

**PROPERTIES OF LIGHT WEIGHT CONCRETE
MADE WITH
EXPANDED PERLITE AND PUMICE**

A Thesis submitted in the partial fulfillment of the requirements for the award of the degree of

**MASTER OF ENGINEERING
IN
STRUCTURAL ENGINEERING**

BY
**BHARVI SHARMA
801724007**

UNDER THE SUPERVISION OF

Dr. Prem Pal Bansal
Associate Professor

Mr. Raju Sharma
Lecturer



THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

CIVIL ENGINEERING DEPARTMENT
THAPAR INSTITUTE OF ENGINEERING & TECHNOLOGY
(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

August, 2019

DECLARATION

I, Bharvi Sharma hereby declare that the work presented in this thesis entitled "**Properties of light weight concrete made with expanded perlite and pumice**" in fulfillment of the requirement for the award of degree of **Master of Engineering in Structural Engineering** submitted at Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of **Dr. Prem Pal Bansal, Associate Professor** and **Mr. Raju Sharma, Lecturer, Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala** from July, 2018 to July, 2019. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date: 11/09/19.....


(Bharvi Sharma)
(801724007)

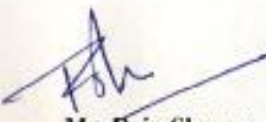
CERTIFICATE

This is to certify that the above declaration made by the student concerned is correct according to the best of my knowledge and belief.

Date: - 11/09/19


Dr. Prem Pal Bansal
Associate Professor

Date: - 11/09/19


Mr. Raju Sharma
Lecturer

ACKNOWLEDGEMENT

This acknowledgment is meant to be credited to all those individuals who were directly or indirectly engaged in my dissertation work.

First of all, I want to convey my gratitude and indebtedness to my Supervisor, Dr. Prem Pal Bansal, Associate Professor and Mr. Raju Sharma, Lecturer, Civil Engineering Department, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala for their profound participation, invaluable and ongoing encouragement throughout this work. I am very grateful to them for always being there whenever I need them.

I prob will not discover enough words to convey my sentiment of gratitude to the entire professors and staff of the Civil Engineering Department of Thapar Institute of Engineering & Technology (Deemed to be University), Patiala for their assistance, encouragement and personal support that helped me to complete my thesis successfully.

The cheerful support of my friend and colleagues is sincerely appreciated. Special words of appreciation go to Mr. Hitesh Bhardwaj, Mr. Manpreet Sidhu, and other laboratory staff, who helped me in my experimental work.

I also acknowledge the support of SAI Lab, TIET, Patiala for Microstructural testing.

Finally, I would like to dedicate this project work to my family members who have always been an excellent source of inspiration and help, particularly in all my academic efforts.

Bhavi
(Bhavi Sharma)

ABSTRACT

In design of concrete structures, light weight concrete plays a prominent role in reducing the density and to increase the thermal insulation. These may relate of both structural integrity & serviceability. More environmental and economical benefits can be achieved if waste materials can be used to replace the fine light weight aggregate. The new sources of structural aggregate which are produced from environmental wastes are natural aggregates, synthetic light weight aggregates. The use of structural grade light weight concrete reduces the self weight and helps to construct larger precast units. Typical lightweight concrete aggregates are expanded clay or shale, expanded perlite, natural porous materials like vermiculite or pumice. Lightweight concrete is made by replacing natural aggregates with lightweight coarse aggregates and fine aggregates. The structural density of normal concrete is 24 KN/m^3 , which is very high, but the density of lightweight concrete varies from 4 KN/m^3 to 22 KN/m^3 . The merits of such materials in LWC are that they are porous in nature. The reduction of material and developing pores are beneficial in reducing dead weight. It is of paramount importance that research on LWC be extended and intensified to incorporate other tests that normally are done on normal concrete. By doing so, the effectiveness of LWC can be compared to normal concrete.

Present research have been carried out by replacing fine aggregates with expanded perlite and pumice aggregates to attain light weight concrete. In this experimental study, various substitutions such as 25%, 50%, 75% and 100% of expanded perlite (EP) and combination of pumice and expanded perlite (PP) with fine aggregates have been done. Properties of fresh concrete like density and workability for each mix entailing expanded perlite and pumice with expanded perlite are evaluated. Compressive, split tensile, flexural strength as well as density, water absorption and total voids volume were determined for 28 days old lightweight concrete samples. Durability properties such as sorptivity, rapid chloride permeability tests are performed. The test result shows an overall strength & weight reduction in various substitutions of fine aggregate with expanded perlite and pumice. Results show that PP mixes are more strong and durable than EP mixes which is due to more compactness of the mix. Microporosity of granules have been observed and visual inspection of their microstructure have been done by using scanning electron microscope (SEM).

TABLE OF CONTENTS

	CONTENT	PAGE NO.
	DECLARATION	i
	CERTIFICATE	ii
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	TABLE OF CONTENTS	v
	LIST OF FIGURES	viii
	LIST OF TABLES	xi
<i>Chapter 1</i>	Introduction	
1.1	Introduction	1
1.2	Lightweight Concrete (LWC)	2
1.3	Guidelines Of Light Weight Concrete	3
1.4	Advantages, Applications And Limitations of LWC	3
1.4.1	Advantages of LWC	3
1.4.2	Application of LWC	4
1.4.3	Limitation of LWC	4
1.5	Production of Light Weight Aggregates	5
1.6	Gaps In The Research Area	5
1.7	Objective of the Dissertation	6
<i>Chapter 2</i>	Literature Review	
2.1	Introduction	7
2.2	Compressive Strength	7
2.3	Split Tensile Strength	14
2.4	Density of Lightweight Concrete	18
2.5	Sorptivity	20
2.6	SEM Analysis of Concrete	20
<i>Chapter 3</i>	Experimental Program	
3.1	Introduction	22
3.2	Material Used	22

3.2.1	Cement	22
3.2.2	Coarse Aggregate	22
3.2.3	Fine Aggregate	23
3.2.4	Expanded Perlite	24
3.2.5	Pumice	26
3.3	Mix Design	27
3.4	Casting and Curing	28
3.5	Laboratory Tests	29
3.5.1	Compressive Strength Test	29
3.5.2	Split Tensile Strength	30
3.5.3	Flexural Strength Test	31
3.5.4	Rapid Chloride Permeability Test (RCPT)	32
3.5.5	Sorptivity Test	34
3.5.6	Density, Absorption, and Void test	35
3.5.7	Scanning Electron Microscope (SEM)	35
<i>Chapter 4</i>	Result and Discussion	
4.1	General	37
4.2	Mechanical Properties	37
4.2.1	Compressive Strength Test	37
4.2.2	Split tensile strength	39
4.2.3	Flexural Strength	40
4.3	Durability Properties	42
4.3.1	Sorptivity	42
4.3.2	Rapid Chloride Permeability Test	43
4.3.3	Density, Absorption, and Percentage of Total Voids	45
4.4	Microstructural Properties	54
4.4.1	SEM OF Normal Concrete (NC)	54
4.4.2	LINE MAPPING OF NORMAL CONCRETE (NC)	54
4.4.3	SEM Of Expanded Perlite (EP1)	57
4.4.4	Line Mapping Of Expanded Perlite (EP1)	57
4.4.5	SEM Of Expanded Perlite (EP4)	60

4.4.6	Line Mapping Of Expanded Perlite (EP4)	60
4.4.7	SEM Of Expanded Perlite & Pumice (PP1)	63
4.4.8	Line Mapping Of Expanded Perlite & Pumice (PP1)	63
4.4.9	SEM Of Expanded Perlite & Pumice (PP4)	66
4.4.10	Line Mapping Of Expanded Perlite & Pumice (PP4)	66
<i>Chapter 5</i>	Conclusions	
5.1	Conclusions	69
5.2	Scope of further work	71
	References	72

LIST OF FIGURES

Fig. No.	Figure Details	Page No.
1.1	Different Types of Concrete	2
2.1	NEPA concrete compressive strength with w/c ratio of 0.5 and 0.7	7
2.2	GEPA concrete compressive strength with w/c ratios of 0.5 and 0.7	8
2.3	Compressive Strength due to Substitution with expanded perlite aggregates(EPA)	8
2.4	Compressive strength of concrete specimens according to EPA ratio and curing conditions	10
2.5	Compression Strength Test at 7 and 28 days	10
2.6	The Results of Compressive strength of PALWC	13
2.7	Graph between A/C and Compressive Strength of Concrete	13
2.8	NEPA concrete flexural tensile strength	14
2.9	GEPA concrete flexural tensile strength	14
2.10	Split Tensile Strength at 7 and 28 Days	16
2.11	Tensile Strength test results of Concrete	18
2.12	NEPA and GEPA Concrete's Oven Dry Density	19
2.13	Expanded perlite filled with aerogel; The gap between expanded perlite and aerogel	21
2.14	Aerogel inside the cementitious material; Aerogel pore structure	21
3.1	Expanded Perlite aggregate	25
3.2	SEM and EDS Analysis of Expanded Perlite (Spectrum 1)	25
3.3	Pumice Aggregates	26
3.4	SEM and EDS Analysis of Pumice (Spectrum 1)	27
3.5	Compressive Strength Test	30
3.6	Split Tensile Strength Test	31
3.7	Flexural Strength Test	32

3.8	Rapid Chloride Permeability Test	33
3.9	Setup for Rapid Chloride Permeability Test	33
3.10	Sorptivity Test	34
3.11	SEM Analysis	36
4.1	Variation in Compressive Strength when EP was added	38
4.2	Variation in Compressive Strength when PP was added	38
4.3	Variation in Split Tensile Strength when EP was added	39
4.4	Variation in Split Tensile Strength when PP was added	40
4.5	Variation in Flexural Strength with EP replacements	41
4.6	Variation in Flexural Strength when PP was added	41
4.7	Variation in Initial Sorptivity value when EP was added	43
4.8	Variation in Initial Sorptivity value when PP was added	43
4.9	Variation in RCPT Results when EP was added	44
4.10	Variation in RCPT Results when EP and PP was added	45
4.11	Variation in Bulk Density with addition of EP	46
4.12	Variation in Bulk Density when PP was added	47
4.13	Variation in Apparent Density when EP was added	48
4.14	Variation in Apparent Density when PP was added	48
4.15	Variation in Absorption with EP replacement	49
4.16	Variation in Absorption when PP was added	50
4.17	Variation in Volume of Permeable Pore Space when Expanded Perlite (EP) was added	51
4.18	Variation in Volume of Permeable Pore Space when Expanded Perlite and Pumice(PP) was added	52
4.19	Variation in Total Void Volume when Expanded Perlite (EP) was added	53
4.20	Variation in Total Void Volume PP was added	53
4.21	SEM image of Normal Concrete(NC) mix	54
4.22	Selected Area of Line Mapping in NC mix	55
4.23	Line Mapping present elements in Normal Concrete (NC) mix	55

4.24	Line Mapping of Normal Concrete(NC) Mix	56
4.25	SEM image of Expanded Perlite(EP1) mix	57
4.26	Selected Area of Line Mapping in EP1 mix	58
4.27	Line Mapping present elements in Expanded Perlite(EP1) mix	58
4.28	Line Mapping of Expanded Perlite(EP1) mix	59
4.29	SEM image of Expanded Perlite(EP4) mix	60
4.30	Selected Area of Line Mapping in EP4 mix	61
4.31	Line Mapping present elements in Expanded Perlite(EP4) mix	61
4.32	Line Mapping of Expanded Perlite (EP4) concrete mix	62
4.33	SEM image of Expanded Perlite and Pumice(PP1) concrete mix	63
4.34	Selected Area of Line Mapping in Expanded Perlite and Pumice(PP1) mix	64
4.35	Line Mapping present elements in Expanded Perlite and Pumice(PP1) mix	64
4.36	Line Mapping of Expanded Perlite and Pumice(PP1) concrete mix	65
4.37	SEM image of Expanded Perlite and Pumice(PP4) concrete mix	66
4.38	Selected Area of Line Mapping in Expanded Perlite and Pumice (PP1) mix	67
4.39	Line Mapping present elements in Expanded Perlite and Pumice(PP4)mix	67
4.40	Line Mapping of Expanded Perlite and Pumice(PP4) mix	68

LIST OF TABLES

Table No.	Table Details	Page No.
2.1	Compressive results of fibrous concrete	9
2.2	Compressive strength after replacing coarse and fine aggregate by Pumice stone	11
2.3	Nomenclature	11
2.4	Compressive strength of various concrete Mixes	12
2.5	Description of Various Mix Proportions	13
2.6	Tensile Strength of various concrete mixes	15
2.7	Tensile Strength of Various Concrete Mixes	17
2.8	Split Tensile Strength	17
2.9	Density of Concrete	19
2.10	Normal Sorptivity and Cracked Sorptivity	20
3.1	Properties of Cement Used	22
3.2	Properties of Coarse Aggregates	23
3.3	Gradation of 10 mm Coarse Aggregate	23
3.4	Gradation of 20 mm Coarse Aggregate	23
3.5	Properties of Fine Aggregates	24
3.6	Gradation of 10 mm Coarse Aggregate	24
3.7	Chemical Composition of Expanded Perlite	26
3.8	Chemical Composition of Pumice	27
3.9	Nomenclature for Various Concrete Mixes	28
3.10	Mix Proportion of Lightweight Concrete	28
3.11	Scheme of Sample Preparation of Lightweight Concrete	29
4.1	Test Results of Compressive Strength (CS) for Lightweight concrete	37
4.2	Test Results of Split Tensile Strength (STS) for LWC	39
4.3	Test Results of Flexural Strength (FS) for Lightweight	40

	concrete	
4.4	Test Results of Sorptivity for Lightweight concrete	42
4.5	Test Results of RCPT for Lightweight concrete	44
4.6	Test Results of Bulk Density for Lightweight concrete	46
4.7	Test Results of Apparent Density for Lightweight concrete	47
4.8	Test Results of Absorption after Immersion and Boiling for Lightweight concrete	48
4.9	Test Results of Volume of Permeable Pore Space for Lightweight concrete	51
4.10	Total Void Volume for Lightweight concrete	52

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

As the world is marching towards its modern days, the development in each and every sector is at its peak. New technologies and research work are being invented with every second. Infrastructure industries are one of the largest growing sectors in which huge sky scrapper type structures with high complexity. Due to this, the consumption of concrete material is sky rocketing. As the concrete comprises of cement, aggregates and water, the demand of these raw materials are near to over exploitation. Cement being the binder material, plays very crucial role in the production of concrete. But there are some serious environmental issues in the process of generation of cement. The cement producing industries have been listed under most polluting firm by the CPCB. The major pollutants which are being emitted from such industries entails Particulate Matter, CO₂, SO₂, and NO₂, etc. The generation of carbon dioxide is at large scale. As from the various sources, it was concluded that the emission of CO₂ from cement production is almost 5% to 6% of the total CO₂ production in the world. This emission has detrimental effects on our eco-system and treats the life of this planet.

Now days, the infrastructures are touching the skies, due to this heavy structural members have to be introduced so that these members can bear the structural load along with the load produced by calamities like earthquake without any failure. In order to fulfill such criteria, the dead weight of the structure becomes very large which has to bear by the bearing soil strata. Due to this reason, the requirement of large footing and large cross-sectional area in the lower portion arises which is a huge problem face by the civil engineers in the modern world. Number of research works and attempts has been carried out in the field of producing light weight concrete. Liang Wang et al. (2018) utilize the expanded perlite filled with aerogel which was new Substitution lightweight material for aggregates while preparing concrete. Different forms of perlites (graded as well as non-graded) were taken and aerogel were introduced into concrete mix one at a time. This new mixed material was used to replaced natural aggregate and mechanical strength as well as thermal conductivity was determined with the help of various tests. Malek Jedidi (2015) experimented on concrete mix while utilization of expanded perlite aggregate (EPA) at different proportions of 0% to 80% by replacing sand and effect was observed on the

strength parameters. With this an attempt has been made to produce lightweight concrete at water cement ratio of 0.7.

1.2. LIGHTWEIGHT CONCRETE (LWC)

Lightweight concrete is made by replacing natural aggregates with lightweight coarse aggregates and fine aggregate. The structural density of normal concrete is 25 KN/m^3 , which is very high, but the structural density of lightweight concrete varies from 9 KN/m^3 to 17 KN/m^3 . Various kinds of lightweight aggregates are utilized in the generation of LWC such as expanded shale, expanded perlite, pumice stone, clay etc. the production of these lightweight aggregates. Sometimes air-cooled blast furnace slag is also used. The merits of such materials in LWC is that they are porous in nature. The reduction of material and developing pores are beneficial in reducing dead weight.

The categorization of lightweight concrete has been done on the basis of the method of production. These are as under:

- With the utilization of highly porous lightweight material having low specific gravity. This type is called as Light-weight Aggregates Concrete.
- With the help of introduction of large pores within the concrete mass. Special care has been done so that difference can be seen between such voids and fine voids. This type is generally known as Aerated or Foamed Concrete.
- This type of concrete is very special as in this type the fine aggregates are missing from the concrete mix. By doing so, the large voids are left behind between coarse aggregates. This type is generally known as No-Fines Concrete.

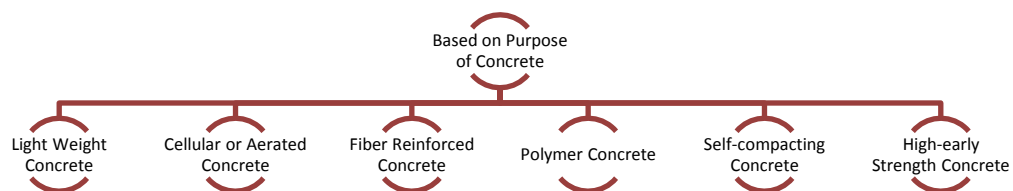


Figure 1.1. Different Types of Concrete.

The categorization of lightweight concrete has been done on the basis of the density and strength. These are as under:

- Low Density concrete: This type of concrete is used when the insulation is to be provided as with the low density around 8 kN/m^3 , heat insulation is very high. But this type of concrete generally has low compressive strength.
- Moderate Strength Concrete: This type of concrete generally has moderate compressive strength.
- Structural Concrete: The reduction of density in such concrete is less when compared to other LWC. As this concrete entails good density, therefore, the compressive strength of this type of concrete is high than other concrete. Expanded shale, clay, slates, slag, fly-ash like substitution materials are used to produce this type of concrete. Since the density of Structural concrete is high, its heat insulation is comparatively low than the others but better than normal weight concrete.

1.3 GUIDELINES OF LIGHT WEIGHT CONCRETE

Light weight concrete mixture is made with light weight coarse aggregates and sometimes a portion or entire fine aggregates may be light weight instead of normal aggregates. Light weight concrete has densities less than 2300 kg/m^3 as compared to normal weight concretes having approx. densities of 2400 kg/m^3 . For structural applications concrete strength should be greater than 17 MPa . Structural light weight concrete provides a more efficient strength to weight ratios in the structural elements.

1.4 ADVANTAGES, APPLICATIONS AND LIMITATIONS OF LWC

1.4.1 Advantages of LWC

As there is a huge need to decrease the structural weight, the various merits of LWC make it even more important. Following are the merits of LWC:

- It has proved to be more economical for transporting cost and labor cost.
- Due to low density of concrete, it can be used as a heat insulation material in walls etc.
- It has led to significant reduction of the dead weight of whole structure in terms of structural weight, footing weight etc.

- By the significant reduction of self-weight, the cost can be reduced as members have to bear light load than Normal Weight Concrete.
- Placing of LWC and construction is easier than the normal weight concrete.
- In the production of lightweight concrete, waste and by-products can be utilized which ultimately reduces the over-exploitation of the raw resources as well and environmental impacts caused by normal weight concrete.

1.4.2 Applications of LWC

Primary use of LWC is the reduction of self-weight of structure, which allows the design engineer to optimize the cross-sectional size of beams and columns, footing, slabs etc. Due to various advantages of LWC, this type of concrete can be used in various situations. Those applications of lightweight concrete are listed below:

- Due to its less dead weight, it can be utilized in composite RCC-steel Structure. Deck slab in steel structures can be constructed with lightweight of concrete.
- Due to its increases heat insulation capacity, it can be used in high temperature areas where normal concrete fails to provide heat insulation.
- LWC is also used in roof repairs, elevated floor slabs or finishing of the existing floor decks.
- LWC is used for locking tiles, curbs, floors, infill-walls, stair steps, etc.

1.4.3 Limitations of LWC

- The rate of carbonation in lightweight concrete is more when compared with the normal weight concrete i.e. the increase in depth within which the corrosion can take place. Insufficient cover will have detrimental effects on concrete structure.
- The design mix is very difficult to obtain as lightweight concrete is sensitive with respect to content of water in concrete.
- Due to porous structure, the ingress of water into the structure is also increased.
- The casting and mixing process becomes difficult and takes longer time than usual.
- Less density of concrete results in reduction in strength and durability.

1.5 PRODUCTION OF LIGHTWEIGHT AGGREGATES

Lightweight aggregate is defined as the aggregate which has dry density lower than the natural aggregates. Variety of lightweight aggregates is available in the market which has different chemical and physical properties. Lightweight aggregates are produced from either raw material or waste or end product of some material. Therefore, it can be produced from:

- **Natural Material:** Natural materials are readily available but the amount of such aggregates is limited depending upon the material. Volcanic Pumice is the most common natural lightweight aggregate which is being used for the production of lightweight concrete.
- **Thermal treatment of natural material:** The process of heating natural material such as clay, slate, shale etc. under its thermal treatment also produces lightweight concrete. Lightweight aggregate like Leca can be produced with this method.
- **Industrial By-Product:** As the utilization of waste production is becoming more and more common in concrete industries, lightweight aggregates are also being produced from the by-products of natural material. Lytag is the waste product of fly ash.
- **Processed Industrial By-Product:** Perlite act as a lightweight aggregate which is produced by processing the industrial by-product pelletized expanded.

1.6 GAPS IN THE RESEARCH AREA

Lightweight concrete has played impeccable role to the construction industry due to its lesser unit weight and higher heat insulation. Vast studies in the area of lightweight concrete have been carried out since 1920s. Major studies have been done by replacing coarse aggregates in the ordinary concrete. These studies shows light weight mixes can be attained considering economical point of view. However by attaining light weight, major properties (mechanical and durability) of the mix were compromised .Some studies also been done by replacing fine aggregates with light weight fine aggregates.

These studies show improved properties with comparatively higher values of unit weight of concrete. Nowadays, researchers are considering usage of two or more lightweight materials in a mix to get durable structural light weight concrete having higher durability, mechanical properties and optimized unit weight of the mix. My research aims to fill this knowledge gap by considering two lightweight aggregates and to analyze the impact on mechanical, durability and

microstructural characteristics of lightweight concrete of different substitutions containing expanded perlite and pumice.

1.7 OBJECTIVE OF THE DISSERTATION

The aim of the present study is to explore the various strength and durability properties of lightweight concrete as a substitution of river sand with expanded perlite and pumice by taking into account the gap in the research area. Following are the objective of the current dissertation:

- To analyze the influence of expanded perlite on concrete at different percentages such as 0%, 25%, 50%, 75% and 100% on properties such as compressive strength, split tensile strength, sorptivity, rapid chloride permeability, density-absorption, and void tests.
- To evaluate the influence of expanded perlite and pumice on concrete at different percentages such as 0%,25%, 50%, 75% and 100% on properties such as compressive strength, split tensile strength, sorptivity, rapid chloride permeability, density-absorption, and void tests.
- To analyze the microstructural property of lightweight structural concrete incorporating expanded perlite and pumice using SEM, EDS, and XRD analysis.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

This section represents the literature of current topic i.e. Lightweight Concrete which has been done in the past decades. Various research works of different researchers were studied in a scrutinized manner to identify the gaps from present study. The literature review was divided into various sections based on the laboratory test performed such as CS test, STS test, Sorptivity, RCPT, SEM etc. on Lightweight concrete. In the production of light weight concrete, different lightweight material like pumice, expanded perlite etc. has been used so that FA and CA can be replaced. The reviewed literature for the present study is discussed in the following sections.

2.2. COMPRESSIVE STRENGTH

Wang et al. (2018) utilizes the expanded perlite filled with aerogel which was new substitution lightweight material for aggregates while preparing concrete. Different forms of perlites (graded as well as non-graded) were taken and aerogel were introduced into concrete mix one at a time. This new mixed material was used to replaced natural aggregate and mechanical strength as well as thermal conductivity was determined with various tests. The results showed that these parameters decreased as the percentage of new material increases. The concrete mix was prepared with 2 w/c ratio i.e. 0.5 and 0.7 so that the behaviour of concrete can be noticed with the change of w/c ratio. The effect of aerogel was also studied in concrete. The results showed that the strength in compression of concrete having 100% well graded EP entailing aerogel is 3.71 MPa and thermal conductivity was found out to be 0.098 W/(m K).

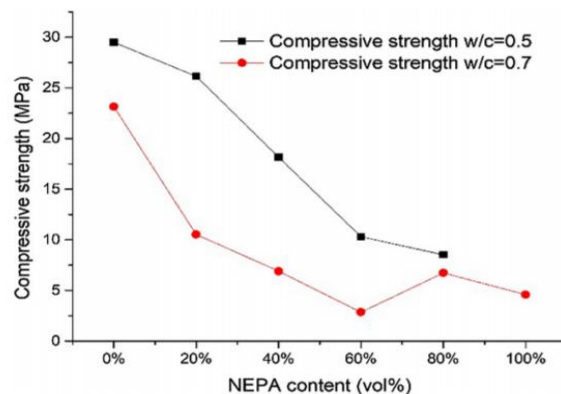


Figure 2.1. NEPA concrete compressive strength with w/c ratio of 0.5 and 0.7. (Wang et al. 2018)

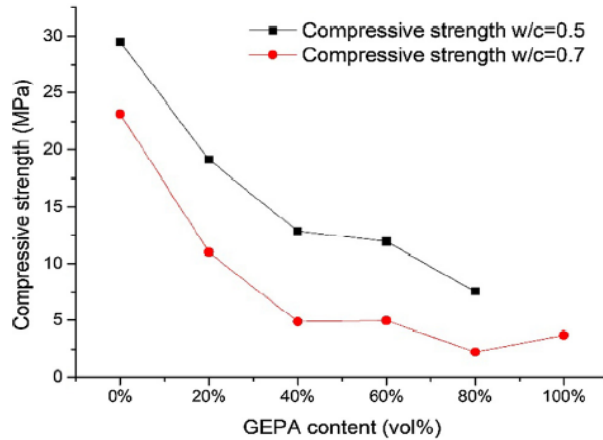


Figure 2.2. GEPA concrete compressive strength with w/c ratios of 0.5 and 0.7. (Wang et al. 2018)

No matter what the w/c ratio is, compressive strength decreases as the proportions of NEPA (Non-graded expanded perlite filled with aerogel) and NEPA (Graded expanded perlite filled with aerogel) increases. But comparing the results of w/c 0.5 and 0.7, the compressive strength of concrete was higher with w/c ratio of 0.5 than w/c ratio of 0.7.

Malek Jedidi (2015) experimented on concrete mix while utilization of expanded perlite aggregate (EPA) at different proportions of 0% to 80% by replacing sand and effect was observed on the strength parameters. This way the production of lightweight concrete at water cement ratio of 0.7 is done. Special care has been given to mixing procedures in order to produce good concrete mix. Compressive strength was decreased when perlite content was increased.

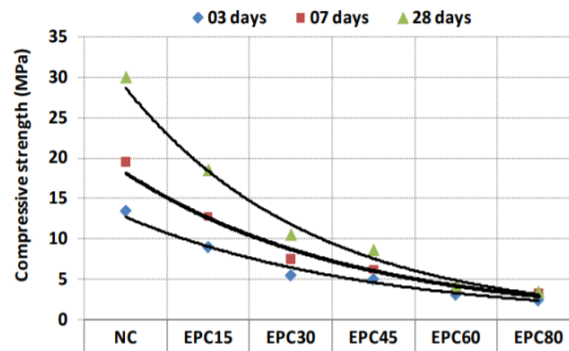


Figure 2.3. Compressive Strength due to Substitution with Expanded Perlite (EPA). (Malek Jedidi, 2015)

The compressive strength result's revealed that its values, at all the curing period, decreases as the proportion of EPA increase from 0 % to 80%. As for the maximum value of CS, it was found out to be for normal concrete i.e. 30MPa. And at the Substitution of natural aggregates with 80% EPA, the value of CS was only 3.4 MPa.

Khonsari et al. (2010) studied the effect of Expanded Perlite (EP) as a Substitution material to aggregates. In current work, the author uses expanded perlite at varying proportions (5%, 10%, 15%, 20%, 30%, and 40%) was utilized for the production of Lightweight concrete. After obtaining various mixes, CS test was conducted at 7 and 28 days with 2 different curing conditions. 2.5% of super-plasticizer was also used.

Table 2.1. Compressive results of Fibrous concrete (*Khonsari et al. 2010*)

Mixtures	Compressive Strength (MPa)				
	7 days	28 days (cubes)			28 days
	Water	Wet Sack	Water	Sulfate	(Cylinder)
EPA0	28.6	41.9	46.7	44.5	38.2
EPA5	29.4	46.9	44.8	42.0	37.9
EPA10	23.3	40.4	38.5	37.0	30.4
EPA15	18.7	38.2	37.0	34.7	31.1
EPA20	15.1	28.3	26.9	23.9	22.9
EPA30	8.6	17.0	15.6	13.4	13.1
EPA40	5.1	9.8	8.5	7.1	7.1

The results of CS has been recorded and it was observed that it was decreased 20% for EPA10, 24% for EPA15, 40% for EPA20, 65% for EPA30. As the proportion of perlite increases, the CS of concrete decreases up to 20% for cylinder and 80% for EPA40. The CS of cylinder was observed less than the compressive strength of cubes.

Turkmen et al. (2007) investigated the concept of self-compacting concrete when the expanded perlite aggregates and nature aggregates were mixed at various proportions. The mixture of cement and silica fumes were added at fixed proportions at 450kg/m³ and 2% super-plasticizers were added. After scrutinizing the results of various mixes, it was observed that the porosity along with the capillarity coefficient of SSC was increased with the use of EPA. But with the increase of EPA proportion, compressive strength decreases. It was observed that the values of CS vary from 53.9Mpa to 38.3 MPa. I was also noticed that the lowest value was found out in EPA15 when cured in CC4 curing condition after 28 days whereas; the highest value belongs to the EPA0 when cured in CC1 curing condition.

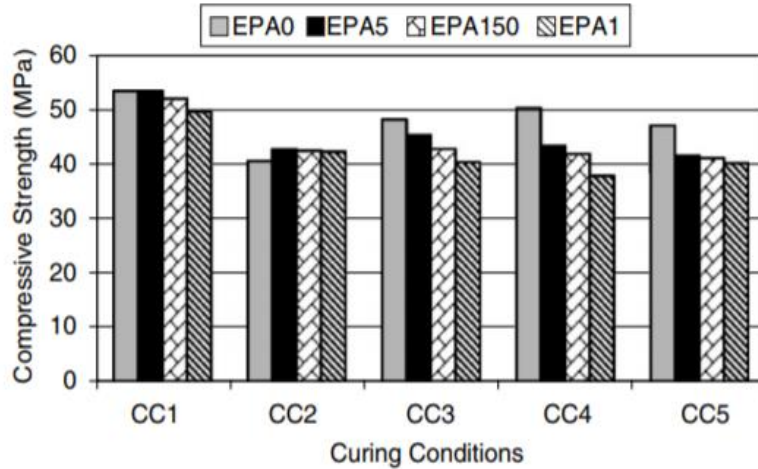


Figure 2.4. Compressive strength of concrete specimens according to EPA ratio and curing conditions. (Turkmen et al. 2007)

Lakshmi et al. (2017) experimented on special concrete like lightweight concrete while adding pumice aggregate to the mix. The conventional aggregate has the biggest disadvantage i.e. high density due to heavy natural aggregates. Due to this, heavy structural members are required and become uneconomical. The low density of lightweight concrete drastically reduces the weight of its own and results in enhanced thermal insulation. In current study, conventional concrete and lightweight concrete of grade M30 was compared by using the poly carboxyl ether admixture. The natural coarse aggregates were substituted with pumice at varying percentage from 20% to 100%. It was observed that at 0% substitution with pumice aggregates, the CS was found out to be the maximum from all the concrete mixes. But with the increase in the proportion of pumice aggregates, the CS tends to decrease till the Substitution is done at 100%.

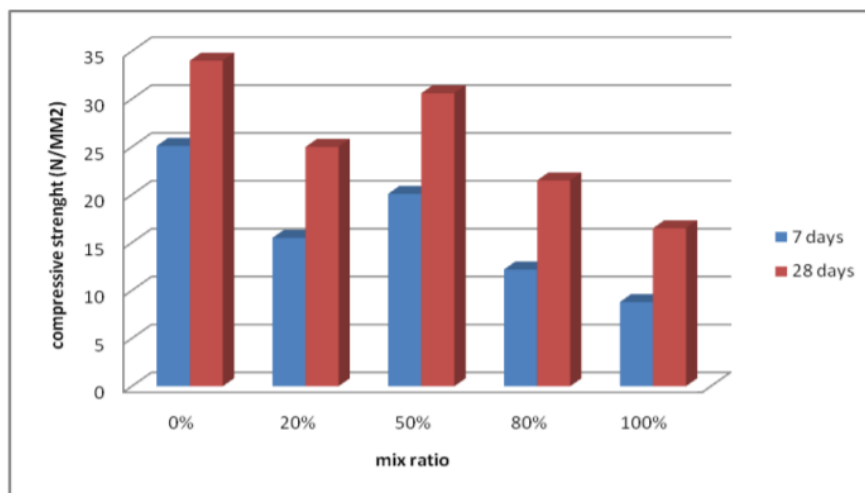


Figure 2.5. Compression Strength test at 7 and 28 days. (Lakshmi et al. 2017)

Bhavana (2017) took an experimental research on lightweight concrete by replacing natural aggregates with pumice stone, ceramic tiles and light weight brick wastes as they all have different properties. The Substitution was done at varying percentage of 10%, 20% and 30% and both the aggregates i.e. coarse and fine aggregates were replaced with these Substitution materials individually. For present study, M20 grade of concrete was prepared and compressive strength was determined.

From the above mentioned results, it was clearly seen that when the fine aggregates were replaced by pumice stone, then better compressive strength results were obtained than that of concrete in which coarse aggregates were replaced. As the percentage of substitution increases, the CS tends to decrease for both the cases i.e. coarse and fine aggregates Substitution.

Table: 2.2. Compressive strength after replacing coarse and fine aggregate by Pumice stone. (*Bhavana 2017*)

Designation	Compressive Strength (MPa)		
	7 Days	14 Days	28 Days
M20 (10% PC)	12.87	14.74	23.50
M20 (20% PC)	11.50	13.68	21
M20 (30% PC)	10.9	12.93	17.98
M20 (10% PF)	14.00	19.50	24.5
M20 (20% PF)	12.50	16.00	23
M20 (30% PF)	10.50	14.00	22.50

Kurt et al. (2016) analyze the effect of pumice powder and pumice aggregates in self-compacting lightweight concrete on various physical and mechanical properties. Along with this, the effect of varying water to binder (cement + mineral) ratio was determined. Substitution of aggregates was done at 0%, 20%, 40%, 60%, 80%, and 100%.

Table 2.3. Nomenclature. (*Kurt et al. 2016*)

Designation	Description
CS	Control sample
PP1	100% Pumice Aggregate and Pumice powder as mineral admixture, $w/(c+m)= 0.35$
PP2	100% Pumice Aggregate and Pumice powder as mineral admixture, $w/(c+m)= 0.40$
PP3	100% Pumice Aggregate and Pumice powder as mineral admixture, $w/(c+m)= 0.45$

Table: 2.4. Compressive strength of various concrete Mixes. (*Kurt et al. 2016*)

MA %	W/(c+m)	MIX	Compressive Strength (MPa)			
			7 Days	28 Days	90 Days	180 Days
0	0.35	CS1	11.8	13.9	14.4	15.5
	0.40	CS2	10.3	12.7	13.1	14.3
	0.45	CS3	8.8	10.6	11.9	12.3
20	0.35	PP1	9.3	13.2	14.5	15.3
	0.40	PP2	8.2	11.7	12.9	13.6
	0.45	PP3	7.2	10.7	11.1	11.7
30	0.35	PP4	8.7	12.5	13.8	14.5
	0.40	PP5	7.8	11.4	12.6	13.2
	0.45	PP6	7.1	10.5	11.5	12.1
40	0.35	PP7	8.1	12.3	13.5	14.3
	0.40	PP8	7.2	11.5	12.6	13.3
	0.45	PP9	7.1	10.5	11.6	12.2

With the increase in miner admixtures i.e. pumice powder, the compressive strength decreases and same criteria was seen when the water to binder (cement + mineral) ratio increases. Maximum compressive strength was achieved when the 0% Substitution is done.

Gunduz (2008) Lightweight concretes production can be done by utilization of waste natural material, low density material. The author studied the usage of pumice which acts as a lightweight aggregate in the production of lightweight concrete. Therefore, pumice aggregate lightweight concrete (PALWC) blocks were prepared having different size of coarse pumice aggregates CPA (ranging from 8mm to 16 mm), medium pumice aggregate MPA (ranging from 4 mm to 8mm) and fine pumice aggregate FPA (ranging from 0 to 4 mm). At first, 25% FPA, 25% MPA and 50% CPA was added to the concrete mix. The different aggregate to cement ratio (A/C) for the concrete mix was taken i.e. 6:1, 8:1, 10:1, 15:1, 20:1, 25:1 and 30:1 by weight.

Table: 2.5. Description of Various Mix Proportions. (Gunduz 2008)

Mixtur e	A/C	C (kg/m ³)	FPA (kg/m ³)	MPA (kg/m ³)	CPA (kg/m ³)	Water (kg/m ³)	W/C
M1	6:1	180	270	270	540	158	0.88
M2	8:1	137	274	274	548	161	1.18
M3	10:1	110	274	274	548	163	1.49
M4	15:1	72	268	268	536	165	2.31
M5	20:1	52	260	260	520	167	3.21
M6	25:1	40	250	250	500	170	4.25
M7	30:1	32	236	3\236	473	172	5.46

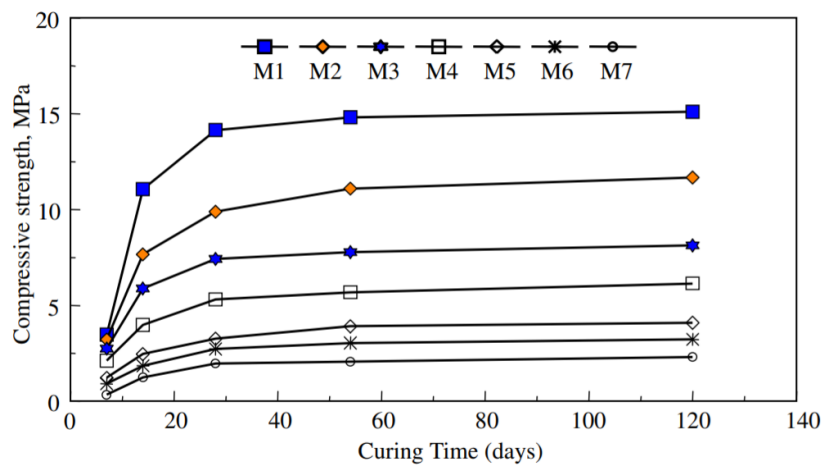


Figure 2.6. The Results of Compressive strength of PALWC. (Gunduz 2008)

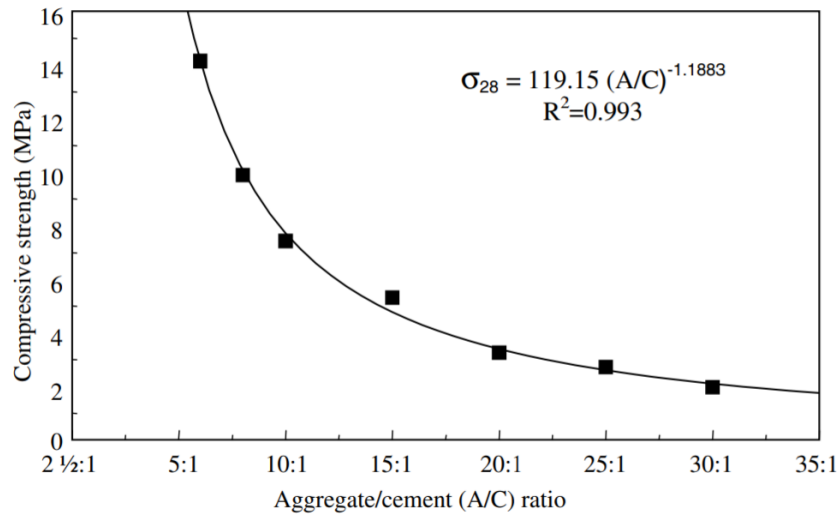


Figure 2.7. Graph between A/C and Compressive Strength of Concrete. (Gunduz 2008)

2.3 TENSILE STRENGTH

Wang et al. (2018) utilizes the expanded perlite filled with aerogel which was new Substitution lightweight material for aggregates while preparing concrete. Different forms of perlites (graded as well as non-graded) were taken and aerogel were introduced into concrete mix one at a time. This new mixed material was used to replaced natural aggregate and mechanical strength as well as thermal conductivity was determined with various tests. The results showed that these parameters decreased as the percentage of new material increases. The concrete mix was prepared with 2 w/c ratio i.e. 0.5 and 0.7 so that the behaviour of concrete can be noticed with the change of w/c ratio. The effect of aerogel was also studied in concrete.

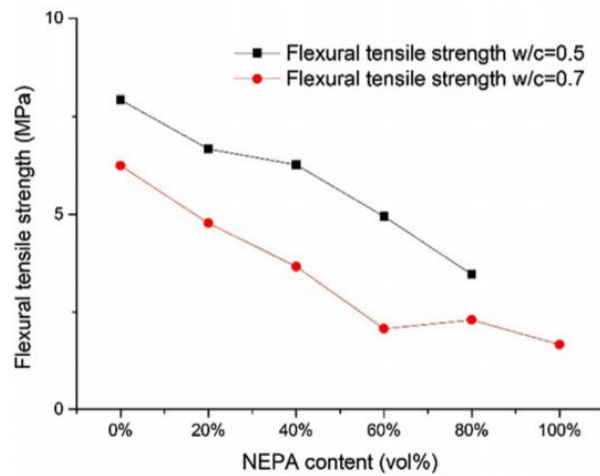


Figure 2.8. NEPA concrete flexural tensile strength. (Wang et al. 2018)

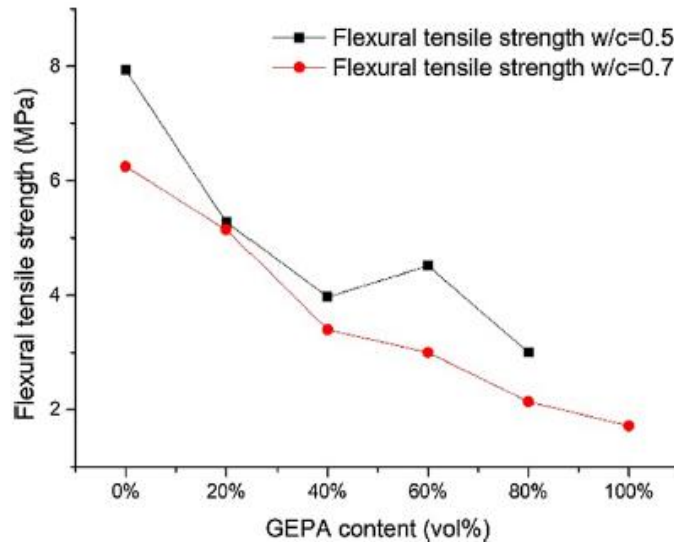


Figure 2.9. GEPA concrete flexural tensile strength. (Wang et al. 2018)

From the results of flexural strength, that with the increase in the proportion of expanded perlite, the flexural strength in both the cases (i.e. NEPA and GEPA) decreases. And concrete with W/C= 0.5 showed higher flexural strength than concrete with W/C=0.7.

Khonsari et al. (2010) studied the effect of Expanded Perlite (EP) as a substitution material to aggregates. In current work, the author uses expanded perlite at varying proportions (5%, 10%, 15%, 20%, 30%, and 40%) in order to produce lightweight concrete. After obtaining various mixes, the tensile strength test was conducted. Total 7 concrete mixes were prepared with the various proportions of Expanded Perlite.

Table: 2.6. Tensile Strength of various concrete mixes. (*Khonsari et al.(2010)*)

Mixture	Tensile Strength (MPa)
EPA0	2.19
EPA5	1.84
EPA10	1.62
EPA15	1.32
EPA20	1.12
EPA30	0.85
EPA40	0.71

The results showed similar pattern to that of compressive strength. The addition of expanded perlite leads to the steep decrease in splitting tensile strength. The percentage reduction for various concrete mixes i.e. EPA5, EPA10, EPA15, EPA20, EPA30, and EPA40 was 16%, 26%, 40%, 49%, 61%, and 68% respectively.

Lakshmi et al. (2017) experimented on special concrete like lightweight concrete while adding pumice aggregate to the mix. The conventional aggregate has the biggest disadvantage i.e. high density due to heavy natural aggregates. Due to this, heavy structural members are required and become uneconomical. The low density of lightweight concrete drastically decreases the self-weight and results in enhanced thermal insulation. In current study, conventional concrete and lightweight concrete of grade M30 was compared by using the poly

carboxyl ether admixture. The natural coarse aggregates were substituted with pumice aggregates at varying % from 20% to 100%.

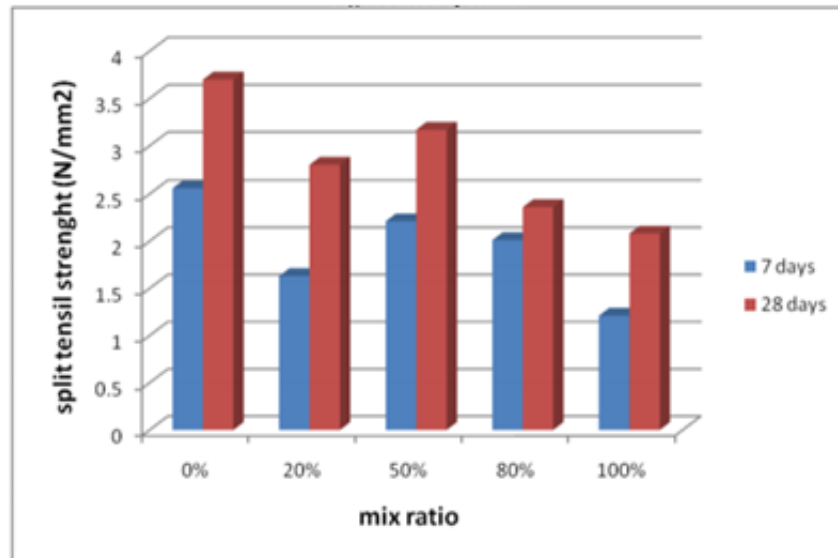


Figure 2.10. Split Tensile Strength at 7 and 28 Days. (Lakshmi et al. 2017)

The results have been represented in the above figure and it can be concluded that when the % of pumice aggregates increases, the TS of lightweight concrete decreases. This decrease in strength was gradual.

Bhavana et al. (2017) investigated on lightweight concrete by substituting natural aggregates with pumice stone, ceramic tiles and light weight brick wastes as they all have different properties. The Substitution was done at varying percentage of 10%, 20% and 30% and both the aggregates i.e. coarse and fine aggregates were replaced with these Substitution materials individually. After preparing respective mixes, the mechanical properties of lightweight concrete were calculated. For present study, M20 concrete was casted and CS was calculated.

When the % of pumice aggregates increases, both the tensile strengths (split as well as flexural) decreases. The values of maximum STS and FS were 2.52 MPa and 3.40 MPa respectively and it was observed when the fine aggregate was substituted by pumice aggregates. When coarse aggregate was substituted 10%, total decrease of 34.31% and 7% was observed in STS and FS respectively. When fine aggregate was replaced 10%, total decrease of 21.77% and 6.31% was observed in STS and FS respectively.

Table: 2.7. Tensile Strength of Various Concrete Mixes. (*Bhavana et al. 2017*)

Designation	Tensile Strength (MPa)			Flexural Strength (MPa)		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
M20 (10% PC)	2.09	1.99	1.78	3.20	3.00	2.80
M20 (20% PC)	1.98	1.68	1.63	2.95	2.73	2.60
M20 (30% PC)	1.88	1.56	1.45	2.85	2.63	2.54
M20 (10% PF)	2.52	2.36	2.12	3.40	3.33	3.20
M20 (20% PF)	2.46	2.22	1.83	3.38	3.22	3.10
M20 (30% PF)	2.38	2.12	1.73	3.15	3.12	3.08

Kurt (2016) analyze the effect of pumice powder and pumice aggregates in self-compacting lightweight concrete on various physical and mechanical properties. Along with this, the consequence of varying water to binder (cement + mineral) ratio was determined. Therefore, 24 concrete mix samples were casted in 2 different groups. Substitution of aggregates was done at 0%, 20%, 40%, 60%, 80%, and 100%.

Table: 2.8. Split Tensile Strength. (*Kurt 2016*)

MA %	W/(c+m)	MIX	STS (MPA)
0	0.35	CS1	1.9
	0.40	CS2	1.9
	0.45	CS3	1.7
20	0.35	PP1	1.9
	0.40	PP2	1.8
	0.45	PP3	1.7
30	0.35	PP4	1.8
	0.40	PP5	1.8
	0.45	PP6	1.7
40	0.35	PP7	1.8
	0.40	PP8	1.8
	0.45	PP9	1.7

Again, same criteria was seen for STS as that of CS. With the increase in percentage of mineral admixture and water to binder ratio, the tensile strength decreases.

Minapu et al. (2014) attempted to study the various properties of lightweight concrete of grade M30. The utilization of Pumice stone (lightweight aggregate) was done in order to partial replace the coarse aggregate. Mineral admixture materials such as fly ash and silica fumes were also added to the concrete.

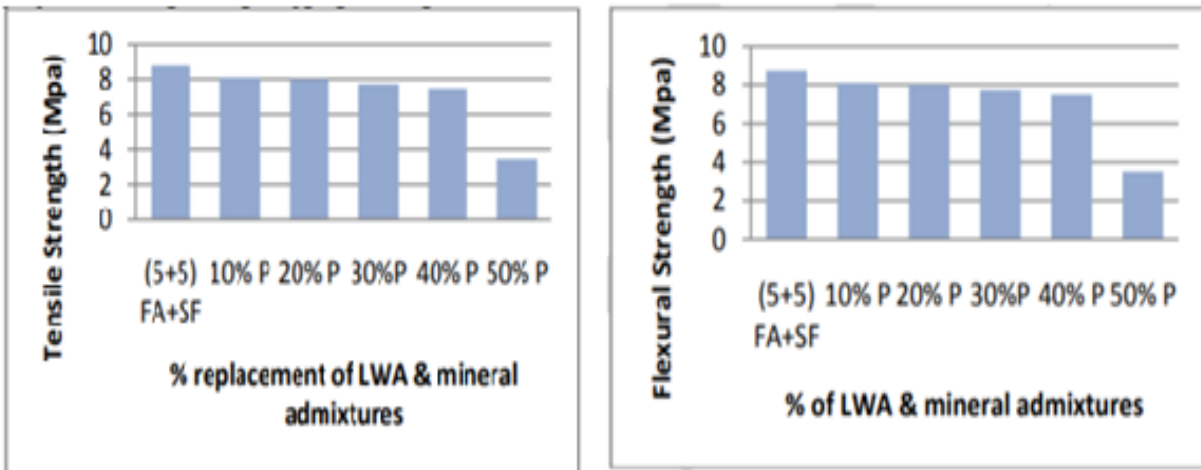


Figure 2.11. Tensile Strength test results of Concrete. (Minapu et al. 2014)

2.4. DENSITY OF LIGHTWEIGHT CONCRETE

Wang et al. (2018) utilizes the expanded perlite filled with aerogel which was new Substitution lightweight material for aggregates while preparing concrete. Different forms of perlites (graded as well as non-graded) were taken and aerogel were introduced into concrete mix one at a time. This new mixed material was used to replaced natural aggregate and mechanical strength as well as thermal conductivity was determined with different tests. The results showed that these parameters decreased as the % of new material increases. The concrete mix was prepared with 2 w/c ratio i.e. 0.5 and 0.7 so that the behaviour of concrete can be noticed with the change of w/c ratio. The effect of aerogel was also studied in concrete.

The density was satisfactorily decreases as the % of EP increases. When the w/c is 0.5, then at same volume content of NEPA/ GEPA, the NEPA density was higher than the GEPA density. When the w/c is 0.7, the GEPA density was lower than the NEPA density

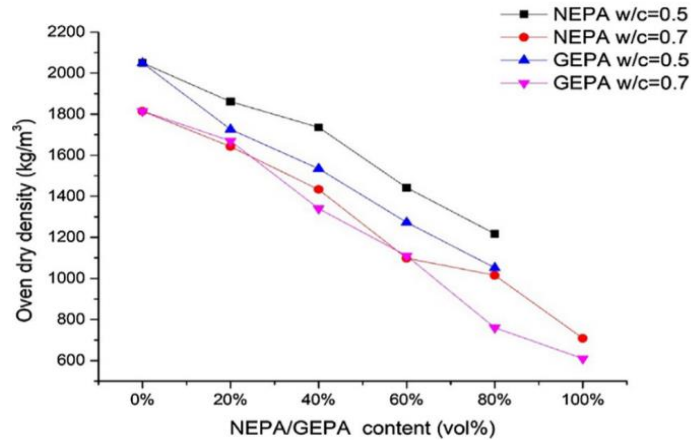


Figure 2.12. NEPA and GEPA Concrete's Oven Dry Density. (Wang et al. 2018)

Bhavana et al. (2017) investigated the lightweight concrete by substituting natural aggregates with pumice stone, ceramic tiles and light weight brick wastes as they all have different properties. The substitution was done at varying percentage of 10%, 20% and 30% and both the aggregates i.e. coarse and fine aggregates were replaced with these substitution materials individually. After preparing respective mixes, the mechanical properties were determined. For present study, M20 grade of concrete was prepared and compressive strength was determined.

Table: 2.9. Density of Concrete. (Bhavana et al. 2017)

Designation	Density of concrete		
	7 Days	14 Days	28 Days
M20 (10% PC)	2400	2365	2330
M20 (20% PC)	2230	2175	2080
M20 (30% PC)	1985	1960	1925
M20 (10% PF)	2320	2375	2410
M20 (20% PF)	2395	2340	2290
M20 (30% PF)	2295	2240	2180

When the coarse aggregate was replaced with pumice aggregates, the lowest dry density was 1925 at 30% Substitution. But when the fine aggregate was replaced by pumice aggregates, the lowest dry density was 2180 at 30% Substitution.

2.5. SORPTIVITY

Khonsari et al. (2010) studied the effect of Expanded Perlite (EP) as a substitution material to aggregates. In current work, the author uses expanded perlite at varying proportions (5%, 10%, 15%, 20%, 30%, and 40%) in order to produce Lightweight concrete. After obtaining various mixes, the tensile strength test was conducted. Total 7 concrete mixes were prepared with the various proportions of Expanded Perlite.

Table: 2.10. Normal Sorptivity and Cracked Sorptivity. (*Khonsari et al. 2010*)

Mixture	Normal Sorptivity (%)	Cracked Sorptivity (%)
EPA 0	1.25	1.44
EPA 5	2.98	3.58
EPA 10	4.07	5.96
EPA 15	6.23	9.58
EPA 20	7.17	11.88
EPA 30	9.01	15.44
EPA 40	10.56	18.58

The test results of sorptivity were represented in the figure above. From the results, it can be concluded that the % of sorptivity increases as the percentage of expanded perlite aggregate increases. Maximum value of normal sorptivity was 10.56% and for cracked sorptivity was 18.58%. Therefore, more sorptivity was observed for cracked case.

2.6 SEM ANALYSIS OF CONCRETE

Liu et al. (2018) utilizes the expanded perlite filled with aerogel which was new substitution lightweight material for aggregates while preparing concrete. Different forms of perlites (graded as well as non-graded) were taken and aerogel were introduced into concrete mix one at a time. This new mixed material was used to replaced natural aggregate and mechanical strength as well as thermal conductivity was determined with different tests. The results showed that these parameters decreased as the percentage of new material increases. The concrete mix was prepared with two w/c ratios i.e. 0.5 and 0.7 so that the behaviour of concrete can be noticed with the change of w/c ratio. The effect of aerogel was also studied in concrete.

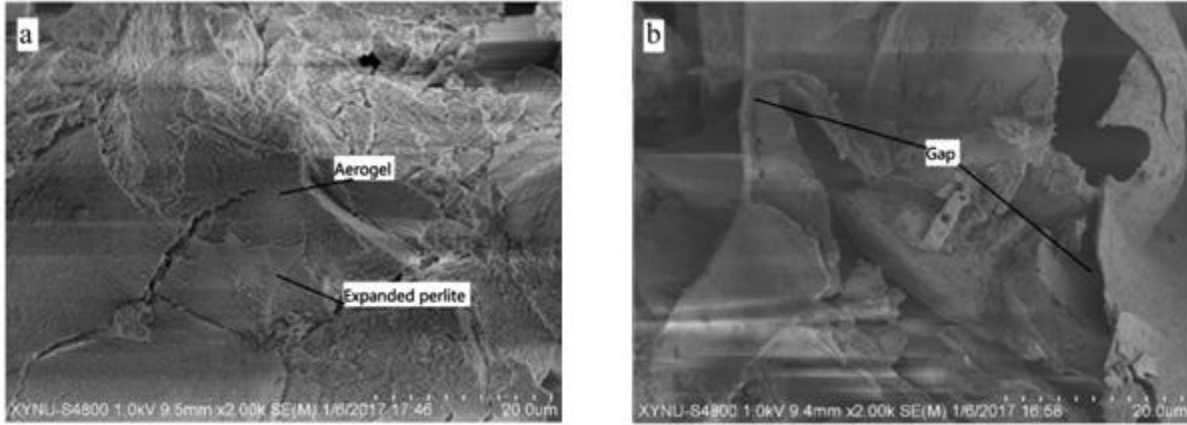


Figure 2.13. (a) Expanded perlite filled with aerogel; (b) the gap between expanded perlite and aerogel.
 (Liu et al. 2018)

Above figure (a) shows that EP's pores are filled with aerogel. Whereas, figure (b) represents the gap which has been left in between the EP and aerogel. This gap was created when the aerogel was shrunk due to ageing and drying.

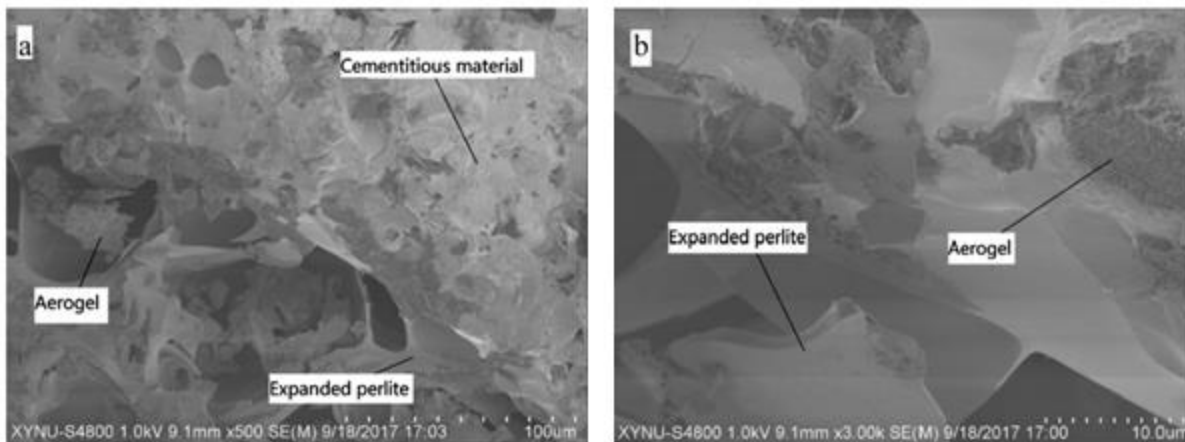


Figure 2.14. (a) Aerogel inside the cementitious material; (b) Aerogel pore structure.
 (Liu et al. 2018)

Above figure (a) shows the expanded perlite and cementitious material with any gaps between them. But there were some pores at the edge which were left unfilled (Figure (b)) due to no aerogel. This was the reason behind the water absorption behavior of NEPA and GEPA.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 INTRODUCTION

The current study is intended to study the effect of lightweight aggregate on concrete by replacing fine aggregates with expanded perlite and Pumice at varying proportions. Various tests on raw materials and obtained concrete samples have been performed. The so obtained lightweight concrete was evaluated for its various characteristics such as CS, STS, FS, water absorption ability, rapid chloride permeability. Along with all these parameters, microstructure analysis of samples was also carried out. Mix design of M30 concrete was performed and quantities of various raw ingredients were calculated.

3.2 MATERIAL USED

3.2.1 Cement

Ordinary Portland cement of grade 43 has been used in current experimental work. The cement (Shree Jee Cement-Brand name) was collected from the manufacturer. The raw cement was tested for its characteristics like consistency, setting time, specific gravity test. Basic characteristics of Ordinary Portland cement used in present study are shown below:-

Table: 3.1. Properties of Cement Used

Characteristics	Values Determined
Initial Setting time	113 min
Final Setting time	435 min
Specific Gravity	3.15

3.2.2 Coarse Aggregate

Coarse aggregates are retained on 4.75 mm Sieve and they are obtained from natural rocks, stone disintegration or crushed gravels. Coarse aggregates are the basic ingredients and give bulk to the concrete which decreases the quantity of cement and reduces the cost. They can be characterized as rounded, angular or smooth. Concrete strength is determined by the shape, size, grading of aggregates as 2/3 of the volume of concrete is filled with aggregates.

In present experimental study, coarse aggregate of size 20mm and 10mm (crushed and angular) was used. The grading of such aggregates was carried out and proportions of 20mm and 10mm was fixed. 20 mm and 10 mm aggregates were used in the ratio of 40:60.

Table: 3.2. Properties of Coarse Aggregates

Characteristics	Values Determined
Specific Gravity	2.71
Total Water Absorption	0.46
Fineness Modulus	6.52
20mm to 10 mm Ratio	40:60

Table: 3.3. Gradation of 10 mm Coarse Aggregate.

S. No	Sieve Size	Mass Retained (gm)	Percentage retained	Cumulative Percentage Retained	Percentage Passing
1	20 mm	46	1.53	1.53	98.47
2	10 mm	1302	43.40	44.93	55.07
3	4.75 mm	1521	50.70	95.63	4.37
4	Pan	131	4.37	100.00	0.00

Table: 3.4. Gradation of 20 mm Coarse Aggregate.

S. No	Sieve Size	Mass Retained (gm)	Percentage retained	Cumulative Percentage Retained	Percentage Passing
1	20 mm	198	6.60	6.60	93.40
2	10 mm	2309	76.97	83.57	16.43
3	4.75 mm	452	15.07	98.63	1.37
4	Pan	41	1.37	100.00	0.00

3.2.3 Fine Aggregates

Fine aggregates pass through 4.75 mm sieve. They are obtained from natural sources like river bed etc. which are formed due to various reasons such as disintegration of rocks, settlement, crushing etc. fine aggregates can be in the form of natural sand, etc. and they are used to fill the voids of concrete and increase the workability of concrete mix. Reduction in shrinkage and cracking are other merits of fine aggregates in concrete mix.

The gradation of fine aggregates involves passing the fine aggregates through series of sieves placed in the decreasing order (sieve size wise) from top to bottom i.e. 4.75 mm, 2.36 mm, 1.18 mm, 600um, 300 um, 150 um. From the results of gradation i.e. sieve analysis, it was found that the fine aggregates were conforming to Zone II.

Table: 3.5. Properties of Fine Aggregates

Characteristics	Values Determined
Type	River Sand
Specific Gravity	2.65
Total Water Absorption	1.16
Fineness Modulus	2.48

Table: 3.6. Gradation of 10 mm Coarse Aggregate.

S. No	Sieve Size	Mass Retained (gm)	Percentage retained	Cumulative Percentage Retained	Percentage Passing
1	4.75 mm	3	0.3	0.3	99.7
2	2.36 mm	142	14.2	14.5	85.5
3	1.18 mm	201	20.1	34.6	65.4
4	600 um	98	9.8	44.4	55.6
5	300 um	229	22.9	67.3	32.7
6	150 um	312	31.2	98.5	1.5
7	Pan	15	1.5	100	0

3.2.4 Expanded Perlite

Perlite is a natural volcanic glass. Apart from perlite, other kinds of natural volcanic glasses are available but the main advantage of perlite is that it expands on heating. Thus it is called as Expanded Perlite.

Expansion of perlite is similar to that of popcorn popping after heating. When expanded, the perlite can have 20 to 30 times of its original bulk density. After heating the raw perlite, the water quantity trapped inside the perlite ore vaporizes which generates the bubble like glass. This heating is carried out at the elevated temperature of 800-850°C approximately. Almost 2.77% to

3.25% of water content is to be target for vaporization. The resultant expanded perlite is known for its high thermal insulation properties and low density.



Figure 3.1. Expanded Perlite aggregate.

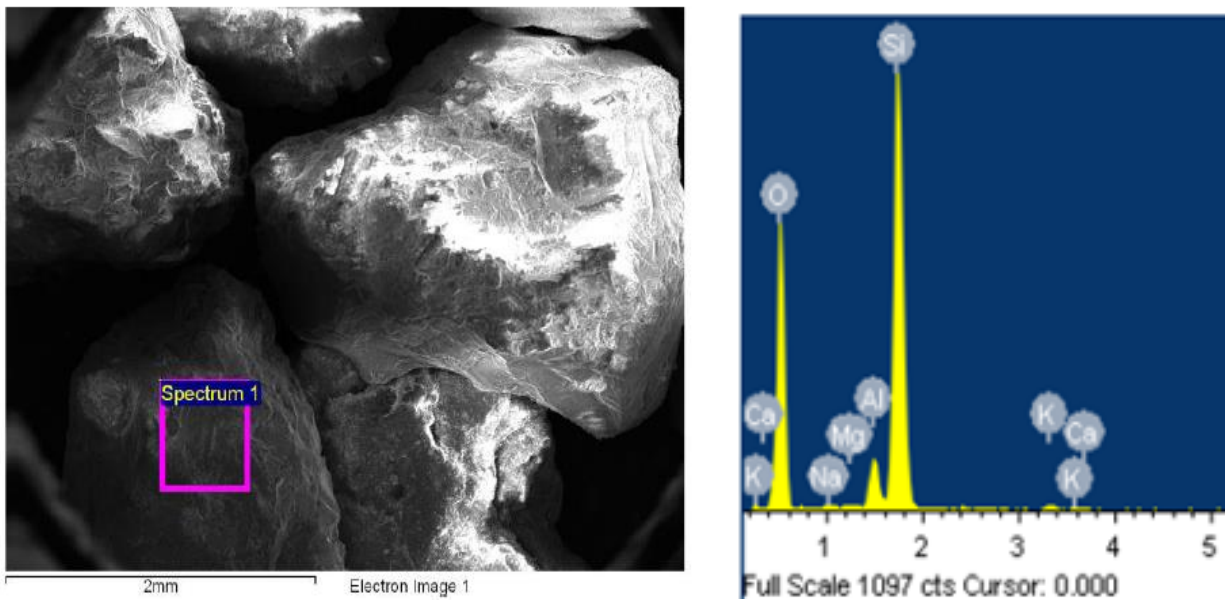


Figure 3.2. SEM and EDS Analysis of Expanded Perlite (Spectrum 1).

Table: 3.7. Chemical Composition of Expanded Perlite.

Element	Weight%	Atomic%	Compound%	Formula
Na K	0.21	0.19	0.29	Na ₂ O
Mg K	0.15	0.13	0.25	MgO
Al K	3.76	2.81	7.10	Al ₂ O ₃
Si K	42.41	30.46	90.72	SiO ₂
K K	1.18	0.61	1.42	K ₂ O
Ca K	0.16	0.08	0.23	CaO
O	52.13	65.73		
Totals	100.00			

3.2.5 Pumice

Pumice (powder or dust) is a volcanic rock having porous type texture which, sometimes, entails crystals. This material is light in weight and light colored. Other similar kind of volcanic rock is Scoria, which have larger vesicles with thicker walls and dark in color. This material is produced when the highly pressurized rock is thrown out from a volcano after being super-heated. The foam like structure of pumice is due to the rapid cooling of super-heated rock which results in rapid depressurization. This process of depressurization leads to formation of vesicles within the structure of pumice. After cooling, the large rocky type structure of pumice is produced which can be transported easily. The low density of pumice makes it the perfect material for lightweight concrete.



Figure 3.3. Pumice Aggregates

Pumice entails highly micro-vesicular glass pyroclastic having ultra-thin walls of igneous rock. They are normally pale in color like white, cream, blue or grey, green-brown or blackish in color. The porosity of this material ranges from 65% to 85% by its volume depending upon its source etc.

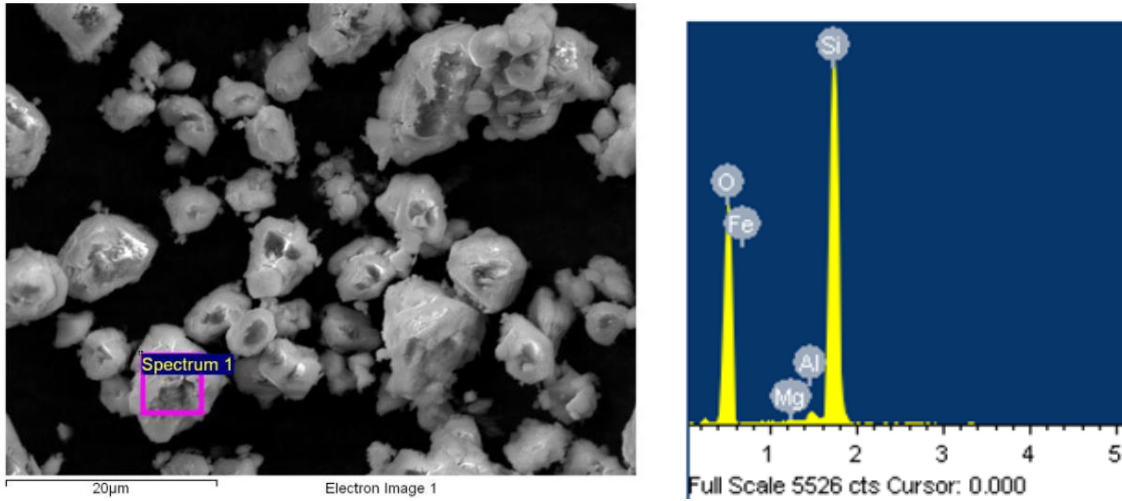


Figure 3.4. SEM and EDS Analysis of Pumice (Spectrum 1).

Table: 3.8. Chemical Composition of Pumice.

Element	Weight%	Atomic%	Compound%	Formula
Mg K	0.14	0.12	0.23	MgO
Al K	0.88	0.66	1.67	Al ₂ O ₃
Si K	45.67	32.63	97.70	SiO ₂
Fe K	0.31	0.11	0.39	FeO
O	53.00	66.48		
Totals	100.00			

3.3 MIX DESIGN

Concrete was prepared in the current experimental project and designed as per the guidelines of BIS method. Following nomenclature was followed for the description of various concrete mixes having different proportions of expanded perlite and pumice. Various concrete mixes were prepared at different substitution proportions with Expanded Perlite and Pumice. The

substitution of fine aggregates was carried out at 25%, 50%, 75% and 100% as shown in the table below.

Table: 3.9. Nomenclature for Various Concrete Mixes.

Designation	Substitution
NC	Normal Concrete
EP1	Substitution of Fine Sand with Expanded Perlite (25%)
EP2	Substitution of Fine Sand with Expanded Perlite (50%)
EP3	Substitution of Fine Sand with Expanded Perlite (75%)
EP4	Substitution of Fine Sand with Expanded Perlite (100%)
PP1	Substitution of Fine Sand with Expanded Perlite (12.5%) and Pumice (12.5%)
PP2	Substitution of Fine Sand with Expanded Perlite (25%) and Pumice (25%)
PP3	Substitution of Fine Sand with Expanded Perlite (37.5%) and Pumice (37.5%)
PP4	Substitution of Fine Sand with Expanded Perlite (50%) and Pumice (50%)

After preparing mix design, the quantities of various ingredients were calculated for normal concrete mix. And then, the quantities of Substitution material along with the raw ingredients were calculated and are represented in the table below.

Table: 3.10. Mix Proportion of Lightweight Concrete.

Mix Type	Cement (kg/m ³)	CA – 10 mm (kg/m ³)	CA – 20 mm (kg/m ³)	FA (kg/m ³)	EP (kg/m ³)	PP (kg/m ³)
NC	410	454	682	666	-	-
EP1	410	454	682	499.5	166.5	-
EP2	410	454	682	333	333	-
EP3	410	454	682	166.5	499.5	-
EP4	410	454	682	-	666	-
PP1	410	454	682	499.5	83.25	83.25
PP2	410	454	682	333	166.5	166.5
PP3	410	454	682	166.5	249.75	249.75
PP4	410	454	682	-	333	333

EP: Expanded perlite.

PP: Pumice.

3.4 CASTING AND CURING

The above mentioned quantities were calculated for one metric cube. But the weighted quantities for various samples were calculated as per the specimen size. The mixing of various ingredients was carried out in mechanical mixer for around 5 minutes until the uniform color is

attained. Side by side, the moulds were prepared and oiled before the casting process. The uniform concrete mix was put into the moulds in 3 different layers and compacted properly with the help of vibrator after each layer. Then the mould is filled up to the brim and extra concrete was chipped off with trowel and then it was left to gain its strength open room for 24 hours before demoulding the sample. Following are the number of samples which were prepared in order to perform various laboratory tests:

Table: 3.11. Scheme of Sample Preparation of Lightweight Concrete

Mix Type	Mechanical Tests			Durability Tests		
	C.S.T	S.T.S.T	F.S.T	R.C.P.T	S.T.	D.A.V.T
NC	3	3	3	3	3	3
EP1	3	3	3	3	3	3
EP2	3	3	3	3	3	3
EP3	3	3	3	3	3	3
EP4	3	3	3	3	3	3
PP1	3	3	3	3	3	3
PP2	3	3	3	3	3	3
PP3	3	3	3	3	3	3
PP4	3	3	3	3	3	3
TOTAL	27	27	27	27	27	27

Total Samples Prepared: 162

C.S.T.: Compressive Strength Test: (150x150x150) mm Cube

S.T.S.T.: Split Tensile Strength Test: (150 D X 300 H) mm Cylinder

F.S.T.: Flexural Strength Test: (150x150x700) mm Beam

R.C.P.T.: Rapid Chloride Permeability Test: (100 D X 50 H) mm Cylinder

S.T.: Sorptivity Test: (100 D X 50 H) mm Cylinder

D.A.V.T.: Density, Absorption & Void Test: (100 D X 50 H) mm Cylinder

3.5 LABORATORY TESTS

3.5.1 Compressive Strength (CS) Test

The uniaxial loading is applied on the concrete sample to calculate the CS of concrete. The load is applied till the failure of samples. For determining the CS of concrete, specimens of size 150x150x150mm were prepared and kept in normal room condition. The demolding of the cube samples was carried out after one full day and then they were immersed in curing tank for different curing periods. Testing was done with CTM which has the load capacity of 5000 Kn.

The load is applied at the rate of 5 KN/sec. The maximum load at which the sample fails was recorded and used to determine the compressive strength of concrete.

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

Where;

σ = compressive stress (MPa)

P = Applied load (N)

A= Cross Sectional area of the specimen (mm²)



Figure 3.5. Compressive Strength Test.

3.5.2 Split Tensile Strength (STS) TEST

The indirect method through which the tensile strength is calculated is called STS Test. The STS of a concrete is defined as the maximum tension which can be withstand by the material without tearing apart. In this method, a cylindrical specimen of size diameter 150mm and height 300mm

is used and load is applied. The failure load is recorded and then the STS is determined by the equation given below.

$$F_{st} = \frac{2P}{\pi dl}$$

Where;

F_{st} = split tensile stress (MPa)

P = Applied load (N)

d = diameter of the cylindrical specimen (mm)

l = length of the cylindrical specimen (mm)



Figure 3.6. Split Tensile Strength Test.

3.5.3 Flexural Strength (FS) TEST

Flexural strength test is another indirect method for calculating the tensile strength of concrete. This test is used to calculate the ability of concrete beam (without reinforcement) to

resist the failure in bending. Tensile strength with this method is usually expressed in modulus of rupture. The flexural test is performed by three point load action or center point load action.

The modulus of rupture can be determined by the following equation (i):

$$f_r = 7.5\sqrt{f'} \quad \dots(i)$$

Where;

f_r : Modulus of rupture

f' : Concrete Compressive Strength



Figure 3.7. Flexural Strength Test.

3.5.4 Rapid Chloride Permeability Test (RCPT)

The ingress of chloride in the concrete structure affects the durability of concrete as the penetration of chloride into the voids weakens the bonding ability and deterioration of steel occurs. Chloride permeability of concrete sample is determined as per the guidelines of the

ASTM C1202-97. For this, samples of 100x 50 mm were prepared and placed in desiccator up to 3 hours and then water was allowed to pass in that desiccator. The immersion of the specimen was carried out for another 18 hours before the testing. The two molds were prepared, out of which one is filled with 3% NaCl solution and second one is filled with 0.3N NaOH solution. The 60V power was supplied for 6 hours and the readings were noted.



Figure 3.8. Rapid Chloride Permeability Test.



Figure 3.9. Setup for Rapid Chloride Permeability Test.

3.5.5 Sorptivity Test

The property to absorb water through capillary action when only one side of concrete sample is immersed in water is called Sorptivity. Sorptivity of a concrete is determined by determining the rate of absorption of water after measuring the weight of sample at specified time intervals as per the guidelines of code. When the ingress of water occurs with the passage of time, the weight of sample increase. The specimen of size dia. 100mm and height 50mm is prepared as per ASTM C1585-04. The top surface along with the sides are sealed with epoxy and bottom surface of sample was immersed in water up to 2-5 mm. Initial and final mass is recorded and sorptivity is determined by using following equation(3.1).

$$S = \frac{I}{\sqrt{t}} \quad \dots\dots (3.1)$$

Where;

S= Rate of Sorptivity in (mm/s^{1/2})

t= Time elapsed in seconds

I= Absorption

‘I’ can be found out using the formula (3.2)

$$I = \frac{m_t}{a \times d} \quad \dots\dots (3.2)$$

Where;

m_t= Changed sample weight into grams

a = Exposed sample weight in mm²

d = Water density in g / mm³



Figure 3.10. Sorptivity Test.

3.5.6 Density, Absorption and Void Test

Density of a material shows how dense it is packed and it can be determined by simply dividing mass with its volume. Absorption is defined as the ability of any material to absorb liquid/fluids. And volume of permeable voids is defined as the volume of voids which can hold permeable fluid in it. These all terms are interlinked with each other and the determination of these parameters reflects the microstructure of concrete specimen. For this purpose, discs of size 100 x 50 mm were prepared and tested at the age of 28 days. Firstly, Initial mass was recorded and then it was kept for drying in oven for 24 hours at 100⁰ C. the specimen was then cooled and mass was recorded. If the mass is less than 0.5% of the lowest value, designate it value “A.” Then the sample was immersed in the water having 21⁰C temperature for 48 hours. If two successive values of the mass of SSD sample at an interval of 24 hours show an increase in the mass of less than 0.5 % of larger value then designate it as “B”. Again the sample was placed in hot water for 5 hours and it was allowed to cool down for further 14 hours. Weigh the sample and refer it as “C”. Specimen was then suspended with the wire in order to record the apparent water mass and refer this weight as “D”. In the end, the density, absorption and permeable voids were calculated from these recorded results.

$$\text{Bulk density, dry} = [A/(C-D)]\rho = g_1$$

$$\text{Apparent density} = [A/(A-D)]\rho = g_2$$

$$\text{Absorption after immersion and boiling (\%)} = [(C-A)/A] \times 100$$

$$\text{Volume of permeable pore space (voids), \%} = (g_2 - g_1)/g_2 \times 100$$

$$\text{Total void volume, \%} = (g_3 - g_1)/g_3 \times 100$$

$$g_1 = \text{bulk density, dry, gm/cm}^3$$

$$g_2 = \text{apparent density, gm/cm}^3$$

$$g_3 = \text{absolute density, gm/cm}^3$$

$$\rho = \text{density of water} = 1 \text{ gm/cm}^3$$

3.5.7 Scanning Electron Microscope (SEM)

SEM is a microscope which utilizes the beam of high energy electrons to produce the images of sample by scanning. During this process, the beams interact with the molecules of the sample and it generates different forms of signals which confirm the information regarding

surface topography and chemical composition. The sample having the area of interest is placed in SEM column in such a way that it faces downwards.

SEM uses the high energy focused of an electron to magnify a specific sample region. A particular sample containing an area of interest is placed at the bottom of the SEM column within the vacuum chamber. Electron is produced by cathode column and strike the specimen. The specimen reflects some of the electrons, and some are absorbed. Two types of signals are detected by the electron microscope in which one is the secondary electron (SE), and the second is backscattered (BSE).



Figure 3.11. SEM Analysis.

CHAPTER 4

RESULT AND DISCUSSION

4.1 GENERAL

In order to produce lightweight concrete, aggregates were replaced with lightweight aggregates like pumice and expanded perlite. After performing the various tests for different characteristics of concrete, all the results were recorded in tabular manner and analyzed in a scrutinized way. Then the discussion was made to figure out the effect of lightweight aggregates on concrete. Different mechanical and durability tests such as CS, STS, FS, sorptivity, SEM were carried out. The results of present study are discussed below.

4.2 MECHANICAL PROPERTIES

4.2.1 Compressive Strength

The results of Compressive strength of lightweight concrete using pumice and expanded perlite have been shown in the table below.

Table: 4.1. Test Results of Compressive Strength (CS) for Lightweight concrete.

Designation	Compressive Strength (MPa)	Standard Error (±MPa)	Designation	Compressive Strength (MPa)	Standard Error (±MPa)
NC	31.200	0.9018	NC	31.200	0.9018
EP1	27.067	0.5206	PP1	29.967	0.5785
EP2	24.934	0.7859	PP2	26.066	0.5206
EP3	21.666	0.6765	PP3	22.200	0.7211
EP4	18.334	0.8812	PP4	19.440	0.5300

When the results of substitution concrete mixes were compared with NC results, it was revealed that compressive strength decreases up to 13.25%, 20.08%, 30.55% and 41.24% for the concrete mix (entailing expanded perlite) EP1, EP2, EP3 and EP4 respectively when compared with normal concrete strength. Concrete properties are dependent upon material constituents, thus as the normal FA is replaced by porous EP, CS is reduced due to low strength of perlite. The similar trend of decrease was observed when the addition of pumice is done. The CS decreases in the order of 3.96%, 16.45%, 28.84% and 37.69% for the concrete mix (entailing expanded perlite and pumice) PP1, PP2, PP3 and PP4 respectively when compared with NC

strength. However this decrease in strength is lower than mix containing expanded perlite, this is due to more compactness of the mix. This variation can be clearly seen from the figures shown below.

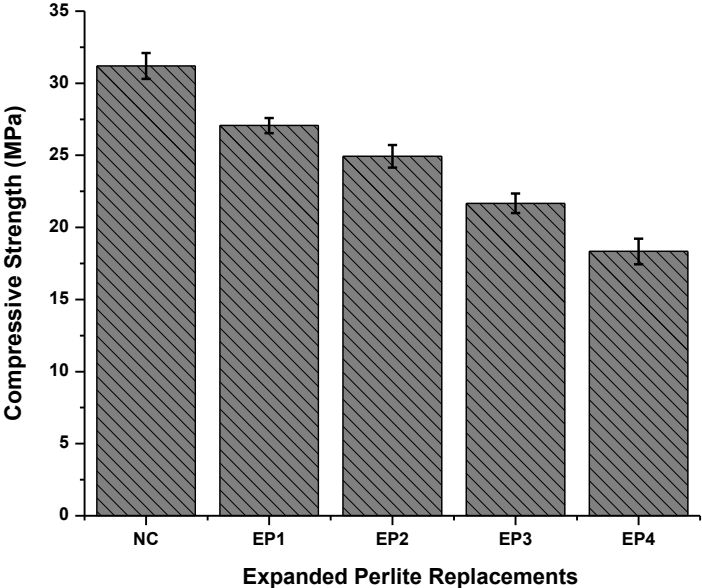


Figure 4.1. Variation in Compressive Strength when EP was added.

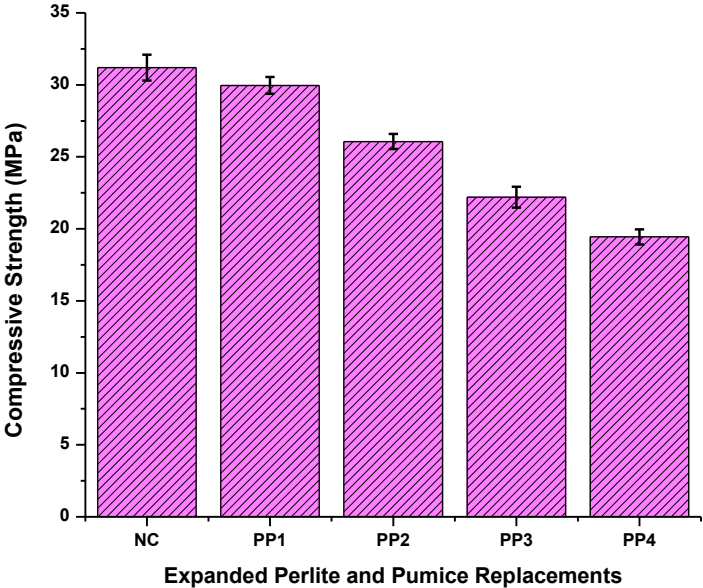


Figure 4.2. Variation in Compressive Strength when EP and PP was added.

4.2.2 Split Tensile Strength

The results of STS of lightweight concrete using pumice and expanded perlite have been shown in the table below. It was noticed that with the increase in the proportion of expanded perlite and pumice, the split tensile strength decreases from 2.516 MPa to 1.243 MPa. This reduction is almost 50.56% when compared with tensile strength of NC mix.

Table: 4.2. Test Results of Split Tensile Strength (STS) for Lightweight concrete.

Designation	Split Tensile Strength (MPa)	Standard Error (±MPa)	Designation	Split Tensile Strength (MPa)	Standard Error (±MPa)
NC	2.516	0.126	NC	2.516	0.126
EP1	2.153	0.093	PP1	2.273	0.067
EP2	2.067	0.145	PP2	2.156	0.150
EP3	1.693	0.112	PP3	1.790	0.116
EP4	1.243	0.096	PP4	1.503	0.148

All the results of EP mix and PP mix were compared with NC mix. It was noticed that split tensile strength decreases in the order of 14.42%, 17.84%, 32.71% and 50.59% for the concrete mix (entailing expanded perlite) EP1, EP2, EP3 and EP4 respectively when compared with normal concrete strength. The similar trend of decrease was observed when the addition of pumice is done. The split tensile strength decreases up to 9.65%, 14.30%, 28.85% and 40.25% for the concrete mix (entailing expanded perlite and pumice) PP1, PP2, PP3 and PP4 respectively when compared with NC strength. Decrease in the tensile strength of mix containing expanded perlite and pumice is attributed to weak porous structure (cracks inheritors) as compared to ordinary concrete. This variation in the results of STS can be seen from the figures shown below.

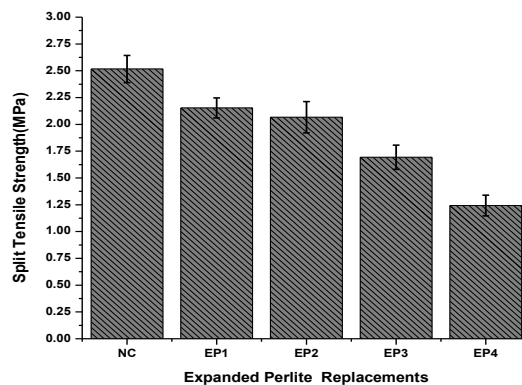


Figure 4.3. Variation in Split Tensile Strength when EP was added.

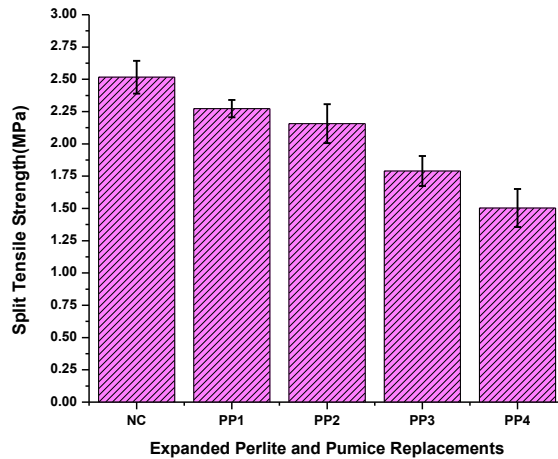


Figure 4.4. Variation in Split Tensile Strength when EP and PP was added.

4.2.3 Flexural Strength

The results of FS have been represented in the table below. The results have been represented in tabular and graphical manner. It was observed that with the increase in the proportion of expanded perlite and pumice, the flexural strength decreases from 2.68 MPa (for control mix) to 1.856 MPa (for PP4). The decrease in flexural strength is more in concrete mix having Pumice than the concrete mix having expanded perlite.

Table: 4.3. Test Results of Flexural Strength (FS) for Lightweight concrete.

Designation	Flexural Strength (MPa)	Standard Error (\pm MPa)	Designation	Flexural Strength (MPa)	Standard Error (\pm MPa)
NC	4.010	0.1619	NC	4.010	0.1619
EP1	3.652	0.1719	PP1	3.736	0.1178
EP2	3.456	0.0982	PP2	3.603	0.0240
EP3	3.000	0.1154	PP3	3.193	0.0497
EP4	2.753	0.0523	PP4	2.893	0.1180

From the figures below, it was noticed that the FS of NC is 4.010 MPa. It can be concluded that FS decreases in the order of 8.9%, 13.8%, 25.18% and 31.34% for the concrete mix (entailing expanded perlite) EP1, EP2, EP3 and EP4 respectively when compared with NC strength.

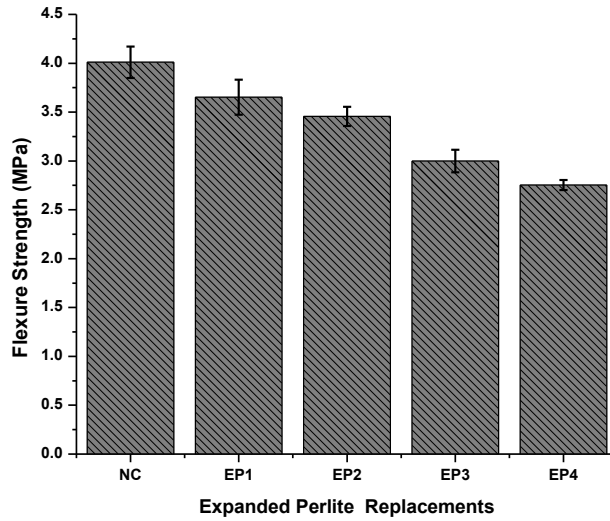


Figure 4.5. Variation in Flexural Strength when EP was added.

From the figures below, it was noticed that the FS of NC is 4.010 MPa. From table, it can be concluded that FS decreases in the order of 6.83%, 10.22%, 20.37% and 27.85% for the concrete mix (entailing expanded perlite and pumice) PP1, PP2, PP3 and PP4 respectively when compared with NC strength. FS trends are similar to compressive STS. NC shows higher strength than other mixes due to more dense matrix as compared to mix containing expanded perlite and pumice.

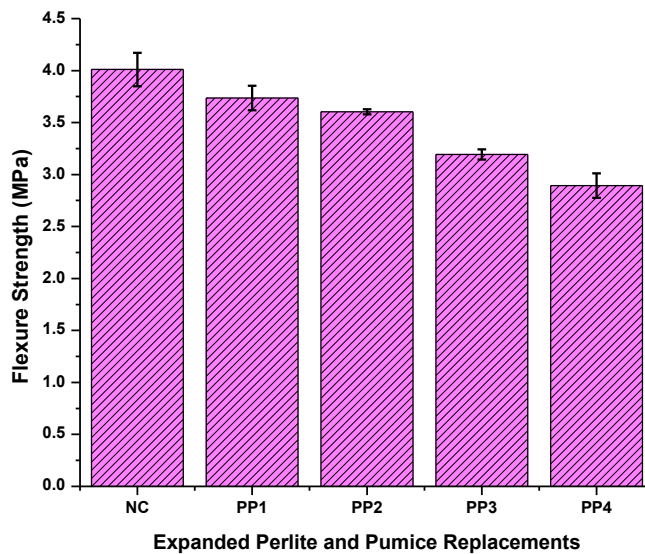


Figure 4.6. Variation in Flexural Strength when EP and PP was added.

4.3 DURABILITY PROPERTIES

4.3.1 Sorptivity

Table below represents the results of sorptivity test of various concrete mixes having pumice and expanded perlite (lightweight aggregates). From the results, it is revealed that normal concrete mix showed the minimum initial sorptivity value i.e. $0.0573 \text{ mm/s}^{1/2}$ as normal concrete is densely packed due to natural raw aggregates. When expanded perlite was added maximum sorptivity value was $0.2542 \text{ mm/s}^{1/2}$ and after adding pumice to the concrete mix along with expanded perlite, maximum sorptivity value was $0.1811 \text{ mm/s}^{1/2}$.

Table: 4.4. Test Results of Sorptivity for Lightweight concrete.

Designation	Initial Sorptivity ($\text{mm/s}^{1/2}$)	Standard Error ($\pm \text{mm/s}^{1/2}$)	Designation	Initial Sorptivity ($\text{mm/s}^{1/2}$)	Standard Error ($\pm \text{mm/s}^{1/2}$)
NC	0.0573	0.0102	NC	0.0573	0.0054
EP1	0.1275	0.0191	PP1	0.0928	0.0090
EP2	0.1510	0.0230	PP2	0.1179	0.0091
EP3	0.1951	0.0252	PP3	0.1348	0.0077
EP4	0.2599	0.0141	PP4	0.1811	0.0099

From the figure given below, it was concluded that the sorptivity of NC is $0.0573 \text{ mm/s}^{1/2}$. The sorptivity increases with the introduction of expanded perlite because of the great volume of voids present in concrete structure. The percentage increase in the value of sorptivity is 122.5%, 163.5%, 240.5% and 353.6% for concrete mix EP1, EP2, EP3 and EP4 respectively when compared with NC value. The mix EP4 shows the maximum sorptivity as 100% substitution was done in this mix type. Therefore, more the substitution more will be the value of sorptivity.

Pumice being the less porous aggregate and have more finess modulus than expanded perlite shows less increase in the initial sorptivity value when it is added along with the expanded perlite as compared to concrete mix having only expanded perlite. The percentage increase in the value of sorptivity is 62%, 105.8%, 135.3% and 216.1% for concrete mix PP1, PP2, PP3 and PP4 respectively when compared with normal concrete value. Therefore, PP4 showed maximum value of sorptivity which is $0.1811 \text{ mm/s}^{1/2}$.

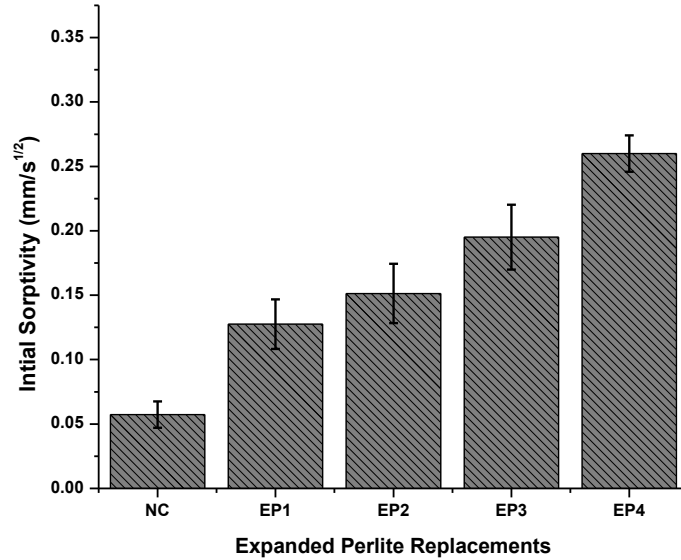


Figure 4.7. Variation in Initial Sorptivity value when EP was added.

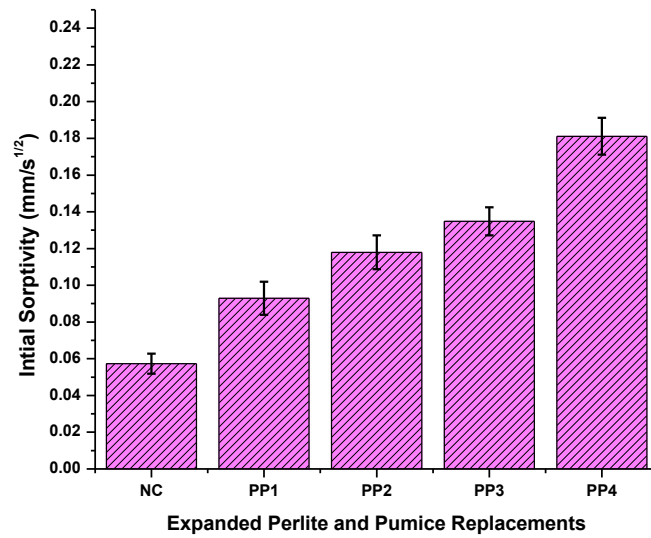


Figure 4.8. Variation in Initial Sorptivity value when EP and PP was added.

4.3.2 Rapid Chloride Permeability Test

Table below showed the values of charge passed through the concrete samples while performing the rapid chloride permeability test. The results of this test have been represented in the table and figures given below. The charged passed from normal concrete mix was 1803.667 coulombs. EP concrete mixes showed higher values of charge passed than PP concrete mixes. Overall charged passed in EP category mix is higher than PP category mix.

Table: 4.5. Test Results of RCPT for Lightweight concrete.

Designation	Charged Passed (Coulombs)	Standard Error (\pm Coulombs)	Chloride ion Permeability
NC	1803.667	43.2833	Low
EP1	2448.020	90.0907	Moderate
EP2	2881.033	58.5064	Moderate
EP3	3573.334	126.7754	Moderate
EP4	4371.633	178.1173	High
NC	1803.667	43.2833	Low
PP1	2021.667	135.8213	Moderate
PP2	2293.022	112.6957	Moderate
PP3	2656.030	199.4893	Moderate
PP4	2928.334	186.6907	Moderate

From the figure given below, it was concluded that the charged passes in EP4 was maximum i.e. 4371.633 coulombs. The value of charged passed increases almost linearly as the percentage of expanded perlite increases. This phenomenon was observed due to the more ingress of chloride in large volume of voids. The percentage increase in the value of charged passed is 35.72%, 59.73%, 98.114% and 142.37% for concrete mix EP1, EP2, EP3 and EP4 respectively when compared with normal concrete value. The concrete mix EP4 shows the maximum chloride ingress as 100% Substitution was done in this mix type. Therefore, more the substitution more will be the value of charged passed.

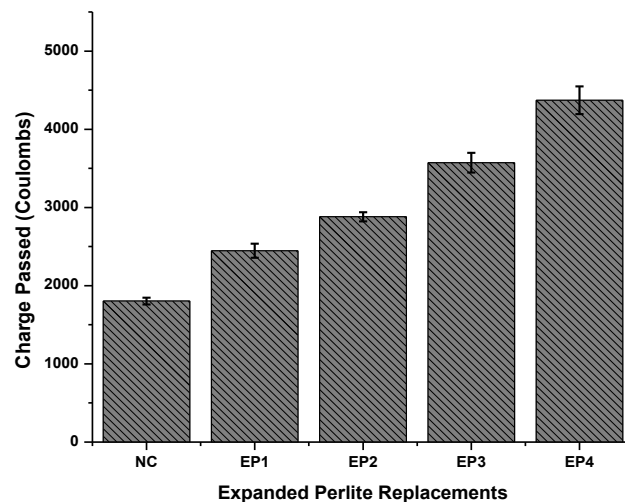


Figure 4.9. Variation in RCPT Results when EP was added.

The value of charged passed increases as the percentage of expanded perlite and pumice increases. Therefore, the percentage increase in the value of charged passed is 12.08%, 27.13%, 47.25% and 62.35% for concrete mix PP1, PP2, PP3 and PP4 respectively when compared with normal concrete value.

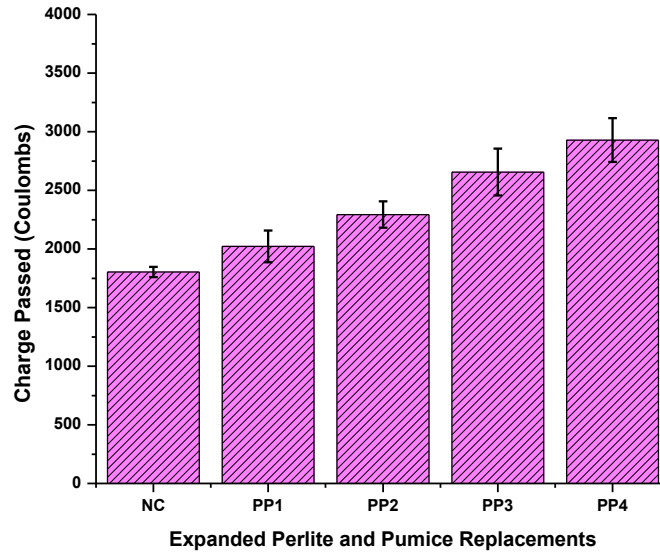


Figure 4.10. Variation in RCPT Results when EP and PP was added.

4.3.3 Density, Absorption and Percentage of Total Voids

4.3.3.1 Density

Table below represents the values of apparent density along with the bulk density of various mixes. And it was noticed that with the substitution of FA with lightweight aggregates, the decrease in both the densities for EP category mix and PP category mix is moderate. This is because the aggregates are less densely packed as compared to NC mix.

Following are the result of bulk density for various concrete mixes. Bulk density for normal concrete mix was found out to be 2.4061 g/cm^3 . Whereas, the maximum bulk density for EP category is 2.3213 g/cm^3 and for PP category is 2.3801 g/cm^3 .

The results of bulk density for EP category mix have been represented in the following figure. It is observed that bulk densities decreases with the substitution, this is due to lighter particles being used per unit volume. And from the figure, the approximately linear decrease in the bulk density can be seen. For EP1, EP2, EP3 and EP4, the bulk density comes out to be

2.2822 g/cm³, 2.1292 g/cm³, 2.0419 g/cm³ and 1.8512 g/cm³. The percentage decrease in bulk density of EP category concrete mix ranges from 5.15% to 23.06%.

Table: 4.6. Test Results of Bulk Density for Lightweight concrete.

Designation	Bulk Density, dry (g/cm ³)	Standard Error (±g/cm ³)	Designation	Bulk Density, Dry (g/cm ³)	Standard Error (±g/cm ³)
NC	2.4061	0.0092	NC	2.4061	0.0092
EP1	2.2822	0.0309	PP1	2.3101	0.0088
EP2	2.1292	0.0572	PP2	2.2289	0.0194
EP3	2.0419	0.0589	PP3	2.1188	0.0150
EP4	1.8512	0.0532	PP4	1.9723	0.0330

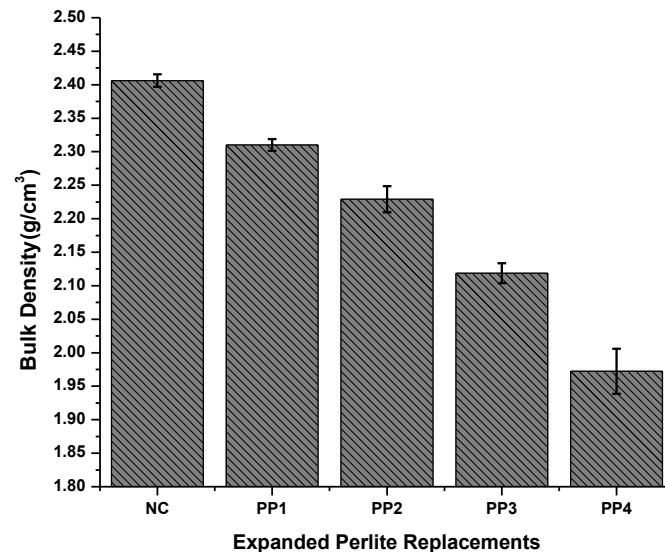


Figure 4.11. Variation in Bulk Density when EP was added.

The results of bulk density for PP category mix have been represented in the following figure and the linear decrease in the bulk density can be seen. For PP1, PP2, PP3 and PP4, the bulk density comes out to be 2.3101 g/cm³, 2.2289 g/cm³, 2.1188 g/cm³ and 1.9723 g/cm³. The percentage decrease in bulk density of PP category concrete mix ranges from 3.98% to 18.02%. Mix containing expanded perlite and pumice are more dense than expanded perlite mix due to more fineness (more dense) of pumice and expanded perlite than expanded perlite only.

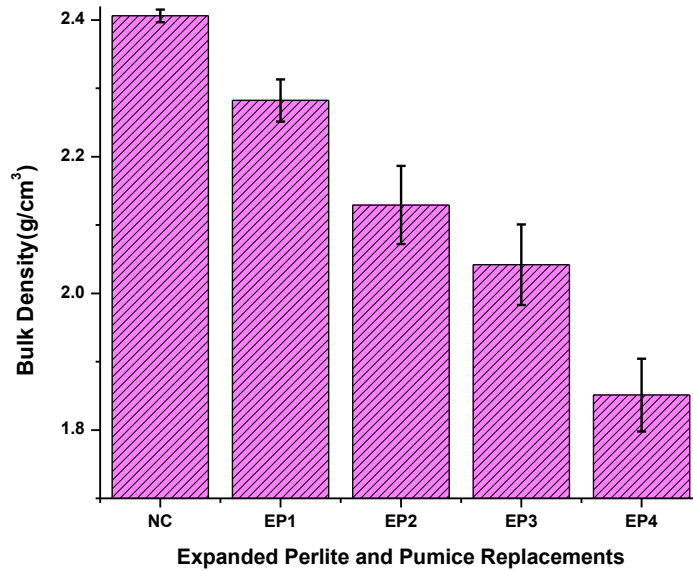


Figure 4.12. Variation in Bulk Density when EP and PP was added.

- Following are the apparent density results:-

Table: 4.7. Test Results of Apparent Density for Lightweight concrete.

Designation	Apparent Density (g/cm ³)	Standard Error (±g/cm ³)	Designation	Apparent Density (g/cm ³)	Standard Error (±g/cm ³)
NC	2.4203	0.0057	NC	2.4203	0.0057
EP1	2.3090	0.0071	PP1	2.3329	0.0144
EP2	2.1611	0.0177	PP2	2.2593	0.0303
EP3	2.0806	0.0144	PP3	2.1574	0.0289
EP4	1.8842	0.0088	PP4	1.9985	0.0764

The results of apparent density for EP category mix have been represented in the figure below. And from the figure the variation in the apparent density can be seen clearly. For EP1, EP2, EP3 and EP4, the apparent density comes out to be 2.3090 g/cm³, 2.1611 g/cm³, 2.0806 g/cm³ and 1.8842 g/cm³. The percentage decrease in apparent density of EP category concrete mix ranges from 4.59% to 22.15%.

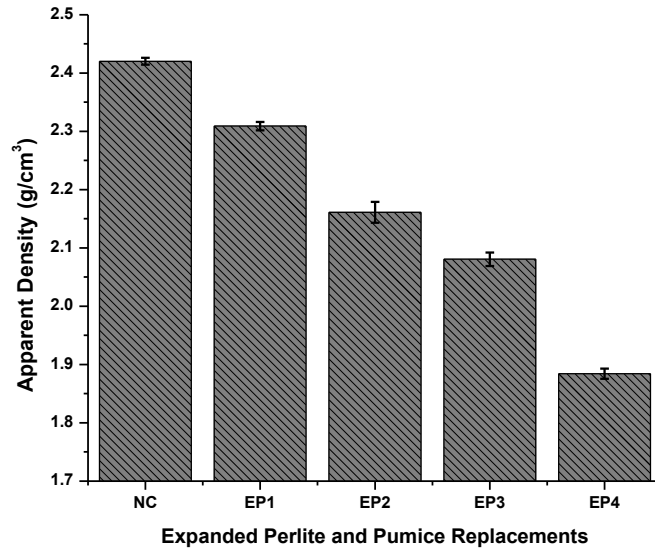


Figure 4.13. Variation in Apparent Density when EP was added.

The results of apparent density for PP category mix have been represented in the figure below. And from the figure the variation in the apparent density can be seen clearly. For PP1, PP2, PP3 and PP4, the apparent density comes out to be 2.3329 g/cm³, 2.2593 g/cm³, 2.1574 g/cm³ and 1.9985 g/cm³. The percentage decrease in apparent density of PP category concrete mix ranges from 3.61% to 17.42%. It shows same trend as of bulk density.

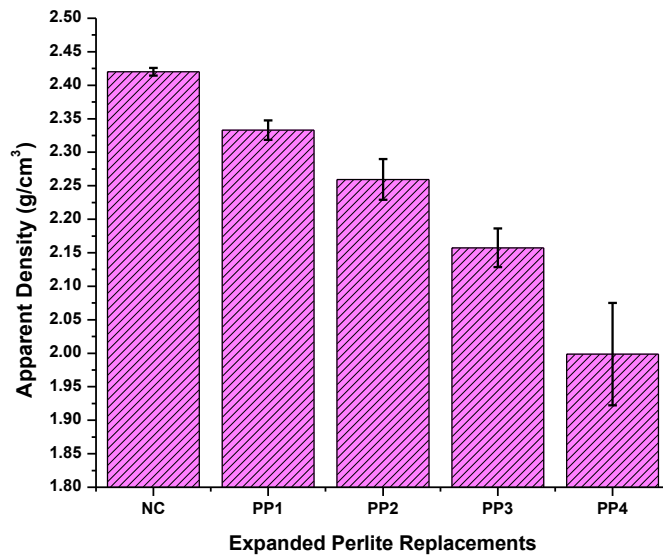


Figure 4.14. Variation in Apparent Density when EP and PP was added

4.3.3.2 Absorption after Immersion

The results of absorption after immersion and boiling were collected and are represented in the table below. From the results, it was observed that the control mix showed minimum value of absorption i.e. 0.3588%.

Table: 4.8. Test Results of Absorption after Immersion and Boiling for Lightweight concrete.

Designation	Absorption, %	Standard Error (± %)	Designation	Absorption, %	Standard Error (±%)
NC	0.3588	0.0202	NC	0.3588	0.0202
EP1	0.6062	0.0289	PP1	0.5005	0.0246
EP2	0.9444	0.0286	PP2	0.8250	0.0324
EP3	1.3515	0.0364	PP3	1.2332	0.0264
EP4	1.9368	0.0813	PP4	1.7568	0.0373

The variation in the absorption values of EP category can be seen from the figure below. As the substitution percentage increases from 25% to 100%, the increases in the absorption was found out to be 68.95%, 163.21%, 276.67% and 439.8% respectively when compared to normal concrete mix value.

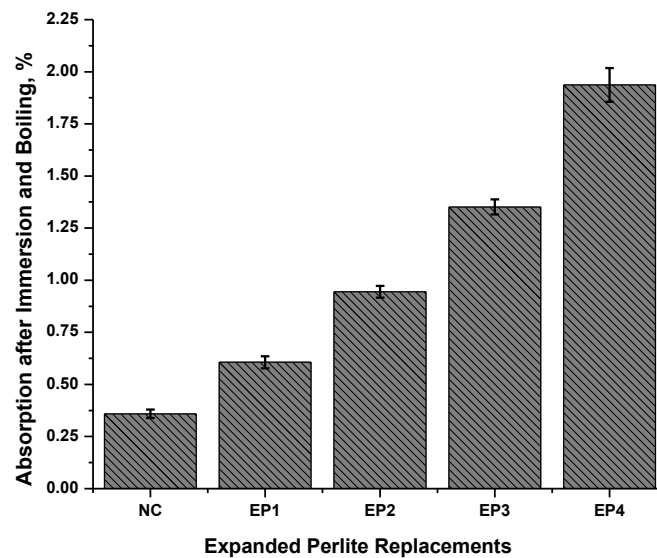


Figure 4.15. Variation in Absorption when EP was added.

The variation in the absorption values of PP category can be seen from the figure below. The value of absorption gradually increases as the percentage of PP increases in concrete. When 25% expanded perlite and pumice was added in the concrete mix i.e. PP1, the increase in the absorption was found out to be 39.49% when compared to normal concrete mix value. As the Substitution percentage increases to 50%, 75% and 100%, the increases in the absorption was found out to be 129.93%, 243.7% and 389.63% respectively when compared to normal concrete mix value.

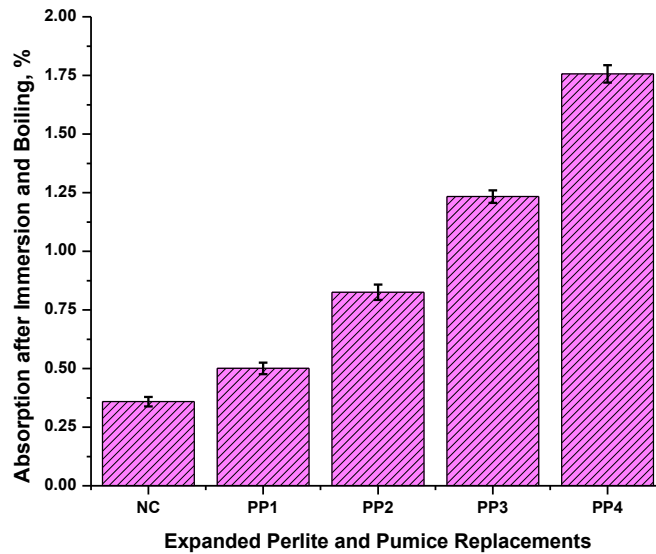


Figure 4.16. Variation in Absorption when EP and PP was added.

4.3.3.3 Volume of Permeable Pore Space

Table 4.9 gives the results of volume of permeable pore space in various concrete mixes. Minimum percentage of volume of permeable pore space is found out to be for normal concrete mix i.e. 0.5774%. Then as the percentage of expanded perlite and pumice increases in EP and PP category, the percentage of volume of permeable pore space also increases. This is due to the grain size of expanded perlite and pumices which results in more number of voids and large voids.

The gradual increase in the percentage of permeable pore space in EP category can be seen from the figure below. As the Substitution percentage increases from 25% to 100%, the percentage increases in the value of volume of pore space was found out to be 81.7%, 153.57%, 200% and 245.35% when compared to normal concrete mix value.

Table: 4.9. Test Results of Volume of Permeable Pore Space for Lightweight concrete.

Designation	The Volume of Pore Space, %	Standard Error (\pm %)	Designation	Volume of Pore Space, %	Standard Error (\pm %)
NC	0.5503	0.0217	NC	0.5503	0.0217
EP1	1.0000	0.1305	PP1	0.8500	0.0585
EP2	1.3954	0.0305	PP2	1.1437	0.0336
EP3	1.6510	0.0364	PP3	1.4586	0.0795
EP4	1.9003	0.0283	PP4	1.7841	0.0432

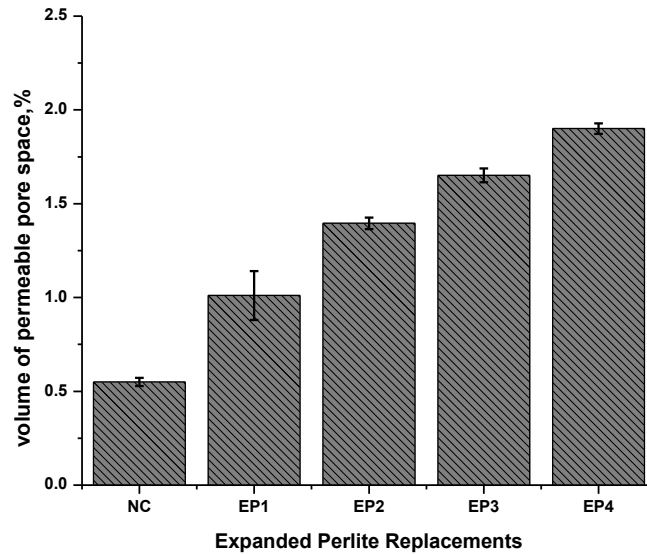


Figure 4.17. Variation in Volume of Permeable Pore Space when EP was added.

The variation in the percentage of permeable pore space in PP category can be seen from the figure below. This increase is almost gradual and linear with the increases in percentage of expanded perlite and pumice in concrete. When 25% expanded perlite plus pumice was added in the concrete mix i.e. PP1, the increase in the value of volume of pore space was found out to be 54.46% when compared to normal concrete mix value. As the Substitution percentage increases to 50%, 75% and 100%, the increases in the value of volume of pore space was found out to be 107.83%, 165.05% and 224.2% respectively when compared to normal concrete mix value.

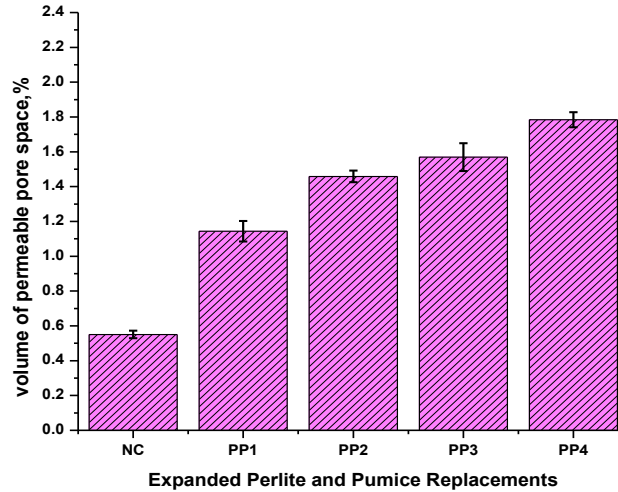


Figure 4.18. Variation in Volume of Permeable Pore Space when EP and PP was added

4.3.3.4 Total Void Volume

The total void volume results have been shown in the table 4.10. The minimum percentage of total void volume was found out to be for the normal concrete mix i.e. 0.5748% and this value increases as the percentage of Substitution material increases either with expanded perlite or with pumice. The overall value of the total void volume was higher for the EP4 mix. This is because of more permeable pore space in structure which was a result of less dense structure.

Table: 4.10. Total Void Volume for Lightweight concrete.

Designation	Total Void Volume, %	Standard Error (± %)	Designation	Total Void Volume, %	Standard Error (± %)
NC	0.5748	0.0559	NC	0.5748	0.0559
EP1	1.8503	0.1321	PP1	1.4177	0.0419
EP2	2.5776	0.0871	PP2	1.9975	0.1940
EP3	3.5135	0.1354	PP3	2.8949	0.1643
EP4	5.0139	0.0202	PP4	4.2141	0.2015

Figure below shows the variation in the total void volume in EP category mixes. And from the figure, the linear increase was observed in the value of total void volume due to less denser packing of aggregates in concrete. The percentage increase in volume of voids of EP1, EP2, EP3 and EP4 concrete mix was 221.9%, 348.4%, 511.3% and 772.3% when compared with normal concrete mix.

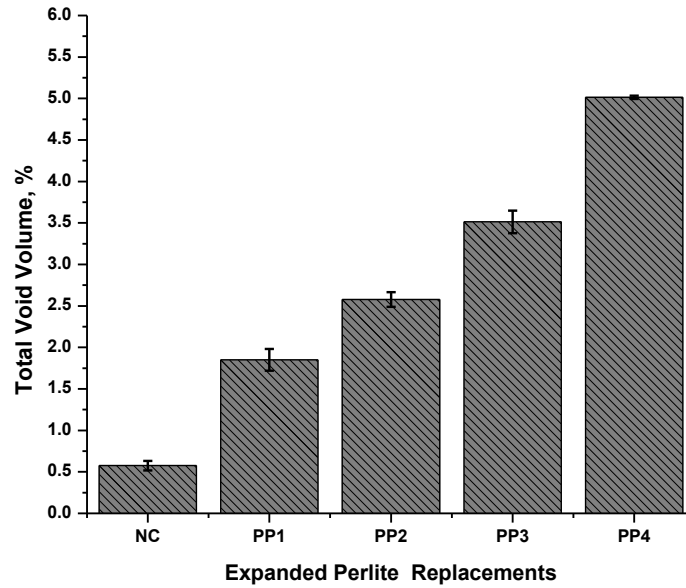


Figure 4.19. Variation in Total Void Volume when EP was added.

Figure below shows the variation in the total void volume in PP category mixes. And from the figure, the linear increase was observed in the value of total void volume. For PP1, PP2, PP3 and PP4, the volume of voids comes out to be 1.4177%, 1.9975%, 2.8949% and 4.2141% respectively. The percentage increase in volume of voids of PP1, PP2, PP3 and PP4 concrete mix was 146.6%, 247.5%, 403.6% and 633.1% when compared with normal concrete mix.

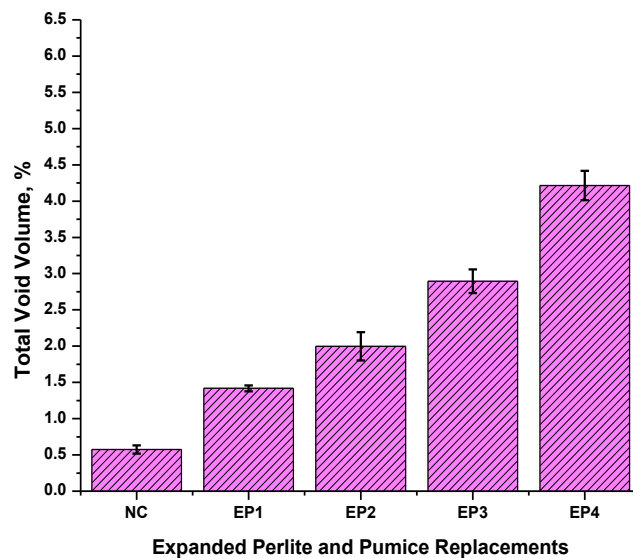


Figure 4.20. Variation in Total Void Volume when EP and PP was added.

4.4 MICROSTRUCTURAL PROPERTIES:

4.4.1 Scanning Electron Microscopy(Sem) Of Normal Concrete (NC)

SEM Figures 4.21 (a-b) show dense and non-porous microstructure with higher solid content. This is due to material constituents which make structure more dense and tough. SEM Figure 4.21 (c-d) represent the uniform distribution of CSH gel. SEM figures depicts lower amount of cracks and voids in the microstructure which enhances the durability properties of the mix.

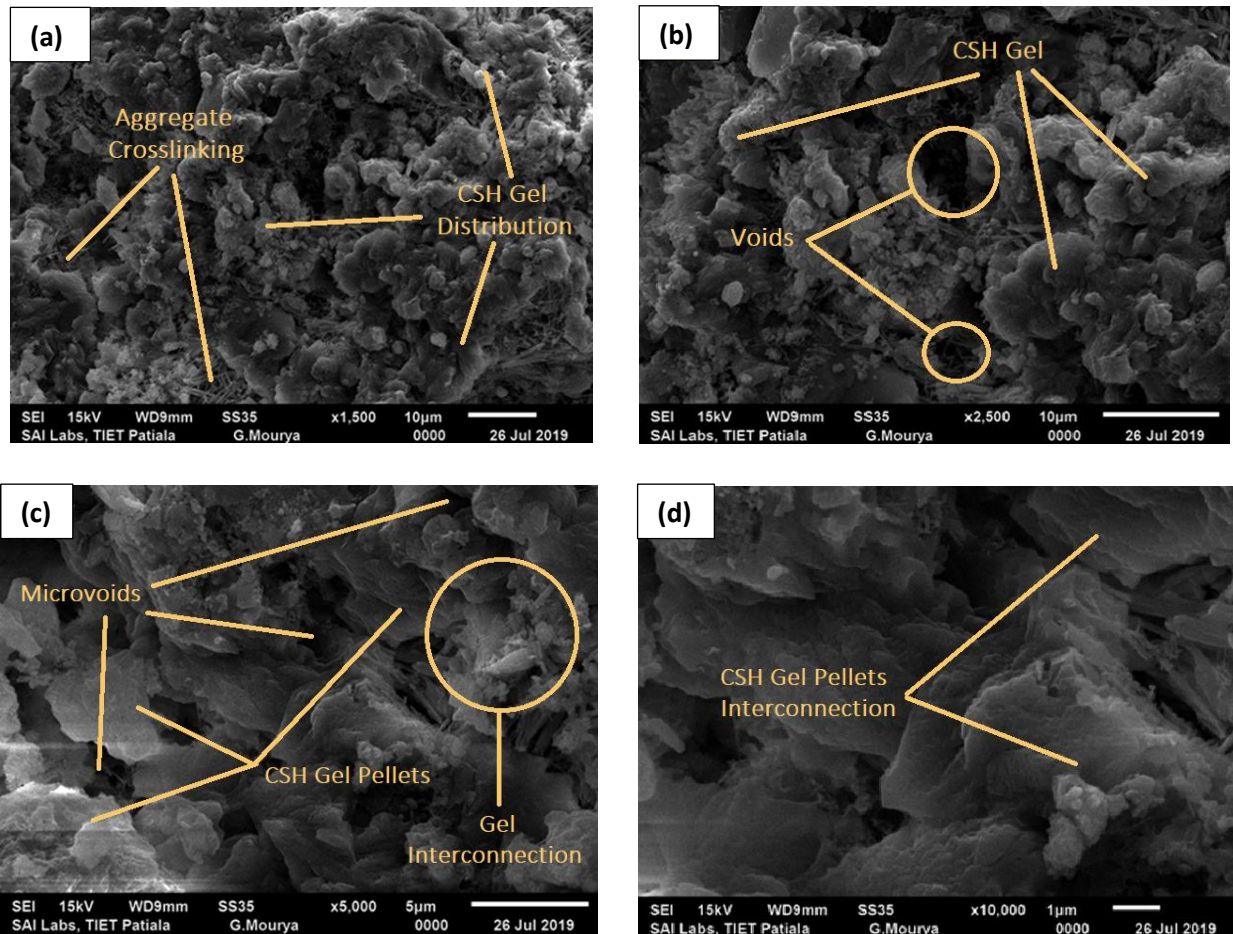


Figure 4.21. SEM image of Normal Concrete(NC) at (a) $\times 1500$, (b) $\times 2500$, (c) $\times 5000$ (d) 10000, magnification levels

4.4.2 Line Mapping Of Normal Concrete (NC)

Line mapping represents strong interconnection between interfacial transition zones of aggregates and CSH gel. Lower left corner of the Figure 4.22 depicts the aggregates in the matrix microstructure whereas upper right corner depicts the strong formation of CSH gel in the mix.

This strong interconnection of interfacial transition zones makes it more durable. Line mapping of the selected area indicates the presence of elements such as carbon, oxygen, magnesium, aluminium, silicon, sulphur, calcium and iron in NC mix as shown in Figure 4.24 (a-h) and combined mapping of the elements is illustrated in Figure 4.23 which gives comparative estimation of elements present in the mix as a whole.

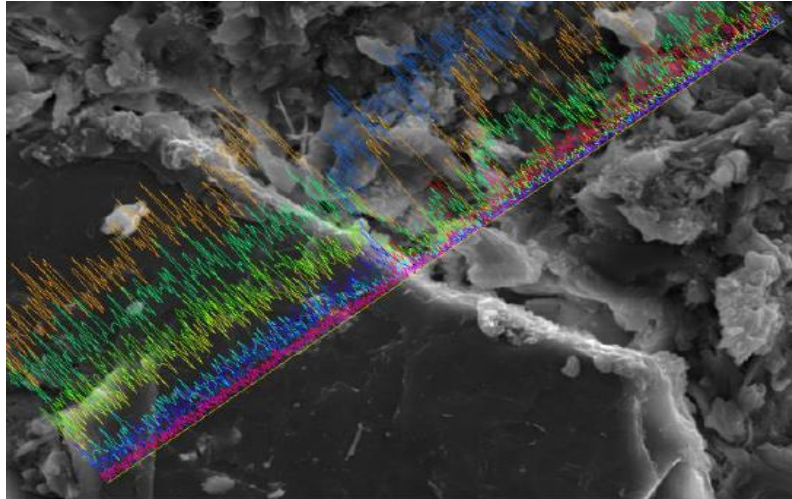


Figure 4.22. Selected area of Line Mapping in NC mix

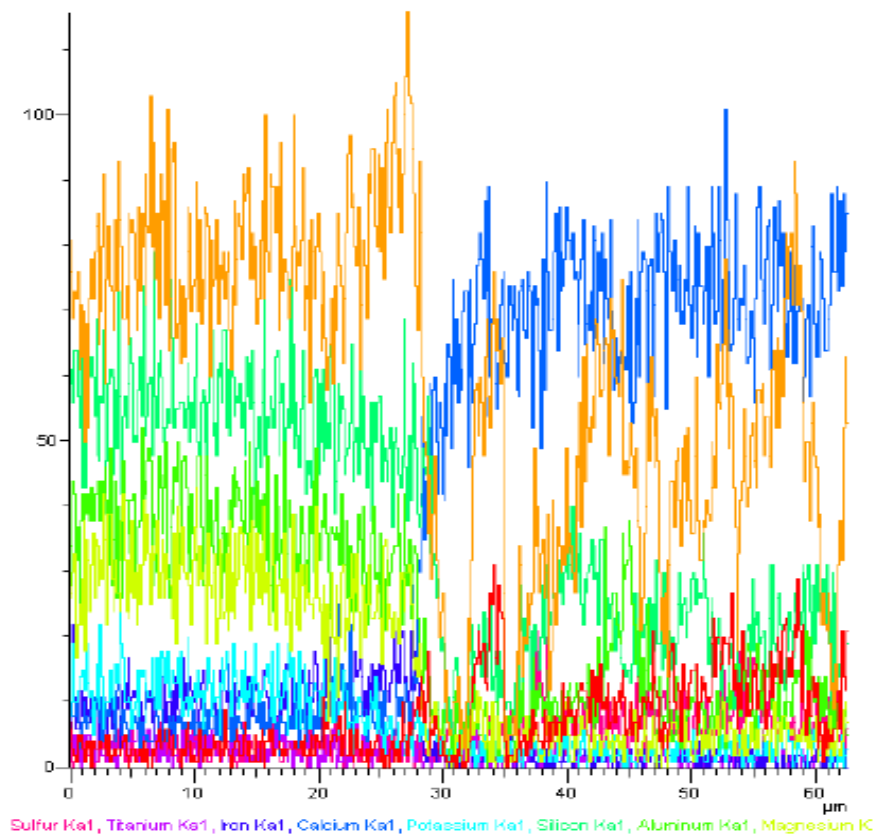


Figure 4.23. Line mapping of Normal Concrete (NC) mix

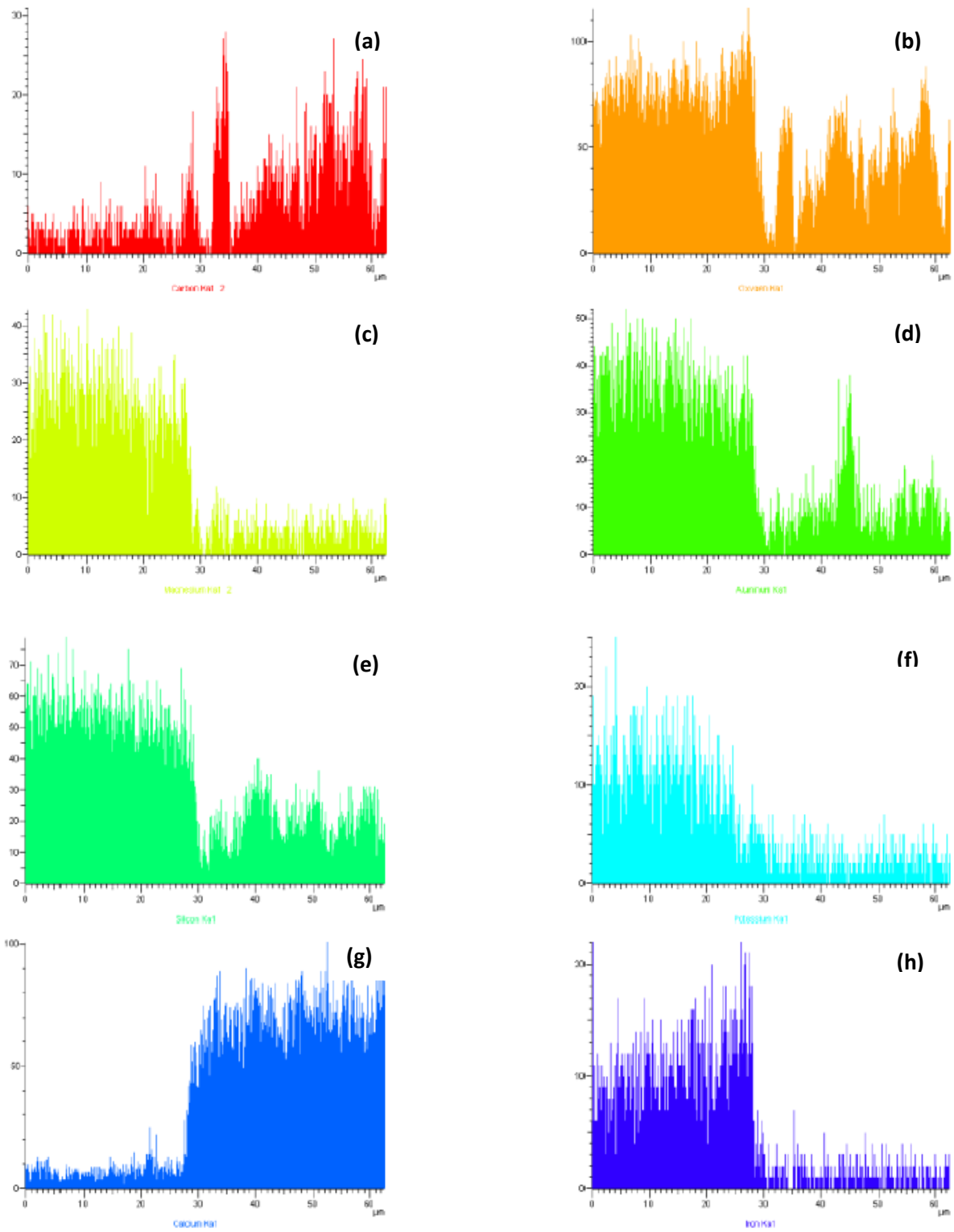


Figure. 4.24. Line Mapping present elements (a) Carbon, (b) Oxygen, (c) Magnesium, (d) Aluminium, (e) Silicon, (f) Sulphur, (g) Calcium, (h) Iron in NC mix.

4.4.3 SEM of Expanded Perlite (EP1)

SEM Figure 4.25 (a, c) shows dense interconnection between aggregate and binder gel (CSH gel). SEM Figure 4.25 (b, d) show the distribution of CSH gel with fewer voids in the microstructure. However these voids are due to lesser fine content in EP mix which subsequently results in decrease in strength than NC mix.

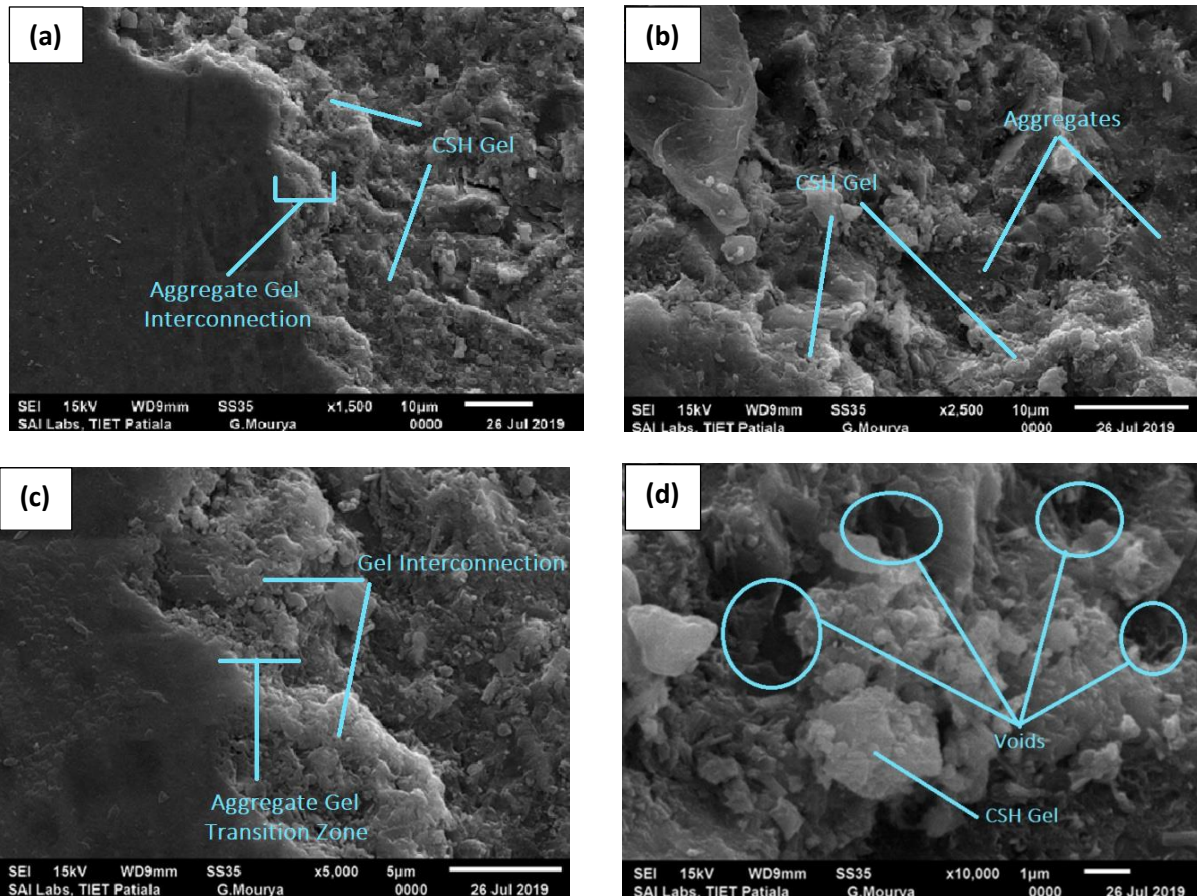


Figure 4.25. SEM image of Expanded Perlite(EP1) at (a) $\times 1500$, (b) $\times 2500$, (c) $\times 5000$, (d) 10000 , magnification levels.

4.4.4 Line Mapping Of Expanded Perlite (EP1)

Line mapping represents the interfacial transition zone between aggregate and CSH gel as shown in Figure 4.26. Line mapping of the selected area indicates the presence of elements such as carbon, oxygen, magnesium, aluminium, silicon, calcium iron and titanium in EP1 mix as shown in Figure 4.28 (a-h) and combined mapping of the elements is illustrated in Figure 4.27 which gives comparative estimation of elements present in the mix as a whole.. Higher calcium and silica content represents strong formation of CSH gel. Magnesium, titanium, carbon and

others are present in lower amount and has minimal impact on the strength of EP1 mix. Line mapping also shows uniform distribution of oxides composition in the mix.

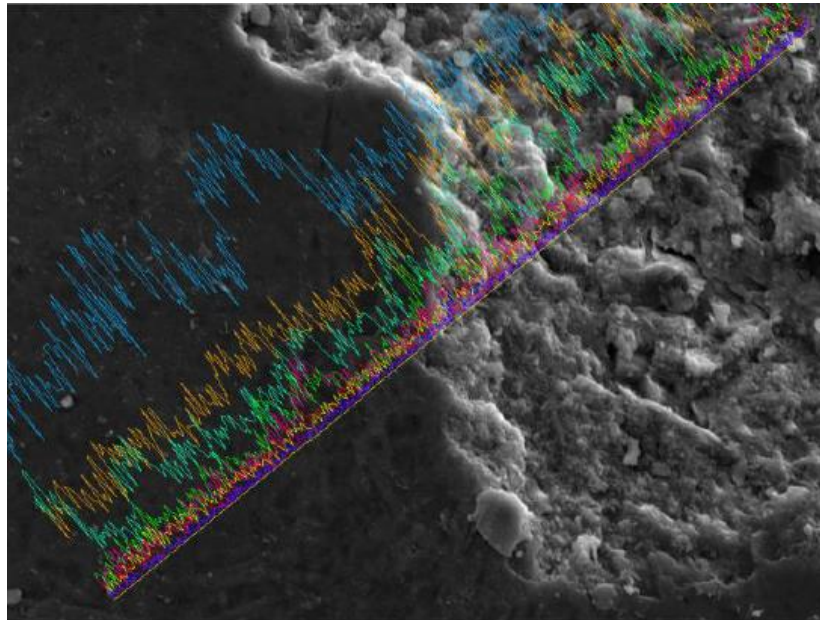


Figure 4.26. Selected area of Line Mapping in EP1 mix

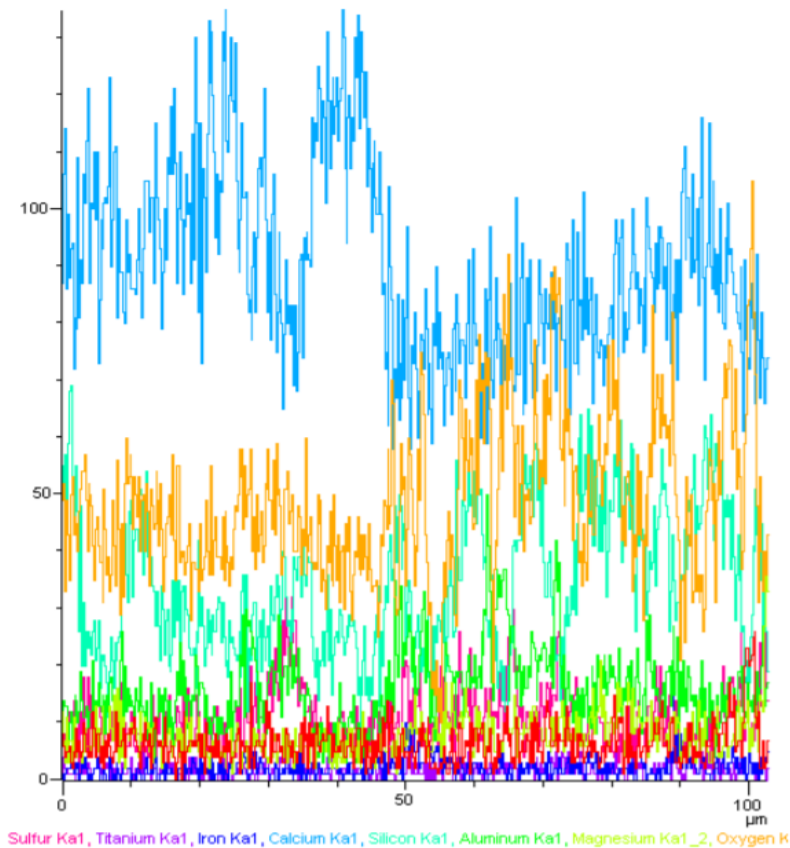


Figure 4.27. Line mapping of Expanded Perlite(EP1) concrete mix.

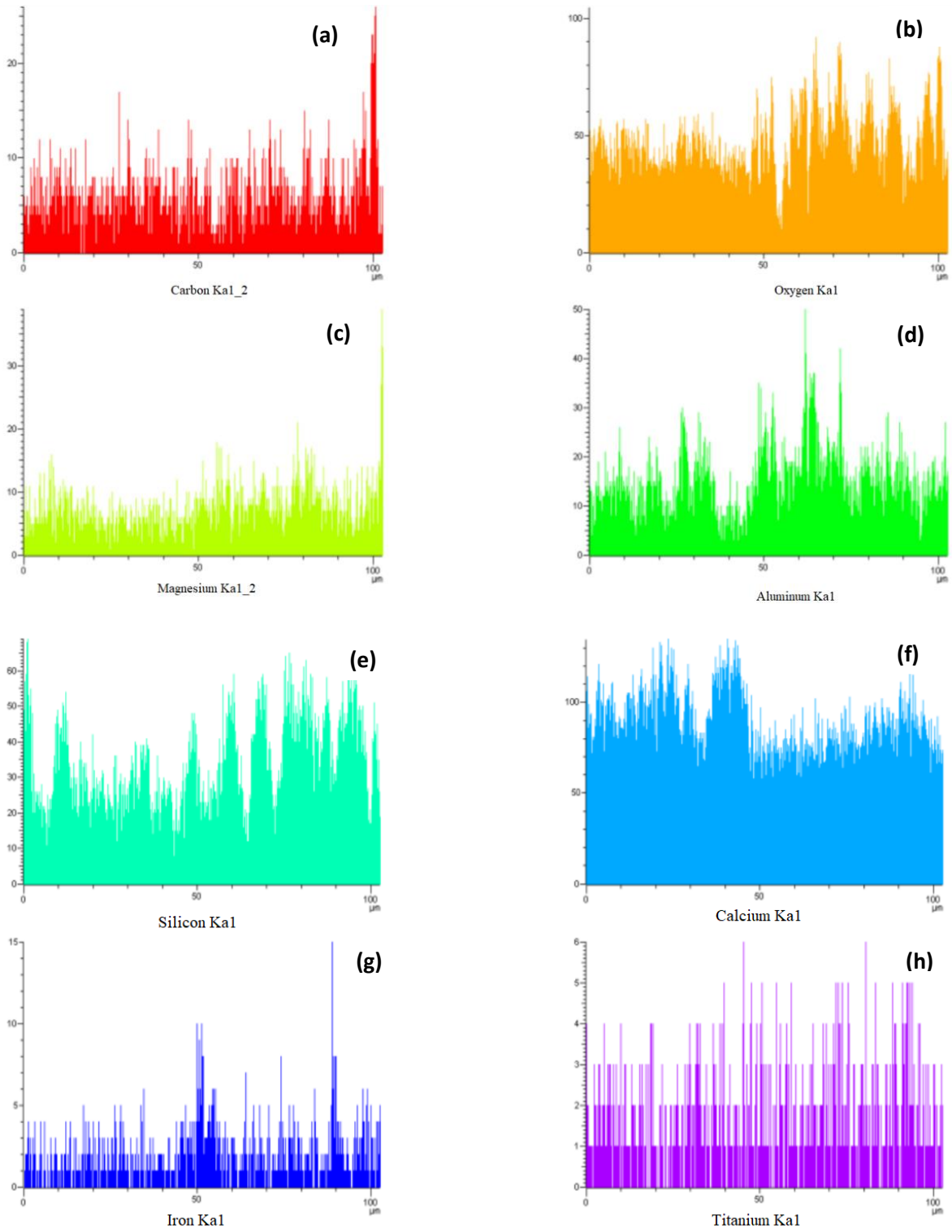


Figure.4.28. Line Mapping present elements (a) Carbon, (b) Oxygen, (c) Magnesium, (d) Aluminium, (e) Silicon, (f) Calcium, (g) Iron, (h) Titanium in EP1 mix.

4.4.5 SEM of Expanded Perlite (EP4)

SEM Figure 4.29 (b) represents cracks between aggregate and gel content. This may be due to outcome of testing. SEM Figures 4.29 (c-d) represents voids and figure 1 represents cracks in the matrix microstructure. Voids is due to higher finer content of expanded perlite which do not account of filling the gaps which further lowers the density and hence strength of the mix. Lower density of expanded perlite too results in strength reduction of EP mix.



Figure 4.29. SEM image of Expanded Perlite(EP4) at (a) $\times 1500$, (b) $\times 2500$, (c) $\times 5000$, (d) 10000 , magnification levels

4.4.6 Line Mapping of Expanded Perlite (EP4)

Line mapping represents the interconnection between aggregate and binder gel content. In line mapping Figure 4.30, lower left corner indicates the presence of aggregates having high silica and oxygen content whereas upper right corner represents the high calcium content. Line mapping of the selected area indicates the presence of elements such as oxygen, aluminium, silicon, calcium, sulphur, titanium, iron, carbon in EP4 mix as shown in Figure 4.32(a-h) and

combined mapping of the elements is illustrated in Figure 4.31 which gives comparative estimation of elements present in the mix as a whole. As chemical composition of expanded perlite is similar to that of river sand, it is hardly differentiable in analyzing particles in the line mapping figures.

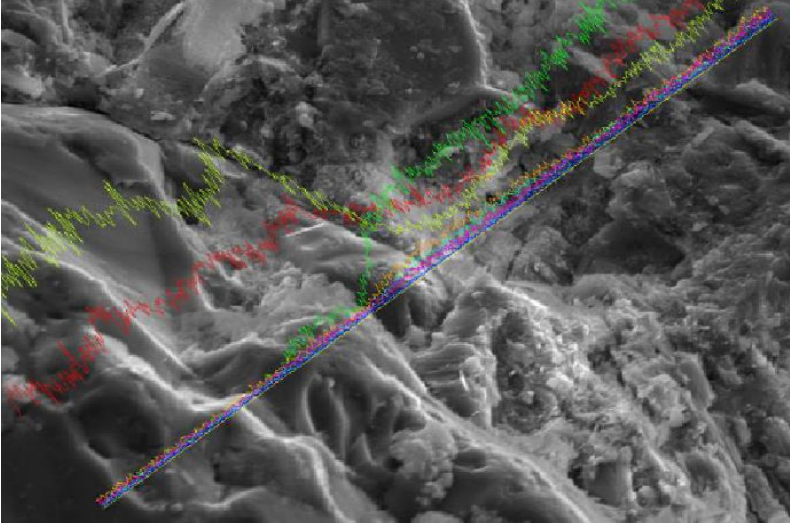


Figure 4.30. Selected Area of Line Mapping in EP4 mix

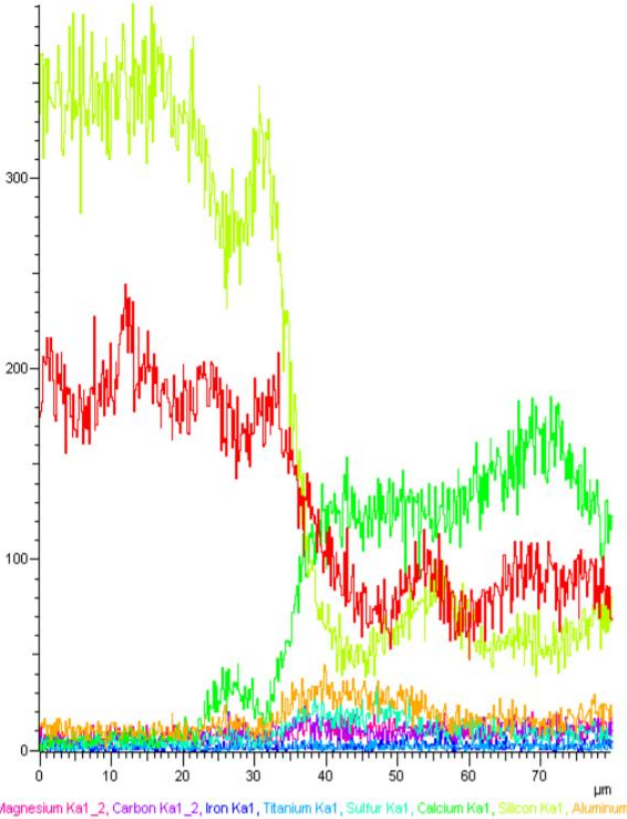


Figure 4.31. Line mapping of Expanded Perlite(EP4) concrete mix.

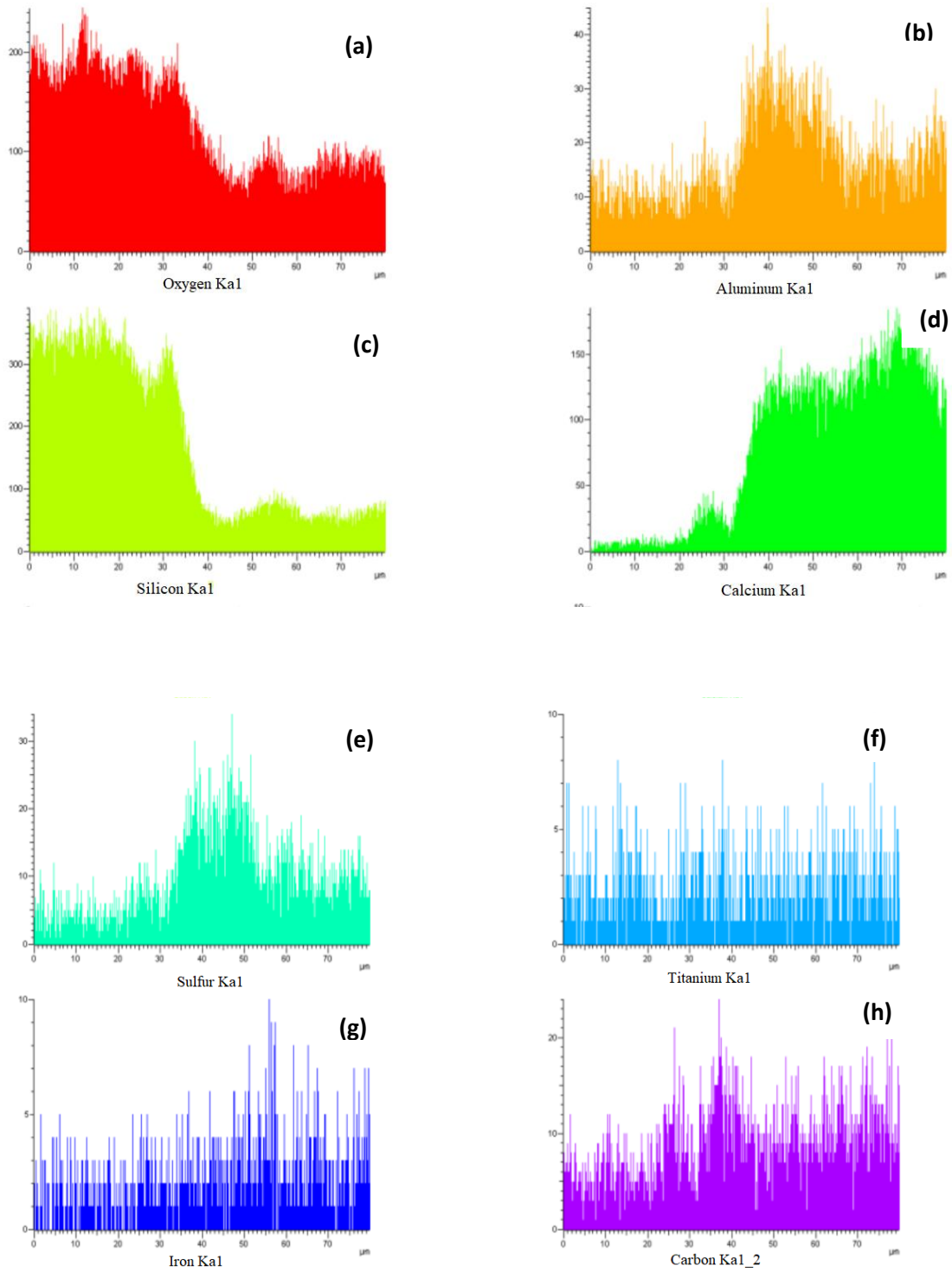


Figure 4.32. Line Mapping present elements (a) Oxygen, (b) Aluminium, (c) Silicon, (d) Calcium, (e) Sulphur, (f) Titanium, (g) Iron, (h) Carbon in EP4 mix.

4.4.7 SEM of Expanded Perlite & Pumice (PP1)

SEM Figure 4.33 (a, c) represents substantial interconnection zone of aggregate and binder gel content (CSH gel). SEM Figure 4.33 (b, d) represents CSH distribution and cross linking of the gel network in the matrix microstructure which makes particles strong to bear external forces. Dense microstructure is attributed due to river sand particles whereas higher density of river sand plays a vital role in making structure durable.

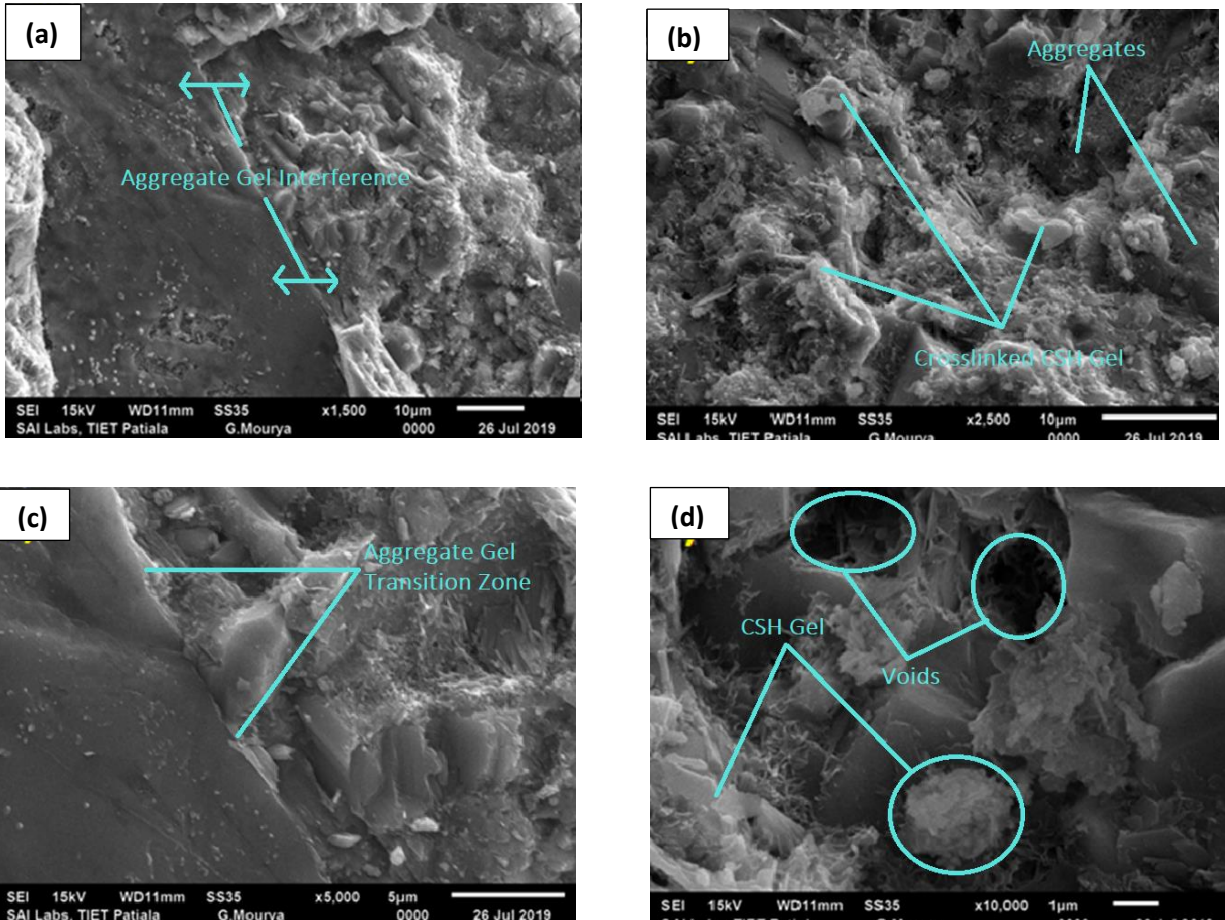


Figure 4.33. SEM image of Expanded Perlite and Pumice(PP1) at (a) $\times 1500$, (b) $\times 2500$, (c) $\times 5000$, (d) 10000, magnification levels

4.4.8 Line Mapping of Expanded Perlite & Pumice (PP1)

Line mapping of PP1 (figure 4.34) indicates interfacial transition zones between aggregates and CSH gel. Zigzag distribution of calcium and silicon along line mapping shows varying distribution of binder gel content. However interconnection among particles is stronger than EP mix, this is due to dense matrix microstructure. Line mapping of the selected area

indicates the presence of elements such as carbon, oxygen, magnesium, aluminium, silicon, sulphur, calcium and titanium in PP1 mix as shown in Figure 4.36 (a-h) and combined mapping of the elements is illustrated in Figure 4.35 which gives comparative estimation of elements present in the mix as a whole.

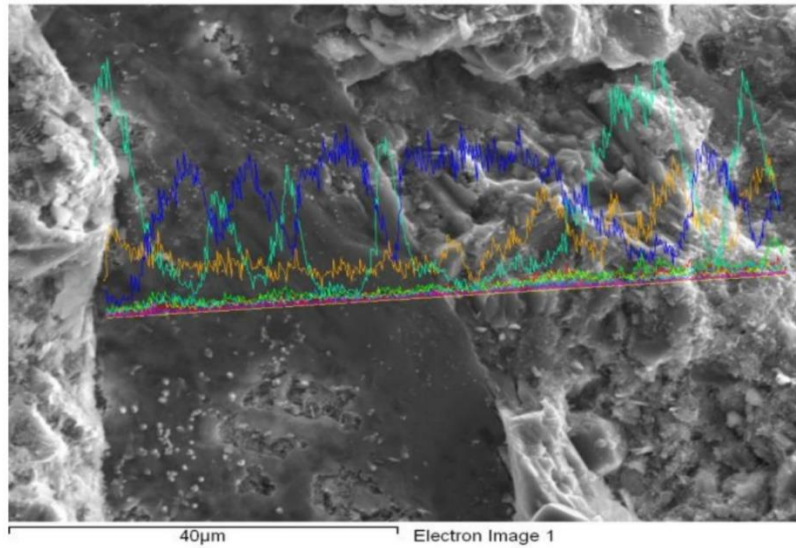


Figure 4.34. Selected Area of Line Mapping in PP1 mix

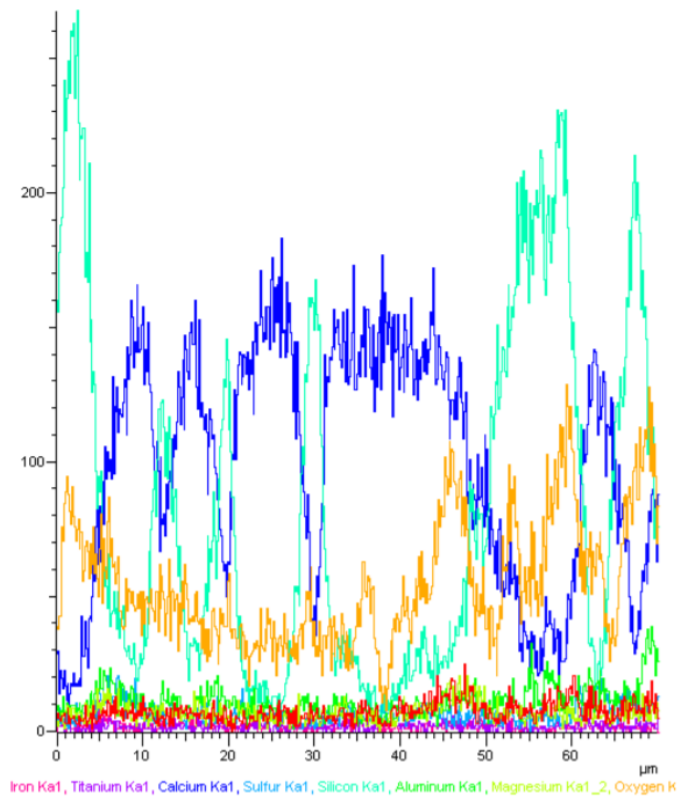


Figure 4.35. Line Mapping of Expanded Perlite and Pumice(PP1) Concrete Mix.

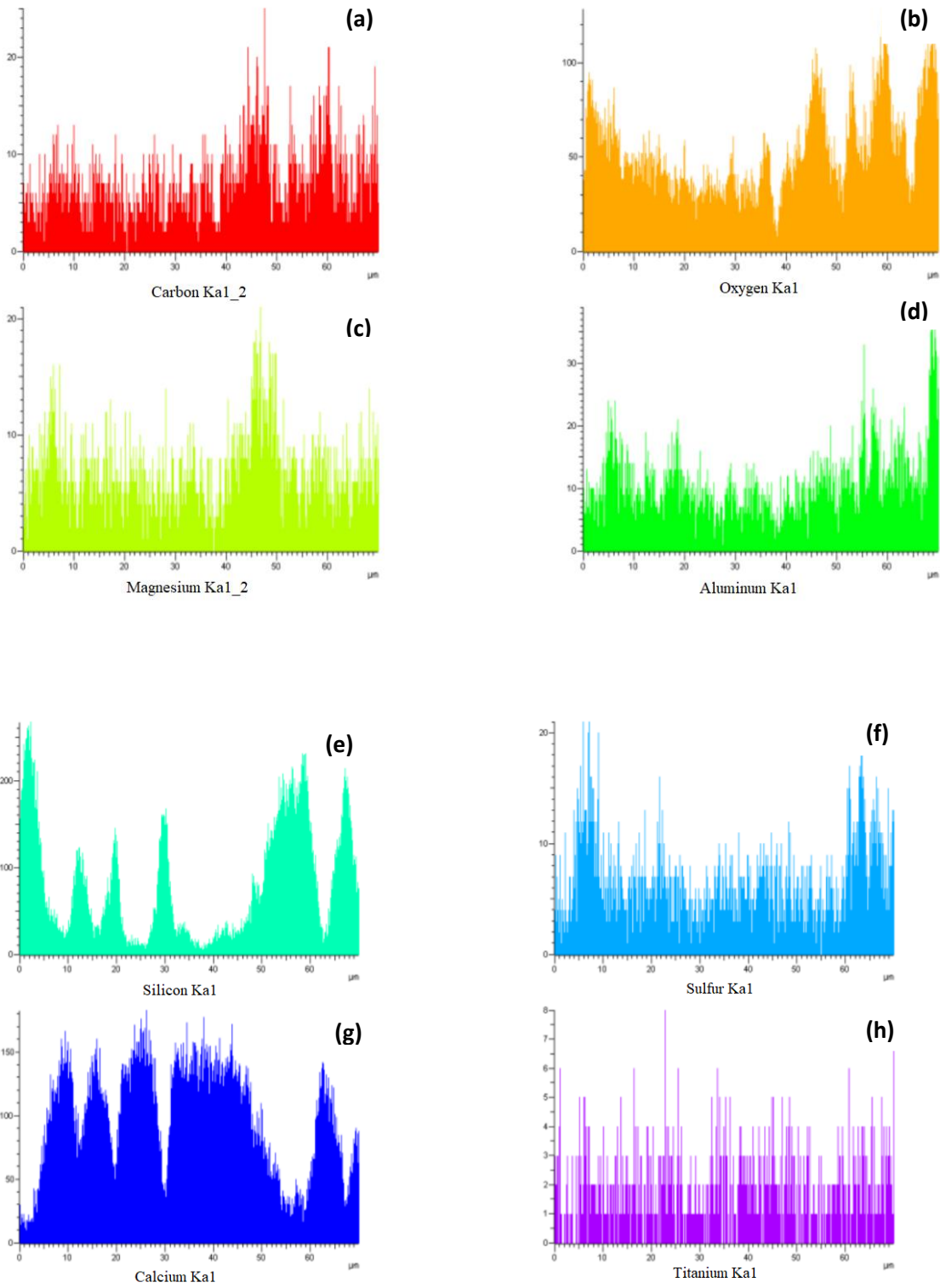


Figure 4.36. Line Mapping present elements (a) Carbon, (b) Oxygen, (c) Magnesium, (d) Aluminium, (e) Silicon, (f) Sulphur, (g) Calcium, (h) Titanium in PP1 mix.

4.4.9 SEM of Expanded Perlite & Pumice (PP4)

SEM Figure 4.37 (a, c) represent cracks in the matrix microstructure and Figure 4.37 (b, d) represent voids in the mix. This clearly indicates less durability of PP4 mix, however its durability is superior than EP4 mix due to presence of finer pumice content than expanded perlite in the mix.

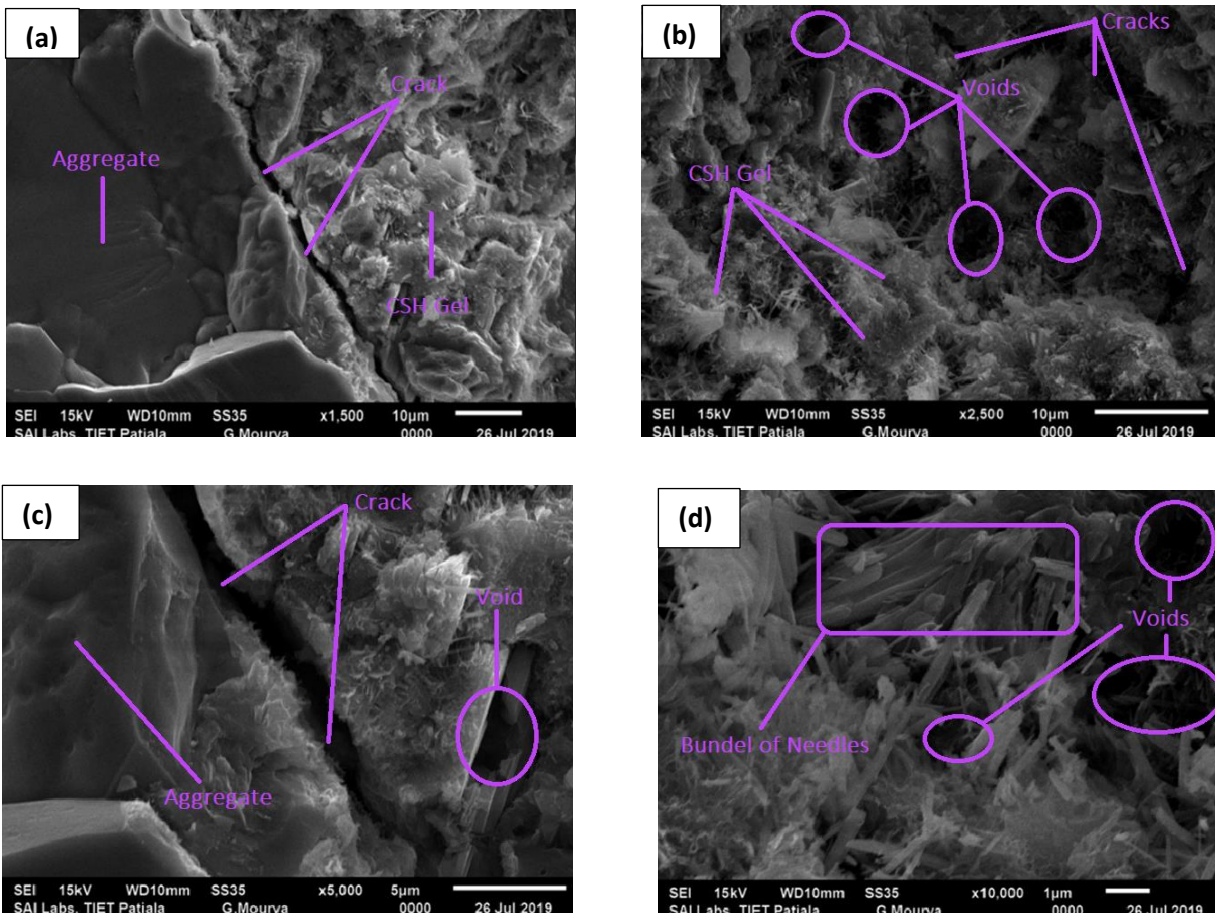


Figure 4.37. SEM image of Expanded Perlite and Pumice(PP4) at (a) $\times 1500$, (b) $\times 2500$, (c) $\times 5000$, (d) 10000, magnification levels.

4.4.10 Line Mapping Of Expanded Perlite & Pumice (PP4)

Line mapping of aggregates gel interference is shown in the Figure 4.38. Line mapping of the selected area indicates the presence of elements such as oxygen, silicon, calcium, titanium, iron, aluminium, sulphur, carbon in PP4 mix as shown in Figure 4.40 (a-h) and combined mapping of the elements is illustrated in Figure 4.39 which gives comparative estimation of elements present in the mix as a whole.. In middle of the line mapping, downturn of the oxygen content represents cracks in the matrix microstructure whereas strong silicon and oxide content

of left hand side represents aggregate. Right hand side of figure indicates the presence of higher calcium content in the mix.

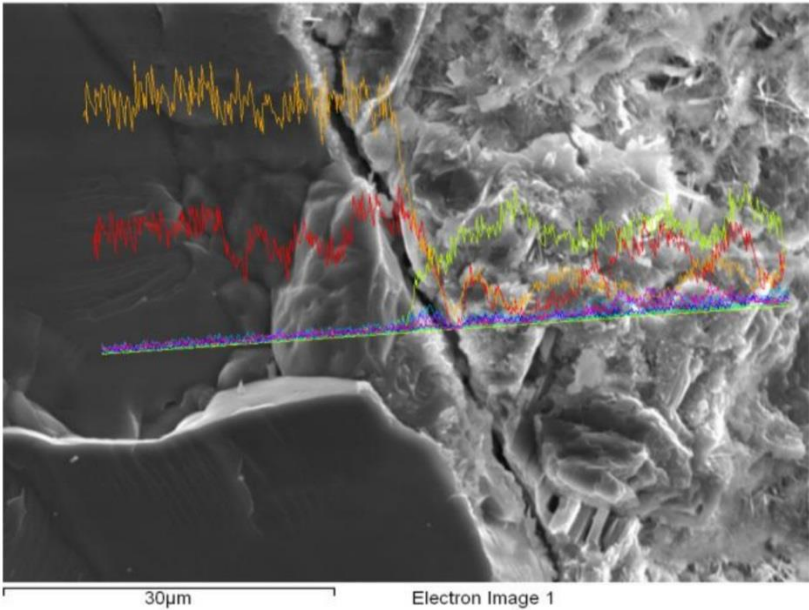


Figure 4.38. Selected Area of Line Mapping in PP4 mix.

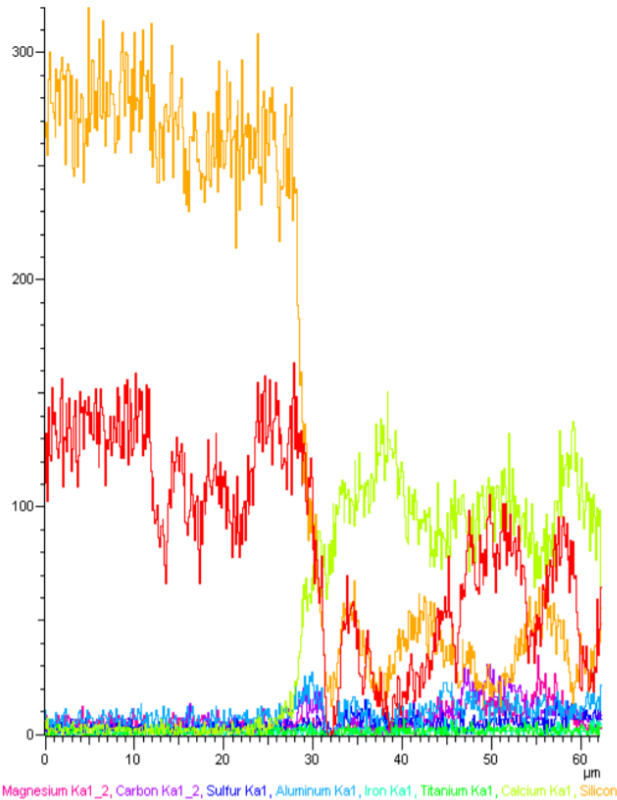


Figure 4.39. Line Mapping of Expanded Perlite and Pumice(PP4) Concrete Mix.

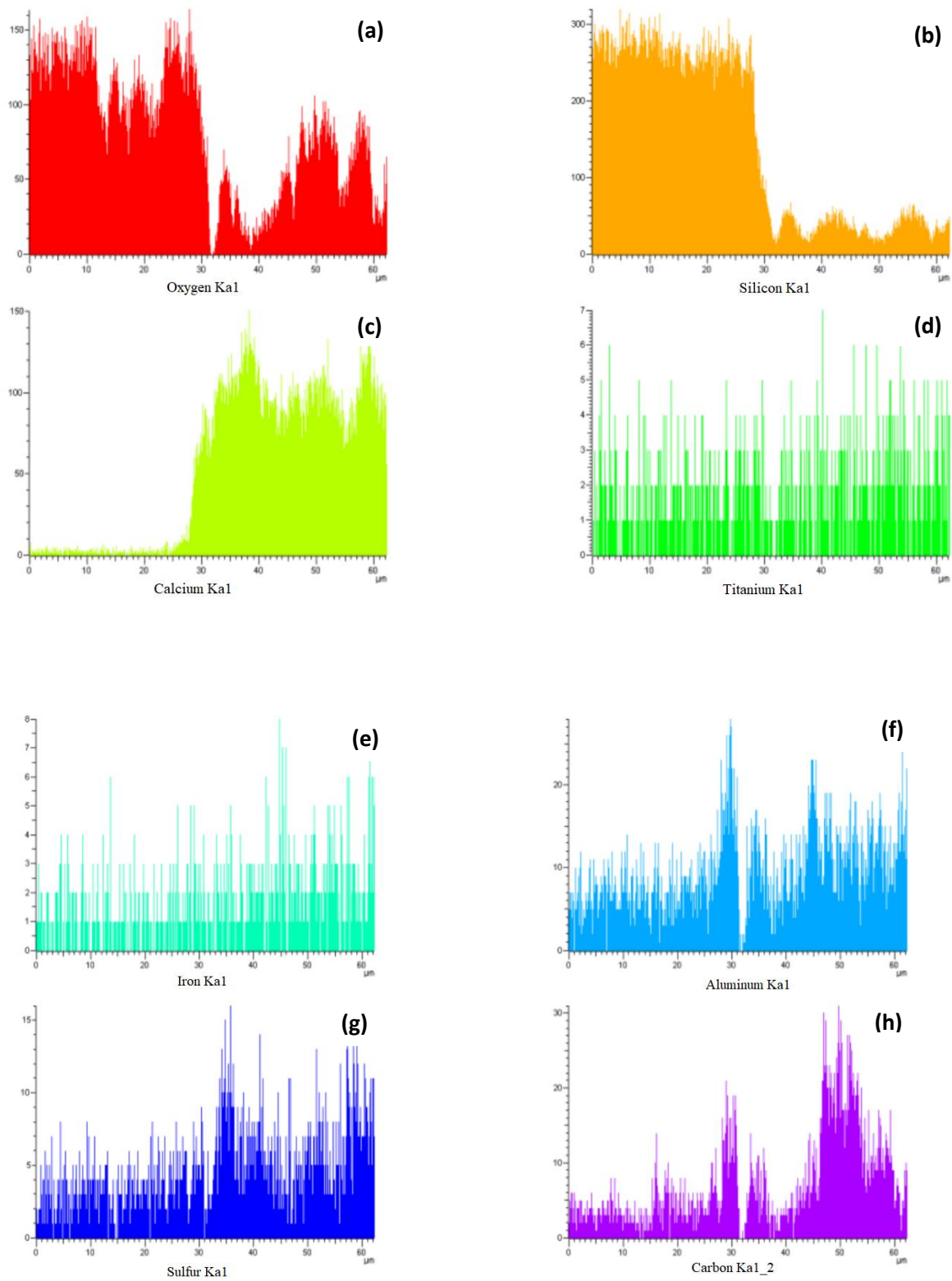


Figure 4.40. Line Mapping present elements (a) Oxygen, (b) Silicon, (c) Calcium, (d) Titanium, (e) Iron, (f) Aluminium, (g) Sulphur, (h) Carbon in PP4 mix.

CHAPTER 5

CONCLUSIONS

5.1 CONCLUSIONS

Research have been carried out by replacing fine aggregates used in normal concrete with expanded perlite and pumice aggregates. In present experimental study, various proportions such as 25%, 50%, 75% and 100% of expanded perlite and pumice as a replacement of fine aggregates are used. The results are drawn from various tests and analysis reports such as compressive strength, split tensile strength, flexural strength, rapid chloride permeability, density-absorption, and void test along with SEM and EDS have been listed. The final conclusions drawn are:

- The compressive strength of normal concrete is 31.20 MPa. Compressive strength decreases up to 13.25%, 20.08%, 30.55% and 41.24% for the concrete mix (entailing expanded perlite) EP1, EP2, EP3 and EP4 respectively when compared with normal concrete compressive strength. The similar trend of decrease has been observed when the replacement of pumice is done. The compressive strength decreases in the order of 3.96%, 16.45%, 28.84% and 37.69% for the concrete mix (entailing expanded perlite and pumice) PP1, PP2, PP3 and PP4 respectively .However, decrease in the compressive strength results of PP mix found to be less than EP mixes due to more compactness of the mix.
- The split tensile strength of NC is 2.516 MPa. Split tensile strength decreases in the order of 14.42%, 17.84%, 32.71% and 50.59% for the mix (entailing expanded perlite) EP1, EP2, EP3 and EP4 respectively. The same decreasing trend was observed when the addition of pumice is done. The split tensile strength decreases up to 9.65%, 14.30%, 28.85% and 40.25%for the concrete mix (entailing expanded perlite and pumice) PP1, PP2, PP3 and PP4 respectively when compared with normal concrete strength . Relatively less decrease in PP samples indicates strong mix than EP mix.
- It has been observed that with the increase in the proportion of expanded perlite and pumice, the flexural strength decreases from 4.010 MPa (for control mix) to 2.753 MPa (for EP4). Therefore, the FS decreases in the order of 8.9%, 13.8%, 25.18% and 31.34% for the concrete mix (entailing expanded perlite) EP1, EP2, EP3 and EP4. Whereas, the

flexural strength decreases in the order of 6.83%, 10.22%, 20.37% and 27.85% for the concrete mix (entailing expanded perlite and pumice) PP1, PP2, PP3 and PP4 respectively when compared with NC strength.

- It has been found from the tests that the sorptivity of control mix is $0.0573 \text{ mm/s}^{1/2}$. The sorptivity increases with the expanded perlite replacements because of the high volume of voids present in concrete structure. The percentage increase in the value of sorptivity is 122.5%, 163.5%, 240.5% and 353.6% for concrete mix EP1, EP2, EP3 and EP4 respectively. The % increase in the value of sorptivity is 62%, 105.8%, 135.3% and 216.1% for concrete mix PP1, PP2, PP3 and PP4 respectively when compared with NC value. Therefore, PP4 showed maximum value of sorptivity which is $0.1811 \text{ mm/s}^{1/2}$.
- The charged passed from NC mix is found to be 1803.67 C. The % increase in the value of charged passed is 35.72%, 59.73%, 98.114% and 142.37% for concrete mix EP1, EP2, EP3 and EP4 as compared to NC mix. The concrete mix EP4 shows the maximum chloride ingress as 100% substitution makes it highly permeable than other mix. Also, % increase in the value of charged passed is 12.08%, 27.13%, 47.25% and 62.35% for concrete mix PP1, PP2, PP3 and PP4 respectively. Overall charged passed in EP category mix is higher than PP category mix which is due to higher permeability of EP mixes.
- It is observed from results that all expanded perlite replacements have unit weights less than 2300 kg/m^3 , hence they are termed as light weight concrete. In case of expanded perlite and pumice replacements, it was observed that 25% replacement (PP1) results in decreased density (due to lesser amount) but not enough to account it as light weight. It has been observed that with the substitution of fine aggregates by lightweight aggregates, decrease in both the densities (apparent density and bulk density) for EP category mix and PP category mix is moderate to low. This is because the aggregates are less densely packed as compared to NC mix. The percentage decrease in bulk density of EP category concrete mix ranges from 5.5% to 23.06% whereas in PP category concrete mix it ranges from 3.98% to 18.02%. Also percentage decrease in apparent density of EP and PP category concrete mix ranges from 4.59% to 22.15% and from 3.61% to 17.42.
- From the results of absorption after immersion and boiling, it has been observed that the control mix showed minimum value of absorption i.e. 0.3588%. The percentage increase

in absorption of EP and PP category concrete mix ranges from 68.95% to 439.8% and 39.49% to 389.63% respectively.

- Minimum percentage of volume of permeable pore space is found out to be for NC mix i.e. 0.5503%. The percentage increase in volume of permeable pore space of EP and PP category concrete mix ranges from 81.7% to 245.35% and 54.46% to 224.2% respectively.
- The minimum percentage of total void volume is found to be 0.5748% for NC mix and this value increases as the percentage of substitution increases either with expanded perlite or with pumice. The overall value of the total void volume is higher for the EP4 mix. This is because of more permeable pore space in structure accounting of less dense structure. The % increase in volume of permeable pore space of EP and PP category concrete mix ranges from 221.9% to 772.3% and 146.6% to 633.1% respectively.

5.2 SCOPE OF FURTHER WORK

The final conclusions of present experimental study indicated that the strength of concrete decreases due to its decrease in density. However, the rate of absorption, total volume of voids and volume of permeable pore space increases as the concrete was less densely packed. However, further work can be investigated in related areas of present experimental work. The scope of future work is as follows:

- In present study, only fine aggregates were replaced with expanded perlite and pumice lightweight aggregates. Therefore, there is a need of replacing coarse aggregates along with the fine aggregates by using expanded perlite and pumice lightweight aggregates at same or varying proportions.
- The present experimental work can also be extended by using different additives such as super-plasticizer, fibers, etc. As the strength of concrete decreases, the fibers can play a very crucial role in binding those aggregates within the concrete structure.
- Moreover, the strength of concrete was checked at 28 days of curing period. Therefore, further study can be carried out by investigating the behavior of lightweight concrete at higher curing periods. The relationship of strength gain and time period can be developed.

REFERENCES

1. Ahmed, Mohammed Asim, Mohammed Faisaluddin, Nadeem Pasha, and Md Mansoor Ahmed. 2017. 'Effect of Alkali Activators on Strength Characteristics of GPC', 6: 14763-70.
2. Al Bakria, AM Mustafa, H Kamarudin, M BinHussain, I Khairul Nizar, Y Zarina, and AR %J Physics Procedia Rafiza. 2011. 'The effect of curing temperature on physical and chemical properties of geopolymers', 22: 286-91.
3. Alaa M. Rashad, ELSEVIER, 2016, A synopsis about perlite as building material – A best practice guide for Civil Engineer, 338-353.
4. A.Suba lakshmi, S.Karthick, Gasper Helden, M.Dinesh Boopathi, V.Balaji Pandian, International Journal of Innovative and Emerging Research in Engineering, 2017, Experimental Investigation On Light Weight Concrete Using Pumice Aggregate, 176-183.
5. Chandra S, Berntson L., science, technology and application. Norwich (New York, USA), 2002, Lightweight aggregate concrete, ISBN 0-8155-1486-7.
6. Canan Tasdemir, Ozkan Sengul, Mehmet Ali Tasdemir, ELSEVIER, 2017, A comparative study on the thermal conductivities and mechanical properties of lightweight concretes, 469–475.
7. Djelal C, Vanhove Y, Magnin A, Cement and Concrete Research 2004, Tribological behavior of self compacting concrete, 34:821–8.
8. Failla A, Mancuso P, Miraglia N, Ruisi V, Published by Ministero della Publica Instuzione, Palermo, 1997, Experimental–theoretical study on pumice aggregate lightweight concrete. Technical Report, The Instuto di Scienza delle Costruzioni, Facolta di Ingegneria, Palermo, pp. 3–22.
9. Ibrahim Turkmen, Abdulhamit Kantarc, ELSEVIER, 2007, Effects of expanded perlite aggregate and different curing conditions on the physical and mechanical properties of self-compacting concrete, 2378–2383.
10. Liang Wanga, Peng Liu, Qiangshan Jing, Yuanzhen Liu, Wenjing Wanga, Yu Zhang, Zhu Li, ELSEVIER, 2018, Strength properties and thermal conductivity of concrete with the addition of expanded perlite filled with aerogel, 747-757.

11. L. Gunduz, ELSEVIER, 2008, The effects of pumice aggregate/cement ratios on the low-strength concrete properties, 721-728.
12. Lakshmi Kumar Minapu, M K M V Ratnam, Dr. U Rangaraju, International Journal of Innovative Research in Science, Engineering and Technology, 2014, Experimental Study on Light Weight Aggregate Concrete with Pumice Stone, Silica Fume and Fly Ash as a Partial Substitution of Coarse Aggregate, 18130-18138.
13. M. Haist, V. Mechtcherine, H. Beitzel, H.S. Müller, O. Wallevik, I. Nielsson, International RILEM Symposium on Self-Compacting Concrete, 2003, Retrofitting of building structures using pumpable self-compacting lightweight concrete, pp. 776–785.
14. Murat Kurt, Muhammed Said Gul, Rüstem Gul, Abdulkadir Cuneyt Aydin, Turkey Kotan, ELSEVIER, 2016, The effect of pumice powder on the self-compactability of pumice aggregate lightweight concrete, 36-46.
15. Murat Emre Dilli, Hakan Nuri Atahan, Cengiz Sengül, ELSEVIER, 2015, A comparison of strength and elastic properties between conventional and lightweight structural concretes designed with expanded clay aggregates, 260–267.
16. Ning Liu, Bing Chen, ELSEVIER, 2014, Experimental study of the influence of EPS particle size on the mechanical properties of EPS lightweight concrete, 227–232.
17. N.Bhavana, CH.Rambabu, International Research Journal of Engineering and Technology, 2016, Study Of Mechanical Properties Of Lightweight Aggregate Concrete By Using Pumice Stone, Ceramic Tiles And CLC Lightweight Bricks, 3071-3079.
18. Osman Unala, Tayfun Uygunog lua, Ahmet Yildiz, ELSEVIER, 2007, Investigation of properties of low-strength lightweight concrete for thermal insulation, 584–590.
19. Person B, Cement and Concrete Research 2001, A comparison between mechanical properties of selfcompacting concrete and the corresponding properties of normal concrete, 31:193–8.
20. R. Khurana, O. Topçu, Second International Symposium on Cement and Concrete Technology in the 2000, Role of Superplasticizers in the development of selfcompacting concrete, vol. I, pp. 473–482.
21. Sonebi M., Cement and Concrete Research 2004, Medium strength self-compacting concrete containing fly ash: modeling using factorial experimental plans, 34:1199–208.

22. Unal O, Uygunoglu T, Yıldız A, Build Environ 2007, Investigation of properties of lowstrength lightweight concrete for thermal insulation, 42(2):584–90.
23. V. Khonsari, E. Eslami & Ah. Anvari, 2010, Effects of expanded perlite aggregate (EPA) on the mechanical behavior of lightweight concrete, 1354-1361.
24. Xie Y, Liu B, Yin J, Zhou S., Cement and Concrete Research 2002, Optimum mix parameters of high strength self-compacting concrete with ultrapulverized fly ash, 32:477–80.