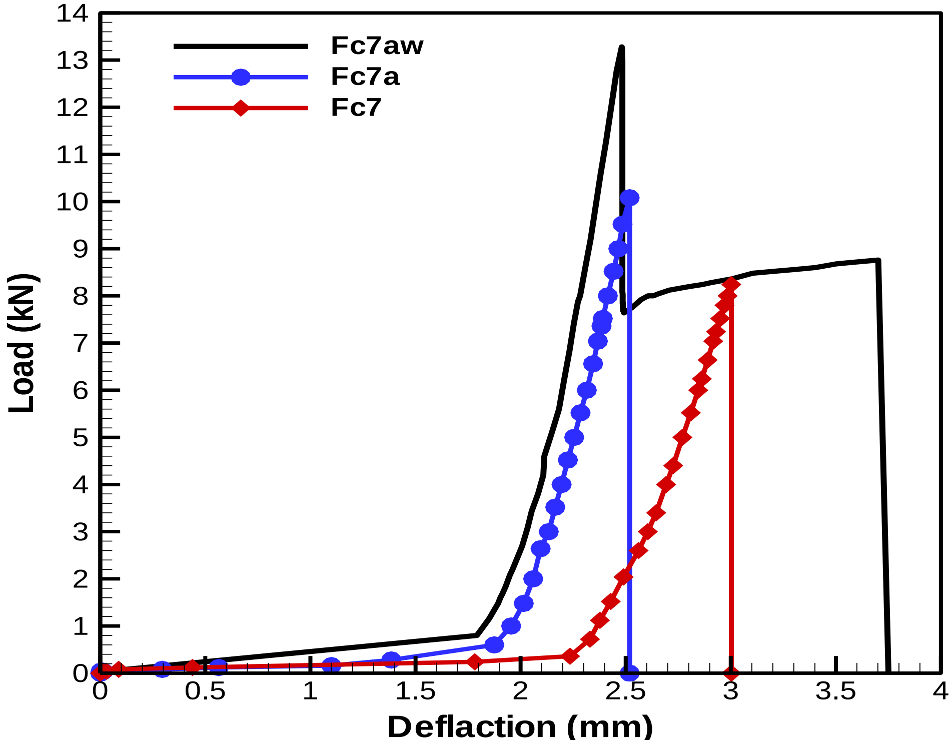


Figure 4.37: Toughness of 1700 kg/m^3 mix

4.7 Ultrasonic pulse Velocity(UPV)

The pulse velocity of specimen of which represented of all mixes were measured according to ASTM C597-09 [188] and the results are given in Table (4.21). Plate (4.6) shows the process of performing the UPV test. Table (4.21) and Figure (4.38) show results of ultrasonic pulse velocity test for all foamed concrete samples. The time taken by the wave to propagate through the cement paste increases due to the presence of voids which show a lower velocity in case of 1300 kg/m^3 mix compared to 1500 kg/m^3 and 1700 kg/m^3 mixes. The wave travels readily through a solid body. Based on Figure (4.38), it can be concluded that for all mixes with the same density, the ultrasonic velocity of mixes modified with fly ash and silica fume (Fca) is higher in comparison to other mixes. The additives forming a new C S H, which filled some of the voids, thereby increasing the density of the cement paste. The velocity decreased when

WPF was added to the same mix The ultrasonic velocities of Fc3aw, Fc5aw, and Fc7aw mixes increased slightely 1.9%, 1.3%, and 2.2%, respectively, in comparison to those of the conventional mixes. On the other hand, the unmodified mixes (Fc) have the lowest velocities due to the presence of large voids which were caused by the high water cement ratio (W/C= 45%). In addition, these mixes did not contain additives that fill some of the voids, and this increases the time taken by the wave to propagate through the mix.

Table (4.21) shows the ultrasonic velocities of conventional mixes, i.e, Fc3, Fc5, and Fc7 are 2.46, 2.642, and 3.08 km/sec, respectively. However, the ultrasonic velocities of mixes modified with additives, i.e. Fc3a, Fc5a, and Fc7a, increased slightely 2.7%, 8.99%, and 8%, respectively, in comparison to those of the conventional mixes.

The higher ultrasonic velocities of Fc7a, Fc5a, and Fc3a in comparison to those of Fc7aw, Fc5aw, and Fc3aw are due to the presence of WPF which reduced the velocity of waves and porosity in comparison to those of the conventional mixes. The results in Table (4.8) are in agreement with those in the case of Effect of Plastic Fibers on Properties of Foamed Concrete [189].

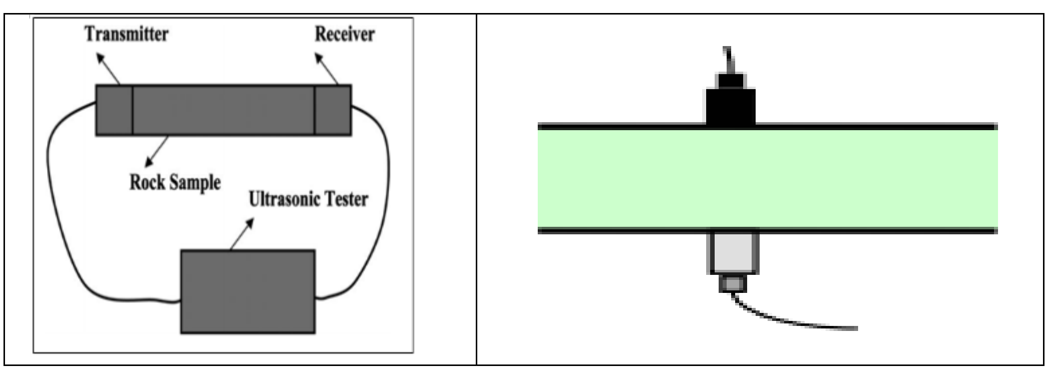


Plate 4-6: Ultrasonic pulse velocity test..

Table 4-21: Ultrasonic velocity test results.

mix	Fc3	Fc3a	Fc3aw	Fc5	Fc5a	Fc5aw	Fc7	Fc7a	Fc7aw
V (kN/Sec)	2.46	2.52	2.50	2.64	2.86	2.67	3.08	3.32	3.14
Increment%	-	2.7	1.9	-	8.59	1.3	-	8	2.2

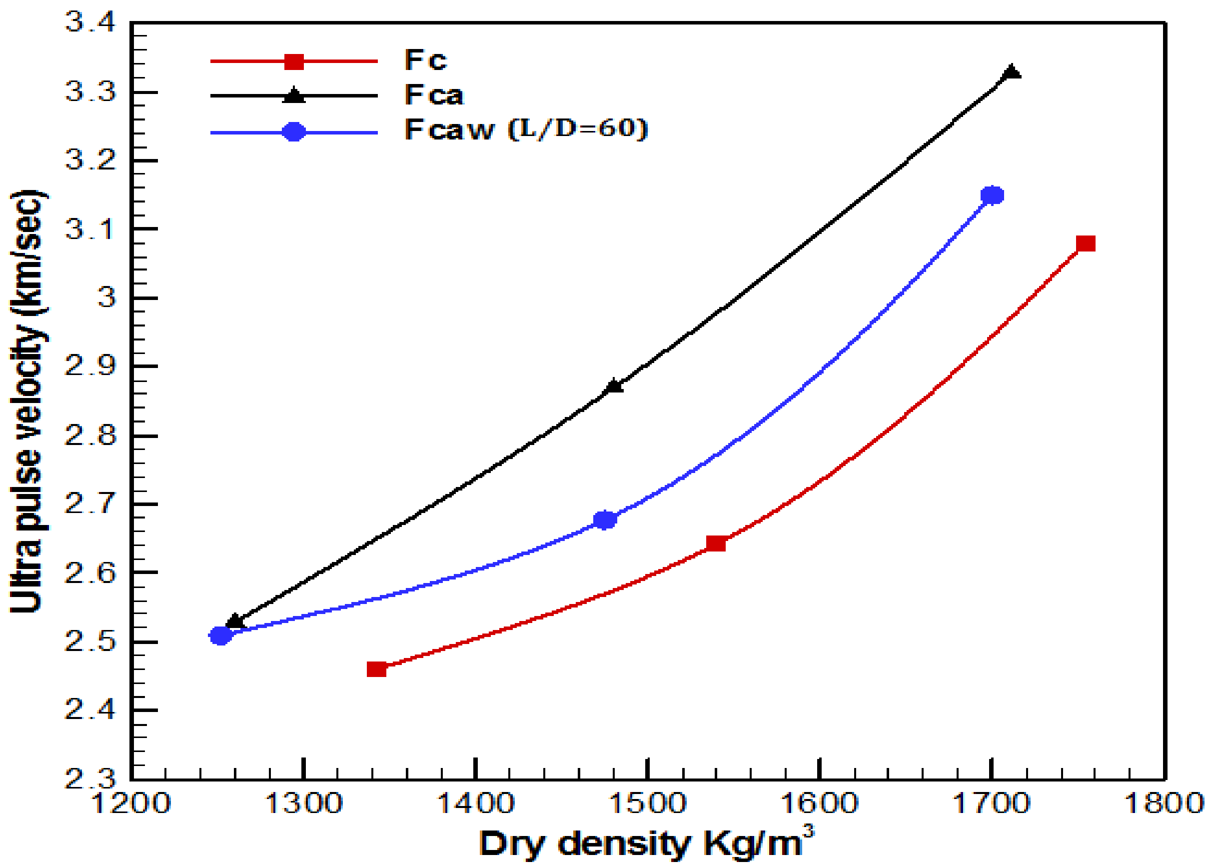


Figure 4.38: Ultrasonic pulse velocity of all investigated mixes.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results of the experiments, the following conclusions can be drawn.

1) The addition of waste plastic fibers (WPF) to foamed concrete generally decreases the dry densities of all investigated mixes by virtue of the WPF having a lower specific gravity than the cement and the sand.
2) The addition of v_f (1%) with L/D=60 resulted in a uniformly distribution of WPF, although the WPF tends to float at high contents of (1%) and low contents of (1%).
3) The consistency of the mixes with the same density can be modified through the addition of additives and WPF. While the addition of foam resulted in a slightly lower consistency in contrast to the unmodified mix. Furthermore, The addition of fly ash and silica fume resulted in higher consistency, which in consequence increased the spread diameter. A addition of WPF resulted in lower consistency. Mixes with higher density (more sand) have lower consistency.
4) For mixes with the same density, the porosity of modified mixes are less than those of the conventional (Fc) and WPF modified mixes (Fcaw). In other hand**,** the absorption of modified mixes (Fca) are lower than those of conventional (Fc) and WPF modified mixes (Fcaw).

5) Mixes with higher densities have higher compressive strength. Since mixes with a particular density (the variable here is the presence or absence of additives and WPF), the mixes modified only with additives (Fca) have the highest compressive strength, followed by the WPF modified mixes (Fcaw) while the unmodified mix (Fc) has the lowest compressive strength**.** For all mixes with all volume fraction, the highest compressive strength was achieved for mixes with L/D=60. The increment of compressive strength for modified mixes1300,1500and 1700 kg/m^3 comparing with conventional mixes fc3,fc5 and fc7 were (108,81)%, (99,81) %, (64.6,50)% for mixes (fc3a,fc3aw), (fc5a,fc5aw), (fc7a,fc7aw) respectively
6) For all mixes with a density of 1500 kg/m^3, the addition of 1% WPF resulted in the highest splitting strength. The mix with a density of 1700 kg/m^3 has the highest splitting strength in contrast to those with densities of 1500 and 1300 kg/m^3.

   For mixes with the same density (the variable is the presence or absence of additives and WPF), the mixes modified with additives and WPF have the highest bending strength. The 1700 kg/m^3 mix has the highest flexural strength in contrast to the mixes of densities of 1300 and 1500 kg/m^3.
7) The mixes modified with additives have the highest modulus of elasticity. The addition of WPF has a minimal effect on modulus of elasticity where only a minimal increase of modulus of elasticity was observed in contrast to the conventional mixes.
8) The addition of WPF resulted in a significant increase in the toughness of the mixes. The Fc7aw mix has the highest toughness, followed by Fc5aw and Fc3aw.

9) For mixes with the same density (the variable is the presence or absence of additives and WPF), the mix modified with additives (Fca) has the highest velocity, followed by the mix modified with WPF(Fcaw) and the unmodified mix. The mix with a density of 1700 kg/m^3 has the highest ultrasonic velocity, followed by the 1500 kg/m^3 and 1300 kg/m^3 mixes.

5.2 Future studies

5.2.1 Investigate the effect of foamed concrete’s properties when different curing methods are used.

5.2.2 Investigate the effect of adding varying volume fractions of additives on the properties of foamed concrete.

5.2.3 Investigate the effect of waste plastic fibers’ shape on the properties of foamed concrete.

5.2.4 Examine the behaviour of foamed concrete when modified with hybrid waste plastic fibers.

5.2.5 Investigate the potential of using this modified foamed concrete as construction units, for instance as blocks or roof tiles.

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APPENDIX A

XRF test of cement

component	Concentration	Concentration %
Na_2O	0.4	0.00617
MgO	0.074	0.0014
Al_2O_3	0.266	0.0041
SiO_2	4.366	0.006
SO_3	1.039	0.01
CaO	54.72	0.84
Fe_2O_3	3.14	0.04
Other symbols are small concenrtation	0.745	

Sum of all concentration (64.75)%

XRF test of Fly Ash.

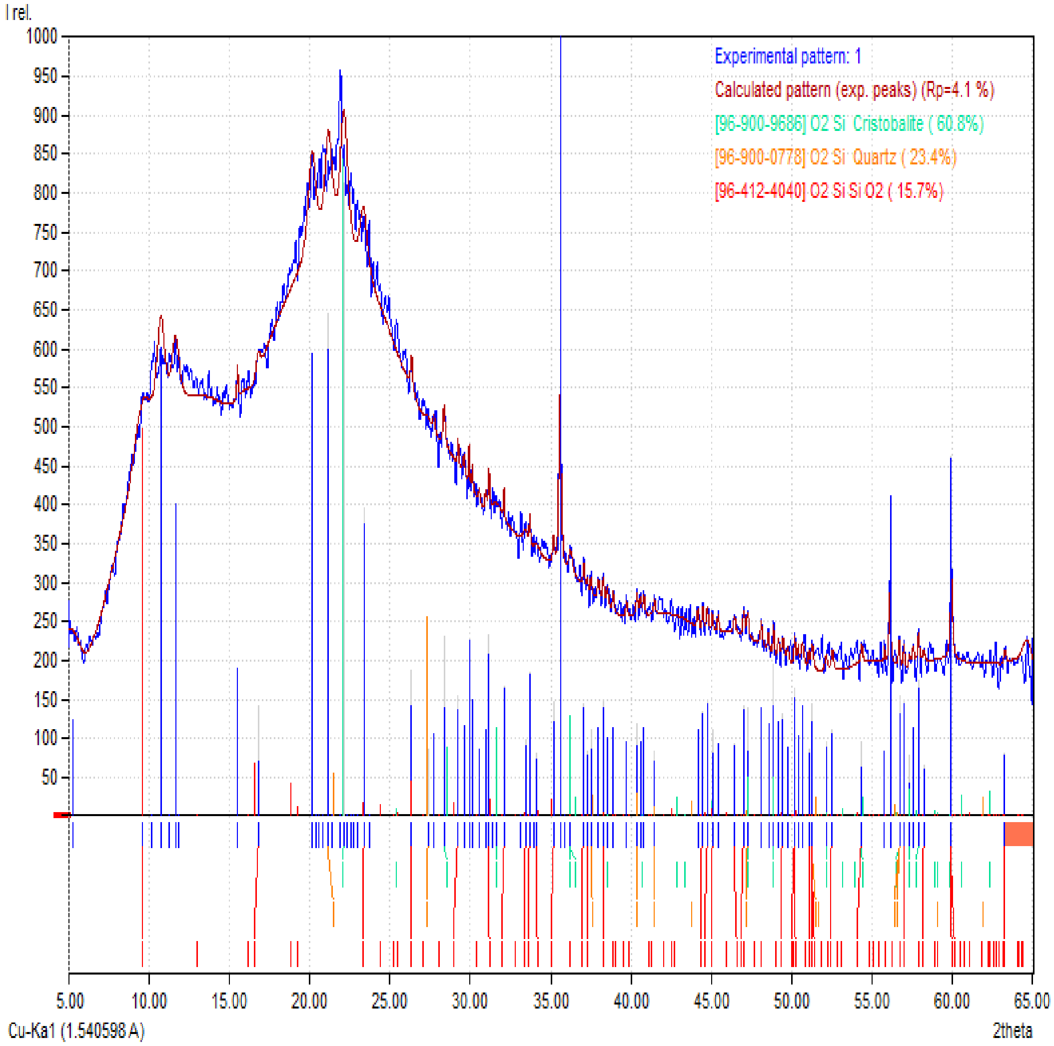
component	Concentration %
Na_2O	0.33
MgO	0.342
Al_2O_3	0.021
SiO_2	21.63
K_2O	1.044
CaO	0.7531
Fe_2O_3	1.4
Other symbols are small concenrtation	1.0669

Total components(26.59)%.

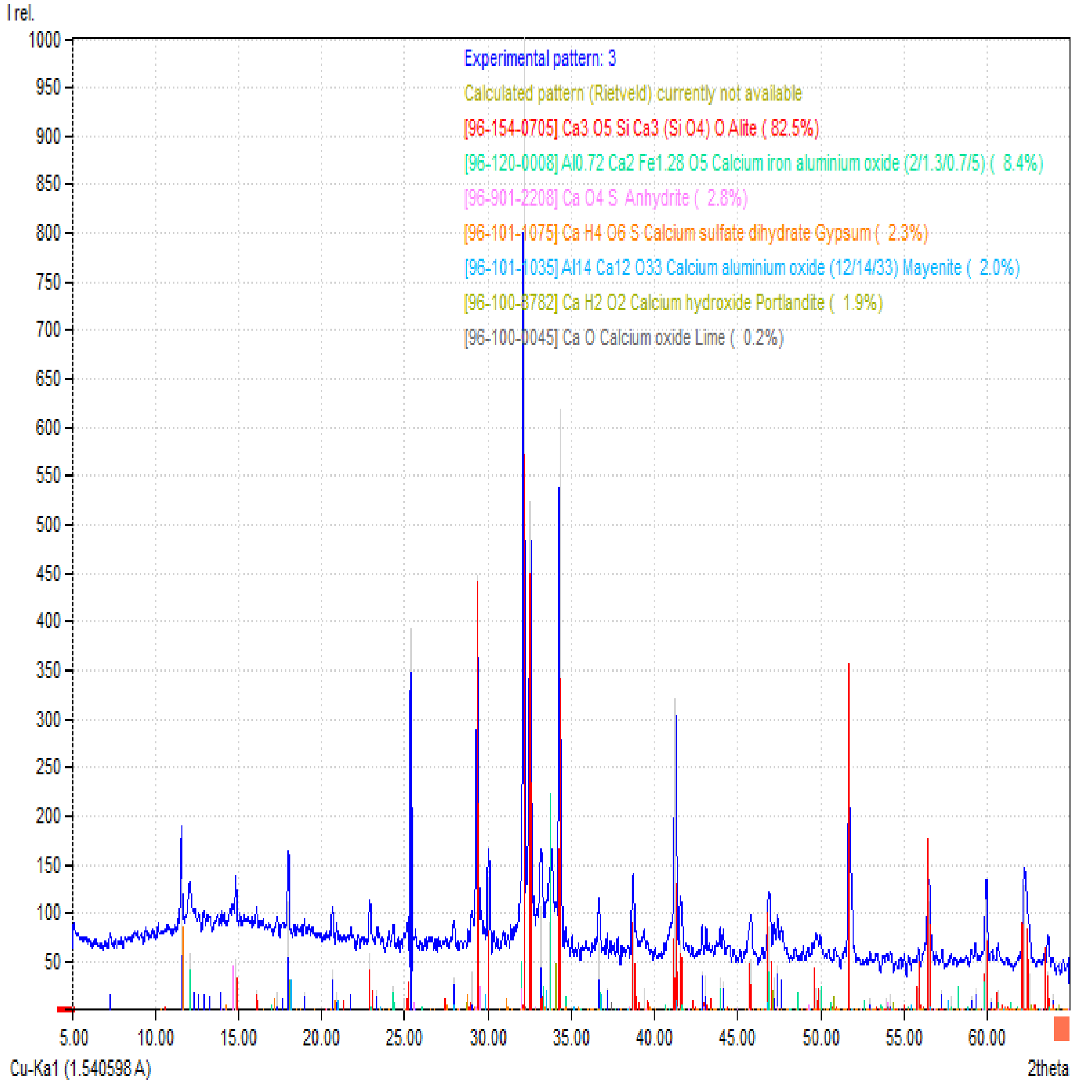
* according to the requirements-of ASTM C618-19((Sio_2+Fe_2o+Al_2o)>70%).

* ((21.63+1.4+0.02)\26.59))=86%, which is more 70%

* Fly ash class F



XRD of silica fume.



XRD of cement.

الخلاصة

الخرسانة الخفيفة الوزن ، هي الخرسانة التي لديها مواصفات خاصة مثل خفة الوزن والعزل الحراري مقارنة بالخرسانة التقليدية .اعادة استخدام البلاستك يكون دور رئيسي في استدامة وادارة الفضلات البلاستيكية ، هذه الدراسة اسست لتحسين خواص خرسانة الفوم باضافة الياف الفضلات البلاستيكية .تم في هذه الدراسة اجراء عدد من الفحوصات لايجاد الخصائص الطرية والصلبة لكثافة 1500 كيلوغرام\م3 للحصول على الخلطة المثلى.تم استخدام نسبة ماء الى رابط ثابتة وهي 35% و350 كيلوغرام\م3 من محتوى السمنت . مسحوق السليكا كنسبة استبدال من السمنت والمادة البوزولانية (الرماد الطيار) صنف (F) 10%و20 % على التوالي و ملدن كنسبة 2% من وزن سمنت. تم اضافة الياف الفضلات البلاستكية بنسب مختلفة (1.75,1.5,1.25,1,0.75,0.5,0.25)% ونسب باعية مختلفة (80,60,40) . اعتمادا على نتائج توزيع الالياف ومقاومة الانضغاط والشد لخلطة 1500 كيلو غرام \م3 وجد ان افضل نسبة باعية قدرها 60 وافضل نسبة الياف 1%. عليه تم اعتماد هذه النسب في انتاج الخلطات لكثافة 1700,1500,1300 كيلوغرام\م3 . فحص القوام تم تنفيذه على كل الكثافات الاسمية 1300,1500,1700 كيلو غرام \م3 لايجاد قطر الانتشار . لتحري تاثير الياف الفضلات البلاستيكية على خصائص الخرسانة الرغوية ،اجريت فحوصات المسامية والامتصاص ومقاومة الانضغاط ومقاومة الانفلاق ومقاومة الانحناء ومعامل مرونة والقساوة باعمار14,7، 28 يوم. كانت نسب الزيادة والنقصان كالاتي : النقصان في المسامية الكلية للخلطات المطورة بالمضافات والالياف 1300و1500و1700 كيلو غرام\م3 بالمقارنة مع الخلطة التقليدية ,Fc7,Fc5,Fc3 وكانت كالاتي (3.7,5.2)%،(2,4.5)%،(5,8.1) لخلطات (Fc3aw,Fc3a)،(Fc5aw,Fc5a)، (Fc7aw, Fc7a) على التوالي . الزيادة في مقاومة الانضغاط في الخلطات المطورة بالمضافات والالياف 1300و1500و1700 كيلو غرام\م3 بالمقارنة مع الخلطة التقليدية , Fc7,Fc5,Fc3 وكانت كالاتي (81,108)% ،(81,99)% ،(50,64) لخلطات (Fc3aw,Fc3a)، (Fc5aw,Fc5a)، (Fc7aw Fc7a,) على التوالي . الزيادة في مقاومة الانفلاق في الخلطات المطورة بالمضافات والالياف 1300 و 1500 و1700 كيلو غرام\م3 بالمقارنة مع الخلطة التقليدية , Fc3, Fc5, Fc7 وكانت كالاتي (132.8,55.1)%، (99.8,74)%، (125.8,85)، لخلطات (Fc3aw,Fc3a) ، (Fc5aw,Fc5a)، (Fc7aw,Fc7a) على التوالي . الزيادة في مقاومة الانحناء في الخلطات المطورة بالمضافات والالياف 1300و 1500و 1700 كيلو غرام\م3 بالمقارنة مع الخلطة التقليدية , Fc7,Fc5,Fc3

وكانت كالاتي (88.4,60.8)% ،(88.4,59.3)%، (125,59.3) لخلطات (Fc3aw,Fc3a)، (Fc5aw Fc5a)، (fc7aw ,fc7a) على التوالي . الزيادة في معامل المرونة في الخلطات المطورة بالمضافات والالياف 1300و 1500و 1700 كيلو غرام\م3 بالمقارنة مع الخلطة التقليدية Fc3 ,Fc5 ,Fc7 وكانت كالاتي (56,410)%، (230,334)%، (120,160) لخلطات (Fc3aw, Fc3a)، (Fc5aw,Fc5a) ،(Fc7aw,Fc7a) على التوالي . ايضا وجد انه القساوة لخلطة Fc7aw هي اعلى من بين كل الخلطات بمقدار 14.34 جول يليه خلطة Fc5aw بمقدار 8.24 جول يليه خلطة Fc3aw بمقدار 7.8جول . النتائج اظهرت ان للالياف والمضافات تاثير ايجابي على الصفات الصلبة ومقاومة الضغط ومعامل مرونة بالمقارنة مع التقليدية وتاثيرا ايجابيا في مجال تحسين خواص الشد بالانشطار والانثناء والقساوة للخلطات ذات المضافات والالياف مقارنة مع الخلطة التقليدية.

جمهوريـــــــــــة العـــــــــراق

وزارة التعليم العالي والبحث العلمي

جامعــة الانـــبار- كلــية الهنــدسة

قســــــم الهنــــــدسة المـدنيـــة

UNIVERSITY OF ANBAR

تقييم إضافة الياف الفضلات البلاستيكية على بعض خواص الخرسانة الرغوية المعدلة

رسالة مقدمة الى مجلس

كلية الهندسة - جامعة الانبار

وهي جزء من متطلبات نيل درجة الماجستير

في علوم الهندسة المدنية

مـن قبـل

نبراس محمود مهيدي المحلاوي

بكالوريوس هندسة مدنية - جامعة الانبار - 1998

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